# Effect of Helium Injection on Diffusion Dominated Air Ingress Accidents in Pebble Bed Reactors

by

Joseph Paul Yurko

Submitted to the Department of Nuclear Engineering In Partial fulfillment of the requirements for the degree of

Master of Science in Nuclear Engineering

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#### Abstract

The primary objective of this thesis was to validate the sustained counter air diffusion (SCAD) method at preventing natural circulation onset in diffusion dominated air ingress accidents. The analysis presented in this thesis starts with a vertically oriented rupture of a coaxial pipe. Air enters into the reactor cavity at a rate dictated by diffusion, until the buoyancy force is strong enough to initiate natural convective flow through the reactor. The SCAD method, developed by Yan et al. reduces the buoyancy force in a high temperature gas reactor (HTGR), during the lengthy diffusion phase, by injecting minute amounts of helium into the top of the reactor to set up a counter helium-air diffusion circuit. By delaying the onset of natural circulation, air enters the reactor only at diffusion transport rates, instead of much higher natural convection transport rates. Thus, the air ingress rate is reduced by several orders of magnitude. Without the continuous convective driven supply of "fresh" air the threat of oxidizing graphite components is significantly reduced.

To validate SCAD a small scale simulated Pebble Bed Reactor (PBR) was constructed and a series of air ingress experiments with and without helium injection were conducted. In addition, Computational Fluid Dynamic (CFD) simulations were performed using FLUENT ® to model the experiment and gain further insight into the behavior of the flow field leading up to the onset of natural circulation. In order to have the CFD predicted natural circulation onset time better match the experimentally determined onset time, the initial helium fraction in the numerical model had to be reduced by 15%. This reduction is within the uncertainty of the experimental set-up.

This change helped display an important feature of the behavior of air ingress accidents. With the initial helium fraction in the simulated reactor at 100% the first half of the transient is a very slow completely diffusion dominated transport phase. The second half of the transient had an air transport rate that had an increasing natural convective transport contribution leading up to the onset of natural circulation and complete natural convective transport. Reducing the initial helium fraction by only 15% caused that initial very slow, pure diffusion transport phase to be bypassed and the natural circulation onset time was dictated by the combined effects of free convection and diffusion transport, not simply diffusion. A full scale PBR experiencing a similar accident will have the core

entirely filled with helium. Thus, for a vertically oriented double ended guillotine (DEG) large-break loss of coolant accident (LB-LOCA) the subsequent air ingress rate will be dictated by the slow diffusion of air into the reactor cavity, for most of the transient.

For the helium injection tests, even at the at the lowest tested injection rate, both the experiment and the CFD simulation showed that natural circulation was prevented over a time period twice as long as the time to onset. The tests showed that without helium injection, natural circulation started after about 117 minutes on average. With helium injection, natural circulation did not start after 240 minutes when the experiment was terminated. Additional injection tests were run where after 240 minutes the helium injection was terminated, but data continued to be taken. In these tests natural circulation confirming the helium injection flow was preventing natural circulation from starting. The lowest tested helium injection rate corresponded to 0.01% of the test assembly's total volume per minute, demonstrating how small of a flow rate is needed for the SCAD method to work. Minimal helium injection is not intended to be an emergency core cooling system but rather a system to prevent or delay natural circulation which would result in a large amount of air ingress.

The system response was formulated non-dimensionally to quantify the impact SCAD has on the driving parameters that impact the onset of natural circulation, namely the buoyancy force, mass flow rate, and density ratio between the hot and cold leg. The results showed that SCAD suppresses the buoyancy force and forces a mass flow (transport) rate that causes any changes in the hot leg density to be counter-acted by density changes in the cold leg. The transport rate that is established is orders of magnitude less than the natural circulation transport rate. Using the driving nondimensional parameters, a methodology was also developed in order to formulate a correlation to estimate the minimum injection rate (MIR) of helium to prevent the onset of natural circulation. In order to properly derive a correlation for the MIR, further experiments and/or simulations are required over different geometrical configurations. The non-dimensional analysis showed that Yan's MIR estimate was conservative for the experimental configuration, and would be conservative for a full scale PBR. Therefore, Yan's MIR calculation was used to provide an order of magnitude estimate for the helium injection rate in a full scale PBR. The resulting MIR of helium for a full scale PBR was 5.36 g/hr, which corresponds to storing only 11.6 kg of helium on-site to prevent the onset of natural circulation for three full months.

The experiment and CFD simulations were performed using an inverted U-tube which simulates a vertically oriented pipe configuration. If the pipe break occurs in a horizontal configuration, the air ingress phenomena could be substantially different depending on the break size and orientation. Thus, this thesis concludes that the method is capable of preventing natural circulation onset as long as air ingress occurs at transport rates comparable to diffusion after the break occurs.

Thesis supervisor: Andrew C. Kadak Title: Professor of the Practice of Nuclear Engineering

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# **Table of Contents**

1. Background	7
1.1 Pebble Bed Reactor (PBR)	7
1.2 Air Ingress Accident Overview	. 10
2. Natural Circulation Prevention	. 11
2.1 Overview	. 11
2.2 Sustained Counter Air Diffusion (SCAD)	. 12
3. Air Ingress Experiment	. 14
3.1 Experimental Overview	. 14
3.2 Apparatus Description	. 14
3.3 Experimental Procedure	. 18
3.3.1 Experimental Preparation	. 18
3.3.2 Measurement Description	. 18
3.4 Project Results	. 19
3.4.1 CFD Results	19
3.4.2 Experimental Data	23
4. FLUENT Analysis Discrepancy	. 27
5. Contributions of Current Work	27
6. Improvements to Previous CFD Model	28
6.1 Overview	28
6.2 Boundary Conditions	29
6.2.1 Porous Media Models	29
6.2.2 Heat Flux Boundary	33
6.2.3 Accurate Temperature Profile	35
6.3 Initial Conditions	36
6.3.1 Full Heating Phase Transient	36
6.3.2 Choice of Operating Density	42
6.3.3 Helium Concentration	45
6.4 Justification for Change	48
7. Non-Dimensional Analysis	50
7.1 Formulation	50
7.2 Important Parameters	52
7.3 Case Comparison	54
8. Injection Modeling	57
8.1 Injection Case CFD Model	57
8.2 CFD Results	58
8.3 Non-Dimensional Parameters Discussion	62
9. MIR Evaluation Methodology	66
10. Full Scale PBR Considerations	68
10.1 MIR Order of Magnitude Estimate	68
10.2 Injection System	69
11. Conclusions	71
12. Recommendations for Future Work	72
13. References	73

14. Appendices	
A1. Experimental Apparatus Design Procedure	
A2. FLUENT Case Summaries	
A3. 1-D Diffusion Matlab Script	
A4. Pebble Wall Temperature UDF	
A5. MIR Matlab Script	

# Table of Figures

Figure 1: Schematic of a Pebble Bed Reactor	8
Figure 2: Fuel Elements	9
Figure 3: On-line Refueling Illustration	9
Figure 4: Phases of Air Ingress for Vertically Oriented Breaks	11
Figure 5: Full Apparatus	.15
Figure 6: FLUENT Computational Mesh	20
Figure 7: Nitrogen Mole Fractions at Apparatus Boundaries	21
Figure 8: FLUENT Mass Flow Results	22
Figure 9: FLUENT Differential Pressure Results	22
Figure 10: All Experimental Data	25
Figure 11: Injection Trial Data	26
Figure 12: Porous Media Investigation Helium Mole Fraction Comparison	33
Figure 13: Temperature Profile Comparison	36
Figure 14: Heating Phase Transient Mesh	38
Figure 15: Pressure Contours at End of Heating Phase Transient	39
Figure 16: Cross-over Leg Circulation Loop	40
Figure 17: Temperature Contours at End of Heating Phase Transient	40
Figure 18: Pressure Profile Comparison Between Different Operating Densities	.44
Figure 19: Operating Density Cross-Over Leg Helium Mole Fraction Compare	.45
Figure 20: 85% Helium Case Mass Flow Rate	47
Figure 21: 85% Helium Case Pebble Column Pressure Difference	.47
Figure 22: Cross-Over Leg Helium Mole Fraction Comparison	49
Figure 23: Non-Dimensional Mass Flux	54
Figure 24: Non-Dimensional Buoyancy Force	55
Figure 25: Density Ratio Comparison	56
Figure 26: Injection Case Comparison	.59
Figure 27: 1 cc/min Injection Case Nitrogen Mole Fraction Contours	.60
Figure 28: Stop Injection Mole Fraction Contours	.61
Figure 29: Non-Dimensional Buoyancy Force Comparison	.63
Figure 30: Density Ratio Comparison.	.64
Figure 31: Non-Dimensional Mass Flux Comparison	.65
Figure 32: NACOK Test Facility	76

## 1. Background

## 1.1 Pebble Bed Reactor (PBR)

For the past thirty years, many in the world have viewed nuclear energy with skepticism and fear. Safety concerns combined with high cost and large regulatory overhead caused few new nuclear plants to be built. However, with the growing demand for more environmentally-friendly energy, nuclear power is making a come-back. Though there are other "clean" options, there are few choices for large scale constant sources of clean energy other than nuclear power [1]. New light water reactor designs, including the Westinghouse AP1000 and GE's ESBWR, are safer and simpler, thus reducing construction cost and increasing public confidence in the technology.

To further improve nuclear power plant safety and reduce cost, Generation IV plants are currently being researched. One of the most advantageous designs is the Pebble Bed Reactor (PBR) shown in Figure 1<sup>1</sup>, which is one type of high temperature gas-cooled reactor (HTGR). The pebble bed reactor is a graphite moderated and reflected thermal neutron spectrum reactor that uses helium as a coolant which operates at a low power density but high outlet temperature. This higher outlet temperature allows for higher thermal efficiency for use in either a direct or indirect gas turbine cycle or an indirect steam cycle for electricity generation. The high outlet temperature compared to light water reactors allows the PBR to be considered for process heat applications such as in oil sands production, thermo-chemical hydrogen production or other uses where high quality heat is needed.

<sup>&</sup>lt;sup>1</sup> Figure 1 provides an illustration of a PBR plant layout. It does not represent pipe configurations used in the scaled down experiment discussed later.



Figure 1: Schematic of a Pebble Bed Reactor [2]

The most important advantage of this technology is a further improvement in safety and an increase in cost effectiveness of the plant due to simplicity in design and higher thermal efficiency. In a PBR, uranium fuel micro-spheres are held in billiard ball sized graphite spheres as shown in Figure 2. This design lowers the power density to the point that a PBR is naturally safe; that is, the core cannot physically meltdown, thus alleviating the greatest public fear of nuclear power. PBRs are more cost-effective because they are not expected to go through costly shut down periods for refueling. Shut downs are avoided by using a process known as on-line refueling. During normal operation, the pebbles cycle through the core. When a pebble's useful operating life is exhausted, it is removed and a new pebble is added during operation. Figure 3 depicts an illustration of the on-line refueling process. Finally, because PBR plant designs are small, smaller units requiring less investment and shorter construction time allow power plants to be functional sooner at less cost.



Figure 2: Fuel Elements [2]



Figure 3: Online Refueling Illustration [3]

The economic case for pebble bed reactors is based on its modular design and construction allowing for factory fabrication of modules with on-site "assembly". The economics of production of a large number of standard smaller units is expected to compete with the overall cost of large base load plants on a cost per kilowatt hour basis.

## 1.2 Air Ingress Accident Overview

Before the Nuclear Regulatory Commission (NRC) approves a new reactor design, the safety of the plant must be established, which includes performing transient and accident analyses of postulated design basis accidents. One of these more significant design basis events is the rupture of a main coolant pipe and subsequent air ingress. The air ingress transport rate is dependent on the orientation of the break. Vertically oriented pipe breaks, as will be discussed, consist of cold air sitting underneath hotter helium gas. Therefore, the air ingress rate is dictated by diffusion. A horizontal break in a large diameter pipe, however, will have additional convective transport due to density gradients that reduce the natural circulation onset time compared to diffusion driven accidents<sup>2</sup>. This work does not account for any phenomena specific to horizontal flow stratified flow.

Because the SCAD method applies to diffusion driven transport rates, only vertical pipe breaks will be discussed. Diffusion dominated air ingress accidents consist of three phases as shown in Figure 4. The furthest left most illustration in Figure 4 is the first phase, the depressurization stage from approximately 7 MPa in a relativity short time depending on the size of the breach. Here, the helium coolant is forced through the pipe breach, meaning no air can enter the reactor vessel. When the pressure in the reactor core equilibrates with the ambient environment in the reactor cavity or building, the second stage, the diffusion stage, begins. Air enters the reactor through a slow diffusion process. As more air enters the reactor, the buoyancy force increases due to the temperature difference in the hot core and the cold leg (side of the reflector), and eventually the buoyancy force becomes larger than the viscous drag, inducing natural circulation. This last stage is shown in the right most illustration in Figure 4. Air enters the reactor through the breach, gets heated up in the core, cools down in the cold leg, and then exits through the breach.

<sup>&</sup>lt;sup>2</sup> Oh, Chang, "Current INL R&D Activities on VHTR Air-Ingress Accident Analysis," Presented at the NGNP Technology Integration Review Process Meeting, March 31, April 1 2009



Figure 4: Phases of Air Ingress for Vertically Oriented Breaks [2]

Though the passive safety features inherent to the PBR design ensure that the ultimate reactor temperature rise for such an event is less than the design limit of the silicon carbide coated particles, concern still exists regarding exposure of the graphite pebble and reflector to ambient air which might cause corrosion and possible exothermic reactions heating up the core further. This is a problem because both the outer zone of the pebbles and the lower and side reflectors of the core structure are made out of graphite. Ingress of air will cause the graphite to oxidize, compromising the structural integrity of the lower graphite structure and possibly reaching the fuel pebbles. The natural circulation phase of the air ingress accident provides a continuous supply of "fresh air" to oxidize the graphite components. Natural circulation, therefore, presents the greatest threat to core integrity and must be prevented.

# 2. Natural Circulation Prevention

## 2.1 Overview

To maintain the design safety goals of the PBR, air ingress accidents must be prevented or sufficiently low in probability to make them very unlikely events and/or a means to mitigate the consequences of air ingress or to prevent the onset of natural circulation through-flow of air must be developed. Most air ingress analyses indicate that air ingress events proceed on a long time scale after depressurization due to the diffusion process. This allows time for repair of the leak or broken pipe since the activity of the helium coolant is generally very low. Additionally, these analyses assume that the source of the air in the reactor cavity is consumed such that the oxidation reaction is limited and confined to only a small portion of the lower reflector, preventing any damage to the fuel or structural integrity of the lower reflector supporting the pebble bed. Whether these assumptions are correct will be evaluated during the licensing process based on the evidence provided.

The simplest approach to prevent air from entering would be the addition of a helium (or other gas such as nitrogen) injection system upon a break of the primary system boundary. Pressure driven forced convective flow through the reactor will thus prevent air from entering into the core [4]. However, to maintain this condition over long periods of time, for example several months, would require large amounts of helium stored onsite. From an economics point of view, storing large amounts of extra helium (or nitrogen) would add additional complexity to the plant, increasing the initial cost and so this simple approach could become very costly for large reactor sizes and the longer the time of interest becomes. Goals for an air ingress prevention method are thus to not only prevent the onset of natural circulation but also at minimal additional cost and so different prevention approaches must be taken.

### 2.2 Sustained Counter Air Diffusion (SCAD)

In order to meet the stated prevention method goals, Yan et al. [5] proposed injecting minute amounts of helium gas from the top of the reactor in order to produce sustained counter air diffusion (SCAD). This process counteracts the increasing buoyancy force, effectively halting the development of natural circulation. A steady-state counter air-helium diffusion process is created in SCAD that attempts to effectively have no bulk gas flow through the core. Air is therefore only allowed to enter the reactor through diffusion, which presents negligible risk to core integrity. In their work, an analytical minimum injection rate (MIR) of helium was developed and used in a benchmarked code

using data taken from a test facility simulating an air ingress event. Yan et al. then used CFD analysis on a full scale high temperature gas reactor to test their MIR strategy. A two-dimensional axi-symmetric mesh of a 600MWt HTGR was created and an air ingress accident was simulated using FLUENT. Without helium injection the air ingress rate into the reactor was 320 kg/hr. This could be reduced to 1 kg/hr by injecting 0.14 kg/hr of helium. Thus, their numerical results showed that by storing only 300 kg of helium, the air ingress into the reactor could be controlled for three full months.

The MIR equation is derived assuming the bulk flow in the hot leg is effectively zero and that the entering air molar flux then exits out the cold leg. The analytical estimate for MIR as derived by Yan is given by Equation 1.

$$N_{He,h} = \frac{c_h D_h}{L} (X_{He,h}^o - X_{He,h}^L)$$
$$N_{He,c} = \frac{c_c D_c}{N^* L} \ln \left( \frac{1 - N^* X_{He,c}^L}{1 - N^* X_{He,c}^o} \right)$$
$$N^* = 1 + \frac{N_{He,h}}{S^* N_{He,c}}$$

**Equation 1** 

where:  $c \equiv molar \text{ concentration } [mol/m<sup>3</sup>],$ 

 $D \equiv$  binary mixture mass diffusivity  $[m^2/s]$ ,

 $L \equiv$  channel length [m],

 $N \equiv \text{molar flux } [\text{mol/m}^2-\text{s}],$ 

 $S^* \equiv$  total flow area ratio of cold to heated channels,

 $X \equiv$  molar fraction with superscripts,

Superscripts:

 $O \equiv top of a particular channel,$ 

 $L \equiv$  bottom of a particular channel,

Subscripts:

.

He  $\equiv$  helium,

 $c \equiv cold channel,$ 

 $h \equiv hot channel.$ 

Equation 1 must be solved iteratively using the Newton method to determine the individual channel helium molar fluxes for given boundary conditions. The MIR is then the sum of the hot and cold leg helium molar fluxes calculated from Equation 1. It should be noted that the MIR equation was derived assuming steady-state and thus predicts the required helium injection rate to ensure the chosen channel boundary mole fractions are maintained (channel boundary mole fractions refer to the mole fractions at the top and bottom of the hot and cold legs). Therefore, the channel boundary mole fractions just before the onset of natural circulation, as computed from CFD analysis or known from experiments, should be chosen to calculate the MIR for a given configuration.

# 3. Air Ingress Experiment

## 3.1 Experimental Overview

To provide a test of the SCAD concept, an experiment was constructed to simulate the onset of air ingress in hot and cold leg system representing a pebble bed core. The objective of the experiment was to numerically predict the onset of natural circulation in a pebble bed configuration using CFD, design an experiment that was appropriately scaled, build the experimental apparatus and then test for onset of natural circulation consistency with numerical predictions. Finally, the configuration was used to test the principle of Sustained Counter Air Diffusion and whether minimal injection of helium did prevent the onset of natural circulation such that it could be used to prevent the phenomenon in real reactors.

## 3.2 Apparatus Description

The test apparatus was an inverted U-tube with one leg heated with a pebble region and the other cooled, sitting atop a 55-gallon drum. The test apparatus was designed to be a scaled down version of the German NACOK test facility. A detailed description of the apparatus design process is given in Appendix A1. The inverted U-tube configuration

was chosen to be consistent with previous air ingress experiments in Japan summarized in Ref. [2] and Ref. [7]. The valves connecting the U-tube to the barrel simulate the rupture of a co-axial pipe with the pipe break directly beneath the core. Figure 5 gives a schematic of the test apparatus giving dimensions and showing the locations of the pebble column, thermocouples, and pitot tubes. The U-tube is connected to the barrel by large valves that are labeled as "big valves". The valves labeled "small valves" are where the helium was injected in order to fill the U-tube with helium.



**Figure 5: Full Apparatus** 

Thermocouples were used to monitor the temperatures of each leg, and Pitot tubes were inserted above and below the pebble region to measure the pressure difference across the pebbles. Helium was injected into the middle of the top horizontal cross-over leg, at the injection location shown in Figure 5.

The apparatus was made primarily of copper pipes with an inner diameter of 2.50 in. The hot and cold legs were connected to the horizontal crossover leg with copper elbows, and to the barrel with 2.5 in. full port valves. Opening the full port valves simulated the pipe break, and they will be referred to as the big valves. The purpose of the 55-gallon barrel was to prevent disturbances in the lab from affecting the pressure sensor readings. Electrical metal tubing (EMT) was bent and screwed to the top of the barrel to support the u-tube. A barrier was screwed and sealed to the inside of the top of the barrel to prevent helium from exiting the cold leg and traveling directly back to the hot leg.

Pure-type soda lime glass pebbles with a diameter of 1.2 cm were placed into the hot leg to represent fuel pebbles. The total pebble region was one meter tall and broken up into three equal parts for temperature monitoring purposes. As seen in Figure 5, thermocouples were placed before and after each pebble section at positions 1-4. Each section was supported with a piece of brass that had been water-jetted into a mesh to reduce its resistance. There were approximately 678 pebbles in each section, giving a porosity of 0.418. Due to jostling during the soldering process, the exact packing structure of a PBR could not be recreated; however this is close to the projected porosity in PBRs of 0.395.

The hot leg was heated with three silicone rubber fiberglass insulated flexible heaters, which were wrapped around the pebble sections and secured with metal hose clamps. These three heaters were plugged into a Variac voltage controller, which was adjusted throughout each trial to maintain the desired temperature of 200°C. Copper tubing with a diameter of 0.25 in. was coiled around the outside of the cold leg and fastened with metal hose clamps. Water was pumped through a Neslab FTC-350a refrigerator and into the copper tubing to cool the leg to 10°C. Thermocouples were placed at positions 5 and 6 in

Figure 5 to monitor cold leg temperatures. All thermocouples were inserted such that their sensing tips were in the center of the pipe. The entire u-tube was insulated with several layers of crinkled aluminum foil. There were enough layers that the hot leg could be touched without gloves; the rest of the apparatus was wrapped similarly.

Because of the low flow rate even after circulation starts, a flow meter would have been unreasonable to identify the start of circulation. The flow meters had 0.25 inch openings in the copper tubes which were 2.5 in. in diameter. This small opening would cause significant resistance and likely prevent circulation from ever starting due to the resistance offered. To be able to determine the time for onset of natural circulation, a different indicator was needed. As will be discussed later, CFD results showed the mass flow spike indicating the onset of circulation corresponds to a measurable change in pressure across the pebble region. Thus, Pitot tubes were screwed into the apparatus above and below the pebble region (at positions 1 and 4 in Figure 5) to monitor the pressure difference over this distance. An MKS Instruments, Inc. Baratron was used to sense the pressure and attached to a digital readout. The thermocouple positions were located above and below each heater, and at the top and bottom of the cold leg. High temperature room-temperature vulcanization (RTV) adhesive sealant held the thermocouples in place and sealed the holes. HP Benchlink Datalogger displayed the temperatures from the thermocouples.

The helium supply tank was attached to the apparatus with plastic tubing, and each end of the tube was fastened with a hose clamp. The tube was attached to a small valve to flush and fill the apparatus. The line also included a flow meter at the top of the apparatus during injection. The regulator kept the flow at a pressure of one atmosphere during the filling stage, and was varied according to injection rate during the injection stage.

#### 3.3 Experimental Procedure

#### 3.3.1 Experimental Preparation

To begin each trial, the u-tube was sealed from the outside environment and the walls were heated or cooled as necessary to the desired temperatures. The apparatus was then flushed with helium so that the tank pressure dropped by 200 psi which corresponds to approximately 0.101 kg of helium, or 67 times the mass that would fill the volume of the apparatus at standard temperature and pressure. (In one trial, the apparatus was flushed with 500 psi with similar results.) Because the primary goal of the experiment was to evaluate SCAD, the depressurization phase of the air ingress accident was neglected. Thus, the start of the experiment corresponded to the end of the blowdown phase when the pressure in the reactor equilibrates with containment. The hot and cold legs were heated to near 200° C and 10° C, respectively, and the helium was heated and cooled to these temperatures. At time zero, both the hot and cold leg big valves were open simultaneously allowing air from the 55 gallon drum to flow in. During injection runs, the helium injection started at the same time as the big valves on the end of either leg were opened.

#### 3.3.2 Measurement Description

The appropriate hot and cold leg temperatures were maintained by controlling the power to the heaters and cooler by monitoring the thermocouple data. When the temperature readings would begin to become too high or low, the power to the heater and cooler were adjusted accordingly.

As described previously, the pressure difference across the pebble column was used to monitor the onset of natural circulation. Thus, the differential pressure across the pebble column was monitored and recorded every several minutes and then at faster intervals when the pressure difference was changing relatively quickly. The Baratron pressure value was zeroed to the "cold" air hydrostatic head before the experimental preparation began. When the differential pressure value became negative, a frictional pressure drop was being experienced by the fluid as it flowed upward through the pebble column.

Thus, natural circulation was considered to start when the differential pressure reading became negative.

## 3.4 Project Results

## 3.4.1 CFD Results

FLUENT®, commercial CFD software, was used to simulate our setup to ensure that air circulation would start within several hours. A 3-D model was created and is shown in Figure 6. The three separate pebble sections are represented as one continuous pebble column equal to 39 in. in height. The pebble column walls and the walls of the upper heated section of the hot leg were held at 200°C while the cold tube walls were set to 10°C. The walls of the cross-over leg and both big valves were set as adiabatic. The barrel walls were set at 20°C. Appendix A2 provides a summary of the solver settings used in this model (referred to as the original model).

Nitrogen gas was used in place of air in the model to reduce computational complexity. The pebble column was modeled using the FLUENT porous media option. Initially, the upside U-tube was filled with helium at 1 atm and the barrel was filled with nitrogen at 1 atm. The initial temperature in each of the zones were 200°C in the upper heated region and pebble column, 50°C in the cross-over leg, 10°C in the cold tube, and 20°C in both big valves and the barrel.



Figure 6: FLUENT Computational Mesh

The FLUENT results are shown in Figures 7 to 9. Figure 7 depicts the nitrogen mole fractions at four different locations in the apparatus: the entrance and exit of the pebble column and the entrance and exit of the cold tube in Figure 6. Figure 8 shows the mass flow rate versus time and Figure 9 gives the pressure difference across the pebbles over time. Natural circulation starts at approximately 280 minutes as indicated by the mass flow spike at that time. The mass flow spike corresponds to the time when the apparatus becomes completely filled with nitrogen, as shown by Figure 7. The pressure difference across the pebble bed was positive, meaning that is the pressure was greater above the pebbles than below during the diffusion phase. At the onset of natural circulation, the pressure difference becomes negative because of the flow through the pebble bed.





Figure 7: Nitrogen mole fractions at apparatus boundaries



**Mass Flow** 

Figure 8: FLUENT results showing mass flow leading up to and at onset of natural circulation



Figure 9: FLUENT results showing change in pressure across pebble region leading up and at onset of natural circulation

#### 3.4.2 Experimental Data

#### **3.4.2.1 Air Only Trials**

In order to better appreciate the natural circulation process in this apparatus, several trials were performed. The first trials consisted of heating the air inside the apparatus on the hot leg and cooling the cold leg. Upon opening the two big valves, the pressure across the pebbles immediately dropped, indicating natural convection flow through the pebble column. Once the valves were closed, the differential pressure quickly returned to its original value. Opening any other combination of valves on the apparatus did not cause the same immediate change in the differential pressure reading. The different valve combinations remained open for several minutes and no indication of flow was seen from the pressure reading. The various valve combinations were as follows: opening the hot big valve and cold small valve, the cold big valve and hot small valve, both small valves, and only one big valve. With the two big valves opened natural circulation was indicated almost immediately, whereas none of the other combinations had the immediate natural circulation onset after the different valves were opened. This suggests that there is a correlation between break size and natural circulation onset time. Opening the big valves, immediately establishes a flow path for the hot air to rise, and then fall as the air is cooled in the cold leg. Even though a flow path existed with the small valves open, it was not sufficient to provide a circulation path immediately for the air and thus no flow resulted.

The air-only trials confirmed the use of monitoring the pressure difference across the pebble column as an indicator for the onset of natural circulation. During the heating phase transient, a pressure "bubble" would be created above the pebble column to counteract the buoyancy force to prevent flow, since no flow path existed. When both big valves were opened, the buoyancy force would overcome this pressure "bubble" because of the existence of an open flow path. The pressure difference across the pebbles would almost immediately become negative indicating flow upward through them. Any other combination of opened valves did not show the pressure difference becoming

negative, it would remain positive, meaning the pressure "bubble" was in place, and preventing the onset of natural circulation.

#### 3.4.2.2 Non-Injection and Injection Trials

A series of experiments were conducted to gain enough data to support findings on the air ingress phenomena. The first series of tests were aimed at developing a consistent data set on air ingress without helium injection. Five tests were conducted without helium injection which showed consistent behavior in terms of the onset of natural circulation. This was followed by a series of tests in which helium injection of various rates was tested to determine whether it prevented the onset of natural circulation. The last series of injection tests was aimed at establishing a minimum injection rate within the limits of the measuring device. In all 11 tests were run -6 non-injection and 5 injection.

Figure 10 is a plot of all data taken during the experiment of non-injection and injection trials. Note that the  $\Delta P$  in Figure 10 is a "zeroed" differential pressure, meaning a value of zero corresponds to the room temperature air hydrostatic head before the start of the experiment. Thus a negative value means a pressure difference across the pebble column greater than the room temperature air hydrostatic head. The absolute pressure difference is then approximately 15 Pa less than the Figure 10 reported value. The important point of Figure 10 is that the differential pressure behavior indicative of natural circulation onset (the  $\Delta P$  drop) only occurred in non-injection cases. All injection cases did not show that same  $\Delta P$  drop behavior, therefore natural circulation never started in any of the injection cases.

The average natural circulation onset time for the non-injection trails was 117 minutes with a standard error of 7 minutes. Injection trials were run for at least 240 minutes, approximately twice the length of time that non-injection runs were run. One lasted for 480 minutes. Natural circulation did not start at any injection rate at or above 1 cc/min, the minimum rate we could measure.



Figure 10: Results of all injection and non-injection trials. Red triangles show the end of the trial in injection runs

In two of the injection runs, data was taken after the injection was turned off. Though the pressure began to drop at different times, the onset time for both was about 120 minutes after injection was turned off as shown in Figure 11. This clearly shows the effectiveness of minimum helium injection as a means to avoid massive air ingress by eliminating or at least significantly delaying natural circulation.



Figure 11: Time until onset in injection trials after injection has been stopped

#### 3.4.2.3 Post-Leak Fixes

After construction on the apparatus was completed, a leak test was performed on the utube. No leaks were found in the simple leak test. After multiple trials a second leak test was performed and a leak was found at one of the thermocouple locations. The thermocouples were only sealed by RTV and it is possible that during the filling process the high velocity helium could have dislodged a proper seal. The leak was fixed and several more non-injection cases and an injection case at 2 cc/min were performed. The subsequent non-injection cases had the longest onset times at approximately 140 minutes each. But, one of the trials showed the pressure difference begin decreasing at a similar time as the previous cases, but showed natural circulation onset about the same time as the other post leak fix case. Thus, the case seems to have enveloped the entire spectrum of conditions in the pre and post leak fix cases. Since the onset time difference was only an additional 20 minutes, it was felt then that the leak had a small impact on the results. The 2 cc/min case performed after the leak was sealed was run for about 4 times as long as the average onset time (approximately 480 minutes) and natural circulation was never developed.

# 4. FLUENT Analysis Discrepancy

Although the experimental data suggests that SCAD does indeed prevent the onset of natural circulation, the FLUENT results over-predicted the natural circulation onset time by over a factor of 2. This point is illustrated by comparing the experimental data, Figure 10, to the FLUENT differential pressure results of Figure 11. The average onset time for the experimental data was about 120 minutes, while the numerical model predicted onset at around 280 minutes. It is important to reconcile the differences in the FLUENT model to allow the CFD results to better reflect the experimental data for a deeper understanding of important phenomenon. The original FLUENT model was created before the experiment was conducted in order to give an estimate for how long the experiment would last. Because of this, the boundary and initial conditions were very simple and ultimately did not accurately reflect those of the experiment. Determining the conditions that were not properly represented will therefore provide further insight into the causes and important parameters that impact the onset of natural circulation. Once the computational model discrepancies are resolved, the evaluation of the validity of SCAD can be more thoroughly examined.

# 5. Contributions of Current Work

Understanding how to model the development of transient natural convection in a postulated HTGR air ingress accident scenario is important. The flow is dictated by the competing buoyancy effects of thermal and concentration gradients. In general, such flows are classified double-diffusive convective flows with combined heat and mass transfer, and thus this research provided insight into proper modeling techniques for this class of flows in commercial CFD software, specifically FLUENT. The impact of various solver settings, controls, initial, and boundary conditions on the flow field behavior and natural circulation onset were evaluated. The most appropriate settings were therefore determined for this class of flows.

The investigation process into improving the computational model also provided further insight into the mechanisms that affect the onset of natural circulation. The important driving parameters were then quantified in terms of non-dimensional numbers that provided relative strengths between different cases. Looking at the flow field non-dimensionally, provided insight into why the original FLUENT model over predicted the onset time.

The current work also provided further insight into SCAD for a PBR. The effectiveness of SCAD on preventing/delaying natural circulation onset was investigated and compared in non-dimensional terms to provide insight for a full scale PBR case. A methodology was formulated in order to determine an empirical correlation for the minimum injection rate required to prevent the onset of natural circulation. That methodology will be described.

# 6. Improvements to Previous CFD Model

#### 6.1 Overview

The following discussion describes in detail the various attempts made in trying to improve the computational model to better reflect the experimental data. The different attempts can be broken into two basic classes, boundary conditions and initial condition changes. Boundary condition changes attempted to better reflect the experimental boundary conditions that were not represented by the initial very simple computational model. The boundary condition investigation examined the impact of the porous media model in FLUENT as well as the use of heat flux wall conditions and more accurate temperature wall profile compared to simple constant wall temperature conditions.

Investigating improved initial conditions was an attempt to accurately account for the heating phase that occurred before opening of the big valves to start the experiment. A full heating phase transient was simulated in the u-tube and used then used as the initial conditions for a full transient simulation. The heating phase transient allowed the initial conditions to capture detailed local circulation loops and non-uniform pressure fields that

were not accounted for in the original initial conditions. The initial helium fraction in the u-tube was also varied to account for the uncertainty in that there was no way to monitor the helium concentration in the u-tube in the experiment.

The investigation concluded that of the various changes examined only the initial u-tube helium fraction had significant impact on the natural circulation onset time. As will be discussed later, any changes to the original model improved the results only up to the point of more closely following the diffusive transport rate in the hot leg and could not decrease the natural circulation onset time by more than 40 to 50 minutes (so onset occurred around 230 minutes rather than 280 minutes). However, lowering the initial helium fraction only 15% in the u-tube decreased the onset time from approximately 280 minutes to about 126 minutes. Because the initial helium fraction in the u-tube was unknown and was not able to be measured given the budgetary constraints on the experiment, it is felt that these results show that the U tube did not contain 100% helium at the start of the tests. The implications of such initial conditions will be discussed later.

## 6.2 Boundary Conditions

#### 6.2.1 Porous Media Models

In FLUENT, it would be computationally unreasonable to model the pebble column as an explicit packed bed. Therefore, a porous media model assumption was used to model the pebble column. Previous studies, including Yan's work modeled the prismatic cores as porous media as well. In FLUENT the user must specify the solid material present in the porous media, which impacts the calculation of the heat transfer properties as well as the porosity of the media. The governing momentum equation is modified by including an additional momentum sink term to account for the added resistance of the porous media. There are several different momentum sink models to use. The choice of momentum sink model as well as values used in the model impact the resistance experienced by the flow from the packed bed. Therefore, a sensitivity study was performed on FLUENT's

porous media model to determine if the model could be impacting the onset of natural circulation.

The original model used the Power Law model, which was consistent with how Brudieu [2] modeled the pebble column in the NACOK experiments. The Power Law momentum sink model is given by:

$$S = -C_0 |u|^{C_1}$$

Equation 2

where:  $S \equiv$  momentum sink term,

 $u \equiv$  fluid velocity [m/s],

 $C_0$  and  $C_1 \equiv$  pressure loss coefficients [6].

The pressure loss coefficients therefore set the resistance to the flow for the porous zone. The original model used the values determined by Brudieu for 10 mm diameter pebbles,  $C_0 = 341$  and  $C_1 = 1.6107$ . However, the pebbles used in the experiment were 12 mm diameter pebbles. Using the given values would then give an effective pebble column resistance for 10 mm pebbles, which would be greater than the resistance for a bed of 12 mm pebbles. In the original pre-experiment model, it was assumed that the increased resistance would be small and may account for additional losses not accounted for in the model.

To check the porous media model, two additional tests of the effect of porous media model were made. First the viscous loss coefficient model was used instead of the power law model, and in the second the porous media model was not used. In the latter case, the pebbles are effectively removed and an open hot leg exists offering no additional resistance to flow. This would provide a lower bound on the resistance experienced in the hot leg and should bound the onset time prediction, if the porous media model has a substantial impact on the computational results.

In the viscous loss coefficient model, the momentum sink term is given by:

$$S = -\left(\frac{\mu}{K}u + C_2 \frac{1}{2}\rho|u|u\right)$$

**Equation 3** 

where:  $\mu \equiv$  fluid viscosity [Pa-s],

 $K \equiv$  porous media permeability  $[m^2]$ ,

 $C_2 \equiv$  inertia loss coefficient [1/m],

 $\rho \equiv$  fluid density [kg/m<sup>3</sup>].

The inertia loss coefficient accounts for added loss from turbulence present through the porous media. Note that for low velocity flows it will have only a small contribution on the momentum sink term and the momentum sink term is simply Darcy's law through porous media. The permeability and inertia loss coefficient are dependent on the geometry and type of porous media. However, for a packed bed, they are easily calculated from:

$$K = \frac{D_p^2 \varepsilon^3}{150(1-\varepsilon)^2}$$

**Equation 4** 

$$C_2 = \frac{3.5(1-\varepsilon)}{D_p \varepsilon^3}$$

**Equation 5** 

where:  $D_p \equiv$  pebble diameter [m],

 $\varepsilon \equiv$  pebble bed porosity.

The original FLUENT model assumed the pebble bed porosity of 0.395 while the actual experiment was above 0.4. For the experiment, the calculated values of the permeability and inertia loss coefficient are:  $K = 1.7067e-7 [m^2]$  and  $C_2 = 2734$ . Since the momentum sink therefore essentially scales with the inverse of the permeability, looking at 1/K for the actual experiment and original FLUENT model gives an idea of how much extra resistance was seen by using the 10 mm pebble assumption. The 1/K value for experiment is:  $1/K = 5.86e6 [m^{-2}]$  while for the original FLUENT model it was:  $1/K = 8.91e6 [m^{-2}]$  (calculated assuming the pebbles were 10 mm with porosity of 0.395).

Thus, the original FLUENT model was about 1.5 times more resistant the actual experimental model.

A FLUENT transient was then re-run with the change to the viscous loss coefficient model as well as the case with no porous media used. The initial conditions and solver settings and schemes were consistent between the original model and the case with no pebbles. The case with the viscous loss model also included changes to solver settings and schemes using higher order schemes and is provided in Appendix A2. The results of the three cases will be compared by examining the behavior of the average helium mole fraction in the cross-over leg. Even though this quantity was not measured, observing its behavior gives insight into the transport rate of nitrogen up the hot leg as well as how that transport rate is changing with time. Looking at the results in this manner therefore assumes once natural circulation starts the cross-over leg helium mole fraction will quickly drop to low values (only a few percent at most).

Figure 12 gives the transient behavior of the average helium mole fraction in the crossover leg for each case. The original FLUENT case results show that when natural circulation starts at about 280 minutes, there is a sharp drop in the helium mole fraction in the cross over leg from about 15% to about 5%. Also note that later on in the transient the rate of nitrogen transport up the hot leg (and so rate of decrease in helium mole fraction in the cross-over leg) increases. The increased transport rate corresponds to the increasing buoyancy force that arises as the configuration gets closer and closer to the onset of natural circulation. The key point of Figure 12 is that the tested porous media cases have very similar transport rates of nitrogen through the u-tube in the first few hours. The no pebble case curve almost exactly follows the original results, while the viscous loss model curve is slightly faster. The slightly different behavior of the viscous loss model case can be explained from the higher order schemes and settings that were applied to this particular case.

Both modified cases were not run out to the onset of natural circulation because the goal of the investigation was to see if the porous media model was impacting the FLUENT

results relative to the experimental data. For the FLUENT results to better match the experimental results, the cross-over leg average helium mole fraction would have to drop to a few percent by about 120 minutes, and not 280 minutes. Since both cases were greater than 80% helium in the cross-over leg by about 2 hours, it was obvious that the porous media model in FLUENT had no major impact on the transport rate of nitrogen during the first few hours and thus do not meaningfully affect the analysis of the onset to natural circulation.





Figure 12: Porous Media Investigation Cross-Over Leg Helium Mole Fraction Comparison

#### 6.2.2 Heat Flux Boundary

The original FLUENT model used a constant wall temperature boundary condition in the hot leg. In reality, however, the power to the externally wrapped heaters was controlled to try and maintain the average gas temperature in the hot leg to be near 200 °C. Thus, higher temperature gas would be located near the walls which could rise at an increased rate than accounted for in the original model. Therefore, to account for this another

FLUENT simulation was run with the pebble column wall set as a heat flux boundary condition.

The experiment consisted of three heaters, and once the hot leg was heated usually the second heater as turned off, so only the bottom and top heaters were required to maintain the temperature. To ease the computational expense, a time-averaged constant wall heat flux was used for the single pebble zone in the computational model. The new heat flux boundary condition model also used the same initial temperature conditions of the original model. A temperature of 200 °C was used in the pebble column. The solver settings and schemes for the heat flux boundary condition case are provided in Appendix A2.

The heat flux simulation did show that the gas was rising faster along the walls, as expected. However, the gas temperature in the pebble column was getting far too high too quickly. Within five minutes, the average temperature in the pebble column was about 330 °C. Continuing to run the transient would have only heated the gas to higher temperatures, and so would have not been accurately modeling the conditions of the experiment. Therefore it was decided that continuing running these simulations was unnecessary.

This exercise therefore suggests if a heat flux boundary condition is desired, accurate temporal and spatial variation in the heat flux is required. In the experiment, with the second heater turned off, even though insulation was wrapped around that part of the hot leg, some heat would have escaped and without knowing the flow rate beforehand it would be very difficult to calculate the heat loss in that portion. Also, adding in proper temporal variation to match the experimental procedure would have complicated the model even further. Using even a simple constant wall heat flux, that is constant in time, required more iterations per time-step and longer processing time per iteration compared to the original model. Therefore to even run the simulation for five minutes of simulation time took considerable longer processing time than the original model. Considering a full scale PBR, using a heat flux boundary condition would then drastically increase the

computing time compared to a simple temperature boundary condition, and so this investigation suggests any improvements to modeling would not justify the increased processing time.

#### 6.2.3 Accurate Temperature Profile

The thermocouple data from the experiment showed that the temperature profile in the hot leg was in fact not a constant axial temperature, but rather varied up the hot leg. Using a constant wall temperature boundary condition, the original FLUENT model would not be able to account for this. A user defined function (UDF) was therefore created to accurately describe the thermocouple data from the experiment. The UDF is given in Appendix A4. This UDF was then set as the pebble zone wall boundary condition in a FLUENT case. The initial temperature profile UDF was a cubic best fit line of the thermocouple experimental data.

Results from this updated temperature boundary condition case showed minimal change to the original FLUENT model results. After 40 minutes, the nitrogen transport rate up the hot leg was consistent with the original model. Again, the model was not run until the onset of natural circulation because doing so would have yielded little insight as to why the transport of nitrogen was proceeding slower than it should in the first few hours.

The reason this case was not providing any significant changes is actually very simple. Figure 13 shows the plot of the UDF best fit temperature profile compared to the constant wall temperature condition versus pebble column height. Only the lower third of the pebble column deviated from the constant wall temperature condition by any significant amount, and this deviation made the lower third of the column at a lower temperature. Thus, the more accurate temperature profile would not provide any means to increase the nitrogen transport rate within the first few hours.

Pebble Column Temp. Distribution



**Figure 13: Temperature Profile Comparison** 

Overall, the investigation into the effect of boundary conditions on the natural circulation onset time showed that more accurate boundary conditions provided little improvement to the computational results. Modifying the boundary conditions had little impact on accelerating the rate of nitrogen transport up the hot leg to allow natural circulation to start sooner, as the experimental data showed. The lack of insight gained from examining the boundary conditions facilitated the investigation of the impact on natural circulation onset from the initial conditions.

## 6.3 Initial Conditions

#### 6.3.1 Full Heating Phase Transient

The original FLUENT model used very simple initial conditions for pressure, velocity, and temperature inside the u-tube. Again, this was because the original FLUENT model was run before the experiment and so were only very rough estimates for what the initial
conditions could be. The original initial pressure field was set to equal pressure everywhere at 1 atm. The original initial velocity field was set to zero everywhere as well. The initial gas temperatures were simply constant temperatures in the different zones.

As described earlier, a heating phase took place before the start of the experiment. The heating phase created the pressure "bubble" described earlier, where the pressure was higher above the pebbles than below. Although, the original FLUENT model, computed a pressure "bubble" early on in the transient, it would not be able to predict any possible over-pressurization that could occur during the heating phase. The over pressurization could have forced out helium out the hot and cold legs when the big valves were opened up that helped draw in air faster due to the depressurization transient.

A heating phase transient simulation was therefore run in FLUENT to account for the dynamics during this period. The experimental heating phase took about an hour, so the simulation lasted for about an hour as well. Single phase helium was used as the working fluid inside the u-tube for the heating phase transient. The u-tube mesh was refined, since the barrel was not part of the simulation, the u-tube could have a much finer mesh than the original at no significant cost to memory. Also, the u-tube bend geometry was improved, from a simple 90° bends in the original mesh, to more accurately representing the curved bends on the apparatus. The improved u-tube mesh is displayed in Figure 14, with the different zones in different colors. To try and setup accurate thermal gradients, the pebble column wall temperature UDF was used as the boundary condition for the pebble column wall as well.



**Figure 14: Heating Phase Transient Mesh** 

Heating phase transient results showed considerable pressurization inside the u-tube. The maximum pressure at the end of the almost one hour simulation was 10.6% higher than atmospheric pressure. The pressure profile followed the trend of the experimental pressure "bubble" where the pressure was higher above the pebbles than below. However, the magnitude was much smaller in the new simulation results, with pressure difference of only about 1 Pa instead of about 15 Pa. The pressure contours inside the u-tube are shown by Figure 15. The maximum pressure, as seen in Figure 15 is located at the bottom of the cold leg. This plot suggests then that the pressure "bubble" effect, where the pressure increases axially up the hot leg forms to counter-act the buoyancy force driving the flow. Inside the cold leg however, the density of the fluid still creates a static head that increases the pressure axially down the cold leg.



Figure 15: Pressure Contours at End of Heating Phase Transient

The results also exhibit considerable local circulation through the cross-over leg. Smaller local circulation loops also exists at the interface between the hot leg big valve and the pebble column as well as at the big valve interface in the cold leg. However, the velocities of these circulation loops are small relative to the velocity magnitude in the cross-over leg circulation loop. The circulation loop inside the cross-over leg is driven by the temperature gradient that exists between the hot and cold leg. The temperature in the cross-over leg decreases from near the hot leg temperature down to the cold leg temperature. Figure 16 shows the plot of the cross-over leg velocity vectors and Figure 17 shows the temperature contours in the u-tube. The large white arrows in Figure 16 show the direction of the circulation loop. The colder gas is on the bottom side of the cross-over leg and traveling to the right and the hotter gas is above it traveling to the left.

-		[m/s]
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1100		
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	6.12e-03	
		<del>Ζ</del> χ
	4.14e-09	

Figure 16: Cross-over Leg Circulation Loop



Figure 17: Temperature Contours at End of Heating Phase Transient

#### 6.3.1.1 Effect of Heating Phase Transient

The results of the heating phase transient were then used as the initial conditions for a full transient simulation including nitrogen inside the barrel. The flow field behavior up to about 0.01 seconds was dominated by the over-pressurization in the u-tube that forced flow down through the hot and cold legs. Most of the flow was forced out the cold leg, due to lower resistance in the cold leg than the hot leg. The pressure difference across the pebble column was as high as about 350 Pa during the depressurization portion of the transient. By about 0.01 seconds however, the pressure fluctuations dampened out and the pressure field returned to the pressure field normally computed by FLUENT.

Due to the u-tube over-pressurization, the calculated gas velocity out the cold leg got as high as 55 m/s. It is believed that if there was gas flowing at those speeds out the cold leg it would have been noticeable during the experiment. Also, during the experiment, when the big valves were opened, no pressure fluctuations were indicated across the pebble column and the pressure difference was never more than 15 Pa. Therefore, the experiment suggests that if there was any over-pressurization in the u-tube, it was not nearly as high as that computed by FLUENT during the heating phase transient. Thus, if over-pressurization would impact the results, accounting for such behavior would not be similar to the conditions in the experiment.

### 6.3.1.2 Effect of Initial Pressure Field

Although the calculated heating phase transient did not accurately reproduce the magnitude of the pressure "bubble" seen in the experiment, it did compute similar trend in the axial change in the pressure up the hot leg. Therefore, to see if the initial pressure field could have an impact on results, the pressure profile from the heating phase transient was scaled to better match the experimental results. Since over-pressurization is not an issue, the pressure field was input with 1 atm at the base of the hot leg. Any simulations run with this as the initial pressure field showed that within a few time-steps the pressure field would dampen out to the usual pressure field. Thus, the initial pressure field does not seem to have any impact on results later on in the transient.

### **6.3.1.3 Effect of Initial Local Circulation Loops**

The effect of initial local circulation loops was evaluated by examining how long it would take FLUENT to predict the circulation loops to develop from a zero velocity field. Since the cross-over leg circulation loop is dictated by the thermal gradient in the cross-over leg, the set up time depends on the set up time for the thermal gradient to be established in the cross-over leg. Cases that used a more realistic temperature profile in the cross-over leg could establish a circulation loop within a few minutes. Cases that set the initial cross-over leg temperature to the hot leg temperature, would take slightly longer. But by 5 to 10 minutes, the circulation loops would be developed. Since the original FLUENT model was more than about 2.5 hours off in the estimate of natural circulation onset, 10 minutes is trivial and therefore, using an initial velocity field of zero everywhere has minimal impact on the natural circulation onset time.

### 6.3.2 Choice of Operating Density

During the investigation into the pressure field, an interesting point of concern was found for how FLUENT calculates the pressure in buoyant flows. When gravity is enabled in FLUENT, a change of variables is applied to the pressure field, as follows:

$$p' = p - \rho_0 gz$$

**Equation 6** 

where:  $p' \equiv static pressure [Pa]$ ,

 $p \equiv absolute pressure [Pa],$ 

 $\rho_0 \equiv$  operating density [kg/m<sup>3</sup>],

 $g \equiv$  gravitational acceleration [m/s<sup>2</sup>],

 $z \equiv$  coordinate in the direction of gravity [m].

The static pressure is used for boundary conditions and post-processing [6]. This technique avoids round-off error and simplifies the setup of pressure boundary conditions. When this change of variables is applied to the momentum equation in the direction of gravity, the body force is therefore calculated as:

 $(\rho - \rho_0)g$ 

#### Equation 7

In natural convection flows, the gravity body force is the driving mechanism for fluid motion. The choice of operating density, therefore, can impact the relative strength of the buoyant force acting on the fluid. Using the correct operating density is thus important to accurately compute the behavior of the flow field in buoyant driven flows.

In the original model, no operating density was set, so the default operating density was used. In FLUENT, the default operating density is the average fluid density through the space. Since the barrel is roughly 20 times larger in volume than the u-tube, the average density is roughly the nitrogen density at room temperature. With helium inside the u-tube for most of the transient, in the u-tube, the operating density is greater than the density in a specific cell volume. Thus, the direction of the gravity body force will be reversed inside the u-tube. The original model, as described earlier, predicted a similar pressure "bubble" effect, witnessed in the experiment, early in the transient. However, in light of the operating density effect, the pressure field was not the result of correctly predicting a pressure "bubble" to counteract the buoyancy force, but rather resulted from a reversed gravity body force. Thus, the fact the pressure increased axially with elevation in the u-tube was because that was the stable hydrostatic condition in the u-tube.

To check this, a case was run with the operating density set to 0 kg/m<sup>3</sup>. The gravity body force will then simply be the density in a particular cell. Figure 18 shows results of the pressure field for the case with operating density of 0 and the original case (default operating density) at similar times (about 10 minutes). The original case is on the right and the peak pressure is in the top of the cross-over leg. However, the case with an operating density set to 0 has the pressure increasing with decreasing elevation with the highest pressure located at the bottom of the barrel. One striking feature of the original case is the almost constant pressure in the barrel. Later cases that used improved solver settings and schemes relative to the original case would also show the pressure increasing

with decreasing height in the barrel and the pressure increasing with increasing height in the u-tube. This confirms that the gravity body force is reversed in the original model.



Figure 18: Pressure Profile Comparison Between Different Operating Densities

To see how this pressure field impacts the onset of natural circulation, the case was run for about 220 minutes. The results are compared in Figure 19 against the original model and the loss coefficient case with higher order schemes from section 6.2.1. Again, the average helium mole fraction in the cross-over is used to compare the transport rate of nitrogen between the different cases. As seen in Figure 19, even with the operating density set to 0, there is little difference in the nitrogen transport rate over the first few hours. If the transient had been continued, judging from the results, natural circulation would probably have started about half an hour sooner than the original results. The case

with 0 operating density has similar solver settings and schemes to the case with the loss coefficient, than to the original case. Therefore, it makes sense that the original case behaves the least like the other two.





Figure 19: Cross-Over Leg Helium Mole Fraction Comparison

Thus, even though the choice of operating density can have a significant impact on the pressure field behavior, it has minimal impact on the nitrogen transport rate during the first hours of interest. Because of this, it was decided to keep using the default operating density since it better represented the experimental pressure "bubble" during the transient.

### 6.3.3 Helium Concentration

The original FLUENT model and all previously described cases assumed 100% helium initially in the u-tube. However, during the experiment there was no way of measuring the helium concentration in the u-tube. The filling process, described earlier, simply passed through a certain volume of helium and assumed then that the u-tube was almost entirely helium. The fill valves were small, 0.125 in. diameter valves located above the

big valves on both legs. The helium was passed through the hot side fill valve and the gas flowed out the cold side fill valve. It was therefore impossible to know the amount of air purged out through the cold side fill valve.

A case was run using an initial helium fraction of 85% in the u-tube. The gas was assumed to be a uniform gas mixture. In reality, the filling process would have left air concentration gradients through the u-tube. Thus, at the start of the experiment helium-air diffusive transport would have been already occurring locally throughout the u-tube. Using a uniform gas mixture is a simple way to test the impact of higher initial air (or in FLUENT's case nitrogen) content in the u-tube. The initial helium fraction of 85% was chosen because in previous cases it would take about 2 hours for the cross-over leg helium mole fraction to drop 15-20%. It would be interesting to see then if starting at 15% nitrogen already throughout would bypass the first few hours of the transient. The case used simple initial temperature conditions and simple boundary conditions with equal pressure field everywhere and zero velocity field everywhere to start.

The results for the case using 85% helium initially showed that natural circulation started around 126 minutes. Figure 20 shows the plot of the mass flow rate versus time in the hot leg and Figure 21 shows the pebble column pressure difference versus time. Again, the pressure drop across the pebbles corresponds to the mass flow spike in the hot leg. The behavior of the pressure difference does not correspond to the experimentally recorded behavior, but the onset time of natural circulation is within the variation of the experimental data as seen by the dashed red lines of Figure 21. Note the time axis is 20 minutes longer in Figure 21 than 20.

### 85% He case: Hot Leg Mass Flow Rate vs Time









Figure 21: 85% Helium Case Pebble Column Pressure Difference

Reducing the initial helium fraction just 15% in the u-tube causes the onset time to be reduced from 4 hours closer to the 2 hour experimental onset time. Because of this, it is felt that the u-tube was therefore not at 100% helium initially, but at a lower helium fraction. The actual helium fraction distribution in the experiment, although not a uniform gas mixture, must have created an effect similar to having a uniform gas mixture at 85% helium fraction initially.

## 6.4 Justification for Change

As described previously, there was no way measure the helium concentration in the utube. Therefore, it was impossible to tell the difference between 100% helium in the utube compared to 90%, 85%, or even 70%. Changing the initial helium fraction is therefore within the uncertainty of the experiment. Also, the computational model shows that indeed the u-tube was mostly helium after the helium filling process. Varying the initial helium fraction was the last change attempted because it was initially assumed that considerable amounts of nitrogen would have to be in the u-tube initially for the onset time to be reduced by an appreciable amount. To get an idea for how only small changes in initial helium fraction can impact the onset time in large ways, the transport rate between cases will be compared.

The average helium mole fraction in the cross-over leg will again be used to compare the different cases. The original FLUENT and the 85% helium case will be compared as well as an additional case that used a higher continuity convergence tolerance than the original model (this case will be referred to as Update A). Again, the solver settings for Update A are given by Appendix A2. Figure 22 shows the average helium mole fraction in the cross-over leg for the different cases, along with the mole fraction computed using a 1-D analytical solution to the diffusion equation. The 1-D diffusion equation was solved using a Matlab script, and is given in Appendix A3. Update A uses the same initial boundary conditions as the original case. Examining Figure 22 shows that Update A follows the behavior of the analytical diffusion solution very well. For almost three-quarters of the transient, Update A follows the diffusive transport trend. Then at some point the buoyancy force begins to boost the transport rate and so Update A diverges

from the analytical diffusion equation. The original case actually proceeds at a slower rate than pure diffusion, therefore the solver schemes must have been affecting the transport rate to actually slow down the transport rates in the original model. Obviously, the 85% helium case starts at a lower initial fraction of helium, but as shown in the figure, the transport rate is higher over the initial hour, and steadily increases over the duration of the transient until the onset of natural circulation.



Average He Mole Fraction in Cross-Over Leg Comparison

Figure 22: Cross-Over Leg Helium Mole Fraction Comparison

Therefore, any of the changes being made to the original model, were effectively pushing it to converge to the diffusive transport rate for a majority of the transient. That is why none of the previous investigations performed showed any considerable change to the transport rate over the first two hours. The buoyant driven flow for 100% helium initially therefore has negligible contribution over the first several hours, and transport is diffusion dominated. Only much later in the transient, when more nitrogen (and thus air) is in the u-tube, does the buoyant driven flow begin to contribute and increase the transport rate.

The 85% helium initial case however, has a constantly increasing nitrogen rate leading up to natural circulation. This suggests that transport is mixed between diffusive mass transport and thermally driven buoyant flow. By starting with a lower helium fraction initially, the lengthy diffusion dominated transport phase was bypassed and flow is a mixed transport for basically the entire transient. The increased nitrogen transport rate due to mixed transport causes the onset time to then be cut in half compared to pure diffusion transport with 100% helium initially.

Past studies, investigating similar phenomena showed good agreement between experimental data and numerical results, [2] [5] [7] [8]. FLUENT was used by References [2], [5], and [7] to model air ingress in upside down u-tube configurations. Brudieu [2] modeled the large NACOK facility while References [5] and [7] modeled smaller scale experiments. Takeda [8] however used a 1-D finite difference solver to simulate the governing equations of mixture continuity, mixture momentum and species continuity. Even though the 1-D finite approach of Takeda did not have the complexity of FLUENT, the numerical solution predicted the experimental data very well. Thus, it is not unreasonable to feel that numerical methods are more than capable of predicting the natural circulation onset time with reasonable accuracy, as long as the experimental conditions are properly modeled. Modifying the initial helium concentration in the utube was within the uncertainty of the experiment. Therefore, it is concluded that decreasing the initial helium concentration only 15% more appropriately modeled the conditions of the experiment which allowed the CFD results to better match the experimental data for natural circulation onset time.

# 7. Non-Dimensional Analysis

## 7.1 Formulation

The previous discussion details that there exists three distinct transport phases leading up to natural circulation. The first is diffusion dominated transport, followed by mixed transport between diffusion and buoyant driven convection, and the last being buoyant

driven convection dominated transport. Once the last phase is reached, natural circulation through-flow in the apparatus is achieved. Figure 22 displayed this phenomenon in the differences between the Update A case and the 85% helium initial case. Update A, shifts after a majority of the transient from diffusion dominated to mixed, to then natural convection dominated. However, the 85% helium initial case begins at a more mixed transport rate and steadily increases to natural convection dominated. To try and characterize the relative strengths of the buoyant driven convection flow, a non-dimensional analysis was performed.

There are two ways to characterize the problem; the first is considering the mechanisms that determine the onset time of natural circulation. Such a method depends on the mass and heat transfer rates that dictate the properties in the flow field. Another method is similar to a pseudo steady-state approach, where the flow rate is evaluated for a given driving density difference. Thus, this approach does not examine what is causing the driving density difference to change over time, but rather simply characterizes the influence the driving density difference has on the flow rate. The non-dimensional analysis will therefore be formulated in such a manner.

The driving density difference between the hot and cold leg therefore must balance out the viscous forces through the u-tube. Neglecting all viscous losses except through the pebble column and assuming laminar Darcy flow the mass flux through the u-tube is given by:

$$G = \frac{(\overline{\rho}_c - \overline{\rho}_h)gHK}{\overline{\upsilon}_h h}$$

**Equation 8** 

where:  $G \equiv mass flux$ ,

 $\overline{\rho} \equiv$  average density per channel (c and h denote cold and hot leg, respectively), g  $\equiv$  gravitational acceleration, H  $\equiv$  hot leg height,

 $K \equiv$  pebble bed permeability,

$$\overline{\nu}_h = \frac{\overline{\mu}_h}{\overline{\rho}_h}$$
, average kinematic viscosity in the hot leg,

 $h \equiv$  height of pebble bed.

The Buckingham Pi theorem was used to determine the non-dimensional parameters. There are eight variables, with a total of three dimensions, so five non-dimensional parameters exist.

### 7.2 Important Parameters

The five non-dimensional parameters are given by Equations 9-11 and 13-14:

$$\Pi_G = \frac{G^2 K}{\overline{\mu}_h^2}$$

**Equation 9** 

Equation 9,  $\Pi_G$ , gives the ratio between the mass flux to viscous forces through the hot leg.

$$\Pi_B = \frac{KH(\Delta\overline{\rho})g}{\overline{\upsilon}_h\overline{\mu}_h}$$

**Equation 10** 

The non-dimensional buoyancy force,  $\Pi_B$ , relates the driving buoyancy force between the hot and cold legs to the viscous forces in the hot leg. Equation 10 is consistent with Darcy modified Grashof numbers for natural convection in porous media [9].

$$\Pi_{DR} = \frac{\Delta \overline{\rho}}{\overline{\rho}_h}$$

**Equation 11** 

Equation 11,  $\Pi_{DR}$ , gives the density ratio between the driving density difference and the average hot leg density. The density ratio describes the contribution of hot leg density to the driving density difference. A higher driving density difference corresponds to having a higher buoyancy force. The density ratio therefore quantifies the changes in the driving

density difference relative to the hot leg. Re-writing the density ratio best explains this concept:

$$\Pi_{DR} = \frac{\Delta \overline{\rho}}{\overline{\rho}_h} = \frac{\overline{\rho}_c - \overline{\rho}_h}{\overline{\rho}_h} = \frac{\overline{\rho}_c}{\overline{\rho}_h} - 1$$

**Equation12** 

As the density in each leg changes over time, if the hot and cold leg densities change at similar rates, the density ratio will remain roughly constant.

The last two non-dimensional parameters are geometry considerations. Equation 13 gives the non-dimensional height and Equation 14 gives the non-dimensional permeability of the pebble bed.

$$\Pi_h = \frac{H}{h}$$

**Equation 12** 

$$\Pi_{K} = \frac{K}{hH}$$

**Equation 13** 

Following the Buckingham Pi theorem, solving for the mass flux can then be reformulated as a function of the non-dimensional parameters, given as:

$$\Pi_G = F(\Pi_B, \Pi_{DR}, \Pi_h, \Pi_K)$$

### **Equation 14**

Thus, for given  $\Pi_B$ ,  $\Pi_{DR}$ ,  $\Pi_h$ , and  $\Pi_K$ , a certain value of  $\Pi_G$  exists. Diffusion dominated transport would then correspond to low values of  $\Pi_B$  and  $\Pi_{DR}$  which gives a low value of  $\Pi_G$ . Mixed transport would correspond to more moderate values of the non-dimensional parameters, since the transport rate corresponds to a combination of both diffusion and buoyant driven flow.

Relating this concept to the onset of natural circulation, the non-dimensional mass flux,  $\Pi_G$ , spikes when the mass flux spikes. Therefore, certain "critical" non-dimensional buoyancy and density ratio values must exist for a given non-dimensional geometry. The "critical" values correspond to the transition from mixed transport to natural convection dominated transport.

# 7.3 Case Comparison

The 85% helium case non-dimensional parameters are compared to the Update A case non-dimensional parameters. The non-dimensional mass flux is given by Figure 23, the non-dimensional buoyancy by Figure 24, and the density ratio by Figure 25. The first point of interest amongst the different figures is that both cases show parameter value spikes near similar value. Also, both cases show  $\Pi_G$  spiking when  $\Pi_B$  and  $\Pi_{DR}$  also jump up several orders of magnitude. Therefore, both cases seem to be exhibiting similar behavior in the transition from mixed transport to natural convection dominated transport which corresponds to the onset of natural circulation.



#### Mass flux:Viscous Parameter Comparison

Figure 23: Non-Dimensional Mass Flux





Figure 24: Non-Dimensional Buoyancy Force

#### **Density Ratio Comparison**



**Figure 25: Density Ratio** 

Figure 23 shows that the mass flux in the 85% helium case is larger early on than in Update A. This is consistent with the previous discussion since Update A does not enter mixed transport until near the end of the transient. The plots of  $\Pi_B$  and  $\Pi_{DR}$  versus time give insight into just why that is happening. At the start of both simulations, the buoyancy force is reduced as air first enters the hot leg, since that increases the average density in the hot leg. After reaching the minimum  $\Pi_B$  value, both cases show a relatively fast increase, but Update A shows a suppression of the buoyancy force where it remains roughly constant for several hours. The density ratio for Update A during that same time interval also decreases, while the 85% helium case does not experience any such behavior.

Comparing the non-dimensional parameter behaviors to Figure 22, at about 180 minutes Update A diverges away from the analytical diffusion solution. Before this time, diffusion transport dominates and this corresponds to the suppression of  $\Pi_B$  and  $\Pi_{DR}$ . After 180 minutes,  $\Pi_B$  and  $\Pi_{DR}$  both begin to increase. Thus, the values of  $\Pi_B$  and  $\Pi_{DR}$ 

around this time seem to correspond to the transition from diffusion dominated to mixed transport. The 85% helium case surpasses these transition values sooner in the transient and so bypass the slow lengthy pure diffusion transport phase. Starting with 85% helium in the u-tube therefore provides conditions that allow the system to enter into mixed transport relatively easily. With 100% helium initially however, once the air begins to enter inside, the concentrations suppress the strength of the buoyancy force and density ratio.

# 8. Injection Modeling

## 8.1 Injection Case CFD Model

The original FLUENT mesh needed to be modified to accommodate the addition of a helium injection location into the middle of the horizontal cross-over leg. The injection valve was 0.125 inch. diameter, and was approximated as a square injection shape to simplify the geometry generation. Since a square shaped was used, the dimensions were modified to maintain the same flow area. The injection valve was modeled as a mass flow injection face in FLUENT located along the side of the cross-over leg wall. The rest of the geometry remained unchanged.

Near the injection face, very fine volume elements were used. Mesh volumes throughout the rest of the u-tube were then reduced to prevent overly skewed volume meshes at element size transition locations. As a comparison, the mesh used in the 85% helium case, a total of 40943 cells were used, with a minimum cell volume of 1.35e-8 m<sup>3</sup> and a maximum cell volume of 1.98e-4 m<sup>3</sup>. The injection case mesh however, used 278443 cells, with a minimum cell volume of 1.76e-11 m<sup>3</sup>, and a maximum cell volume of 1.89e-4 m<sup>3</sup>. The injection case minimum cell volume of 1.89e-4 m<sup>3</sup>. The injection case minimum cell volume of 1.89e-4 m<sup>3</sup>. The injection case minimum cell volume of 1.89e-4 m<sup>3</sup>. The injection case minimum cell volume of 1.89e-4 m<sup>3</sup>. The injection case minimum cell volume of 1.89e-4 m<sup>3</sup>. The injection case minimum cell volume of 1.89e-4 m<sup>3</sup>. The injection case minimum cell volume of 1.89e-4 m<sup>3</sup>. The injection case minimum cell volume of 1.89e-4 m<sup>3</sup>. The injection case minimum cell volume corresponds to cells adjacent to the injection face. Both cases have similar maximum cell volume values since the bottom of the barrel was meshed similar in both cases.

A FLUENT case was run using the minimum tested helium injection rate of 1 cc/min or 2.78e-9 kg/s, through the injection face. The same initial conditions were used as the

85% helium case without injection. Solver schemes and under-relaxation factors (URFs) were chosen to aid in convergence so the solver settings were slightly different than the 85% helium case without injection. The solver settings are summarized in Appendix A2.

The simulation was run out to four hours since the experimental data showed that natural circulation did not start during the entire four hour transient with 1 cc/min helium injection. To see what would happen, at about two hours, the injection flow was turned off by setting the injection face to a wall condition rather than a mass flow injection face. In two experimental cases, after injection was turned off, natural circulation began about two hours later. The goal was to see if FLUENT would predict similar behavior.

## 8.2 CFD Results

Two injection simulations were performed: (1) injection for the entire transient will be referred to as the injection case; (2) stop injection case in which injection flow was shut off after two hours into the transient.

Before discussing the results of the injection cases, it is important to point out that the mass flow rate in the hot leg as reported by FLUENT was negative in sign. At first, when this behavior was witnessed, it was felt that perhaps the injection was forcing flow down the hot leg, due to the pressure gradient. However, upon inspection it was found that the normal vector on the mesh surfaces in the hot leg were defined in the opposite direction from the previous mesh. Thus, when gas traversed the mesh surfaces in the upward direction the dot product between the gas velocity vector and mesh surface normal vector produced a negative sign. Examining velocity vectors in both cases showed indeed that the gas flow was in the upward direction in the hot leg. The "negative" mass flow rate as reported by FLUENT is actually in the positive upward direction. Therefore, both injection case results are consistent with the previous non-injection case results.

The overall conclusion from the two injection simulations is that the SCAD method is indeed preventing the onset of natural circulation. Figure 26 compares average helium mole fraction in the cross-over leg for the 85% helium case with the injection case (at a

rate of 1 cc/min) and the stop injection case. The obvious result is that with injection the helium cushion in the cross-over leg is maintained; once the injection flow is turned off the transport rate of nitrogen (air in the actual experiment) increases significantly leading to the onset of natural circulation.





**Figure 26: Injection Cases Comparison** 

As shown by Figure 26 the helium mole fraction in the cross-over leg, for the injection case, decreases at a very slow rate, even slower than the pure diffusion transport rate shown in Figure 22. The behavior also seems to be leveling off to a near constant value of about 73% at the end of the simulation. Figure 27 shows nitrogen mole fraction contours throughout the entire apparatus at various times during the injection case simulation. Red indicates 100% nitrogen, as is the case inside the barrel. The last three times are at about the 2, 3, and 4 hour marks, respectively and show that the nitrogen mole fraction contours are steadying out. The concept of steadying out is consistent with the derivation of SCAD to force a steady-state situation. Figure 27 also shows that SCAD simply prevents the onset of natural circulation; it does not prevent air from

entering the apparatus, as described earlier. The nitrogen (air) fraction, reaches a steady value in the core, however the rate that air is replenished is dictated by a reduced transport rate, dictated by diffusion rather than by natural convection, as in the case of natural circulation. The graphite oxidation rate is dictated by the rate that air is replenished in the core, thus even though air will be inside the core, with a greatly diminished air replenishing rate, SCAD maintains the core integrity during air ingress.



Figure 27: 1 cc/min Injection Case Nitrogen Mole Fraction Contours

The stop injection case was run for an additional 78 minutes after the injection was turned off at 120.66 minutes after the start of the simulation. At the end of the simulation the average helium mole fraction in the cross-over leg was about 11% and the average mass flow rate was of the same order of magnitude as the natural circulation rate in the 85% helium case, at  $\sim 10^{-5}$  kg/s. Figure 26 shows the rapid increase in the nitrogen transport rate after injection is turned off. As a comparison, about 25 minutes after the injection flow was shut off, the average helium mole fraction in the cross-over leg is about 52% in the stop injection case, while at the same time in the injection case, the cross-over leg is about 75% helium. Nitrogen contours throughout the apparatus at

various times are given in Figure 28. As expected, with the increased nitrogen transport rate, the u-tube quickly fills with nitrogen leading up to the onset of natural circulation. Due to time constraints and the uncertainty of the odd reported negative mass flow rate, the simulation was ended at that time. But, it is felt that data up to this point shows the impact of SCAD on preventing the onset of natural circulation.



**Figure 28: Stop Injection Mole Fraction Contours** 

In the actual experiment, two tests continued taking data after the injection flow was shut off. These two tests had injection flow for about 4 hours, unlike the 2 hours used in the FLUENT simulation before turning off injection and the FLUENT case was at the lowest experimentally tested injection rate. The tests that continued running after injection flow was shut off used injection rates of 2 cc/min and 7 cc/min. These tests showed natural circulation starting about 2 hours after turning off injection, while FLUENT shows natural circulation about to start at only around 80 minutes after shutting off injection. A possible reason for this difference is discussed in the following section.

## 8.3 Non-Dimensional Parameters Discussion

Looking at the problem with the same non-dimensional parameters derived earlier allows the relative strength of the driving forces in the injection cases to be compared to the noninjection cases. This approach provides some insight into the behaviors of the different cases.

Figure 29 compares  $\Pi_B$  between the injection cases and non-injection cases, respectively. The first observation for the non-dimensional buoyancy force is that early on in the transient (the first half hour or so) the 85% helium case and the injection case behave nearly the same. Early on, the buoyancy force should be primarily impacted by the nitrogen that enters in from the bottom of the hot leg, since the injected helium must first diffuse from the middle of the cross-over leg. Then as  $\Pi_B$  in the non-injection case continues to increase, the injection case  $\Pi_B$  starts to level off, due to the counter-diffusion of helium down the hot leg. The injection case  $\Pi_B$  then remains roughly constant for the remainder of the transient. Figure 29 also shows update A, the case from earlier that very closely followed the pure diffusion rate in the hot leg, starting with 100% helium in the utube. The buoyancy force, in update A, only exceeds the injection case buoyancy force in the last half hour of the transient. This is another example of how in the case with 100% helium initially, the transport rate is from pure diffusion and is very slow.

#### Buoyancy: Viscous Parameter Comparison



Figure 29: Non-Dimensional Buoyancy Force Comparison

The stop injection case non-dimensional buoyancy force, as shown in Figure 29 remains roughly constant over the first 20 minutes after injection was shut off. After this time however, the driving buoyancy force begins to increase, with a trend similar to the trend seen in update A. It is interesting to note that in update A, the buoyancy force begins to increase around the similar time after the buoyancy force had been roughly constant. The difference is that in the stop injection case, the magnitude of the buoyancy that value started to increase from was about twice that of the value update A.

The density ratio,  $\Pi_{DR}$ , for the different cases is shown in Figure 30. The injection case density ratio, does not drop as low as the 85% helium case, but as the non-dimensional buoyancy force remains roughly constant for most of the transient. The 85% helium case density ratio, follows the trend of its non-dimensional buoyancy force and continuously increases until spiking at the onset of natural circulation. Thus, injection allows the density ratio to be higher earlier on than a non-injection case, but prevents the density ratio from exceeding the critical value. The fact that  $\Pi_{DR}$  remains roughly constant for

most of the transient, suggests that the cold and hot leg densities are changing at similar rates. Thus, SCAD tries to force a transport rate that causes the change in hot leg density to be counter-acted by a subsequent change in the cold leg density so that the critical density ratio is never reached. This concept is consistent with Equation 1 in that it solves for a helium injection rate such that the air enters the hot leg via diffusion and exits out the cold leg. The change in hot leg density is therefore "passed" along into the cold leg.

In the stop injection case, the density ratio remains roughly constant for almost half an hour after injection is shut off. After this point it begins to increase rapidly until spiking up near the onset of natural circulation.



Density Ratio Comparison

**Figure 30: Density Ratio Comparison** 

The non-dimensional mass flux is shown in Figure 31. The striking feature is that update A exceeds the injection case at about 2 hours, while the  $\Pi_B$  and  $\Pi_{DR}$  values for update A did not exceed the injection case until near the end of the transient. The point of injection is to prevent a large mass flow spike, thereby maintaining transport via diffusion or near

diffusion rates. Even though the injection case has higher  $\Pi_B$  and  $\Pi_{DR}$  values than update A, the counter-diffusion of helium and air in the hot leg created by SCAD keeps the mass flow rate at a low rate throughout the transient. The stop injection case confirms this idea because once injection is turned off, the non-dimensional mass flux increases significantly, even though as described earlier, the driving buoyancy and density ratio values remain roughly the same. The  $\Pi_B$  value for the injection case was steadying out to a value similar to the 85% injection case at about 50 minutes. The  $\Pi_G$  value that the stop injection case spikes up to shortly after the injection flow was turned off, is similar to the 85% helium case  $\Pi_G$  value at 50 minutes as well. Thus, the FLUENT results show that once the injection flow is turned off, the driving buoyancy force dictates the flow rate and the mass flux through the hot leg adjusts appropriately. Injecting at a lower rate would decrease the steady-state driving buoyancy force.



Massflux:Viscous Parameter Comparison

Figure 31: Non-Dimensional Mass Flux Comparison

As mentioned previously, two experimental tests turned off injection flow after 4 hours and at around 2 hours later natural circulation began. FLUENT therefore predicted natural circulation onset after turning off injection faster than seen in the experiment. The two tests, however, used higher injection rates, 2 cc/min and 7 cc/min, than the injection rate used in FLUENT (1 cc/min). Again, the FLUENT injection was chosen because that matched the lowest injection rate experimentally tested. Applying the reasoning from the non-dimensional discussion, using a higher injection rate would drive down the buoyancy force. Thus, when injection flow was turned off, the corresponding mass flow spike, for the 2 cc/min and 7 cc/min tests, would have been less than in the 1 cc/min case modeled by FLUENT.

Figure 11, in section 3.4.2.2 gives insight into this concept. The differential pressure data for the 2 cc/min injection test begins to drop sooner than the 7 cc/min test. But then the 2 cc/min test shows the differential pressure being "held up" until another rapid differential decrease occurs near the onset of natural circulation. The dropping in differential pressure is indicative of fluid starting to flow at a higher rate through the pebble column. The 2 cc/min test begins dropping sooner because it would allow a higher buoyancy force than the 7 cc/min test. The "hold up" behavior suggests then that the air that entered drove down the buoyancy force and more air then had to enter in order for the buoyancy force to increase again. However, the concept that injecting helium at a higher rate reduces the driving buoyancy force makes physical sense and agrees with the available experimental data.

# 9. MIR Evaluation Methodology

Extending the non-dimensional analysis presented earlier allows a formulation for determining the MIR for a configuration. Yan's injection rate equation, Equation 1, assumed that the bulk flow through the hot leg approached zero, thereby having the molar fluxes of helium and air cancel out. The flow rate through the hot leg (the core) was then controlled only by the concentration gradients in the hot leg. However, in reality some bulk flow would occur due to the buoyancy force and the following methodology allows for the MIR to be determined empirically by handling the flow rate non-dimensionally.

Thus, the following methodology establishes a MIR condition from empirical data or CFD results.

The first step is to perform non-injection simulations for a given geometry ( $\Pi_{\rm K}$  and  $\Pi_{\rm h}$  values) to determine the critical  $\Pi_{\rm G}$ ,  $\Pi_{\rm B}$ , and  $\Pi_{\rm DR}$  values, corresponding to the onset of natural circulation. The second step requires determining a correlation between the mass flux and the driving parameters. To account for the injection flow's impact on the bulk flow rate, an additional variable is introduced into the Buckingham Pi process, the injection mass flow rate,  $\dot{m}_{IN}$  which produces an additional Pi group,  $\Pi_{\rm IN}$ . The non-dimensional injection rate was computed to be:

$$\Pi_{IN} = \frac{\dot{m}_{IN}^2}{\left(\Delta\rho\right)^2 H^3 Kg}$$

**Equation 15** 

Equation 15 is thereby modified to be:

$$\Pi_G = F(\Pi_{IN}, \Pi_B, \Pi_{DR}, \Pi_K, \Pi_h)$$

**Equation 16** 

The correlation given by Equation 17 is what must be determined empirically from data or CFD results. Different injection rates must be run for different geometries and driving temperature differences. The geometry parameters are the permeability, K, total height, H, and core height, h, and thus set the geometry non-dimensional parameters  $\Pi_K$  and  $\Pi_h$ . The driving temperature difference between the hot and cold legs set the driving buoyancy parameters  $\Pi_B$  and  $\Pi_{DR}$ . Running the various simulations will give a time history of the non-dimensional mass flux through the hot leg for each specific configuration. The quasi-steady-state values for the driving parameters for the various configurations can then be used to determine the correlation relating the non-dimensional mass flux to the non-dimensional injection rate, buoyancy force, density ratio, as well as the geometry constraints. The critical values for  $\Pi_G$ ,  $\Pi_B$ , and  $\Pi_{DR}$  for a given geometry ( $\Pi_K$  and  $\Pi_h$  values) are then substituted into Equation 17. By solving for the non-dimensional injection rate, the MIR for a given configuration is then determined. Denoting critical values with a \*, the MIR correlation is then:

$$\Pi_{MR} = G(\Pi_G^*, \Pi_B^*, \Pi_{DR}^*, \Pi_K, \Pi_h)$$

Equation 17

The minimum injection rate value can then be determined from the definition of the nondimensional value in Equation 16.

The MIR value predicted by Equation 18 allows some bulk flow through the core as dictated by the buoyancy force. The buoyant driven flow is what caused the experiment to differ from the MIR predicted by Equation 1. Originally, the MIR was estimated to be about 7 cc/min; however the fixes in the FLUENT model changed the mole fractions at the boundaries before the onset of natural circulation. The MIR value from Equation 1 was recomputed using values from the 85% helium case. The flow conditions at about 94 minutes were chosen to be the limiting values since mass flow rate after this time begins to increase very quickly leading up to the onset of natural circulation. The recomputed injection rate is about 17 cc/min. Obviously, since the experiment did not observe natural circulation for an injection rate as low as 1 cc/min, Equation 1 can provide a very conservative estimate.

# 10. Full Scale PBR Considerations

## 10.1 MIR Order of Magnitude Estimate

To provide an order of magnitude estimate, Equation 1 is used to estimate the MIR value for the full scale PBMR. As described previously, this would give a conservative estimate, but it provides a ballpark number to give an idea of the amount of helium gas that must be stored on site. The dimensions of the full scale PBMR were taken from Ref. [10]. Equation 1 was solved assuming the same boundary mole fraction values used in the model. The Matlab script used to iteratively solve for the MIR is provided in Appendix A5. The entire system was assumed to be at atmospheric pressure and the hot leg temperature was chosen to be at 1600°C and the cold leg temperature at 280°C, per the analysis in Ref. [7]. With these assumptions, the MIR as estimated by Equation 1 was found to be about 1.5e-6 kg/s, or 5.36 g/hr of helium. If injection flow is required for 3 months, the amount of helium required for storage is only 11.6 kg. This value is very small, and as shown by the previous discussion should be conservative. The truly minute amount of helium required for storage demonstrates the power of the SCAD method at preventing the onset of natural circulation for air ingress accidents with diffusion dominated air ingress accidents.

## 10.2 Injection System

Air ingress CFD work on the full scale PBMR has been done and reported in Ref. [11] by the PBMR Ltd. Company. The report discussed that air ingress would have little impact on core integrity and that the problem could be easily averted by inert gas injection into the core. The findings of that work are compared to the insights and lessons learned from this current work.

The CFD model in Ref. [11] was far more complicated than the simple geometry consisting of the u-tube in this experiment. The PBMR CFD model included the entire power conversion side of the system. Double-ended guillotine (DEG) breaks were also investigated, but because the hot and cold legs are not coaxial pipes in the latest PBMR design, the entire piping network must be modeled. Having this entire structure can greatly impact the development of natural convection flow since the effective cold leg is not just in the reactor vessel but also the piping network through the power conversion system. The current work modeled the entire system as a simple upside down u-tube, with equal flow areas and no resistances inside the cold leg. Therefore, the current experiment is an absolute worst case scenario if the reactor vessel was completely cut-off from the rest of the piping network of a DEG of a coaxial pipe.

The PBMR report also examined inert gas injection at decreasing the air ingress flow rates. Injection of helium and nitrogen were compared at preventing air ingress. Helium was found to be more effective, and the investigation found that injection rate of nitrogen scaled almost linearly with the air ingress rate. However, the PBMR report looked at injection rates to stop air ingress completely. This is completely different from the goal of the SCAD method. The required injection rates for nitrogen illustrates this difference since injection rates were on the order of 100 g/s depending on the break location. Although this mass flow rate appears very small, it is far larger than the injection rate value estimated by Equation 1. In order to stop air ingress over a 3 month period would therefore require storing around 800,000 kg of nitrogen on site. Storing such an enormous mass of nitrogen gas would not just be a financial burden for the plant but also a logistic problem to fit an additional amount of gas on site.

The non-dimensional analysis presented in section 7, gives insight as to why using nitrogen is less effective than helium at stopping air ingress. Injecting nitrogen is essentially injecting air into the reactor, which is similar to increasing the initial nitrogen fraction in the FLUENT model. The injection flow is thus aiding the air ingress rate at increasing the buoyancy force overtime by artificially increasing the system density faster than it would normally. The only way to then stop air ingress is to pump in enough nitrogen to create forced convection flow out of the system, thereby sustaining a longer depressurization phase. That is why the injection rates investigated by the PBMR report are so much larger than the injection rate values required to maintain SCAD. For this kind of prevention method, helium requires a lower injection rate than nitrogen because it does not artificially increase the density as much as the nitrogen does.

# 11. Conclusions

This thesis investigated the driving parameters that affect the onset of natural circulation in a pebble bed reactor as well as the prevention of natural circulation through the SCAD method. Commercial CFD software, FLUENT, was used to model an air ingress experiment, which provided insight into the dynamics of the development of the conditions that lead to natural circulation onset. By formulating the problem nondimensionally, the understanding of just how the SCAD method works at preventing the onset of natural circulation was improved. It was shown that for the transport rates near the order of magnitude of diffusive rates the SCAD method is able to suppress the buoyancy force so that natural circulation is prevented.

The SCAD method offers significant advantages over simply replacing coolant gas inventory to prevent air from entering the reactor core for vertically oriented pipe breaks. As demonstrated by the simple analysis, only a small investment in helium inventory is required to prevent natural circulation onset over a 3 month period. Again it is important to note that the experiment and confirmatory CFD results validate this estimate for air ingress rates comparable to diffusion. Due to the experiment configuration, stratified flow and effects from subsequent lower plenum gas heating due to a large horizontal pipe break could be not addressed. Further analysis is required to evaluate the impact horizontal break phenomena have on the natural circulation onset time in a PBR.

A methodology was developed in order to allow an empirical correlation of the MIR that could validate the injection rate estimated by using Yan's MIR equation. In summary, based on the air ingress experiments which simulated hot and cold leg configurations with and without helium injection, and benchmarked computational fluid dynamics analyses, minimal helium injection appears to be a means to avoid or delay natural circulation after a postulated pipe break in a pebble bed high temperature reactor thus mitigating the consequences of air ingress accidents.

# **12. Recommendations for Future Work**

The methodology presented in this work is performed assuming that outside of the reactor is ambient air at room and atmospheric pressure. In reality, after blowdown the containment gas will be a mixture of helium and air at a temperature and pressure dictated by the containment volume and core coolant inventory. Therefore, the containment pressure, temperature and gas mixture concentration must be varied to determine the impact each has on natural circulation onset time. In addition, graphite oxidation reactions must be accounted for to fully model the accident. This information will be very useful in order to properly size the containment building for a future HTGR.

The MIR correlation must also be determined in order to properly validate the injection rate of a full scale PBR. A fair number of computational simulations or experimental tests are required in order to have enough data to properly correlate the relationship among the driving parameters. Using computational data, due to the time required for a single simulation (several weeks to months, depending on the size of the computational domain) a scaled model will need to be used. The scaling should follow the scaling outlined in this work. To expand upon the current scaling methodology, a correlation for the onset time can be determined if transfer processes are also taken into account in the scaling process. Doing so would allow correlations for both the natural circulation onset time and MIR values to be determined.

When analyzing a full scale PBR, it must be determined if stratified flow in horizontal pipe breaks will drastically alter the natural circulation onset time. Analysis following recent work conducted at INL should be conducted at prototypical PBR geometry sizes to quantify this effect [12]. Results of this analysis show that air ingress is dependent on break size, location and orientation, and the full range of conditions must be evaluated to determine a proper air ingress mitigation process. The work in Ref. [12] showed that the NACOK facility geometry facilitated diffusion controlled natural circulation onset times. Therefore, similar analysis must be performed for a full scale PBR to evaluate if horizontal break phenomena can drastically reduce the natural circulation onset time.
Should such analysis show that a full scale PBR is influenced by horizontal break phenomena the air ingress method must be determined to handle the must faster accident progression not seen by diffusion dominated accidents. However, if the analysis shows that PBR geometry is not affected, then the current methodology and framework would apply for evaluating natural circulation onset and its prevention.

# 13. References

[1] "Atomic Renaissance", The Economist, 8 Sept. 2007, pp. 71-73

 [2] Brudieu, Marie-Anne and Kadak, Andrew C., "Blind Benchmark Predictions of NACOK Air Ingress Tests Using Computational Fluid Dynamics". In 3<sup>rd</sup> International Topical Meeting on High Temperature Reactor Technology. Johannesburg, South Africa, 2006

[3] Rycroft, C., Grest, G., Landry, J., Bazant, M., "Analysis of Granular Flow in a Pebble Bed Nuclear Reactor," Phys. Rev. E 74, 021306, 2006

[4] Takeda, Tetsuaki and Hishida, Makoto., "Study on the Passive Safe Technology for the Prevention of Air Ingress During the Primary-Pipe Rupture Accident of HTGR," Nuclear Engineering and Design, No. 200, 2000, pp. 251-259

[5] Yan, X. L., Takeda, T., Nishihara, T., Ohashi, K., Kunitomi, K., Tsuji, N., "A Study of Air Ingress and Its Prevention in HTGR," Nucl. Technol., 163, Sept. 2008

[6] FLUENT Inc. 2006, FLUENT 6.0 User's Guide

[7] Zhai, T., Kadak, A., No, H.C., "Air Ingress Benchmarking with Computational Fluid Dynamics Analysis," 2<sup>nd</sup> Int. Topical Meeting on High Temperature Reactor Technology, Beijing China, Sept. 2004 [8] Hishida, M., Takeda, T., "Study on Air Ingress During an Early Stage of a Primary-Pipe Rupture Accident of a High Temperature Gas Cooled Reactor," Nuclear Engineering and Design, 126, pp. 175-187, 1991

[9] Trevisan, O.V., Bejan, A., "Natural Convection With Combined Heat and Mass Transfer Buoyancy Effects in a Porous Medium," Int. J. Heat Mass Transfer, Vol. 38, No. 8, pp. 1597-1611, 1985

[10] Technical Description of the PBMR Demonstration Power Plant, PBMR (Pty) Ltd.

[11] Schmitz, W., Koster, A., "Air Ingress and Corrosion Potential for PBMR Direct
 Cycle," 4<sup>th</sup> Int. Topical Meeting on High Temperature Reactor Technology, Washington,
 DC USA, Sept. 2008

[12] Oh, C.H., Kim, E.S., Hyung, S.K., No, H.C., Cho, N.Z., INL/EXT-09-16465, "FY-09 Report: Experimental Validation of Stratified Flow Phenomena, Graphite Oxidation, and Mitigation Strategies of Air Ingress Accidents", http://www.inl.gov/technicalpublications/Documents/4455020.pdf

# 14. Appendices

# A1. Experimental Apparatus Design Procedure

The German NACOK (Naturzug im Core mit Korrosion) air ingress test facility was used as the basis for the experimental apparatus. A detailed description of NACOK is given by Ref. [2], but the facility can reach temperatures up to 1200°C and is 7.3 m tall. The main goals for the facility included determining the natural circulation air mass flow rate and its dependence on temperature and geometry, and determining the natural circulation onset time. Figure 32 gives an illustration of the NACOK facility.



# NACOK

Figure 32: NACOK Test Facility

Since the goal is to evaluate the natural circulation onset time, the phenomena of interest are the transport rate of air during the diffusion phase of the air ingress accident. Therefore, the buoyancy force to viscous drag force must be maintained during the diffusion phase. In fluid flow through porous media, the Bond number, Bo, describes the ratio between buoyancy and surface tension, and the Capillary number, Ca, defines the ratio between viscous forces and surface tension. Taking the ratio between these numbers gives the ratio between the buoyancy force and viscous drag force. This new non-dimensional number is given as:

$$\frac{Bo}{Ca} = \frac{\Delta \rho g K}{\mu u}$$

**Equation 18** 

where:

 $\Delta \rho \equiv$  density difference between hot leg and cold leg,

 $g \equiv$  gravitational acceleration,

 $K \equiv$  permeability of the porous media,

 $\mu \equiv$  dynamic viscosity,

 $u \equiv$  fluid velocity through the porous media.

The Bo/Ca value for NACOK was evaluated using the test data to determine the average gas velocity through the pebble column. The permeability was computed using the equations in section 6.2.1 and the density difference computed using the temperatures of the hot and cold leg.

To maintain the NACOK Bo/Ca value, FLUENT was used to compute the gas velocity through the pebble column for different u-tube operating temperatures and geometry configurations. The design process was therefore iterative in nature, relying on the FLUENT predicted average gas velocity through the pebble column during the diffusion phase of an air ingress accident. After multiple iterations, the resulting design was the original FLUENT case described throughout this thesis. The Bo/Ca value for the resulting original FLUENT case is given in Table 1.

	Table 1. Thiai Design Characteristics								
Bo/Ca	Bo/Ca	Total	Pebble	Diffusion	Pipe	Total			
NACOK	Experiment	Height	Section	Length	Diameter	Volume			
	-	-	Height						
8.00	10.77	1.54 m	1 m	2.2 m	6.35 cm	$0.00920 \text{ m}^3$			
						(9209.5 cc)			

**Table 1: Final Design Characteristics** 

It is important to note that the scaling methodology considered for the experimental apparatus design is very different from the driving parameters discussed in this thesis. The design process was done very early on in the development of this work while the non-dimensional methodology described in this thesis was the culmination of the experience gained from the experiment and CFD analysis. Thus, the test apparatus design process illustrates the state of knowledge at the beginning of this thesis. Even though this design process was very simplified, it resulted in a very challenging and interested problem that lead to an improved understanding of the various phenomena involved in an air ingress accident.

# A2. FLUENT Case Summaries

Summaries for each FLUENT case described in this thesis are given. Each summary includes descriptions of the models used, the boundary condition settings, the solver controls including discretization schemes and URFs, and the material properties.

## **Original FLUENT Case**

FLUENT Version: laminar, Release: Title:	3d, pbns, unsteady) 6.3.26	spe,	lam,	unsteady	(3d,	pressure-	-based,	species,
Models								
Model				Settin	ngs			-
Space Time Visco Heat Solid Radia	us Transfer ification tion	and M	eltin	3D Unstea Lamina Enable g Disab None	ady, ar ed led	1st-Order	Implicit	-

Species Transport	Non-Reacting (2 species)
Coupled Dispersed Phase	Disabled
Pollutants	Disabled
Pollutants	Disabled
Soot	Disabled

## Boundary Conditions

\_\_\_\_\_

#### Zones

name	id	type
barrel	2	fluid
cold leg	3	fluid
cold valve	4	fluid
cross-over leg	5	fluid
hot top	6	fluid
hot valve	7	fluid
pebbles	8	fluid
wall	9	wall
outlet	10	interior
cold exit	11	interior
cold_enter	12	interior
hot_exit	13	interior
pebble_exit	14	interior
pebble_enter	15	interior
inlet	16	interior
barrel_walls	17	wall
new_cold_valve	18	wall
cold_walls	19	wall
cross_over_walls	20	wall
hot_top_walls	21	wall
hot_valve_walls	22	wall
pebble_walls	23	wall
default-interior	25	interior
default-interior:001	1	interior
default-interior:024	24	interior
default-interior:026	26	interior
default-interior:027	27	interior
default-interior:028	28	interior
default-interior:029	29	interior

Boundary Conditions

#### barrel

Condition

#### Value

	Material Name				
mixture-	mixture-template				
	Specify source terms?	no			
	Source Terms	()			
	Specify fixed values?	no			
	Local Coordinate System for Fixed Velocities	no			

Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial res	istance? no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	
aluminum	

cold\_leg

TT. ] -	Condition	
varue		
	Material Name	
mixture-	template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	()
	Motion Type	0
	X-Velocity Of Zone (m/s)	0

	V-Velocity Of Zone (m/s)	0
	Z-Velocity of Zone (m/s)	Õ
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	0
	CO Coefficient for Power-Law	0
	Cl Coefficient for Power-Law	0
	Porosity	Ţ
- 1 4	Solid Material Name	
aıumınum		
col	Ld_valve	
	Condition	
Value		

Material Name	
mixture-template	
Specify source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0

X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial res	sistance? no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	
aluminum	

cross-over\_leg

Condition

Value

Material Name	
mixture-template	
Specify source terms?	· no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0

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Y-Component of Rotation-Axis0Z-Component of Rotation-Axis1Deactivated ThreadnoPorous zone?noConical porous zone?noX-Component of Direction-1 Vector1Y-Component of Direction-1 Vector0Z-Component of Direction-2 Vector0X-Component of Direction-2 Vector1Z-Component of Direction-2 Vector0X-Component of Direction-2 Vector1Z-Component of Cone Axis Vector1Y-Component of Cone Axis Vector0X-Coordinate of Point on Cone Axis (m)1Y-Coordinate of Point on Cone Axis (m)1Y-Coordinate of Point on Cone Axis (m)0Relative Velocity Resistance Formulation?yeDirection-1 Viscous Resistance (1/m2)0Direction-2 Viscous Resistance (1/m2)0Direction-3 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0Co Coefficient for Power-Law0Co Coefficient for Power-Law0Consity1Solid Material Name1	X-Component of Rotation-Axis	0
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X-Component of Direction-2 Vector0Y-Component of Direction-2 Vector1Z-Component of Direction-2 Vector0X-Component of Cone Axis Vector1Y-Component of Cone Axis Vector0Z-Component of Cone Axis Vector0X-Coordinate of Point on Cone Axis (m)1Y-Coordinate of Point on Cone Axis (m)0Z-Coordinate of Point on Cone Axis (m)0Half Angle of Cone Relative to its Axis (deg)0Relative Velocity Resistance Formulation?yeDirection-1 Viscous Resistance (1/m2)0Direction-3 Viscous Resistance (1/m2)0Direction-1 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0Co Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name1	Z-Component of Direction-1 Vector	0
Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? ye Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 1 Co Coefficient for Power-Law 0 Cl Coefficient for Power-Law 0 Porosity 1 Solid Material Name	X-Component of Direction-2 Vector	0
Z-Component of Direction-2 Vector0X-Component of Cone Axis Vector1Y-Component of Cone Axis Vector0Z-Component of Cone Axis Vector0X-Coordinate of Point on Cone Axis (m)1Y-Coordinate of Point on Cone Axis (m)0Z-Coordinate of Point on Cone Axis (m)0Z-Coordinate of Point on Cone Axis (m)0Half Angle of Cone Relative to its Axis (deg)0Relative Velocity Resistance Formulation?yeDirection-1 Viscous Resistance (1/m2)0Direction-3 Viscous Resistance (1/m2)0Direction-1 Inertial Resistance (1/m2)0Direction-2 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0Direction-4 for Power-Law0Cl Coefficient for Power-Law0Porosity1Solid Material Name1	Y-Component of Direction-2 Vector	1
X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? ye Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 Porosity 1 Solid Material Name	Z-Component of Direction-2 Vector	0
Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? ye Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 Porosity 1 Solid Material Name	X-Component of Cone Axis Vector	1
Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? ye Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 Porosity 1 Solid Material Name	Y-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? ye Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 Porosity 1 Solid Material Name	Z-Component of Cone Axis Vector	0
Y-Coordinate of Point on Cone Axis (m)0Z-Coordinate of Point on Cone Axis (m)0Half Angle of Cone Relative to its Axis (deg)0Relative Velocity Resistance Formulation?yeDirection-1 Viscous Resistance (1/m2)0Direction-2 Viscous Resistance (1/m2)0Direction-3 Viscous Resistance (1/m2)0Choose alternative formulation for inertial resistance?noDirection-1 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0Co Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name1	X-Coordinate of Point on Cone Axis (m)	1
Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? ye Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 Porosity 1 Solid Material Name	Y-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)0Relative Velocity Resistance Formulation?yeDirection-1 Viscous Resistance (1/m2)0Direction-2 Viscous Resistance (1/m2)0Direction-3 Viscous Resistance (1/m2)0Choose alternative formulation for inertial resistance?noDirection-1 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0Co Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name1	Z-Coordinate of Point on Cone Axis (m)	0
Relative Velocity Resistance Formulation?yeDirection-1 Viscous Resistance (1/m2)0Direction-2 Viscous Resistance (1/m2)0Direction-3 Viscous Resistance (1/m2)0Choose alternative formulation for inertial resistance?noDirection-1 Inertial Resistance (1/m)0Direction-2 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0Co Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name1	Half Angle of Cone Relative to its Axis (deg)	0
Direction-1 Viscous Resistance (1/m2)0Direction-2 Viscous Resistance (1/m2)0Direction-3 Viscous Resistance (1/m2)0Choose alternative formulation for inertial resistance?noDirection-1 Inertial Resistance (1/m)0Direction-2 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0C0 Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name1	Relative Velocity Resistance Formulation?	yes
Direction-2 Viscous Resistance (1/m2)0Direction-3 Viscous Resistance (1/m2)0Choose alternative formulation for inertial resistance?noDirection-1 Inertial Resistance (1/m)0Direction-2 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0C0 Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name1	Direction-1 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)0Choose alternative formulation for inertial resistance?noDirection-1 Inertial Resistance (1/m)0Direction-2 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0C0 Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name1	Direction-2 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?noDirection-1 Inertial Resistance (1/m)0Direction-2 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0C0 Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name	Direction-3 Viscous Resistance (1/m2)	0
Direction-1 Inertial Resistance (1/m)0Direction-2 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0C0 Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name	Choose alternative formulation for inertial resistance?	no
Direction-2 Inertial Resistance (1/m)0Direction-3 Inertial Resistance (1/m)0C0 Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name	Direction-1 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)0C0 Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name	Direction-2 Inertial Resistance (1/m)	0
C0 Coefficient for Power-Law0C1 Coefficient for Power-Law0Porosity1Solid Material Name1	Direction-3 Inertial Resistance (1/m)	0
Cl Coefficient for Power-Law 0 Porosity 1 Solid Material Name	CO Coefficient for Power-Law	0
Porosity 1 Solid Material Name	C1 Coefficient for Power-Law	0
Solid Material Name	Porosity	1
	Solid Material Name	

aluminum

hot\_top

Condition

Value

Material Name	
mixture-template	
Specify source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
-	

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	Deactivated Thread Porous zone? Conical porous zone? X-Component of Direction-1 Vector Y-Component of Direction-1 Vector Z-Component of Direction-2 Vector X-Component of Direction-2 Vector Z-Component of Direction-2 Vector X-Component of Cone Axis Vector Y-Component of Cone Axis Vector Z-Component of Cone Axis Vector X-Coordinate of Point on Cone Axis (m) Y-Coordinate of Point on Cone Axis (m) Y-Coordinate of Point on Cone Axis (m) Half Angle of Cone Relative to its Axis (deg) Relative Velocity Resistance Formulation? Direction-1 Viscous Resistance (1/m2) Direction-3 Viscous Resistance (1/m2) Choose alternative formulation for inertial resistance? Direction-1 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) Co Coefficient for Power-Law C1 Coefficient for Power-Law	no no 1 0 0 1 0 1 0 1 0 0 1 0 0 1 0 0 0 0 0
	Porosity	1
	Solid Material Name	
aluminum		
hot	z_valve	
Value	Condition	
	Matorial Namo	
mixture-t	remplate	
mineare	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	()
	Motion Type X-Velecity Of Zene (m/s)	0
	X-Velocity of Zone $(m/s)$ Y-Velocity of Zone $(m/s)$	0
	Z-Velocity Of Zone (m/s)	Õ
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	U 1
	Deactivated Thread	r no
	Porous zone?	no
	Conical porous zone?	no
	configur porous zone.	110

X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

pebbles

```
Condition
Value
      _____
_____
_____
_____
_____
      Material Name
mixture-template
      Specify source terms?
                                                no
      Source Terms
((mass) (x-momentum) (y-momentum) (z-momentum) (species-0) (energy))
      Specify fixed values?
                                                no
      Local Coordinate System for Fixed Velocities
                                                no
      Fixed Values
                                                ((x-
velocity (inactive . #f) (constant . 0) (profile )) (y-velocity
(inactive . #f) (constant . 0) (profile )) (z-velocity (inactive . #f)
(constant . 0) (profile )) (species-0 (inactive . #f) (constant . 0)
(profile )) (temperature (inactive . #f) (constant . 0) (profile )))
      Motion Type
                                                0
      X-Velocity Of Zone (m/s)
                                                0
      Y-Velocity Of Zone (m/s)
                                                0
      Z-Velocity Of Zone (m/s)
                                                0
      Rotation speed (rad/s)
                                                0
      X-Origin of Rotation-Axis (m)
                                                0
      Y-Origin of Rotation-Axis (m)
                                                0
      Z-Origin of Rotation-Axis (m)
                                                0
      X-Component of Rotation-Axis
                                                0
```

1.6107 0.395000 glass	<pre>Y-Component of Rotation-Axis Z-Component of Rotation-Axis Deactivated Thread Porous zone? Conical porous zone? X-Component of Direction-1 Vector Y-Component of Direction-1 Vector Z-Component of Direction-2 Vector X-Component of Direction-2 Vector Z-Component of Direction-2 Vector X-Component of Cone Axis Vector Y-Component of Cone Axis Vector X-Component of Cone Axis Vector X-Coordinate of Point on Cone Axis (m) Y-Coordinate of Point on Cone Axis (m) Y-Coordinate of Point on Cone Axis (m) Half Angle of Cone Relative to its Axis (deg) Relative Velocity Resistance Formulation? Direction-1 Viscous Resistance (1/m2) Direction-2 Viscous Resistance (1/m2) Choose alternative formulation for inertial resistan Direction-1 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) Direction-4 for Power-Law C1 Coefficient for Power-Law Porosity 01 Solid Material Name</pre>	0 1 no yes no 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0 0 yes 0 0 0 0 ce? no 0 0 341
wa	11	
	Condition	Value
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall?	0 0 copper 1 300 0 300 no 0 0 yes no

Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation

Define wall velocity components?

no

X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant , 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

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outlet
```

```
Condition Value
```

cold\_exit

Condition Value

cold\_enter

```
Condition Value
```

#### hot\_exit

Condition Value

pebble\_exit

```
Condition Value
```

#### pebble\_enter

Condition Value

#### inlet

Condition Value

barrel\_walls

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Wall Thickness (m)0Heat Generation Rate (w/m3)0Material NamealumirThermal BC Type0Temperature (k)293Heat Flux (w/m2)0Convective Heat Transfer Coefficient (w/m2-k)0Free Stream Temperature (k)300Enable shell conduction?0Wall Motion0Shear Boundary Condition0Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?0X-Component of Wall Translation1Y-Component of Wall Translation0Z-Component of Wall Translation (m/s)0Y-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0Y-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0Z-Component of Kall Translation (m/s)0Z-Component of Rotation-Axis Origin (m)0X-Position of Rotation-Axis Origin (m)0X-Component of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-Component of Shear stress (pascal)0X-component of shear stress (pascal)		condition	Value
<pre>Wall Thickness (m) 0 Heat Generation Rate (w/m3) 0 Material Name alumir Thermal BC Type 0 Temperature (k) 293 Heat Flux (w/m2) 0 Convective Heat Transfer Coefficient (w/m2-k) 0 Free Stream Temperature (k) 300 Enable shell conduction? no Wall Motion 0 Shear Boundary Condition 0 Define wall motion relative to adjacent cell zone? yes Apply a rotational velocity to this wall? no Velocity Magnitude (m/s) 0 X-Component of Wall Translation 1 Y-Component of Wall Translation 0 Define wall velocity components? no X-Component of Wall Translation 0 Define wall velocity components? no X-Component of Wall Translation (m/s) 0 Y-Component of Wall Translation (m/s) 0 External Emissivity 1 External Radiation Temperature (k) 00 (0) (((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Component of Rotation-Axis Origin (m) 0 X-Component of Rotation-Axis Direction 0 X-Component of Rotation-Axis Direction 1 X-Component of Shear stress (pascal) 0 Y-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0</pre>			
Heat Generation Rate (w/m3)0Material NamealuminThermal BC Type0Temperature (k)293Heat Flux (w/m2)0Convective Heat Transfer Coefficient (w/m2-k)0Free Stream Temperature (k)300Enable shell conduction?noWall Motion0Shear Boundary Condition0Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation1Y-Component of Wall Translation0Z-Component of Wall Translation (m/s)0Z-Component of Rotation-Axis Origin (m)0X-Position of Rotation-Axis Direction0X-Position of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-Component of Shear stress (pascal)0X-component of shear stress (pascal		Wall Thickness (m)	0
Material NamealumirThermal BC Type0Temperature (k)293Heat Flux (w/m2)0Convective Heat Transfer Coefficient (w/m2-k)0Free Stream Temperature (k)300Enable shell conduction?noWall Motion0Shear Boundary Condition0Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation1Y-Component of Wall Translation0Z-Component of Wall Translation (m/s)0Z-Component of Rotation-Axis Origin (m)0X-Position of Rotation-Axis Origin (m)0X-Position of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-Component of Shear stress (pascal)0X-component of shear stres		Heat Generation Rate (w/m3)	0
Thermal BC Type0Temperature (k)293Heat Flux (w/m2)0Convective Heat Transfer Coefficient (w/m2-k)0Free Stream Temperature (k)300Enable shell conduction?noWall Motion0Shear Boundary Condition0Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation1Y-Component of Wall Translation0Define wall velocity components?noX-Component of Wall Translation (m/s)0Z-Component of Rotation-Axis Origin (m)0X-Position of Rotation-Axis Origin (m)0X-Position of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-Component of Rotation-Axis Direction1X-component of Shear stress (pascal)0X-component of shear stress (pascal)0X-componen		Material Name	aluminum
Temperature (k)293Heat Flux (w/m2)0Convective Heat Transfer Coefficient (w/m2-k)0Free Stream Temperature (k)300Enable shell conduction?noWall Motion0Shear Boundary Condition0Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation1Y-Component of Wall Translation0Define wall velocity components?noX-Component of Wall Translation (m/s)0Z-Component of Rotation-Axis Origin (m)0Z-Component of Rotation-Axis Origin (m)0X-Position of Rotation-Axis Direction0X-Component of Rotation-Axis Direction1X-Component of Rotation-Axis Direction1X-Component of Shear stress (pascal)0X-component of shear stress (pascal)0 <td></td> <td>Thermal BC Type</td> <td>0</td>		Thermal BC Type	0
Heat Flux (w/m2)0Convective Heat Transfer Coefficient (w/m2-k)0Free Stream Temperature (k)300Enable shell conduction?noWall Motion0Shear Boundary Condition0Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation0Z-Component of Wall Translation0Define wall velocity components?noX-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0External Emissivity1External Radiation Temperature (k)300(((constant . 0) (profile )))0Rotation Speed (rad/s)0X-Component of Rotation-Axis Origin (m)0Z-Position of Rotation-Axis Origin (m)0Z-Position of Rotation-Axis Direction1X-component of Rotation-Axis Direction1X-component of Shear stress (pascal)0Y-component of shear stress (pascal)0Z-component of shear stress (pascal)0Z-component of shear stress (pascal)0X-component of shear stress (pascal)0X-component of shear stress (pascal)0X-component of shear stress (pascal)0X-component		Temperature (k)	293
Convective Heat Transfer Coefficient (w/m2-k) 0 Free Stream Temperature (k) 300 Enable shell conduction? no Wall Motion 0 Shear Boundary Condition 0 Define wall motion relative to adjacent cell zone? yes Apply a rotational velocity to this wall? no Velocity Magnitude (m/s) 0 X-Component of Wall Translation 1 Y-Component of Wall Translation 0 Define wall velocity components? no X-Component of Wall Translation (m/s) 0 Y-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) 0 X-Component of Wall Translation (m/s) 0 X-Component of Wall Translation (m/s) 0 External Emissivity 1 External Radiation Temperature (k) 300 (((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Component of Rotation-Axis Origin (m) 0 Z-Position of Rotation-Axis Direction 0 X-Component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of shear stress (pascal) 0 Y-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0		Heat Flux (w/m2)	0
Free Stream Temperature (k)300Enable shell conduction?noWall Motion0Shear Boundary Condition0Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation1Y-Component of Wall Translation0Z-Component of Wall Translation0Z-Component of Wall Translation (m/s)0X-Component of Wall Translation (m/s)0Z-Component of Rotalion Temperature (k)300(0)(0)(((constant . 0) (profile )))0Rotation Speed (rad/s)0X-Position of Rotation-Axis Origin (m)0Z-Position of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-Component of Shear stress (pascal)0X-component		Convective Heat Transfer Coefficient (w/m2-k)	0
Enable shell conduction? no Wall Motion 0 Shear Boundary Condition 0 Define wall motion relative to adjacent cell zone? yes Apply a rotational velocity to this wall? no Velocity Magnitude (m/s) 0 X-Component of Wall Translation 1 Y-Component of Wall Translation 0 Define wall velocity components? no X-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) 0 ((((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Direction 0 X-Component of Rotation-Axis Direction 0 X-Component of Rotation-Axis Direction 1 X-Component of Rotation-Axis Direction 1 X-Component of Rotation-Axis Direction 1 X-Component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 0 Z-component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of Shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0		Free Stream Temperature (k)	300
Wall Motion0Shear Boundary Condition0Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation1Y-Component of Wall Translation0Z-Component of Wall Translation0Define wall velocity components?noX-Component of Wall Translation (m/s)0Y-Component of Wall Translation (m/s)0Z-Component of Rotalion-Axis Origin (m)0K-Position of Rotation-Axis Origin (m)0X-Position of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-Component of Shear stress (pascal)0Y-component of shear stress (pascal)0X-component		Enable shell conduction?	no
Shear Boundary Condition0Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation1Y-Component of Wall Translation0Z-Component of Wall Translation0Define wall velocity components?noX-Component of Wall Translation (m/s)0Y-Component of Wall Translation (m/s)0X-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0External Emissivity1External Radiation Temperature (k)300(((constant . 0) (profile )))0Rotation Speed (rad/s)0X-Position of Rotation-Axis Origin (m)0Y-Position of Rotation-Axis Origin (m)0X-Component of Rotation-Axis Direction0Y-Component of Rotation-Axis Direction1X-component of Shear stress (pascal)0Y-component of shear stress (pascal)0Y-component of shear stress (pascal)0Y-component of shear stress (pascal)0Surface tension gradient (n/m-k)0Specularity Coefficient0		Wall Motion	0
Define wall motion relative to adjacent cell zone?yesApply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation1Y-Component of Wall Translation0Z-Component of Wall Translation0Define wall velocity components?noX-Component of Wall Translation (m/s)0Y-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0External Emissivity1External Radiation Temperature (k)300(0)(0)(((constant . 0) (profile )))0Rotation Speed (rad/s)0X-Position of Rotation-Axis Origin (m)0Y-Position of Rotation-Axis Direction0Y-Component of Rotation-Axis Direction0Y-Component of Rotation-Axis Direction0Y-Component of Shear stress (pascal)0Y-component of shear stress (pascal)0<		Shear Boundary Condition	0
Apply a rotational velocity to this wall?noVelocity Magnitude (m/s)0X-Component of Wall Translation1Y-Component of Wall Translation0Z-Component of Wall Translation0Define wall velocity components?noX-Component of Wall Translation (m/s)0Y-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0External Emissivity1External Radiation Temperature (k)300(((constant . 0) (profile )))0Rotation Speed (rad/s)0X-Component of Rotation-Axis Origin (m)0Z-Position of Rotation-Axis Origin (m)0Z-Position of Rotation-Axis Direction0X-Component of Shear stress (pascal)0Z-component of shear stress (pasc		Define wall motion relative to adjacent cell zone?	yes
Velocity Magnitude (m/s) 0 X-Component of Wall Translation 1 Y-Component of Wall Translation 0 Z-Component of Wall Translation 0 Define wall velocity components? no X-Component of Wall Translation (m/s) 0 Y-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) 0 External Emissivity 1 External Radiation Temperature (k) 300 (() (((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Origin (m) 0 Z-Position of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 1 X-Component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0		Apply a rotational velocity to this wall?	no
X-Component of Wall Translation 1 Y-Component of Wall Translation 0 Z-Component of Wall Translation 0 Define wall velocity components? no X-Component of Wall Translation (m/s) 0 Y-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) 0 External Emissivity 1 External Radiation Temperature (k) 300 (0) (((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Origin (m) 0 Z-Position of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 1 X-Component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of Shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0		Velocity Magnitude (m/s)	0
Y-Component of Wall Translation 0 Z-Component of Wall Translation 0 Define wall velocity components? no X-Component of Wall Translation (m/s) 0 Y-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) 1 External Emissivity 1 External Radiation Temperature (k) 300 (((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Origin (m) 0 Z-Position of Rotation-Axis Origin (m) 0 X-Component of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of Shear stress (pascal) 0 Y-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0		X-Component of Wall Translation	1
Z-Component of Wall Translation 0 Define wall velocity components? no X-Component of Wall Translation (m/s) 0 Y-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) 0 External Emissivity 1 External Radiation Temperature (k) 300 (()) (((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Origin (m) 0 Z-Position of Rotation-Axis Origin (m) 0 X-Component of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 1 X-Component of Rotation-Axis Direction 1 X-component of Shear stress (pascal) 0 Y-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0		Y-Component of Wall Translation	0
Define wall velocity components?noX-Component of Wall Translation (m/s)0Y-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0External Emissivity1External Radiation Temperature (k)300(((constant . 0) (profile )))0Rotation Speed (rad/s)0X-Position of Rotation-Axis Origin (m)0Y-Position of Rotation-Axis Origin (m)0Z-Position of Rotation-Axis Origin (m)0X-Component of Rotation-Axis Direction0X-Component of Rotation-Axis Direction1X-component of Shear stress (pascal)0Y-component of shear stress (pascal)0Z-component of shear stress (pascal)0X-component of shear stress (pascal)0X-responent of shear stress (pascal)0X-responen		Z-Component of Wall Translation	0
X-Component of Wall Translation (m/s)0Y-Component of Wall Translation (m/s)0Z-Component of Wall Translation (m/s)0External Emissivity1External Radiation Temperature (k)300(0)(0)(((constant . 0) (profile )))0Rotation Speed (rad/s)0X-Position of Rotation-Axis Origin (m)0Y-Position of Rotation-Axis Origin (m)0Z-Position of Rotation-Axis Origin (m)0X-Component of Rotation-Axis Direction0X-Component of Rotation-Axis Direction0X-component of Rotation-Axis Direction1X-component of Shear stress (pascal)0Y-component of shear stress (pascal)0X-component of shear stress (pascal)0Surface tension gradient (n/m-k)0Specularity Coefficient0		Define wall velocity components?	no
Y-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) 0 External Emissivity 1 External Radiation Temperature (k) 300 (0) (((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Origin (m) 0 Z-Position of Rotation-Axis Origin (m) 0 X-Component of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 0 Z-Component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of shear stress (pascal) 0 Y-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0		X-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s) 0 External Emissivity 1 External Radiation Temperature (k) 300 (0) (((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Origin (m) 0 Z-Position of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of shear stress (pascal) 0 Y-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0		Y-Component of Wall Translation (m/s)	0
External Emissivity1External Radiation Temperature (k)300 (0)(((constant . 0) (profile )))0Rotation Speed (rad/s)0X-Position of Rotation-Axis Origin (m)0Y-Position of Rotation-Axis Origin (m)0Z-Position of Rotation-Axis Origin (m)0X-Component of Rotation-Axis Direction0Y-Component of Rotation-Axis Direction1X-component of Rotation-Axis Direction1X-component of shear stress (pascal)0Y-component of shear stress (pascal)0X-component of shear stress (pascal)0Surface tension gradient (n/m-k)0Specularity Coefficient0		Z-Component of Wall Translation (m/s)	0
External Radiation Temperature (k)300 (0)(((constant . 0) (profile )))Rotation Speed (rad/s)0X-Position of Rotation-Axis Origin (m)0Y-Position of Rotation-Axis Origin (m)0Z-Position of Rotation-Axis Origin (m)0X-Component of Rotation-Axis Direction0Y-Component of Rotation-Axis Direction0Z-Component of Rotation-Axis Direction1X-component of shear stress (pascal)0Y-component of shear stress (pascal)0Z-component of shear stress (pascal)0Surface tension gradient (n/m-k)0Specularity Coefficient0		External Emissivity	1
(0) (((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Origin (m) 0 X-Component of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of shear stress (pascal) 0 Y-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0		External Radiation Temperature (k)	300
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) 0 X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Origin (m) 0 Z-Position of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 0 Z-Component of Rotation-Axis Direction 1 X-component of Rotation-Axis Direction 1 X-component of shear stress (pascal) 0 Y-component of shear stress (pascal) 0 Z-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0</pre>			(0)
now cold value		Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 0 1 0 0 0 0 0 0
new_cold_valve	new	_cold_valve	
Condition Value		Condition	Value
Condition Value	new	Surface tension gradient (n/m-k) Specularity Coefficient _cold_valve Condition	0 0 Value

	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	ye
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	-	
	External Radiation Temperature (k)	30
	External Radiation Temperature (k)	30 (0
	External Radiation Temperature (k)	30) (0)
(((cor	External Radiation Temperature (k)	30 (0
(((cor	External Radiation Temperature (k) Istant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m)	30 (0 0
(((cor	External Radiation Temperature (k) Istant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m)	30 (0 0 0
(((cor	External Radiation Temperature (k) Istant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m)	30 (0 0 0 0
( ( (cor	External Radiation Temperature (k) Istant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction	30) (0 0 0 0 0
( ( (cor	External Radiation Temperature (k) Istant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction X-Component of Rotation-Axis Direction	30 (0 0 0 0 0 0
( ( (cor	External Radiation Temperature (k) Istant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction	30 <sup>-</sup> (0 0 0 0 0 0 0 0
( ( (cor	External Radiation Temperature (k) Istant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of Rotation-Axis Direction X-component of shear stress (pascal)	30 <sup>-</sup> (0 0 0 0 0 0 0 1
( ( (cor	External Radiation Temperature (k) Istant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction X-component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal)	30 (0 0 0 0 0 0 0 1 0 0
( ( (cor	External Radiation Temperature (k) Instant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction X-component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal)	30 (0 0 0 0 0 0 0 1 0 0 0
( ( (cor	External Radiation Temperature (k) Instant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n(m-k))	30 <sup>-</sup> (0 0 0 0 0 0 0 1 0 0 0 0

cold\_walls

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	0
Temperature (k)	283
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1

External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0
cross_over_walls	
Condition	Value

Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1
Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . U) (profile )))	0
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0

Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 0
hot_top_walls	
Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	0
Temperature (k)	473
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion Chear Boundary Canditian	0
Define wall motion relative to adjacent cell zerol	0
Apply a rotational valocity to this wall?	yes
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
I-Component of Rotation-Axis Direction	0
X-component of shear stross (pageal)	1
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0
hot_valve_walls	
Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1

Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zono?	VOS
Apply a rotational velocity to this wall?	yes
Nelocity Magnitudo (m/s)	0
X-Component of Wall Translation	1
X-Component of Wall Translation	1
7-Component of Wall Translation	0
Define well wele serve water?	0
V Comparent of Moll man like ( ( )	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	Ô
Surface tension gradient $(n/m-k)$	0
Specularity Coefficient	0
pebble walls	
Condition	Value
	value
Wall Thickness (m)	0
Heat Generation Rate $(w/m3)$	0
Material Name	Conner
Thermal BC Type	0
Temperature (k)	173
Heat Flux $(m/m^2)$	475
Convective Heat Transfor Coofficient (w/m2-k)	0
Even Stream Temperature $(k)$	200
Free Stream remperature (K)	300
Mall Motion	0
Choor Boundary Condition	0
Shear Boundary Condition	U
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0

Define wal X-Component Y-Component Z-Component External Er External Ra	l velocity components? t of Wall Translation (m/s) t of Wall Translation (m/s) t of Wall Translation (m/s) missivity adiation Temperature (k)	no 0 0 1 300 (0)
(((constant . 0) (p) Rotation Sp X-Position Z-Position X-Component Y-Component Z-Component X-component Y-component Surface ter Specularity	rofile ))) peed (rad/s) of Rotation-Axis Origin (m) of Rotation-Axis Origin (m) of Rotation-Axis Origin (m) t of Rotation-Axis Direction t of Rotation-Axis Direction t of Rotation-Axis Direction t of shear stress (pascal) t of shear stress (pascal)	0 0 0 0 0 1 0 0 0 0 0
default-interi	lor	
Condition	Value	
default-interi	Lor:001	
Condition	Value	
default-interi	.or:024	
Condition	Value	
default-interi	or:026	
Condition	Value	
default-interi	or:027	
Condition	Value	
default-interi	or:028	
Condition	Value	
default-interi	or:029	
Condition	Value	

```
Solver Controls
-----
 Equations
   Equation Solved
    -----
   Flow yes
he yes
Energy yes
 Numerics
   Numeric
    Absolute Velocity Formulation yes
 Unsteady Calculation Parameters
   Time Step (s) 0.2
   Max. Iterations Per Time Step 100
 Relaxation
```

Variable	Relaxation Factor
Pressure Density	0.60000002
Body Forces	0.69999999
Momentum	0.4000001
he	0.8000001
Energy	0.89999998

Linear Solver

Variable	Solver Type	Termination Criterion	Residual Reduction Tolerance
Pressure X-Momentum	V-Cycle Flexible	0.1	0 7
Y-Momentum	Flexible	0.1	0.7
Z-Momentum he	Flexible Flexible	0.1	0.7 0.7
Energy	Flexible	0.1	0.7

Enabled

Pressure-Velocity Coupling

Parameter Value -----Type SIMPLE

Discretization Scheme

Variable Scheme ------

```
Pressure Body Force Weighted
     Density First Order Upwind
Momentum First Order Upwind
     he First Order Upwind
     Energy
              First Order Upwind
  Solution Limits
     Quantity
                              Limit
     Minimum Absolute Pressure 1
     Maximum Absolute Pressure 5e+10
     Maximum Temperature 1
Maximum Temperature 5000
Material Properties
_____
  Material: glass (solid)
     Property
                         Units Method Value(s)
     Density kg/m3 constant 2440
Cp (Specific Heat) j/kg-k constant 840
     Thermal Conductivity w/m-k constant 0.93699998
  Material: copper (solid)
     Property
                  Units Method Value(s)
     Density kg/m3 constant 8978
Cp (Specific Heat) j/kg-k constant 381
Thermal Conductivity w/m-k constant 387.60001
  Material: (helium . mixture-template) (fluid)
     Property
                              Units Method Value(s)
     j/kg-k kinetic-theory #f
w/m-k kinetic-theory #f
kg/m-s kinetic-theory #f
kg/kgmol constant 4.0026002
ength angstrom constant 2.576
     Cp (Specific Heat)
     Thermal Conductivity
     Viscositv
     Molecular Weight
     L-J Characteristic Length angstrom constant
     L-J Energy Parameter k constant
                                                       10.2
     Degrees of Freedom
                                       constant
                                                        3
     Speed of Sound
                             m/s none
                                                        #f
  Material: helium (fluid)
     Property
                                 Units Method Value(s)
     kg/m3 constant 0.1625
j/kg-k constant 5193
w/m-k constant 0.152
kg/m-s constant 1.99e-0
     Density
     Cp (Specific Heat)
     Thermal Conductivity
                                  kg/m-s constant 1.99e-05
kg/kgmol constant 4.0026
angstrom constant 0
     Viscosity
     Molecular Weight
     L-J Characteristic Length
```

	L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom	k 1/k	constant 0 constant 0 constant 0
	Speed of Sound	m/s	none #f
Ма	terial: mixture-template (mixtur	ce)	
Value	Property e(s)	Units	Method
	Mixture Species n2) () ())		names
#f	Density	kg/m3	ideal-gas
"- #f	Cp (Specific Heat)	j/kg-k	mixing-law .
#f	Thermal Conductivity	w/m-k	mass-weighted-mixing-law
# <del>-</del>	Viscosity	kg∕m-s	mass-weighted-mixing-law
#⊥ #f	Mass Diffusivity	m2/s	kinetic-theory
" ±	Thermal Diffusion Coefficient	kg/m-s	kinetic-theory
π⊥ Ω	Thermal Expansion Coefficient	1/k	constant
, #f	Speed of Sound	m/s	none

Material: (nitrogen . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Degrees of Freedom Speed of Sound	j/kg-k w/m-k kg/m-s kg/kgmol angstrom k m/s	kinetic-theory kinetic-theory kinetic-theory constant constant constant constant none	#f #f #f 28.013399 3.681 91.5 5 #f

Material: nitrogen (fluid)

Units	Method	Value(s)
kg/m3	constant	1.138
j/kg-k	constant	1040.67
w/m-k	constant	0.0242
kg/m-s	constant	1.663e-05
kg/kgmol	constant	28.0134
angstrom	constant	3.621
k	constant	97.53
1/k	constant	0
	constant	0
m/s	none	#f
	Units kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	Units Method kg/m3 constant j/kg-k constant w/m-k constant kg/m-s constant kg/kgmol constant angstrom constant k constant 1/k constant m/s none

## Material: oxygen (fluid)

Property		Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Le L-J Energy Parameter Thermal Expansion Coe Degrees of Freedom Speed of Sound	ngth fficient	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	1.2999 919.31 0.0246 1.919e-05 31.9988 3.458 107.4 0 0 #f
Material: water-vapor (f	luid)			
Property		Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Le. L-J Energy Parameter Thermal Expansion Coe Degrees of Freedom Speed of Sound Material: air (fluid)	ngth fficient	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	0.5542 2014 0.0261 1.34e-05 18.01534 2.605 572.4 0 0 #f
Property		Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Len L-J Energy Parameter Thermal Expansion Coe: Degrees of Freedom Speed of Sound	ngth fficient	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	1.225 1006.43 0.0242 1.7894e-05 28.966 3.711 78.6 0 0 #f
Material: aluminum (solid	d)			
Property	Units	Method	Value(s)	
Density Cp (Specific Heat) Thermal Conductivity	kg∕m3 j∕kg-k w∕m-k	constant constant constant	2719 871 202.4	

# **No Pebbles FLUENT Case**

```
FLUENT
Version: 3d, pbns, spe, lam, unsteady (3d, pressure-based, species,
laminar, unsteady)
Release: 6.3.26
Title:
Models
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Model Settings \_\_\_\_\_ Space 3D Time Unsteady, 1st-Order Implicit Viscous Laminar Heat Transfer Enabled Solidification and Melting Disabled Coupled Dispersed Phase Disabled Dispersed Phase Disabled Dispersed Phase Disabled Dispersed Phase Dispersed P Radiation None Pollutants Disabled Soot Disabled

#### Boundary Conditions

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Zones

name	id	type
barrel	2	fluid
cold leg	3	fluid
cold valve	4	fluid
cross-over leg	5	fluid
hot top	6	fluid
hot valve	7	fluid
pebbles	8	fluid
wall	9	wall
outlet	10	interior
cold_exit	11	interior
cold_enter	12	interior
hot_exit	13	interior
pebble_exit	14	interior
pebble_enter	15	interior
inlet	16	interior
barrel_walls	17	wall
new_cold_valve	18	wall
cold_walls	19	wall
cross_over_walls	20	wall
hot_top_walls	21	wall
hot_valve_walls	22	wall
pebble_walls	23	wall
default-interior	25	interior
default-interior:001	1	interior
default-interior:024	24	interior
default-interior:026	26	interior

default-interior:027	27	interior
default-interior:028	28	interior
default-interior:029	29	interior

Boundary Conditions

barrel

Condition

Value \_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 Porosity 1

Solid Material Name aluminum

cold\_leg

Condition

Value	condición	
varue		
	Material Name	
mixture-	template	
mincure	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	()
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	Õ
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	2-Coordinate of Point on Cone Axis (m)	0
	Hall Angle of Cone Relative to its Axis (deg)	0
	Directional Viscous Resistance formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	Õ
	CO Coefficient for Power-Law	õ
	C1 Coefficient for Power-Law	õ
	Porosity	1
	Solid Material Name	-

aluminum

cold\_valve

# Condition

	CONDICION	
vaiue		
	Material Name	
mixture-	-template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	()
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	Õ
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	7-Component of Direction-1 Vector	0
	A component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	1
	7 Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	1
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	2-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	Ţ
	Y-Coordinate of Point on Cone Axis (m)	0
	2-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	U
	Direction-2 Inertial Resistance (1/m)	U
	Direction-3 Inertial Resistance (1/m)	0
	CU Coefficient for Power-Law	0
	Cl Coefficient for Power-Law	0
	Porosity	1
	Solid Material Name	

aluminum

cross-over\_leg

Condition Value \_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0  $\cap$ Y-Origin of Rotation-Axis (m) Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? ves Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m)  $\cap$ Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 Porosity 1 Solid Material Name

#### aluminum

hot\_top

Condition

Value

\_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m)  $\cap$ Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 0 Z-Component of Direction-1 Vector X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 0 C1 Coefficient for Power-Law 1 Porosity Solid Material Name aluminum hot\_valve

Condition

Value

\_\_\_\_\_\_

	Material Name	
mixture-	template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	()
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	0
	CU COEFFICIENT FOR POWER-Law	0
	CI Coefficient for Power-Law	0
	Porosity Solid Material Nerg	T
~ ]	Solla Material Name	
a⊥um⊥num		

pebbles

Condition

V	а	1	u	e

varue		

Material Name	
mixture-template	
Specify source terms?	no
Source Terms	
((mass) (x-momentum) (y-momentum) (z-momentum) (species-0) (energy	łλ))
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	((x-
<pre>velocity (inactive . #f) (constant . 0) (profile )) (y-velocity</pre>	
(inactive . #f) (constant . 0) (profile )) (z-velocity (inactive	e. #f)
(constant . 0) (profile )) (species-0 (inactive . #f) (constant	. 0)
(profile )) (temperature (inactive . #f) (constant . 0) (profile	e )))
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	Õ
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
7-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
7-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	<u> </u>
7-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	no
Direction-1. Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
4830000	
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	-
0.39500001	
Solid Material Name	
alass	
34000	

wall

	Condition	Value
		0
	Wall Thickness (m)	0
	Heat Generation Rate (W/M3)	0
	Material Name	1 Copper
	Termerature (k)	300
	Heat Flux (w(m2)	300
	Convoctive Heat Transfer Coefficient (w/m2-k)	0
	Eroo Stroom Temperature (k)	300
	Frable shall conduction?	200
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	ves
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
		(0)
((cons	Potation (prolife )))	0
	V-Desition of Potation-Avia Origin (m)	0
	X rosition of Rotation-Axis Origin (m)	0
	7-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
0.	utlet	
	Condition Value	
	old exit	
C	old_enter	

```
hot_exit
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Condition Value

pebble\_exit

Condition Value

#### pebble\_enter

Condition Value

## inlet

Condition Value

barrel\_walls

Condition	Value

Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	aluminum
Thermal BC Type	0
Temperature (k)	293
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
V-Position of Rotation-Axis Origin (m)	0
7-Resition of Rotation-Axis Origin (m)	0
V-Component of Rotation-Axis Direction	0
X-Component of Rotation-Axis Direction	0 0
I Component of Rotacton Akts Direction	5

Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0
now cold value	
Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1
Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0
cold_walls	
Condition	Value
CONDICION	
	0
Wall Thickness (m)	U

	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	0
	Temperature (k)	283
	Heat Flux $(w/m^2)$	0
	Convoctive Heat Transfer Coefficient $(W/m^2-k)$	0
	Error Stroom Tomporature (k)	300
	Field shall conduction?	900 DO
	Enable shell conduction:	0
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
		(0)
(((consta	ant () (profile )))	
(((conbec	Rotation Speed (rad/s)	0
	X-Position of Botation-Axis Origin (m)	0
	X-Resition of Rotation-Axis Origin (m)	0
	Z-Regition of Rotation-Axis Origin (m)	0
	V Component of Potation-Avia Direction	0
	X-Component of Rotation Axis Direction	0
	Y-Component of Rotation-Axis Direction	1
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
cro	oss_over_walls	
		170
	Condition	varue
	Wall Thickness (m)	0
	Wall Inickness (m)	0
	Metarial Name	conner
	Material Name	1
	Inermal BC Type	300
	Temperature (k).	500
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (W/m2-K)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	U
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
		1
---------	--	---
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	T Component of Wall Translation (m/s)	0
	Z-Component of wall fighterion (m/s)	1
	External Emissivity	1
	External Radiation Temperature (k)	300
		(0)
(((con:	stant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	Y-Component of Rotation-Axis Direction	0
	X Component of Rotation-Axis Direction	0
	F-Component of Rotation-Axis Direction	1
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
1	not top walls	
	Condition	Value
	Wall Thickness (m)	0
	Wall Thickness (m)	0
	Wall Thickness (m) Heat Generation Rate (w/m3)	0 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name	0 0 copper
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type	0 0 copper 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k)	0 0 copper 0 473
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2)	0 0 copper 0 473 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k)	0 Copper 0 473 0 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k)	0 0 copper 0 473 0 0 300
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction?	0 0 copper 0 473 0 0 300 no
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion	0 copper 0 473 0 300 no 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition	0 copper 0 473 0 300 no 0 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone?	0 0 copper 0 473 0 0 300 no 0 0 0 0 ves
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall?	0 0 copper 0 473 0 0 300 no 0 0 0 yes no
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Valecity Magnitude (m/s)	0 0 copper 0 473 0 300 no 0 300 no 0 yes no 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s)	0 0 copper 0 473 0 300 no 0 yes no 0 1
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation	0 0 copper 0 473 0 300 no 0 300 no 0 yes no 0 1
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation	0 0 copper 0 473 0 0 300 no 0 300 no 0 yes no 0 1 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation	0 0 copper 0 473 0 0 300 no 0 300 no 0 yes no 0 1 0 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Z-Component of Wall Translation	0 0 copper 0 473 0 300 no 0 300 no 0 yes no 0 1 0 0 1 0 0 0 no
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation	0 0 copper 0 473 0 0 300 no 0 300 no 0 yes no 0 1 0 0 1 0 0 1
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s)	0 0 copper 0 473 0 0 300 no 0 300 no 0 yes no 0 1 0 0 1 0 0 0 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s)	0 0 copper 0 473 0 0 300 no 0 0 yes no 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity	0 copper 0 473 0 0 300 no 0 yes no 0 1 0 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0
	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 copper 0 473 0 0 300 no 0 yes no 0 1 0 0 1 0 0 1 300 1 300 1 300 1 300 1 300 1 300 1 300 1 300 1 300 300
	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 copper 0 473 0 0 300 no 0 yes no 0 1 0 0 1 0 0 1 300 (0)
	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 copper 0 473 0 300 no 0 yes no 0 1 0 0 1 0 0 1 300 (0)
	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 copper 0 473 0 300 no 0 yes no 0 1 0 0 1 0 0 1 300 (0)
(((con	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 copper 0 473 0 300 no 0 yes no 0 1 0 0 0 1 300 (0)

X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

hot\_valve\_walls

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1
Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone	? yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

pebble\_walls

Condition		Value
Wall Thickne		0
Heat Generat	ion Rate (w/m3)	0
Material Nam		copper
Thermal BC T	've	0
Temperature	(k)	473
Heat Flux (w	(m <sup>2</sup> )	0
Convective H	Meat Transfer Coefficient (w/m2-k)	0
Free Stream	Temperature (k)	300
Enable shell	conduction?	no
Wall Motion	conduction.	0
Shear Rounda	ry Condition	0
Define well	metion relative to adjagent call game?	V
Derline warr	motion relative to adjacent ceri zone:	yes
Apply a rota	itional velocity to this wall?	0
Velocity Mag	(nitude (m/s)	0
X-Component	of Wall Translation	1
Y-Component	or wall Translation	U
Z-Component	of Wall Translation	U
Define wall	velocity components?	no
X-Component	of Wall Translation (m/s)	0
Y-Component	of Wall Translation (m/s)	0
Z-Component	of Wall Translation (m/s)	0
External Emi	ssivity	1
External Rad	liation Temperature (k)	300
		(0)
Z-Position c Z-Position c X-Component Y-Component Z-Component Y-component Z-component Surface tens Specularity	of Rotation-Axis Origin (m) of Rotation-Axis Origin (m) of Rotation-Axis Direction of Rotation-Axis Direction of Rotation-Axis Direction of shear stress (pascal) of shear stress (pascal) of shear stress (pascal) sion gradient (n/m-k) Coefficient	0 0 1 0 0 0 0 0
default-interic	pr	
Condition	Value	
default-interic	pr:001	
Condition	Value	
default-interic	pr:024	
Condition	Value	

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default-interior:026
```

Condition Value

default-interior:027

Condition Value

default-interior:028

Condition Value

default-interior:029

Condition Value

### Solver Controls

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Equations

Equation	Solved
Flow	yes
he	yes
Energy	yes

Numerics

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

Time	Step (s)				0.2
Max.	Iterations	Per	Time	Step	100

Relaxation

Variable	Relaxation	Factor
Pressure	0.6000002	
Density	0.80000001	
Body Forces	0.69999999	
Momentum	0.40000001	
he	0.80000001	
Energy	0.89999998	

Linear Solver

```
Solver Termination Residual Reduction
Type Criterion Tolerance
     Variable Type
     PressureV-Cycle0.1X-MomentumFlexible0.1Y-MomentumFlexible0.1Z-MomentumFlexible0.1heFlexible0.1EnergyFlexible0.1
                                          0.7
                                         0.7
                                         0.7
                                         0.7
   Pressure-Velocity Coupling
     Parameter Value
     _____
     Type SIMPLE
  Discretization Scheme
     Variable Scheme
     _____
     Pressure Body Force Weighted
     Density First Order Upwind
     Momentum First Order Upwind
     he First Order Upwind
Energy First Order Upwind
  Solution Limits
     Quantity
                           Limit
      _____
     Minimum Absolute Pressure 1
     Minimum Absolute FressureIMaximum Absolute Pressure5e+10Minimum Temperature1Maximum Temperature5000
Material Properties
______
  Material: glass (solid)
                Units Method Value(s)
     Property
     _____
     Density kg/m3 constant 2440
     Cp (Specific Heat) j/kg-k constant 840
Thermal Conductivity w/m-k constant 0.93699998
  Material: copper (solid)
     Property
                          Units Method Value(s)
     Density kg/m3 constant 8978
Cp (Specific Heat) j/kg-k constant 381
Thermal Conductivity w/m-k constant 387.60001
```

Material: (helium . mixture-template) (fluid)

	Property	Uni	ts I	Method	Value(s)
	Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Degrees of Freedom Speed of Sound	j/kc w/m· kg/I kg/I ang: k m/s	g-k -k n-s kgmol strom	kinetic-theory kinetic-theory kinetic-theory constant constant constant constant none	#f #f 4.0026002 2.576 10.2 3 #f
Ma	terial: helium (fluid)				
	Property		Units	Method	Value(s)
Ма	Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficies Degrees of Freedom Speed of Sound terial: mixture-template (mix	nt	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmo angstrom k 1/k m/s	constant constant constant l constant m constant constant constant constant none	0.1625 5193 0.152 1.99e-05 4.0026 0 0 0 0 0 #f
Value	Property (s)		Units	Method	
( (he	Mixture Species n2) () ())			names	
₩F	Density		kg/m3	ideal-gas	
" ~ # f	Cp (Specific Heat)		j/kg-k	mixing-law	
″- #f	Thermal Conductivity		w/m-k	mass-weighted	l-mixing-law
#f	Viscosity		kg∕m-s	mass-weighted	l-mixing-law
# F	Mass Diffusivity		m2/s	kinetic-theor	У
#⊥ #f	Thermal Diffusion Coefficien	nt	kg∕m-s	kinetic-theor	У
π⊥ 0	Thermal Expansion Coefficien	nt	1/k	constant	
	Speed of Sound		m/s	none	

Material: (nitrogen . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	j/kg-k	kinetic-theory	#f
Thermal Conductivity	w/m-k	kinetic-theory	#f

Viscosity	kg/m-s	kinetic-theory	#f
Molecular Weight	kg/kgmol	constant	28.013399
L-J Characteristic Length	angstrom	constant	3.681
L-J Energy Parameter	k	constant	91.5
Degrees of Freedom		constant	5
Speed of Sound	m/s	none	#f

Material: nitrogen (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	1.138 1040.67 0.0242 1.663e-05 28.0134 3.621 97.53 0 0 #f

Material: oxygen (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.2999
Cp (Specific Heat)	j/kg-k	constant	919.31
Thermal Conductivity	w/m-k	constant	0.0246
Viscosity	kg/m-s	constant	1.919e-05
Molecular Weight	kg/kgmol	constant	31.9988
L-J Characteristic Length	angstrom	constant	3.458
L-J Energy Parameter	k	constant	107.4
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: water-vapor (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant constant	0.5542 2014 0.0261 1.34e-05 18.01534 2.605 572.4 0 0 #f
opeed of bound	, 0		" <del>-</del>

Material: air (fluid)

Property	Units	Method	Value(s)	
Density	kg/m3	constant	1.225	

Cp (Specific Heat)	j/kg-k	constant	1006.43
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.7894e-05
Molecular Weight	kg/kgmol	constant	28.966
L-J Characteristic Length	angstrom	constant	3.711
L-J Energy Parameter	k	constant	78.6
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2719
Cp (Specific Heat)	j/kg-k	constant	871
Thermal Conductivity	w/m-k	constant	202.4

# Loss Coefficient FLUENT Case

FLUENT Version: 3d, pbns, spe, lam, unsteady (3d, pressure-based, species, laminar, unsteady) Release: 6.3.26 Title:

Models

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Model	Settings
Model Space Time Viscous Heat Transfer Solidification and Melting Radiation Species Transport Coupled Dispersed Phase Pollutants Pollutants	3D Unsteady, 1st-Order Implicit Laminar Enabled Disabled None Non-Reacting (2 species) Disabled Disabled Disabled
Soot	Disabled

Boundary Conditions

Zones

name	id	type
barrel	2	fluid
cold leg	3	fluid
cold valve	4	fluid
cross-over leg	5	fluid
hot top	6	fluid
hot valve	7	fluid
pebbles	8	fluid
wall	9	wall
outlet	10	interior
cold_exit	11	interior
cold_enter	12	interior
hot_exit	13	interior
pebble_exit	14	interior
pebble_enter	15	interior
inlet	16	interior
barrel_walls	17	wall
new_cold_valve	18	wall
cold_walls	19	wall
cross_over_walls	20	wall
hot_top_walls	21	wall
hot_valve_walls	22	wall
pebble_walls	23	wall
default-interior	25	interior
default-interior:001	1	interior
default-interior:024	24	interior
default-interior:026	26	interior
default-interior:027	27	interior
default-interior:028	28	interior
default-interior:029	29	interior

Boundary Conditions

barrel

Condition

Value

Matorial Name	
material Name	
specity source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0

Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

### aluminum

cold\_leg

Condition

Value

varue								

Material Name	
mixture-template	
Specify source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
101040 2000.	110

Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
C0 Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

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aluminum

cold\_valve

Condition

Value

Material Name	
mixture-template	
Specify source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0

	7-Component of Direction-1 Vector	0
	Z-component of Direction 1 Vector	0
	X-component of Direction-2 vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	V-Coordinate of Point on Cone Axis (m)	Ô
	7 Coordinate of Point on Cone Axis (m)	0
	Z-COOLINALE OF POINT ON CONE AXIS (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	0
	CO Coefficient for Power-Law	0
	C1 Coefficient for Power-Law	Õ
	Porocity	1
	Colid Material Name	T
	Solid Material Name	
aluminu.	.[[	
С	ross-over_leg	
	Condition	
Value		
	Material Name	
mixture	-template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	()
	Motion Type	0
	$\begin{array}{c} \text{Notion 1ype} \\ \text{X-Valacity Of Zerra } (\pi/a) \end{array}$	0
	X-Velocity of Zone (m/s)	0
	Y-velocity of Zone (m/s)	U
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical narous conol	no
	CONTERT DOTOUS ZONE?	
	X-Component of Direction-1 Vector	1
	X-Component of Direction-1 Vector	1
	X-Component of Direction-1 Vector Y-Component of Direction-1 Vector	1 0
	X-Component of Direction-1 Vector Y-Component of Direction-1 Vector Z-Component of Direction-1 Vector	1 0 0
	X-Component of Direction-1 Vector Y-Component of Direction-1 Vector Z-Component of Direction-1 Vector X-Component of Direction-2 Vector	1 0 0 0

	Z-Component of Direction-2 Vector X-Component of Cone Axis Vector	0 1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 viscous Resistance (1/m2)	0
	Direction-1 Inertial Periotance (1/m)	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	CO Coefficient for Power-Law	0
	C1 Coefficient for Power-Law	0
	Porosity	1
	Solid Material Name	-
aluminum		
hot	t_top	
	Condition	
Value	Condition	
Varue		
	Material Name	
mixture-	template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	()
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	I-Velocity OI Zone (m/s)	0
	Potation speed (rad(s)	0
	X-Origin of Potation-lyic (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	Õ
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	A-component of Cone Axis Vector	1 O
	T COMPONENT OF COME WYTE AECTOL	V

Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

```
aluminum
```

hot\_valve

Condition

Material Name	
mixture-template	
Specify source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0

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С

pebbles

L -		
_	Condition	
Value		
	Material Name	
mixture-	template	
	Specify source terms?	no
	Source Terms	
((mass)	(x-momentum) (y-momentum) (z-momentum) (species-0) (energy	))
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	((x-
velocity	<pre>v (inactive . #f) (constant . 0) (profile )) (y-velocity</pre>	
(inactiv	re . #f) (constant . 0) (profile )) (z-velocity (inactive	. #f)
(constan	(constant.) (profile )) (species-0 (inactive . #f) (constant .	0)
(profile	<pre> )) (temperature (inactive . #f) (constant . 0) (profile Mation Time</pre>	)))
	Motion Type V Velecity Of Zene (m/c)	0
	X-Velocity of Zone $(m/s)$	0
	Z = Volocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	yes
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	2-Component of Direction-2 Vector	0

4820000	X-Component of Cone Axis Vector Y-Component of Cone Axis Vector Z-Component of Cone Axis Vector X-Coordinate of Point on Cone Axis (m) Y-Coordinate of Point on Cone Axis (m) Z-Coordinate of Point on Cone Axis (m) Half Angle of Cone Relative to its Axis (deg) Relative Velocity Resistance Formulation? Direction-1 Viscous Resistance (1/m2) Direction-2 Viscous Resistance (1/m2)	1 0 1 0 0 0 0 0	
0.395000	Direction-3 Viscous Resistance (1/m2) Choose alternative formulation for inertial resistan Direction-1 Inertial Resistance (1/m) Direction-2 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) C0 Coefficient for Power-Law C1 Coefficient for Power-Law Porosity 01	0 nce? no 0 0 0 0 0	
glass	Solid Material Name		
wa	1		
	Condition	Value	
			•
	Wall Thickness (m)	0	
	Heat Generation Rate (w/m3)	0	
	Material Name	copper	
	Thermal BC Type	1	
	Temperature (k)	300	
	Heat Flux (w/m2)	0	
	Convective Heat Transfer Coefficient (w/m2-k)	0	
	Free Stream Temperature (k)	300	
	Enable shell conduction?	no	
	Wall Motion Shear Boundary Condition	0	
	Define wall motion relative to adjacent cell zone?	Ves	
	Apply a rotational velocity to this wall?	no	
	Velocity Magnitude (m/s)	0	
	X-Component of Wall Translation	1	
	Y-Component of Wall Translation	0	
	Z-Component of Wall Translation	0	
	Define wall velocity components?	no	
	X-Component of Wall Translation (m/s)	0	
	Z-Component of Wall Translation (m/s)	0	
	External Emissivity	1	
	External Radiation Temperature (k)	300	
	-	(0)	
(((consta	ant . 0) (profile )))		
	Rotation Speed (rad/s)	0	
	X-Position of Rotation-Axis Origin (m)	0	
	Y-Position of Rotation-Axis Origin (m)	0	

Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

#### outlet

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Condition Value

cold\_exit

Condition Value

cold\_enter

Condition Value

### hot\_exit

Condition Value

### pebble\_exit

Condition Value

### pebble\_enter

С	0	n	d	i	t	i	0	n				V	а	1	u	е
_	_	_	_		-	_	_	_	_	_	_	-	-	_	_	-

#### inlet

Condition Value

### barrel\_walls

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	aluminum
Thermal BC Type	0
Temperature (k)	293
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0

	<pre>Free Stream Temperature (k) Enable shell conduction? Wall Motion Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	300 no 0 yes no 0 1 0 0 0 0 0 0 0 1 300 (0)
(((const	ant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	()
		0
	Specularity Coefficient	0
ne	Specularity Coefficient w_cold_valve	0
ne	Specularity Coefficient w_cold_valve Condition	0 Value
ne	Specularity Coefficient w_cold_valve Condition	0 Value
ne	Specularity Coefficient w_cold_valve Condition	Value
ne	Specularity Coefficient w_cold_valve Condition 	Value
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 0 copper
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 copper 1 300
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 copper 1 300
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 copper 1 300 0
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 0 0 0 0 0 300 0 300
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 0 0 0 0 0 300 0 0 300
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 0 0 0 0 0 300 0 0 0 0 0 0 0 0 0 0
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 0 0 0 0 0 300 0 0 0 0 0 0 0 0
ne	Specularity Coefficient Specularity Coefficient w_cold_valve Condition 	Value 0 0 0 0 0 0 0 300 0 0 0 0 0 0 0 0 0 0
ne	Specularity Coefficient w_cold_valve Condition 	Value O Copper 1 300 0 300 no 0 yes no
ne	Specularity Coefficient Specularity Coefficient w_cold_valve Condition 	Value O Copper 1 300 0 300 no 0 yes no 0
ne	Specularity Coefficient w_cold_valve Condition 	Value O Copper 1 300 0 300 no 0 yes no 0 1
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 0 0 0 0 0 300 0 0 300 0 0 0 9 0 0 0 0
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 copper 1 300 0 300 no 0 0 yes no 0 1 0 0
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 copper 1 300 0 0 300 no 0 0 yes no 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
ne	Specularity Coefficient Specularity Coefficient w_cold_valve Condition 	Value 0 0 0 0 0 0 0 300 0 0 300 0 0 0 0 0 0
ne	Specularity Coefficient w_cold_valve Condition 	Value 0 0 copper 1 300 0 300 no 0 yes no 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

•

Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient</pre>	0 0 0 0 0 1 0 0 0 0 0 0 0
cold_walls	
Condition	Value
<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 0 copper 0 283 0 0 300 no 0 0 yes no 0 0 1 0 0 0 0 0 1 0 0 0 1 300 0 0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction</pre>	0 0 0 0 0 0 1

X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 0 0
cross_over_walls	
Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1
Temperature (K)	300
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature $(k)$	300
Enable shell conduction?	no ·
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s) V-Component of Wall Translation	1
X-Component of Wall Translation	0
Z-Component of Wall Translation	Õ
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1 1
External Radiation Temperature (K)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (M) X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	õ
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0
hot_top_walls	
Condition	Value
Mall Thickness (m)	0
Heat Generation Rate (w/m3)	0

	Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	copper 0 473 0 0 300 no 0 0 yes no 0 1 0 0 1 0 0 0 1 0 0 0 1 300 (0)
		(0)
(((const	ant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient t_valve_walls Condition	0 0 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation	0 0 copper 1 300 0 300 no 0 300 no 0 0 yes no 0 1

	Y-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 0 0 0 0 1 300 (0)
(((const	ant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 0 0 0 1 0 0 0 0 0 0
pe	bble_walls	Value
		0
	<pre>Wall Informetsion Rate (w/m3) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 copper 0 473 0 300 no 0 yes no 0 1 0 0 1 0 0 0 0 1 300 (0)
(((const	ant . 0) (profile )))	0

Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

default-interior

Condition Value default-interior:001 Condition Value \_\_\_\_\_ default-interior:024 Condition Value \_\_\_\_\_ default-interior:026 Condition Value \_\_\_\_\_ default-interior:027 Condition Value \_\_\_\_\_ default-interior:028 Condition Value \_\_\_\_\_ default-interior:029 Condition Value \_\_\_\_\_

Solver Controls

Equations

Equation	Solved
Flow	yes
he	yes
Energy	yes

Numerics

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

Time	Step (s)				0.0099999998
Max.	Iterations	Per	Time	Step	100

Relaxation

Variable	Relaxation Factor
Pressure	0.6000002
Density	0.80000001
Body Forces	0.69999999
Momentum	0.40000001
he	0.8000001
Energy	0.89999998

#### Linear Solver

Variable	Solver Type	Termination Criterion	Residual Reduction Tolerance
Pressure	V-Cycle	0.1	
X-Momentum	Flexible	0.1	0.7
Y-Momentum	Flexible	0.1	0.7
Z-Momentum	Flexible	0.1	0.7
he	Flexible	0.1	0.7
Energy	Flexible	0.1	0.7

Pressure-Velocity Coupling

Parameter	Value
Туре	PISO
Skewness-Neighbour Coupling	yes
Skewness Correction	1
Neighbour Correction	1

Discretization Scheme

Variable	Scheme	
Pressure	PRESTO!	
Density	Third-Order	MUSCL
Momentum	Third-Order	MUSCL
he	Third-Order	MUSCL
Energy	Third-Order	MUSCL

Solution Limits

Quantity	1		Limit
Minimum Maximum	Absolute	Pressure	1 50+10
Minimum	Temperati	ire	1
Maximum	Temperatu	ure	5000

### Material Properties

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Material: glass (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2440
Cp (Specific Heat)	j/kg-k	constant	840
Thermal Conductivity	w/m-k	constant	0.93699998

Material: copper (solid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat)	kg/m3 j/kg-k	constant constant	8978 381
Thermal Conductivity	w/m-k	constant	381.00001

Material: (helium . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	j/kg-k	kinetic-theory	#f
Thermal Conductivity	w/m-k	kinetic-theory	#f
Viscosity	kg/m-s	kinetic-theory	#f
Molecular Weight	kg/kgmol	constant	4.0026002
L-J Characteristic Length	angstrom	constant	2.576
L-J Energy Parameter	k	constant	10.2
Degrees of Freedom		constant	3
Speed of Sound	m/s	none	# f

Material: helium (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	0.1625
Cp (Specific Heat)	j/kg-k	constant	5193
Thermal Conductivity	w/m-k	constant	0.152
Viscosity	kg/m-s	constant	1.99e-05
Molecular Weight	kg/kgmol	constant	4.0026
L-J Characteristic Length	angstrom	constant	0
L-J Energy Parameter	k	constant	0
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	# f

Material: mixture-template (mixture)

	Property	Units	Method
Value	s(s)		
	Mixture Species		names
((he	n2) () ())		
11.0	Density	kg/m3	ideal-gas
# I	Cp (Specific Heat)	j/kg-k	mixing-law
# I	Thermal Conductivity	w∕m-k	mass-weighted-mixing-law
#f	Viscosity	kg/m-s	mass-weighted-mixing-law
#f	Mass Diffusivity	m2/s	kinetic-theory
#f	Thermal Diffusion Coefficient	kg/m-s	kinetic-theory
#f	Thermal Expansion Coefficient	1/k	constant
0	Speed of Sound	m/s	none
#f			

Material: (nitrogen . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Degrees of Freedom Speed of Sound	j/kg-k w/m-k kg/m-s kg/kgmol angstrom k m/s	kinetic-theory kinetic-theory constant constant constant constant none	#f #f 28.013399 3.681 91.5 5 #f
-			

Material: nitrogen (fluid)

riopercy	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	1.138 1040.67 0.0242 1.663e-05 28.0134 3.621 97.53 0 0 #f

Material: oxygen (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.2999
Cp (Specific Heat)	j/kg-k	constant	919.31

Thermal Conductivity	w/m-k	constant	0.0246
Viscosity	kg∕m-s	constant	1.919e-05
Molecular Weight	kg/kgmol	constant	31.9988
L-J Characteristic Length	angstrom	constant	3.458
L-J Energy Parameter	k	constant	107.4
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	# f

Material: water-vapor (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	0.5542 2014 0.0261 1.34e-05 18.01534 2.605 572.4 0 0 #f

Material: air (fluid)

Property	Units	Method	Value(s)
			1 225
Density	kg/m3	Constant	1.220
Cp (Specific Heat)	j/kg-k	constant	1006.43
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.7894e-05
Molecular Weight	kg/kgmol	constant	28.966
L-J Characteristic Length	angstrom	constant	3.711
L-J Energy Parameter	k	constant	78.6
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2719
Cp (Specific Heat)	j/kg-k	constant	871
Thermal Conductivity	w/m-k	constant	202.4

## Heat Flux FLUENT Case

FLUENT Version: 3d, pbns, spe, lam, unsteady (3d, pressure-based, species, laminar, unsteady) Release: 6.3.26 Title:

### Models

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Model	Settings
Model Space Time Viscous Heat Transfer Solidification and Melting Radiation	3D Unsteady, 1st-Order Implicit Laminar Enabled Disabled None
Species Transport Coupled Dispersed Phase Pollutants Pollutants Soot	Non-Reacting (2 species) Disabled Disabled Disabled Disabled

Boundary Conditions

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#### Zones

name	id	type
barrel	2	fluid
cold leg	3	fluid
cold valve	4	fluid
cross-over leg	5	fluid
hot top	6	fluid
hot valve	7	fluid
pebbles	8	fluid
wall	9	wall
outlet	10	interior
cold exit	11	interior
coldenter	12	interior
hot exit	13	interior
pebble exit	14	interior
pebble enter	15	interior
inlet -	16	interior
barrel walls	17	wall
new cold valve	18	wall
cold_walls	19	wall
cross_over_walls	20	wall
hot_top_walls	21	wall
hot_valve_walls	22	wall
pebble_walls	23	wall
default-interior	25	interior
default-interior:001	1	interior
default-interior:024	24	interior
default-interior:026	26	interior
default-interior:027	27	interior
default-interior:028	28	interior
default-interior:029	29	interior

Boundary Conditions

barrel

	Condition	
Value		
	Material Name	
mixture-	template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	0
	Motion Type	0
	X-Velocity Of Zone $(m/s)$	0
	7 - Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	Õ
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-I Vector	0
	2-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	1
	7-Component of Direction-2 Vector	n n
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2) Change alternative formulation for inertial registance?	0
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	õ
	CO Coefficient for Power-Law	0
	C1 Coefficient for Power-Law	0
	Porosity	1
	Solid Material Name	
aluminum	1	

cold\_leg

Condition Value

\_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 X-Velocity Of Zone (m/s) 0 0 Y-Velocity Of Zone (m/s) Z-Velocity Of Zone (m/s) 0 0 Rotation speed (rad/s) X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 0 Y-Component of Rotation-Axis Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 0 X-Component of Direction-2 Vector 1 Y-Component of Direction-2 Vector Z-Component of Direction-2 Vector 0 1 X-Component of Cone Axis Vector 0 Y-Component of Cone Axis Vector Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 0 Direction-2 Viscous Resistance (1/m2) Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 0 C1 Coefficient for Power-Law 1 Porosity Solid Material Name

\_\_\_\_\_

#### aluminum

cold valve

Condition

Value

\_\_\_\_\_

```
Material Name
mixture-template
        Specify source terms?
                                                                 no
        Source Terms
                                                                  ()
        Specify fixed values?
                                                                 no
        Local Coordinate System for Fixed Velocities
                                                                 no
        Fixed Values
                                                                 ()
                                                                 0
        Motion Type
        X-Velocity Of Zone (m/s)
                                                                 0
        Y-Velocity Of Zone (m/s)
                                                                 0
        Z-Velocity Of Zone (m/s)
                                               1
                                                                 0
                                                                 0
        Rotation speed (rad/s)
        X-Origin of Rotation-Axis (m)
                                                                 0
        Y-Origin of Rotation-Axis (m)
                                                                 0
        Z-Origin of Rotation-Axis (m)
                                                                 0
                                                                 0
        X-Component of Rotation-Axis
                                                                 0
        Y-Component of Rotation-Axis
                                                                 1
        Z-Component of Rotation-Axis
        Deactivated Thread
                                                                 no
        Porous zone?
                                                                 no
        Conical porous zone?
                                                                 no
        X-Component of Direction-1 Vector
                                                                 1
        Y-Component of Direction-1 Vector
                                                                 0
        Z-Component of Direction-1 Vector
                                                                 0
        X-Component of Direction-2 Vector
                                                                 0
        Y-Component of Direction-2 Vector
                                                                 1
        Z-Component of Direction-2 Vector
                                                                 0
        X-Component of Cone Axis Vector
                                                                 1
                                                                 0
        Y-Component of Cone Axis Vector
                                                                 0
        Z-Component of Cone Axis Vector
        X-Coordinate of Point on Cone Axis (m)
                                                                 1
                                                                 0
        Y-Coordinate of Point on Cone Axis (m)
                                                                 0
        Z-Coordinate of Point on Cone Axis (m)
        Half Angle of Cone Relative to its Axis (deg)
                                                                 0
        Relative Velocity Resistance Formulation?
                                                                 ves
        Direction-1 Viscous Resistance (1/m2)
                                                                 0
                                                                 0
        Direction-2 Viscous Resistance (1/m2)
        Direction-3 Viscous Resistance (1/m2)
                                                                 0
        Choose alternative formulation for inertial resistance?
                                                                 no
        Direction-1 Inertial Resistance (1/m)
                                                                 0
                                                                 0
        Direction-2 Inertial Resistance (1/m)
                                                                 0
        Direction-3 Inertial Resistance (1/m)
        CO Coefficient for Power-Law
                                                                 0
        C1 Coefficient for Power-Law
                                                                 0
        Porosity
                                                                 1
        Solid Material Name
aluminum
     cross-over leq
        Condition
Value
        _____
_____
        Material Name
mixture-template
        Specify source terms?
```

```
no
```

Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

hot\_top

Condition

Condition	
Value	
Material Name	
mixture-template .	
Specify source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no

```
140
```

Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
Y-Origin of Potation=Axis (m)	Ô
V Origin of Rotation Axis (m)	0
r-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
X-Component of Direction-2 Vector	1
7-Component of Direction-2 Vector	ñ
Z component of Cone Axis Vector	1
X-Component of Cone Axis Vector	
r-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	Õ
CO Coefficient for Bower-Law	Õ
Cl Coefficient for Douor-Law	0
CI COEFFICIENT IOF POwer-Law	1
Porosily	Т
Solid Material Name	

### aluminum

hot\_valve

```
Condition
```

Value \_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? Source Terms no () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () 0 Motion Type 0 X-Velocity Of Zone (m/s)  $% \left( M^{2}\right) =0$ 

	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	7-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	ves
	Direction-1 Viscous Resistance (1/m2)	Ō
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	0
	CO Coefficient for Power-Law	0
	Cl Coefficient for Power-Law	0
	Porosity	1
	Solid Material Name	
aluminum		
peb	bbles	
	Condition	
Value		
VALUE		

		· – – – –
M	Material Name	
mixture-te	emplate	
2	Specify source terms?	no
2	Source Terms	
((mass) (x	x-momentum) (y-momentum) (z-momentum) (species-0) (energy)	)
S	Specify fixed values?	no
I	Local Coordinate System for Fixed Velocities	no
F	Fixed Values	((x-
velocity (	(inactive . #f) (constant . 0) (profile )) (y-velocity	

(inactive (constant	e . #f) (constant . 0) (profile )) (z-velocity (inact t . 0) (profile )) (species-0 (inactive . #f) (consta	live . #f)
(profile	)) (temperature (inactive . #f) (constant . 0) (prof	(ile )))
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	yes
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	no
	Direction-1 Viscous Resistance (1/m2)	
5860000		
	Direction-2 Viscous Resistance (1/m2)	
5860000		
	Direction-3 Viscous Resistance (1/m2)	
5860000		
	Choose alternative formulation for inertial resistance	e? no
	Direction-1 Inertial Resistance (1/m)	2734
	Direction-2 Inertial Resistance (1/m)	2734
	Direction-3 Inertial Resistance (1/m)	2/34
	CO Coefficient for Power-Law	0
	Cl Coefficient for Power-Law	U
	Porosity	
0.4000000		
-	Solid Material Name	
giass		
Wd.		
	Condition	Value
		varue
	<b></b>	
	Wall Thickness (m)	0
	Walt Intermess ( $m/m^{2}$ )	0
	Matorial Name	conner
	Thermal BC Type	1
	Incluat De Type	-

Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
Encernar nadiation remperature (n)	(0)
	(-)
(((constant , 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	õ
7-Position of Rotation-Axis Origin (m)	õ
X-Component of Rotation-Axis Direction	Õ
Y-Component of Rotation-Axis Direction	Ô
2-Component of Rotation-Axis Direction	1
Y-component of shear stress (nascal)	0
Y-component of shear stress (pascal)	0
7-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Spocularity Coofficient	0
opecutaticy coefficient	0
outlet	
Condition Value	

Condition Value

cold\_exit

Condition Value

cold\_enter

Condition Value

hot\_exit

Condition Value

pebble\_exit
Condition Value	
pebble_enter	
Condition Value	
inlet	
Condition Value	
barrel_walls	
Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	aluminum
Thermal BC Type	0
Temperature (k)	293
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (W/m2-K)	200
Free Stream Temperature (K)	300 no
Mall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	ves
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
2-Component of Wall Translation (m/s)	1
External Radiation Temperature (k)	300
External Nauration Temperature (K)	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	U
Y-component of shear stress (pascal)	0
2-component of snear stress (pascal)	0
Specularity Coefficient	Ő
opcoulding, coorrigation	-

new\_cold\_valve

	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	1
	Temperature (k)	300
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	U
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
		(0)
(((const	ant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	U
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
cc	ld_walls	
	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	0 .
	Temperature (k)	283
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	-	

Enable shell conduction Wall Motion Shear Boundary Condition Define wall motion relat Apply a rotational velot Velocity Magnitude (m/s X-Component of Wall Trat Z-Component of Wall Trat Define wall velocity con X-Component of Wall Trat Y-Component of Wall Trat Z-Component of Wall Trat External Emissivity External Radiation Temp	n? ative to adjacent cell zone? bocity to this wall? anslation anslation bomponents? anslation (m/s) anslation (m/s) boerature (k)	no 0 yes no 0 1 0 0 0 0 0 0 1 300 (0)
(((constant . 0) (profile )))		
Rotation Speed (rad/s)		0
X-Position of Rotation-	-Axis Origin (m)	0
I-POSITION OI ROTATION- Z-Position of Rotation-	-Axis Origin (m) -Axis Origin (m)	0
X-Component of Rotation	n-Axis Direction	õ
Y-Component of Rotatior	n-Axis Direction	0
Z-Component of Rotation	-Axis Direction	1
X-component of shear st	ress (pascal)	0
Y-component of shear st	cress (pascal)	0
Surface tension gradier	(n/m-k)	0
Specularity Coefficient		0
cross_over_walls		
Condition		Value
		0
Wall Thickness (m)	(	0
Material Name	///////////////////////////////////////	copper
Thermal BC Type		1
Temperature (k)		300
Heat Flux (w/m2)		0
Convective Heat Transfe	er Coefficient (w/m2-k)	0
Free Stream Temperature	e (K)	300
Wall Motion	1 2	0
Shear Boundary Conditio	on	0
Define wall motion rela	tive to adjacent cell zone?	yes
Apply a rotational velo	ocity to this wall?	no
Velocity Magnitude (m/s	3)	U 1
X-Component of Wall Tra X-Component of Wall Tra	anstation	1 0
Z-Component of Wall Tra	anslation	õ
Define wall velocity co	omponents?	no
X-Component of Wall Tra	anslation (m/s)	0
Y-Component of Wall Tra	inslation (m/s)	0
Z-Component of Wall Tra	anslation (m/s)	0

External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0
Speculaticy coefficient	0

hot\_top\_walls

	Condition	Value
	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Emissivity</pre>	0 0 copper 0 473 0 0 300 no 0 0 yes no 0 1 0 0 0 0 0 0 0 0 1 0 0 0 0 1 0 0 0 0 1 300
		(0)
(((consta	nt . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal)	0 0 0 0 0 1 0

	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
hot	valve_walls	
	Condition	Value
		_
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	1
	Temperature (k)	300
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
		(0)
(((consta	ant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
peł	bble_walls	
		57 - ]
	Condition	value
		0
	Wall INICKNESS (M)	0
	Heat Generation Rate (W/M3)	0
	Materiai Name	copper

•

1 473 8889.0596 0 300 no 0 yes no 0 1 0 0 1 0 0 0 0 1 300 (0)
0 0 0 0 0 0 1 0 0 0 0 0

default-interior:027

## Condition Value

```
Solver Controls
```

```
_____
```

## Equations

Equation	Solved
Flow	yes
he	yes
Energy	yes

#### Numerics

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

Time	Step (s)			0.15000001
Max.	Iterations	Per Time	Step	200

#### Relaxation

Variable Relaxation Factor Pressure 0.30000001 Density 1 Body Forces 1 Momentum 0.69999999 he 1 Energy 1

## Linear Solver

Variable	Solver	Termination	Residual Reduction
	Type	Criterion	Tolerance
Pressure X-Momentum Y-Momentum	V-Cycle Flexible Flexible	0.1 0.1 0.1	0.7 0.7

Z-Momentum	Flexible	0.1	0.7
he	Flexible	0.1	0.7
Energy	Flexible	0.1	0.7

Pressure-Velocity Coupling

Parameter	Value
Туре	SIMPLE

Discretization Scheme

Variable	Scheme	
Pressure	PRESTO!	
Density	Third-Order	MUSCL
Momentum	Third-Order	MUSCL
he	Third-Order	MUSCL
Energy	Third-Order	MUSCL

Solution Limits

Quantity	Limit
Minimum Absolute Pressure	1
Maximum Absolute Pressure	5e+10
Minimum Temperature	1
Maximum Temperature	5000

## Material Properties

\_\_\_\_\_

Material: glass (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2440
Cp (Specific Heat)	j∕kg-k	constant	840
Thermal Conductivity	w/m-k	constant	0.93699998

Material: copper (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	8978
Cp (Specific Heat)	j/kg-k	constant	381
Thermal Conductivity	w/m-k	constant	387.60001

Material: (helium . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	j/kg-k	kinetic-theory	#f
Thermal Conductivity	w/m-k	kinetic-theory	#f
Viscosity	kg/m-s	kinetic-theory	#f
Molecular Weight	kg/kgmol	constant	4.0026002
L-J Characteristic Length	angstrom	constant	2.5510001

L-J Energy Parameter Degrees of Freedom Speed of Sound	k m/s	cons cons none	tant tant	10.22 3 #f
Material: helium (fluid)				
Property	Uni	ts 1	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Len L-J Energy Parameter Thermal Expansion Coef Degrees of Freedom Speed of Sound	kg/ j/k w/m kg/ gth ang k ficient 1/k m/s	m3 ( g-k ( -k ( m-s ( kgmol ( strom (	constant constant constant constant constant constant constant constant constant	0.1625 5193 0.152 1.99e-05 4.0026 0 0 0 0 0 #f
Material: mixture-templat	e (mixture)			
Property .ue(s)	Uni	ts Met	thod	
Mixture Species e n2) () ())		nar	nes	
Density	kg/:	m3 ide	eal-gas	
Cp (Specific Heat)	· j/k	g−k mi≯	xing-law	
Thermal Conductivity	w/m	-k ide	eal-gas-mix	ing-law
Viscosity	kg/i	m-s ide	eal-gas-mix	ing-law
Mass Diffusivity	m2/	s kir	netic-theor	У
Thermal Diffusion Coef	ficient kg/n	m-s kir	netic-theor	У
Thermal Expansion Coef Speed of Sound	ficient 1/k m/s	cor nor	nstant ne	0
Material: (nitrogen . mix	ture-template	) (fluid)	)	
Property	Units	Metho	bd	Value(s)

liopercy	011100	meenoa	varac (5)
Cp (Specific Heat)	j/kg-k	kinetic-theory	 #f
Thermal Conductivity	w/m-k	kinetic-theory	#f
Viscosity	kg/m-s	kinetic-theory	#f
Molecular Weight	kg/kgmol	constant	28.013399
L-J Characteristic Length	angstrom	constant	3.7980001
L-J Energy Parameter	k	constant	71.400002
Degrees of Freedom		constant	5
Speed of Sound	m/s	none	# f

Material: nitrogen (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.138
Cp (Specific Heat)	j/kg-k	constant	1040.67
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.663e-05
Molecular Weight	kg/kgmol	constant	28.0134
L-J Characteristic Length	angstrom	constant	3.621
L-J Energy Parameter	k	constant	97.53
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: oxygen (fluid)

Units	Method	Value(s)
kg/m3	constant	1.2999
j/kg-k	constant	919.31
w/m-k	constant	0.0246
kg/m-s	constant	1.919e-05
kg/kgmol	constant	31.9988
angstrom	constant	3.458
k	constant	107.4
1/k	constant	0
	constant	0
m/s	none	# f
	Units kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	Units Method kg/m3 constant j/kg-k constant w/m-k constant kg/m-s constant kg/kgmol constant angstrom constant k constant 1/k constant m/s none

Material: water-vapor (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	0.5542
Cp (Specific Heat)	j/kg-k	constant	2014
Thermal Conductivity	w/m-k	constant	0.0261
Viscosity	kg∕m-s	constant	1.34e-05
Molecular Weight	kg/kgmol	constant	18.01534
L-J Characteristic Length	angstrom	constant	2.605
L-J Energy Parameter	k	constant	572.4
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	# f

Material: air (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.225
Cp (Specific Heat)	j/kg-k	constant	1006.43
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.7894e-05
Molecular Weight	kg/kgmol	constant	28.966
L-J Characteristic Length	angstrom	constant	3.711
L-J Energy Parameter	k	constant	78.6
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0

Speed of Sound

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat)	kg/m3 j/kg-k	constant constant	2719 871
Thermal Conductivity	w/m-k	constant	202.4

## Accurate Temperature Boundary Condition FLUENT Case

```
FLUENT
Version: 3d, pbns, spe, lam, unsteady (3d, pressure-based, species,
laminar, unsteady)
Release: 6.3.26
Title:
Models
____
  Model
                             Settings
   ЗD
  Space
  Time
                             Unsteady, 1st-Order Implicit
  Viscous
                             Laminar
                             Enabled
  Heat Transfer
  Solidification and Melting Disabled
Radiation None
  SoliditionNoneRadiationNon-ReactSpecies TransportNon-ReactCoupled Dispersed PhaseDisabledDisabledDisabled
                            Non-Reacting (2 species)
  Pollutants
                            Disabled
  Pollutants
                             Disabled
  Soot
                             Disabled
Boundary Conditions
_____
  Zones
                          id type
     name
     _____
```

barrel	2	fluid
cold_leg	3	fluid
cold_valve	4	fluid
cross-over leg	5	fluid
hot top	6	fluid
hot valve	7	fluid
pebbles	8	fluid
wall	9	wall
outlet	10	interior
cold_exit	11	interior
cold enter	12	interior
hot exit	13	interior
pebble_exit	14	interior
pebble enter	15	interior
inlet	16	interior
barrel_walls	17	wall
new cold_valve	18	wall
cold_walls	19	wall
cross_over_walls	20	wall
hot_top_walls	21	wall
hot_valve_walls	22	wall
pebble_walls	23	wall
default-interior	25	interior
default-interior:001	1	interior
default-interior:024	24	interior
default-interior:026	26	interior
default-interior:027	27	interior
default-interior:028	28	interior
default-interior:029	29	interior

Boundary Conditions

#### barrel

#### Condition

Deactivated Thread

```
Value
```

.

\_\_\_\_\_ -----Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () 0 Motion Type 0 X-Velocity Of Zone (m/s) Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis

1 no

Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

cold leg

Condition

Value \_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 X-Velocity Of Zone (m/s) 0 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 0 Y-Origin of Rotation-Axis (m) Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1

```
0
        Y-Component of Direction-1 Vector
        Z-Component of Direction-1 Vector
                                                                  0
        X-Component of Direction-2 Vector
                                                                 0
        Y-Component of Direction-2 Vector
                                                                 1
                                                                 0
        Z-Component of Direction-2 Vector
        X-Component of Cone Axis Vector
                                                                 1
                                                                 0
        Y-Component of Cone Axis Vector
                                                                 0
        Z-Component of Cone Axis Vector
        X-Coordinate of Point on Cone Axis (m)
                                                                 1
        Y-Coordinate of Point on Cone Axis (m)
                                                                 0
        Z-Coordinate of Point on Cone Axis (m)
                                                                 0
        Half Angle of Cone Relative to its Axis (deg)
                                                                 0
        Relative Velocity Resistance Formulation?
                                                                 yes
        Direction-1 Viscous Resistance (1/m2)
                                                                 0
        Direction-2 Viscous Resistance (1/m2)
                                                                 0
        Direction-3 Viscous Resistance (1/m2)
                                                                 0
        Choose alternative formulation for inertial resistance? no
        Direction-1 Inertial Resistance (1/m)
                                                                 Ο
        Direction-2 Inertial Resistance (1/m)
                                                                 0
                                                                 0
        Direction-3 Inertial Resistance (1/m)
                                                                 0
        CO Coefficient for Power-Law
        C1 Coefficient for Power-Law
                                                                 0
        Porosity
                                                                 1
        Solid Material Name
aluminum
     cold valve
        Condition
Value
        _____
_____
        Material Name
mixture-template
        Specify source terms?
                                                                 no
        Source Terms
                                                                 ()
        Specify fixed values?
                                                                 no
        Local Coordinate System for Fixed Velocities
                                                                 no
        Fixed Values
                                                                 ()
        Motion Type
                                                                 0
        X-Velocity Of Zone (m/s)
                                                                 0
        Y-Velocity Of Zone (m/s)
                                                                 0
                                                                 0
        Z-Velocity Of Zone (m/s)
                                                                 0
        Rotation speed (rad/s)
        X-Origin of Rotation-Axis (m)
                                                                 0
                                                                 0
        Y-Origin of Rotation-Axis (m)
        Z-Origin of Rotation-Axis (m)
                                                                 0
        X-Component of Rotation-Axis
                                                                 0
        Y-Component of Rotation-Axis
                                                                 0
        Z-Component of Rotation-Axis
                                                                 1
        Deactivated Thread
                                                                 no
        Porous zone?
                                                                 no
        Conical porous zone?
                                                                 no
        X-Component of Direction-1 Vector
                                                                 1
        Y-Component of Direction-1 Vector
                                                                 0
        Z-Component of Direction-1 Vector
                                                                 0
        X-Component of Direction-2 Vector
                                                                 0
```

```
Y-Component of Direction-2 Vector
                                                          1
Z-Component of Direction-2 Vector
                                                          0
X-Component of Cone Axis Vector
                                                          1
                                                          0
Y-Component of Cone Axis Vector
                                                          0
Z-Component of Cone Axis Vector
X-Coordinate of Point on Cone Axis (m)
                                                          1
Y-Coordinate of Point on Cone Axis (m)
                                                          0
Z-Coordinate of Point on Cone Axis (m)
                                                          0
Half Angle of Cone Relative to its Axis (deg)
                                                          0
Relative Velocity Resistance Formulation?
                                                          yes
Direction-1 Viscous Resistance (1/m2)
                                                          0
Direction-2 Viscous Resistance (1/m2)
                                                          0
Direction-3 Viscous Resistance (1/m2)
                                                          0
Choose alternative formulation for inertial resistance? no
Direction-1 Inertial Resistance (1/m)
                                                          0
Direction-2 Inertial Resistance (1/m)
                                                          0
Direction-3 Inertial Resistance (1/m)
                                                          0
                                                          0
CO Coefficient for Power-Law
C1 Coefficient for Power-Law
                                                          0
                                                          1
Porosity
Solid Material Name
```

\_\_\_\_\_

#### aluminum

cross-over leg

Condition

```
Value
```

```
Material Name
mixture-template
        Specify source terms?
                                                                   no
         Source Terms
                                                                   ()
         Specify fixed values?
                                                                   no
         Local Coordinate System for Fixed Velocities
                                                                   no
         Fixed Values
                                                                   ()
        Motion Type
                                                                   0
        X-Velocity Of Zone (m/s)
                                                                   0
        Y-Velocity Of Zone (m/s)
                                                                   0
        Z-Velocity Of Zone (m/s)
                                                                   0
        Rotation speed (rad/s)
                                                                   0
        X-Origin of Rotation-Axis (m)
                                                                   0
                                                                   0
        Y-Origin of Rotation-Axis (m)
         Z-Origin of Rotation-Axis (m)
                                                                   0
        X-Component of Rotation-Axis
                                                                   0
        Y-Component of Rotation-Axis
                                                                   0
         Z-Component of Rotation-Axis
                                                                   1
        Deactivated Thread
                                                                   no
        Porous zone?
                                                                   no
        Conical porous zone?
                                                                   no
        X-Component of Direction-1 Vector
                                                                   1
        Y-Component of Direction-1 Vector
                                                                   0
        Z-Component of Direction-1 Vector
                                                                   0
        X-Component of Direction-2 Vector
                                                                   0
                                                                   1
        Y-Component of Direction-2 Vector
                                                                   0
         Z-Component of Direction-2 Vector
        X-Component of Cone Axis Vector
                                                                   1
```

Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2) .	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

\_\_\_\_\_

aluminum

hot\_top

\_ \_

Condition

Value

Material Name	
mixture-template	
Material Name mixture-template Specify source terms? Source Terms Specify fixed values? Local Coordinate System for Fixed Velocities Fixed Values Motion Type X-Velocity Of Zone (m/s) Y-Velocity Of Zone (m/s) Z-Velocity Of Zone (m/s) Rotation speed (rad/s) X-Origin of Rotation-Axis (m) Y-Origin of Rotation-Axis (m) X-Origin of Rotation-Axis (m) X-Component of Rotation-Axis Y-Component of Rotation-Axis Z-Component of Rotation-Axis Z-Component of Rotation-Axis Sectivated Thread Porous zone? Conical porous zone? X-Component of Direction-1 Vector X-Component of Direction-2 Vector X-Component of Cone Axis Vector X-Component of Cone Axis Vector X-Component of Cone Axis Vector X-Component of Cone Axis Vector	
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1

Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Z-Coordinate of Point on Cone Axis (m) Half Angle of Cone Relative to its Axis (deg) Relative Velocity Resistance Formulation? Direction-1 Viscous Resistance (1/m2) Direction-2 Viscous Resistance (1/m2) Choose alternative formulation for inertial resistance? Direction-1 Inertial Resistance (1/m) Direction-2 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) CO Coefficient for Power-Law C1 Coefficient for Power-Law Porosity	
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

hot\_valve

Condition

Value

#### \_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 · Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0

Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance	? no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

Value

pebbles

Condition

\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms ((mass) (x-momentum) (y-momentum) (z-momentum) (species-0) (energy)) Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values ((xvelocity (inactive . #f) (constant . 0) (profile )) (y-velocity (inactive . #f) (constant . 0) (profile )) (z-velocity (inactive . #f) (constant . 0) (profile )) (species-0 (inactive . #f) (constant . 0) (profile )) (temperature (inactive . #f) (constant . 0) (profile ))) Motion Type 0 0 X-Velocity Of Zone (m/s) Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 1 Z-Component of Rotation-Axis Deactivated Thread no Porous zone? ves Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0

	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	no
	Direction-1 Viscous Resistance (1/m2)	
5860000		
	Direction-2 Viscous Resistance (1/m2)	
5860000		
	Direction-3 Viscous Resistance (1/m2)	
5860000		
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	2734
	Direction-2 Inertial Resistance (1/m)	2734
	Direction-3 Inertial Resistance (1/m)	2734
	CO Coefficient for Power-Law	0
	Cl Coefficient for Power-Law	0
	Porosity	
0.4000000	)1	

0.40000001 Solid Material Name

```
glass
```

wall

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1
Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0

.

Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

#### outlet

Condition	Value

cold\_exit

Condition Value

## cold\_enter

Condition Value

## hot\_exit

Condition Value

## pebble\_exit

Condition Value

## pebble\_enter

С	0	n	d	i	t	i	0	n				V	а	1	u	е
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## inlet

С	0	n	d	i	t	i	0	n				V	а	1	u	е
_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_	_

## barrel\_walls

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	aluminum
Thermal BC Type	0
Temperature (k)	293
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0

	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	Ves
	Apply a rotational velocity to this wall?	yes no
	Nologity Magnitudo (m/s)	0
	Verocity Magnitude (M/S)	1
	X Component of Wall Hanslation	1
	r-component of wall franslation	0
	2-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
		(0)
(((C	onstant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Botation-Axis Direction	1
	X-component of shear stress (nascal)	1 0
	X-component of shear stress (pascal)	0
	Component of Sheat Stress (pascal)	0
	7 component of cheer strees (peece)	
	Z-component of shear stress (pascal)	0
	Z-component of shear stress (pascal) Surface tension gradient (n/m-k)	0
	2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0
	2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve	0 0 0
	2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition	0 0 Value
	2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition	0 0 Value
	Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition 	0 0 Value
	Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition Wall Thickness (m) Heat Concration Rate (w(m3))	0 0 Value 0
	Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition 	0 0 Value 0 0
	Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition 	0 0 Value 0 0 copper
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0 0
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0 0 300
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0 0 300 no
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0 0 300 no 0
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0 0 300 no 0 0
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0 0 300 no 0 0 yes
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0 0 300 no 0 0 yes no
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 copper 1 300 0 300 no 0 300 no 0 yes no 0
	<pre>2-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 0 copper 1 300 0 0 300 no 0 300 no 0 0 yes no 0 1
	<pre>Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 0 0 0 300 0 0 300 0 0 300 0 0 300 0 0 300 0 0 1 0
	<pre>Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 0 0 0 300 0 0 300 0 0 300 0 0 300 0 0 0 9 9 9 9
	<pre>Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation</pre>	0 0 0 Value 0 0 0 0 0 0 300 0 0 300 0 0 300 0 0 0
	<pre>Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
	<pre>Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient new_cold_valve Condition </pre>	0 0 0 Value 0 0 0 0 0 0 300 0 0 300 0 0 300 0 0 300 0 0 0 9 9 8 no 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0

Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient</pre>	0 0 0 0 0 1 0 0 0 0 0 0 0
cold_walls	
Condition	Value
<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 0 copper 0 283 0 0 300 no 0 0 yes no 0 0 1 0 0 0 0 1 300 0 0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction</pre>	0 0 0 0 0 0 1

	X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 0 0
cro	ss_over_walls	
	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	1
	Temperature (K)	300
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	7-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
·		(0)
(((consta	nt. 0) (profile )))	2
	Rotation Speed (rad/s) V Disition of Detation Duis Onimin (m)	0
	X-Position of Rotation-Axis Origin (m)	0
	7-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
2	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
:	Surface tension gradient (n/m-k)	0
:	Specularity Coefficient	0
hot	_top_walls	
(	Condition	Value
	 Wall Thickness (m)	0
1	Heat Generation Rate $(w/m3)$	0
	near concruction nucle ("/mo)	~

	Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	copper 1 0 0 300 no 0 yes no 0 1 0 0 0 1 300 (0)
(((consta	<pre>ant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient </pre>	0 0 0 0 0 1 0 0 0 0 0
	Condition	Value
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation	0 0 copper 0 386.5 0 0 300 no 0 0 yes no 0 1

	Y-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 0 0 0 0 1 300
		(0)
(((cons	tant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
		•
р	ebble_walls	
	Condition	Value
	Wall Thickness (m)	0
	Wall Thickness (m) Heat Generation Rate (w/m3)	0 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name	0 0 copper
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type	0 0 copper 0
	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k)	0 0 copper 0 (profile
udf peb	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall temp BC)	0 0 copper 0 (profile
udf peb	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) _wall_temp_BC) Heat Flux (w/m2)	0 0 copper 0 (profile 8889.0596
udf peb	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) _wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k)	0 0 copper 0 (profile 8889.0596 0
udf peb	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) _wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k)	0 0 copper 0 (profile 8889.0596 0 300
udf peb	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) _wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction?	0 0 copper 0 (profile 8889.0596 0 300 no
udf peb	Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion	0 0 copper 0 (profile 8889.0596 0 300 no 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone?</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 0 0 ves
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall?</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 0 yes po
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s)</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 0 yes no 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 0 yes no 0 1 0 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components?</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 300 no 0 yes no 0 1 0 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0 0 0 0 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s)</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 yes no 0 1 0 0 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s)</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 yes no 0 1 0 0 0 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 yes no 0 1 0 0 0 1 0 0
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 0 yes no 0 0 1 0 0 0 1 200
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) _wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0 0 0 0 0 1 300 0 0 1 300
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) _wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0 0 0 1 0 0 0 1 300 0 0 1 300 (0)
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0 0 0 0 0 1 300 0 0 1 300 (0)
udf peb	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0 0 0 0 1 300 0 0 1 300 (0)

X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

default-interior

Condition Value

default-interior:001

Condition Value

#### default-interior:024

Condition Value

default-interior:026

Condition Value

default-interior:027

Condition Value

default-interior:028

Condition Value

default-interior:029

Condition Value

Solver Controls

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Equations

Equation	Solved
Flow	yes
he	yes
Energy	yes

Numerics

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

Time	Step (s)				0.2
Max.	Iterations	Per	Time	Step	200

Relaxation

Variable	Relaxation	Factor
Pressure	0.6000002	
Density	0.80000001	
Body Forces	0.89999998	
Momentum	0.4000001	
he	1	
Energy	1	

Linear Solver

Variable	Solver	Termination	Residual Reduction
	Type	Criterion	Tolerance
Pressure X-Momentum Y-Momentum Z-Momentum he Energy	V-Cycle Flexible Flexible Flexible Flexible Flexible	0.1 0.1 0.1 0.1 0.1 0.1 0.1	0.7 0.7 0.7 0.7 0.7 0.7

Pressure-Velocity Coupling

Parameter Value Type SIMPLE

Discretization Scheme

Variable	Scheme
Pressure	Body Force Weighted
Density	First Order Upwind
Momentum	First Order Upwind
he	First Order Upwind
Energy	First Order Upwind

## Solution Limits

Quantity Limit

Minimum	Absolute	Pressure	1
Maximum	Absolute	Pressure	5e+10
Minimum	Temperatu	ire	1
Maximum	Temperati	ire	5000

Material Properties

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Material: glass (solid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat)	kg/m3 j/kg-k	constant constant	2440 840
Thermal Conductivity	w/m-k	constant	0.93699998

Material: copper (solid)

Property	Units	Method	Value(s)
Density	kq/m3	constant	8978
Cp (Specific Heat)	j/kg-k	constant	381
Thermal Conductivity	w/m-k	constant	387.60001

Material: (helium . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	j/kg-k	kinetic-theory	# f
Thermal Conductivity	w/m-k	kinetic-theory	# f
Viscosity	kg/m-s	kinetic-theory	#f
Molecular Weight	kg/kgmol	constant	4.0026002
L-J Characteristic Length	angstrom	constant	2.5510001
L-J Energy Parameter	k	constant	10.22
Degrees of Freedom		constant	3
Speed of Sound	m/s	none	#f

Material: helium (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	0.1625
Cp (Specific Heat)	j/kg-k	constant	5193
Thermal Conductivity	w/m-k	constant	0.152
Viscosity	kg/m-s	constant	1.99e-05
Molecular Weight	kg/kgmol	constant	4.0026
L-J Characteristic Length	angstrom	constant	0
L-J Energy Parameter	k	constant	0
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: mixture-template (mixture)

Property Units Method Value(s)

Mixture Species n2) () ())		names	
Density	kg/m3	ideal-gas	
Cp (Specific Heat)	j/kg-k	mixing-law	
Thermal Conductivity	w/m-k	ideal-gas-mixing-law	
Viscosity	kg/m−s	ideal-gas-mixing-law	
Mass Diffusivity	m2/s	kinetic-theory	
Thermal Diffusion Coefficient	kg/m-s	kinetic-theory	
Thermal Expansion Coefficient Speed of Sound	1/k m/s	constant none	0
	Mixture Species n2) () ()) Density Cp (Specific Heat) Thermal Conductivity Viscosity Mass Diffusivity Thermal Diffusion Coefficient Thermal Expansion Coefficient Speed of Sound	Mixture Species n2) () ()) Density kg/m3 Cp (Specific Heat) j/kg-k Thermal Conductivity w/m-k Viscosity kg/m-s Mass Diffusivity m2/s Thermal Diffusion Coefficient kg/m-s Thermal Expansion Coefficient 1/k Speed of Sound m/s	Mixture Speciesnamesn2) () ())Densitykg/m3ideal-gasCp (Specific Heat)j/kg-kmixing-lawThermal Conductivityw/m-kideal-gas-mixing-lawViscositykg/m-sideal-gas-mixing-lawMass Diffusivitym2/skinetic-theoryThermal Diffusion Coefficientkg/m-skinetic-theoryThermal Expansion Coefficient1/kconstantSpeed of Soundm/snone

Material: (nitrogen . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	j/kg-k	kinetic-theory	#f
Thermal Conductivity	w/m-k	kinetic-theory	# f
Viscosity	kg∕m-s	kinetic-theory	#f
Molecular Weight	kg/kgmol	constant	28.013399
L-J Characteristic Length	angstrom	constant	3.7980001
L-J Energy Parameter	k	constant	71.400002
Degrees of Freedom		constant	5
Speed of Sound	m/s	none	# f

Material: nitrogen (fluid)

Property	Units	Method	Value(s)
			1 1 2 0
Density	kg/m3	constant	1.138
Cp (Specific Heat)	j/kg-k	constant	1040.67
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.663e-05
Molecular Weight	kg/kgmol	constant	28.0134
L-J Characteristic Length	angstrom	constant	3.621
L-J Energy Parameter	k	constant	97.53
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: oxygen (fluid)

	Mechoa	value(s)
Density kg/m3	constant	1.2999
Cp (Specific Heat) j/kg-k	constant	919.31
Thermal Conductivity w/m-k	constant	0.0246
Viscosity kg/m-s	constant	1.919e-05

L-J Characteristic Length	angstrom	constant	3.458
L-J Energy Parameter	k	constant	107.4
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	# £

Material: water-vapor (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	0.5542
Cp (Specific Heat)	j/kg-k	constant	2014
Thermal Conductivity	w/m-k	constant	0.0261
Viscosity	kg/m-s	constant	1.34e-05
Molecular Weight	kg/kgmol	constant	18.01534
L-J Characteristic Length	angstrom	constant	2.605
L-J Energy Parameter	k	constant	572.4
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	# f

Material: air (fluid)

	varue (5)
	1 005
Density Kg/m3 constant	1.225
Cp (Specific Heat) j/kg-k constant	1006.43
Thermal Conductivity w/m-k constant	0.0242
Viscosity kg/m-s constant	1.7894e-05
Molecular Weight kg/kgmol constant	28.966
L-J Characteristic Length angstrom constant	3.711
L-J Energy Parameter k constant	78.6
Thermal Expansion Coefficient 1/k constant	0
Degrees of Freedom constant	0
Speed of Sound m/s none	#f

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2719
Cp (Specific Heat)	j/kg-k	constant	871
Thermal Conductivity	w∕m-k	constant	202.4

## Full Heating Phase Transient FLUENT Case

FLUENT Version: 3d, dp, pbns, lam, unsteady (3d, double precision, pressurebased, laminar, unsteady) Release: 6.3.26 Title: Models ------

Model	Settings
Space Time Viscous Heat Transfer Solidification and Melting Radiation Species Transport Coupled Dispersed Phase Pollutants Pollutants Soot	3D Unsteady, 1st-Order Implicit Laminar Enabled Disabled None Disabled Disabled Disabled Disabled Disabled Disabled

Boundary Conditions

Zones

name	id	type
cold valve	2	fluid
cold_leg	3	fluid
crossover	4	fluid
hot_top	5	fluid
pebbles	6	fluid
hot_valve	7	fluid
cold_valve_walls	8	wall
outlet	9	wall
cold_leg_bot.	10	interior
cold_leg_walls	11	wall
cold_leg_top	12	interior
crossover_walls	13	wall
hot_top_exit	14	interior
pebble_exit	15	interior
hot_top_wall	16	wall
pebblewalls	17	wall
hot_valve_wall	18	wall
pebble_enter	19	interior
inlet	20	wall
default-interior	22	interior
default-interior:001	1	interior
default-interior:021	21	interior
default-interior:023	23	interior
detault-interior:024	24	interior
default-interior:025	25	interior

Boundary Conditions

cold\_valve

Condition

Value

# \_\_\_\_\_\_

	-	
	Material Name	
holium	hateriar wante	
nerran	Creatify acurac termal	
	Specify Source terms?	no
	Source lerms	
((mass)	(x-momentum) (y-momentum) (z-momentum) (energy))	
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	((x-
velocity	<pre>/ (inactive . #f) (constant . 0) (profile )) (y-velocity</pre>	
(inactiv	re . #f) (constant . 0) (profile )) (z-velocity (inactive	. #f)
(constar	<pre>it . 0) (profile )) (temperature (inactive . #f) (constant</pre>	. 0)
(profile	e )))	
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	Ô
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	7-Component of Rotation-Axis	1
	Departimeted Thread	1
		110
	Conical parava same?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	2-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	Ō
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	õ
	CO Coefficient for Power-Law	0
	C1 Coefficient for Power-Law	0
·	Porosity	1
	Solid Material Name	T
	POTTA NACETTAT NAME	

aluminum

cold\_leg

Condition

Value		
	Material Name	
helium		
	Specify source terms?	no
	Source Terms	110
((mass)	(x-momentum) (y-momentum) (z-momentum) (energy))	
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	((x-
velocity	<pre>y (inactive . #f) (constant . 0) (profile )) (y-velocity</pre>	
(inactiv	<pre>re . #f) (constant . 0) (profile )) (z-velocity (inactive</pre>	. #f)
(constar	nt . 0) (profile )) (temperature (inactive . #f) (constant	. 0)
(profile		
	Motion Type X Molocity Of Kone (m(c)	0
	X-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-I Vector	1
	2-Component of Direction-1 Vector	0
	X-Component of Direction-1 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	0
	CO Coefficient for Power-Law	0
	C1 Coefficient for Power-Law	0
	Porosity	1

Solid Material Name

aluminum

crossover

Condition

Value

\_\_\_\_\_\_ \_\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ Material Name helium Specify source terms? no Source Terms ((mass) (x-momentum) (y-momentum) (z-momentum) (energy)) Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values ((xvelocity (inactive . #f) (constant . 0) (profile )) (y-velocity (inactive . #f) (constant . 0) (profile )) (z-velocity (inactive . #f) (constant . 0) (profile )) (temperature (inactive . #f) (constant . 0) (profile ))) Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s)  $\cap$ Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis Ο Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0

	Direction-2 Inertial Resistance (1/m)	0	
	Direction-3 Inertial Resistance (1/m)	0	
	CO Coefficient for Power-Law	0	
	Cl Coefficient for Power-Law	0	
	Porosity	1	
	Solid Material Name		
aluminum			

hot\_top

Condition Value \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ -----Material Name helium Specify source terms? no Source Terms ((mass) (x-momentum) (y-momentum) (z-momentum) (energy)) Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values ((xvelocity (inactive . #f) (constant . 0) (profile )) (v-velocity (inactive . #f) (constant . 0) (profile )) (z-velocity (inactive . #f) (constant . 0) (profile )) (temperature (inactive . #f) (constant . 0) (profile ))) Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) Ο Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes

Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

pebbles

Condition Value \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_\_ \_\_\_\_\_ Material Name helium Specify source terms? no Source Terms ((mass) (x-momentum) (y-momentum) (z-momentum) (energy)) Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values ((xvelocity (inactive . #f) (constant . 0) (profile )) (y-velocity (inactive . #f) (constant . 0) (profile )) (z-velocity (inactive . #f) (constant . 0) (profile )) (temperature (inactive . #f) (constant . 0) (profile ))) Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? yes Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0
X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 5860000 Direction-2 Viscous Resistance (1/m2) 5860000 Direction-3 Viscous Resistance (1/m2) 5860000 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 2734 Direction-2 Inertial Resistance (1/m) 2734 Direction-3 Inertial Resistance (1/m) 2734 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 Porosity 0.4000001 Solid Material Name glass hot valve Condition Value \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_ Material Name helium Specify source terms? no Source Terms ((mass) (x-momentum) (y-momentum) (z-momentum) (energy)) Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values ((xvelocity (inactive . #f) (constant . 0) (profile )) (y-velocity (inactive . #f) (constant . 0) (profile )) (z-velocity (inactive . #f) (constant . 0) (profile )) (temperature (inactive . #f) (constant . 0) (profile ))) Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m)  $\cap$ Y-Origin of Rotation-Axis (m) Ω Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis  $\cap$ Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no

X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

cold\_valve\_walls

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	0
Temperature (k)	291.79999
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0

Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	. 0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

## outlet

Condition	Value
<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Rotalion-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction Z-Component of Shear stress (pascal) Z-component of shear stress (pascal)</pre>	Value 0 0 copper 1 300 0 0 300 no 0 0 0 0 0 0 0 0 0 0 0 0 0
Specularity Coefficient	0

cold\_leg\_bot.

Condition Value

cold\_leg\_walls

.

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	coppei
Thermal BC Type	0
Temperature (k)	283
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
2-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
2-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Position of Rotation-Axis Origin (m)	0
2-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
7-Component of Rotation Axis Direction	0
Y-component of shear stress (pageal)	1
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient $(n/m-k)$	0
Specularity Coefficient	0
	0
ld_leg_top	
Condition Value	
ossover_walls	
Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1 .
Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no

Wall Motion

Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Direction Y-Component of Rotation-Axis Direction X-Component of Rotation-Axis Direction X-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient hot_top_exit Condition Value 	0 yes no 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
hot_top_wall	
Condition	Value
<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation</pre>	0 0 copper 1 300 0 300 no 0 0 yes no 0 1 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0

Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

pebble\_\_walls

.

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	0
Temperature (k)	(profile
udf peb wall temp BC)	-
Heat Flux (w/m2)	15500
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
Rotation Speed (rad/s) V. Dasitism of Datation Duis Oninin (n)	0
X-Position of Rotation-Axis Origin (m)	0
I-Position of Rotation-Axis Origin (m)	0
Z-POSICION OF ROCACION-AXIS OFIGIN (M)	0
X-Component of Rotation-Axis Direction	0
7-Component of Rotation-Axis Direction	0
A-component of chear stress (passal)	Ţ
A-component of shear stress (pascal)	0
r-component of snear stress (pascal)	U

Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

hot\_valve\_wall

Condition	Value
Wall Thickness (m) Heat Generation Rate (w/m3) Material Name	0 0 copper
Thermal BC Type	0
Temperature (k)	386.5
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

# pebble\_enter

Condition Value

## inlet

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1

Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m	2-k) 0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent c	ell zone? yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

default-interior

Condition Value

default-interior:001

Condition Value

default-interior:021

Condition Value

default-interior:023

Condition Value

default-interior:024

Condition Value

#### default-interior:025

Condition Value

Solver Controls

Equations

Equation	Solved
Flow	yes
Energy	yes

Numerics

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

```
Time Step (s) 0.0099999998
Max. Iterations Per Time Step 200
```

Relaxation

Variable	Relaxation Factor
Pressure	0.4000001
Density	0.6000002
Body Forces	1
Momentum	0.6000002
Energy	1 .

Linear Solver

Variable	Solver Type	Termination Criterion	Residual Reduction Tolerance
Pressure	V-Cycle	0.1	
X-Momentum	Flexible	0.1	0.7
Y-Momentum	Flexible	0.1	0.7
Z-Momentum	Flexible	0.1	0.7
Energy	Flexible	0.1	0.7

#### Pressure-Velocity Coupling

Parameter	Value
Туре	PISO
Skewness-Neighbour Coupling	yes
Skewness Correction	1
Neighbour Correction	1

#### Discretization Scheme

Variable	Scheme	e	
Pressure	PRESTO	)!	
Density	First	Order	Upwind
Momentum	First	Order	Upwind
Energy	First	Order	Upwind

#### Solution Limits

Quantity	7		Limit
Minimum	Absolute	Pressure	1
Maximum	Absolute	Pressure	5e+10
Minimum	Temperatu	ıre	1
Maximum	Temperatu	ure	5000

## Material Properties

\_\_\_\_\_

## Material: glass (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2440
Cp (Specific Heat)	j/kg−k	constant	840
Thermal Conductivity	w/m−k	constant	0.93699998

ż

Material: copper (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	8978
Cp (Specific Heat)	j/kg-k	constant	381
Thermal Conductivity	w/m-k	constant	387.60001

## Material: helium (fluid)

	Property	Units	Method	
Value	(s)			
	Density	kg/m3	ideal-gas	#f
	Cp (Specific Heat)	j/kg-k	kinetic-theory	#f
	Thermal Conductivity	w/m-k	kinetic-theory	#f
	Viscosity	kg∕m-s	kinetic-theory	#f
	Molecular Weight	kg/kgmol	constant	
4.002	6002			
	L-J Characteristic Length	angstrom	constant	
2.551	0001			
	L-J Energy Parameter	k	constant	10.22
	Thermal Expansion Coefficient	1/k	constant	0
	Degrees of Freedom		constant	3
	Speed of Sound	m/s	none	#f
	opeed of boand	, -		

Material: air (fluid)

Densitykg/m3constant1.225Cp (Specific Heat)j/kg-kconstant1006.4Thermal Conductivityw/m-kconstant0.0242Viscositykg/m-sconstant1.7894Molecular Weightkg/kgmolconstant28.966L-J Characteristic Lengthangstromconstant3.711L-J Energy Parameterkconstant78.6Thermal Expansion Coefficient1/kconstant0Degrees of Freedomconstant0Speed of Soundm/snone#f	3 e-05

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2719
Cp (Specific Heat).	j/kg−k	constant	871
Thermal Conductivity	w/m−k	constant	202.4

# Zero Operating Density FLUENT Case

```
FLUENT
Version: 3d, pbns, spe, lam, unsteady (3d, pressure-based, species,
laminar, unsteady)
Release: 6.3.26
Title:
```

Models

Model	Settings
Space	3D
Time	Unsteady, 1st-Order Implicit
Viscous	Laminar
Heat Transfer	Enabled
Solidification and Melting	Disabled
Radiation	None
Species Transport	Non-Reacting (2 species)
Coupled Dispersed Phase	Disabled
Pollutants	Disabled
Pollutants	Disabled
Soot	Disabled

Boundary Conditions

Zones

name id type

barrel	2	fluid
cold leg	3	fluid
cold valve	4	fluid
cross-over leg	5	fluid
hot top	6	fluid
hot valve	7	fluid
pebbles	8	fluid
wall	9	wall
outlet	10	interior
cold exit	11	interior
cold enter	12	interior
hot exit	13	interior
pebble_exit	14	interior
pebble enter	15	interior
inlet	16	interior
barrel_walls	17	wall
new cold_valve	18	wall
cold_walls	19	wall
cross_over_walls	20	wall
hot_top_walls	21	wall
hot_valve_walls	22	wall
pebble_walls	23	wall
default-interior	25	interior
default-interior:001	1	interior
default-interior:024	24	interior
default-interior:026	26	interior
default-interior:027	27	interior
default-interior:028	28	interior
default-interior:029	29	interior

Boundary Conditions

barrel

Condition

```
Value
```

\_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () no Specify fixed values? no Local Coordinate System for Fixed Velocities () Fixed Values 0 Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 1 Z-Component of Rotation-Axis Deactivated Thread no

Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

\_\_\_\_\_

## aluminum

cold\_leg

Condition

```
Value
```

Material Name		
mixture-template		
Specify source terms?	no	
Source Terms	()	
Specify fixed values?	no	
Local Coordinate System for Fixed Velocities	no	
Fixed Values	()	
Motion Type	0	
X-Velocity Of Zone (m/s)	0	
Y-Velocity Of Zone (m/s)	0	
Z-Velocity Of Zone (m/s)	0	
Rotation speed (rad/s)	0	
X-Origin of Rotation-Axis (m)	0	
Y-Origin of Rotation-Axis (m)	0	
Z-Origin of Rotation-Axis (m)	0	
X-Component of Rotation-Axis	0	
Y-Component of Rotation-Axis	0	
Z-Component of Rotation-Axis	1	
Deactivated Thread	no	
Porous zone?	no	
Conical porous zone?	no	
X-Component of Direction-1 Vector	1	
A component of pressering forest		

Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

\_\_\_\_\_

## aluminum

cold\_valve

```
Condition
```

Material Name		
mixture-template		
Specify source	e terms?	no
Source Terms		()
Specify fixed	values?	no
Local Coordina	ate System for Fixed Velocities	no
Fixed Values		()
Motion Type		0
X-Velocity Of	Zone (m/s)	0
Y-Velocity Of	Zone (m/s)	0
Z-Velocity Of	Zone (m/s)	0
Rotation spee	d (rad/s)	0
X-Origin of R	otation-Axis (m)	0
Y-Origin of R	otation-Axis (m)	0
Z-Origin of R	otation-Axis (m)	0
X-Component o	f Rotation-Axis	0
Y-Component o	f Rotation-Axis	0
Z-Component o	f Rotation-Axis	1
Deactivated T	hread	no
Porous zone?		no
Conical porou	s zone?	no
X-Component o	f Direction-1 Vector	1
Y-Component o	f Direction-1 Vector	0
Z-Component o	f Direction-1 Vector	0
X-Component o	f Direction-2 Vector	0
-		

Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	Ø
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

cross-over\_leg

Condition

Material Name	
mixture-template	
Specify source terms?	n
Source Terms	(
Specify fixed values?	n
Local Coordinate System for Fixed Velocities	n
Fixed Values	(
Motion Type	С
X-Velocity Of Zone (m/s)	C
Y-Velocity Of Zone (m/s)	C
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	C
Y-Origin of Rotation-Axis (m)	С
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	C
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	n
Porous zone?	n
Conical porous zone?	n
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	C
Z-Component of Direction-1 Vector	C
X-Component of Direction-2 Vector	C
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	C
X-Component of Cone Axis Vector	1

Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

\_\_\_\_\_

aluminum

hot\_top

Condition

Material Name			
mixture-template			
Specify source terms?	no		
Source Terms	()		
Specify fixed values?	no		
Local Coordinate System for Fixed Velocities	no		
Fixed Values	()		
Motion Type	0		
X-Velocity Of Zone (m/s)	0		
Y-Velocity Of Zone (m/s)	0		
Z-Velocity Of Zone (m/s)	0		
Rotation speed (rad/s)	0		
X-Origin of Rotation-Axis (m)	0		
Y-Origin of Rotation-Axis (m)	0		
Z-Origin of Rotation-Axis (m)	0		
X-Component of Rotation-Axis	0		
Y-Component of Rotation-Axis	0		
Z-Component of Rotation-Axis	1		
Deactivated Thread	no		
Porous zone?	no		
Conical porous zone?	no		
X-Component of Direction-1 Vector	1		
Y-Component of Direction-1 Vector	0		
Z-Component of Direction-1 Vector	0		
X-Component of Direction-2 Vector	0		
Y-Component of Direction-2 Vector	1		
Z-Component of Direction-2 Vector	0		
X-Component of Cone Axis Vector	1		
Y-Component of Cone Axis Vector	0		
Z-Component of Cone Axis Vector	0		
X-Coordinate of Point on Cone Axis (m)	1		

Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

hot\_valve

Condition

```
Value
```

## +-----

Material Name		
mixture-template		
Specify source terms?	no	
Source Terms	()	
Specify fixed values?	no	
Local Coordinate System for Fixed Velocities	no	
Fixed Values	()	
Motion Type	0	
X-Velocity Of Zone (m/s)	0	
Y-Velocity Of Zone (m/s)	0	
Z-Velocity Of Zone (m/s)	0	
Rotation speed (rad/s)	0	
X-Origin of Rotation-Axis (m)	0	
Y-Origin of Rotation-Axis (m)	0	
Z-Origin of Rotation-Axis (m)	0	
X-Component of Rotation-Axis	0	
Y-Component of Rotation-Axis	0	
Z-Component of Rotation-Axis	1	
Deactivated Thread	no	
Porous zone?	no	
Conical porous zone?	no	
X-Component of Direction-1 Vector	1	
Y-Component of Direction-1 Vector	0	
Z-Component of Direction-1 Vector	0	
X-Component of Direction-2 Vector	0	
Y-Component of Direction-2 Vector	1	
Z-Component of Direction-2 Vector	0	
X-Component of Cone Axis Vector	1	
Y-Component of Cone Axis Vector	0	
Z-Component of Cone Axis Vector	0	
X-Coordinate of Point on Cone Axis (m)	1	
Y-Coordinate of Point on Cone Axis (m)	0	
Z-Coordinate of Point on Cone Axis (m)	0	
Half Angle of Cone Relative to its Axis (deg)	0	

Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

pebbles

Condition

Value

\_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms ((mass) (x-momentum) (y-momentum) (z-momentum) (species-0) (energy)) Specify fixed values? no Local Coordinate System for Fixed Velocities no ((x-Fixed Values velocity (inactive . #f) (constant . 0) (profile )) (y-velocity (inactive . #f) (constant . 0) (profile )) (z-velocity (inactive . #f) (constant . 0) (profile )) (species-0 (inactive . #f) (constant . 0) (profile )) (temperature (inactive . #f) (constant . 0) (profile ))) 0 Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? yes Conical porous zone? no X-Component of Direction-1 Vector 1 0 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 1 Y-Component of Direction-2 Vector 0 Z-Component of Direction-2 Vector 1 X-Component of Cone Axis Vector 0 Y-Component of Cone Axis Vector

		~
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	7 Coordinate of Point on Cono Avis (m)	0
	2-coordinate of Formet on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	U
	Relative Velocity Resistance Formulation?	no
	Direction-1 Viscous Resistance (1/m2)	
5860000		
3880000	$\mathbf{P}_{1}^{\prime}$ , $\mathbf{P}_{2}^{\prime}$ , $\mathbf{P}$	
	Direction-2 viscous Resistance (1/m2)	
5860000		
	Direction-3 Viscous Resistance (1/m2)	
5860000		
0000000	Choose alternative formulation for inertial resistance?	no
	Division in a matrix in a matrix and the second sec	2734
	Direction-I inertial Resistance (1/m)	2734
	Direction-2 Inertial Resistance (l/m)	2/34
	Direction-3 Inertial Resistance (1/m)	2734
	CO Coefficient for Power-Law	0
	C1 Coofficient for Power-Law	0
	Contractent for fower haw	Ŭ
	Porosity	
0.400000	01	

Solid Material Name

glass

wall

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1
Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zon	e? yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant 0) (profile )))	
Retation Speed (rad/s)	0
Nucleuron Speed (rau/S) V-Docition of Potation-Avis Origin (m)	0
A-rosition of Potation-Axis Origin (m)	0
I-POSICION OF ROCACION-AXIS OFIGIN (M)	v

.

Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

#### outlet

Condition Value

cold\_exit

Condition Value

cold\_enter

Condition Value

## hot\_exit

Condition Value

## pebble\_exit

Condition Value

## pebble\_enter

Condition Value

#### inlet

\_ \_

Condition Value

## barrel\_walls

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	aluminum
Thermal BC Type	0
Temperature (k)	293
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0

	<pre>Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity</pre>	300 no 0 yes no 0 1 0 0 0 0 0 0 0 0 1
	External Radiation Temperature (k)	300
(((const	ant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 0 0 0 0 1 0 0 0 0 0 0
ne	w_cold_valve	
	Condition	Value
		0
	Wall Thickness (m)	0
	Material Name	copper
	Thermal BC Type	1
	Temperature (k)	300
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0

	Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 1 300 (0)
(((consta	ant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 0 0 0 0 1 0 0 0 0 0 0
col	ld_walls	Value
	Condition	value
	<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 copper 0 283 0 0 300 no 0 yes no 0 1 0 0 1 0 0 0 1 300 (0)
(((consta	ant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction	0 0 0 0

X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction

.

	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
С	ross_over_walls	
	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	coppe
	Thermal BC Type	1
	Temperature (k)	300
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
		(0)
(((cons	tant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
		0
	Z-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction	0
	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction	0 0 0
	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction	0 0 0 1
	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal)	0 0 0 1 0
	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal)	0 0 1 0 0
	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal)	0 0 1 0 0 0
	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k)	0 0 1 0 0 0 0
	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 1 0 0 0 0 0
h	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient ot_top_walls	0 0 1 0 0 0 0 0
h	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient ot_top_walls Condition	0 0 1 0 0 0 0 0 0 0 0 0
h	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient ot_top_walls Condition	0 0 1 0 0 0 0 Value
h	Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient ot_top_walls Condition 	0 0 1 0 0 0 0 0 Value

	Mațerial Name	copper
	Thermal BC Type	1
	Temperature (k)	4/3
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	200
	Free Stream Temperature (K)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone:	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	
	Y-Component of Wall Translation	0
	2-Component of Wall Translation	0
	Define wall velocity components?	0
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	2-Component of Wall Translation (m/s)	1
	External Emissivity	1
	External Radiation Temperature (K)	300
		(0)
( ( ( aanat	ant = 0  (nrofile )))	
(((Consta	Betation Speed (rad/s)	0
	V-Desition of Potation-Axis Origin (m)	0
	X-Position of Rotation-Axis Origin (m)	0
	I-Position of Rotation-Axis Origin (m)	0
	Z-POSICION OF Rotation Axis Direction	0
	X-Component of Rotation-Axis Direction	0
	7 Component of Rotation-Axis Direction	1
	Z-Component of Rocarion-Axis Direction	1
	X-component of shear stress (pascal)	0
	r-component of shear stress (pascal)	0
	$\Sigma$ -component of sheaf stress (pascal)	0
	Surface tension gradient (II/III-K)	0
	Speculaticy coefficient	0
ho	t valve walls	
	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	1
	Temperature (k)	300
	Heat Flux $(w/m^2)$	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	ENADIE SNEIT CONQUELION:	110
	Wall Motion	0
	Wall Motion Shear Boundary Condition	0
	Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone?	0 0 ves
	Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall?	no 0 yes no
	Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s)	0 0 yes no 0
	Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation	0 0 yes no 0 1

Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 0 0 0 0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient</pre>	0 0 0 0 0 1 0 0 0 0 0 0
pebble_walls	
Condition	Value
	0
Wall Thickness (m)	0
Upst Concration Rate (W/mil)	()
Heat Generation Rate (w/m3) Material Name	U
Heat Generation Rate (w/m3) Material Name Thermal BC Type	0 copper 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k)	0 copper 0 (profile
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb wall temp BC)	0 copper 0 (profile
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2)	0 copper 0 (profile 8889.0596
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k)	0 copper 0 (profile 8889.0596 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k)	0 copper 0 (profile 8889.0596 0 300
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction?	0 copper 0 (profile 8889.0596 0 300 no
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion	0 copper 0 (profile 8889.0596 0 300 no 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define well entire relative to adjacent call gong?	0 copper 0 (profile 8889.0596 0 300 no 0 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall?	0 copper 0 (profile 8889.0596 0 300 no 0 0 yes no
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s)	0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation	0 copper 0 (profile 8889.0596 0 300 no 0 0 yes no 0 1
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation	0 copper 0 (profile 8889.0596 0 300 no 0 0 yes no 0 1 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation	0 copper 0 (profile 8889.0596 0 300 no 0 0 yes no 0 1 0 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components?	0 copper 0 (profile 8889.0596 0 300 no 0 0 yes no 0 1 0 0 0 no
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s)	0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0 0 1 0 0 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s)	0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0 0 0 0 0 0 0 0 0 0 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s)	0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0 0 0 0 0 0 0 0 0 0
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 copper 0 (profile 8889.0596 0 300 no 0 0 yes no 0 1 0 0 0 0 0 0 1 300
Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) udf peb_wall_temp_BC) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 copper 0 (profile 8889.0596 0 300 no 0 yes no 0 1 0 0 0 0 0 0 1 300 0 0 1 300 (0)

Rotation Speed (rad/s)

X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

default-interior

Condition Value

#### default-interior:001

Condition Value

#### default-interior:024

Condition Value

default-interior:026

Condition Value

## default-interior:027

Condition Value

#### default-interior:028

Condition Value

#### default-interior:029

Condition Value

#### Solver Controls

-----

#### Equations

Equation	Solved
Flow	yes
he	yes
Energy	yes

Numerics

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

Time	Step (s)				0.1
Max.	Iterations	Per	Time	Step	200

Relaxation

Variable	Relaxation	Factor
Pressure	0.3000001	
Density	1	
Body Forces	1	
Momentum	0.69999999	
he	1	
Energy	1	

Linear Solver

Variable	Solver	Termination	Residual Reduction
	Type	Criterion	Tolerance
Pressure X-Momentum Y-Momentum Z-Momentum he Energy	V-Cycle Flexible Flexible Flexible Flexible Flexible	0.1 0.1 0.1 0.1 0.1 0.1 0.1	0.7 0.7 0.7 0.7 0.7 0.7

Pressure-Velocity Coupling

Parameter Value Type SIMPLE

Discretization Scheme

Variable	Scheme
Pressure	Body Force Weighted
Density	First Order Upwind
Momentum	First Order Upwind
he	First Order Upwind
Energy	First Order Upwind

Solution Limits

Quantity Limit

Minimum	Absolute	Pressure	1
Maximum	Absolute	Pressure	5e+10
Minimum	Temperatu	ire	1
Maximum	Temperatu	ıre	5000

#### Material Properties

#### ------

Material: glass (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2440
Cp (Specific Heat)	j/kg-k	constant	840
Thermal Conductivity	w/m-k	constant	0.93699998

Material: copper (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	8978
Cp (Specific Heat)	j/kg-k	constant	381
Thermal Conductivity	w/m-k	constant	387.60001

Material: (helium . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat) Thermal Conductivity	j/kg-k w/m-k	kinetic-theory kinetic-theory	#f #f #f
Viscosity Molecular Weight L-J Characteristic Length	kg/m-s kg/kgmol angstrom	constant constant	#1 4.0026002 2.5510001
L-J Energy Parameter	k	constant	10.22
Speed of Sound	m/s	none	5 #f

Material: helium (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	0.1625
Cp (Specific Heat)	j/kg-k	constant	5193
Thermal Conductivity	w/m-k	constant	0.152
Viscosity	kg/m-s	constant	1.99e-05
Molecular Weight	kg/kgmol	constant	4.0026
L-J Characteristic Length	angstrom	constant	0
L-J Energy Parameter	k	constant	0
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: mixture-template (mixture)

Property Units Method Value(s)

	Mixture Species		names	
((he	n2) () ())			
	Density	kg/m3	ideal-gas	
#f				
	Cp (Specific Heat)	j/kg-k	mixing-law	
#£				
	Thermal Conductivity	w/m-k	ideal-gas-mixing-law	
#f				
	Viscosity	kg/m−s	ideal-gas-mixing-law	
# ±				
	Mass Diffusivity	mz/s	kinetic-theory	
Η Í		1	binatia theory	
11.6	Thermal Diffusion Coefficient	kg/m-s	KINECIG-CNEOLÀ	
ΨĽ	Thermal Europaien Coofficient	1/1	constant	Ω
	Speed of Sound	1/K m/s	nono	0
	sheed of sound	m/ 5	110110	

#f

Material: (nitrogen . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cn (Cnocific Noct)		kingtig-theory	 # f
Thermal Conductivity	J∕Kg-K w/m-k	kinetic-theory	#1 #f
Viscosity	kg/m-s	kinetic-theory	#f
Molecular Weight	kg/kgmol	constant	28.013399
L-J Characteristic Length	angstrom	constant	3.7980001
L-J Energy Parameter	k	constant	71.400002
Degrees of Freedom		constant	5
Speed of Sound	m/s	none	#f

Material: nitrogen (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	1.138 1040.67 0.0242 1.663e-05 28.0134 3.621 97.53 0 0 #f

Material: oxygen (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.2999
Cp (Specific Heat)	j/kg-k	constant	919.31
Thermal Conductivity	w/m-k	constant	0.0246
Viscosity	kg/m-s	constant	1.919e-05
Molecular Weight	kg/kgmol	constant	31.9988

L-J Characteristic Length	angstrom	constant	3.458
L-J Energy Parameter	k	constant	107.4
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: water-vapor (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k	constant constant constant constant constant constant constant constant constant	0.5542 2014 0.0261 1.34e-05 18.01534 2.605 572.4 0 0
speed of sound	10/5	none	n <b>1</b>

Material: air (fluid)

Property	Units	Method	Value(s)
Density	 kq/m3	constant	1.225
Cp (Specific Heat)	j/kg-k	constant	1006.43
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.7894e-05
Molecular Weight	kg/kgmol	constant	28.966
L-J Characteristic Length	angstrom	constant	3.711
L-J Energy Parameter	k	constant	78.6
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2719
Cp (Specific Heat)	j/kg-k	constant	871
Thermal Conductivity	w/m-k	constant	202.4

## 85% Helium Initial FLUENT Case

FLUENT Version: 3d, dp, pbns, spe, lam, unsteady (3d, double precision, pressure-based, species, laminar, unsteady) Release: 6.3.26 Title: Models

Model	Settings
Space Time Viscous Heat Transfer Solidification and Melting Radiation Species Transport Coupled Dispersed Phase Pollutants Pollutants Soot	3D Unsteady, 1st-Order Implicit Laminar Enabled Disabled None Non-Reacting (2 species) Disabled Disabled Disabled Disabled

Boundary Conditions

Zones

name	id	type
barrel	2	fluid
cold leg	3	fluid
cold valve	4	fluid
cross-over leq	5	fluid
hot top	6	fluid
hot valve	7	fluid
pebbles	8	fluid
wall	9	wall
outlet	10	interior
cold exit	11	interior
coldenter	12	interior
hot exit	13	interior
pebble exit	14	interior
pebble enter	15	interior
inlet	16	interior
barrel walls	17	wall
new cold valve	18	wall
cold walls	19	wall
cross over walls	20	wall
hot top walls	21	wall
hot_valve_walls	22	wall
pebble_walls	23	wall
default-interior	25	interior
default-interior:001	1	interior
default-interior:024	24	interior
default-interior:026	26	interior
default-interior:027	27	interior
default-interior:028	28	interior
default-interior:029	29	interior

Boundary Conditions

barrel

Condition

\_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () no Specify fixed values? Local Coordinate System for Fixed Velocities no Fixed Values () 0 Motion Type X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) Z-Origin of Rotation-Axis (m) 0 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 0 X-Component of Direction-2 Vector Y-Component of Direction-2 Vector 1 0 Z-Component of Direction-2 Vector 1 X-Component of Cone Axis Vector 0 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 1 X-Coordinate of Point on Cone Axis (m) 0 Y-Coordinate of Point on Cone Axis (m) Z-Coordinate of Point on Cone Axis (m) 0 0 Half Angle of Cone Relative to its Axis (deg) Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law C1 Coefficient for Power-Law 0 1 Porosity Solid Material Name aluminum

\_\_\_\_\_

cold leg

Condition

Value

\_\_\_\_\_

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Material Name
mixture-template
         Specify source terms?
                                                                    no
         Source Terms
                                                                    ()
         Specify fixed values?
                                                                    no
         Local Coordinate System for Fixed Velocities
                                                                    no
                                                                    ()
         Fixed Values
                                                                    0
         Motion Type
         X-Velocity Of Zone (m/s)
                                                                    0
                                                                    0
         Y-Velocity Of Zone (m/s)
                                                                    0
         Z-Velocity Of Zone (m/s)
                                                                    0
         Rotation speed (rad/s)
         X-Origin of Rotation-Axis (m)
                                                                    0
         Y-Origin of Rotation-Axis (m)
                                                                    0
                                                                    0
         Z-Origin of Rotation-Axis (m)
                                                                    0
         X-Component of Rotation-Axis
                                                                    0
         Y-Component of Rotation-Axis
         Z-Component of Rotation-Axis
                                                                    1
         Deactivated Thread
                                                                    no
         Porous zone?
                                                                    no
         Conical porous zone?
                                                                    no
         X-Component of Direction-1 Vector
                                                                    1
         Y-Component of Direction-1 Vector
                                                                    0
         Z-Component of Direction-1 Vector
                                                                    0
         X-Component of Direction-2 Vector
                                                                    0
         Y-Component of Direction-2 Vector
                                                                    1
         Z-Component of Direction-2 Vector
                                                                    0
         X-Component of Cone Axis Vector
                                                                    1
         Y-Component of Cone Axis Vector
                                                                    0
                                                                    0
         Z-Component of Cone Axis Vector
         X-Coordinate of Point on Cone Axis (m)
                                                                    1
                                                                    0
         Y-Coordinate of Point on Cone Axis (m)
                                                                    0
         Z-Coordinate of Point on Cone Axis (m)
                                                                    0
         Half Angle of Cone Relative to its Axis (deg)
         Relative Velocity Resistance Formulation?
                                                                    yes
         Direction-1 Viscous Resistance (1/m2)
                                                                    0
                                                                    0
         Direction-2 Viscous Resistance (1/m2)
         Direction-3 Viscous Resistance (1/m2)
                                                                    0
         Choose alternative formulation for inertial resistance?
                                                                    no
         Direction-1 Inertial Resistance (1/m)
                                                                    0
                                                                    0
         Direction-2 Inertial Resistance (1/m)
         Direction-3 Inertial Resistance (1/m)
                                                                    0
         CO Coefficient for Power-Law
                                                                    Ο
                                                                    0
         C1 Coefficient for Power-Law
                                                                    1
         Porosity
         Solid Material Name
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aluminum

cold\_valve

	Source Terms Specify fixed values?	() no
	Local Coordinate System for Fixed Velocities Fixed Values	no ()
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	I-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Polativo Volocity Posistance Formulation?	VAS
	Direction-1 Viscous Resistance $(1/m^2)$	ус <u>з</u> 0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	0
	CO Coefficient for Power-Law	0
	Cl Coefficient for Power-Law	0
	Porosity	1
	Solid Material Name	
aluminum		
cro	oss-over_leg	
	Condition	
Value	CONDICION	
varue		
	Material Name	
mixture-t	cemplate	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no

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Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
Y-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	Õ
7-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
V-Component of Direction-1 Vector	1
X-Component of Direction-1 Vector	Û.
7-Component of Direction-1 Vector	Ő
X-Component of Direction-2 Vector	Õ
X-Component of Direction-2 Vector	1
7-Component of Direction-2 Vector	<u> </u>
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
7-Component of Cone Axis Vector	Õ
X-Coordinate of Point on Cone Axis (m)	1
X-Coordinate of Point on Cone Axis (m)	Ô
7-Coordinate of Point on Cone Axis (m)	õ
Half Angle of Cone Relative to its Axis (deg)	Õ
Rolative Velocity Resistance Formulation?	Ves
Direction-1 Viscous Resistance (1/m2)	усс 0
Direction -2 Viscous Resistance $(1/m^2)$	Ő
Direction -3 Viscous Resistance $(1/m^2)$	Õ
Choose alternative formulation for inertial resistance	~ no
Direction-1 Inertial Resistance (1/m)	
Direction-2 Inertial Resistance (1/m)	Õ
Direction-3 Inertial Resistance (1/m)	Õ
CO Coofficient for Power-Law	Õ
C1 Coefficient for Power-Law	õ
Porosity	1
Solid Material Name	-
Soffa Hacoffar Hamo	

aluminum

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hot\_top

Condition

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Value
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\_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 0 X-Velocity Of Zone (m/s)

aluminum	<pre>Y-Velocity Of Zone (m/s) Z-Velocity Of Zone (m/s) Rotation speed (rad/s) X-Origin of Rotation-Axis (m) Y-Origin of Rotation-Axis (m) X-Component of Rotation-Axis Y-Component of Rotation-Axis Y-Component of Rotation-Axis Deactivated Thread Porous zone? Conical porous zone? X-Component of Direction-1 Vector Y-Component of Direction-1 Vector X-Component of Direction-2 Vector X-Component of Direction-2 Vector Y-Component of Direction-2 Vector X-Component of Direction-2 Vector X-Component of Direction-2 Vector Y-Component of Direction-2 Vector X-Component of Direction-2 Vector X-Component of Cone Axis Vector Y-Component of Cone Axis Vector X-Coordinate of Point on Cone Axis (m) Y-Coordinate of Point on Cone Axis (m) A-Coordinate of Point on Cone Axis (m) Half Angle of Cone Relative to its Axis (deg) Relative Velocity Resistance Formulation? Direction-2 Viscous Resistance (1/m2) Direction-3 Viscous Resistance (1/m2) Direction-3 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) OC Coefficient for Power-Law Coorsity Solid Material Name</pre>	0 0 0 0 0 0 0 1 0 0 0 1 0 0 0 0 0 0 0 0
hot	valve	
Value	Condition	
mixture-t	Material Name template Specify source terms? Source Terms Specify fixed values? Local Coordinate System for Fixed Velocities Fixed Values Motion Type X-Velocity Of Zone (m/s) Y-Velocity Of Zone (m/s) Z-Velocity Of Zone (m/s) Rotation speed (rad/s)	no () no no () 0 0 0 0 0
X-Origin of Rotation-Axis (m)	0	
---	-----	
Y-Origin of Rotation-Axis (m)	0	
Z-Origin of Rotation-Axis (m)	0	
X-Component of Rotation-Axis	0	
Y-Component of Rotation-Axis	0	
Z-Component of Rotation-Axis	1	
Deactivated Thread	no	
Porous zone?	no	
Conical porous zone?	no	
X-Component of Direction-1 Vector	1	
Y-Component of Direction-1 Vector	0	
Z-Component of Direction-1 Vector	0	
X-Component of Direction-2 Vector	0	
Y-Component of Direction-2 Vector	1	
Z-Component of Direction-2 Vector	0	
X-Component of Cone Axis Vector	1	
Y-Component of Cone Axis Vector	0	
Z-Component of Cone Axis Vector	0	
X-Coordinate of Point on Cone Axis (m)	1	
Y-Coordinate of Point on Cone Axis (m)	0	
Z-Coordinate of Point on Cone Axis (m)	0	
Half Angle of Cone Relative to its Axis (deg)	0	
Relative Velocity Resistance Formulation?	yes	
Direction-1 Viscous Resistance (1/m2)	0	
Direction-2 Viscous Resistance (1/m2)	0	
Direction-3 Viscous Resistance (1/m2)	0	
Choose alternative formulation for inertial resistance?	no	
Direction-1 Inertial Resistance (1/m)	0	
Direction-2 Inertial Resistance (1/m)	0	
Direction-3 Inertial Resistance (1/m)	0	
CO Coefficient for Power-Law	0	
C1 Coefficient for Power-Law	0	
Porosity	1	
Solid Material Name		

aluminum

pebbles

Condition

Value \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms ((mass) (x-momentum) (y-momentum) (z-momentum) (species-0) (energy)) Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values ((xvelocity (inactive . #f) (constant . 0) (profile )) (y-velocity (inactive . #f) (constant . 0) (profile )) (z-velocity (inactive . #f) (constant . 0) (profile )) (species-0 (inactive . #f) (constant . 0) (profile )) (temperature (inactive . #f) (constant . 0) (profile )))

	Motion Type		0
	X-Velocity Of Zone (m/s)		0
	X-Velocity of Zone (m/s)		0
	Z-Velocity Of Zone (m/s)		0
	Potation speed (rad/s)		Ô
	V-Origin of Potation-Axis (m)		õ
	X-Origin of Rotation-Axis (m)		0 0
	7 Origin of Rotation-Axis (m)		0
	Z-Origin of Rotation-Axis (m)		0
	X-Component of Rotation-Axis		0
	Y-Component of Rotation-Axis		1
	Z-Component of Rotation-Axis		Ţ
	Deactivated Thread		no
	Porous zone?		yes
	Conical porous zone?		no
	X-Component of Direction-1 Vector		Ţ
	Y-Component of Direction-1 Vector		0
	Z-Component of Direction-1 Vector		0
	X-Component of Direction-2 Vector		0
	Y-Component of Direction-2 Vector		1
	Z-Component of Direction-2 Vector		0
	X-Component of Cone Axis Vector		1
	Y-Component of Cone Axis Vector		0
	Z-Component of Cone Axis Vector		0
	X-Coordinate of Point on Cone Axis (m)		1
	Y-Coordinate of Point on Cone Axis (m)		0
	Z-Coordinate of Point on Cone Axis (m)		0
	Half Angle of Cone Relative to its Axis (deg)		0
	Relative Velocity Resistance Formulation?		no
	Direction-1 Viscous Resistance (1/m2)		
5860000			
	Direction-2 Viscous Resistance (1/m2)		
5860000			
	Direction-3 Viscous Resistance (1/m2)		
5860000			
	Choose alternative formulation for inertial resistant	ce?	no
	Direction-1 Inertial Resistance (1/m)		2734
	Direction-2 Inertial Resistance (1/m)		2734
	Direction-3 Inertial Resistance (1/m)		2734
	CO Coefficient for Power-Law		0
	C1 Coefficient for Power-Law		0
	Porosity		
0.400000	)01		
0.100000	Solid Material Name		
alass	borra nacorrar namo		
91000			
wa	all		
	Condition	Value	9
	Wall Thickness (m)	0	
	Heat Generation Rate (w/m3)	0	
	Material Name	coppe	∋r
	Thermal BC Type	1	
	Temperature (k)	300	
	Heat Flux (w/m2)	0	
	Convective Heat Transfer Coefficient (w/m2-k)	0	

Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

#### outlet

Condition Value

cold\_exit

Condition Value

cold\_enter

Condition Value

## hot\_exit

Condition Value

pebble\_exit

Condition Value

```
pebble_enter
```

Condition Value

inlet

Condition Value

## barrel\_walls

	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	aluminum
	Thermal BC Type	0
	Temperature (k)	293
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
		(0)
(((consta	<pre>nt . 0) (profile )))</pre>	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	U

new\_cold\_valve

Condition

Value

	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	connor
		copper
	Thermal BC Type	Ţ
	Temperature (k)	300
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Convective near fransfer coefficient (w/m2 k)	200
	Free Stream Temperature (K)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	VAS
	Define wait motion relative to adjacent cerr zone.	yes
	Apply a rotational velocity to this wall?	10
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	7-Component of Wall Translation	0
	Define well welegity componente?	no.
	Define wall velocity components?	0
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	Fytornal Emissivity	1
	External Dadiation Tomporature ();)	200
	External Radiation Temperature (K)	500
		(0)
(((consta	Ant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient Id_walls Condition	0 0 0 0 0 0 1 0 0 0 0 0 0 0
	Condition	Value 
	Wall Thickness (m)	0
	Heat Concration Data (W/m3)	0
	near Generation Rate (W/MS)	U
	Material Name	copper
	Thermal BC Type	0
	Temperature (k)	283
	Heat Flux (w/m2)	0
	Convective Next Transfor Coefficient (11/m2 1-)	0
	convective near fransfer coefficient (W/M2-K)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0

Shear Boundary Condition

	Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	yes no 0 1 0 0 0 0 0 0 1 300 (0)
(((consta	ant . 0) (profile )))	0
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	7-Position of Potation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
cro	oss over walls	
	Condition	Value
	 Condition	Value
	Condition 	Value 
	Condition 	Value O O
	Condition 	Value 0 0 copper
	Condition 	Value 0 0 copper 1
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k)	Value 0 0 copper 1 300
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2)	Value 0 0 copper 1 300 0
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k)	Value 0 0 copper 1 300 0
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k)	Value 0 0 copper 1 300 0 0 300
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction?	Value 0 0 copper 1 300 0 300 no
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition	Value 0 0 copper 1 300 0 300 no 0 0
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone?	Value 0 0 copper 1 300 0 300 no 0 0 0 200 no 0 0 0
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall?	Value 0 0 copper 1 300 0 0 300 no 0 0 yes no
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s)	Value 0 0 copper 1 300 0 0 300 no 0 0 yes no 0
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation	Value 0 0 copper 1 300 0 0 300 no 0 0 yes no 0 1
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation	Value 0 0 copper 1 300 0 300 no 0 300 no 0 yes no 0 1 0
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation	Value 0 0 copper 1 300 0 0 300 no 0 0 yes no 0 1 0 0
	Condition Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components?	Value 0 0 copper 1 300 0 0 300 no 0 yes no 0 1 0 0 1 0 0 0 no
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s)	Value 0 0 copper 1 300 0 0 300 no 0 0 yes no 0 1 0 0 1 0 0 0
	Condition 	Value 0 0 copper 1 300 0 0 300 no 0 0 yes no 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s)	Value 0 0 copper 1 300 0 0 300 no 0 0 yes no 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0
	Condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity	Value 0 0 copper 1 300 0 0 300 no 0 0 yes no 0 1 0 0 1 0 0 0 1 1 0 0 1

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(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0
hot_top_walls	
Condition	Value

Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	0
Temperature (k)	473
Heat Flux $(w/m^2)$	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	ves
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
X-Component of Wall Translation	0
7-Component of Wall Translation	0
Define well velocity components?	0
V Component of Wall Translation (m/s)	0
X-Component of Wall Translation (m/s)	0
7-Component of Wall Translation (m/s)	0
External Emissivity	1
External Dadiation Tomporature (k)	300
External Radiation Temperature (K)	(0)
	(0)
(((aconstant ()) (profile )))	
Rotation Speed (rad/s)	$\cap$
X-Position of Potation-Axis Origin (m)	0
X-Position of Rotation-Axis Origin (m)	0
7-Position of Potation-Axis Origin (m)	0
X-rosicion of Rotation-Axis Direction	0
X-Component of Rotation-Axis Direction	0
R Component of Rotation Avia Direction	1
Z-component of Rocation-Axis Direction	1 O
x-component of shear stress (pascal)	0
i-component of shear stress (pascal)	U
Z-component of shear stress (pascal)	U
Surface tension gradient (n/m-k)	U

Specularity Coefficient

hot\_valve\_walls

	Condition '	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	1
	Temperature (k)	300
	Heat Flux (W/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	300
	Field shell conduction?	500 no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	2-Component of Wall Translation (m/s)	0
	External Emissivity	300 T
	External Radiación Temperature (K)	(0)
		(0)
(((const	ant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	2-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	7-component of shear stress (pascal)	0
	Surface tension gradient $(n/m-k)$	0
	Specularity Coefficient	Ő
pe	bble_walls .	
	Condition	Value
		0
	Wall Inickness (M) Heat Concration Pate (W/m <sup>2</sup> )	0
	neat Generation Rate (W/MS) Matorial Namo	v
	Thormal PC Turo	oopher
	Termar bu type Temperature (k)	473
	Heat Flux $(w/m^2)$	0
	neae rran (#/ mz)	0

~

Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 300 no 0 yes no 0 1 0 0 0 0 0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient</pre>	0 0 0 0 1 0 0 0 0 0 0 0
default-interior	
Condition Value	
default-interior:001	
Condition Value	
. default-interior:024	
Condition Value	
default-interior:026 Condition Value	
default-interior.027	
Condition Value	

#### default-interior:028

Condition Value

#### default-interior:029

Condition Value

#### Solver Controls

\_\_\_\_\_

Equations

Equation	Solved
Flow	yes
he	yes
Energy	yes

#### Numerics

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

						·			
Time	Step (	s)							0.2
Max.	Iterat	ion	S	Per	Tim	le	Ste	∋p	200

Relaxation

Variable	Relaxation Factor
Pressure	0.6000002
Density	0.69999999
Body Forces	1
Momentum	0.4000001
he	1
Energy	1

Linear Solver

Variable	Solver Type	Termination Criterion	Residual Reduction Tolerance
Pressure	V-Cycle	0.1	
X-Momentum	Flexible	0.1	0.7
Y-Momentum	Flexible	0.1	0.7
Z-Momentum	Flexible	0.1	0.7
he	Flexible	0.1	0.7
Energy	Flexible	0.1	0.7

Pressure-Velocity Coupling

```
Parameter Value
-----
Type SIMPLE
```

Discretization Scheme

Scheme
Body Force Weighted
First Order Upwind

Solution Limits

Quantity	l		Limit
Minimum	Absolute	Pressure	1
Maximum	Absolute	Pressure	5e+10
Minimum	Temperati	ıre	1
Maximum	Temperati	ıre	5000

Material Properties

-----

Material: glass (solid)

Property	Units	Method	Value(s)
Density		constant	2440
Cp (Specific Heat)	j/kg-k	constant	840
Thermal Conductivity	w/m-k	constant	0.93699998

Material: copper (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	8978
Cp (Specific Heat)	j/kg-k	constant	381
Thermal Conductivity	w/m-k	constant	387.60001

Material: (helium . mixture-template) (fluid)

Units	Method	Value(s)
	·	
]∕kg−k	kinetic-theory	# I
w/m-k	kinetic-theory	#f
kg/m-s	kinetic-theory	#f
kg/kgmol	constant	4.0026002
angstrom	constant	2.5510001
k	constant	10.22
	constant	3
m/s	none	#f
	Units j/kg-k w/m-k kg/m-s kg/kgmol angstrom k m/s	Units Method j/kg-k kinetic-theory w/m-k kinetic-theory kg/m-s kinetic-theory kg/kgmol constant angstrom constant k constant m/s none

#### Material: helium (fluid)

	Property	Units	Method	Value(s)
	Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	0.1625 5193 0.152 1.99e-05 4.0026 0 0 0 0 0 4 f
Má	aterial: mixture-template (mixtu:	re)		
Value	Property e(s)	Units	Method	
	Mixture Species		names	
((he	Mixture Species n2) () ()) Density	kg/m3	names ideal-gas	
((he #f	Mixture Species n2) () ()) Density Cp (Specific Heat)	kg/m3 j∕kg-k	names ideal-gas mixing-law	
 ((he #f #f	Mixture Species n2) () ()) Density Cp (Specific Heat) Thermal Conductivity	kg/m3 j/kg-k w/m-k	names ideal-gas mixing-law ideal-gas-mi	
 ((he #f #f #f	Mixture Species n2) () ()) Density Cp (Specific Heat) Thermal Conductivity	kg/m3 j/kg-k w/m-k kg/m-s	names ideal-gas mixing-law ideal-gas-mi	xing-law
 ((he #f #f #f #f	Mixture Species n2) () ()) Density Cp (Specific Heat) Thermal Conductivity Viscosity	kg/m3 j/kg-k w/m-k kg/m-s	names ideal-gas mixing-law ideal-gas-mi ideal-gas-mi	xing-law xing-law
 ((he #f #f #f #f #f	Mixture Species n2) () ()) Density Cp (Specific Heat) Thermal Conductivity Viscosity Mass Diffusivity	kg/m3 j/kg-k w/m-k kg/m-s m2/s	names ideal-gas mixing-law ideal-gas-mi ideal-gas-mi kinetic-theo	xing-law xing-law ry
 ((he #f #f #f #f #f #f	Mixture Species n2) () ()) Density Cp (Specific Heat) Thermal Conductivity Viscosity Mass Diffusivity Thermal Diffusion Coefficient	kg/m3 j/kg-k w/m-k kg/m-s m2/s kg/m-s	names ideal-gas mixing-law ideal-gas-mi ideal-gas-mi kinetic-theo kinetic-theo	xing-law xing-law ry ry

Material: (nitrogen . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	j/kg-k	kinetic-theory	 #f
Thermal Conductivity	w/m-k	kinetic-theory	#f
Viscosity	kg/m-s	kinetic-theory	#f
Molecular Weight	kg/kgmol	constant	28.013399
L-J Characteristic Length	angstrom	constant	3.7980001
L-J Energy Parameter	k	constant	71.400002
Degrees of Freedom		constant	5
Speed of Sound	m/s	none	#f

#### Material: nitrogen (fluid)

Property	Units	Method	Value(s)

Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	1.138 1040.67 0.0242 1.663e-05 28.0134 3.621 97.53 0 0 #f
Material: oxygen (fluid)			
Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant none	1.2999 919.31 0.0246 1.919e-05 31.9988 3.458 107.4 0 0 #f
Material: water-vapor (fluid)			
Property	Units 	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	<pre>Units kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s</pre>	Method constant constant constant constant constant constant constant constant none	Value(s) 0.5542 2014 0.0261 1.34e-05 18.01534 2.605 572.4 0 0 #f
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound Material: air (fluid)	Units kg/m3 j/kg-k w/m-k kg/kgmol angstrom k l/k m/s	Method constant constant constant constant constant constant constant constant none	Value(s) 0.5542 2014 0.0261 1.34e-05 18.01534 2.605 572.4 0 0 #f
Property Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound Material: air (fluid) Property	Units kg/m3 j/kg-k w/m-k kg/kgmol angstrom k 1/k m/s Units	Method constant constant constant constant constant constant constant none Method	Value(s) 0.5542 2014 0.0261 1.34e-05 18.01534 2.605 572.4 0 0 #f Value(s)

Material: aluminum (solid)

229

Property	Units	Method	Value(s)
Density Cp (Specific Heat)	kg/m3 j/kg-k	constant constant	2719 871
Thermal Conductivity	w/m-k	constant	202.4

### **Update A FLUENT Case**

```
FLUENT
Version: 3d, pbns, spe, lam, unsteady (3d, pressure-based, species,
laminar, unsteady)
Release: 6.3.26
Title:
Models
Settings
   Model
   _____
                                3D
   Space
                                Unsteady, 1st-Order Implicit
   Time
   Viscous
                                Laminar
  viscous
Heat Transfer
                                Enabled
   Solidification and Melting Disabled
  RadiationNoneSpecies TransportNon-Reacting (2 species)Coupled Dispersed PhaseDisabledPollutantsDisabled
                                 Disabled
   Pollutants
                                 Disabled
   Soot
Boundary Conditions
_____
   Zones
                   id type
      name
      _____
     barrel 2 fluid
cold_leg 3 fluid
cold_valve 4 fluid
cross-over_leg 5 fluid
hot_top 6 fluid
      hot_top
hot_valve
pebbles
                           7
                                  fluid
                             8 fluid
      wall9walloutlet10interiorcold_exit11interiorcold_enter12interiorhot_exit13interior
      not_exit15interiorpebble_exit14interiorpebble_enter15interiorinlet16interior
      barrel walls 17 wall
```

new_cold_valve	18	wall
cold_walls	19	wall
cross over walls	20	wall
hot_top_walls	21	wall
hot_valve_walls	22	wall
pebble_walls	23	wall
default-interior	25	interior
default-interior:001	1	interior
default-interior:024	24	interior
default-interior:026	26	interior
default-interior:027	27	interior
default-interior:028	28	interior
default-interior:029	29	interior

Boundary Conditions

barrel

Condition

```
Value
```

	Material Name	
mixture-	template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	()
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes

	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	0
	CO Coefficient for Power-Law	0
	Cl Coefficient for Power-Law	0
	Porosity	1
	Solid Material Name	
aluminum		

cold\_leg

Value	Condition	
	Material Name	
mixture	-template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	()
	Motion Type V Velecity Of Zene (m/e)	0
	X-Velocity Of Zone (m/s)	0
	7 Velocity Of Zone (m/s)	0
	2-Velocity of zone (m/s)	0
	X-Origin of Rotation-Axis (m)	0
	X-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0 0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	no
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	U
	Direction-2 Viscous Resistance (1/m2)	U
	Direction-3 viscous Kesistance (1/m2)	U

	Choose alternative formulation for inertial resistance? Direction-1 Inertial Resistance (1/m) Direction-2 Inertial Resistance (1/m) C0 Coefficient for Power-Law C1 Coefficient for Power-Law Porosity Solid Material Name	no 0 0 0 0 1
aluminum		
co	ld_valve	
Value	Condition	
VALAC		
	Material Name	
mixture-	template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values:	no
	Fixed Values	()
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	1
	Departivated Thread	1 no
	Percus zone?	no
	Conical norous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1 O
	Y-Component of Cone Axis Vector	0
	X-Component of Cone Axis Vector X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0

Direction-3 Inertial Resistance	(1/m) 0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

\_\_\_\_\_

aluminum

cross-over\_leg

Condition

```
Value
```

\_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 0 Z-Velocity Of Zone (m/s) Rotation speed (rad/s) 0 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 1 Z-Component of Rotation-Axis Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 0 Direction-2 Viscous Resistance (1/m2) Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 0 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law

# Porosity Solid Material Name

### aluminum

# hot\_top

Condition

Value

Material Name	
mixture-template	
Specify source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

\_\_\_\_\_

aluminum

hot valve

Condition

Value \_\_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 X-Velocity Of Zone (m/s) 0 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) Z-Origin of Rotation-Axis (m) 0 0 X-Component of Rotation-Axis Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 0 Y-Component of Direction-1 Vector Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 0 Direction-2 Viscous Resistance (1/m2) Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 0 C1 Coefficient for Power-Law Porosity 1 Solid Material Name

aluminum

pebbles

```
Condition
```

Value		
	Material Name	
mixture-	-template	
	Specify source terms?	no
	Source Terms	
((mass)	(x-momentum) (y-momentum) (z-momentum) (species-0) (energy	))
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	((x-
velocity	<pre>y (inactive . #f) (constant . 0) (profile )) (y-velocity</pre>	
(inactiv	ze . #f) (constant . 0) (profile )) (z-velocity (inactive	. #±;
(constar	nt. 0) (profile )) (species-0 (inactive . #f) (constant.	0)
(profile	e )) (temperature (inactive . #1) (constant . 0) (profile	)))
	Motion Type	0
	X-Velocity of Zone $(m/s)$	0
	7-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	yes
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	1
	7-Component of Direction-2 Vector	0
	Y-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	Ū.
	Z-Component of Cone Axis Vector	õ
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	no
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-5 inertial resistance (1/m)	0 3/11
	Cl Coefficient for Power-Law	) H L
1 6107	OF COCTITCICITC IOI LOMOT DAW	
1.010/		

Porosity 0.39500001

Solid Material Name

```
glass
```

wall

	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	1
	Temperature (k)	300
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (K)	(0)
( ( const	cant () (profile )))	
(((const	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0.
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
οι	tlet	
	Condition Value	

cold\_exit

Condition Value

```
_____
```

cold\_enter

Condition Value

hot\_exit

Condition Value

pebble\_exit

Condition Value

## pebble\_enter

Condition Value

#### inlet

Condition Value

#### barrel\_walls

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	aluminum
Thermal BC Type	0
Temperature (k)	293
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)

(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

new\_cold\_valve

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1
Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0

Specularity Coefficient

0 .

cold\_walls

	Condition	Value
	Mall Thickness (m)	0
	Heat Concration Rate $(w/m^3)$	0
	Material Name	conner
	Thormal PC Tupo	o
		202
	$\frac{1}{1} = \frac{1}{1} = \frac{1}$	205
	Heat Flux (W/MZ) Generation West Musesfer Coofficient (w(m2, k)	0
	Convective Heat Transfer Coefficient ( $W/m2-K$ )	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
	-	(0)
(cons	tant . 0) (profile )))	0
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	7-component of shear stress (nascal)	0
	Z component of shear stress (pascar)	
	Surface tension gradient (n/m-k)	0
	Surface tension gradient (n/m-k) Specularity Coefficient	0
С	Surface tension gradient (n/m-k) Specularity Coefficient	0
С	Surface tension gradient (n/m-k) Specularity Coefficient ross_over_walls Condition	0 0 Value
с	Surface tension gradient (n/m-k) Specularity Coefficient ross_over_walls Condition	0 0 Value
с	Surface tension gradient (n/m-k) Specularity Coefficient ross_over_walls Condition	0 0 Value
c	<pre>Surface tension gradient (n/m-k) Specularity Coefficient  Condition</pre>	0 0 Value 0
с	Surface tension gradient (n/m-k) Specularity Coefficient ross_over_walls Condition 	0 0 Value 0 0
с	<pre>Z component of shear stress (pascar) Surface tension gradient (n/m-k) Specularity Coefficient ross_over_walls Condition </pre>	0 0 Value 0 0 copper
с	Surface tension gradient (n/m-k) Specularity Coefficient ross_over_walls Condition 	0 0 Value 0 0 copper 1
с	<pre>Surface tension gradient (n/m-k) Specularity Coefficient  condition Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k)</pre>	Value 0 0 0 copper 1 300

	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
	<b>-</b> • • •	(0)
(((const	ant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
he		
10	C_COP_Walls	
	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	0
	Temperature (k)	473
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0

Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient</pre>	0 0 0 0 0 1 0 0 0 0 0 0 0
hot_valve_walls Condition	Value
Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 0 copper 1 300 0 300 no 0 yes no 0 1 0 0 0 1 0 0 1 300 (0)
(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction	0 0 0 0 0

	Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal)	1 0 0 0
	Surface tension gradient (n/m-k) Specularity Coefficient	0 0
	pebble_walls	
	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	0
	Temperature (k)	4/3
	Heat Flux (W/M2) Convoctive Heat Transfor Coofficient (W/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-component of Wall Translation	
	2-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300 (0)
( ( (cor	nstant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	7-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0

default-interior

Condition Value

default-interior:001

```
Condition Value
  _____
default-interior:024
  Condition Value
  _____
default-interior:026
  Condition Value
  _____
default-interior:027
  Condition Value
  _____
default-interior:028
  Condition Value
  _____
default-interior:029
  Condition Value
```

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Solver Controls

Equations

Equation	Solved
Flow	yes
he	yes
Energy	yes

Numerics

~

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

Time	Step (s)				0.2
Max.	Iterations	Per	Time	Step	100

Relaxation

Variable Relaxation Factor

Pressure	0.6000002
Density	0.8000001
Body Forces	0.69999999
Momentum	0.4000001
he	0.80000001
Energy	0.89999998

Linear Solver

PressureV-Cycle0.1X-MomentumFlexible0.10.7Y-MomentumFlexible0.10.7Z-MomentumFlexible0.10.7heFlexible0.10.7EnergyFlexible0.10.7	Variable	Solver Type	Termination Criterion	Residual Reduction Tolerance
	Pressure X-Momentum Y-Momentum Z-Momentum he Energy	V-Cycle Flexible Flexible Flexible Flexible Flexible	0.1 0.1 0.1 0.1 0.1 0.1 0.1 0.1	0.7 0.7 0.7 0.7 0.7 0.7 0.7

Pressure-Velocity Coupling

Parameter	Value
Туре	SIMPLE

Discretization Scheme

Variable	Scheme
Pressure	Body Force Weighted
Density	First Order Upwind
Momentum	First Order Upwind
he	First Order Upwind
Energy	First Order Upwind

Solution Limits

Quantity	Limit		
Minimum	Absolute	Pressure	1
Maximum	Absolute	Pressure	5e+10
Minimum	Temperatu	ire	1
Maximum	um Temperature		

Material Properties

,

Material: glass (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2440
Cp (Specific Heat)	j/kg-k	constant	840
Thermal Conductivity	w/m-k	constant	0.93699998

Material: copper (solid)

Property	Units	Method	Value(s)
Density	kq/m3	constant	8978
Cp (Specific Heat)	j/kg-k	constant	381
Thermal Conductivity	w/m-k	constant	387.60001

Material: (helium . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	j/kg-k	kinetic-theory	#f
Thermal Conductivity	w/m-k	kinetic-theory	#f
Viscosity	kg/m-s	kinetic-theory	# f
Molecular Weight	kg/kgmol	constant	4.0026002
L-J Characteristic Length	angstrom	constant	2.576
L-J Energy Parameter	k	constant	10.2
Degrees of Freedom		constant	3
Speed of Sound	m/s	none	#f

Material: helium (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k	constant constant constant constant constant constant constant constant	0.1625 5193 0.152 1.99e-05 4.0026 0 0 0 0
Speed of Sound	m/s	none	#f

Material: mixture-template (mixture)

	Property	Units	Method
Value	e(s)		
( (he	Mixture Species		names
((IIC	Density	kg/m3	ideal-gas
# L	Cp (Specific Heat)	j/kg-k	mixing-law
ΨI	Thermal Conductivity	w/m-k	mass-weighted-mixing-law
# I	Viscosity	kg/m-s	mass-weighted-mixing-law
# ±	Mass Diffusivity	m2/s	kinetic-theory
# İ	Thermal Diffusion Coefficient	kg/m-s	kinetic-theory
#f	Thermal Expansion Coefficient	1/k	constant
U			

247

Speed of Sound m/s none #f

#### Material: (nitrogen . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	j/kg-k	kinetic-theory	#f
Thermal Conductivity	w/m-k	kinetic-theory	#f
Viscosity	kg∕m-s	kinetic-theory	#f
Molecular Weight	kg/kgmol	constant	28.013399
L-J Characteristic Length	angstrom	constant	3.681
L-J Energy Parameter	k	constant	91.5
Degrees of Freedom		constant	5
Speed of Sound	m/s	none	#f

Material: nitrogen (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	1.138 1040.67 0.0242 1.663e-05 28.0134 3.621 97.53 0 0 #f

Material: oxygen (fluid)

Units	Method	Value(s)
kg/m3	constant	1.2999
j/kg-k	constant	919.31
w/m-k	constant	0.0246
kg/m-s	constant	1.919e-05
kg/kgmol	constant	31.9988
angstrom	constant	3.458
k	constant	107.4
1/k	constant	0
	constant	0
m/s	none	# f
	Units kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	Units Method kg/m3 constant j/kg-k constant w/m-k constant kg/m-s constant kg/kgmol constant angstrom constant k constant 1/k constant m/s none

Material: water-vapor (fluid)

Property	Units	Method	Value(s)
		accetant	0 5542
Density	kg/m3	Constant	0.5542
Cp (Specific Heat)	j/kg-k	constant	2014
Thermal Conductivity	w/m-k	constant	0.0261
Viscosity	kg/m-s	constant	1.34e-05
Molecular Weight	kg/kgmol	constant	18.01534
L-J Characteristic Length	angstrom	constant	2.605
L-J Energy Parameter	k	constant	572.4

Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

.

Material: air (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.225
Cp (Specific Heat)	j/kg-k	constant	1006.43
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.7894e-05
Molecular Weight	kg/kgmol	constant	28.966
L-J Characteristic Length	angstrom	constant	3.711
L-J Energy Parameter	k	constant	78.6
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2719
Cp (Specific Heat)	j/kg-k	constant	871
Thermal Conductivity	w/m-k	constant	202.4

## Injection (1cc/min) FLUENT Case

```
FLUENT
Version: 3d, dp, pbns, spe, lam, unsteady (3d, double precision,
pressure-based, species, laminar, unsteady)
Release: 6.3.26
Title:
```

```
Models
```

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Model	Settings
Space Time Viscous Heat Transfer Solidification and Melting Radiation Species Transport Coupled Dispersed Phase Pollutants Pollutants Spot	3D Unsteady, 1st-Order Implicit Laminar Enabled Disabled None Non-Reacting (2 species) Disabled Disabled Disabled Disabled

Boundary Conditions

Zones

,

	name	id	type	
	barrel	2	fluid	
	cold leg	3	fluid	
	cold_valve	4	fluid	
	cross-over_leg	5	fluid	
	hot_top	6	fluid	
	hot valve	7	fluid	
	pebbles	8	fluid	
	injection_point	9	mass-flow-inlet	
	outlet	10	interior	
	cold exit	11	interior	
	cold_enter	12	interior	
	hot exit	13	interior	
	pebble exit	14	interior	
	pebble_enter	15	interior	
	inlet	16	interior	
	barrel walls	17	wall	
	new cold valve	18	wall	
	cold walls	19	wall	
	cross over walls	20	wall	
	hot top walls	21	wall	
	hot valve walls	22	wall	
	pebble walls	23	wall	
	default-interior	25	interior	
	default-interior:001	1	interior	
	default-interior:024	24	interior	
	default-interior:026	26	interior	
	default-interior:027	27	interior	
	default-interior:028	28	interior	
	default-interior:029	29	interior	
	derault interior.025	29	Inceliot	
Во	undary Conditions			
	barrel			
	Condition			
Value				
	Material Name			
mixtu	re-template			
	Specify source terr	ns?		no
	Source Terms			()
	Specify fixed value	es?		no
	Local Coordinate Sy	ystem	for Fixed Velocities	no
	Fixed Values			()
	Motion Type			0
	X-Velocity Of Zone	(m/s)		0
	Y-Velocity Of Zone	(m/s)		0
	Z-Velocity Of Zone	(m/s)		0
	Rotation speed (rac	1/s)		0
	X-Origin of Rotatic	n–Axi	is (m)	0
	Y-Origin of Rotatio	n-Axi	is (m)	0
	Z-Origin of Rotatio	n-Axi	is (m)	0 0
	A OFTATU OF ROCACTO			0

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X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0
X-Component of Direction-2 Vector	0
Y-Component of Direction-2 Vector	1
Z-Component of Direction-2 Vector	0
X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

aluminum

cold\_leg

Condition

```
Value
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Material Name	
mixture-template	
Specify source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1

aluminum	Deactivated Thread Porous zone? Conical porous zone? X-Component of Direction-1 Vector Y-Component of Direction-1 Vector X-Component of Direction-2 Vector Y-Component of Direction-2 Vector X-Component of Cone Axis Vector Y-Component of Cone Axis Vector X-Component of Cone Axis Vector X-Coordinate of Point on Cone Axis (m) Y-Coordinate of Point on Cone Axis (m) X-Coordinate of Point on Cone Axis (m) Half Angle of Cone Relative to its Axis (deg) Relative Velocity Resistance Formulation? Direction-1 Viscous Resistance (1/m2) Direction-3 Viscous Resistance (1/m2) Direction-1 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) CO Coefficient for Power-Law C1 Coefficient for Power-Law Porosity Solid Material Name	no no 1 0 0 1 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0
CO.	Condition	
Value		
	Material Name	
mixture-	template	
	Specify source terms?	no
	Source Terms	()
	Specify fixed values:	no
	Fixed Values	()
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	2-component of Kotation-Axis	1 DO
	Percus zone?	no
	Conical porous zone?	no
	-	
X-Component of Direction-1 Vector	1	
---	-----	
Y-Component of Direction-1 Vector	0	
Z-Component of Direction-1 Vector	0	
X-Component of Direction-2 Vector	0	
Y-Component of Direction-2 Vector	1	
Z-Component of Direction-2 Vector	0	
X-Component of Cone Axis Vector	1	
Y-Component of Cone Axis Vector	0	
Z-Component of Cone Axis Vector	0	
X-Coordinate of Point on Cone Axis (m)	1	
Y-Coordinate of Point on Cone Axis (m)	0	
Z-Coordinate of Point on Cone Axis (m)	0	
Half Angle of Cone Relative to its Axis (deg)	0	
Relative Velocity Resistance Formulation?	yes	
Direction-1 Viscous Resistance (1/m2)	0	
Direction-2 Viscous Resistance (1/m2)	0	
Direction-3 Viscous Resistance (1/m2)	0	
Choose alternative formulation for inertial resistance?	no	
Direction-1 Inertial Resistance (1/m)	0	
Direction-2 Inertial Resistance (1/m)	0	
Direction-3 Inertial Resistance (1/m)	0	
CO Coefficient for Power-Law	0	
Cl Coefficient for Power-Law	0	
Porosity	1	
Solid Material Name		

\_\_\_\_\_

# aluminum

cross-over\_leg

```
Condition
```

\_ \_ \_

```
Value
```

Material Name	
mixture-template	
Specify source terms?	no
Source Terms	()
Specify fixed values?	no
Local Coordinate System for Fixed Velocities	no
Fixed Values	()
Motion Type	0
X-Velocity Of Zone (m/s)	0
Y-Velocity Of Zone (m/s)	0
Z-Velocity Of Zone (m/s)	0
Rotation speed (rad/s)	0
X-Origin of Rotation-Axis (m)	0
Y-Origin of Rotation-Axis (m)	0
Z-Origin of Rotation-Axis (m)	0
X-Component of Rotation-Axis	0
Y-Component of Rotation-Axis	0
Z-Component of Rotation-Axis	1
Deactivated Thread	no
Porous zone?	no
Conical porous zone?	no
X-Component of Direction-1 Vector	1
Y-Component of Direction-1 Vector	0
Z-Component of Direction-1 Vector	0

	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	0
	Direction-2 Viscous Resistance (1/m2)	0
	Direction-3 Viscous Resistance (1/m2)	0
	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Resistance (1/m)	0
	Direction-2 Inertial Resistance (1/m)	0
	Direction-3 Inertial Resistance (1/m)	0
	CO Coefficient for Power-Law	0
	Cl Coefficient for Power-Law	0
	Porosity	1
	Solid Material Name	
aluminum		

hot\_top

Condition

```
Value
        _____
        Material Name
mixture-template
        Specify source terms?
                                                              no
        Source Terms
                                                              ()
        Specify fixed values?
                                                              no
        Local Coordinate System for Fixed Velocities
                                                              no
        Fixed Values
                                                              ()
                                                              0
        Motion Type
        X-Velocity Of Zone (m/s)
                                                              0
        Y-Velocity Of Zone (m/s)
                                                              0
        Z-Velocity Of Zone (m/s)
                                                              0
        Rotation speed (rad/s)
                                                              0
                                                              0
        X-Origin of Rotation-Axis (m)
                                                              0
        Y-Origin of Rotation-Axis (m)
                                                              0
        Z-Origin of Rotation-Axis (m)
                                                              0
        X-Component of Rotation-Axis
                                                              0
        Y-Component of Rotation-Axis
                                                              1
        Z-Component of Rotation-Axis
        Deactivated Thread
                                                              no
        Porous zone?
                                                              no
        Conical porous zone?
                                                              no
                                                              1
        X-Component of Direction-1 Vector
        Y-Component of Direction-1 Vector
                                                              0
                                                              0
        Z-Component of Direction-1 Vector
                                                              0
        X-Component of Direction-2 Vector
                                                              1
        Y-Component of Direction-2 Vector
                                                              0
        Z-Component of Direction-2 Vector
```

X-Component of Cone Axis Vector	1
Y-Component of Cone Axis Vector	0
Z-Component of Cone Axis Vector	0
X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
Cl Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

```
aluminum
```

hot\_valve

Condition

```
Value
```

\_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template no Specify source terms? Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no () Fixed Values 0 Motion Type X-Velocity Of Zone (m/s) 0 0 Y-Velocity Of Zone (m/s) Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 1 Z-Component of Rotation-Axis Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 0 Y-Component of Direction-1 Vector Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 1 Y-Component of Direction-2 Vector 0 Z-Component of Direction-2 Vector X-Component of Cone Axis Vector 1 0 Y-Component of Cone Axis Vector

Z-Component of Cone Axis Vector

0

X-Coordinate of Point on Cone Axis (m)	1
Y-Coordinate of Point on Cone Axis (m)	0
Z-Coordinate of Point on Cone Axis (m)	0
Half Angle of Cone Relative to its Axis (deg)	0
Relative Velocity Resistance Formulation?	yes
Direction-1 Viscous Resistance (1/m2)	0
Direction-2 Viscous Resistance (1/m2)	0
Direction-3 Viscous Resistance (1/m2)	0
Choose alternative formulation for inertial resistance?	no
Direction-1 Inertial Resistance (1/m)	0
Direction-2 Inertial Resistance (1/m)	0
Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

```
aluminum
```

pebbles

Value	Condition	
varue		
	Material Name	
mixture-	-template	
	Specify source terms?	no
	Source Terms	
((mass)	(x-momentum) (y-momentum) (z-momentum) (species-0) (energy	))
	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	((x-
velocity	y (inactive . #f) (constant . 0) (profile )) (y-velocity	
(inactiv	ve . #f) (constant . 0) (profile )) (z-velocity (inactive	. #1)
(constar	<pre>ht . 0) (profile )) (species-0 (inactive . #I) (constant . )) (transfile</pre>	()
(prollie	Mation Turne (Inactive . #1) (Constant . 0) (profile	)))
	Molion Type	0
	X = Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	0
	Z-Component of Rotation-Axis	1
	Deactivated Thread	no
	Porous zone?	yes
	Conical porous zone?	no
	X-Component of Direction-1 Vector	1
	Y-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0

	Y-Component of Direction-2 Vector Z-Component of Direction-2 Vector X-Component of Cone Axis Vector Y-Component of Cone Axis Vector Z-Component of Cone Axis Vector X-Coordinate of Point on Cone Axis (m) Y-Coordinate of Point on Cone Axis (m) Z-Coordinate of Point on Cone Axis (m) Half Angle of Cone Relative to its Axis (deg Relative Velocity Resistance Formulation? Direction-1 Viscous Resistance (1/m2)	1)	1 0 1 0 1 0 0 0 9 9 9 9 9
5860000	Direction-2 Viscous Resistance (1/m2)		
5860000	Direction-3 Viscous Resistance (1/m2)		
5860000	Choose alternative formulation for inertial Direction-1 Inertial Resistance (1/m) Direction-2 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) C0 Coefficient for Power-Law C1 Coefficient for Power-Law Porosity	resistance?	no 2734 2734 2734 0 0
0.400000	01 Solid Matorial Name		
glass			
in	jection_point		
	Condition	Value	
	Mass Flow Specification Method Mass Flow-Rate (kg/s) Mass Flux (kg/m2-s) Average Mass Flux (kg/m2-s) Upstream Torque Integral (n-m) Upstream Total Enthalpy Integral (w/m2) Total Temperature (k) Supersonic/Initial Gauge Pressure (pascal) Direction Specification Method Reference Frame Coordinate System X-Component of Flow Direction Y-Component of Flow Direction Z-Component of Flow Direction X-Component of Axis Direction	0 2.78e-09 1 1 1 293 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0	
	Z-Component of Axis Direction X-Coordinate of Axis Origin (m) Y-Coordinate of Axis Origin (m) Z-Coordinate of Axis Origin (m)	0 0 0 (((constant	. 1)

```
Condition Value
```

cold\_exit

Condition Value

cold enter

Condition Value

hot\_exit

Condition Value

#### pebble\_exit

Condition Value

#### pebble enter

Condition Value

#### inlet

Condition Value

#### barrel walls

```
Value
       Condition
                         _____
       _____
_____
       Wall Thickness (m)
                                                        0
       Heat Generation Rate (w/m3)
                                                        0
       Material Name
                                                        aluminum
       Thermal BC Type
                                                        0
                                                        293
       Temperature (k)
                                                        0
       Heat Flux (w/m2)
       Convective Heat Transfer Coefficient (w/m2-k)
                                                        0
                                                        300
       Free Stream Temperature (k)
       Enable shell conduction?
                                                        no
       Wall Motion
                                                        0
       Shear Boundary Condition
                                                        0
       Define wall motion relative to adjacent cell zone?
                                                        yes
       Apply a rotational velocity to this wall?
                                                        no
       Velocity Magnitude (m/s)
                                                        0
       X-Component of Wall Translation
                                                        1
        Y-Component of Wall Translation
                                                        0
        Z-Component of Wall Translation
                                                        0
        Define wall velocity components?
                                                        no
```

X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient</pre>	0 0 0 0 0 1 0 0 0 0 0 0
new_cold_valve Condition	Value
<pre>Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)</pre>	0 0 copper 1 300 0 300 no 0 yes no 0 yes no 0 1 0 0 0 1 300 0 0 1 300 (0)
<pre>(((constant . 0) (profile )))     Rotation Speed (rad/s)     X-Position of Rotation-Axis Origin (m)     Y-Position of Rotation-Axis Origin (m)     Z-Position of Rotation-Axis Origin (m)     X-Component of Rotation-Axis Direction</pre>	0 0 0 0

Y-Component of	Rotation-Axis Direction	0
Z-Component of	Rotation-Axis Direction	1
X-component of	shear stress (pascal)	0
Y-component of	shear stress (pascal)	0
Z-component of	shear stress (pascal)	0
Surface tensic	n gradient (n/m-k)	0
Specularity Co	efficient	0

# cold\_walls

	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	0
	Temperature (k)	283
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
	-	(0)
(cons	tant . 0) (profile )))	
(00110	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation-Axis Direction	0
	Y-Component of Rotation-Axis Direction	0
	Z-Component of Rotation-Axis Direction	1
	X-component of shear stress (pascal)	0
	Y-component of shear stress (pascal)	0
	Z-component of shear stress (pascal)	0
	Surface tension gradient (n/m-k)	0
	Specularity Coefficient	0
С	ross_over_walls	
	Condition	Value

	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	1
	Temperature (k)	300
	Heat Flux (w/m2)	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Free Stream Temperature (k)	300
	Enable shell conduction?	no
	Wall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	no
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	1
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
		(0)
(((const	ant . 0) (profile )))	
	Rotation Speed (rad/s)	0
	X-Position of Rotation-Axis Origin (m)	0
	Y-Position of Rotation-Axis Origin (m)	0
	Z-Position of Rotation-Axis Origin (m)	0
	X-Component of Rotation Axis Direction	0
	7 Component of Rotation-Axis Direction	1
	Y-component of shear stress (pascal)	1
	X-component of shear stress (pascal)	0
	7-component of shear stress (pascal)	0
	Surface tension gradient $(n/m-k)$	0
	Specularity Coefficient	0
	spectrulity oberrietene	0
ha	t top walls	
	_ •_	
	Condition	Value
		<u>^</u>
	Wall Thickness (m)	U
	Heat Generation Rate (w/m3)	U
	Material Name	copper 1
	Thermal BC Type	1
	Heat Flux (W/m2)	0
	neau riux (W/MZ) Convoctivo Heat Transfer Coofficient (W/m2-k)	0
	Free Stream Temperature $(k)$	300
	Free Scream remperature (K)	500 no
	Mall Motion	0
	Shear Boundary Condition	0
	Define wall motion relative to adjacent cell zone?	ves
	Apply a rotational velocity to this wall?	no
	APPLY a tocactomat verocity to ento watt.	

Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 1 0 0 n 0 0 0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient</pre>	0 0 0 0 0 1 0 0 0 0 0 0 0
hot_valve_walls	
Condition	Value
Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone Apply a rotational velocity to this wall?	0 0 copper 1 300 0 300 no 0 0 2 ? yes po

(((constant . 0) (profile )))

262

(0)

Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

pebble\_walls

Condition Value

Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	0
Temperature (k)	473
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	ves
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
7-Component of Wall Translation	0 0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
X component of Wall Translation (m/s)	Õ
7-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
Execute Radiación temperature (R)	(0)
	(-,
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

#### default-interior

Condition Value

default-interior:001

Condition Value

default-interior:024

Condition Value

default-interior:026

Condition Value

.

default-interior:027

Condition Value

default-interior:028

Condition Value

default-interior:029

Condition Value

Solver Controls

Equations

Equation	Solved
Flow	yes
ne Enorgy	yes
спетду	yes

Numerics

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

Time Step (s) 0.0099999998

264

Max. Iterations Per Time Step 200

Relaxation

```
VariableRelaxation FactorPressure0.60000002Density0.5Body Forces1Momentum0.40000001he1Energy1
```

Linear Solver

Variable	Solver Type	Termination Criterion	Residual Reduction Tolerance
Pressure	V-Cycle	0.1	
X-Momentum	Flexible	0.1	0.7
Y-Momentum	Flexible	0.1	0.7
Z-Momentum	Flexible	0.1	0.7
he	Flexible	0.1	0.7
Energy	Flexible	0.1	0.7

Pressure-Velocity Coupling

Parameter	Value
Туре	PISO
Skewness-Neighbour Coupling	yes
Skewness Correction	1
Neighbour Correction	1

Discretization Scheme

Variable	Scheme
Pressure	PRESTO!
Density	Second Order Upwind
Momentum	Second Order Upwind
he	Power Law
Energy	Second Order Upwind

Solution Limits

Quantity	1		Limit
Minimum	Absolute	Pressure	1
Maximum	Absolute	Pressure	5e+10
Minimum	Temperatu	ire	1
Maximum	Temperatu	ire	5000

Material Properties

-----

Material: glass (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2440
Cp (Specific Heat)	j/kg-k	constant	840
Thermal Conductivity	w/m-k	constant	0.93699998

# Material: copper (solid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat)	kg/m3 i/ka-k	constant constant	8978 381
Thermal Conductivity	w/m-k	constant	387.60001

Material: (nitrogen-new . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	j/kg-k	kinetic-theory	#f
Thermal Conductivity	w/m-k	kinetic-theory	#f
Viscosity	kg/m-s	kinetic-theory	#f .
Molecular Weight	kg/kgmol	constant	28.013399
L-J Characteristic Length	angstrom	constant	3.7980001
L-J Energy Parameter	k	constant	71.400002
Degrees of Freedom		constant	5
Speed of Sound	m/s	none	#f

Material: (helium . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat)	i/ka-k	kinetic-theory	 #f
Thermal Conductivity	w/m-k	kinetic-theory	# f
Viscosity Molecular Meight	kg/m-s	kinetic-theory	#f 4 0026002
L-J Characteristic Length	angstrom	constant	2.5510001
L-J Energy Parameter	k	constant	10.22
Degrees of Freedom	m / a	constant	3 # f
speed of sound	111/ S	none	# <u>1</u>

Material: helium (fluid)

	Property	Units	Method	
Value	(s)			
	Density	kg/m3	ideal-gas	#f
	Cp (Specific Heat)	j/kg-k	kinetic-theory	#f
	Thermal Conductivity	w/m-k	kinetic-theory	#f
	Viscosity	kg∕m-s	kinetic-theory	#f
	Molecular Weight	kg/kgmol	constant	
4.0026	5002			
	L-J Characteristic Length	angstrom	constant	
2.5510	0001			
	L-J Energy Parameter	k	constant	10.22
	Thermal Expansion Coefficient	1/k	constant	0

	Degrees of Freedom Speed of Sound	m/s	constant none	3 #f
Ma	terial: nitrogen-new (fluid)			
Value	Property (s)	Units	Method	
28.01 3.798 71.40 Ma	Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight 3399 L-J Characteristic Length 0001 L-J Energy Parameter 0002 Thermal Expansion Coefficient Degrees of Freedom Speed of Sound terial: mixture-template (mixtur	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	ideal-gas kinetic-theory kinetic-theory constant constant constant constant constant none	#f #f #f #f 0 5 f
Value	Property (s)	Units	Method	
((he #f #f #f #f #f #f #f	Mixture Species n2-new) () ()) Density Cp (Specific Heat) Thermal Conductivity Viscosity Mass Diffusivity Thermal Diffusion Coefficient	kg/m3 j/kg-k w/m-k kg/m-s m2/s kg/m-s 1/k	names ideal-gas mixing-law ideal-gas-mixing-la ideal-gas-mixing-la kinetic-theory kinetic-theory constant	аw аw О
#f	Speed of Sound	m/s	none	0

Material: nitrogen (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.138
Cp (Specific Heat)	j/kg-k	constant	1040.67
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.663e-05
Molecular Weight	kg/kgmol	constant	28.0134
L-J Characteristic Length	angstrom	constant	3.621

L-J Energy Parameter	k	constant	97.53
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: oxygen (fluid)

Property	Units	Method	Value(s)
Property Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k	constant constant constant constant constant constant constant constant constant	1.2999 919.31 0.0246 1.919e-05 31.9988 3.458 107.4 0
Speed of Sound	m/s	none	# 1

Material: water-vapor (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	0.5542 2014 0.0261 1.34e-05 18.01534 2.605 572.4 0 0 #f
-			

Material: air (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity	kg/m3 j/kg−k w/m−k	constant constant constant	1.225 1006.43 0.0242
Viscosity	kg/m-s	constant	1.7894e-05
Molecular Weight	kg/kgmol	constant	28.966
L-J Characteristic Length	angstrom	constant	3./11
Thermal Expansion Coefficient	r 1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: aluminum (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2719
Cp (Specific Heat)	j/kg-k	constant	871
Thermal Conductivity	w/m-k	constant	202.39999

# Stop Injection FLUENT Case

FLUENT Version: 3d, dp, pbns, spe, lam, unsteady (3d, double precision, pressure-based, species, laminar, unsteady) Release: 6.3.26 Title:				
Models 				
Model		Settings		
Space Time Viscous Heat Transfer Solidification and Meltin Radiation Species Transport Coupled Dispersed Phase Pollutants Pollutants Soot	ıđ	3D Unsteady, 1st-Order Implicit Laminar Enabled Disabled None Non-Reacting (2 species) Disabled Disabled Disabled Disabled		
Boundary Conditions				
Zones	id	type		
barrel cold_leg cold_valve cross-over_leg hot_top hot_valve pebbles injection_point outlet cold_exit cold_exit cold_enter hot_exit pebble_exit pebble_enter inlet barrel_walls new_cold_valve cold_walls cross_over_walls hot_top_walls pebble_walls	2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23	<pre>fluid fluid wall interior interior interior interior interior wall wall wall wall wall wall wall wal</pre>		

default-interior	25	interior
default-interior:0	01 1	interior
default-interior:0	24 24	interior
default-interior:0	26 26	interior
default-interior:0	27 27	interior
default-interior:0	28 28	interior
default-interior:0	29 29	interior

Boundary Conditions

```
barrel
```

Value

Condition

\_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 0 X-Component of Rotation-Axis Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 0 Z-Component of Cone Axis Vector X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 0 Direction-2 Inertial Resistance (1/m)

Direction-3 Inertial Resistance (1/m)	0
CO Coefficient for Power-Law	0
C1 Coefficient for Power-Law	0
Porosity	1
Solid Material Name	

\_\_\_\_\_

#### aluminum

cold leg

Condition

#### Value

\_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 Cl Coefficient for Power-Law 0

Porosity Solid Material Name

#### aluminum

### cold\_valve

Condition

Value

\_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values ()Motion Type 0 X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 0 Y-Origin of Rotation-Axis (m) Z-Origin of Rotation-Axis (m) 0 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector 0 Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 0 Direction-2 Inertial Resistance (1/m) Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 1 Porosity Solid Material Name

\_\_\_\_\_

aluminum

cross-over\_leg

Condition

Value

	-	
. Mat	cerial Name	
mixture-temp	plate	
Spe	ecify source terms?	no
Soi	irce Terms	()
Spe	ecify fixed values?	no
Loc	cal Coordinate System for Fixed Velocities	no
Fi>	ked Values	()
Mot	cion Type	0
X-7	/elocity Of Zone (m/s)	0
Y-1	/elocity Of Zone (m/s)	0
Z-V	/elocity Of Zone (m/s)	0
Rot	lation speed (rad/s)	0
X-0	)rigin of Rotation-Axis (m)	0
Y-0	)rigin of Rotation-Axis (m)	0
Z-0	)rigin of Rotation-Axis (m)	0
X-0	lomponent of Rotation-Axis	0
Y-0	Component of Rotation-Axis	0
Z-0	Component of Rotation-Axis	1
Dea	activated Thread	no
Poi	rous zone?	no
Cor	nical porous zone?	no
X-0	Component of Direction-1 Vector	1
Y-0	Component of Direction-1 Vector	0
Z-(	Component of Direction-1 Vector	0
X-0	Component of Direction-2 Vector	0
Y-0	Component of Direction-2 Vector	1
Z-0	Component of Direction-2 Vector	0
Х-С	Component of Cone Axis Vector	1
Y-(	Component of Cone Axis Vector	0
Z-0	Component of Cone Axis Vector	0
Х-(	Coordinate of Point on Cone Axis (m)	1
Y-0	Coordinate of Point on Cone Axis (m)	0
Z-0	Coordinate of Point on Cone Axis (m)	0
Hal	lf Angle of Cone Relative to its Axis (deg)	0
Rel	lative Velocity Resistance Formulation?	yes
Dii	rection-1 Viscous Resistance (1/m2)	0
Din	rection-2 Viscous Resistance (1/m2)	0
Dii	rection-3 Viscous Resistance (1/m2)	0
Cho	pose alternative formulation for inertial resistance?	no
Din	rection-1 Inertial Resistance (1/m)	0
Din	rection-2 Inertial Resistance (1/m)	0
Din	rection-3 Inertial Resistance (1/m)	0
CO	Coefficient for Power-Law	0
C1	Coefficient for Power-Law	0
Poi	rosity	1
Sol	lid Material Name	

aluminum

hot\_top

Condition

Value \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no () Fixed Values 0 Motion Type X-Velocity Of Zone (m/s) 0 Y-Velocity Of Zone (m/s) 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) 0 X-Origin of Rotation-Axis (m) 0 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 X-Component of Rotation-Axis 0 Y-Component of Rotation-Axis 1 Z-Component of Rotation-Axis Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 0 Y-Component of Direction-1 Vector Z-Component of Direction-1 Vector 0 0 X-Component of Direction-2 Vector 1 Y-Component of Direction-2 Vector Z-Component of Direction-2 Vector 0 X-Component of Cone Axis Vector 1 Y-Component of Cone Axis Vector 0 0 Z-Component of Cone Axis Vector X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 0 Z-Coordinate of Point on Cone Axis (m) Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? ves Direction-1 Viscous Resistance (1/m2) 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) 0 Choose alternative formulation for inertial resistance? no  $\cap$ Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) CO Coefficient for Power-Law 0 C1 Coefficient for Power-Law 0 Porositv 1 Solid Material Name

#### aluminum

hot valve

Condition

Value

\_\_\_\_\_ \_\_\_\_\_ Material Name mixture-template Specify source terms? no Source Terms () Specify fixed values? no Local Coordinate System for Fixed Velocities no Fixed Values () Motion Type 0 0 X-Velocity Of Zone (m/s) Y-Velocity Of Zone (m/s) 0 0 Z-Velocity Of Zone (m/s) 0 Rotation speed (rad/s) X-Origin of Rotation-Axis (m) 0 Y-Origin of Rotation-Axis (m) 0 Z-Origin of Rotation-Axis (m) 0 0 X-Component of Rotation-Axis Y-Component of Rotation-Axis 0 Z-Component of Rotation-Axis 1 Deactivated Thread no Porous zone? no Conical porous zone? no X-Component of Direction-1 Vector 1 Y-Component of Direction-1 Vector 0 0 Z-Component of Direction-1 Vector 0 X-Component of Direction-2 Vector Y-Component of Direction-2 Vector 1 Z-Component of Direction-2 Vector 0 1 X-Component of Cone Axis Vector 0 Y-Component of Cone Axis Vector Z-Component of Cone Axis Vector 0 X-Coordinate of Point on Cone Axis (m) 1 Y-Coordinate of Point on Cone Axis (m) 0 Z-Coordinate of Point on Cone Axis (m) 0 Half Angle of Cone Relative to its Axis (deg) 0 Relative Velocity Resistance Formulation? yes Direction-1 Viscous Resistance (1/m2) 0 0 Direction-2 Viscous Resistance (1/m2) 0 Direction-3 Viscous Resistance (1/m2) Choose alternative formulation for inertial resistance? no Direction-1 Inertial Resistance (1/m) 0 Direction-2 Inertial Resistance (1/m) 0 Direction-3 Inertial Resistance (1/m) 0 CO Coefficient for Power-Law 0 0 C1 Coefficient for Power-Law 1 Porosity Solid Material Name

# aluminum

#### pebbles

Condition

## Value


	Matorial Name	
mixturo-	tomplate	
IIIIXCUIE	Specify source terms?	no
	Source Terms	
((mass)	(x-momentum) (x-momentum) (z-momentum) (species-0) (energy	))
((11000))	Specify fixed values?	no
	Local Coordinate System for Fixed Velocities	no
	Fixed Values	((x-
velocity	(inactive . #f) (constant . 0) (profile )) (y-velocity	
(inactiv	re . #f) (constant . 0) (profile )) (z-velocity (inactive	. #f)
(constan	t. 0) (profile )) (species-0 (inactive . #f) (constant .	0)
(profile	)) (temperature (inactive . #f) (constant . 0) (profile	)))
	Motion Type	0
	X-Velocity Of Zone (m/s)	0
	Y-Velocity Of Zone (m/s)	0
	Z-Velocity Of Zone (m/s)	0
	Rotation speed (rad/s)	0
	X-Origin of Rotation-Axis (m)	0
	Y-Origin of Rotation-Axis (m)	0
	Z-Origin of Rotation-Axis (m)	0
	X-Component of Rotation-Axis	0
	Y-Component of Rotation-Axis	1
	2-Component of Rotation-Axis	no
	Deactivated Inread	Ves
	Conject porcus zono?	no
	V-Component of Direction-1 Vector	1
	X-Component of Direction-1 Vector	0
	Z-Component of Direction-1 Vector	0
	X-Component of Direction-2 Vector	0
	Y-Component of Direction-2 Vector	1
	Z-Component of Direction-2 Vector	0
	X-Component of Cone Axis Vector	1
	Y-Component of Cone Axis Vector	0
	Z-Component of Cone Axis Vector	0
	X-Coordinate of Point on Cone Axis (m)	1
	Y-Coordinate of Point on Cone Axis (m)	0
	Z-Coordinate of Point on Cone Axis (m)	0
	Half Angle of Cone Relative to its Axis (deg)	0
	Relative Velocity Resistance Formulation?	yes
	Direction-1 Viscous Resistance (1/m2)	
5860000		
	Direction-2 Viscous Resistance (1/m2)	
5860000	$\mathbf{D}' = (1/2)$	
500000	Direction-3 Viscous Resistance (1/m2)	
5860000	Choose alternative formulation for inertial resistance?	no
	Direction-1 Inertial Peristance (1/m)	2734
	Direction-2 Inertial Resistance (1/m)	2734
	Direction-3 Inertial Resistance (1/m)	2734
	CO Coefficient for Power-Law	0
	Cl Coefficient for Power-Law	õ
	Porosity	Ŭ

0.40000001

Solid Material Name

glass

injection point Condition Value \_\_\_\_\_ -----Wall Thickness (m) 0 Heat Generation Rate (w/m3) 0 Material Name copper Thermal BC Type 1 300 Temperature (k) Ω Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Ο Free Stream Temperature (k) 300 Enable shell conduction? no Wall Motion 0 0 Shear Boundary Condition Define wall motion relative to adjacent cell zone? yes Apply a rotational velocity to this wall? no Velocity Magnitude (m/s) 0 X-Component of Wall Translation 0 Y-Component of Wall Translation 0 Z-Component of Wall Translation -1 Define wall velocity components? no X-Component of Wall Translation (m/s) 0 0 Y-Component of Wall Translation (m/s) 0 Z-Component of Wall Translation (m/s) External Emissivity 1 External Radiation Temperature (k) 300 (0) (((constant . 1) (profile ))) 0 Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) 0 Y-Position of Rotation-Axis Origin (m) . 0 Z-Position of Rotation-Axis Origin (m) 0 1 X-Component of Rotation-Axis Direction 0 Y-Component of Rotation-Axis Direction 0 Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) 0 Y-component of shear stress (pascal) 0 Z-component of shear stress (pascal) 0 Surface tension gradient (n/m-k) 0 Specularity Coefficient 0 outlet Condition Value \_\_\_\_\_

cold\_exit

Condition Value

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cold_enter
```

```
Condition Value
```

hot\_exit

Condition Value

pebble\_exit

Condition Value

pebble\_enter

Condition Value

inlet

Condition Value

barrel\_walls

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	aluminum
Thermal BC Type	0
Temperature (k)	293
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
-	(0)

.

(((constant . 0) (profile ))) Rotation Speed (rad/s)

0

X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction X-component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 0 0 1 0 0 0 0 0
new_cold_valve	
Condition	Value
	0
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0 Gorror
Material Name	1 Copper
Thermal BC Type	300
$\begin{array}{c} \text{Henter (k)} \\ \text{Henter (k)} \end{array}$	0
Convective Heat Transfer Coefficient (w/m2-k)	Õ
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation Axis Direction	0
r-component of Rotation-Axis Direction	1
A-component of choor stross (pascal)	- 0
X-COMPONENT OF shear stress (pascal)	0
I-COMPONENT OF Shear Stress (pascal)	0
$\Delta$ -component of snear stress (pascal)	0
Surrace cension gradient (n/m=k)	Ŭ
pheometric, contractions	-

cold\_walls

	Condition	Value
	Wall Thickness (m)	0
	Heat Generation Rate (w/m3)	0
	Material Name	copper
	Thermal BC Type	0
	Tomporature (k)	283
	$H_{oot} = F_{hys} (w/m^2)$	0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Error Stroom Temporature (k)	300
	Free Stream Temperature (K)	n0
	Mable Sheri conduction:	0
	Wall Motion Observ Deursdemu Condition	0
	Snear Boundary Condition	V
	Define wall motion relative to adjacent cell zone?	yes
	Apply a rotational velocity to this wall?	10
	Velocity Magnitude (m/s)	0
	X-Component of Wall Translation	
	Y-Component of Wall Translation	0
	Z-Component of Wall Translation	0
	Define wall velocity components?	no
	X-Component of Wall Translation (m/s)	0
	Y-Component of Wall Translation (m/s)	0
	Z-Component of Wall Translation (m/s)	0
	External Emissivity	1
	External Radiation Temperature (k)	300
	•	(0)
CI	Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Origin (m) X-Component of Rotation-Axis Direction Y-Component of Rotation-Axis Direction X-component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Z-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient	0 0 0 0 0 1 0 0 0 0 0
	Condition	Value
		0
	Wall Thickness (m)	0
	Heat Generation Rate (W/m3)	U
	Material Name	copper
	Thermal BC Type	1
	Temperature (k)	300
	Heat Flux (w/m2)	0
		0
	Convective Heat Transfer Coefficient (w/m2-k)	0
	Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k)	0 300

280

•

Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Z-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity External Radiation Temperature (k)	0 . 0 yes no 0 1 1 0 0 0 no 0 0 0 0 1 300 (0)
<pre>(((constant . 0) (profile ))) Rotation Speed (rad/s) X-Position of Rotation-Axis Origin (m) Y-Position of Rotation-Axis Origin (m) Z-Position of Rotation-Axis Direction Y-Component of Rotation-Axis Direction Z-Component of Rotation-Axis Direction X-component of shear stress (pascal) Y-component of shear stress (pascal) Surface tension gradient (n/m-k) Specularity Coefficient</pre>	0 0 0 0 0 0 1 0 0 0 0 0
hot_top_walls Condition	Value
Wall Thickness (m) Heat Generation Rate (w/m3) Material Name Thermal BC Type Temperature (k) Heat Flux (w/m2) Convective Heat Transfer Coefficient (w/m2-k) Free Stream Temperature (k) Enable shell conduction? Wall Motion Shear Boundary Condition Define wall motion relative to adjacent cell zone? Apply a rotational velocity to this wall? Velocity Magnitude (m/s) X-Component of Wall Translation Y-Component of Wall Translation Define wall velocity components? X-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Y-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) Z-Component of Wall Translation (m/s) External Emissivity	0 0 copper 1 300 0 300 no 0 yes no 0 1 0 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 1 0 0 0 0 0 0 0 0 0 0 0 0 0
	28

External Radiation Temperature (k)	300 (0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
7-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0 .
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0

hot\_valve\_walls

Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	1
Temperature (k)	300
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components?	no
X-Component of Wall Translation (m/s)	0
Y-Component of Wall Translation (m/s)	0
Z-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((constant . 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0

Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k)	0
Specularity Coefficient	0
pebble_walls	
Condition	Value
Wall Thickness (m)	0
Heat Generation Rate (w/m3)	0
Material Name	copper
Thermal BC Type	0
Temperature (k)	473
Heat Flux (w/m2)	0
Convective Heat Transfer Coefficient (w/m2-k)	0
Free Stream Temperature (k)	300
Enable shell conduction?	no
Wall Motion	0
Shear Boundary Condition	0
Define wall motion relative to adjacent cell zone?	yes
Apply a rotational velocity to this wall?	no
Velocity Magnitude (m/s)	0
X-Component of Wall Translation	1
Y-Component of Wall Translation	0
Z-Component of Wall Translation	0
Define wall velocity components:	0
X-Component of Wall Translation (M/S)	0
T-Component of Wall Translation (m/s) T-Component of Wall Translation (m/s)	0
External Emissivity	1
External Radiation Temperature (k)	300
	(0)
(((accestant 0) (profile )))	
Rotation Speed (rad/s)	0
X-Position of Rotation-Axis Origin (m)	0
Y-Position of Rotation-Axis Origin (m)	0
Z-Position of Rotation-Axis Origin (m)	0
X-Component of Rotation-Axis Direction	0
Y-Component of Rotation-Axis Direction	0
Z-Component of Rotation-Axis Direction	1
X-component of shear stress (pascal)	0
Y-component of shear stress (pascal)	0
Z-component of shear stress (pascal)	0
Surface tension gradient (n/m-k) Specularity Coefficient	0
default-interior	
Condition Value	
default-interior:001	
Condition Value	

```
default-interior:024
```

Condition Value

default-interior:026

Condition Value

default-interior:027

Condition Value

default-interior:028

Condition Value

default-interior:029

Condition Value

Solver Controls

Equations

Equation	Solved
Flow	yes
he	yes
Energy	yes

#### Numerics

Numeric			Enabled
Absolute	Velocity	Formulation	yes

Unsteady Calculation Parameters

Time	Step (s)				0.12
Max.	Iterations	Per	Time	Step	200

#### Relaxation

Variable	Relaxation	Factor
Pressure	0.60000002	
Density	0.5	
Body Forces	1	

Momentum	0.4000001
he	1
Energy	1

Linear Solver

Variable	Solver	Termination	Residual Reduction
	Type	Criterion	Tolerance
Pressure X-Momentum Y-Momentum Z-Momentum he Energy	V-Cycle Flexible Flexible Flexible Flexible Flexible	0.1 0.1 0.1 0.1 0.1 0.1 0.1	0.7 0.7 0.7 0.7 0.7 0.7

Pressure-Velocity Coupling

Parameter	Value
Туре	PISO
Skewness-Neighbour Coupling	yes
Skewness Correction	1
Neighbour Correction	1

Discretization Scheme

Variable	Scheme
Pressure	PRESTO!
Density	Second Order Upwind
Momentum	Second Order Upwind
he	Power Law
Energy	Second Order Upwind

Solution Limits

Quantity			Limit
Minimum	Absolute	Pressure	1
Maximum	Absolute	Pressure	5e+10
Minimum	Temperatu	ire	1
Maximum	Temperatu	ıre	5000

Material Properties

Material: glass (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	2440
Cp (Specific Heat)	j/kg-k	constant	840
Thermal Conductivity	w/m-k	constant	0.93699998

Material: copper (solid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	8978
Cp (Specific Heat)	j/kg-k	constant	381
Thermal Conductivity	w/m-k	constant	387.60001

Material: (nitrogen-new . mixture-template) (fluid)

Property	Units	Method	Value(s)
Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Degrees of Freedom Speed of Sound	j/kg-k w/m-k kg/m-s kg/kgmol angstrom k m/s	kinetic-theory kinetic-theory kinetic-theory constant constant constant constant none	#f #f #f 28.013399 3.7980001 71.400002 5 #f

Material: (helium . mixture-template) (fluid)

	Property	Units	Method	Value(s)
	Cp (Specific Heat)	j/kg-k	kinetic-theory	 #f
	Thermal Conductivity	w/m-k	kinetic-theory	#f
	Viscosity	kg/m-s	kinetic-theory	#f
	Molecular Weight	kg/kgmol	constant	4.0026002
	L-J Characteristic Length	angstrom	constant	2.5510001
	L-J Energy Parameter	k	constant	10.22
	Degrees of Freedom		constant	3
	Speed of Sound	m/s	none	#f
Má	aterial: helium (fluid)			
		** * .		

Propercy	UNILS	Method	
Value(s)			
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight	kg/m3 j/kg-k w/m-k kg/m-s kg/kamol	ideal-gas kinetic-theory kinetic-theory kinetic-theory constant	#f #f #f #f
4.0026002	ng, ngmor	oonocane	
L-J Characteristic Length 2.5510001 L-J Energy Parameter Thermal Expansion Coefficient	angstrom k 1/k	constant constant constant	10.22 0
Degrees of Freedom Speed of Sound	m/s	constant none	3 #f
Material: nitrogen-new (fluid)			
Property Value(s)	Units	Method	

	Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol	ideal-gas kinetic-th kinetic-th kinetic-th constant	#f eory #f eory #f eory #f	
28.01	3399 L-J Characteristic Length	angstrom	constant		
5.190	L-J Energy Parameter	k	constant		
71.40	00002 Thermal Expansion Coefficient Degrees of Freedom	1/k	constant constant	0 5	
	Speed of Sound	m/s	none	#f	
Ma	aterial: mixture-template (mixtu:	re)			
Value	Property e(s)	Units	Method		
((he	Mixture Species		names		
	Density	kg/m3	ideal-gas		
# L	Cp (Specific Heat)	j/kg-k	mixing-law		
#f	Thermal Conductivity	w/m-k	ideal-gas-mi	xing-law	
#f	Viscosity	kg/m-s	ideal-gas-mi	xing-law	
#f	Mass Diffusivity	m2/s	kinetic-thec	orv	
#f	Thermal Diffusion Coofficient	ka/m-s	kinetic-thec	- vrv	
#f		. ()	Kincere ence	,	0
#f	Thermal Expansion Coefficient Speed of Sound	n/s	none		0
Ma	aterial: nitrogen (fluid)				
	Property	Units	Method	Value(s)	
	Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	1.138 1040.67 0.0242 1.663e-0 28.0134 3.621 97.53 0 0 #f	5
Ma	aterial: oxygen (fluid)				

Property	Units	Method	Value(s)

Density	kg/m3	constant	1.2999
Cp (Specific Heat)	j/kg-k	constant	919.31
Thermal Conductivity	w∕m-k	constant	0.0246
Viscosity	kg/m-s	constant	1.919e-05
Molecular Weight	kg/kgmol	constant	31.9988
L-J Characteristic Length	angstrom	constant	3.458
L-J Energy Parameter	k	constant	107.4
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: water-vapor (fluid)

Property	Units	Method	Value(s)
Density Cp (Specific Heat) Thermal Conductivity Viscosity Molecular Weight L-J Characteristic Length L-J Energy Parameter Thermal Expansion Coefficient Degrees of Freedom Speed of Sound	kg/m3 j/kg-k w/m-k kg/m-s kg/kgmol angstrom k 1/k m/s	constant constant constant constant constant constant constant constant none	0.5542 2014 0.0261 1.34e-05 18.01534 2.605 572.4 0 0 #f

Material: air (fluid)

Property	Units	Method	Value(s)
Density	kg/m3	constant	1.225
Cp (Specific Heat)	j/kg-k	constant	1006.43
Thermal Conductivity	w/m-k	constant	0.0242
Viscosity	kg/m-s	constant	1.7894e-05
Molecular Weight	kg/kgmol	constant	28.966
L-J Characteristic Length	angstrom	constant	3.711
L-J Energy Parameter	k	constant	78.6
Thermal Expansion Coefficient	1/k	constant	0
Degrees of Freedom		constant	0
Speed of Sound	m/s	none	#f

Material: aluminum (solid)

Property	Units	Method	Value(s)
	l		2710
Density	kg/m3	Constant	2719
Cp (Specific Heat)	j/kg-k	constant	871
Thermal Conductivity	w∕m-k	constant	202.39999

# A3. 1-D Diffusion Matlab Script
```
%% Determine analytical solution to diffusion equation for 62x
 experiment
 %% Determine onset time when buoyant force is greater than helium
 %% Parameters
 clear all
 close all
 % 62x apparatus dimensions
 H = 60.5; % total hot leg height [in.]
 h = 39; % pebble bed height [in.]
 poro = 0.4; % porosity
 % calculate diffusion path length
 Ld = (poro/(1-poro))*h+H; % [in.]
 Ld = Ld*0.0254; \% [m]
 H = H*0.0254; % convert height to [m]
 % cross over leg
 Lc = 0.2921; % cross over leg length [m]
 % temperatures
 Th = 200; % hot leg temp [degC]
 Th = Th + 273;  [K]
 Tc = 10; % cold leg temp [degC]
Tc = Tc + 273; % [K]
 % compute total concentration
g = 9.81; \ [m/s^2]
P = 101325; % operating pressure [Pa]
Rbar = 8.314; % gas constant [J/mol-K]
chot = P/Rbar/Th; % total concentration in hot leg [mol/m^3]
ccold = P/Rbar/Tc; % tot. concentration in cold leg [mol/m<sup>3</sup>]
%% Diffusion Coefficient
MHe = 4.0026; % [kg/kmol]
MAir = 28.9536; % [kg/kmol]
vHe = 2.88; % helium diffusion volume
vAir = 20.1; % air diffusion volume
% hot leg diffusion coefficient
Dhot = 1e-4*1e-
3*Th^1.75*sqrt((MHe+MAir)/(MHe*MAir))/(vHe^(1/3)+vAir^(1/3))^2;
% cold leg diffusion coefficient
Dcold = 1e-4*1e-
3*Tc^1.75*sqrt((MHe+MAir)/(MHe*MAir))/(vHe^(1/3)+vAir^(1/3))^2;
%% Driving Density Difference At Steady-State Natural Circulation
% at this point in time, all air circulating through apparatus
Rair = Rbar/(MAir/1000); % air gas constant [J/kg/K]
% hot leg density
rhoHA = P/Rair/Th; % [kg/m^3]
% cold leg density
rhoCA = P/Rair/Tc; % [kg/m^3]
% driving density difference
diffSS = rhoCA-rhoHA; % [kg/m^3]
%% Height Intervals
ih = 10; % intervals in hot leg
ic = 10; % intervals in cold leg
dh = Ld/ih;
dc = H/ic;
xH = 0:dh:Ld; % hot leg position points
xC = 0:dc:H; % cold leg position points
xH = xH';
xC = xC';
```

```
%% Cross over leg temps.
ico = 10; % intervals in cross overleg
dco = Lc/ico;
xCO = 0:dco:Lc;
Tco = Th + xCO.*(Tc-Th)/Lc;
%% Boundary Condition
% Use solution for 1-D diffusion up both hot and cold legs, with
% ambient air concentration at inlet
Tam = 293; % [K]
cOh = P/Rbar/Tam; % hot leg inlet condition [mol/m^3]
c0c = P/Rbar/Tam; % cold leg inlet condition [mol/m^3]
%% Solve Diffusion Eqn
% total concentrations in hot and cold legs
cHt = P/Rbar/Th; % hot leg [mol/m^3]
cCt = P/Rbar/Tc; % cold leg [mol/m^3]
MAir = MAir/1000; % [kg/mol]
MHe = MHe/1000; % [kg/mol]
% run time
run = 6; % hours
run = run*3600; % [s]
dt = 1; % time interval [s]
t = 0.0001:dt:run; % time vector
tmin = t./60; % time vector in minutes
% preset vectors
difLH = zeros(length(t),1);
difLC = zeros(length(t), length(xH));
cAH = zeros(length(t),length(xH));
XXAH = zeros(length(t),length(xH));
rhoHOT = zeros(length(t),length(xH));
cAC = zeros(length(t),length(xC));
XXAC = zeros(length(t),length(xC));
rhoCOLD = zeros(length(t),length(xC));
cAFH = zeros(length(t),length(xCO));
cAFC = zeros(length(t),length(xCO));
cACO = zeros(length(t),length(xCO));
cTCO = zeros(length(t),length(xCO));
XXCO = zeros(length(t),length(xCO));
rhoCO = zeros(length(t), length(xCO));
% Time Loop
for j = 1: length(t)
    difLH(j) = sqrt(4*Dhot*t(j)); % hot leg characteristic diffusion
   difLC(j) = sqrt(4*Dcold*t(j));% cold leg characteristic diffusion
    % hot leg loop
    for k = 1:length(xH)
        % air mole concentration at point k at time j
        cAH(j,k) = c0h.*erfc(xH(k)/difLH(j)); % [mol/m^3]
        if cAH(j,k)>cHt
           cAH(j,k)=cHt;
       end
        % mole fraction at point k at time j
       XXAH(j,k) = cAH(j,k)/cHt;
        % gas mixture density at at point k at time j
       rhoHOT(j,k) = P*(XXAH(j,k)*MAir+(1-XXAH(j,k))*MHe)/(Rbar*Th);
   end
```

290

```
% Average hot leg density
    %AVGHOT(j) = mean(rhoHOT(j,k));
    % cold leg loop
    for l = 1: length(xC)
        % air mole concentration at point 1 at time j
        cAC(j,1) = c0c.*erfc(xC(1)/difLC(j)); % [mol/m^3]
        if cAC(j,l)>cCt;
            cAC(j, 1) = cCt;
        end
        % mole fraction at point 1 at time j
        XXAC(j,1) = cAC(j,1)/cCt;
        % gas mixture density at point 1 at time j
        rhoCOLD(j,l) = P*(XXAC(j,l)*MAir+(1-XXAC(j,l))*MHe)/(Rbar*Tc);
    end
    % Average cold leg density
    %AVGCOLD(j) = mean(rhoCOLD(j,1));
    % DRIVING DENSITY DIFFERENCE
    %diffDR(j) = AVGCOLD(j)-AVGHOT(j);
    % cross-over leg loop
    for m = 1: length(xCO)
        % air mole concentration contribution from hot leg
        cAFH(j,m) = c0h.*erfc((xCO(m)+Ld)/difLH(j));
        % air mole concentration contribution from cold leg
        cAFC(j,m) = cOc.*erfc((Lc-xCO(m)+H)/difLC(j));
        % sum from hot and cold legs
        cACO(j,m) = cAFH(j,m) + cAFC(j,m);
        % total concentation at each point
        cTCO(j,m) = P/Rbar/Tco(m);
        % mole fraction at each point
        XXCO(j,m) = cACO(j,m)/cTCO(j,m);
        % density at each point
        rhoCO(j,m) = P*(XXCO(j,m)*MAir+(1-
XXCO(j,m))*MHe)/(Rbar*Tco(m));
    end
end
%% COMPUTE AVERAGE VALUES AT EACH TIME STEP
% Average hot leg density at each time step
AVGHOT = mean(rhoHOT,2);
% Average cold leg density at each time step
AVGCOLD = mean(rhoCOLD, 2);
% Driving density difference at each time step
diffDR = AVGCOLD-AVGHOT;
% Average cross-over leg density at each time step
AVGCROSS = mean(rhoCO,2);
% Average mole fraction in cross-over leg at each time step
AVGXX = mean(XXCO,2);
AVGHEX = 1-AVGXX; % average helium mole fraction
% Compare helium cushion to buoyancy force
HeCushion = diffDR - AVGCROSS.*(Lc/H);
% difference in hot leg and cross over leg density
hotCOdiff = AVGCROSS-AVGHOT;
% perhaps this is the cushion
HECUS2 = hotCOdiff - AVGCROSS.*(Lc/H);
%% PLOTS
%plot(tmin, HeCushion, tmin, HECUS2)
%figure
```

291

%plot(tmin,AVGHEX)
%figure
%plot(tmin,diffDR,tmin,AVGCROSS)
%plot(tmin,diffDR(:))
%figure
%plot(tmin,XXAH(:,2),tmin,XXAH(:,3),tmin,XXAH(:,4),tmin,XXAH(:,10),tmin
,XXAH(:,11))
%figure
%plot(tmin,AVGHOT,tmin,AVGCOLD)

## A4. Pebble Wall Temperature UDF

#include "udf.h"

DEFINE\_PROFILE(peb\_wall\_temp\_BC, thread, index)

```
{
    real x[ND_ND];
    real y;
    face_t f;

    begin_f_loop(f, thread)
        {
            F_CENTROID(x,f,thread);
            y = x[1];
            F_PROFILE(f, thread, index) = 689.31*(y*y*y)-1686.8*y*y+1291.8*y+169.1;
        }
    end_f_loop(f, thread)
}
```

## A5. MIR Matlab Script

```
%% Determine the Helium MIR
clear all
%% Make guesses for what molar concentrations are:
M_He = 4; % molar mass of He
M_Air = 29; % molar mass of air
R = 8.314; % gas constant for He [(m3*Pa)/(K*mol)]
P = 103000; % atmospheric pressure [Pa]
Th = 1600+273; % hot leg temperature [K]
Tc = 552; % cold leg temperature [K]
% molar concentration in hot leg (value from FLUENT)
c_h = P/(R*Th); % [mol/m^3]
% molar concentration in cold leg (value from FLUENT)
c_c = P/(R*Tc); % [mol/m^3]
```

```
%% He mole fraction boundary conditions taken from FLUENT results Xh_o = 0.46399277; %top Xh_L = 0.014123678; %bottom
```

```
Xc_o = 0.55848438;%0.75; %top
Xc_L = 0.081556395; %bottom
```

```
%% Estimate Mass Diffusivity
DvolHe = 2.88;
DvolAir = 20.1;
```

293

```
Dh = 1e-
7*Th^1.75*(((M_He+M_Air)/(M_He*M_Air))^(1/2))/((DvolHe^(1/3)+DvolAir^(1/3))^2
); % [m^2/s]
Dc = 1e-
7*Tc^1.75*(((M_He+M_Air)/(M_He*M_Air))^(1/2))/((DvolHe^(1/3)+DvolAir^(1/3))^2
);
%% Find the MIR of He
Lc = 19.33; % cold leg height [m]
Lh = 19.33; % hot leg height [m]
Ah = 0.5542; % hot leg flow area [m^2]
Ac = 0.7559; % cold leg flow area [m<sup>2</sup>]
Sstar = Ac/Ah;
 % molar flux of He in hot leg
Nh = c_h * Dh * (Xh o - Xh L) / Lh;
Iterate to solve for Nc
diff = 1;
counter = 0;
Nc1_g = 100 Nh; i initial guess for Nc
Nc1 = 10*Nh;
%Nstar_g = 1 + Nh/(Sstar*Ncl); % initial guess for Nstar
Nstar = 1 + Nh/(Sstar*Nc1);
U = [Nc1; Nstar];
Rmat = [1;1];
R1 = U(1) - c_c*Dc*log(abs((1-Nstar*Xc_L)/(1-Nstar*Xc_o)))/(Nstar*Lc);
R2 = U(2) - (1 + Nh/(Sstar*Nc1));
*Derivative matrix
d1dN = 1;
d1dNs = -(c c*Dc/Lc)* \dots
    (((log(abs((1-Nstar*Xc L)/(1-Nstar*Xc o))))*(-1/Nstar^2)) + ...
    ((1/Nstar)*(((1-Nstar*Xc o)*-Xc L) - ((1-Nstar*Xc L)*-Xc o))/((1-
Nstar*Xc L)*(1-Nstar*Xc o))));
d2dN = Nh/(Sstar*(Nc1^2));
d2dNs = 1;
dMatrix = [dldN dldNs; d2dN d2dNs];
Rmat = [R1; R2];
Delta = dMatrix\-Rmat;
U = U + (Delta);
Ncl=abs(U(1));
Nstar=abs(U(2));
counter = counter + 1;
end;
IJ
N He = U(1) + Nh;
Nh=Nh*A;
Nc=U(1) *A*Sstar;
N He molpers = Nh + Nc; %mol/s
N_He_kgpers = N_He_molpers*M_He/1000; %kg/s
```

```
294
```

N\_He\_molpers

N\_He\_kgpers