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The Effect of Heat Transfer on Friction Factors in Fanning's Equation.

by

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Head of Department ______________________

June 1, 1928.

Professor A. L. Merrill,
Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Mass.

Dear Sir-

We submit herewith a thesis entitled "The Effect of Heat Transfer on the Friction Factors in Fanning's Equation" in partial fulfillment of the requirements for the degree of Master of Science in Chemical Engineering Practice.

Respectfully submitted,

ACKNOWLEDGMENT

The authors wish to express their appreciation to Professor W. H. McAdams for his ever available suggestions and criticisms.

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The Effect of Heat Transfer on the Friction Factor in Fanning's Equation.

While it is a quite definitely established fact, that the Fanning equation[1] fits all cases of isothermal flow of fluids through pipes, some data in a thesis by White[2] seems to indicate that the actual pressure drop as measured during the heating of a fluid in an interchanger is considerably less than one would predict by the use of this equation. But as White was not primarily interested in the pressure drop, he did not attempt to correlate his observations or to explain this deviation. And his results cover too small a range to warrant using them as a basis of calculation. Many industries now make use of fluid to fluid heat exchangers and similar types of apparatus, so this thesis was undertaken with a view to providing a more reliable basis for the calculation of pressure drops in the design of such equipment.

The apparatus required for this investigation is quite similar to that required in the actual determination of heat transfer coeficients. So it was thought advisable to take sufficient data to make possible the calculation of bath friction factors and heat transfer coefficients. To make sure that the experimental method and apparatus gave results in accord with the established curve of friction factors, several runs were made both with water and with oil covering a range of the modulus $\left(\frac{DuS}{z}\right)$ from 0.02 to 5.0. Thus this range includes both viscous and turbulent motion and the critical range that lies between these two. Also as another check on the method used, the actual heat transfer coefficients have been figured and compared with the work of Morris and Whitman[3]. The greater part of the work, however, was the study of the effect of heating and cooling on the actual value of the friction factor for fluids flowing in horizontal pipes.

APPARATUS AND METHOD

The apparatus used for the determination of friction factors and heat transfer coefficients is shown diagrammatically in Figure 1, while the important dimensions are given in Figure 2. It consists of two main units, (C) the heater and, (E) the cooler. The tube through which the fluid under consideration flowed was alike in both units. It was a standard 3/8-inch I. P. S. copper tube with internal and external diameters of 0.494 and 0.675 inches respectively. To allow any eddy currents, caused by bends, contractions or enlargements in the pipe, to become negligible; the fluid passed through a straight section of the tube over one hundred diameters long before entering either the heating or cooling zone. This "calming" section was a continuation of the standard copper tube. A turbulence chamber $^{(D_1-_2)}$ was placed at the exit of both units to thoroughly mix the stream coming from the exchanger and thus insure that the temperature read would be a true average of the stream. These turbulence chambers consisted of two slotted copper discs placed a short distance apart with the slots in one disc at right angles to those

DESCRIPTION FIGURE I

A - Oil storage tank

B - Air separator

C - Heating unit

D - Turbulence chambers

E - Cooling unit

F - Auxiliary cooler

G - Steam separator

H - Steam Condensate trap

I - Cooling water storage tank

K - Gas-fired superheater

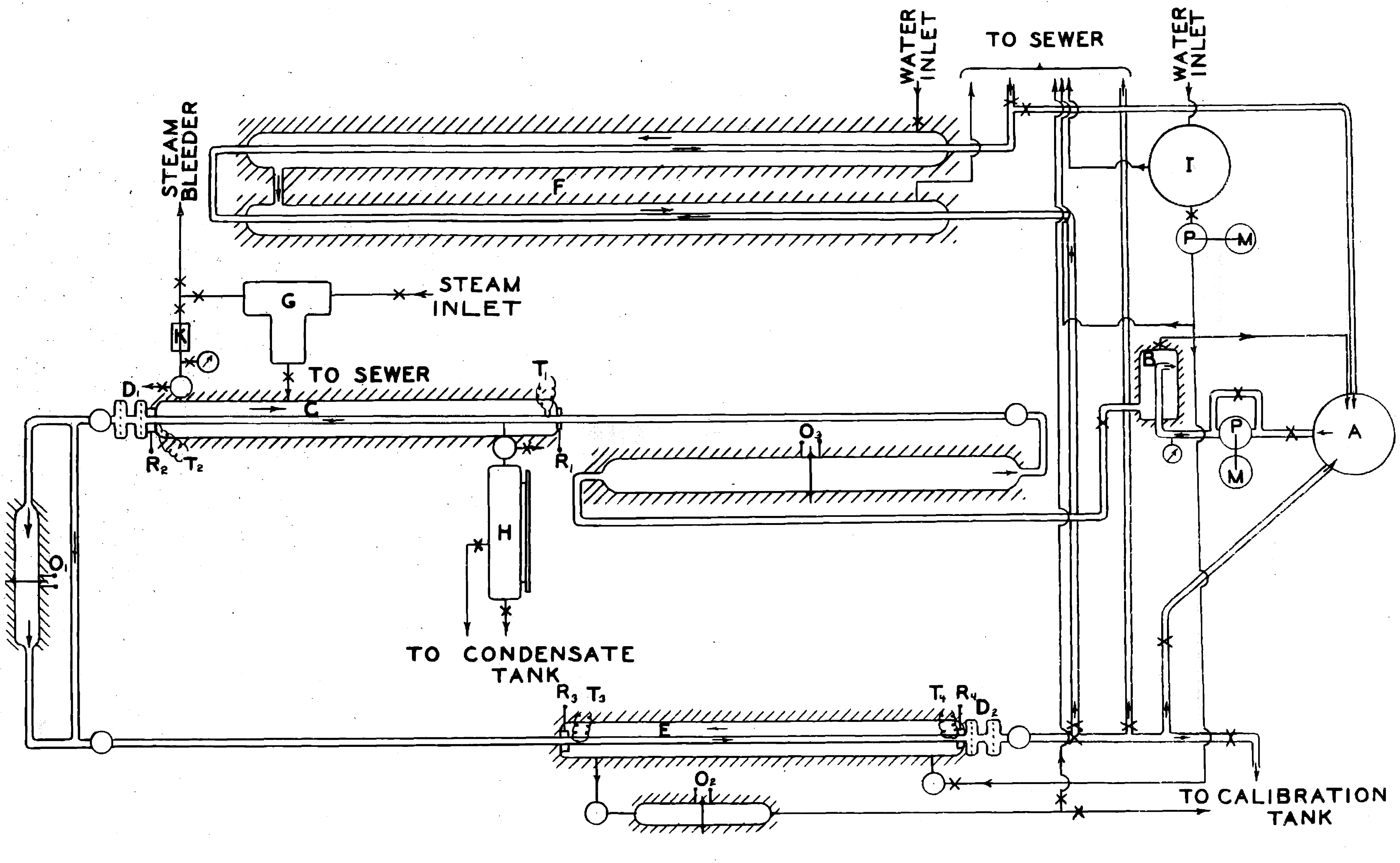
M - Motors

O - Orifice leads

P - Pumps

R - Piezometer rings

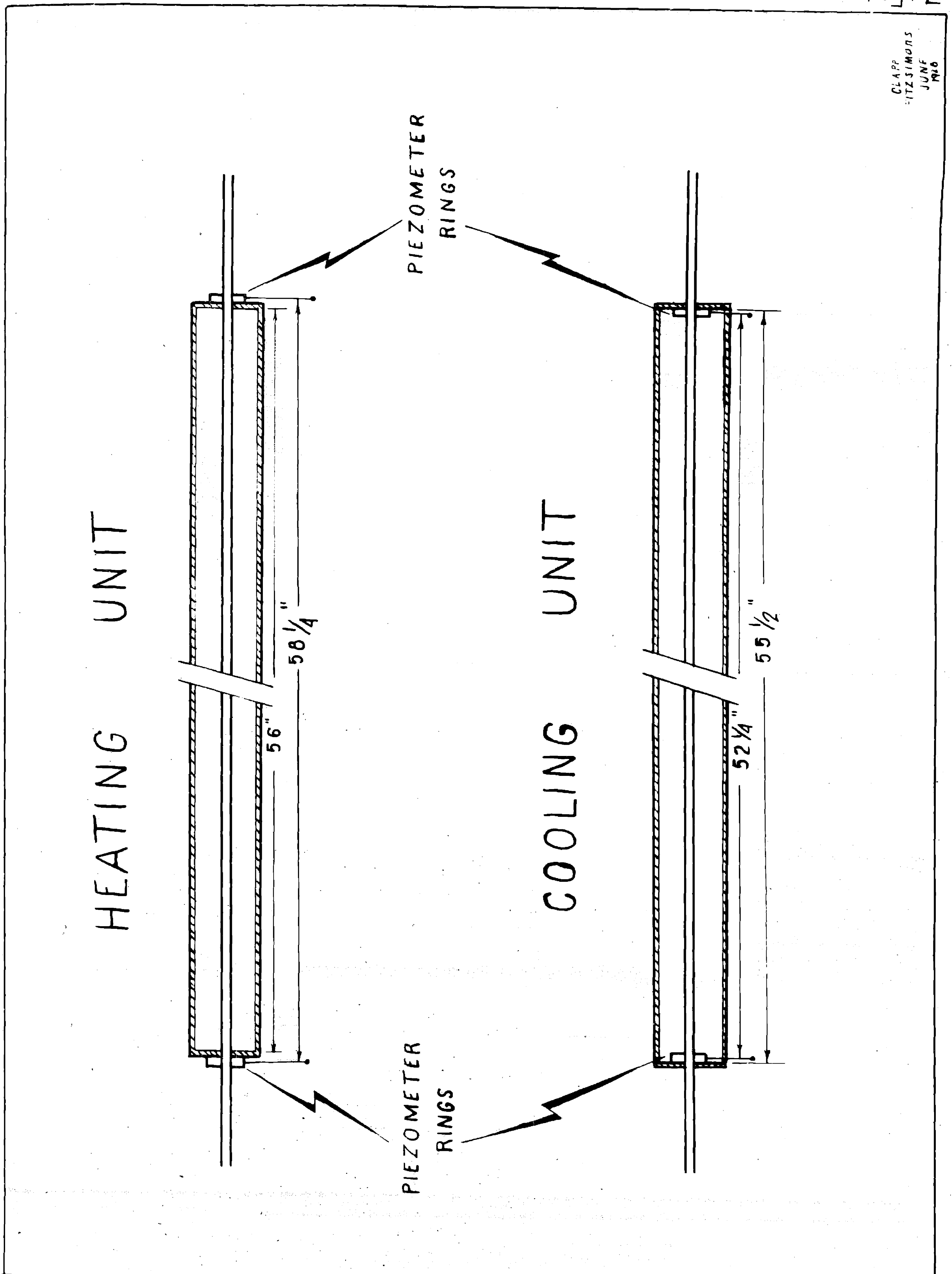
T - Thermocouples



CLAPP
FITZSIMONS
JUNE – 1928.

FIG. 1

Fig. 2



HEATING UNIT
COOLING UNIT
PIEZOMETER RINGS
PIEZOMETER RINGS
PIEZOMETER RINGS
PIEZOMETER RINGS
56"
58 1/4"
52 1/4"
55 1/2"
CLAPP
FITZSIMONS
JUNE

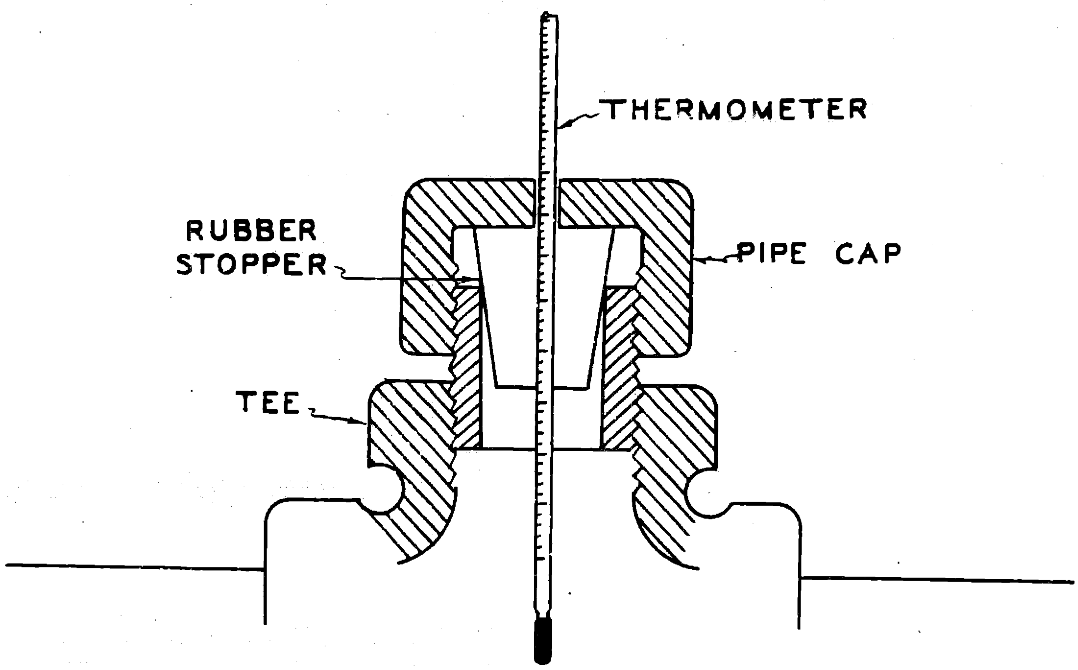
in the second. It was assumed that the changes in velocity and direction of the cooling water leaving the jacket would mix it sufficiently to give the same result. The exchangers and "calming" sections were all thoroughly lagged beyond all thermometer wells.

To allow room for the thermometer bulbs the 3/8-inch pipe was enlarged into a 1-inch tee to form the well. Each thermometer was fitted with a rubber stopper and held firmly in place by means of a pipe cap as shown in Figure 3A. All thermometers were compared with a set of German Standard thermometers P. T. R. 89859-60 (1922) and found to be sufficiently accurate for this investigation. Thermometers used in measuring the oil temperatures at the entrance and exit to both units had a scale of 0-100°C in 17.5 inches, graduated in tenths making possible a reading to within 0.02 degrees. Thermometers used for measuring steam temperatures had a scale of 100-150°C in 13.5 inches, graduated in tenths. Those used for measuring cooling water temperatures had a scale of 0-30°C in 9.5 inches, graduated in tenths, making possible a reading to within 0.02 degrees.

Measurements of the static pressure were made in all cases with a specially designed piezometer ring,

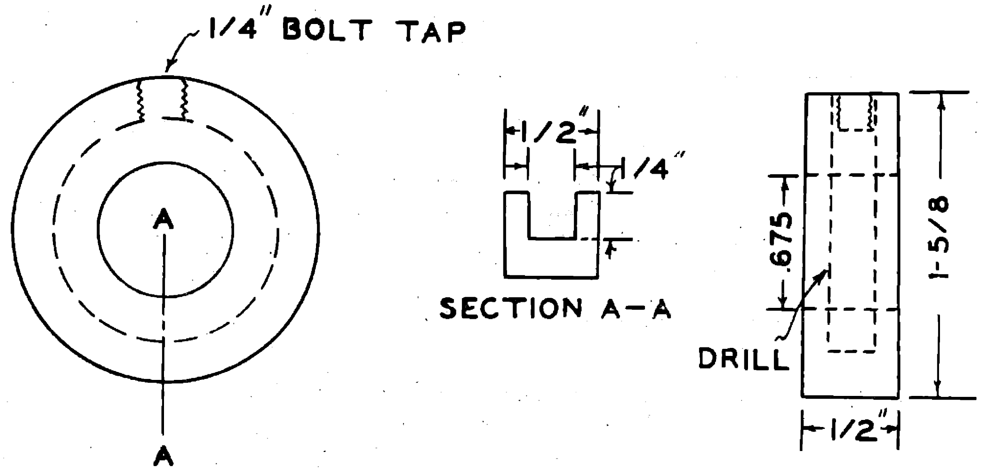
FIG. 3A

THERMOMETER WELL



PIEZOMETER RING

FIG. 3B



CLAPP
FITZSIMONS
JUNE — 1928.

Figure 3-B. In the heating unit, due to the high temperatures maintained in the jacket it was necessary to place the rings on the outside as close as possible to the entrance and exit of the jacket. In the cooler it was possible to place the rings on the inside. The length under consideration, therefore, varied slightly with the unit, that in the heater and cooler being 58.25 inches and 52.25 inches respectively. While the length exposed to the heating medium was 56 inches and that to the cooling medium was 55.5 inches.

The outside wall temperature of the pipe was measured at the entrance and exit of each unit by means of a No. 22 gauge copper-ideal thermocouple soldered into slots in the tube wall. A Leeds, Northrop student potentiometer was used, the scale of which was divided into tenths of a millivolt making possible a reading within five hundredths of one degree Centigrade. As a cold junction, ice in distilled water was used, and all thermocouples were calibrated in place.

As this is a continuous system, calibrated orifices were used in measuring the velocity of the fluid. For low velocities, (O_1) orifice No. 1 was used and for high velocities (O_3) orifice No. 3 was used. By means of a by-pass around No. 1 and screw clamps on the leads running from the orifice to the instrument board the same manometer was used on both orifices. Orifice No. 1 consisted of chambers of standard 2-inch iron pipe and a 0.023-inch galvanized iron plate with the hole made by a 0.25-inch reamer. The static pressure openings were located at 1.6 and 0.8 inches from the plate on the upstream and downstream sides respectively. Orifice No. 3 consisted of chambers of standard 3-inch iron pipe and a 0.023 -inch galvanized iron plate with the hole made by a 0.375-inch reamer. The static pressure openings were located at 2 6/16 and 1 3/16 inches from the plate on the upstream and downstream sides respectively. (O_2), Orifice No. 2, used for measuring the flow of the cooling water was identical with No. 1. All the static pressure outlets were of 1/4-inch O. D. heavy walled brass tube and were situated at the bottom of the chambers to prevent any air collecting in them. By a proper arrangement of manometers it was possible to read the pressure drop across either the heater or the cooler, directly in inches of the fluid flowing for low drops and in inches of mercury for the higher values.

To keep a constant velocity of the cooling water through the jacket it was found necessary to fill a large storage tank from the water main and then pump the water through the jacket with a Gould pump run by a constant speed motor. The amount of water through the jacket being regulated by means of a by-pass.

When making runs with water it was necessary to install an air separator (B) to remove as much air as possible from the water before running it through the heater. This was very effective with water but because of the greater viscosity of oil it was necessary to submerge the circulating pump in a bath of oil to prevent air getting into the system and then the oil being circulated was heated to and held at a high temperature until practically all of the dissolved air had escaped from the storage tank. The circulating pump was a Kinney rotary pump run by a constant speed motor. The amount of fluid through the apparatus was regulated by means of a by-pass.

For low temperature runs an auxiliary cooler (F) was used to keep the oil at a constant temperature but for the high temperature runs the fluid flowing was shunted directly to the storage tank after leaving the cooling unit without passing through the auxiliary cooler.

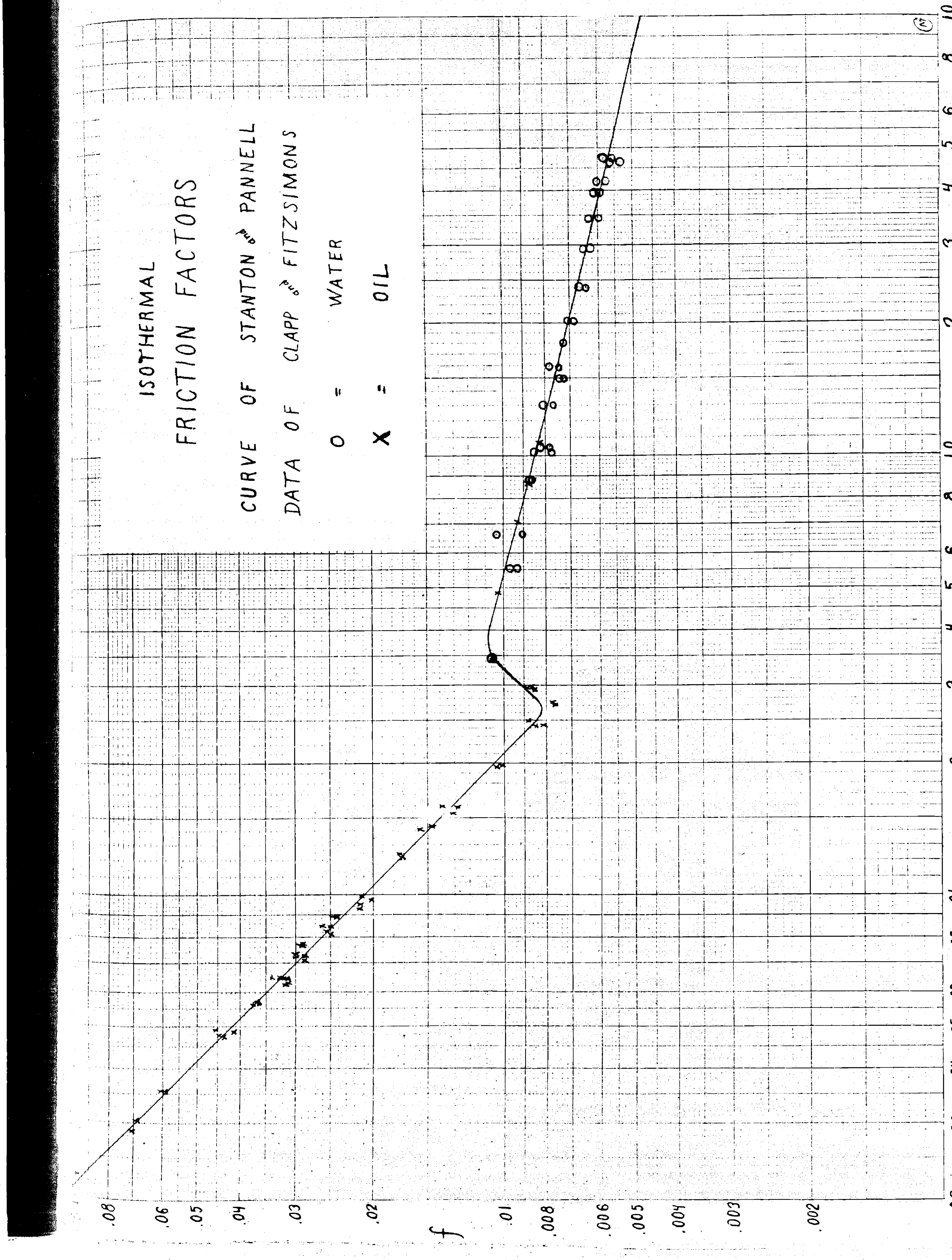
In order to be sure of a supply of dry saturated steam in the heating unit all steam lines were thoroughly lagged and enough steam was bled from the line to insure the operation of the steam separator. Also a small gas-fired super-heater was installed between the separator and the heating unit and operated so as to furnish dry saturated steam in the runs in which heat balances were desired. By means of an expansion valve the steam pressure could be varied from atmospheric to 50-lb. gauge. Heat balances were made, in all runs using water, as a check on the method and were found to be within a very few percent in all cases, v. Table I, showing the heat lost to the surroundings to be negligible. It was necessary to collect the condensate formed in the heating unit in cold water to prevent flashing. In the case of the runs made with oil, because of the poor coefficients less condensate was formed. While this tends to make the percentage lost slightly larger it may still be assumed negligible. And as the length of each run was quite short the amount of condensate formed could not be measured with any accuracy and no attempt was made to figure heat balances on these runs. Likewise, because of the large amount of cooling water used its rise in temperature was too small to justify the calculation of heat balances on this unit.

The standard tubes in both main units were cleaned each day while using water as a fluid. Also before each run it was necessary to remove any trace of air that collected in the manometer arms. When using water direct from the mains and discharging it without recirculation quite a bit of air collected in these arms, but when using oil with the circulating pump submerged this was eliminated.

DISCUSSION OF RESULTS

Very little information was available on this problem. The data taken by White[2] have been recalculated by Spurdle[4] and seem to indicate that the actual pressure drop is less than the value predicted by the Fanning equation, when the fluid is being heated. And there were no data available on the actual value of the pressure drop during cooling. Saph and Schoder have done a large amount of work in establishing a relation between the friction factor (f) and the modulus ($\frac{DuS}{z}$) for isothermal conditions. This work is summarized in a plot by Spurdle. Stanton and Pannell[6] have also done considerable work on isothermal conditions and their results agree with the curve established by Saph and Schoder. Therefore this curve may be considered a correct representation of the conditions existing during isothermal flow. In this investigation a number of isothermal runs were made with both oil and water and it was found that the friction factors calculated from these agreed very nicely with the established curve over its entire length. Figure 4. Thus showing that the experimental method and apparatus would produce results in accord with previous work. These runs were made before

Fig. 4



ISOTHERMAL
FRICTION FACTORS
CURVE OF STANTON and PANNELL
DATA OF CLAPP and FITZSIMONS
O = WATER
X = OIL
f
$\frac{Dus}{Z}$

the pump was immersed in a bath of the liquid under consideration, to eliminate the last traces of air from the system. Hence it is thought that results could be obtained after the pump was immersed that would agree even more closely with Stanton and Pannell's curve. Velocite "B" was the oil used in all oil runs.

The results obtained seem to show that the pressure drop is dependent to quite an extent on the viscosity of the film sliding along the pipe wall. That is, for the heating of fluids this film is much hotter than the main stream and therefore has a greater fluidity, causing the main stream to move through the pipes as a slug slipping over the less viscous film, with an actual pressure drop less than that predicted by the Fanning equation in which the viscosity of the main body of the fluid is used in determining the friction factor (f). While for the cooling of fluids the opposite takes place, the film being much colder than the main stream has a greater viscosity and retards the flow, causing a greater pressure drop than predicted.

Two methods of allowing for this film effect were proposed. First, since the average viscosity of the main body does not give correct results, by choosing some other viscosity such as the film viscosity, or perhaps some mean between the two it would still be possible to use the Fanning equation with the friction factors for isothermal flow. But this method presents one big disadvantage. In order to determine the temperature of the film, trial and error work is necessary to find the correct pipe temperature to use.

The second method, one which is more desirable in engineering practice because of its simplicity, is as follows. Since the viscosity is a function of the temperature and this film effect is dependent on the difference between the viscosity of the main body and that of the film, it is obvious that it should be possible to allow for the film effect by taking into consideration the temperature difference between the average temperature of the main body of the fluid being heated or cooled and the inside pipe wall temperature. As the velocity of a fluid is increased, however, the type of flow changes from viscous to turbulent. In the turbulent range, while there is still a thin film slipping along the pipe wall, it is very much thinner and hence the effect referred to above is evident to a less extent. As the turbulence is made more violent at still higher velocities it wears this film down extremely thin and the film effect becomes negligible.

Any attempt to express this varying effect of the temperature difference in mathematical form would give rise to quite complicated equations. Therefore, it was deemed advisable to allow for it by constructing a series of curves showing the friction factor which, when substituted in the Fanning equation will give the actual pressure drop for the various temperature differences. These curves are plotted from the data obtained in runs H_{1-66}, v. Table II. In the viscous range, they appear to be nearly parallel to the isothermal curve while in the turbulent range they approach it as predicted. Since the properties of the fluid are taken at the average temperature of the main body of the fluid, this set of curves present a simple solution to the problem, one quite easy to use in calculations for design work.

HEAT TRANSFER COEFFICIENTS

As the main object of this thesis was the investigation of the pressure drop, the conditions under which some runs were made did not make the data collected suitable for calculating heat transfer coefficients. Therefore, for heating, only such runs that had a rise in the temperature of the main body of the fluid of over 2.5°C, in flowing through the tube, were used. And for cooling only those having a fall in temperature of over 1°C were used.

The coefficients were calculated and plotted as suggested by Morris and Whitman, Figure 6. While all of the points for both the heating and cooling of oil in turbulent range seem to be a bit lower than their curve, they are on the whole in quite good agreement. For heating water, however, the points seem to be much lower than their suggested curve. As there was no apparent reason for this, there seemed to be a question as to where the curve should be drawn. Some data obtained by Baldwin and Sherwood[7] in 1924 on the heating of water were recalculated and plotted on the same coordinates. These points also fall some distance below the curve of Morris and Whitman and seem to be in good agreement with the results obtained in this investigation. Hence it is suggested that the slope of the curve be reduced in this range.

The data obtained on the cooling of water are all that are available at this time. They seem to indicate that the coefficients for cooling water are approximately the same as for heating it.

The calculations of these coefficients are given in Table V.

CONCLUSION

Friction factors for both heating and cooling of fluids in the viscous and turbulent ranges have been determined. The results seem to be correlated best by a series of curves above and below the established isothermal curve and symetrical with it.

Heat transfer coefficients for oil and water have been determined. The results on oil seem to agree with the curve of Morris and Whitman. In their article they propose one curve for heating and that values 75 per cent of these be used for cooling. The results obtained for water, however, are much lower. Results of Baldwin and Sherwood on water are also lower, indicating that the curve proposed by Morris and Whitman should have a flatter slope in this range.

Figure 5 shows (f) plotted against $\left(\frac{DuS}{z}\right)$ for isothermal, heating and cooling conditions.

Figure 6 shows $\left(\frac{hD}{k}\right)/\left(\frac{cz}{k}\right)^{0.37}$ plotted against $\left(\frac{DuS}{z}\right)$ for heating and cooling. The curve shown is Morris and Whitman's for heating, and cooling is 75 per cent of the heating value.

Figure 7 shows White's data plotted on the curves adopted in this investigation. All of his values seem to run low, but as this is also the case with his isothermal runs some of the deviation is obviously due to errors in his experimental method. Because of this it seems advisable to use the curves as drawn and any errors resulting from this will simply increase the factor of safety.

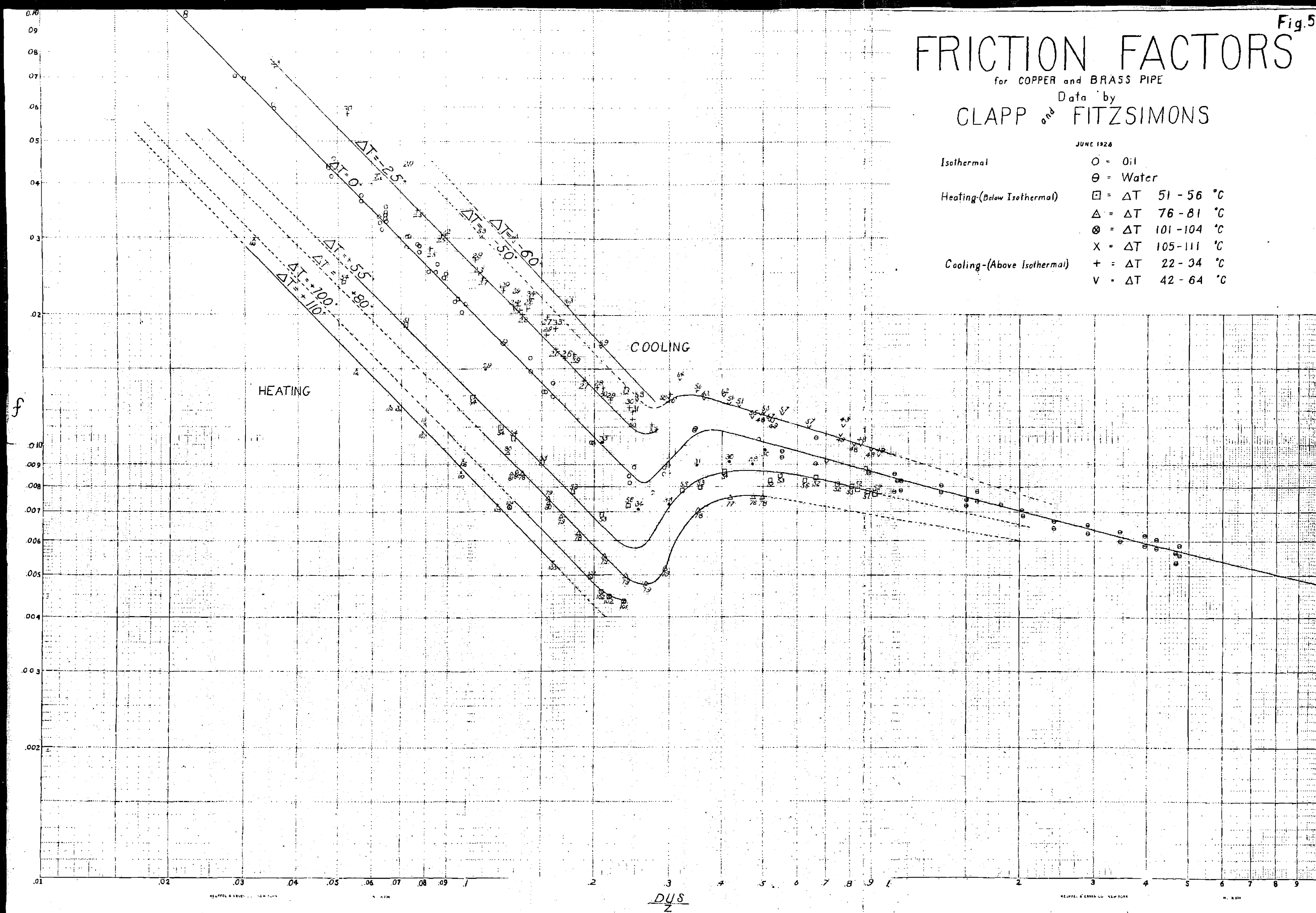
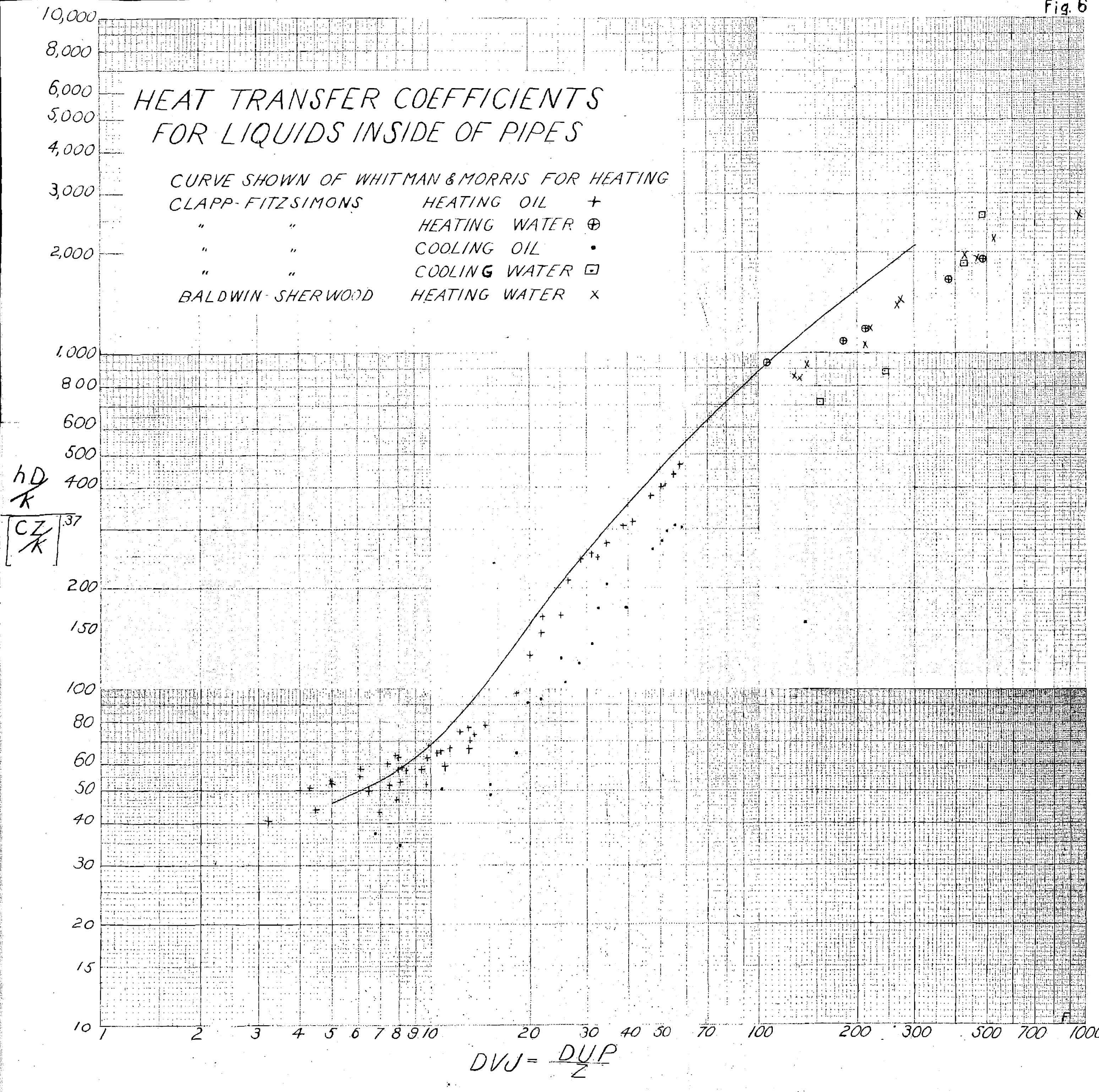


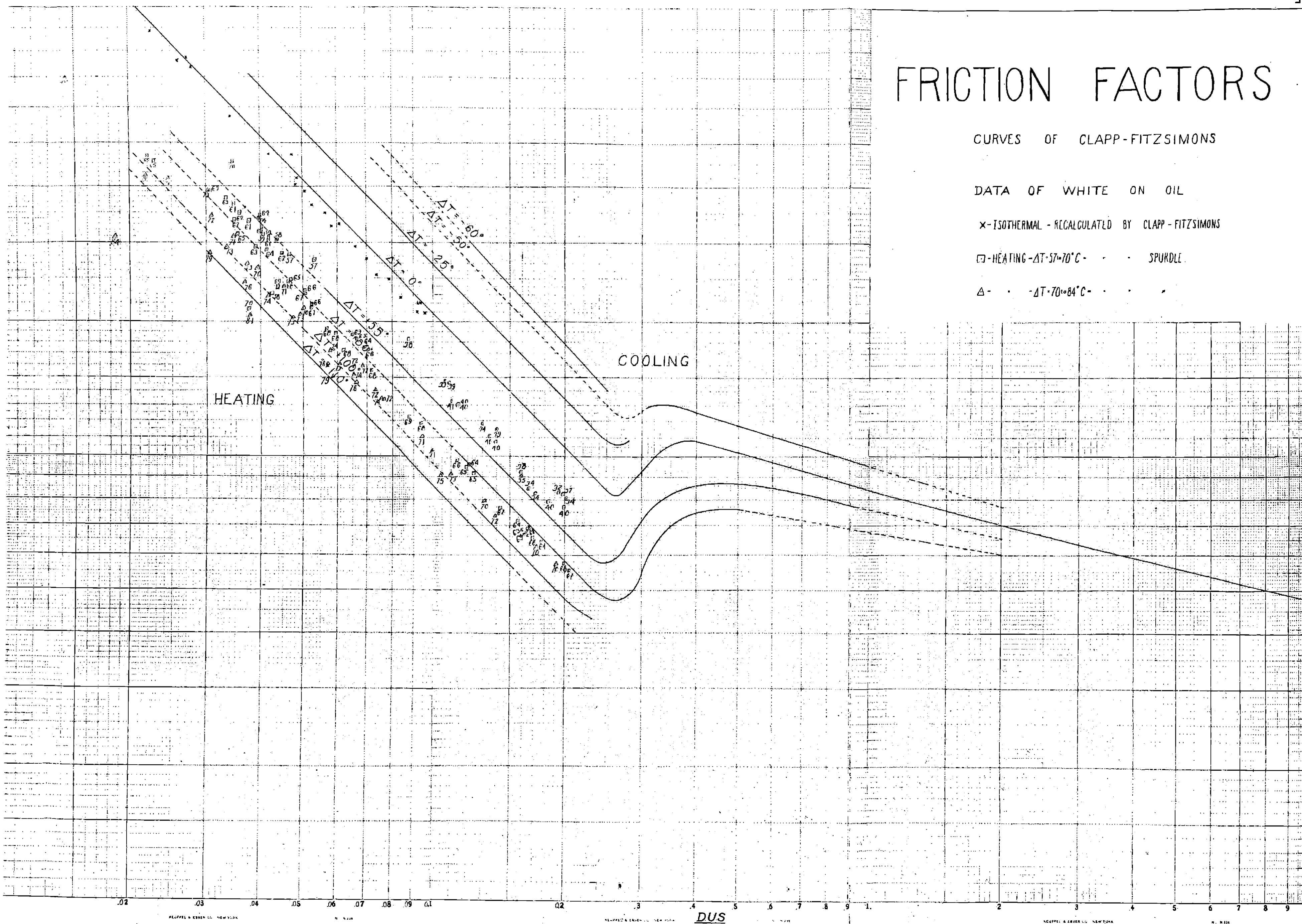
Fig. 5
FRICTION FACTORS
for COPPER and BRASS PIPE
Data by
CLAPP and FITZSIMONS
JUNE 1928
Isothermal
O = Oil
Θ = Water
Heating-(Below Isothermal)
⊡ = ΔT 51 - 56 °C
Δ = ΔT 76 - 81 °C
⊗ = ΔT 101 - 104 °C
X = ΔT 105 - 111 °C
Cooling-(Above Isothermal)
+ = ΔT 22 - 34 °C
V = ΔT 42 - 64 °C
COOLING
HEATING
ΔT = -25°
ΔT = 0°
ΔT = -50°
ΔT = -60°
ΔT = +55°
ΔT = +80°
ΔT = +100°
ΔT = +110°
f
DUS/Z

Fig. 6



HEAT TRANSFER COEFFICIENTS
FOR LIQUIDS INSIDE OF PIPES
CURVE SHOWN OF WHITMAN & MORRIS FOR HEATING
CLAPP-FITZSIMONS HEATING OIL +
" " HEATING WATER ⊕
" " COOLING OIL •
" " COOLING WATER ⊡
BALDWIN-SHERWOOD HEATING WATER ×
10,000
8,000
6,000
5,000
4,000
3,000
2,000
1,000
800
600
500
400
200
150
100
80
60
50
40
30
20
15
10
1
2
3
4
5
6
7
8
9
10
20
30
40
50
70
100
200
300
500
700
1000
$\frac{hD/k}{[CZ/k]^{.37}}$
$DVJ = \frac{DUP}{Z}$

Fig. 7


FRICTION FACTORS
CURVES OF CLAPP-FITZSIMONS
DATA OF WHITE ON OIL
x-ISOTHERMAL - RECALCULATED BY CLAPP-FITZSIMONS
□-HEATING -ΔT-57-70°C - - - SPURDLE
Δ- - -ΔT-70-84°C- - - -
ΔT = 60°
ΔT = 50°
ΔT = 25°
ΔT = 0°
ΔT = 55°
COOLING
HEATING
.02
.03
.04
.05
.06
.07
.08
.09
0.1
0.2
.3
.4
.5
.6
.7
.8
.9
1.
2
3
4
5
6
7
8
9
10
DUS/Z

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RECOMMENDATIONS

For future work on this problem it would be well to equip the storage tank, for the oil, with a steam coil to maintain constant temperature at the high levels.

The circulating pump should be kept immersed in the fluid under consideration.

It would be desirable to have more turbulent flow of the cooling water in the jacket. This could be obtained in two ways. First, by enlarging the orifice to permit a greater velocity. This would require a large amount of cooling water and make it practically impossible to obtain heat balances on this unit. Second, by reducing the cross sectional area of the annular space in the jacket. This would lead to difficulties in construction.

An attempt should be made to use a wider range of temperature differences in the cooling unit.

Also it is advised that a study be made of the effect of a high temperature difference in the turbulent range for bath units. To do this, it would be necessary to use an oil with a lower viscosity than the one studied here.

APPENDIX A

NOMENCLATURE

A_c = Area of cooling surface

A_H = Area of heating surface

c = Specific heat

D = Diameter of the pipe in inches

f = Friction factor in the Fanning's Equation

g = Gravitational constant = 32.2 ft/sec^2

h = Heat transfer coefficient for fluids expressed in B. t. u. per hour per sq. ft. per degree F temperature difference

ΔH = Liquid head in inches

J = Fluidity = $\frac{1}{Z}$

k = Thermal conductivity; for oil a constant = 0.078

L = Length of pipe in inches

Q/θ = C. h. u. or B. t. u. per hour

R_o = Reading of Orifice manometer in inches of mercury in contact with oil

S = Specific gravity

S_o = " " at orifice

S_T = " " at average temperature of fluid in pipe

T_o = Temperature of fluid at orifice °C

T_T = Average temperature of fluid in tube °C.

T_1 = Temperature of steam entering jacket

T_2 = " " " leaving "

T_3 = Temperature of cooling water entering jacket

T_4 = " " " " leaving "

t_1 = " " fluid entering heater

t_2 = " " " leaving "

t_3 = " " " entering cooler

t_4 = " " " leaving cooler

t' = Average temperature of fluid in tube °F

ΔT = The effective temperature difference through the fluid film

u = Velocity in feet per second

Z = Viscosity of fluid in centipoises relation to water

ρ =, density of fluid = 62.3S

CALIBRATIONS

The diameter of the standard tubes was measured by filling each tube with water, the ends being carefully sealed and weighing the amount of water. In both cases they were as specified 0.494 inches I. D.

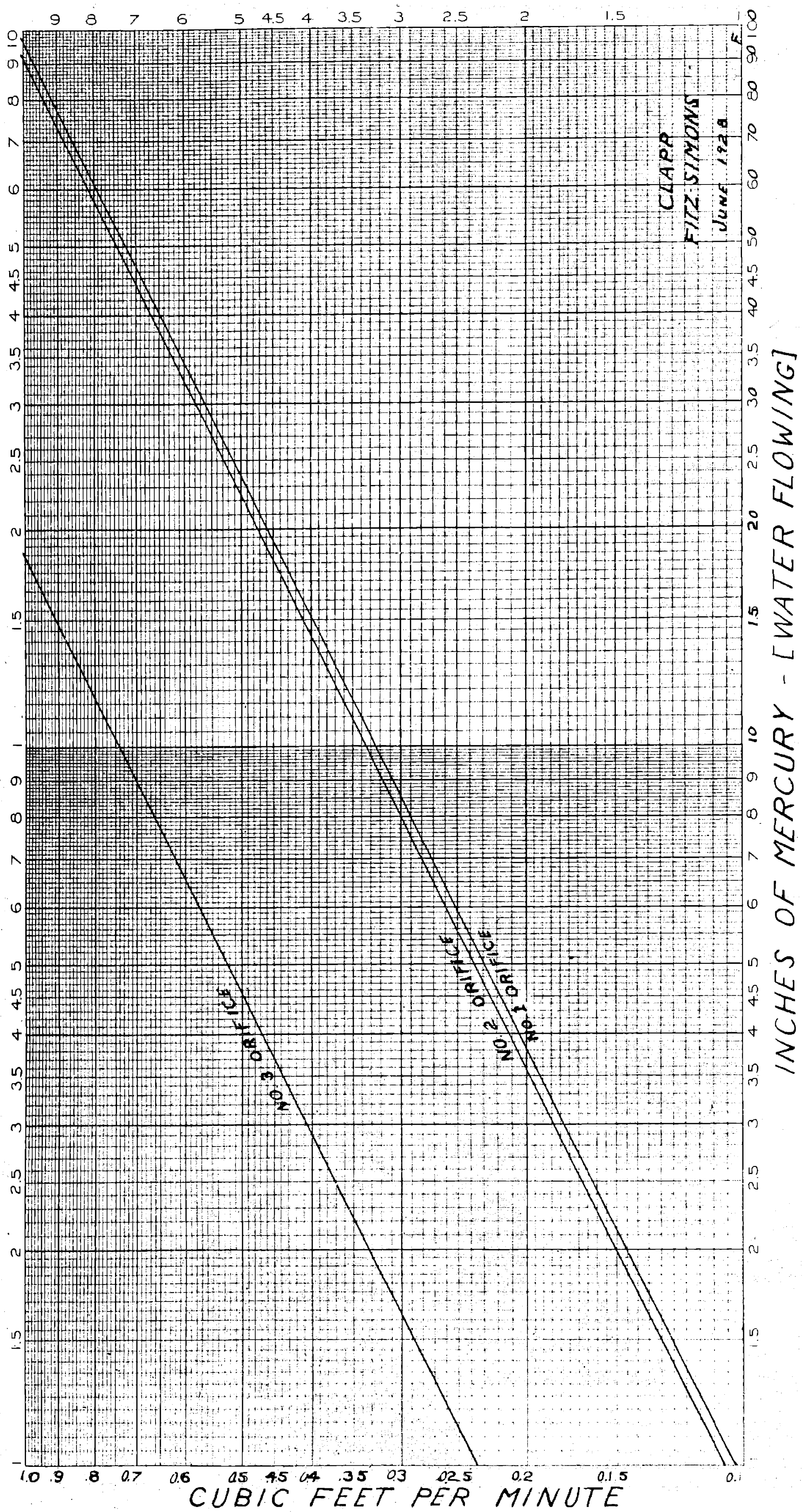
All orifices were calibrated by weighing the amount of water pumped through at a constant velocity in a given period of time. This was done at several different velocities for each orifice. When this data was plotted it was found to be within two per cent of the curve calculated from the theoretical equation for sharp-edged orifices. Figure 8, Table IV.

Thermocouples in the cooling unit were calibrated by running water at constant temperature through the system until equilibrium was reached in the unit. This was done at several different temperature levels. Thermocouples in the heating unit were calibrated by admitting steam, at different pressures, into the jacket and taking the reading of the pressure by a calibrated gauge after equilibrium was established between the pipe and jacket, Figure 9.

It was necessary to keep the pressure at the discharge end of the pump below 40 lb. gauge, as this was the maximum pressure the circulating system would withstand. All pressure gauges used were calibrated with an Ashton Tester in the Mechanical Engineering Department.

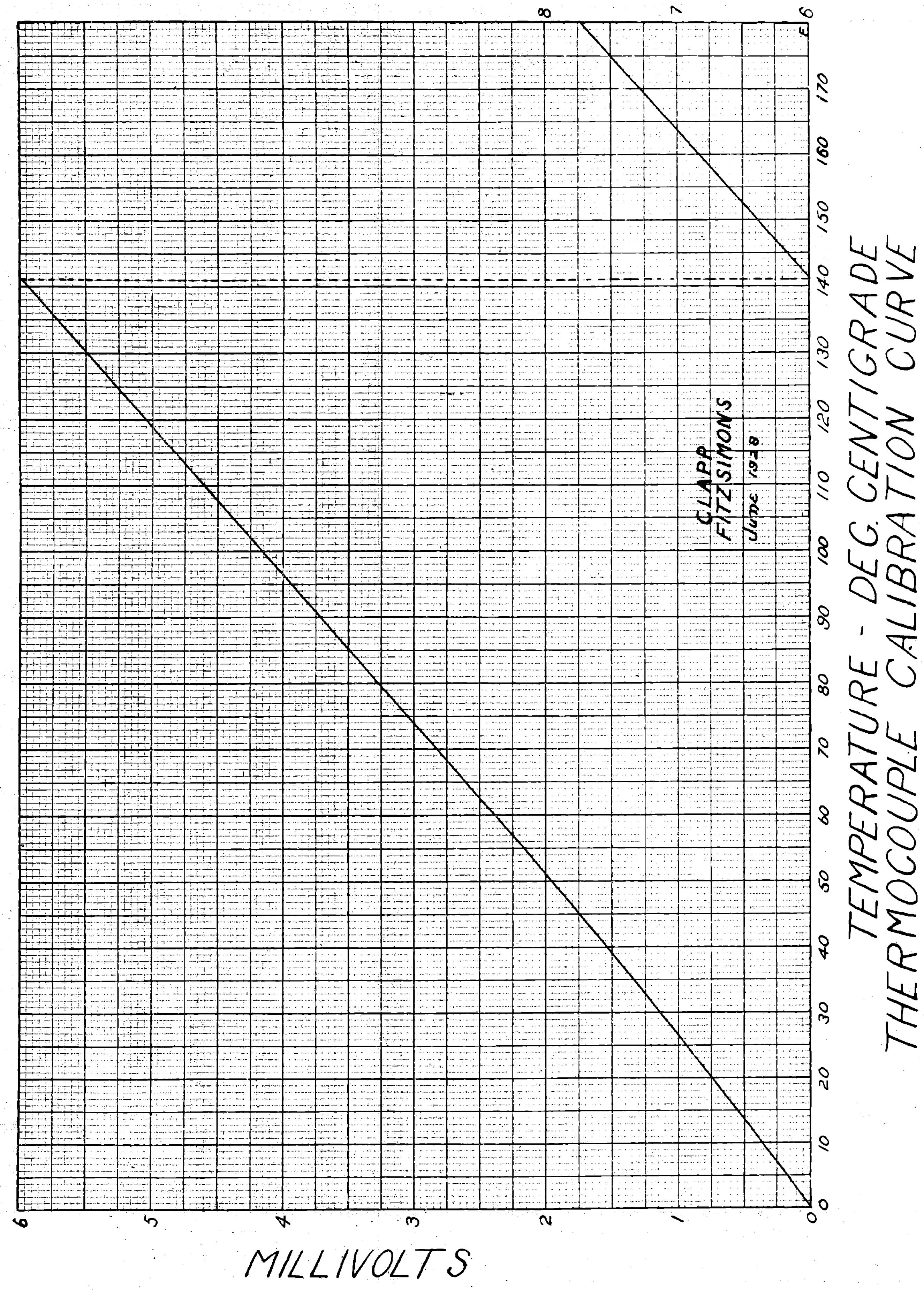
Due to a change in design it was necessary to replace the standard copper tube in the heater with a similar one. This was done between runs C_8 and D_1.

Fig. 8



ORIFICE CURVES

Fig. 9



TEMPERATURE - DEG. CENTIGRADE
THERMOCOUPLE CALIBRATION CURVE
MILLIVOLTS
CLAPP
FITZSIMONS
JUNE 1928
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
1
2
3
4
5
6
7
8
9

DESCRIPTION OF RUNS

Series A - Calibration of Orifice No. 1 and No. 3

" B - " " " No. 2

" C - Heating and Cooling of water

" D - Isothermal on Water

" E - " " Oil (Velocite "B")

" H - Heating and Cooling of Oil (Velocite "B")

The standard tubes under observation were thoroughly cleaned at regular intervals which using water, between runs C_4 and C_5; C_6 and C_7; D_{11} - D_{12}. Also they were cleaned again after all the water had been removed from the apparatus, before refilling it with Velocite "B".

COMPUTATIONS

It was assumed that the mercury in the manometers and the oil or water in contact with it was at an average temperature of 25° C., at which temperature the specific gravity of mercury is 13.53 and that of oil 0.89.

$$\text{Velocity in tube} = \frac{(\text{cu. ft. per sec. at orifice})}{(\text{cross section area of pipe})} \times \frac{(\text{S. g. at orifice})}{(\text{S. gr. at ave. temp. of fluid})}$$

$$u = \frac{\text{ft.}^3/\text{min.}}{(60)\dfrac{(\pi)\ (0.494)^2}{(4)\ (144)}} \times \frac{S_O}{S_T} = \frac{1}{0.0795} \times \text{ft.}^3/\text{min.} \times \frac{S_O}{S_T}$$

$$f_{(\text{for new heater})} = \frac{gD\,\Delta H}{24\ L\ u^2} = \frac{(32.2)(0.494)}{(24)(58.25)} \times \frac{\Delta H}{u^2} = 0.01137\ \frac{\Delta H}{u^2}$$

$$f_{(\text{for cooler})} = \frac{(32.2)(0.494)}{(24)(52.25)} \times \frac{\Delta H}{u^2} = 0.01267\ \frac{\Delta H}{u^2}$$

$$f_{(\text{for old heater})} = \frac{(32.2)(0.494)}{(24)(57.75)} \times \frac{\Delta H}{u^2} = 0.012\cancel{6}7\ \frac{\Delta H}{u^2}$$

$$A_H = \frac{(56)\ (\pi)}{144} \times 0.494 = 0.603 \text{ sq. ft.}$$

$$A_C = \frac{(55.5)(\pi)}{144} \times 0.494 = 0.598 \text{ sq. ft.}$$

To convert inches of mercury to inches of oil.

$$\text{Inches of Hg.} \times \frac{13.53 - 0.89}{S_T} = \text{inches of Hg.} \times \frac{12.64}{S_T}$$

To convert inches of cold oil in manometer to inches of oil at the average temperature of the fluid in the tube

$$\Delta H_{\text{(hot oil)}} = \Delta H_{\text{(cold oil)}} \frac{0.89}{S_T}$$

The orifice curves are plotted cubic feet per minute vs. inches of mercury in contact with water. To convert reading of mercury in contact with oil to inches of mercury in contact with water

$$R_o \times \frac{13.53-0.89}{S_T} \times \frac{1}{13.53-1} \times \frac{S_T}{S_o} = R_o \times \frac{1.008}{S_o}$$

$$c = \left(\frac{t'+670}{2030}\right) (2.1 + \text{sp.gr. at } 60^\circ \text{ F.})$$

$$c = \frac{0.593}{10^3} (t'+670)$$

FLUID PROPERTIES

SPECIFIC HEAT - Fig. 10

For oil the specific heat was calculated by means of the Whitman and Fortsch[8] equation.

SPECIFIC GRAVITY - Fig. 11

The specific gravity of the oil was determined by means of a specific gravity bottle.

THERMAL C ONDUCTIVITY - Fig. 12

The Morris and Whitman procedure was followed in determining the modulus of heat transfer coefficients and their value of (k) for oil was taken, $k = 0.078$. For water, however, the Jakob[9] equation was used.

VISCOSITY - Fig. 13.

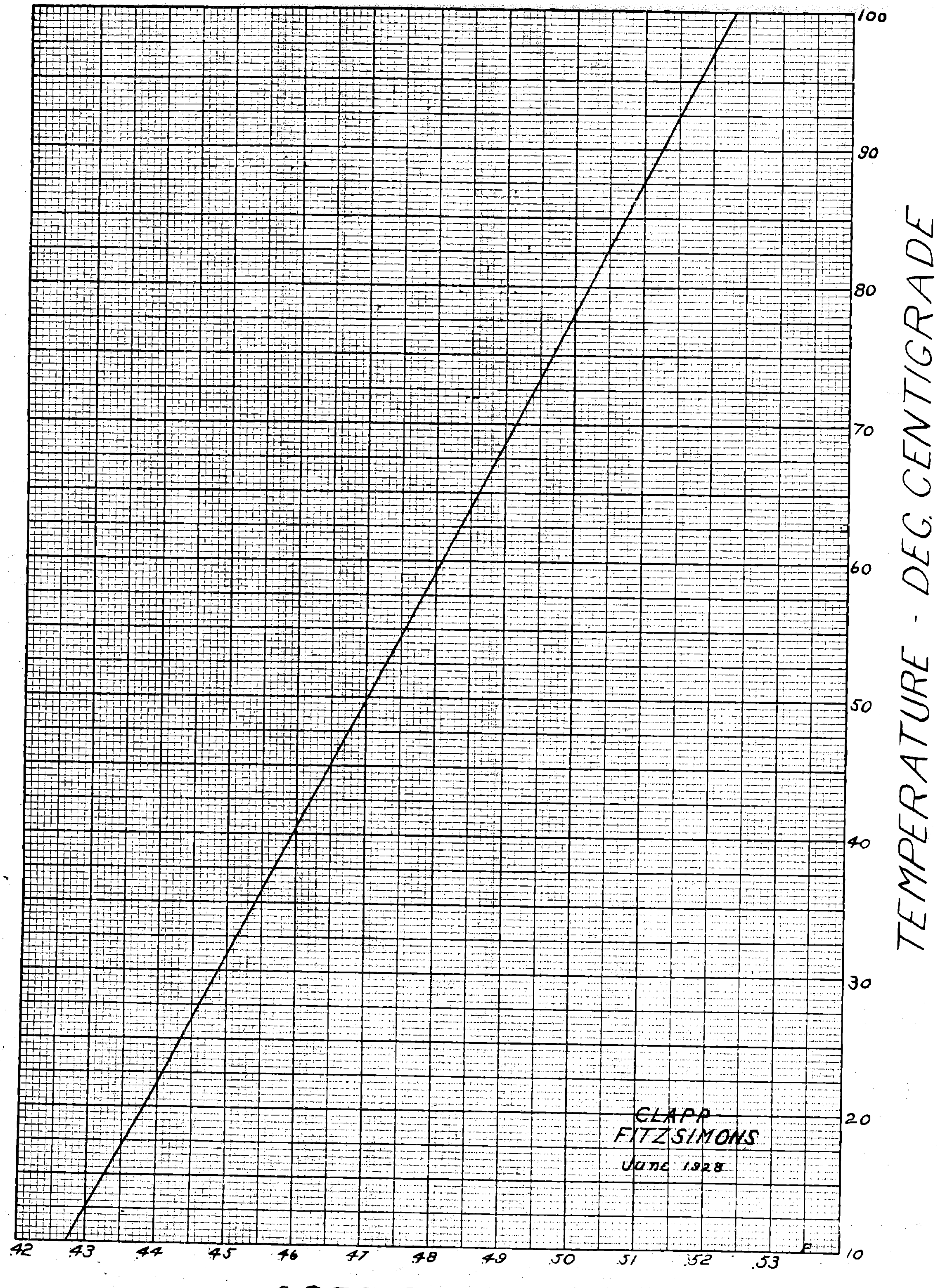
The viscosity of Velocite "B" was determined by means of a Saybolt viscosimeter over the entire range from 0-100°C. The thermometer used to determine these temperatures was that used to measure t_1.

EFFECTIVE TEMPERATURE DIFFERENCE

In the runs made with water where the change in temperature difference was relatively great a logarithmic mean value was used. The change in the temperature differences when oil was used was relatively small so that the arithmetic mean was used. Since a standard copper tube was used the inside pipe wall temperature may be assumed to be the same as the outside wall temperature. In the cooling jacket the arithmetic mean of the two end thermocouples was used when the ratio of the two was less than 2, while for other cases the logarithmic mean was used.

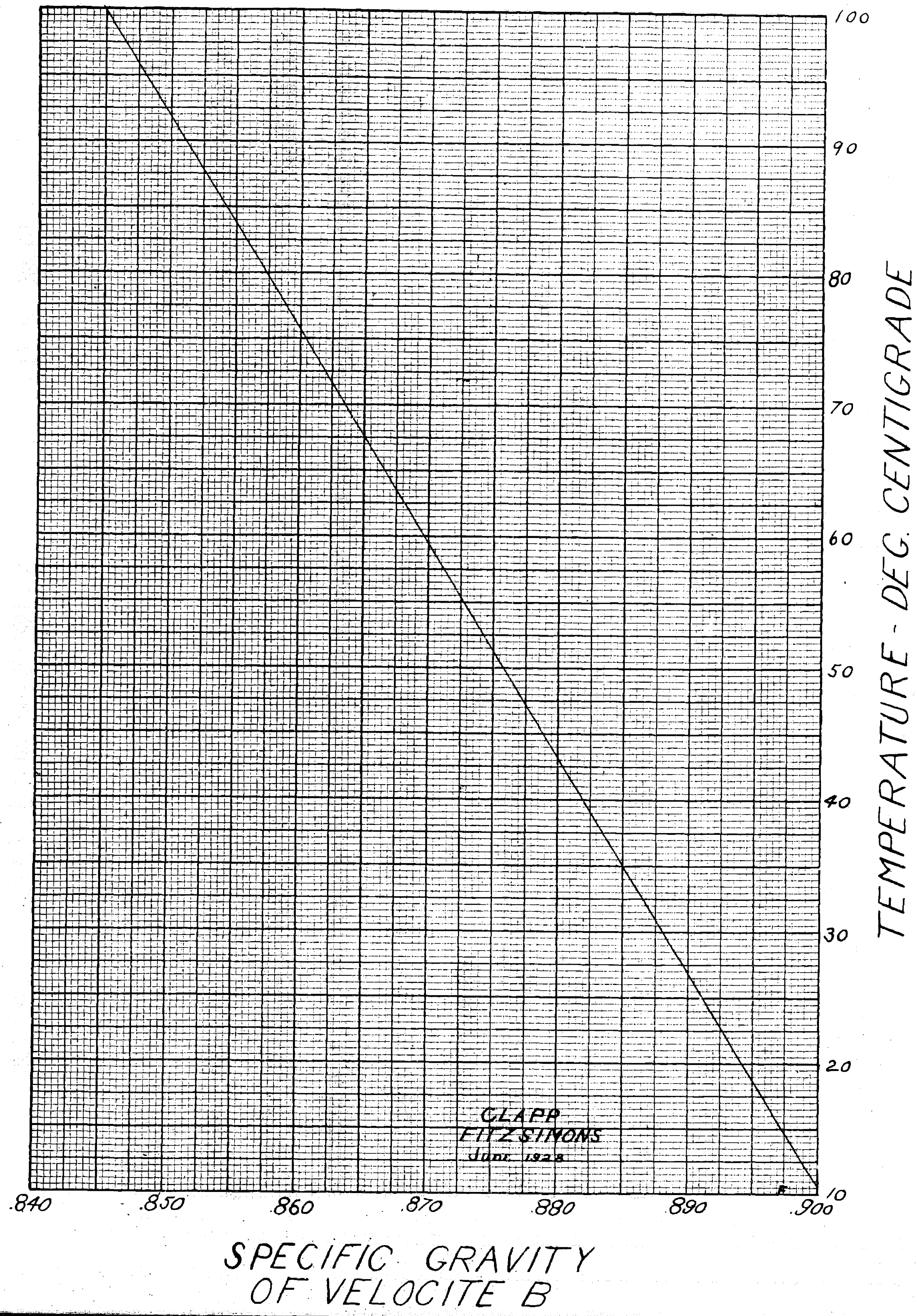
The specific gravity, viscosity and fluidity of water was taken from E. C. Bingham's[10] book on "Fluidity and Plasticity."

Fig. 10



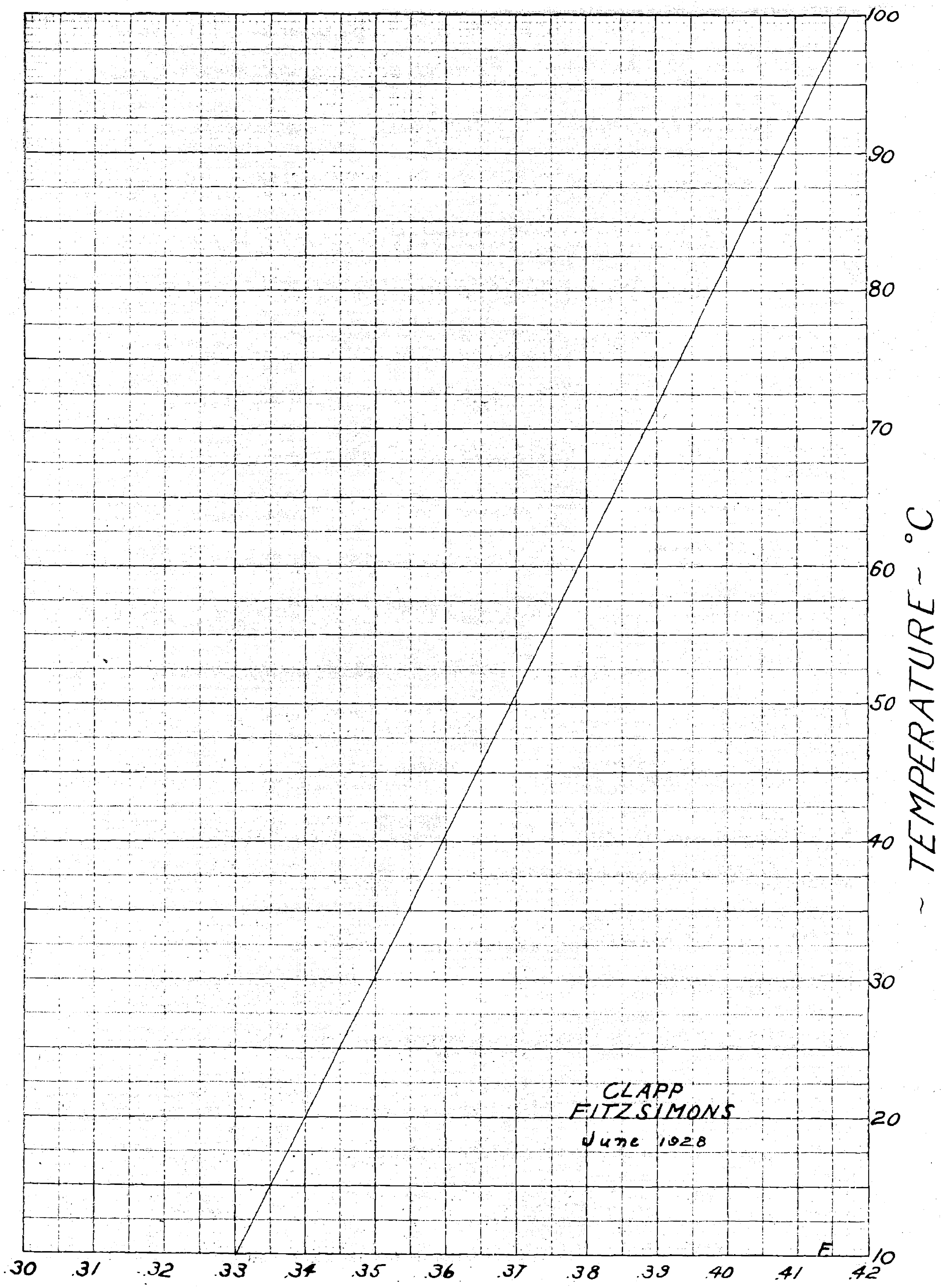
CALCULATED FROM WHITMAN-FORTSCH EQUATION [IND. ENG. CHEM. 18, 795]

Fig. 11



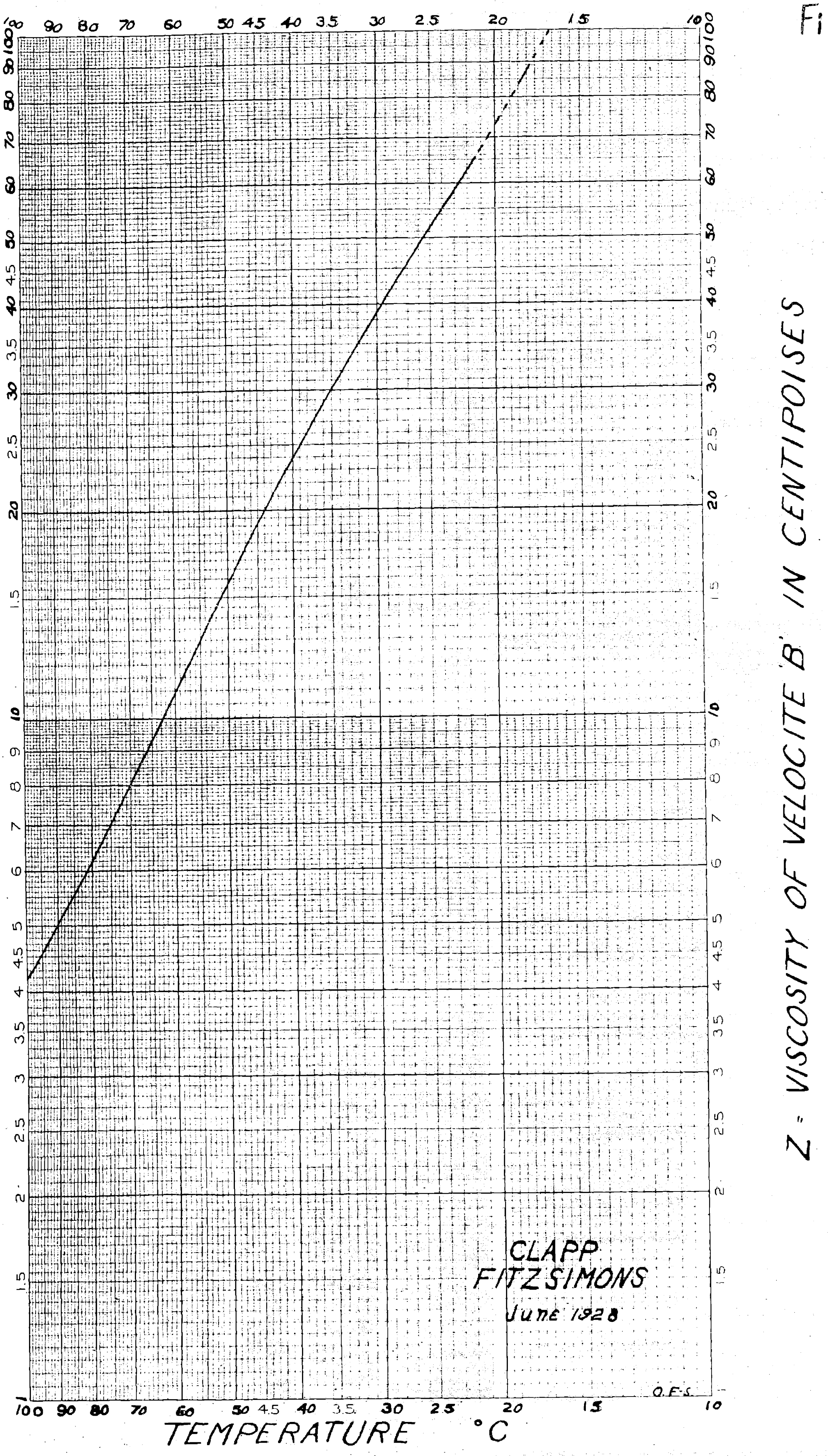
100
90
80
70
60
50
40
30
20
10
TEMPERATURE - DEG. CENTIGRADE
.840
.850
.860
.870
.880
.890
.900
SPECIFIC GRAVITY
OF VELOCITE B
CLAPP
FITZSIMONS
June 1928

Fig. 12



K FOR WATER, JAKOB, ANN. PHYSIK 63, 537 1920

Fig. 13


Z - VISCOSITY OF VELOCITE 'B' IN CENTIPOISES
TEMPERATURE °C
100 90 80 70 60 50 45 40 35 30 25 20 15 10
1 1.5 2 2.5 3 3.5 4 4.5 5 6 7 8 9 10 15 20 25 30 35 40 45 50 60 70 80 90 100
CLAPP
FITZSIMONS
June 1928
O.F.S.

APPENDIX B

Table I

HEAT BALANCES

Heater

Run No.	lb./min fluid	Temp. Rise °C	B. t. u. gained by fluid	lb. of steam	Latent Heat	B. t. u. lost by steam	B. t. u. unaccounted for	%
C2	13.0	52.35	26,150	16.0	955.3	15,300	-10,850	71.0
3	23.6	36.30	23,350	23.5	"	22,450	+ 900	4.0
4	26.2	23.00	13,070	13.94	"	13,310	+ 240	1.8
5	48.0	27.95	28,900	29.94	"	28,600	+ 300	1.05
6	30.6	25.14	22,180	24.45	"	23,400	- 1220	5.22
7	24.1	12.38	15,000	14.12	949.0	13,420	+ 1580	11.78

Cooler

Run No.	lb./min fluid	Temp. Fall °C	B. t. u. lost by fluid	lb./min cooling water	Temp. Rise °C	B. t. u. gained by cooling water	B. t. u. unaccounted for	%
2	13.0	5.2	2600	19.2	3.55	2620	+ 20	0.77
3	23.6	2.35	1512	16.4	3.48	1557	+ 35	2.97
4	26.2	4.8	2730	26.8	4.58	2660	- 70	2.56
5	38.0	0.9	931	13.3	3.05	875	- 56	6.02
6	30.6	3.4	3000	13.45	7.86	3050	+ 50	1.67
7	24.1	9.99	- - -	32.3	18.95	30,700	- - -	- - -

Table II

OIL DATA

RECORDED DATA

Run No	Description	Liquid – Deg. Cent. Heater Inlet	Heater Exit	Cooler Inlet	Cooler Exit	Pipe Wall – Millivolts Heater Inlet	Heater Exit	Cooler Inlet	Cooler Exit	Cooling Water Inlet	Cooling Water Exit	Steam Temp. Inlet	Steam Temp. Exit	Lb/in²	Friction Drop Heater Element In.		Friction Drop Cooler Element In.		Orifice Reading No.	Main Line Inches	Cooling Water
H *1	Heating & Cooling of Oil	27.2	42.7	42.3	38.05	6.40	6.40	0.75	0.48	13.05	13.4	148.2	148.2	53	OIL	10.5	OIL	20.1	1	0.33	5.82
*2	" " "	32.2	44.2	43.9	42.2	6.37	6.37	0.82	0.50	13.00	13.5	147.4	147.4	52	"	16.7	Hg	2.44	1	8.44	5.95
4	" " "	30.2	45.9	41.1	40.4	6.33	6.33	0.80	0.50	13.80	14.22	147.6	147.8	53	"	9.4	OIL	21.1	1	1.94	2.93
5	" " "	33.2	42.2	41.2	40.1	6.35	6.35	0.79	0.50	13.70	14.3	148.0	148.0	53	"	14.8	Hg	2.64	1	6.08	2.93
6	" " "	35.6	42.63	42.43	41.3	6.40	6.40	0.73	0.50	13.70	14.3	148.1	148.1	53.5	"	16.7	"	3.01	1	8.51	3.64
7	" " "	37.2	43.8	43.6	42.4	6.38	6.38	0.78	0.50	13.70	14.3	147.7	147.1	53	"	16.8	"	3.02	1	9.75	3.60
8	" " "	38.9	44.75	44.55	43.7	6.40	6.40	0.75	0.50	13.68	14.22	147.6	147.6	52.5	Hg	1.42	"	3.35	1	13.59	4.48
9	" " "	41.3	46.5	46.3	45.5	6.38	6.38	0.78	0.52	13.79	14.45	147.9	147.8	52.5	"	1.52	"	3.71	1	18.46	4.23
10	" " "	33.5	39.5	39.6	38.5	6.37	6.37	0.70	0.50	13.7	14.2	147.4	147.5	53	"	1.81	"	4.42	3	2.65	4.42
11	" " "	35.5	40.8	40.75	39.9	6.37	6.37	0.73	0.50	13.68	14.2	147.8	147.9	52.5	"	1.79	"	4.62	3	3.97	4.37
12	" " "	37.1	42.0	42.0	41.2	6.35	6.35	0.79	0.50	13.68	14.25	147.9	148.0	52.5	"	1.95	"	5.06	3	4.44	3.00
13	" " "	41.1	45.5	45.3	44.7	6.39	6.39	0.83	0.53	13.70	14.40	147.8	148.1	53	"	1.95	"	5.02	3	5.77	4.04
14	" " "	43.0	47.0	46.8	46.2	6.41	6.41	0.81	0.51	13.70	14.50	148.1	148.1	53.5	"	2.24	"	5.55	3	7.45	4.09
15	" " "	44.0	47.9	47.7	47.1	6.41	6.41	0.80	0.50	13.70	14.50	148.2	148.0	53.5	"	2.25	"	5.62	3	8.07	4.29
16	" " "	44.6	48.2	48.1	47.6	6.38	6.38	0.82	0.52	13.70	14.45	148.0	148.3	53.5	"	2.39	"	5.70	3	8.60	4.25
17	" " "	45.5	49.1	48.9	48.3	6.40	6.40	0.85	0.52	13.70	14.50	148.3	148.2	53.5	"	2.49	"	5.82	3	9.32	4.26
18	" " "	51.7	54.9	54.9	53.9	5.63	5.63	1.10	0.58	13.65	15.30	132.5	132.4	30.0	"	2.90	"	6.60	3	9.30	4.35
19	" " "	51.0	53.6	53.5	52.8	5.60	5.60	1.01	0.53	13.60	14.90	131.3	131.3	29.0	"	2.33	"	4.94	3	8.15	4.32
20	" " "	50.2	52.9	52.8	52.2	5.59	5.59	1.00	0.54	13.60	14.50	130.9	130.6	28.5	"	2.12	"	4.51	3	7.02	4.33
21	" " "	50.8	53.95	53.75	52.9	5.60	5.60	0.98	0.53	13.60	14.40	131.3	131.3	29.0	"	1.72	"	3.81	3	5.10	4.31
22	" " "	50.3	53.75	53.55	52.8	5.58	5.58	0.95	0.52	13.60	14.35	130.6	130.7	28.0	"	1.90	"	2.88	3	2.83	4.35
23	" " "	49.9	53.85	53.60	52.7	5.51	5.51	0.92	0.54	13.60	14.30	128.7	129.6	27.0	"	1.19	"	2.55	3	2.12	4.41
24	" " "	88.4	94.65	94.55	90.9	6.31	6.31	1.92	0.85	14.00	19.7	147.0	147.0	52.0	"	2.48	"	2.95	3	4.96	2.75
25	" " "	91.85	98.10	97.9	94.1	6.31	6.31	2.70	1.00	14.0	23.0	147.0	147.2	52.5	"	4.45	"	4.89	3	9.59	12.55
26	" " "	92.4	98.4	98.3	94.4	6.31	6.31	2.75	1.00	14.0	22.6	146.7	146.5	52.0	"	4.15	"	4.62	3	8.75	17.80
27	" " "	92.4	98.5	98.4	94.4	6.39	6.33	2.72	1.02	14.0	22.5	147.0	147.3	52.5	"	3.69	"	4.20	3	7.76	17.95
28	" " "	91.6	97.8	97.6	93.7	6.31	6.31	2.70	1.06	13.9	21.8	142.9	147.2	52.0	"	3.60	"	4.02	3	7.43	17.90
29	" " "	91.4	97.6	97.5	93.5	6.33	6.33	2.69	1.02	13.9	21.6	147.0	146.9	52.0	"	3.16	"	3.64	3	6.47	17.90
30	" " "	92.8	98.7	98.6	94.2	6.33	6.33	2.27	0.93	13.9	21.7	147.4	147.3	52.0	"	2.48	"	2.90	3	4.88	18.10
31	" " "	91.0	97.1	97.0	92.0	6.31	6.31	2.07	0.90	13.9	20.5	146.9	146.8	52.0	"	1.83	"	2.27	3	3.49	18.40
32	" " "	91.6	97.5	97.1	92.6	6.28	6.28	1.97	0.83	14.0	20.3	146.8	146.8	52.0	"	1.54	"	1.89	1	16.30	18.1
33	" " "	91.7	96.9	96.6	92.0	6.33	6.33	1.72	0.75	14.0	19.6	147.9	147.9	52.0	"	0.99	"	1.32	1	10.05	17.8
34	" " "	89.4	94.4	94.1	89.9	6.33	6.33	1.52	0.75	14.0	18.6	147.3	147.9	52.0	"	0.61	"	1.00	1	6.96	18.2
35	" " "	91.7	97.3	96.9	91.9	—	—	—	—	13.9	15.8	147.5	147.5		OIL	11.0	OIL	16.3	1	8.55	18.1
36	" " "	89.7	92.9	92.6	89.3	—	—	—	—	13.9	14.6	147.6	147.6		"	4.8	"	9.1	1	4.08	18.1
37	" " "	87.8	92.7	92.1	88.6	6.33	6.33	0.68	0.5	13.9	14.5	147.3	147.3		OIL	3.1	OIL	6.4	1	2.10	18.2
38	" " "	86.4	92.8	92.0	88.0	6.33	6.33	0.70	0.52	13.9	14.45	147.7	147.7		"	2.7	"	5.1	1	1.18	18.2
40	" " "	80.6	82.9	82.6	79.0	4.52	4.52	0.72	0.52	14.3	14.9	111.5	111.0		"	3.2	"	5.7	1	1.29	18.2
41	" " "	77.3	78.5	78.4	76.8	4.52	4.52	0.82	0.54	13.8	14.6	110.2	111.1		"	9.3	"	13.9	1	5.78	8.4
42	" " "	77.3	78.6	78.6	76.5	4.62	4.62	0.88	0.58	13.8	14.9	112.1	111.7		"	9.7	"	15.6	1	8.60	8.3
43	" " "	80.4	82.7	82.5	79.6	4.57	4.57	1.22	0.69	13.7	16.4	113.3	109.7		Hg	2.46	Hg	2.04	1	24.24	8.28
44	" " "	79.4	81.6	81.5	78.7	4.52	4.52	1.12	0.65	13.7	16.4	109.8	110.0		"	2.04	"	2.48	1	19.45	8.35
45	" " "	78.2	80.6	80.5	77.6	4.55	4.55	1.10	0.62	13.7	15.8	110.0	110.6		"	1.50	"	2.01	1	14.77	8.35
46	" " "	78.2	80.0	79.9	77.5	4.60	4.60	0.95	0.60	13.5	15.3	112.5	111.7		OIL	12.9	OIL	20.5	1	10.90	8.2
47	" " "	80.9	83.5	83.3	80.3	4.52	4.52	1.30	0.70	13.55	16.5	111.9	112.0		Hg	2.90	Hg	3.15	3	4.93	8.3
48	" " "	37.9	41.1	41.1	40.5	5.03	5.03	0.60	0.48	13.5	13.8	120.4	120.4		"	2.70	"	5.66	3	5.25	20.4
49	" " "	37.3	40.5	40.4	39.9	5.02	5.02	0.60	0.48	13.4	13.7	119.2	119.1		"	2.75	"	5.93	3	5.32	20.5
51	" " "	37.9	41.0	40.9	40.3	5.00	5.00	0.58	0.48	13.4	13.7	119.2	119.4	16	"	2.95	"	6.28	3	5.60	20.5
52	" " "	38.7	41.6	41.5	40.9	5.02	5.02	0.60	0.48	13.4	13.7	119.9	119.9		"	3.22	"	6.54	3	7.22	20.4
53	" " "	39.3	42.1	42.0	41.5	5.03	5.03	0.60	0.49	13.4	13.7	120.2	120.1		"	3.31	"	6.77	3	8.04	20.4
54	" " "	39.3	41.9	41.7	41.3	4.95	4.95	0.60	0.45	13.45	13.75	119.0	119.0		"	3.65	"	7.43	3	9.69	20.45
55	" " "	51.3	55.3	54.7	52.9	4.40	4.40	0.58	0.48	13.4	13.7	107.6	107.0		OIL	9.1	OIL	18.7	1	2.96	20.6
56	" " "	50.7	55.9	55.0	53.2	4.42	4.42	0.57	0.45	13.4	13.7	107.7	107.0		"	5.8	"	12.7	1	1.50	20.5
57	" " "	51.1	54.2	53.7	52.6	4.40	4.40	0.54	0.42	13.43	13.75	107.0	106.4		"	13.4	Hg	1.76	1	6.44	20.5
58	" " "	51.4	54.2	53.8	52.7	4.41	4.41	0.52	0.48	13.43	13.77	107.0	106.4		"	15.4	"	2.01	1	8.70	20.5
59	" " "	51.7	54.35	54.0	52.9	4.41	4.41	0.60	0.48	13.43	13.80	107.2	106.5		"	16.2	"	2.08	1	9.75	20.7
60	" " "	52.2	54.7	54.4	53.4	4.40	4.40	0.61	0.45	13.43	13.80	107.6	106.8		Hg	1.34	"	2.37	1	12.88	20.7
61	" " "	52.9	55.1	54.8	53.8	4.41	4.41	0.62	0.49	13.45	13.82	108.0	107.0		"	1.51	"	2.81	1	16.95	20.7
62	" " "	53.4	55.5	55.2	54.3	4.42	4.42	0.62	0.48	13.45	13.83	107.9	106.9	7	"	1.83	"	3.22	1	23.27	20.5
63	" " "	65.8	72.1	71.9	6.96	6.29	6.29	0.92	0.57	13.3	15.0	146.1	146.0	50	"	3.25	"	4.74	3	7.12	15.2
64	" " "	56.3	60.8	60.7	59.2	6.77	6.77	0.76	0.51	13.3	14.5	136.7	136.7		"	3.95	"	6.42	3	9.28	15.2
65	" " "	64.8	71.2	70.9	68.7	6.20	6.20	1.00	0.60	13.45	15.3	144.2	144.2		"	4.31	"	5.99	3	9.34	15.2
66	" " "	66.2	72.8	72.6	70.3	6.30	6.30	1.05	0.58	13.45	15.3	147.4	147.4		"	4.45	"	5.94	3	9.70	15.2

FRICTION CALCULATIONS

HEATER

Run No	Ave. Temp. T_T	S_T	Temp. at Orifice T_o	S_o	"Hg × 12.48/S_T, "Oil × .89/S_T ΔH	$R \times \frac{1.000}{S_o}$	Ft³/min. at Orifice	$\frac{FT^3/min \times S_o}{0.0795\ S_T}$ u	U^2	$\frac{0.01137\ \Delta H}{U^2}$ f	Z/s at T_T	$\frac{DUS}{Z}$	ΔT
*1	35.5	0.885	42.5	0.881	10.57	0.378	0.063	0.789	0.623	0.192	33.5	0.01165	112.7
*2	38.2	0.883	44.0	0.881	16.82	9.65	0.314	3.94	15.6	0.01825	29.6	0.0657	109.2
4	38.1	0.883	43.5	0.880	9.47	2.22	0.152	1.905	3.625	0.0297	29.7	0.0317	109.7
5	37.7	0.884	41.7	0.881	14.90	6.95	0.268	3.36	11.35	0.0149	30.2	0.0550	110.3
6	39.1	0.883	42.5	0.881	16.83	9.73	0.315	3.95	15.6	0.0123	28.4	0.0687	109.0
7	40.5	0.882	43.7	0.880	16.95	11.17	0.338	4.24	18.0	0.0107	26.6	0.0788	107.2
8	41.8	0.881	44.6	0.879	20.4	15.52	0.400	5.02	25.2	0.0092	25.3	0.0980	106.0
9	43.9	0.880	46.4	0.878	21.8	21.2	0.469	5.88	34.6	0.00775	23.2	0.1255	103.9
10	36.5	0.884	33.5	0.886	25.9	20.1	0.407	5.13	26.4	0.0112	31.8	0.0797	111.0
11	38.2	0.883	35.5	0.885	25.6	38.4	0.460	5.80	33.7	0.00963	29.6	0.0960	109.7
12	39.6	0.883	37.1	0.881	27.9	5.06	0.525	6.61	43.7	0.00825	27.7	0.1180	108.4
13	43.3	0.880	41.4	0.881	28.0	6.60	0.602	7.57	57.5	0.00833	23.7	0.158	107.8
14	45.5	0.879	42.0	0.880	32.2	8.54	0.683	8.60	74.1	0.00493	21.7	0.196	102.6
15	46.0	0.878	44.0	0.880	32.4	9.24	0.710	8.95	80.1	0.00459	21.3	0.208	102.0
16	46.4	0.878	44.6	0.879	33.5	9.86	0.733	9.24	85.4	0.00445	21.0	0.217	101.9
17	47.9	0.878	46.5	0.879	35.0	10.70	0.769	9.61	92.9	0.00431	20.2	0.235	100.9
18	53.3	0.874	51.7	0.875	42.0	10.71	0.763	9.61	92.3	0.00517	16.2	0.293	79.1
19	52.3	0.875	51.0	0.875	33.7	9.39	0.715	9.00	81.0	0.00479	16.8	0.285	79.0
20	51.6	0.875	50.2	0.876	30.6	8.08	0.663	8.35	69.9	0.00497	17.25	0.299	79.0
21	52.4	0.874	50.8	0.875	24.9	5.88	0.568	7.16	51.3	0.00552	16.75	0.211	78.9
22	52.0	0.875	50.3	0.876	18.8	3.25	0.429	5.33	28.5	0.00750	17.0	0.155	78.7
23	51.9	0.875	49.9	0.876	16.35	2.44	0.369	4.65	21.7	0.00856	17.1	0.195	77.7
24	91.5	0.850	88.4	0.852	36.8	5.87	0.566	7.13	50.8	0.00823	5.65	0.629	55.5
25	95.0	0.848	91.8	0.850	66.3	11.37	0.788	9.94	98.8	0.00764	5.95	0.917	52.1
26	95.4	0.848	92.4	0.850	61.8	10.38	0.753	9.50	90.3	0.00778	5.30	0.885	51.2
27	95.4	0.848	92.4	0.850	55.0	9.20	0.708	8.93	79.7	0.00784	5.30	0.892	51.7
28	94.7	0.848	91.6	0.850	53.6	8.81	0.698	8.74	76.4	0.00797	5.37	0.803	52.6
29	94.6	0.848	91.4	0.850	47.1	7.67	0.645	8.13	66.1	0.00809	5.38	0.747	52.4
30	95.8	0.848	92.8	0.850	37.0	5.78	0.562	7.08	50.1	0.00839	5.28	0.661	51.5
31	94.0	0.849	91.0	0.851	27.2	4.14	0.479	6.04	36.5	0.00846	5.49	0.549	52.8
32	94.6	0.848	97.3	0.847	22.9	19.40	0.440	5.63	31.7	0.00824	5.38	0.517	52.2
33	94.3	0.849	96.8	0.847	14.75	11.95	0.351	4.40	19.4	0.00864	5.40	0.402	53.6
34	91.9	0.850	94.3	0.849	9.17	8.26	0.292	3.66	13.30	0.00789	5.69	0.321	55.4
35	94.5	0.848	97.1	0.847	11.52	10.18	0.323	4.06	16.48	0.00795	5.68	0.359	53.0
36	91.3	0.850	92.8	0.850	5.02	4.84	0.223	2.81	7.90	0.00721	5.78	0.240	56.3
37	90.3	0.851	92.4	0.850	3.24	2.49	0.161	2.02	4.08	0.00801	5.79	0.1725	57.0
38	89.6	0.852	92.4	0.850	2.82	1.40	0.121	1.52	2.31	0.01385	5.80	0.1277	58.1
40	81.8	0.856	82.8	0.856	3.32	1.518	0.126	1.584	2.52	0.01498	7.03	0.1113	29.2
41	77.9	0.859	78.5	0.858	9.63	6.79	0.263	3.30	10.89	0.01005	7.80	0.209	33.2
42	77.9	0.859	78.6	0.858	10.05	10.10	0.320	4.02	16.16	0.00706	7.80	0.254	33.8
43	81.5	0.857	82.6	0.856	36.3	28.5	0.540	6.78	46.0	0.00896	7.10	0.472	28.2
44	80.5	0.857	81.6	0.856	30.1	22.9	0.487	6.12	37.5	0.00912	7.25	0.417	29.5
45	79.4	0.858	80.6	0.857	22.1	17.37	0.422	5.30	28.1	0.00894	7.49	0.349	31.2
46	79.1	0.858	80.0	0.857	13.37	12.82	0.365	4.58	21.0	0.00723	7.53	0.300	32.6
47	82.2	0.856	80.9	0.857	42.8	5.80	0.563	7.07	50.0	0.00973	6.95	0.503	29.8
48	39.5	0.882	37.9	0.883	38.7	5.98	0.571	7.19	51.7	0.00850	27.0	0.1278	80.9
49	38.9	0.883	37.3	0.884	39.4	6.07	0.576	7.26	52.6	0.00851	28.5	0.1257	80.2
51	39.4	0.882	37.9	0.883	42.2	6.39	0.591	7.44	55.4	0.00865	28.0	0.1312	79.9
52	40.2	0.882	38.7	0.883	46.2	8.24	0.672	8.46	71.6	0.00733	26.8	0.1560	79.7
53	40.7	0.882	39.3	0.883	47.4	9.17	0.706	8.90	79.2	0.00680	26.3	0.1672	74.4
54	40.6	0.882	39.3	0.883	52.9	11.06	0.777	9.78	95.6	0.00622	26.3	0.1897	78.4
55	53.3	0.874	55.0	0.873	9.27	3.41	0.188	2.36	5.57	0.01898	16.2	0.0719	53.7
56	53.3	0.874	55.4	0.873	5.90	1.73	0.134	1.685	2.84	0.0236	16.2	0.0519	53.7
57	52.6	0.874	54.0	0.873	13.65	7.43	0.277	3.48	12.11	0.01280	16.7	0.1030	53.8
58	52.8	0.874	54.0	0.873	15.68	10.05	0.321	4.03	16.24	0.01097	16.6	0.1200	53.6
59	53.0	0.874	54.2	0.873	16.50	11.25	0.340	4.27	18.23	0.01028	16.4	0.1286	53.5
60	53.4	0.874	54.6	0.873	19.38	14.87	0.392	4.93	24.3	0.00907	16.2	0.1503	53.4
61	54.0	0.873	54.9	0.873	21.9	19.55	0.450	5.66	32.0	0.00778	15.8	0.1772	53.0
62	54.4	0.873	55.3	0.873	26.5	26.80	0.525	6.60	43.6	0.00690	15.6	0.209	72.5
63	69.0	0.864	65.8	0.866	47.4	8.87	0.672	8.46	71.6	0.00751	10.0	0.418	77.0
64	58.5	0.871	56.3	0.872	57.2	10.73	0.765	9.63	92.7	0.00701	13.6	0.350	78.2
65	68.0	0.865	64.8	0.867	6.28	10.86	0.772	9.73	94.7	0.00753	10.2	0.471	76.2
66	69.5	0.864	66.2	0.866	64.8	11.28	0.785	9.90	98.0	0.00752	9.85	0.497	77.9

COOLER

Run No	T_p	T_T	S_T	"Hg × 12.48/S_T, Oil × .89/S_T ΔH	$\frac{FT^3/min \times S_o}{0.0795\ S_T}$ u	U^2	$\frac{0.01267\ \Delta H}{U^2}$ f	Z/s at T_T	$\frac{DUS}{Z}$	ΔT
*1	17	40.2	0.882	2.03	0.793	0.629	0.404	27.0	0.01452	23
*2	18	43.1	0.880	35.0	3.95	15.6	0.0284	23.8	0.0820	25
4	18	40.7	0.882	21.3	1.900	3.64	0.0740	26.5	0.356	23
5	17	40.6	0.882	37.8	3.36	11.35	0.0422	26.5	0.0627	24
6	17	41.8	0.881	43.2	3.96	15.7	0.0348	25.2	0.0760	25
7	18	49.0	0.880	49.3	4.25	18.1	0.0303	24.0	0.0874	25
8	17	44.2	0.880	48.1	5.025	25.3	0.0241	22.8	0.1088	27
9	18	45.9	0.879	53.3	5.91	35.0	0.0193	21.4	0.1365	28
10	17	39.0	0.883	63.2	5.19	26.4	0.0303	28.5	0.0890	22
11	17	40.4	0.882	66.1	5.81	33.8	0.0240	26.8	0.1072	23
12	18	41.6	0.881	72.5	6.63	44.1	0.0208	25.4	0.1290	24
13	19	45.0	0.879	72.0	7.59	57.6	0.0158	22.1	0.1698	26
14	18	46.0	0.878	79.8	8.80	74.2	0.0136	21.3	0.204	28
15	18	47.4	0.877	80.8	8.96	80.4	0.01275	20.3	0.219	29
16	18	47.8	0.877	82.1	9.24	85.5	0.0122	19.8	0.221	30
17	19	48.6	0.877	83.8	9.63	92.9	0.01145	19.9	0.247	30
18	23	54.4	0.873	95.5	9.61	92.5	0.01300	15.7	0.303	26
19	21	53.3	0.874	71.4	9.01	81.2	0.01113	16.3	0.273	33
20	21	52.3	0.875	65.2	8.35	69.8	0.01183	16.8	0.246	31
21	21	53.4	0.874	55.1	7.15	51.2	0.01364	16.25	0.218	32
22	20	53.2	0.874	41.7	5.34	28.5	0.01850	16.3	0.162	33
23	19	53.2	0.874	36.8	4.65	21.6	0.02155	16.3	0.141	34
24	36	92.8	0.850	49.8	7.19	50.8	0.01092	5.54	0.636	57
25	42	96.0	0.848	72.0	9.94	98.8	0.00933	5.26	0.933	49
26	48	96.3	0.847	68.9	9.50	90.3	0.00966	5.29	0.897	48
27	48	96.4	0.847	62.6	8.94	79.9	0.00939	5.23	0.844	48
28	48	95.6	0.848	59.9	8.74	76.4	0.00993	5.30	0.814	48
29	46.5	95.5	0.848	54.3	8.13	66.1	0.01040	5.30	0.758	49
30	42	96.4	0.847	49.3	7.09	50.3	0.01091	5.29	0.669	43
31	39	94.5	0.849	33.8	6.04	36.5	0.01179	5.39	0.559	57
32	37	94.8	0.848	28.2	5.63	31.7	0.01126	6.37	0.518	57
33	39	94.3	0.849	19.67	4.40	19.4	0.01284	5.40	0.402	62
34	30	91.0	0.851	14.85	3.66	13.4	0.01404	5.71	0.316	64
35	—	94.4	0.849	17.10	4.05	16.4	0.01321	5.40	0.370	—
36	—	90.9	0.851	9.52	2.80	7.84	0.01530	5.79	0.241	—
37	17	90.3	0.851	6.69	2.02	4.08	0.0207	5.78	0.1725	63
38	17	90.0	0.851	5.33	1.52	2.31	0.0292	5.82	0.129	63
40	17	80.8	0.857	5.92	1.58	2.50	0.0300	7.20	0.1083	53
41	19	77.6	0.859	14.40	3.30	10.89	0.01674	7.85	0.208	59
42	20	77.5	0.859	16.15	4.02	16.16	0.01266	7.86	0.252	58
43	26	81.1	0.857	41.8	6.78	46.0	0.0115	7.14	0.469	55
44	24	80.1	0.857	36.6	6.12	37.5	0.01235	7.32	0.413	58
45	23	79.1	0.858	29.6	5.30	28.1	0.01334	7.52	0.348	56
46	21	78.7	0.858	21.2	4.58	21.0	0.01278	7.63	0.297	58
47	27	81.8	0.856	40.5	7.07	50.0	0.01177	7.02	0.497	55
48	15	40.8	0.882	81.2	7.19	51.7	0.0199	2.63	0.135	26
49	15	40.2	0.882	85.0	7.26	52.7	0.0204	2.70	0.133	25
51	15	40.6	0.882	90.0	7.44	55.4	0.0206	2.66	0.138	26
52	15	41.2	0.881	93.8	8.45	71.4	0.01665	2.58	0.162	26
53	15	41.8	0.881	97.1	7.90	62.4	0.01972	2.52	0.155	27
54	15	41.5	0.881	106.7	9.79	95.8	0.01410	2.55	0.189	27
55	15	53.8	0.873	19.05	2.36	5.6	0.0491	16.0	0.0790	29
56	14	54.1	0.873	12.45	1.685	2.84	0.0578	15.75	0.0528	30
57	14	53.1	0.874	25.4	3.48	12.11	0.0266	16.3	0.1055	29
58	14	53.2	0.874	29.1	4.03	16.24	0.0227	16.3	0.1229	29
59	15	53.5	0.874	30.1	4.27	18.23	0.0209	16.2	0.1309	29
60	15	53.9	0.874	34.3	4.93	24.3	0.01788	15.95	0.153	29
61	15	54.3	0.873	40.7	5.66	32.0	0.01610	15.75	0.178	29
62	15	54.7	0.873	46.6	6.60	43.6	0.01353	15.5	0.210	30
63	20	70.7	0.863	69.4	8.48	71.9	0.01222	9.54	0.438	51
64	18	59.9	0.870	93.2	9.64	92.9	0.01270	13.15	0.362	42
65	22	69.8	0.864	87.7	9.74	94.9	0.0117	9.78	0.492	48
66	22	71.4	0.863	86.9	9.91	98.2	0.0112	9.34	0.524	49

CLAPP
FITZSIMONS

Table III

WATER DATA

RECORDED DATA

Run	No.	Description	Liquid - Deg Cent. Heater Inlet	Heater Exit	Cooler Inlet	Cooler Exit	Pipe Wall - Millivolts Heater Inlet	Heater Exit	Cooler Inlet	Cooler Exit	Cooling Water Inlet	Cooling Water Exit	Steam Inlet	Steam Exit	wt m lb	lb/in²	Length of Run min	Friction Drop Heater Element	Heater Inches	Cooler Element	Cooler Inches	Orifice Reading Main Line No.	Main Line Inches	Cooling Water
C	2	Heating & Cooling of Water	5.65	58.0	57.6	52.4	3.64	4.53	1.72	0.82	6.10	9.65	114.8	112.4	16.0	8.10	21.34	water	4.05	water	4.32	1	4.22	8.59
	3	"	10.75	47.1	46.7	44.3	3.47	4.50	1.48	0.90	9.25	12.73	113.8	112.3	23.5	8.0	15.75	"	11.35	"	10.30	1	13.90	6.25
	4	"	4.92	72.2	71.8	67.0	3.80	4.57	2.41	1.11	9.12	13.70	112.4	117.4	13.94	8.0	12.05		14.57	"	12.30	1	17.13	16.93
	5	"	9.80	37.8	37.4	36.5	3.04	4.42	1.32	0.90	9.10	12.15	117.8	117.0	29.94	8.0	11.98	Hg	2.64	Hg	2.97	3	10.79	4.18
	6	"	43.8	68.8	68.4	65.1	3.75	4.53	2.76	1.37	9.10	16.96	112.7	112.3	24.5	8.0	16.01	Water	14.5	water	15.33	1	23.43	4.25
	7	"	83.3	101.7	100.6	90.6	4.64	4.89	3.65	1.91	9.70	28.2	119.0	117.4	14.12	12.0	27.88	"	9.2	"	13.69	1	14.6	24.53
	8	"	75.2	96.5	95.6	80.9	4.50	4.72	3.38	1.70	9.45	26.6	118.1	115.0	—	10.0		"	3.06	"	6.10	1	3.32	16.3
D	1	Isothermal on Water	6.0	6.1	6.2	6.5												water	2.5	water	2.3	1	1.32	
	2	"	6.1	6.2	6.2	6.5												"	3.7	"	3.1	1	2.36	
	3	"	6.1	6.2	6.2	6.4												"	5.7	"	4.9	1	4.19	
	4	"	6.0	6.1	6.1	6.3												"	8.8	"	8.6	1	7.34	
	5	"	4.9	5.0	5.0	5.2												"	13.9	"	12.2	1	13.06	
	6	"	4.9	5.0	5.0	5.2												"	10.6	"	9.8	1	10.45	
	7	"	4.9	5.0	5.0	5.1												"	7.7	"	6.6	1	6.56	
	8	"	4.9	5.0	5.0	5.1												"	5.6	"	5.1	1	4.59	
	9	"	5.0	5.1	5.1	5.2												"	3.45	"	3.5	1	2.58	
	10	"	5.0	5.2	5.2	5.3												"	2.35	"	2.2	1	1.75	
	11	"	5.0	5.2	5.2	5.5												"	1.05	"	0.95	1	0.68	
	12	"	11.0	11.1	11.2	11.3												"	5.25	"	4.3	1	4.27	
	13	"	11.0	11.1	11.2	11.3												"	8.05	"	6.9	1	6.95	
	14	"	10.9	11.0	11.0	11.15												"	11.6	"	9.9	1	10.43	
	15	"	10.8	10.9	10.9	11.0												"	14.2	"	5.3	1	13.81	
	16	"	10.7	10.75	10.7	10.85												"	17.6	"	15.3	1	17.40	
	17	"	10.8	10.8	10.75	10.9												"	23.4	"	20.2	1	24.44	
	18	"	10.15	10.25	10.25	10.35												Hg	2.67	Hg	2.29	3	8.71	
	19	"	10.3	10.4	10.35	10.4												"	3.66	"	3.13	3	9.64	
	20	"	10.45	10.5	10.5	10.6												"	4.52	"	3.90	3	12.34	
	21	"	10.25	10.3	10.25	10.3												"	5.15	"	4.41	3	14.20	
	22	"	10.3	10.3	10.3	10.3												"	5.91	"	5.02	3	17.50	
	24	"	10.3	10.3	10.3	10.3												"	6.37	"	5.48	3	18.20	

FRICTION CALCULATION

Run	No.	Heater ΔH Inches	ft/min at Orifice	Temp at Orifice	Ave temp of fluid	S_o	S_1	u	u^2	$0.01147 \frac{\Delta H}{u^2}$ f	Z	S	$\frac{Dus}{Z}$	ΔT	Cooler ΔH Inches	Ave temp of fluid	S_r	u	u^2	$0.01267 \frac{\Delta H}{u^2}$ f	Z	S	$\frac{Dus}{Z}$	ΔT
C	2	4.05	0.205	58.0	34.7	0.985	0.994	2.55	6.52	0.00713	0.728	0.995	1.72	77.7	4.33	55.0	0.986	2.58	6.63	0.00826	0.508	0.986	2.47	21.0
	3	11.35	0.378	47.1	30.2	0.989	0.996	4.72	22.25	0.00585	0.800	0.998	2.90	82.1	10.3	45.5	0.990	4.75	22.55	0.00578	0.595	0.990	3.90	13.2
	4	14.57	0.420	72.2	61.5	0.976	0.983	5.24	27.5	0.00607	0.458	0.980	5.55	51.6	12.3	69.5	0.978	5.27	27.8	0.00561	0.410	0.978	6.21	22.2
	5	33.25	0.770	37.8	24.6	0.993	0.997	9.85	93.1	0.00410	0.904	0.997	5.25	87.4	37.4	37.0	0.993	9.09	93.8	0.00505	0.698	0.993	6.80	8.7
	6	14.5	0.491	68.8	57.3	0.978	0.985	6.13	37.6	0.00442	0.488	0.985	6.13	56.0	15.3	68.8	0.979	8.17	38.1	0.00510	0.425	0.980	7.03	24.2
	7	9.2	0.387	101.1	96.2	0.958	0.961	4.85	23.5	0.00448	0.296	0.962	7.76	21.2	13.7	95.6	0.961	4.85	23.55	0.00736	0.298	0.961	7.72	24.4
	8	3.06	0.186	95.6	87.3	0.962	0.968	2.32	5.39	0.00651	0.328	0.970	3.38	27.7	8.1	88.3	0.966	2.33	5.43	0.01424	0.325	0.966	3.42	—
D	1	2.5	0.118		6.1			1.48		0.01316	1.47	1	0.496		2.3					0.01335				
	2	3.7	0.157		6.2			1.98		0.01088	1.466	1	0.624		3.1					0.01006				
	3	5.7	0.208		6.2			2.62		0.00957	1.466	1	0.881		4.9					0.00908				
	4	8.8	0.275		6.1			3.46		0.00843	1.47	1	1.162		8.8					0.00910				
	5	13.9	0.368		5.0			4.63		0.00744	1.52	1	1.505		12.2					0.00721				
	6	10.6	0.328		5.0			4.10		0.00724	1.52	1	1.332		9.8					0.00738				
	7	7.7	0.260		5.0			3.27		0.00825	1.52	1	1.062		6.6					0.00782				
	8	5.6	0.217		5.0			2.73		0.00862	1.52	1	0.886		5.1					0.00867				
	9	3.35	0.164		5.1			2.07		0.00902	1.518	1	0.663		3.5					0.01838				
	10	2.35	0.135		5.2			1.70		0.00935	1.517	1	0.553		2.2					0.00967				
	11	1.05	0.084		5.2			1.06		0.01080	1.514	1	0.345		0.95					0.01078				
	12	5.25	0.210		11.15			2.64	7.0	0.00853	1.268	1	1.028		4.3					0.00777				
	13	8.05	0.268		11.15			3.37	11.38	0.00805	1.268	1	1.31		6.9					0.00787				
	14	11.6	0.327		11.0			4.11	16.90	0.00780	1.272	1	1.591		9.9					0.00741				
	15	14.2	0.374		10.9			4.70	22.20	0.00727	1.278	1	1.816		—					—				
	16	17.6	0.423		10.75			5.32	28.30	0.00707	1.281	1	2.045		15.3					0.00685				
	17	23.4	0.502		10.86			6.31	39.9	0.00668	1.280	1	2.43		20.2					0.00640				
	18	33.6	0.608		10.25			7.65	58.6	0.00651	1.300	1	2.90		28.9					0.00624				
	19	46.1	0.725		10.36			9.12	83.2	0.00630	1.298	1	3.46		39.4					0.00598				
	20	57.9	0.820		10.51			10.32	106.4	0.00617	1.290	1	3.95		49.1					0.00584				
	21	64.9	0.878		10.27			11.05	122.0	0.00604	1.300	1	4.20		55.8					0.00577				
	22	74.5	0.975		10.30			12.26	150.5	0.00563	1.299	1	4.85		63.2					0.00532				
	24	80.3	0.993		10.30			12.49	156.0	0.00585	1.299	1	4.74		69.0					0.00559				

OIL DATA

RECORDED DATA

Run	No	Description	Liquid - Deg. Cent Heater Inlet	Heater Exit	Cooler Inlet	Cooler Exit	Ave. temp. of fluid Heater	Ave. temp. of fluid Cooler	Friction Drop Heater Element	Heater Inches	Cooler Element	Cooler Inches	Orifice Reading No	Orifice Reading Inches
E	4	Isothermal on Oil	32.1	34.1	32.8	33.1	34.1	32.95	Hg	2.03	Hg	1.85	1	2.55
	5	"	33.3	34.75	34.1	34.6	34.75	34.35	"	3.32	"	2.71	1	6.41
	6	"	35.9	37.5	36.3	36.6	37.5	36.45	"	3.48	"	2.96	1	8.70
	7	"	37.0	37.7	37.4	37.1	37.7	37.25		4.05	"	3.55	1	13.85
	8	"	37.65	38.25	38.0	37.8	38.25	37.8	"	4.65	"	3.97	1	19.10
	9	"	38.6	38.9	38.8	38.6	38.75	38.7		5.48	"	4.85	3	5.18
	10	"	39.1	39.15	39.1	39.0	39.13	39.1	"	6.30	"	5.25	3	6.59
	11	"	38.2	38.3	38.2	38.1	38.25	38.2	"	7.80	"	6.55	3	9.20
	12	"	49.4	53.6	53.4	53.6	—	53.5			"	3.25	3	6.70
	13	"	82.7	68.9	69.2	69.3	—	69.2			"	5.30	3	9.40
	14	"	73.6	80.8	80.6	80.8	—	80.6			"	5.25	3	10.48
	15	"	82.0	89.1	89.2	89.0	—	89.1			"	5.10	3	10.65
	16	"	93.0	98.8	98.5	98.4	—	98.45			"	4.90	3	10.98
	18	"	30.6	30.4	30.3	30.1	30.5	30.2		9.12		7.97	3	6.00
	19	"	30.7	30.7	30.7	30.5	30.7	30.6	"	8.62	"	7.33	3	5.45
	20	"	31.1	31.1	31.1	31.0	31.1	31.05		7.37	"	6.37	3	4.18
	21	"	31.25	31.25	31.25	31.2	31.25	31.23	"	6.08	"	5.25	3	2.90
	22	"	30.8	30.8	30.75	30.65	30.8	30.7	"	7.13	"	6.07	1	20.74
	23	"	31.3	31.3	31.3	31.15	31.3	31.225		6.79	"	5.85	1	19.66
	24	"	31.4	31.4	31.4	31.3	31.4	31.35		5.96	"	5.10	1	15.30
	25	"	31.6	31.6	31.5	31.4	31.6	31.45		5.04	"	4.38	1	11.65
	26	"	31.7	31.7	31.6	31.5	31.7	31.55	"	4.13	"	3.65	1	8.17
	27	"	31.65	31.65	31.55	31.55	31.65	31.55	"	3.17	"	2.77	1	4.55
	28	"	31.8	31.9	31.8	31.65	31.85	31.63	"	1.93	"	1.76	1	1.72
	29	"	61.6	62.1	61.9	61.8	61.85	61.85		2.88	"	2.68	1	29.15
	30	"	61.7	62.15	61.9	61.8	61.93	61.85	"	2.82	"	2.45	1	27.95
	31	"	61.8	62.1	61.8	61.75	61.95	61.78	"	2.16	"	1.94	1	24.28
	32	"	61.7	61.9	61.7	61.5	61.8	61.6	"	1.81	"	1.68	1	19.23
	33	"	60.1	60.15	59.9	59.9	60.13	59.9	0.1	23.90	0.1	21.30	1	14.53
	34	"	58.9	58.9	58.6	58.6	58.9	58.6	"	20.00	"	18.00	1	9.34
	35	"	58.0	58.0	57.75	57.75	58.0	57.76		13.30		11.8	1	3.77
	36	"	56.8	56.7	56.7	56.5	56.75	56.8	"	9.20		8.6	1	1.80

FRICTION DATA

Run	No	Heater S_r S_o	ΔH	R	ft/min at Orifice	u	u^2	$0.01137 \frac{\Delta H}{u^2}$ f	$\frac{Z}{S}$	$\frac{Dus}{Z}$	Cooler S_r	S_o	ΔH	K	ft/min at Orifice	u	u^2	$0.01267 \frac{\Delta H}{u^2}$ f	$\frac{Z}{S}$	$\frac{Dus}{Z}$
E	4	0.886	29.0	2.90	0.173	2.17	4.73	0.0697	35.5	0.0302			26.4					0.0706	37.5	0.0287
	5	0.885	47.4	7.30	0.273	3.43	11.78	0.0457	34.5	0.0490			38.7					0.0415	35.1	0.0483
	6	0.884	49.6	9.92	0.318	4.00	16.00	0.0353	30.5	0.0648			42.2					0.0334	31.8	0.0621
	7	0.884	57.9	15.8	0.403	5.07	25.7	0.0256	30.3	0.0826			50.7					0.0250	30.8	0.0813
	8	0.883	66.5	21.8	0.475	5.97	35.7	0.0212	29.6	0.0995			56.8					0.02015	30.1	0.0979
	9	0.883	78.5	5.91	0.570	7.17	51.3	0.0174	28.8	0.1230			69.4					0.01712	29.0	0.1222
	10	0.883	90.1	7.51	0.640	8.05	64.9	0.0158	28.3	0.1406			75.2					0.01470	28.3	0.1414
	11	0.883	111.8	10.50	0.760	9.56	91.5	0.0139	29.6	0.1596			93.7					0.01298	29.6	0.1597
	12	—	—	—	—	—		—			0.874	0.876	47.0	7.70	0.648	8.18	67.0	0.00888	16.2	0.249
	13	—	—	—	—	—					0.864	0.868	77.5	10.91	0.772	9.76	95.3	0.01032	9.90	0.487
	14	—	—	—							0.857	0.861	77.4	12.28	0.818	10.35	107.0	0.00916	7.78	0.702
	15	—	—	—							0.852	0.856	75.6	12.52	0.825	10.44	108.8	0.00880	5.92	0.872
	16	—	—	—							0.846	0.849	73.1	13.03	0.840	10.60	112.5	0.00823	5.08	1.03
	18	0.888	129.9	6.81	0.611	7.69	59.1	0.0249	42.5	0.0893			113.5					0.0243	43.0	0.0883
	19	0.888	122.8	6.19	0.581	7.30	53.3	0.0261	42.3	0.0852			105.2					0.0250	42.6	0.0846
	20	0.888	105.0	4.75	0.511	6.43	41.3	0.0288	41.1	0.0773			90.7					0.0278	41.1	0.0772
	21	0.887	86.5	3.29	0.425	5.34	28.6	0.0343	40.9	0.0645			74.8					0.0331	41.0	0.0642
	22	0.888	101.5	23.5	0.492	6.16	38.3	0.0301	41.7	0.0732			86.5					0.0286	42.2	0.0723
	23	0.887	96.7	22.3	0.480	6.03	36.5	0.0301	41.0	0.0726			83.5					0.0290	38.8	0.0768
	24	0.887	84.2	17.36	0.422	5.31	28.2	0.0339	40.8	0.0643	Same as Heater	Same as Heater	72.6	Same as Heater	Same as Heater	Same as Heater	Same as Heater	0.0326	40.5	0.0648
	25	0.887	71.8	13.22	0.370	4.65	21.7	0.0376	40.3	0.0589			62.5					0.0364	40.5	0.0588
	26	0.887	58.8	9.27	0.308	3.87	15.0	0.0445	40.0	0.0470			52.0					0.0438	40.3	0.0474
	27	0.887	45.2	5.16	0.231	2.90	8.43	0.0608	40.4	0.0354			39.5					0.0594	40.3	0.0355
	28	0.887	27.5	1.95	0.143	1.80	3.23	0.0967	39.9	0.0223			25.1					0.0984	40.3	0.0221
	29	0.869	41.9	33.8	0.590	7.42	55.1	0.00864	12.3	0.298			38.9					0.00894	12.3	0.298
	30	0.869	41.0	32.4	0.577	7.26	52.7	0.00885	12.25	0.293			35.7					0.00857	12.3	0.292
	31	0.869	31.4	28.2	0.540	6.79	46.2	0.00772	12.25	0.274			28.2					0.00772	12.3	0.273
	32	0.869	26.3	22.3	0.481	6.05	36.6	0.00816	12.3	0.243			24.5					0.00847	12.4	0.241
	33	0.870	24.4	16.63	0.416	5.23	27.3	0.01016	13.0	0.199			21.8					0.01012	13.1	0.1975
	34	0.870	20.5	10.81	0.333	4.19	17.55	0.01327	13.5	0.1533			18.4					0.01327	13.7	0.151
	35	0.871	13.6	4.35	0.212	2.66	7.11	0.0217	13.8	0.0952			12.04					0.0215	14.0	0.939
	36	0.872	9.4	2.08	0.147	1.85	3.425	0.0312	14.5	0.0631			8.18					0.0324	14.6	0.825

CLAPP
FITZSIMONS
JUNE 1928

Calibration of Orifices

Series	Run No.	Description	Average Manometer Reading	Time in min	lb. of water	lb. per min.	Temp of water	ft³/min at Orifice
A	1	Orifice No. 2	5.55	12.95	200	15.44	5°C	0.248
	2	"	2.28	20.27	200	9.87	"	0.158
	3	"	7.47	11.18	200	17.89	"	0.287
	4	"	20.54	6.76	200	29.57	"	0.475
	5	"	11.05	9.23	200	21.66	"	0.348
	6	"	5.43	13.10	200	15.27	"	0.245
	7	"	15.03	7.89	200	25.34	"	0.407
	8	"	15.27	7.81	200	25.60	"	0.411
B	1	Orifice No. 1-A	1.21	14.14	100	7.07	"	
	2	"	2.68	9.41	100	10.63	"	
	3	"	4.91	14.02	200	14.27	"	
	4	"	8.34	10.86	200	18.42	"	
	5	"	12.37	8.91	200	22.46	"	
	6	"	16.75	7.68	200	26.06	"	
	7	Orifice No. 1	7.36	5.85	100	17.10	"	0.274
	8	"	13.55	4.30	100	23.26	"	0.373
	9	"	9.65	5.09	100	19.64	"	0.315
	10	"	2.08	5.45	50	9.18	"	0.147
	11	"	4.35	7.58	100	13.20	"	0.212
	101	Orifice No. 3	2.28	4.50	100	22.20	"	0.356
	102	"	5.50	4.39	150	34.20	"	0.549
	103	"	9.22	5.64	250	44.40	"	0.713
	104	"	14.16	5.50	300	54.60	"	0.876
	105	"					"	

CLAPP
FITZSIMONS
JUNE 1928

Table V

HEAT TRANSFER COEFICIENTS-CALCULATIONS

Series	Run	Fluid Flowing	Temp. change in fluid °C	k	c	lb./hr.	Chu/hr.	ΔT °C	h	hD/K	cz/h	$(cz/k)^{.37}$	$\frac{hD/k}{(cz/k)^{.37}}$	Dup/z
C	2	Heating Water	52.3	0.351	1.00	780	40800	77.8	870	1222	2.07	1.309	934	107.3
	3	" "	36.3	0.349	"	1416	51400	82.3	1040	1472	2.29	1.359	1085	181
	4	" "	23.0	0.379	"	1572	36100	51.0	1172	1530	1.208	1.072	1428	346
	5	" "	28.0	0.344	"	2880	80500	87.5	1530	1635	2.63	1.430	1143	328
	6	" "	25.1	0.375	"	1836	46200	50.1	1390	1828	1.304	1.103	1636	382
	7	" "	12.4	0.412	"	1445	17950	21.2	1400	1680	0.718	0.885	1900	485
	8	" "	21.3	0.403	"	695	14850	27.7	888	1090	0.814	0.927	1175	211
H	6	Heating Velocite "B"	7.03	0.078	0.458	1041	3360	109.	51.1	324	147.5	6.36	51.0	4.26
	7	" " "	6.6	"	0.460	1117	3390	107.	52.4	331	138.3	6.20	53.4	4.92
	8	" " "	5.85	"	0.461	1315	3550	106.	55.5	352	130.8	6.07	58.0	6.11
	9	" " "	5.2	"	0.463	1540	3710	104.	59.2	375	121.2	5.90	63.6	7.83
	10	" " "	6.0	"	0.455	1350	3690	111.	55.1	349	164.0	6.60	52.8	4.97
	11	" " "	5.3	"	0.457	1525	3700	110.	55.9	354	153.0	6.43	55.0	6.03
	12	" " "	4.9	"	0.459	1735	3870	108.	59.2	375	144.0	6.29	59.7	7.36
	13	" " "	4.4	"	0.463	1980	4040	105.	64.0	405	123.8	5.95	68.1	9.86
	14	" " "	4.0	"	0.465	2250	4190	103.	67.7	428	113.6	5.76	74.3	12.23
	15	" " "	3.9	"	0.466	2340	4260	102	69.3	438	111.6	5.72	76.6	12.97
	16	" " "	3.6	"	0.466	2410	4050	102	65.9	417	110.2	5.70	73.1	13.55
	17	" " "	3.6	"	0.467	2510	4210	101.	69.2	438	106.0	5.62	78.0	16.66
	18	" " "	3.2	"	0.474	2500	3790	79.1	79.4	503	86.0	5.20	96.8	18.27
	19	" " "	2.6	"	0.473	2340	2880	79.0	60.5	383	89.2	5.27	72.7	16.53
	20	" " "	2.7	"	0.472	2170	2770	79.0	58.2	368	91.2	5.32	69.3	14.90
	21	" " "	3.15	"	0.473	1860	2770	78.9	58.3	369	88.7	5.26	70.2	13.15
	22	" " "	3.45	"	0.472	1287	2060	78.7	43.4	275	90.0	5.28	52.1	9.67
	23	" " "	3.95	"	0.472	1205	2250	77.7	48.0	364	90.4	5.30	57.3	8.42
	24	" " "	6.25	"	0.514	1805	5800	55.5	173.	1097	31.6	3.59	306	38.8
	25	" " "	6.25	"	0.518	2510	8140	52.1	259	1640	30.1	3.53	465	57.2
	26	" " "	6.0	"	0.518	2390	7440	51.2	241	1527	29.8	3.52	435	55.2
	27	" " "	6.1	"	0.518	2250	7110	51.7	228	1445	29.8	3.53	409	51.8
	28	" " "	6.2	"	0.517	2210	7080	52.6	223	1413	30.2	3.53	400	50.1
	29	" " "	6.2	"	0.517	2050	6570	52.4	208	1318	30.3	3.53	373	46.6
	30	" " "	5.9	"	0.519	1785	5450	51.5	175.5	1112	29.8	3.51	316	41.3
	31	" " "	6.1	"	0.517	1525	4810	52.8	151.0	958	30.5	3.54	271	34.2
	32	" " "	5.9	"	0.517	1421	4340	52.2	138.0	875	30.2	3.53	248	32.2
	33	" " "	5.2	"	0.517	1113	2990	53.6	92.4	586	30.3	3.53	166	25.0
	34	" " "	5.0	"	0.515	926	2390	55.4	71.5	453	31.6	3.59	126	20.0
	35	" " "	5.6	"	0.517	1025	2970	53.0	92.9	588	31.4	3.58	165	22.0
	36	" " "	3.2	"	0.514	709	1165	56.3	34.3	217	32.3	3.82	60.0	15.0
	37	" " "	4.9	"	0.513	518	1288	57.0	37.4	237	32.3	3.62	65.5	10.8
	38	" " "	6.4	"	0.512	384	1260	58.0	35.9	227	32.5	3.63	62.5	7.96
C	2	Cooling Water	5.2	0.351	1.00	780	7310	21.0	582	819	1.448	1.147	713	154
	3	" "	2.35	0.345	"	1416	5990	13.2	757	1084	1.726	1.227	884	243
	4	" "	5.8	0.360	"	1572	13600	22.2	1023	1402	1.140	1.050	1335	387
	5	" "	0.9	0.339	"	2880	6690	67.2	1662	2420	2.060	1.307	1852	427
	7	" "	10.0	0.377	"	1445	26500	24.4	1813	2370	0.790	0.916	2590	481
H	1	Cooling Velocite "B"	4.25	0.078	0.460	208	406	23.	29.5	187	140.0	6.23	30.0	0.904
	24	" " "	3.65	"	0.516	1805	3390	57.	99.3	629	31.1	3.57	176.	39.7
	25	" " "	3.8	"	0.519	2510	4950	49.	169.0	1070	29.8	3.50	306	58.2
	26	" " "	3.9	"	0.519	2390	4850	48	166.5	1070	29.4	3.48	308	55.9
	27	" " "	4.0	"	0.519	2250	4670	48	162.0	1028	29.4	3.48	296	52.6
	28	" " "	3.9	"	0.518	2210	4430	48	154.0	976	29.8	3.51	276	50.7
	29	" " "	4.0	"	0.518	2050	4250	49	145.0	918	29.8	3.51	261	47.3
	30	" " "	4.4	"	0.519	1785	4070	43	158.0	1000	29.4	3.48	287	41.7
	31	" " "	5.0	"	0.517	1525	3940	57	115.5	728	29.7	3.51	207	34.5
	32	" " "	4.5	"	0.518	1421	3320	57	97.3	616	30.3	3.53	175	32.3
	33	" " "	4.6	"	0.517	1113	2640	62	68.5	434	30.4	3.53	123	25.1
	34	" " "	4.2	"	0.514	926	2000	64	52.2	330	32.3	3.82	91.2	19.7
	37	" " "	3.5	"	0.513	518	920	63	24.4	1545	32.3	3.08	50.2	10.76
	38	" " "	4.0	"	0.513	384	780	63	19.6	1240	32.5	3.63	34.2	8.05
	40	" " "	3.6	"	0.503	467	730	53	23.0	1456	39.8	3.91	37.2	6.77
	41	" " "	1.6	"	0.500	506	675	59	19.1	1210	43.2	4.03	30.0	12.98
	42	" " "	2.1	"	0.500	1027	1078	58	31.0	1965	43.3	4.03	48.8	15.10
	43	" " "	2.9	"	0.503	1730	2520	55	76.5	485	39.4	3.90	125	29.30
	44	" " "	2.8	"	0.502	1560	2190	56	65.3	412	40.3	3.93	105	25.8
	45	" " "	2.9	"	0.501	1362	1965	56	58.6	371	41.4	3.96	93.7	21.7
	46	" " "	2.4	"	0.501	1160	1405	58	40.5	257	42.0	3.99	64.4	18.5
	47	" " "	3.0	"	0.504	2360	2720	55	82.7	254	38.8	3.87	13.6	310

CLAPP
FITZSIMONS
JUNE 1928