Thesis.

The results of an experiment on cylinder condensation, using steam superheated to a temperature of 590° F. with a pressure of 70 lbs. per sq. in.

The apparent cut-off at the front end being $\frac{4.38}{20}$ ths and at the crank end $\frac{4.18}{20}$.

Thos. D. Plimpton. '75

This experiment is one of a series, made in the Mechanical Engineering Laboratory of the Institute during the past winter for Mr George B. Dixwell. This series was intended to settle some points in regard to superheated steam not before experimented upon. Mr Dixwell, after a careful study of the experiments of Chief Engineer Isherwood, believing that cylinder condensation was due in a great measure to the reëvaporation during the expansion and return stroke of the steam condensed in doing the work of expansion, in warming the cylinder and by radiation, thus causing the inner surface of the cylinder to cool down to a temperature near that of the exhaust steam, which again causes condensation at the next stroke, and so the operation goes on, first condensation and then reëvaporation.

Also believing that this loss of power may be effectually remedied by superheating the steam to such a point that it may contain heat enough, more than that of saturated steam at the same pressure, to do all the work of expansion plus that lost by radiation.

In working up this experiment the principal things to be found are

1° The horse power, the water used per horse power per hour and the total heat of the steam which leaves the engine as shown by calorimetry.

2° The approximate equations of the expansion curves for the mean cards from each end of the cylinder, and by the use of them finding the point of cutoff for each end.

3° The amount of cylinder condensation or superheating at different points of the stroke

4° The total heat contained in the steam or steam and water in the cylinder at different

points of the stroke after cut off.
In order to do this it was necessary to make some preliminary experiments to ascertain some data in regard to the leakage and clearance but what they were found to be, will be seen farther on.

The apparatus used and situated in the Mechanical Engineering Laboratory of the Institute is described in the Presidents report for the year ending Sept, 30th 1874, with the exception of a cylinder pyrometer and an adjustable cut off rod, which have been added since the report came out.
The pyrometer is a thin brass tube pierced with holes, situated in a

groove cut in the cylinder head, to which it is fixed at one end, the other being free to move, which it does under the expansive action of the heat in the steam; This motion is communicated to the hand of a dial on the out side of the head by a steel spindle passing through the head, and other mechanism. The dial is divided into 360 equal parts, that is the circumference of it is.

The adjustable cut-off is a rod attached to the governor stand and cut off mechanism, whose length can be changed, thereby changing the cut-off.

The following description of the experiment is taken largely from the report of the experiment.

"The superheater was fired at 8 A.M. and a current of steam allowed to pass through it from the supply boilers into the circulation for heating the building as is usually done.

In order to heat up the calorimeter a portion of the steam was turned into the large tank about noon, and the pump occasionally worked to even the temperature. Wet steam from the boiler was allowed to mix with the superheated steam in order to prevent the burning of the rubber hose.

The water was of a uniform temperature of 150°F at about 1-30 P.M., and the steam was shut off. During this time the outlet valve of the small tank was open to save the trouble of watching to see when it had filled.

The valve to empty the large tank was opened at 1-47, before which the reading of the upper thermometer was 149.5°F. the lower 150°F.

The weight of the tank empty was 651 lbs
The weight of the tank filled was 1921 lbs
The large tank being refilled, which takes about 30 minutes, the temperature of the water flowing in was 38.5°F.

"The engine was started at about

1,45. The cut off was set and the load adjusted and preparations made to commence the experiment.
After some preliminaries which took until $3^h 15'$ the engine was stopped, and the fires replenished so that there would be no trouble from them during the experiment. When the engine was stopped the temperature of the superheated steam was only 560°F, but when the engine was started again, which was done as soon as the pressure had risen to 70 lbs, the temperature had risen to 590°F which was the temperature desired. Both indicators being on cards were taken simultaneously at both

ends and the points of cut off readjusted the crank end one having to be shortened a little to correspond with the other.

Everything being ready now the operators took their places which are as follows. Operator no 1 at the counter, to give the signal for the readings every 300 revolutions of the engine by ringing the gong once 30 revolutions before the time once 10, and once at the time of the readings; he also notes the time. Operators 2 & 3 work the indicators; 4. reads and records the reading of the standard guage. No. 5 reads and records both the steam thermometer and pyrometer; no 6 changes the quick opening valves at the beginning and end of the experiment, and notes everything about the small tank; no 7 takes the temperature at the top and bottom of the large tank also weighs it. No 8 regulates the pressure of the steam by throttling it as it passes into the small boiler; no 9 reads the guage on the large boilers and no 10 reads the cylinder pyrometer; also another works the agitating pump of the large tank.

The signal for the first set of readings and the changing of the quick opening valves; that is, the turning of the exhaust steam into the calorimeter, was struck at 4h 40' 14" at the 847100th revolution indicated by the counter. The valves were changed back again temporarily during the time from 5h 49' 26" to 6h 11' 22" from counter 851125 to 851600 owing to the breaking of the wire which drives the indicators. The engine was stopped and the wire repaired and the engine allowed to make nearly 500 revolutions after starting, before the experiment was continued. The experiment was concluded when the temperature of the water in the large tank had reached its initial temperature of 150°F. The last bell was rung at 7h 51' 38" when the counter turned the 857820th revolution.

While the engine was stopped a new string was attached to the paper cylinder of the indicator at the front end in such a way as was afterward discovered, that at one end of its motion the driving portion of the string was obliged to ride over the end of the string which is attached to the paper cylinder, instead of keeping at the bottom of the groove where it should remain, to give a correct motion to the card. The string had been attached at the wrong point and when this point came to the end of its motion, it forced the driving part of the string out of line a distance equal to the thickness of the string and shortened the card by a corresponding amount. This occured when the pencil was tracing the extremity of the expansion curve. Subsequent examination shew that all of the cards taken at the front end after these repairs were made, were about 1/10 of one inch less in length than those taken previously. This difference was doubtless due to the fault just mentioned.

Instead of using the real length of the card in working up those found in this condition, the final ordinate was laid off not at the end of the diagram but beyond it at a distance from the ordinate of initial pressure equal to the mean length of the cards taken before the error was introduced. The mean length of the twelve cards taken before the engine was stopped is 4,88".

At about 5^h 20' operator no 7 discovered that the small tank was leaking badly. Examination shew that there was an open crack in the west end at about 5" from the top extending across from side to side. The tank was immediately emptied, the small supply valve closed and the weight empty observed and recorded. It was decided to fill the tank during the rest of the experiment only as far as the opening instead of filling it full as usual and compute the probable amount of water lost from the rate at which it runs in.

The temperature of the water was not observed till the tank had begun to fill after it was thus suddenly emptied.

The expansion tank above the large tank began to leak towards the end of the experiment. It ran down and quite a quantity collected upon the cover of large tank but none seemed to run off upon the floor. Two pails were finally placed beneath the leak to prevent the loss of the water. Though their weight was 10 lbs the scales did not show this addition.

It was ascertained after the experiment that the frame of the large tank scales had swelled in such a way that the platform rested

upon it at a point near the middle on the southern edge, and touched within $1/32''$ at a similar point on the northern edge. This injured the sensitiveness of the scales, but how great an error it introduced when when the tank was full of water and the greater load was acting, it is not easy to tell. It may be that the weight was as much as 40 lbs more than that indicated, but it is not likely that the error could have been more than that amount.
The temperature of the engine room at the commencement of the experiment was 74°F. Half an hour after the end it stood at 86°F. The temperature of the calorimeter room

during the experiment was about 108°.
The hight of the barometer in the physical laboratory at the beginning of the experiment was 29,57", half an hour after its conclusion was 29,35"
The mean of these two readings corresponds to about 14.43 lb. per sq. inch.

The speed of the engine was very regular during the whole experiment no trouble arising on this account as there had in some former experiments

Record of Readings

Counter	Time	Diff. Time	St'd Guage	Boiler Guage	Steam Thermom.	Steam Pyrom.	Temp. Lar. Tank Top	Temp. Lar. Tank Bottom	Weight Lar. Tank
847100	4h 40' 14		70	72,3	318°	590°	50°	50	7960
847400	45-25	5' 11"	69,9	74,4	318°	590°	53°	52°	7960
847700	50-33	5' 8"	69,9	72,8	318°	590°	56	55	7959
848000	55-42	5-9	70,4	73,8	318°	590°	59	59°	7960
848300	5h 0' 51"	5-9	70	75	318°	590°	62	62	7960
848600	6-0	5-9	70,1	73,	318°	590°	66°	65°	7960
848900	11-9	5-9	70	74,4	318°	590°	68°	68°	7960
849200	16-19	5-10	70	74,	318°	590°	73°	71°	7960
849500	21-29	5-10	70	73,4	318°	590	75	74	7960
849800	26-36	5-7	70,1	73,	318°	590°	77°	77°	7960
850100	31-45	5-9	70,1	73,4	318°	590	81	80	7960
850400	36-51	5-6	70,1	74,	318°	591°	84°	83°	7960
850700	42-6	5-15	70,	73,3	318°	592°	88°	87°	7960
851000	47-17	5-11	69,8	74,	318°	580°	91°	90°	7959
851125	49-26	2-9		74,8					
851600	6h 11' 22"		69,9	74,6	318°	575°	92°	91°	7957
851900	16-34	5-12	69,9	73,3	318°	584°	96°	95°	7954
852200	21-44	5-10	69,5	75,5	318°	580°	99°	99°	7954

Record of Readings. (continued)

Counter	Time	Diff Time	St'd Gauge	Boiler Gauge	Steam Thermom	Steam Pyrom.	Temp Top	Tar. Tank Bottom	Weight Tar. Tank
852500	6h 26'-55"	5'-11"	70,3	73,1	318	590	103	102	7954
852800	32-5	5'-10"	69,9	73,9	318	590	106	105	7954
853100	37-15	5-10	70,1	72,7	318	590	110	108	7953
853400	42-26	5-11	69,9	74,1	318	590	113	112	7953
853700	47-26	5'-0"	70	73,2	318	590	115	114	7953
854000	52-45	5'-19"	70	72,4	318	590	118	117	7951
854300	57-55	5-10	70,2	73.	318	590	121	120	7951
854600	7h 3'-6"	5-11	70	73,5	318	589,5	124	123	7951
854900	8-15	5'-9"	70,2	74,	318	590	128	125	7950
855200	13-25	5-10	69,9	74,	318	590	129	128	7950
855500	18-35	5-10	69,9	73,5	318	590	133	132	7949
855800	23-45	5-10	70.	74.	317,5	590	135	134	7949
856100	28-55	5'-10"	69,9	73.	318	590	138	137	7949
856400	34-5	5-10	70,1	73.	318	590	141	140	7949
856700	39-15	5-10	70,	74.	318	590	144	143	7949
857000	44-25	5'-10"	70,1	74.	318	590	146	145	7948
857300	49-35	5-10	70,2	75.	318	590	149	148	7948
857420	7h 51'-39"	2'-4"	70,2		318	590	151	150	7948
							150	150	

Record of small tank readings

Weight of Sm. Tank.	Differences or Weight of Water	Time	Diff.	Temp.	Wt. of Water corrected for leakage of Sm. Tank
empty 199		4h 40-15"			
225		46'-58"	6'-43"		
250		52-28	5'-30"		
275		58-37	6'-9"		
300		5h 3'-50"	5'-13"		
325	126	9'-15"	5'-25"		
350		15-31	6'-16"		209.7
Wt & temp. before emptying not taken					
empty 205				76°	
250		5h 39'-10"			
275		44-55"	5'-45"		
Engine stoped					
300		6h-12'-50"			
325		17'-42"	4'-52"		
328,5	123,5			85°	123,5
empty 205					
225		6h 21-57"	4' 15"		
250		27'-15"	5'-18"		
275		32'-45"	5'-30"		
300		38-8	6'-23"		

Record of small tank readings (continued)

Weight of Sm. Tank	Diff. or Wt. of Water	Time	Diff.	Temp.	Wt. of Water corrected for leakage of Sm. Tank.
325		6h-43'-30"	5'-22"		
327	122			99°	122
empty 206					
225		6h-48'-20"	4'-50"		
250		54'-5"	5'-45"		
275		59'-52"	5'-47"		
300		7h-5'-45"	5'-53"		
325		11'-35"	5'-50"	113°	
331	125				125
empty 206					
225		7h-17'-18"	5'-43"		
250		22'-55"	5'-37"		
275		28'-35"	5'-40"		
300		34'-32"	5'-57"		
325		40'-5"	5'-33"	127°	
329	123				123
empty 207					
250		7h-57'-26"	11'-20"		
254	47				47
		8h-25'		131°	

The dial of the cylinder pyrometer being graduated arbitrarily it is necessary in order to get the temperature by it, to have a table showing the temperatures corresponding to the different points on the dial. Such a table was partially made both before and after the experiment, but the indications given when the temperature was rising do not agree very well with those given when the temperature was falling neither do the results of the two trials agree. It was also afterwards found that the end of the brass tube was not so firmly fixed but that the needle could be moved by pressing backward and forward on the tube with the finger, when the cylinder head was taken out after the experiment.

Owing to this uncertainty, I will not give the record of readings, but simply say that it indicated considerably higher during the experiment than it did during either of the trials with saturated steam at 70 lbs pressure except the first one or two readings taken just after the stop in the middle of the experiment which were as low as those given for saturated steam. The extent of the oscillations of the needle was quite uniform but the mean reading increased as the experiment continued.

While the engine was running preparatory to the beginning of the experiment a U shaped thermopile was placed on the indicator cock at the front end, one end being in the steam and the other dipping into a cup of oil. The needle of the galvanometer was prevented from turning in but one direction by stops so that it would not move until the temperature of the oil was equal that of the steam in the indicator cock. The thermometer placed in the oil shew a temperature of 325.4 F. at first, but the last reading before the engine stoped was 338 F. at which time the temperature shown by the steam pyrometer had fallen to 560° F. After the fires had been fixed and the engine started, the

following temperatures were taken.
Temp, of the oil rising 327,2°F.
" " " " falling 332,6°F.

Several experiments were made to ascertain the leakage and although they did not give exactly the same results, the results which I have sed are perhaps as near the truth as the others. These results are as follows, for one admission valve 1 1/8 lbs in 5 minuits. out of piston and one exhaust 6 7/8 lbs in 5 minuits. In ascertaining this the engine was placed on one of its centres and saturated steam used.

The clearance with the new cylinder head and pyrometer was ascertained by a water measurement to be

.037 of the stroke at the front end and .031 at the crank end.

The cards were divided into 20 equal parts and 21 ordinates measured, but on account of the number I give only the mean for each end. In finding the mean back pressure as given by the mean card I leave out the two end pressures, and to find the mean pressure acting on the piston I add together the half sum of the extreme pressures and the intermediate pressures, and divide by 20.

The mean compression for the Front end was .0135, for the Crank end was .0085 of the total length of the card.

Mean card.

Front end. Steam Pressure	Exhaust Pressure	Diff.	Crank end Steam Pressure	Exhaust Pressure.	Diff.
67,8	*13,2	54,6	65,6	*10,5	55,1
66.	1,1	64,9	62,8	,9	61,9
64,4	1,1	63,3	62,1	,9	61,2
62,2	1,1	61,1	60,2	,8	59,4
59,8	1,1	58,7	57,7	,9	56,8
49,6	1,1	48,5	45,1	,9	44,2
38,7	1,1	37,6	33,6	,9	32,7
30,4	1,1	29,3	28,2	,8	27,4
26,1	1,1	25,0	23,6	,9	22,7
22,2	1,0	21,2	19,8	,9	18,9
19,0	1,0	18,0	16,6	,8	15,8
16,3	1,1	15,2	14,3	,9	13,4
14,2	1,1	13,1	12,4	,9	11,5
12,5	1,1	11,4	10,7	,9	9,8
11,0	1,1	9,9	9,2	,9	8,3
9,5	1,1	8,4	8,0	,8	7,2
8,3	1,1	7,2	7,0	,9	6,1
7,1	1,1	6,0	6,0	,8	5,2
6,2	1,2	5,0	5,1	,9	4,2
5,4	1,2	4,2	4,4	,8	3,6
4,5	*1,7	2,8	3,6	*1,1	2,5
Mean back Pressure	1,1			.87	
Mean pressure acting on piston.		26,835			24,95

Front End.

Area of cylinder (8.01" dia) = 50.4053

Length of stroke — — 2' = 24"

Mean speed 58.087 rev. per minute

" pressure (page) 26.835 lbs

Horse Power = $\frac{50.4053 \times 26.835 \times 58.087 \times 2'}{33000}$

= 4.761982

Crank End.

Area of cylinder — 50.4053

" " piston (1 7/16" dia) = 1.623

Effective area of cylinder = 48.7823

Length of Stroke — — 2' = 24"

Mean speed 58.087 rev. per minute

" pressure (page) 24.95 lbs.

Horse power = $\frac{48.7823 \times 24.95 \times 58.087 \times 2}{33000}$

= 3.932866

HP at Front end = 4.761982

HP " Crank end = 3.932866

Total HP — = 8.694848

Total heat of steam (from 32°) by the Calorimeter considering the specific heat of water as unity.

Small tank—

			T. units
209,7 lbs	water from	(32°-76°) contains	9226,8
123,5 "	" "	(32°-85°) "	6545,5
122 "	" "	(32°-99°) "	8174,
125 "	" "	(32°-113°) "	10125,
123 "	" "	(32°-127°) "	11685,
47 "	" "	(32°-131°) "	4653,
750,2 "			

Large tank—

7303 lbs water from (38,3-150) "		816415,3
750,2 " " originally contained		866824,6
1 " " " "		1155,46

Mean back pressure at Front end = 1,1
" " " Crank end = ,87
" " " ,98

Total heat of saturated steam at ,98 lbs pressure calculated by the formula in Rankine's Steam Engine = 1147,T.U. total heat = 1146 + .3(T' − 212) British thermal units. In using this formula the temperature must first be ascertained from the pressure by table VI in the same work.

Water per horse power per hour

750,2 lbs water used in 169,5 minutes is equivalent to $\frac{60}{169,5} \times 750,2 = 265,50$ per hour.

$\frac{26550}{8,6948} = 30,54$ lbs = pounds per hour used to produce one horse-power

Front end

Volume of cylinder = .700074. Vol. of clearance = .0259027. Clearance = .037 of stroke

Point	Pressure from Indicator	Absolute Pressure	Vol. in times of piston displacement	Vol. Steam & Water in cubic feet	Wt of Steam per cubic foot in fractions of a lb, on the Supposition that it is Saturated	Wt of Steam at certain points disregarding vol. of Water, on the Supposition that it is Saturated.
0	67.8	82.23	.037	.02550		
1	66.0	80.43	.087	.06091		
2	64.4	78.83	.137	.09591		
3	62.2	76.63	.187	.13091		
4	59.8	74.23	.237	.16592		
4.35	59.07	73.5	.2545	.178179	.1724	.030718
5	49.6	64.03	.287	.20092	.151476	.030435
6	38.7	53.13	.337	.23592	.12707	.029978
7	30.4	44.83	.387	.27093	.108295	
8	26.1	40.53	.437	.30593	.098504	.030134
9	22.2	36.63	.487	.34093	.088566	
10	19.	33.43	.537	.37594	.082102	.030865
11	16.3	30.73	.587	.41094	.075948	
12	14.2	28.63	.637	.44595	.07106	.031689
13	12.5	26.93	.687	.48095	.06708	
14	11.0	25.43	.737	.51595	.06357	.032802
15	9.5	23.93	.787	.55096	.06004	
16	8.3	22.73	.837	.58596	.05719	.033511
17	7.1	21.53	.887	.62096	.05434	
18	6.2	20.63	.937	.65597	.05219	.034235
19	5.4	19.83	.987	.69097	.05029	
20	4.5	18.93	1.037	.72598	.04814	.034849

Crank End.

Volume of piston displacement ,677532

" " clearance ,0210035

Clearance = ,031 of Stroke

Point.	Indic'r Pressure	Absolute Pressure	Vol. in terms of Piston displacement	Vol Steam & Water in cu. ft.	Wt. steam per cubic ft. in fractions of a lb. on the supposition that it is saturated.	Wt steam at certain points of Stroke disregarding vol of water, on the supposition that it is Saturated.
0	65,6	80,03	,031	,02100		
1	62,8	77,23	,081	,05488		
2	62,1	76,53	,131	,08875		
3	60,2	74,63	,181	,12263		
4	57,7	72,13	,231	,15651		
4,18	57,17	71,60	,240	,162607	,1683	,027367
5,	45,1	59,53	,281	,19039	,14147	,026934
6	33,6	48,03	,331	,22426	,1155	,025902
7	28,2	42,63	,381	,25814	,10329	,026663
8	23,6	38,03	,431	,29202	,09279	,027097
9	19,8	34,23	,481	,32589	,08400	,027375
10	16,6	31,03	,531	,35977	,07664	,027573
11	14,3	28,73	,581	,39364		
12	12,4	26,83	,631	,42752	,06675	,028537
13	10,7	25,13	,681	,46120		
14	9,2	23,63	,731	,49528	,05933	,029385
15	8,0	22,43	,781	,52915		
16	7,0	21,43	,831	,56303	,05410	,030460
17	6,0	20,43	,881	,59691		
18	5,1	19,53	,931	,63078	,04957	,031268
19	4,4	18,83	,981	,66466		
20	3,6	18,03	1,031	,69854	,04599	,032126

In the two preceding tables the absolute pressure was found by adding 14.80, the atmospheric pressure at the time as given by the barometer in the physical laboratory, to the indicator pressure. The weight of steam per cubic foot on the supposition that it is saturated is got from table IV, Rankine's Steam Engine, by interpolation. And the last column is the product of the volume into the wt. per cubic foot.

In order to obtain the point of cut-off I find the equation to the expansion curve on the supposition that it is of the form $P = A + \frac{B}{v} + \frac{C}{v^2}$. To find the values of A, B, & C, I took 3 equations putting in the values of

P & v for 3 different points as given in the table, v being the volume in terms of piston displacement & P = absolute pressure.

The equations found for the Front end is $P = 5,2917 + \frac{13,103883}{v} + \frac{1,077368}{v^2}$

Crank end is $P = 6,183 + \frac{11,15421}{v} + \frac{1,078}{v^2}$

These values for A, B & C, may not be correct to the no. of decimal places to which they are carried, but I think correct enough for the purpose of finding the point of cutoff.

To find the cutoff for the front end let $P = 5,2917 + \frac{13,103883}{,247} + \frac{1,077368}{,247^2}$ $= 75.83$. .247 corresponding to point 4,2 Now drawing a diagram I find the point 4,35 and pressure 73,5 where the expansion line meets the line showing the decrease in pressure before the cutoff.

Proceeding in the same way I find the point of cut-off for the crank end to be 4,18 & the pressure at cutoff to be 71,60 above the absolute zero.

Weight of steam present in the cylinder during expansion, from the weight of water collected in small tank corrected for clearance and leakage of one admission valve into exhaust.

Leakage of one admission valve into exhaust = 1/8 lbs. in 5 minutes or 38,133 lbs during the whole experiment.

Wt of water collected in small tank

= 750,22 lbs. Weight of water corrected for this leakage = 712,0672 lbs
Wt of steam as shown by the indicator at cut off in Front end ,030718 lb

Crank end ,027367 lb
,058085

Front End.

,058085 : ,030718 :: 712,067 : 376,5735 which is the proportionate amount passing through the front end of the cylinder as shown by the small tank corrected for leakage of one admission valve into exhaust.

No. of revolutions of engine 9855.

376,5735 ÷ 9855 = ,038201 lbs = wt of steam passing through the engine per stroke.

Wt. of steam in cylinder at point of compression as calculated from the pressure and volume = .001556 supposing it to be saturated steam. Adding this to the weight got from small tank. .038201 + .001560 = .039761 = wt. of steam + water in front end per stroke corrected for clearance and leakage of one admission valve into exhaust.

Crank End.

.058085 : .027367 :: 712.067 : 335.4935 = proportionate wt. of water passing through crank end.

335.4935 ÷ 9855. = .034043 = wt. of water passing through crank end per stroke.

.034043 + .001212 = .035255 = wt in cylinder per stroke at crank end corrected for clearance and leakage.

The leakage of one admission valve is 1⅛ lbs in 5 minutes which is equivalent to ,00375 lbs per second. Time in seconds during which one degree is passed over by crank pin supposing its motion to be uniform

$= \frac{168.48 \times 60}{360 \times 9855} = ,0028662.$

,0028662 × ,00375 = ,000010748 = leakage into cylinder per degree.

The leakage out of piston and one exhaust valve = 6⅞ lbs in 5 minutes = ,022917 lbs per second.

,0028662 × ,022917 = ,00006568 = leakage out of cylinder per degree through piston and exhaust.

Front End.

Wt in cylinder from small tank corrected for clearance and leakage of crank admission valve = ,03876 lbs

Leakage in, per degree ,00010748

" out, " " ,00006568

Point	No. Degrees passed over by crank pin since beginning of stroke.	Number degrees from point to end of stroke	Leakage into cylinder from point to end of stroke.	Weight in cylinder corrected for leakage into cylinder.	Leakage out of cylinder from beginning of stroke to point.	Wt. in cylinder from small tank corrected for clearance & leakage in and out.
4,35	51,35°	128,65°	,0013827	,0383783	,0033727	,0350056
5	55,75°	124,25°	,0013354	,0384256	,0036617	,0347639
6	61,875°	118,125°	,0012696	,0384914	,004064	,0344274
8	73,5°	106,5°	,0114466	,03861634	,0048275	,03378804
10	84,875°	95,125°	,0010224	,0387386	,0055746	,033164
12	96,375°	83,625°	,0008988	,0388622	,0063299	,0325323
14	108,5°	71,5°	,0007685	,0389925	,0071268	,0318657
16	122,5°	57,5°	,000618	,039143	,0080458	,0310972
18	139,75°	40,25°	,0004326	,0393284	,0091789	,0301495
20	180,°	0,0°	,0000000	,039761	,0118224	,0279386

Crank End.

Wt. in cylinder per stroke from small tank corrected for clearance and leakage of front admission valve ,035255.

Leakage in. per degree ,00010148

" out. " " = ,00006568

Point.	No degrees passed over by crank pin since beginning of stroke.	No of degrees from point to end of stroke.	Leakage into cylinder from point to end of stroke.	Wt in cylinder corrected for leakage in.	Leakage out of cylinder from beginning of stroke to point.	Wt. in cylinder from small tank corrected for clearance & leakage in and out.
4,18	58,85°	121,11°	,00120165	,0339533	,0038677	,0300854
5	64,75°	115,25°	,0012087	0340163	,0042728	,0297435
6	71,5°	108,5°	001166	034087	,004696	,029353
8	83,625°	96,375°	,0010358	0342192	,00549247	,0287267
10	95,125°	84,875°	,0008123	,0343427	,0062478	,0280949
12	106,5°	73,5°	,00780	0344657	,0069949	,0274701
14	118,125°	61,875°	,00665	0345750	,00775845	,02683115
16	130,75°	49,25°	,00052834	,0347257	,0085877	,026138
18	145,875°	34,125°	,00036678	,0348882	,00958107	,02536613
20	180°	0,00°	,000000	,035255	,0118224	,0234326

Front end,

Pressures obtained from small tank measurement on the supposition that the total weight of steam in the cylinder was dry saturated steam.

A	B	C	D	E	F
Point	Wt. of steam in cylinder found from sm. tank meas. corrected for clearance & leakage in & out. (see) page 39	Vol. steam & water in cylinder in cu. ft. (see) page 31	Density of steam by sm. tank meas. (Column B ÷ C)	Absolute Pressure from Column D.	Pressure above the Atmosphere (Column E - 14.43)
4.35	.0350056	.178177	.19646	84.4455	70.0155
5	.0347639	.20092	.17302	73.766	59.336
6	.0344274	.23592	.14593	61.087	46.657
8	.03378884	.30593	.110446	45.775	31.345
10	.033164	.37594	.088216	36.04	21.61
12	.0325323	.44595	.07295	29.44	15.01
14	.0318657	.51595	.06176	24.66	10.23
16	.0310972	.58596	.05307	20.96	6.53
18	.0301495	.65597	.04596	18.02	3.59
20	.0279386	.72598	.0371065	14.35	-.08

Crank end

Pressures obtained from small tank measurement, with corrections, on the supposition that the whole weight of steam in the cylinder was dry saturated steam.

A	B	C	D	E	F
Point	Wt of steam in cylinder found from sm. tank meas. corr. for clearance & leakage in & out. (See page 40)	V. of steam & water in cylinder in cu. ft. (See page 32)	Density of steam by sm. tank meas.nt (column B ÷ C)	Absolute pressure from column D.	Pressure above the Atmosphere (Column E - 14,43)
4,18	,0300854	,162607	,18502	79,2218	64,8918
5	,0297435	,19039	,15622	66,16	51,73
6	,029393	,22426	,13106	54,853	40,423
8	,0287267	,29202	,09837	40,47	26,04
10	,0280849	,35977	,078094	31,818	17,488
12	,0274701	,42752	,06425	25,89	11,46
14	,0268316	,49528	,0541745	21,46	7,03
16	,026138	,56303	,04642	18,21	3,78
18	,025366	,63078	,040212	15,629	1,199
20	,0234326	,69854	,033545	12,888	-1,542

The crank angles are taken from the table in Auchincloss' Link & Valve Motions, in which the ratio of the connecting rod to the crank is as 5½ : 1. Except the angles for the point of cut off which were calculated trigonometrically.

The leakage in and out is calculated on the assumption that the leakage varies only as the time, and is independent of the pressure or condition of the steam, and of the position of the different parts of the engine. Which assumption very likely leads to a considerable error.

Column E on page & is obtained by interpolation from table IV Rankine's Steam Engine. The pressure are those which would have acted in the cylinder, had all the water collected in the small tank, (corrected for leakage of valves and piston, correctly) plus that retained in the cylinder at exhaust closure been dry saturated steam, during the expansion.

It will be seen, by comparing these pressures with those given by the indicator, that during the first of the expansion they are much higher than those given by the indicator but decrease more rapidly as the expansion goes on, and from point 14 and beyond for the front end, and 12 and beyond for the crank end are below those given by the indicator.

This shows that before the point where the two curves cross each other there was water in the cylinder and beyond the steam was super heated somewhat.

The following table is useful in getting the temperature of the steam at those points where it was superheated

Rankine's Steam Engine.

	Table IX.	Table VI.		$\frac{pv}{144 V_{sat}}$		
T Temperature.	pv Product of Pressure and volume of Steam gas per pound.	V_{sat} Volume of Saturated Steam at given temperature	P_{sat} Pressure of Saturated Steam at given temperature,	P_{sup} Pressure of superheated steam at given temperature,	$\frac{P''_{sat} - P'_{sat}}{P''_{sup} - P'_{sup}}$	$\frac{P''_{sat} - P'_{sat}}{T_2 - T_1}$
194	55582	37,26	10,16	10,43		
					1,04	3,56
212	57520	26,36	14,7	15,15		
					1,05	2,95
230	59058	19,03	20,8	21,556		
					1,059	2,24
248	60596	14,1	28,83	30,06		
					1,065	1,73
266	62134	10,48	39,25	41,17		

POINT	A	B	C	D	E	F	G
	Pressure of saturated steam from sm. tank. Column E, pages 41 & 42	Pressure there would have been in the cylinder had the steam been superheated just enough to be converted from saturated steam into steam gas. Computed from table page by interpolation.	Pressure in the cylinder from Indicator 3rd Col^n (Pgs 31 & 32)	Temperature of saturated steam corresponding to pressures given in Col^n A or of steam gas in the condition expressed at head of Col^n B	Absolute Temperature — Col^n D + 461,2°	Absolute Temperature of superheated steam of pressure given in Col^n C, assuming as true that the temp. is propotional to the pressure. Col^n F = E×C / B. See § 202 Rankine	Ordinary Temperature of Superheated Steam in Cylinder. Col^n F − 461,2
Front End							
14	24,66	25,65	25,43	238,65	699,85	699,8	236,6
16	20,96	21,72	22,73	230,36	691,56	723,7	262,5
18	18,02	18,64	20,63	223,62	684,82	757,8	296,7
20	14,35	14,79	18,93	210,69	671,89	859,96	398,8
Crank End							
12	25,89	26,95	26,83	241,4	702,6	699,4	237,2
14	21,46	22,25	23,63	231,48	692,68	735,64	274,44
16	18,21	18,84	21,43	222,35	683,55	777,5	316,3
18	15,63	16,13	19,53	214,34	675,54	817,93	356,73
20	12,89	13,27	18,03	104,81	666,01	904,9	443,7

Steam in the condition expressed in column B, page 46 has the same temperature as that in column A, the first effect in superheating steam being to dry the saturated steam and raise the pressure without affecting the temperature.

The temperatures given in column G for the points 18 & 20 seem rather high especially the latter when it is seen that the temperature at the beginning of the stroke could not have been more than 320° if the steam was cooled down and condensed from 580°, or thereabout, on entering the cylinder. This would seem to show that the leakage had been estimated too great,

Total Heat.

Front End.

As calculated from the indicator measurement.

Column D is found by interpolation from table VI Rankine Steam Engine.

A	B	C	D	E	F
Point.	Pressure by the Indicator (page 31)	Wt of Steam computed from Indicator. (page 31)	Total heat in foot lbs. corresponding to pressures in col.n B per lb steam. Rankine table VI	Total heat in foot lbs, for wt. steam given in col.n C $E = C \times D$	No. thermal units heat in wt. steam given in col.n C, $E \div 772$
4,35	73,5	,030718	907257	27868,94	36,1
5	64,03	,030435	905083	27546,2	35,67
6	53,13	,029978	902270	27048,25	35,04
8	40,93	,030134	898300	27069,37	35,07
10	33,43	,030865	895629	27644,59	35,81
12	28,63	,031689	893536	28326,26	36,7
14	25,43	,032807	891959	29258,04	37,9
16	22,73	,033511	890496	29841,4	38,66
18	20,63	,034235	889294	30444,58	39,44
20	18,93	,034949	888201	31041,74	40,21

Total Heat,
Crank End,

As calculated from the indicator measurement.

Column D is found by interpolation from table VI Rankine's Steam Engine.

A	B	C	D	E	F
Point	Pressure given by the Indicator (page 32)	Wt Steam as given by the Indicator, (page 32)	Total Heat in foot lbs, per lb of steam corresponding to pressures in colⁿ B	Total Heat in ft, lbs, for wt steam given in colⁿ C E = C × D	No thermal units heat in Wt, steam given in colⁿ C F = E ÷ 772
418	71,6	,027367	906842	24817,54	32,15
5	59,53	,026934	903977	24347,72	31,53
6	48,03	,025902	900715	23330,32	30,22
8	38,03	,027097	897400	24316,85	31,5
10	31,03	,027573	894589	24666,5	31,95
12	26,83	,028537	892649	25473,52	33,
14	23,63	,029385	891005	26182,18	33,91
16	21,43	,030460	889761	27002,12	34,97
18	19,53	,031268	888584	27784,24	35,99
20	18,03	,032126	887613	28515,46	36,94

Total heat, Front End.

A	B	C	D	E	F	G	H
Point.	Temperatures corresponding to the pressures given by the Indicator Found by interpolation from table	Column B−32°	Wt. of steam & water by small tank (See page 41)	Wt. steam from Indicator. (See page 31)	Wt. Water. Colⁿ D−E.	Number of thermal units contained in water Colⁿ C×F	Real Total heat in British Thermal Units in cylinder.
435	305°	273°	,035006	030918	,004288	1,17	37,27
5	297°	265°	,034764	030435	,004329	1,16	36,87
6	285°	253°	,034427	029978	,004449	1,13	36,17
8	268°	246°	,033787	030134	,003655	,90	35,97
10	257°	225°	,033164	030865	,002299	,52	36,33
12	248°	216°	,032532	031689	,000843	,18	36,87

A	B		D	I	K	H
	Temperature of steam in cylinder. See page 46			Total Heat in foot lbs. per lb. of steam, for superheated steam at Temp. in colⁿ B. Found by interpolation from Rankine's table IX	Total Heat in ft. lbs. for Wt steam given in Colⁿ D. Colⁿ D×I	Colⁿ K÷772
14	233		,031866	917443	29235,24	37,87
16	263		,031097	928573	28875,83	37,41
18	297		,030150	941187	28376,29	36,76
20	399		,027939	978881	27368,55	35,45

Total Heat, Crank End.

A	B	C	D	E	F	G	H
Point.	Temperature corresponding to pressure given by Indicator	Column B − 32°	Wt steam & water by small tank (see page 42)	Wt. steam from Indicator, (See page 32)	Wt. Water, Colⁿ D−E	Number of thermal units contained in Water Colⁿ C×F	Real Total Heat in British Thermal Units in cylinder.
4,18	304	272	,030085	,027367	,002718	,74	32,89
5	291	259	,029744	,026934	,002810	,73	32,26
6	278	246	029393	,025802	,003491	,86	31,08
8	264	232	,028728	027097	,001631	,38	31,88
10	252	220	,028095	,027573	,000522	,11	32,06

A	B	C	D	I	K	H
	Temper of steam that is superheated in cylender, See page 46			Total Heat in foot lbs, per lb. for superheated steam at the temp. in colⁿ B. Found by interpolation from Rankine's table IX	Total Heat in foot lbs. for wt. steam given in colⁿ D = colⁿ D×I	Colⁿ K÷772
12	237,2		,027470	918927	25242,92	32,57
14	274,4		,026832	932654	25024,97	32,41
16	316,3		026138	948236	24784,99	32,1
18	356,7		025366	963447	24438,8	31,66
20	443,7		023433	995724	23332,8	30,22

Column B (pages 50 & 51) shows the temperature of the steam during the expansion. The temperatures for the first part where the steam was saturated are found from the pressures given by the indicator by interpolation in table VI Rankine's Steam Engine. The other temperatures of the steam when it was superheated are taken from column G page 46.

Column F shows the weight of water in the cylinder due to cylinder condensation, which was not wholly suppressed. It will be seen that the weight increases slowly up to point 6 when it falls off to less than nothing at point 14 for the front end and 12 for the crank end for at these points the steam has commenced to be superheated.

Column G gives the heat contained in the water given in column F.

The first part of column H is the sum of column G and the total heat of the steam shown by the indicator, column F pages 48 + 49. the rest of column H is deduced directly from the temperature and the weight as given by the small tank measurement after applying corrections.

The total heat per lb. of the steam in the superheater having a temperature of 550°F is 1048850,2 foot lbs. reduced to British thermal units is 1359,96 while the total heat of the exhaust steam as shown by the calorimeter was only 1155.46, which shows that over 200 thermal units were lost in passing through the engine by work and radiation.