A Study of Heat Transfer In a Double Pipe Condenser and a Brine Cooler and Some of Its Effects On Refrigeration Plant Operation

THESIS

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Preface

Ever since the advent of Mechanical refrigeration, accurate information relative to the heat transfer characteristics of double pipe coolers and condensers has been in demand. It is in partial answer to this demand and for scientific information that this investigation was undertaken.

These tests were conducted in the Experimental Engineering Laboratory at the Georgia School of Technology during the period November 15, 1927, to February 15, 1928. The authors wishe to thank the faculty members of the Experimental Engineering Department of the Georgia School of Technology for their kind assistance in setting up equipment and in taking data.

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I Object of Investigation

Since the patenting of the first compression refrigeration machine in 1834 by Jacob perkins of England and the first absorption machine in 1855 by Carre of France,[1] considerable experimental work has been devoted to the study of heat transfer in refrigeration equipment. While the subject of heat transfer was not studied by using refrigeration mediums as brine, ammonia, etc., the results obtained by using other heat carrying mediums such as steam, water, etc., were used.

The subject of heat transfer as a subject of mathematical and physical interest was first taken up by Newton as early as 1690.[2] His results were inaccurate and misleading as well as being based upon inadequate data. Perhaps the first work of scientific value was produced by Fourier of France in 1823.[3] His work was purely mathematical and stands as the first correct statements regarding some of the theoretical considerations in the flow of heat.

The subject was first investigated experimentally by Poisson in 1833,[2] Peclet in 1841,[2] and Joule in 1861.[4] The first two experi-

[1] Matthews, Fred E: Elementary Machanical Refrigeration, McGraw-Hill, 1912, p. 17.

[2] Orrok, George A: The Transmission of Heat in Surface Condensers, A.S.M.E., Transactions, 1910, Vol. XXXII, p. 1139.

[3] Glazebrook: Dictionary of Applied Physics, Macmillan and Co., Ltd., London, England, Vol. I, p. 429.

[4] Joule, J.P: Condenser Tube Experiments, Philosophical Transactions, Royal Society, London, Vol. 151, p. 133.

menters failed to bring to light anything of value due to the fact that they failed to take account of the heat transfer surfaces. In 1861 and 1870 the idea of surface resistance was suggested. Since this time surface resistance as well as the kind of heat carrying mediums has been the center of study in heat transfer work. Among the recent experimenters who have contributed some very valuable information are Professor Ser of Paris in 1887,[5] Gustav H. Hagemann in 1883,[5] J. Alex Smith in 1905,[6] Clement and Garland of the University of Illinois in 1909,[7] and George A. Orrok of New York in 1910.[5] The experiments of these men were carried on using steam and water as the heat carrying mediums such as take place in steam surface condenser- water on one side of the surface and condensing steam on the other.

The late John R. Allen of the University of Michigan[8] altered the subject by using condensing steam on one side of the transmitting surface and still air on the other. This type of heat transfer, using forced convertion, has been summarized in a short paper pre-

[5] Orrok, George A: The Transmission of Heat in Surface Condensers, A.S.M.E., Transactions 1910, Vol. XXXII, p. 1139.

[6] Smith, J. Alex: Experiments on Surface Condensers, Engineering, Vol. 181, p. 395.

[7] Clement, J.K. and Garland, C.M: A Study in Heat Transmission, Bulletin 40, University of Illinois.

[8] Allen, John.R: Notes on Heating and Ventilation, Domestic Engineer, Chicago, 1905.

sented to the A.S.M.E. in December of 1927 by Edwin R. Cox.[9]

Heat transfer from hot gases and radiation on one side of the surface to boiling water on the other has been studied extensively by the Babcock and Wilcox Company of New York,[10] Messers Krusinger and Ray of the Department of Interior in 1912,[11] and by Professor Huber O. Croft of the University of Illinois in 1927.[12]

It will be noticed that the above experiments do not use a combination of the refrigeration mediums. The only published information on heat transfer using ammonia as one of the mediums was that obtained by Professors Kratz and Macintire, and Mr. Gould of the University of Illinois,[13] December 1927. Their work deals only with the study of heat transfer for condensing ammonia on one side and water on the other in various designs of condensers.

The results of tests applicable to this investigation, and up to the time of the work done at the University of Illinois, might be stated briefly as follows:

1. *Investigators are at considerable* variance as to the effect

[9] Cox, Edwin R: General Heat Transfer Formulas, A.S.M.E., Dec. 5-8, 1927.

[10] Babcock and Wilcox Co: Steam, pp. 326-329.

[11] Kreisinger and Ray: The Transmission of Heat into Steam Boilers, Department of Interior, 1912.

[12] Croft, Huber O: Heat Transmission through Boiler Tubes, University of Illinois, Bulletin No. 168, 1927.

[13] Ibid: Bulletin No. 171, 1927.

of the velocity of the water in steam condensers on the heat transfer. Some give the relation as a direct function of the velocity, others as the velocity raised to the one-half power, and still others as the velocity raised to the one-third power.

2. The coefficient of heat transfer is constant for varying mean temperature differences in ammonia-brine coolers, and varies as the seven eights root of the mean temperature difference in steam condensers.

3. The heat flow through thin wall tubes is independent of the thickness of the wall for ordinary commercial pipe sizes.

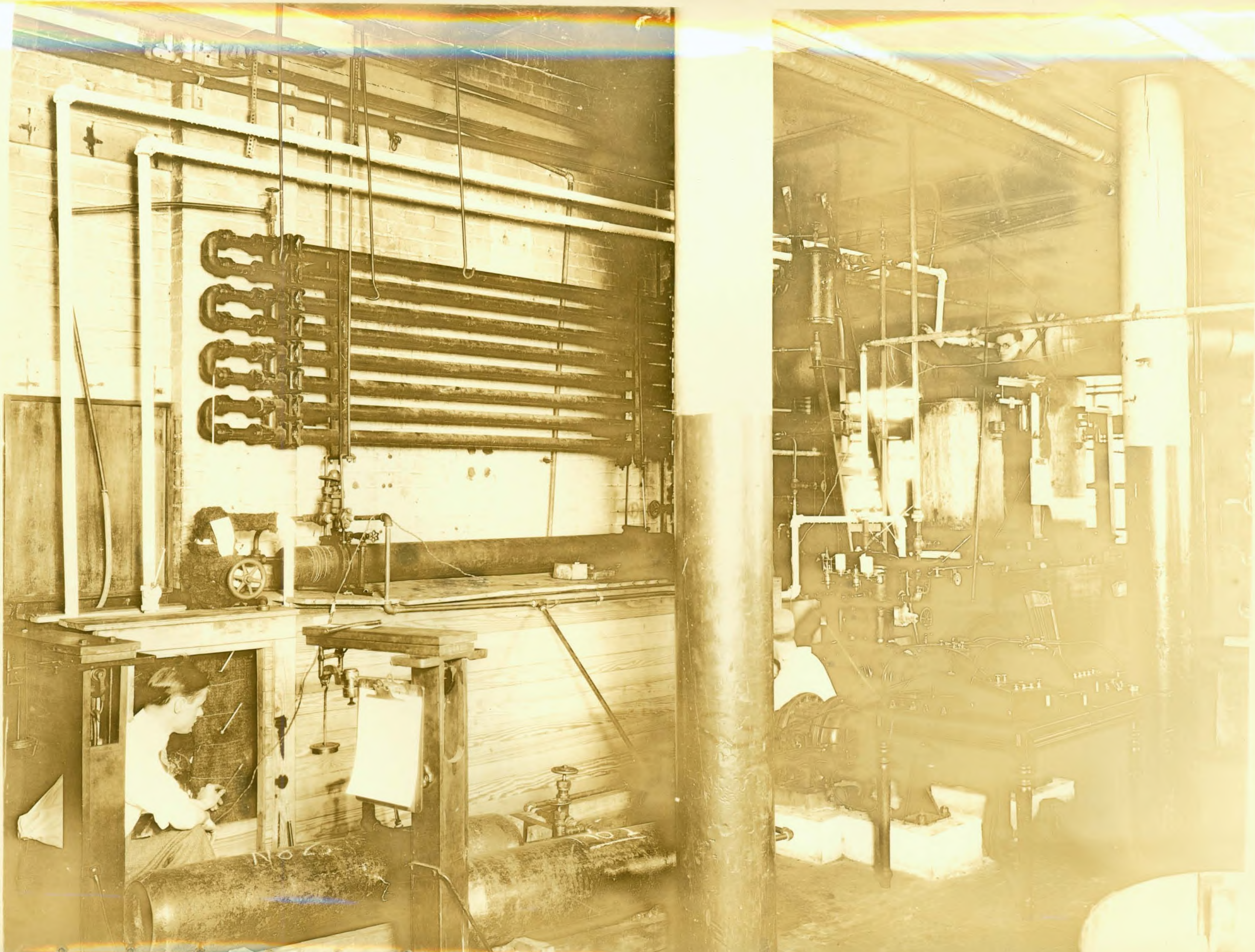
4. The coefficient of heat transfer is dependent upon the character of the heat transmitting surfaces.

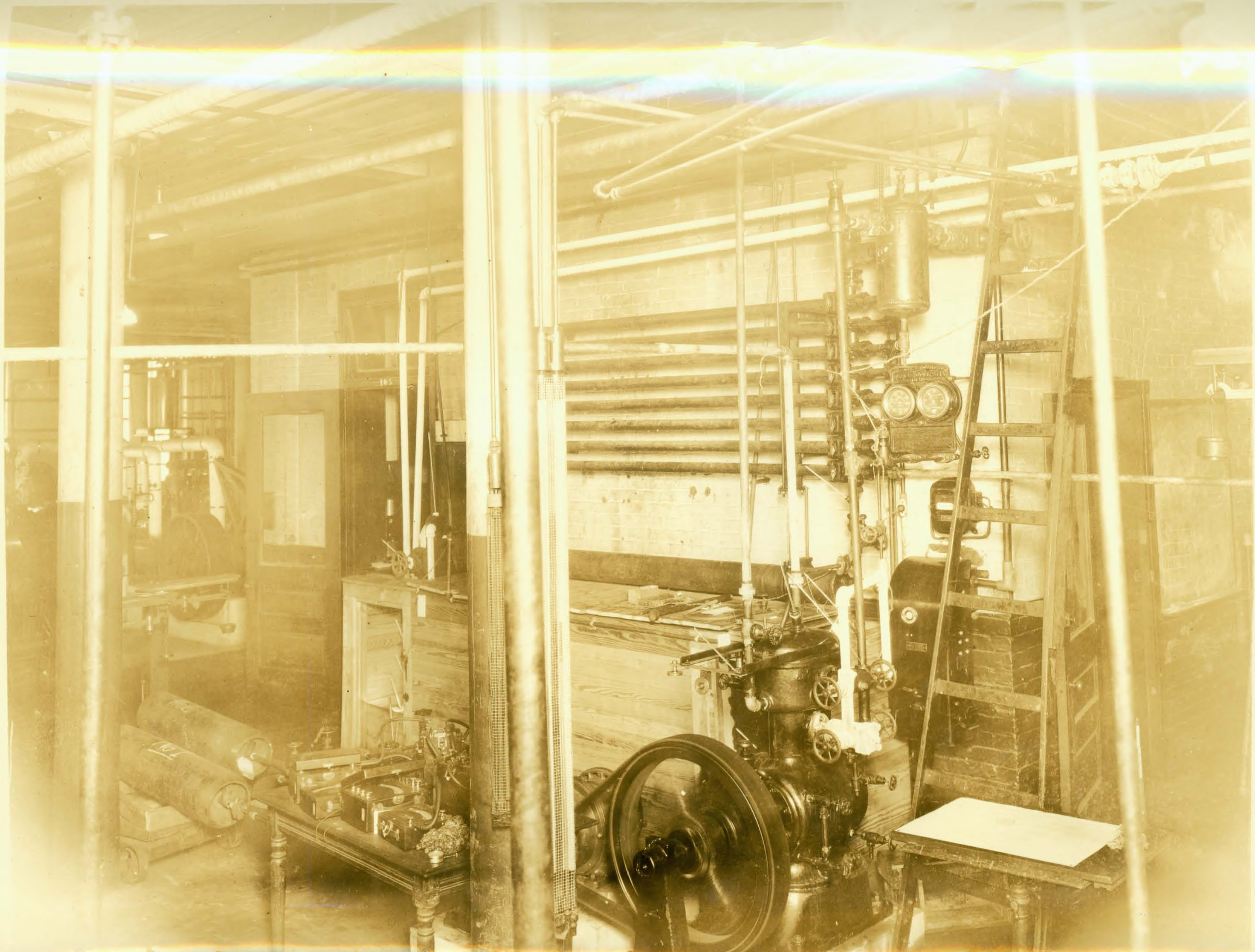
The test data supporting the above conclusions regarding ammonia equipment is scattered and unorganized, and often conflicting results appear. The objects of the tests that follow were: First, to determine the heat transfer characteristics of a double pipe cooler actually using ammonia on one side of the heat transfer surfaces and brine on the other. It should be noted that the ammonia was in a state of ebulsion. Second, to determine some of the heat transfer characteristics of double pipe condensers using condensing ammonia vapor on one side of the heat transfer surfaces and water on the other. It should be noted that the ammonia was being condensed. Third, to study the relation of heat transfer to compressor operation with a view of making some determinations for economical plant operation. This, of course, can be approached only by a study of the relative costs of power and the cost of water circulated.

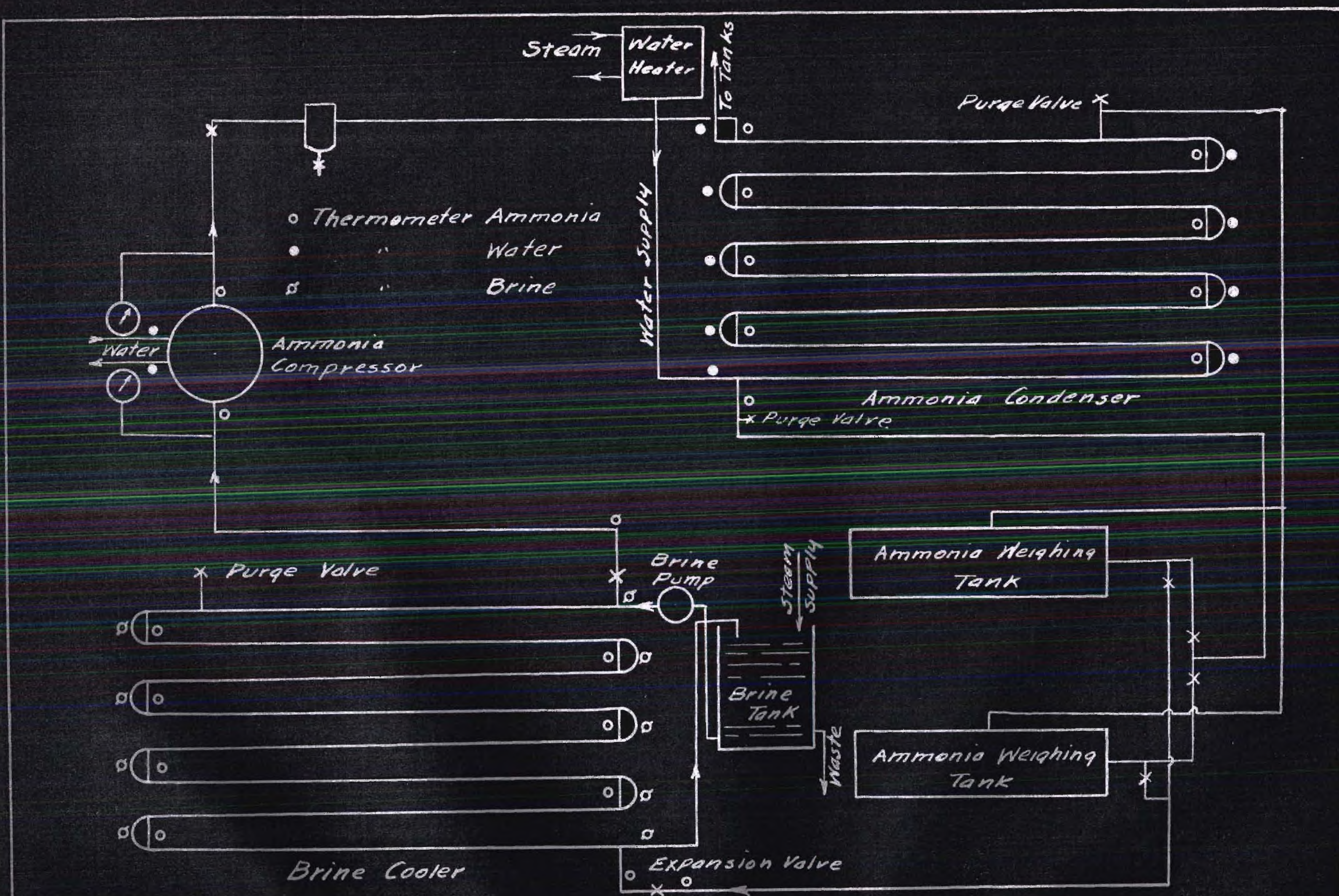
II Description of Apparatus

The cooler used in these tests was a double pipe counter flow cooler consisting of eight 1 1/4 inch pipes inside of 2 inch pipes ten feet long manufactured by the Frick Company. A picture of the coil is shown on page 12 and 13 and also a schematic sketch is shown on page 14. The ammonia entered one end of the bottom pipe, followed along the space between the 1 1/4 and 2 inch pipes, and was removed at one end of the top coil. The brine entered the 1 1/4 inch pipe at the top and was removed at about the same location as the ammonia entered. Thermometer wells were placed in each of the brine return bends, in each of the ammonia return connections, and in the pipes where both mediums entered and were removed from the coil. The location of the wells is best shown in figure 3, page 14. The cooler was insulated by twelve inches of granulated cork on all sides and two thickness of seven-eights inch tongue and groved boards with one thickness of beaver board nailed between. The thermometer wells and brine return bends were well insulated with one inch thick hair felt. The quality of the insulation was better than is found in average commercial practice.

The condenser used was an exact duplication of the cooler. The coils were uninsulated except for the thermometer wells; These were well covered with one inch hair felt. The superheated ammonia gas entered the top of the condenser and was removed as a liquid from the bottom coil. The ammonia occupied the same relative space in the condenser as in the cooler. The cooling water entered the bottom coil and was removed from the top pipe; thus the counter flow arrangement being used.







SCHEMATIC ARRANGEMENT

The ammonia was compressed by a 4 inch by 4 inch twin, vertical, single acting, closed frame, Frick compressor belt driven by a 7 1/2 horse power induction motor at speeds of 300 and 175 revolutions per minutes depending on conditions. The temperature of the brine and cooling water was regulated by turning steam into submerged heating coils in the storage tanks for these respective liquids. See sketch on page 14. The weights of ammonia, water, and brine circulated were obtained by direct weighing on Fairbanks scales sensitive to one-fourth pound throughout their range. The quantity of water circulated in the condenser tests using 20 and 25 gallons per minute was determined by calibrated measuring pits. The electric power supplied the compressor motor was measured by Jewel A.C. indicating watt meters calibrated by the Georgia Power Company.

It seemed advisable to use thermometers owing to the fact that they would be the logical instrument used in industry. They were also placed so that no contrasting temperatures were near them. The thermometers used were Tycos precision thermometers reading directly to 1/10 degree Fahrenheit.

III Method of Conducting Tests

In order to obtain the heat transfer characteristics for the cooler over the commercial ranges ordinarily used, it was decided to vary the mean temperature difference from 4 degrees Fahrenheit to 20 degrees Fahrenheit and the brine velocity from 75 feet per minute to 400 feet per minute. By using 4 degree increments of a mean temperature difference and running the brine at 75, 150, 250, 350 and 400 feet per minute for each mean temperature difference, a series of twenty five runs were necessary. There were then five runs in which the velocity was constant and the mean temperature difference varied from 4 degrees to 20 degrees Fahrenheit. Also, five runs in which the mean temperature difference was constant and the velocity varied from 75 feet per minute to 400 feet per minute. The effect of both mean temperature difference and velocity could then be studied independently. The temperatures were taken at each of the points indicated on the cooling coil as well as such other data as might throw some reflection on the results. The ammonia was so regulated as to give flooded conditions at all times. The temperature of the ammonia showed no superheating due to compression in the compressor.

The condenser characteristics were obtained by running a series of forty-eight tests. A series of four tests were run in which the rate of cooling water entering was 60, 70, 80 and 90 degrees Fahrenheit. The ammonia compressed was then so adjusted for each of these temperatures that a pressure corresponding to a saturation temperature of two degrees above the temperature of the water leaving the condenser resulted. A second series of four tests were run with the same conditions except that the quantity of ammonia compressed was so adjusted that the resulting pressure obtained corresponded to a saturation temperature of five degrees above the temperature of the water leaving the condenser. A third series of five runs were made with the ammonia pressure in the condenser corresponding to a saturation temperature of eight degrees above the temperature of the water leaving the condenser. Thus, twelve runs were made with 60, 70, 80 and 90 degree cooling water and the rate of consumption of water was five gallons per minute. These tests were then repeated using 10,15,and 22 gallons per minute.

From the data obtained, the effect of the velocity of the cooling water, the effect of the mean temperature difference, and the effect of the pressure could be studied independently. By observing the power consumption of the compressor, the refrigeration effect and the quantity of water used; a study of the cost of operation under the various conditions could be made.

The above conditions were obtained by the use of submerged heating coils in the storage tanks in the cooling water and brine. The temperature could be kept quite constant due to the fact that there was always at least 1200 pounds of the brine or water present. Thus it would take a considerable quantity of heat to influence the temperature one way or another.

The amount of ammonia circulated in the cooler test was adjusted by changing the driving pulley to give 300 or 175 R.P.M., and also by passing back some of the compressed ammonia.

The cooler and condenser coils were examined before and after the test. In both cases the surfaces were found free of any diliterious materials which would have affected heat transfer. Excessive purging was resorted to as a means of freeing the system of air.

IV Results of Cooler Test

The results of the cooler test are tabulated on page 20 and the observed data are shown on pages 35, 36, 37, 38, 39, 40, 41 and 42. Items 1 to 6 inclusive of the result sheet are self explanatory. The brine range, item 7, was obtained by taking the difference of the temperature of the brine entering and leaving the cooler. The total heat transfer or cooling effect, item 8, was calculated from the brine range, weight of brine circulated per hour, and the specific heat of the brine. The effective length of cooling pipe, item 9, was that length of one and one-fourth inch pipe exposed to brine on one side and ammonia liquid or vapor on the other. The average heat transfer per feet length of pipe, item 10, was obtained by dividing the total heat transferred per hour by the effective length of the cooling pipe. The pipe areas, items 11 and 12, were calculated from values given by the National Tube Company.

In all heat transfer work, it has been an accepted fact that the mean temperature difference of the mediums on both sides of the transmitting surfaces causes the flow of heat to take place. Just what the mean temperature difference in coolers and condensers might be is not uniformly agreed upon by engineers. The test codes of the American Society of Mechanical Engineers recommend the logarithmic mean temperature difference, while the manufacturers of double pipe coolers and condensers use the arithmetic mean temperature difference.

The arithmetical mean temperature difference, item 13, was calculated using the following formula:

RESULT SHEET – COOLER TRANSFER TESTS – SERIES 1.

No.		Unit	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
1	Length of Run	Min	120	120	120	120	120	60	60	120	120	60	60	120	120	120	60	60	60	120	120	60	90	65	120	120	60
2	Weight of Brine	#	7739	7215.5	6851	6441	6534	7735	7544	13783	10624	6580	11,354	22920	23,566	21513	11536	15620	17074	32063	34588	15920	24383	20501	37573	38763	18984
3	Sp. Gr. Brine 60°		1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.175	1.18	1.18	1.18
4	Ave. Sp. Heat Brine	BTU/°F	.737	.736	.736	.7365	.7365	.737	.736	.736	.7365	.7365	.736	.736	.736	.736	.7365	.736	.736	.736	.7365	.7365	.736	.736	.736	.736	.736
5	Cross Sectional Area Flow	□"	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5
6	Velocity of Flow	ft/sec	1.395	1.303	1.237	1.163	1.18	2.805	2.733	2.487	1.666	2.38	4.116	4.152	4.25	3.89	4.17	5.66	6.182	5.79	6.24	5.75	5.89	6.85	6.78	7.00	6.85
		ft/min	83.7	78.2	74.2	69.8	70.8	168.2	164	149.2	115.2	142.6	247	249.2	255.1	233.5	250	340	371	345.5	374.5	345	353.4	411	407	414	411
7	Brine Range	°F	9.78	7.14	6.37	6.48	4.63	6.0	4.7	4.5	4.6	2.2	4.6	3.55	2.87	2.7	1.76	3.0	2.4	2.33	1.8	1.44	3.44	2.2	2.1	1.7	1.3
8	Total Heat Transfer	Tons	2.308	1.575	1.3375	1.3125	.928	2.85	2.17	1.89	1.5	.89	3.2	2.49	2.07	1.78	1.25	2.88	2.53	2.29	1.91	1.405	3.43	2.55	2.41	2.02	1.515
		BTU/Hr	27690	18950	16050	15750	11140	34200	26100	22800	18000	10660	38450	29930	24850	21400	15040	34520	30400	27450	22900	16890	41100	30680	29000	24250	18160
9	Effective Length Pipe	Ft	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33	73.33
10	Heat Transfer Per Foot	B.T.U.	377	258	218.5	214.5	151.7	467	356	266.5	245.5	145	525	457	420	292	227	471	415	374.2	312.5	231	561	419	395.5	331	210
11	Inside Pipe Area I.S.	□'	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	264.7	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47
12	Outside Pipe Area O.S.	□'	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88	31.88
13	Arithmetical M.T.D	°F	18.255	11.68	9.75	10.46	4.51	21.88	14.37	12.02	8.75	3.7	22.88	16.4	13.37	8.4	4.51	19.77	14.8	10.98	8.35	4.40	22.8	18	12.045	8.15	5.42
14	Logarithmical M.T.D	°F	17.52	11.1	9.04	9.00	4.00	21.7	14.0	11.82	8.22	3.42	22.15	17.02	13.4	8.26	4.5	19.6	14.32	10.98	8.22	4.45	23.35	16.7	12.02	8.09	5.39
15	Actual M.T.D	°F	17.49	11.6	9.12	9.54	3.86	21.7	14.1	11.86	8.4	3.44	22.2	16.9	13.4	8.3	4.5	19.7	14.5	11.0	8.3	4.4	230	17.0	12.0	8.1	5.4
16	K ~ Arith. M.T.D BTU/Hr/°F/□'	O.S.	47.6	50.9	55.55	52.2	77.4	49.0	57.0	59.6	64.6	90.5	52.9	53.4	58.3	80	104.5	55.2	64.5	78.5	86	139	56.7	53.5	75.7	93.5	105.4
		I.S.	57.35	61.3	62.1	56.9	93.2	59.1	68.6	71.7	77.8	105	63.8	64.2	70.2	96.4	126	66.5	82.4	94.5	103.5	167.3	68.2	64.4	91.2	112.5	126.7
17	K ~ Log. M.T.D. "	O.S.	54.6	53.6	55.8	54.9	97	49.3	58.5	60.5	68.6	97.8	54.5	61.8	58.2	81.5	104.7	55.3	66.6	78.5	87.2	139	55.2	57.6	75.7	94.2	106
		I.S.	59.75	64.5	67.1	66.1	105	59.5	70.3	72.9	82.6	118	65.6	66.1	70.1	98.0	126.2	66.6	80.3	94.5	105.5	143	66.5	69.4	91.2	113.4	127.2
18	K ~ Actual M.T.D. "	O.S.	54.7	51.3	55.2	51.8	90.4	49.3	58.4	60.5	68.3	97.6	54.45	61.9	58.2	81.25	104.7	55.3	66.4	78.5	87.3	138.3	55.0	57.9	75.6	94.2	106
		I.S.	59.8	61.8	66.4	62.4	108.6	59.5	70.4	72.9	82.3	118	65.55	66.2	70.1	97.9	126.2	66.5	80.1	94.4	105.7	142	66.2	69.6	91.1	113.4	127.2
19	Brine Film Coef BTU/□'/sec	B.T.U.	.282	.281	.280	.278	.2785	.321	.320	.310	.292	.308	.352	.358	.361	.347	.358	.390	.408	.39	.406	.39	.392	.422	.421	.425	.422
20	Steel Coef "	B.T.U.	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
21	Ammonia Film Coef "	B.T.U.	.0178	.0193	.0205	.020	.0321	.01777	.02125	.022	.0252	.033	.0195	.01965	.0209	.0305	.0402	.01971	.024	.0288	.0332	.0458	.01968	.0205	.02755	.0360	.0397
22	ΔT Brine Surface	°F	1.03	.707	.597	.594	.419	1.117	.856	.773	.647	.313	1.147	.872	.723	.648	.44	.93	.782	.739	.600	.454	1.1	.76	.724	.707	.451
23	ΔT Steel Wall	°F	.242	.165	.140	.1375	.0972	.296	.228	.1495	.1572	.0804	.3365	.260	.217	.189	.1312	302	.266	.24	.2	.1473	.359	.2685	.254	.212	.1585
24	ΔT Ammonia Film	°F	16.24	10.228	8.303	8.255	3.47	20.05	12.88	10.88	7.39	3.03	20.7	15.89	12.48	7.39	3.916	18.27	13.3	10.0	7.53	3.86	21.9	15.72	11.05	7.06	4.79

$$\text{Arith. M.T.D.} = \frac{(T_i - t_o) + (T_o - t_i)}{2}$$

In which: T_i is the temperature of ammonia entering

T_o is the temperature of the ammonia leaving

t_i is the temperature of the brine entering

t_o is the temperature of the brine leaving

The logarithmetical mean temperature difference, item 14, was calculated using the following formula:[14]

$$\text{Log. M.T.D.} = \frac{O_i - O_o}{\log_e \frac{O_i}{O_o}} \quad \text{or} \quad \frac{O_o - O_i}{\log_e \frac{O_o}{O_i}}$$

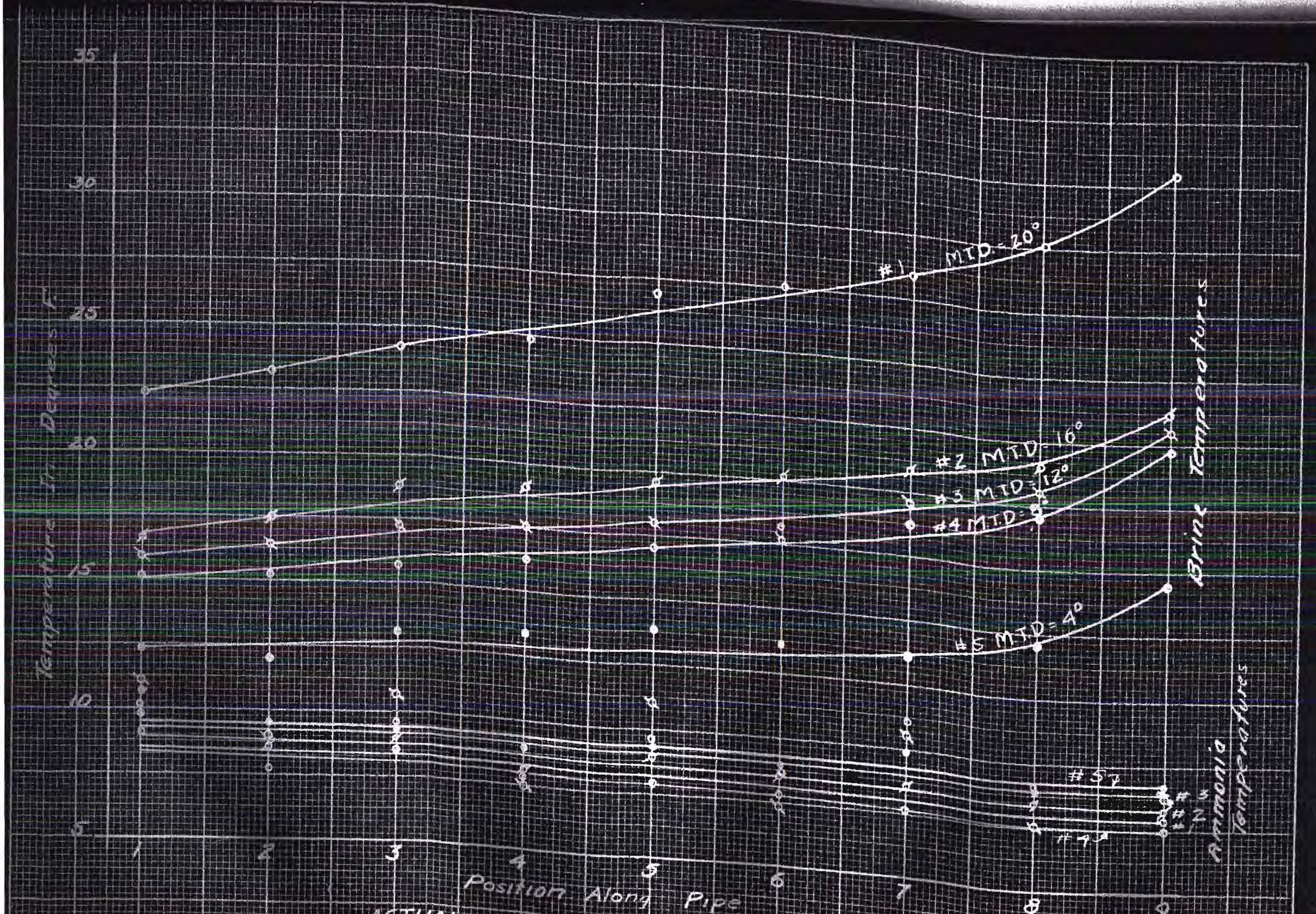
In which: O_i is the temperature difference of the ammonia entering and the temperature of the brine leaving.

O_o is the temperature difference of the ammonia leaving and the temperature of the brine entering.

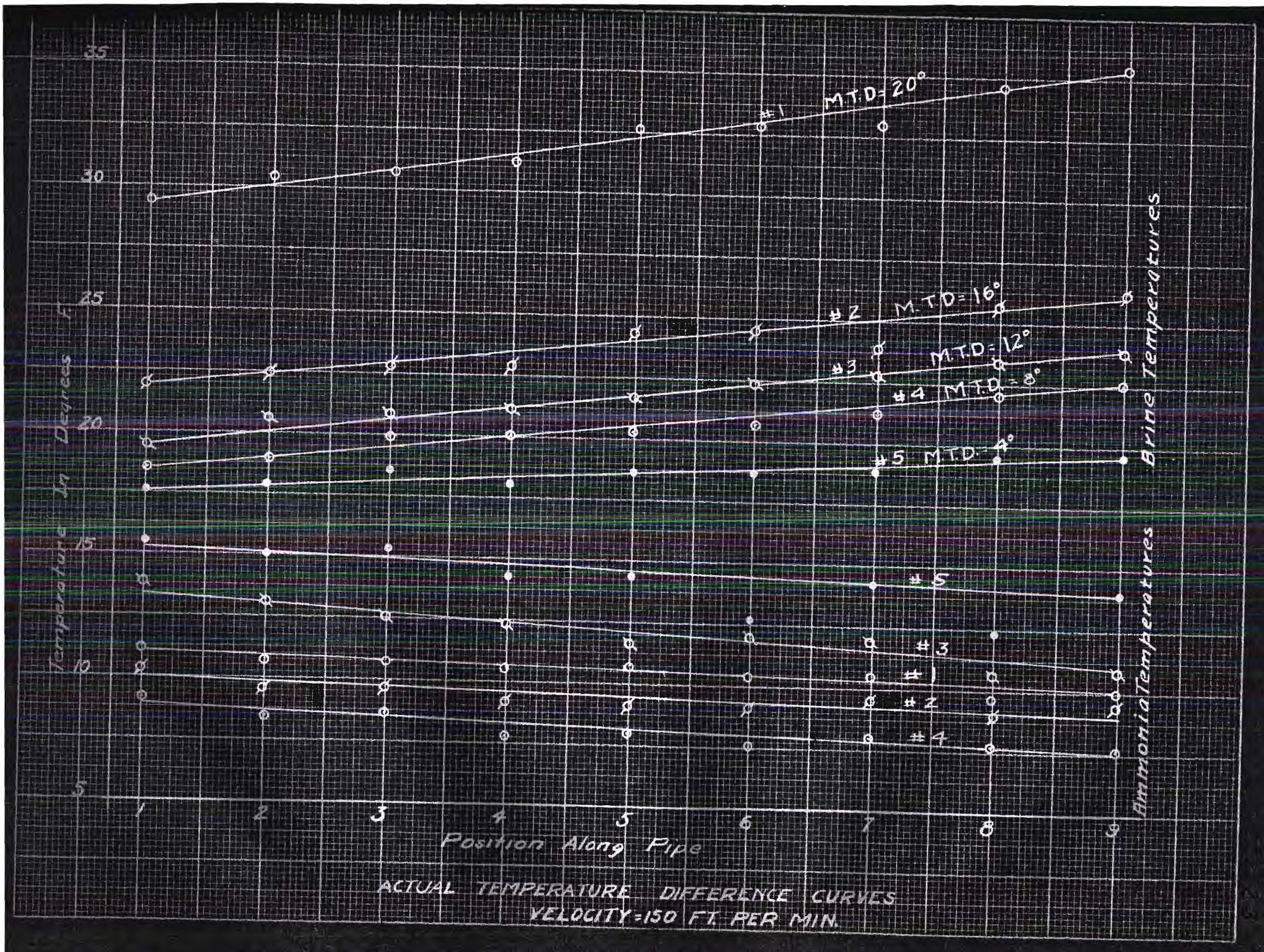
Correction was made to take care of the decrease of ammonia temperature at the outlet. The theoretical proof of this formula is presented very well in "Steam Power Plants" by Hirshfeld and Barnard of Cornell University, pages 624 to 650.

The actual mean temperature difference, item 14, was obtained by plotting curves with the temperatures of the ammonia and brine

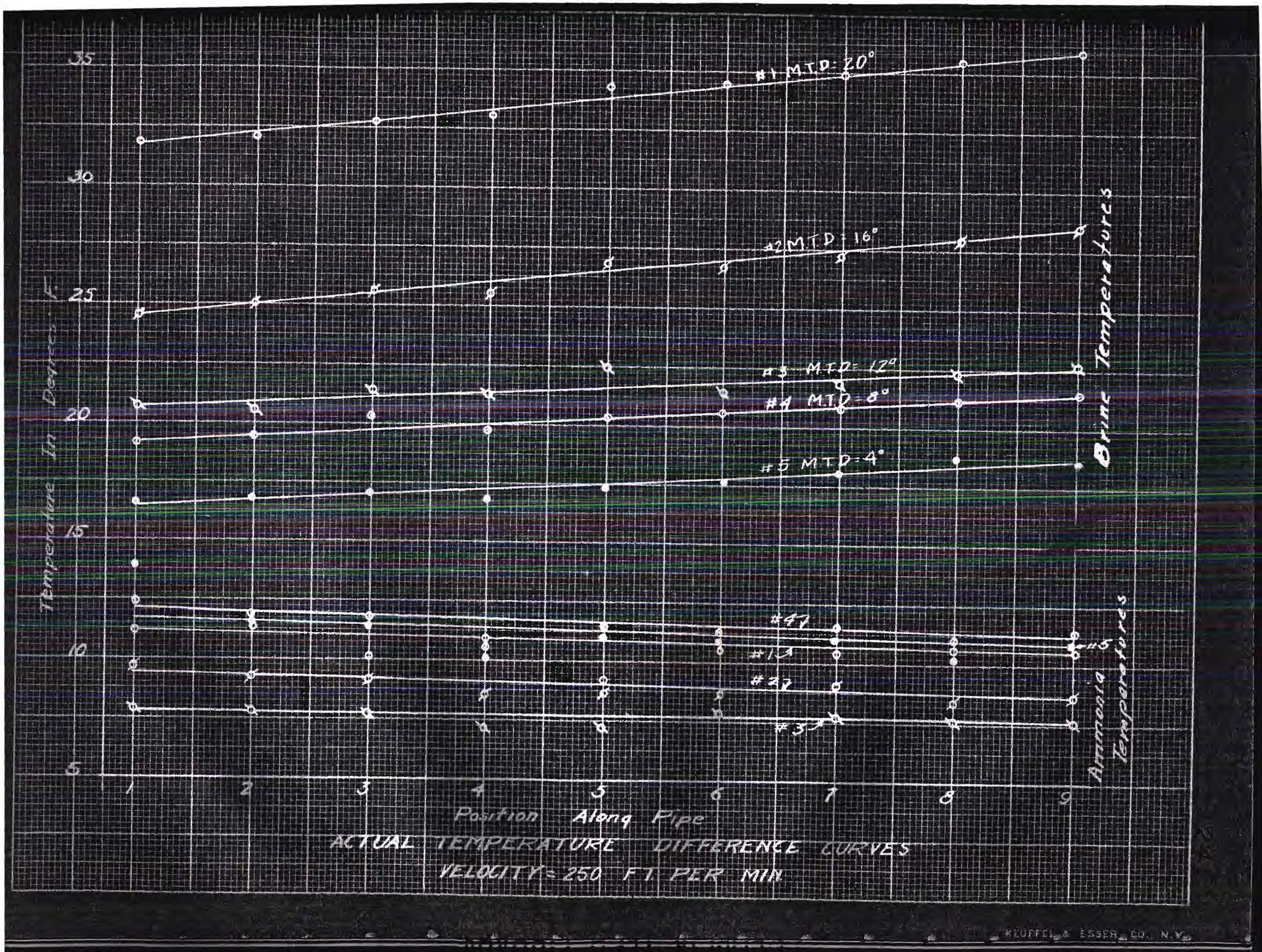
[14] Hirshfeld, C.F. and Barnard, William N: Elements Steam Power Engineering, John Wiley and Sons, New York, pp. 624-650, 796.



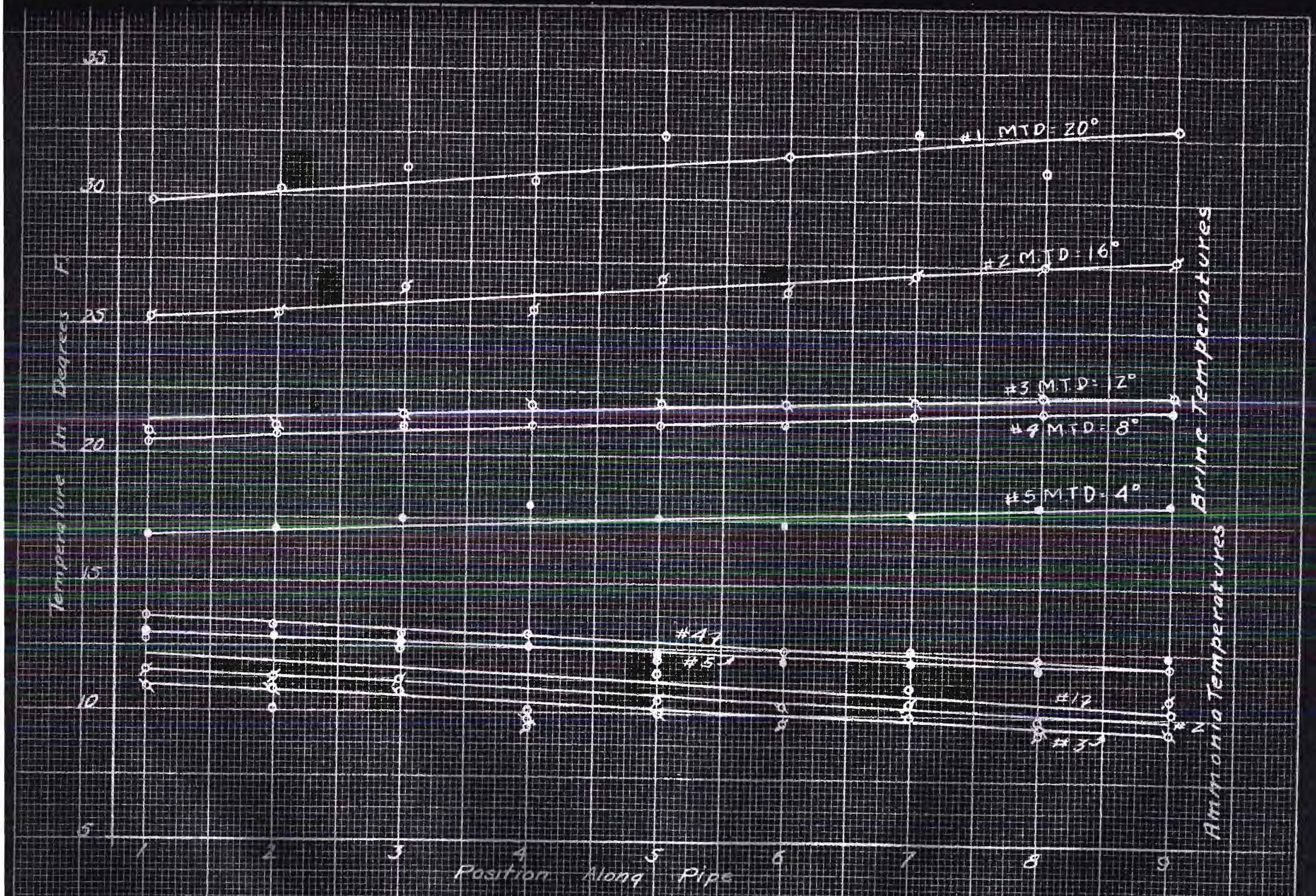
ACTUAL TEMPERATURE DIFFERENCE CURVES
VELOCITY = 75 FT PER MIN



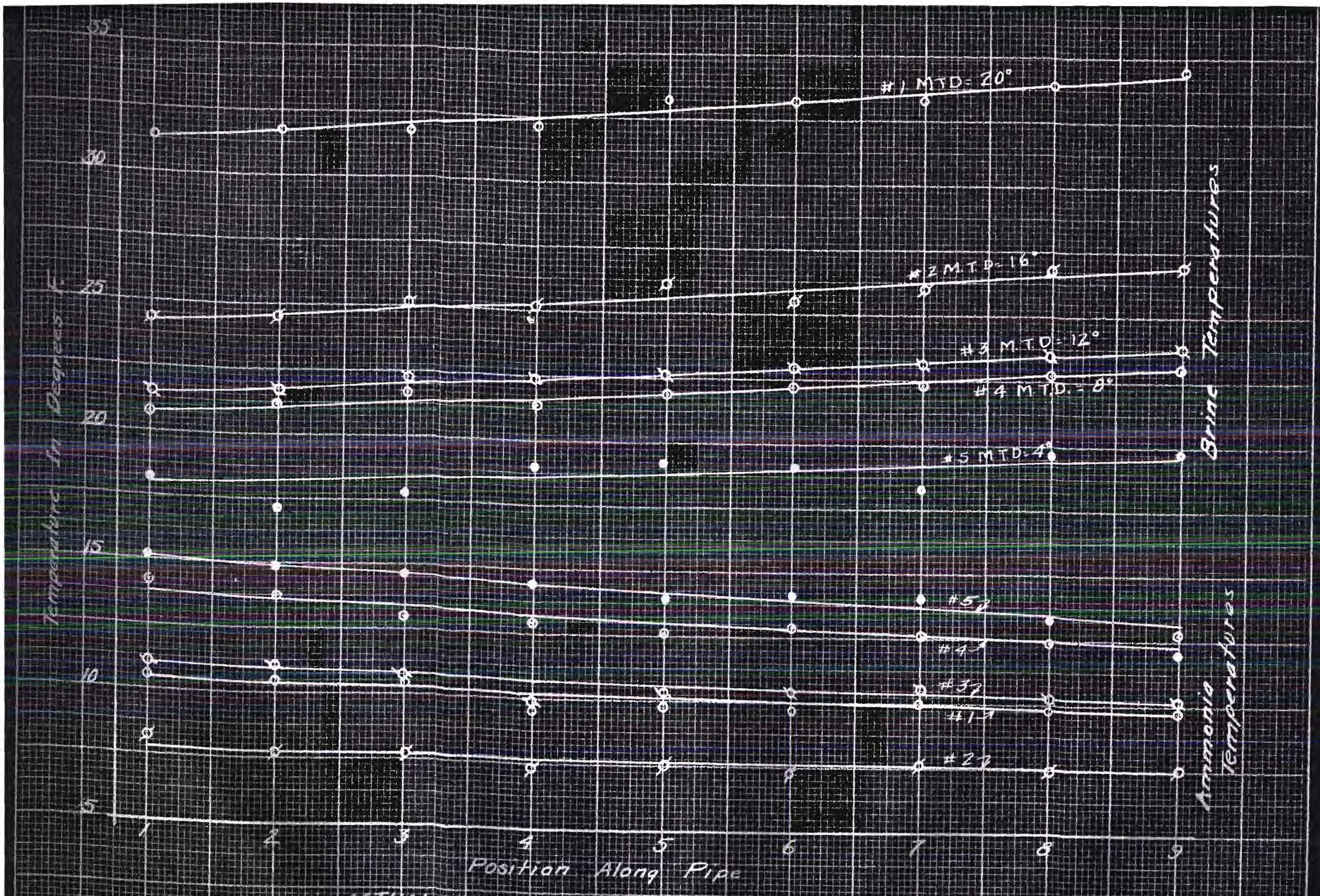
ACTUAL TEMPERATURE DIFFERENCE CURVES
VELOCITY=150 FT. PER MIN.



35
30
25
20
15
10
5
Temperature In Degrees F.
#1 M.T.D.=20°
#2 M.T.D.=16°
#3 M.T.D.=12°
#4 M.T.D.=8°
#5 M.T.D.=4°
Brine Temperatures
#4
#1
#5
#2
#3
Ammonia Temperatures
1
2
3
4
5
6
7
8
9
Position Along Pipe
ACTUAL TEMPERATURE DIFFERENCE CURVES
VELOCITY=250 FT. PER MIN.
KEUFFEL & ESSER CO. N.Y.



ACTUAL TEMPERATURE DIFFERENCE CURVES
VELOCITY = 350 FT PER MIN.



ACTUAL TEMPERATURE DIFFERENCE CURVES
VELOCITY = 400 FT PER MIN.

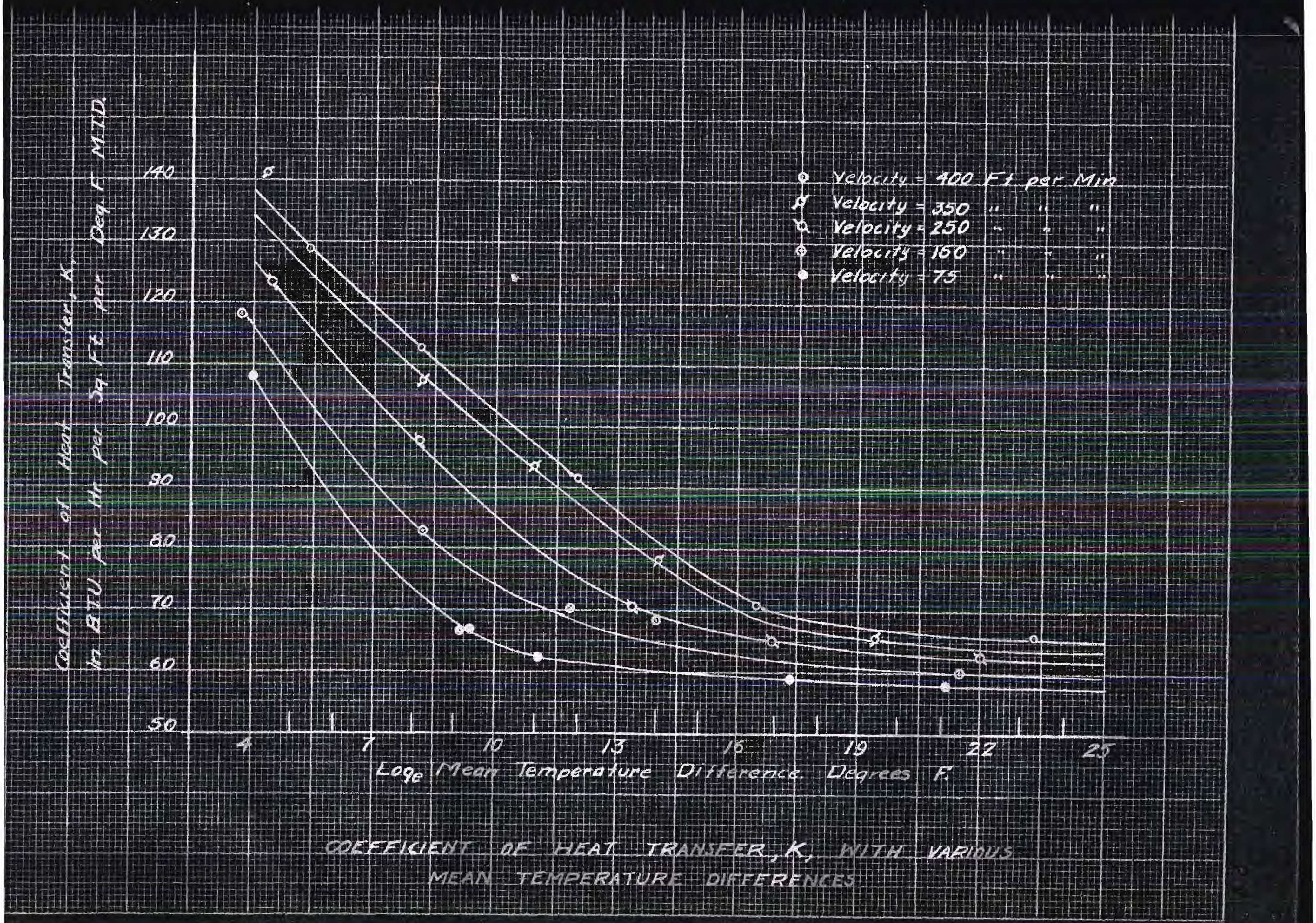
as ordinates and the position along the cooler pipe as abscissa, pages 21, 22, 23, 24, 25 and 26. By determining the inclosed area with a planimeter, the average ordinate in degrees for the area could be determined.

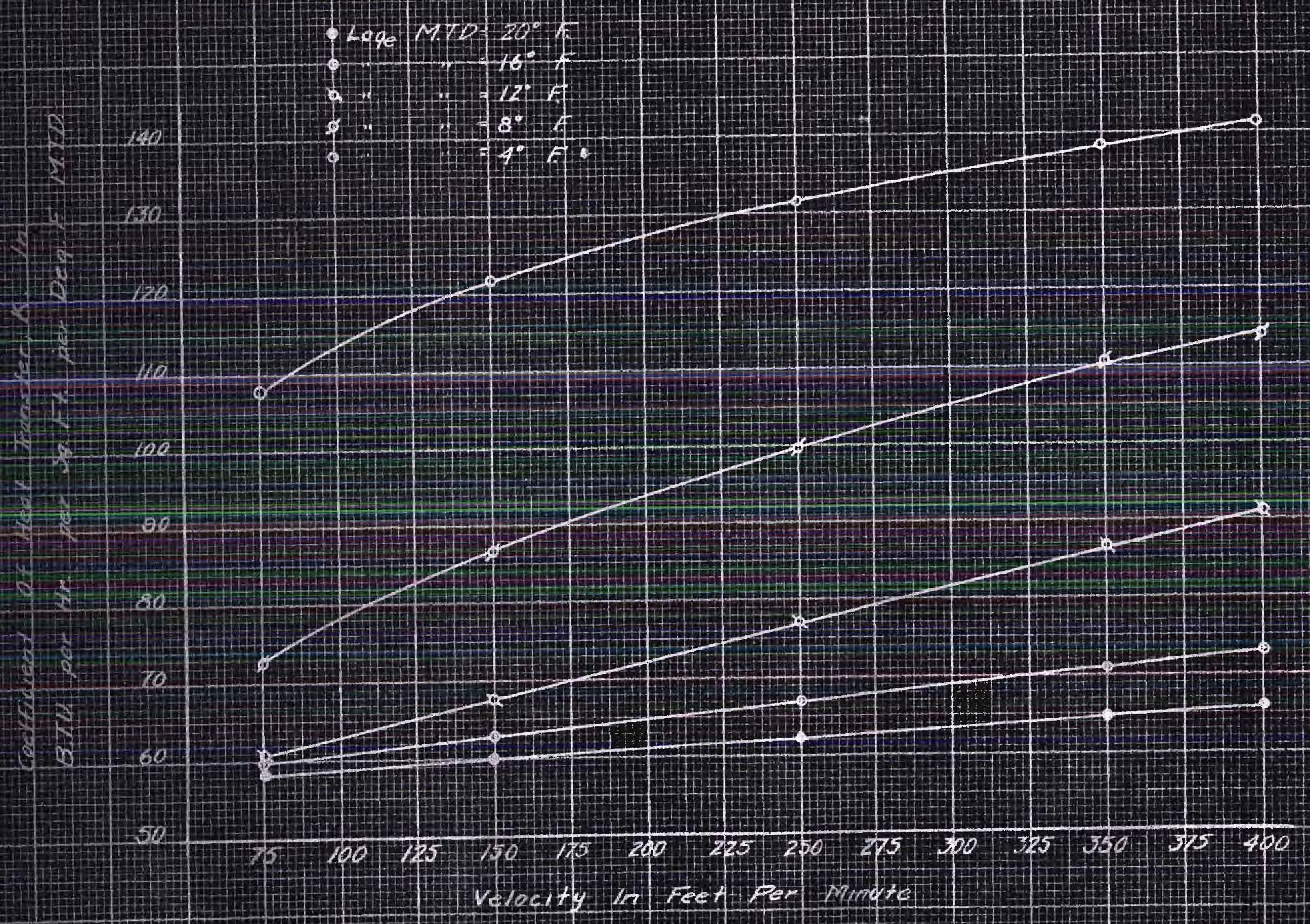
The results show that there is no great variation in the mean temperature difference by using the various methods of determination. The arithmetical seems to be consistently high while the logarithmetic and actual agree very well throughout the entire range. The greatest difference appears with the slow velocities where the brine range was large.

In view of these results and the ease with which the necessary information could be obtained, it was decided to use the logarithmical mean temperature difference in determining the heat transfer characteristics.

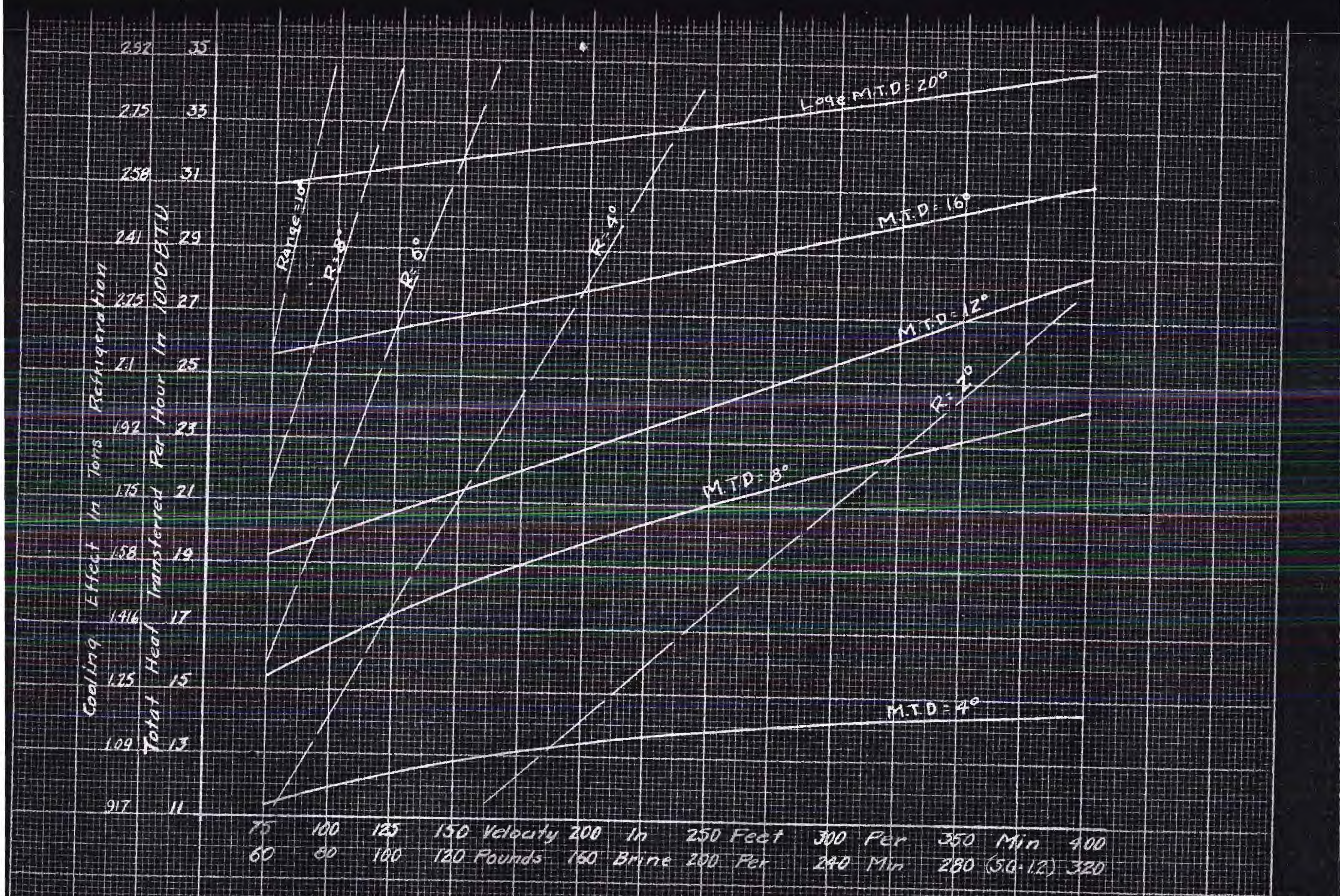
The coefficient K in B.T.U. per square foot per hour per mean temperature difference, items 16, 17, and 18, were calculated for each of the mean temperature differences determined.

The values of K based on the logarithmetical mean temperature difference are plotted on page 28. These curves show the relation to the coefficient of heat transfer with respect to the mean temperature difference for various velocities. While the curves for the various velocities exhibit similiar characteristics, there seems to be no simple mathematical law that will exactly express the exact relation of K and the mean temperature difference. Roughly the relation may be expressed as $K = \frac{C}{(\text{M.T.D.})^{.455}}$ in which C

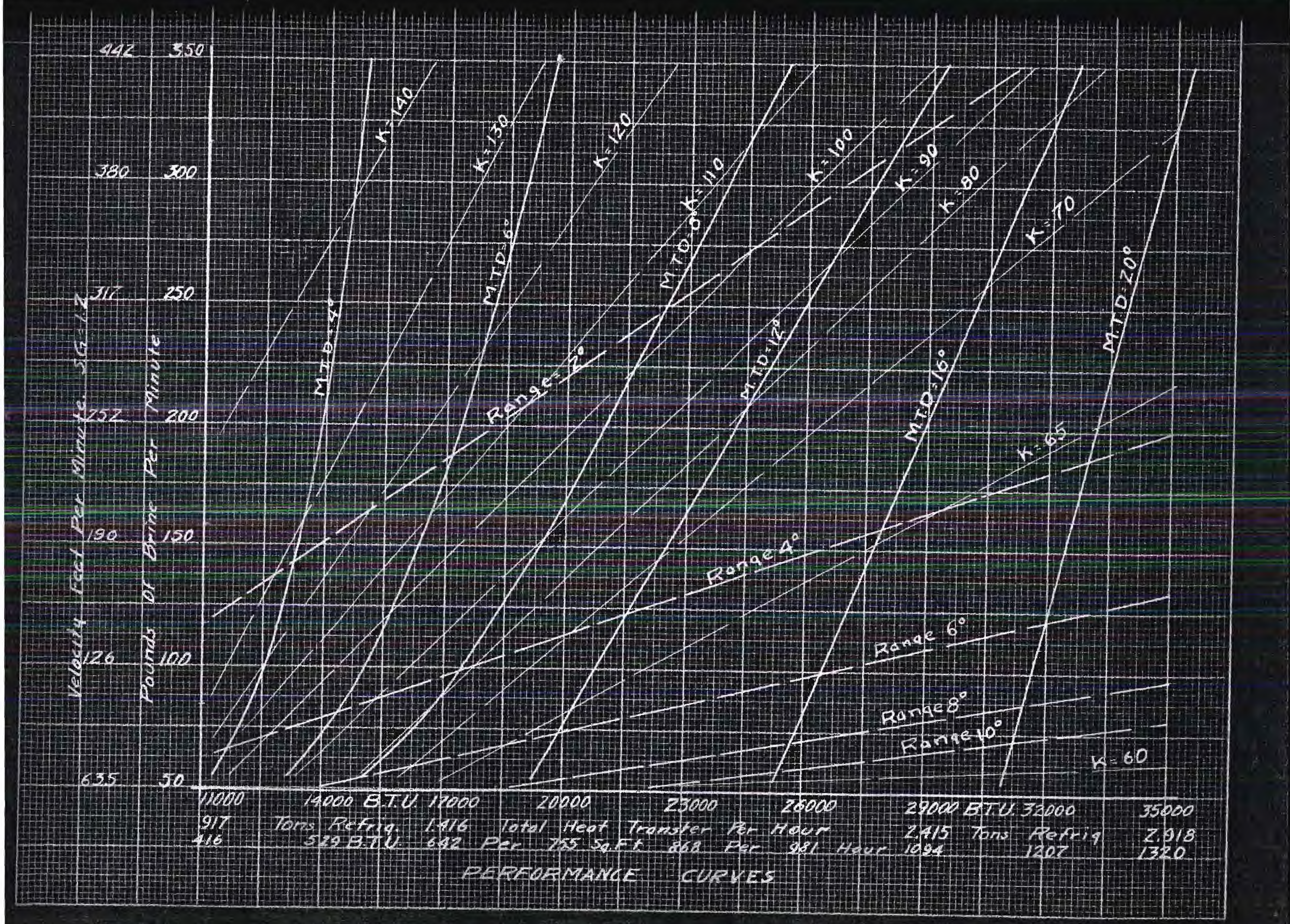

Coefficient of Heat Transfer, K
In BTU per Hr per Sq. Ft. per Deg. F. M.T.D.
140
130
120
110
100
90
80
70
60
50
4
7
10
13
16
19
22
25
Loge Mean Temperature Difference, Degrees F.
Velocity = 400 Ft per Min
Velocity = 350 " " "
Velocity = 250 " " "
Velocity = 150 " " "
Velocity = 75 " " "
COEFFICIENT OF HEAT TRANSFER, K, WITH VARIOUS MEAN TEMPERATURE DIFFERENCES



COEFFICIENT OF HEAT TRANSFER, K.
WITH VARIOUS VELOCITIES.



TOTAL HEAT TRANSFERRED ~ VELOCITY CURVES



PERFORMANCE CURVES

is a constant varying from 308 for a velocity of 75 feet per minute to 264 for a velocity of 400 feet per minute.

With the use of the curves on page 31 another set of curves were drawn in which K was plotted as ordinate and the velocity as abscissa for various mean temperature differences. The curves show an increase of velocity to increase the coefficient K - the relationship being a straight line except for mean temperature difference of eight and four degrees. The curvature for these two M.T.D. is slight.

The relation of K, the velocity, and the mean temperature difference may be expressed roughly by the following equation:

$$K = \frac{196 + \frac{v}{6}}{(\text{M.T.D.})^{.455}}$$

In which: v is the velocity in feet per minute

M.T.D. is the $\log_e$ mean temperature difference

The results obtained with the formula are correct at 4 and 16 degrees M.T.D. but are large at 9 degrees for low velocities and are small at 90 for high velocities.

The curves on page 30 show the total heat transferred per hour in the cooler plotted as ordinates and the velocities in feet per minute as abscissa. Using the above expression for K, the total heat transfer may be calculated by the following formula:

$$H = A\left(196 + {}^{v}/6\right)(\text{M.T.D.})^{.545}$$

In which: H is the total heat transferred per hour

A is the inside area of the heat transfer surface v is the velocity in feet per minute

M.T.D. is the $\log_e$ mean temperature difference

The brine range was calculated from the values of total heat weight of brine circulated per hour, and the specific heat of the brine for the various conditions.

The curves shown on page 31 are simply the previous three sets of curves drawn to a common set of coordinates. Pounds of brine circulated per minute and velocity of brine in feet per minute were plotted as ordinates and the total heat transferred per hour in B.T.U. and tons of refrigeration and the heat transferred per square foot per hour were plotted as abscissa. These coordinates were chosen because they seemed to be the best suited to commercial needs. By limiting any two of the variables in a cooler, the others may be found at once on the curve sheet. These curves are called the performance curves for the cooler. An example will illustrate the use of these curves. Assume that 23,000 B.T.U. per hour is needed with brine having a range of four degrees. By following the 23,000 B.T.U. ordinate up to the four degree range line and reading to the left, it will be seen that 133 pounds of brine per minute are necessary and that a mean temperature difference of 13 degrees must be maintained. The coefficient of heat transfer will be about 68.

The surface coefficients are given as items 19, 20, and 21. The brine surface was assumed to be the same as the surface coefficient of water. This coefficient varies directly as the velocity from a value of .3 B.T.U. for a velocity of 2 feet per second to the value of .65 B.T.U. for a velocity of 16 feet per second.

The coefficient of conduction of steel was taken as an average value for the conductance of steel and boiler plate. This was given in C.G.S. units in foreign books,[15] but was converted to the F.P.S. system by multiplying by 2903.[16] The coefficient for the ammonia was then calculated using the relation:

$$\frac{K}{3600} = \frac{1}{\frac{1}{C_s} + \frac{1}{C_b} + \frac{1}{C_a}}$$

In which: C_s = Coefficient of steel

C_b = Coefficient of brine

C_a = Coefficient of ammonia

K = Log_e coefficient of heat transfer

These show very clearly where the greatest resistance to heat flow occurs. The temperature gradients through the two surfaces and the steel pipe also show that the ammonia surface offers from about 8 to 16 times as much resistance as the brine surface.

[15] Glazebrook: Dictionary of Applied Physics, Macmillan and Co., Ltd., London, England, Vol. I, p. 439.

[16] Ibid: pp. 420-460.

Time-Run #	High Press.	Low Press.	Wt Brine	Wt Ammonia	Comp T. NH$_3$ In	Comp T. NH$_3$ Out	Brine Temp In Cooler No 29	28	27	26	25	24	23	22	21	Ammonia Temp In Cooler 1A	1	2	3	4	5	6	7	8	9	R.P.M.
	#/□"	#/□"	#	#	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
1	155	25			12	85	25.4	21.6	26	22.5	28.7	23.7	30.1	21.5	34.3	67.2	-5.0	12.8	17.9	10.9	19.0	11.9	17.1	13.0	1.0	307
	130	17			18	61	19.6	17.5	24.1	20.0	27.4	23.1	28.7	27.2	28.6	70.6	9.5	0.0	-4.6	-0.5	-3.0	1.3	10.6	1.4	3.9	310
	154	21			4	100	17.4	19.5	20.3	20.0	22.6	23.8	24.6	26.6	32.3	77.5	7.0	7.4	6.6	6.5	3.4	6.7	6.3	6.6	6.2	310
	153	23			4	86	21.5	20.0	25	20.8	27.2	24.9	27.4	27.2	29.3	75.0	7.4	-14.0	7.2	-5.0	7.0	5.1	6.2	11.0	2.2	308
120 Min	156	21			4	86	20.8	26.6	23.4	26.0	25.3	30.0	23.6	29.5	31.2	67.9	24.8	14.2	14.3	14.0	7.0	9.2	12.3	7.0	14.4	310
	152	30			10	85	23	25.6	25.6	22.8	27.8	30.0	29.2	31.0	33.0	79.0	11.2	16.2	12.9	15.1	13.4	14.8	13.9	14.0	14.6	310
	157	29			13	87.5	23.4	23.8	25.8	25.0	28.3	29.0	30.2	32.0	33.8	73.0	14.6	11.2	14.0	10.8	13.9	9.7	13.0	10.0	10.8	309
	150	26			9.5	82.5	23.6	25.5	26.3	28.0	29.4	30.8	31.2	34.0	34.8	71.8	11.8	12.0	11.9	10.8	12.0	10.8	11.5	10.1	10.6	308
	150	25	7739	181.5	9.5	85	21.8	23.8	25.2	25.0	27.8	29.0	29.8	31.8	33.5	78.6	8.4	10.0	8.6	8.8	9.0	9.3	8.3	9.2	8	308
Ave	150.7	25.2			9.83	84.2	21.83	22.66	24.63	23.34	27.17	27.14	28.31	28.87	32.3	73.4	9.96	7.75	9.87	7.93	9.08	8.76	11.02	9.14	7.97	308
2	155	25			11.5	86	16.6	18.0	18.8	19.0	19.8	20.0	21.8	22.0	24.1	76.6	11.5	10.8	11.0	9.9	11.0	10.0	11.0	10.0	9.4	310
	140	25			11.0	81.0	16.8	17.5	18.7	17.0	19.7	19.2	20.8	20.2	23.5	79.0	10.8	0.0	10.4	-0.5	10.5	4	9.8	3.0	7.9	310
	145	20			7.0	92.0	16.2	18.8	18.2	18.5	19.5	18.8	20.0	19.8	23.4	81.5	10.8	10.8	10.8	9.8	10.8	9.9	10.0	9.6	7.0	310
	160	23			9.0	87.0	15.4	15.8	17.1	18.0	18.4	19.0	19.1	20.2	22.6	73.0	8.2	8.5	8.4	7.6	8.5	7.7	7.8	8.0	6.8	311
120 Min	152	19			4.0	85.0	13.3	14.9	15.3	15.0	16.8	16.7	17.6	18.4	21.4	68.4	4.6	5.6	3.6	4.4	3.8	4.7	3.4	4.8	3.8	305
	140	15			-1	96.0	18.5	17.8	19.8	19.0	19.6	21.2	19.0	23.9	21.8	54.8	9.5	11.8	8.8	11.4	10.8	11.5	11.2	9.8	11.0	310
	160	25			12	96.0	17.5	20.0	20.2	22.0	22.0	24.0	21.8	21.8	26.4	81.0	9.5	10.8	9.0	10.0	7.0	10.8	4.5	10.8	1.6	306
	135	20			2	80.0	18.6	19.6	20.4	20.0	22.2	22.4	23.3	24.6	26.8	72.0	12.8	12.6	12.5	11.8	12.4	11.7	11.6	12.0	10.8	310
	150	26	7215	204.5	12	81.5	16.6	17.8	18.56	18.56	19.75	20.16	20.4	21.36	23.7	73.3	9.7	8.86	9.33	8.05	9.35	8.8	8.66	8.5	7.8	309
Ave	148.5	22			7.5	87.2	16.6	17.8	18.56	18.56	19.75	20.16	20.4	21.36	23.7	73.3	9.7	8.86	9.33	8.05	9.35	8.8	8.66	8.5	7.8	309
3	155	20			6.0	84.0	14.1	15.0	16.0	16.0	17.5	18.2	19.0	21.4	22.9	72	6.2	7.0	5.0	6.0	4.8	6.4	4.2	6.3	2.8	304
	155	23			8.0	85.0	15.2	16.2	17.0	17.0	18.0	18.6	20.0	20.8	24.3	72	7	7.8	7.5	6.9	8.0	6.9	7.3	6.2	6.2	310
	155	20			5.0	90.0	15.8	16.2	17.5	16.0	18.1	18.0	19.0	20.0	23.0	81	9.6	10.8	10.7	9.8	11.0	8.6	11.2	9.8	11.0	300
	160	25			10.0	86.0	15.6	16.1	16.3	15.5	17.4	17.0	17.5	19.4	22.3	78.2	11.6	12.0	11.0	9.8	11.0	9.8	10.0	9.4	9.0	310
120 Min	150	25			10.0	75.0	14.8	16.2	15.7	16.0	17.2	18.0	17.6	20.0	22.9	71	12.0	6.7	11.0	5.8	11.0	7.0	11.1	6.8	10.8	310
	158	27			14.0	86.0	16.5	15.0	17.2	15.0	18.0	17.0	18.0	19.8	22.3	72	9.0	5.8	13.8	5.5	14.0	6.2	13.6	6.2	9.3	305
	148	26			6.0	80.0	17.6	18.0	18.5	18.8	19.0	19.5	20.0	21.5	23.4	78	14.5	13.0	14.0	13.0	14.5	9.5	14.0	14.0	14.0	310
	150	25			13.0	85.0	18	18.8	18.5	18.5	19.0	18.0	19.5	20.5	23.3	74	15.5	8.0	15.0	8.0	15.0	8.0	14.8	10.0	9.6	307
	150	25	6851	304	8.0	82.0	17	18.5	18.0	17.0	18.7	19.0	20.0	21.0	23.0	74.5	14.5	6.0	13.5	6.0	14.0	5.0	13.0	2.0	12	310
	153.4	24			8.9	83.7	16.07	16.66	17.19	16.64	18.1	18.14	18.96	20.5	23.04	74.7	11.1	8.57	11.28	7.87	11.48	7.49	11.02	7.86	9.41	307

Time ∿ Run #	High Press.	Low Press.	Wt Brine	Wt Ammonia	Comp T.		Brine Temp In Cooler									Ammonia Temp In Cooler										R.P.M.
					NH_3 In	NH_3 Out	No 29	28	27	26	25	24	23	22	21	1A	1	2	3	4	5	6	7	8	9	
	#/□"	#/□"	#	#	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	
4	155	25			10	86	16.2	16.0	17.2	16.0	17.8	18.0	19.0	20.0	21.8	72	12.5	12.7	10.6	12.5	11.0	11.8	10.2	11.3	9.8	175
	155	25			11	82	17.4	18.0	18.4	17.5	19.2	19.8	19.8	21.0	230	78	13.0	12.2	11.4	12.0	11.0	12.0	11.0	12.5	10.1	175
	153	26			12	81.5	17.9	17.4	18.8	17.8	19.7	19.8	19.9	21.0	230	77	14.3	12.5	12.3	12.0	120	11.8	11.8	11.7	11.2	180
	130	25			10	73	16.4	16.6	17.9	17.0	18.8	18.6	19.0	20.8	22.6	75	12.5	10.0	10.8	9.2	10.2	9.2	10.0	9.0	9.1	175
120 Min	150	23			6	84	14.6	15.0	16.3	16.0	17.7	17.6	18.3	19.8	22.0	78	8.0	5.8	5.5	5.0	5.7	5.2	5.2	4.9	5.1	175
	150	22			6	82	14.8	17.6	16.2	18.0	17.3	17.5	17.8	19.0	21.5	77	8.0	6.6	6.0	5.8	6.0	5.8	5.4	3.9	4.6	175
	145	22			6	79	14.8	15.0	16.3	15.0	17.4	17.4	17.5	19.0	21.4	75	9.9	7.2	8.0	6.4	7.2	6.6	7.2	6.0	6.0	175
	145	22			6	82	14.0	14.3	15.8	15.8	17.0	16.6	18.0	18.5	20.3	73	8.8	5.5	6.5	4.0	6.0	5.0	6.0	4.0	3.4	175
	150	21	6441	102.5	6	85	13.2	13.6	15.0	14.0	16.2	16.0	16.5	18.0	20.2	68	6.5	9.0	6.4	8.0	5.5	7.6	6.0	6.0	5.8	175
Ave	148.1	23.4			8.11	81.6	15.5	15.9	16.9	16.34	17.9	17.9	18.4	19.7	21.8	75	10.4	9.06	8.6	8.3	8.3	8.33	8.1	7.7	7.23	176
5	160	25			10.0	82	10.5	10	11.2	10.0	11.5	11.0	11.0	12.0	13.8	65	10.0	5.2	10.0	4.0	9.0	3.6	10.0	3.0	7.0	176
	140	25			10.0	78	11.9	11.8	12.0	11.0	12.0	12.0	11.8	13.0	14.8	76	10.6	11.0	10.3	10.0	10.0	11.0	10.0	11.0	9.6	180
	145	25			10.2	79	12.2	12.0	13.0	12.0	13.0	13.0	12.8	14.0	15.7	76	11.1	11.0	11.0	10.0	10.0	11.0	10.4	10.4	10.0	181
	150	25			12.0	83	13.0	13.0	13.5	14.5	13.5	13.8	12.6	14.0	16.1	78	12.0	12.0	12.0	11.5	11.5	11.8	11.5	12.0	11.0	176
120 Min	140	25			11.0	79	12.8	13.0	13.5	13.0	14.0	14.0	13.8	16.0	16.7	77	11.0	8.0	10.9	7.0	10.0	7.5	10.2	7.0	8.6	180
	150	25			10.0	82	12.5	13.0	13.5	13.0	14.0	14.0	14.0	16.0	17.0	78	11.1	11.0	11.0	10.2	10.9	10.8	11.0	11.0	10.1	175
	150	26			11.0	82	13.2	13.0	13.8	13.0	14.0	14.2	13.9	16.0	17.2	74	11.0	11.0	10.8	10.0	10.2	10.5	10.5	10.0	10.3	173
	150	25			10.0	82	12.5	13.0	13.5	13.0	14.1	14.2	14.0	16.0	17.3	70	11.0	10.0	10.2	9.6	9.8	9.5	10.0	9.1	8.8	181
	152	25	6534	175.6	10.5	84	12.8	13.0	14.0	13.0	14.2	14.1	14.0	16.0	17.3	74	11.0	10.1	10.2	9.8	10.0	10.8	9.9	10.7	10.0	176
Ave	147.5	25.11			10.5	81.3	12.4	12.5	13.11	12.5	13.37	13.37	13.1	14.77	16.21	74	10.98	9.9	10.7	9.11	10.16	9.6	10.4	9.36	9.49	177.6
8	150	25			8.0	78	19.6	20.0	21.5	20.5	22.5	22.2	23.0	24.0	24.9	65	8.5	5.0	8.0	7.5	7.5	6.0	7.8	8.0	7.0	
	155	24			9.5	77	19.6	20.0	21.0	20.0	21.8	22.0	22.0	23.0	24.0	72	10.2	10.0	10.5	9.5	10.0	10.0	10.0	10.2	9.1	
	125	25			8.0	82	18.8	20.0	20.2	20.0	21.0	21.0	21.0	22.0	22.9	68	11.0	9.0	11.0	9.0	10.0	9.0	10.0	10.0	9.6	
	145	25			9.0	79	18.6	19.0	20.0	19.5	20.8	20.5	20.5	22.0	22.9	72	10.0	9.5	9.5	8.0	9.0	9.0	9.0	9.0	8.1	
120 Min	143	26			9.5	80	18.5	19.0	19.9	20.5	20.5	20.0	21.0	22.0	22.7	74	10.0	10.0	10.0	8.5	9.5	9.1	9.3	9.0	8.8	
	145	25			8.0	86	18.0	19.2	19.4	18.0	20.0	20.0	20.0	21.8	22.0	76	8.0	9.0	9.0	8.0	9.0	7.5	8.5	8.0	7.8	
	158	23			6.0	84	17.0	18.0	18.7	18.0	19.3	19.0	19.0	20.0	22.0	74	7.5	6.0	7.0	6.0	7.0	6.5	7.0	7.0	6.0	
	155	24	13783	231	7.0	82	17.0	17.8	18.3	18.0	19.0	18.5	19.0	20.0	21.0	74	7.5	6.5	7.0	6.0	7.0	6.6	7.0	7.0	6.2	
	146	25			9.0	84	17.0	18.0	18.5	18.0	19.0	18.5	19.0	20.0	20.3	77	10.0	9.5	9.7	8.0	9.0	9.0	9.1	9.0	9.0	
Ave	146.9	24.6			8.22	84	18.2	19.0	20.2	20.2	20.4	20.7	21.2	21.8	22.7	72.4	9.1	8.28	9.0	7.33	8.07	7.31	8.43	7.88	7.76	

Time-Run #	High Press	Low Press	Wt Brine	Wt Ammonia	Comp T NH₃ In	Comp T NH₃ Out	Brine Temp In Cooler No 29	28	27	26	25	24	23	22	21	1A	Ammonia Temp In Cooler 1	2	3	4	5	6	7	8	9	R.P.M.
	#/□"	#/□"	#	#	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	R.P.M.
7	139	24			8.0	78	23.0	23.5	24.5	24.0	25.2	25.5	26.0	27.0	27.8	74	9.0	8.0	8.5	7.5	8.0	7.5	8.0	9.0	8.0	301
60 Min	139	26			10.0	78	22.1	22.5	23.5	23.0	24.5	25.0	24.5	26.0	27.0	74	11.5	10.5	11.0	10.0	10.5	10.5	10.5	10.0	10.2	300
	150	26			10.5	82	22.0	22.5	23.4	23.0	24.0	24.0	24.0	26.0	26.8	71	11.0	10.0	11.0	10.0	10.0	10.2	10.8	10.5	10.1	301
	149	26			10.0	81	21.3	22.0	22.8	22.0	23.8	24.0	24.0	25.0	26.0	76	10.5	10.0	10.0	8.0	9.0	9.0	9.8	8.0	9.6	302
	150	22	7544	125.5	7.0	86	20.5	21.0	22.0	21.0	22.5	23.0	23.0	24.0	24.8	74	10.8	10.0	10.5	10.0	10.0	10.0	10.0	10.0	9.8	300
Ave	145.2	24.8			9.1	81	21.78	22.5	22.84	22.7	24.5	24.5	23.6	25.8	26.48	73.8	10.5	9.5	9.6	8.8	9.0	9.14	9.7	8.7	9.54	301
10	120	28			12	72	14.6	14.0	15.4	14.0	15.2	15.0	14.5	16.0	16.1	62	14.0	13.0	13.5	12.0	12.0	7.0	13.0	12.0	12.0	171
60 Min	150	30			14	86	16.2	17.0	17.4	16.0	17.5	17.0	18.0	18.0	18.1	64	15.5	11.0	15.1	10.0	15.0	9.0	15.0	9.0	14.0	175
	156	30			15	86	17.6	18.0	18.5	17.5	19.0	19.0	18.0	20.0	20.1	77	16.0	16.0	16.0	15.0	15.0	15.0	15.2	14.0	14.2	170
	158	30			16	86	19.0	19.5	20.2	19.0	20.2	20.0	20.0	22.0	22.1	76	16.0	15.0	15.2	16.5	15.0	13.0	14.9	12.0	15.0	177
	160	32	6580	123	17	90	20.2	20.8	21.1	20.0	21.1	21.0	20.0	22.0	22.1	79	17.0	16.0	17.0	16.5	16.0	16.5	16.0	16.0	15.5	176
Ave	149	30			14.8	84	17.7	18.1	19.0	18.3	18.6	18.6	18.8	19.8	19.9	71.6	15.7	15.0	15.4	14.2	14.3	12.1	14.8	11.8	14.2	174
11	175	27			11	136	31.6	32.0	32.0	33.0	34.5	35.0	35.0	36.0	36.2	76	13.0	13.0	12.2	12.0	12.0	13.0	12.0	13.0	10.8	301
60 Min	135	26			11	94	31.4	32.0	32.0	33.0	34.0	34.0	34.0	35.0	35.7	72	14.5	12.0	13.5	12.0	13.0	12.0	13.0	12.0	13.0	300
	120	24			8	112	29.4	31.2	32.2	31.5	32.5	33.0	32.6	33.0	35.0	64	8.8	9.0	8.0	9.0	7.0	9.2	7.7	9.0	8.8	302
	145	24			8	114	30.4	31.8	32.8	32.0	33.6	35.6	33.8	35.6	35.4	61	8.5	10.0	7.8	10.0	7.6	10.4	7.7	9.8	8.2	300
	160	27	11354	102	14	86	31.8	32.2	32.5	33.0	34.2	34.2	34.0	35.0	36.3	62	12.4	15.0	11.8	14.5	11.0	14.8	11.2	14.8	13.5	301
Ave	147	25.6			10.4	108	31.1	31.9	32.9	33.2	34.76	34.86	35.0	35.6	35.7	67	11.3	11.5	10.1	11.2	9.5	11.5	10.3	10.9	10.8	301
15	165	26			10.5	90	13.2	14.0	14.2	14.0	16.7	16.7	16.4	16.1	16.1	88	11.5	10.2	11.0	10.3	10.2	10.3	10.5	10.2	10.6	171
60 Min	165	26			11.0	88	16.0	15.6	16.2	15.8	17.8	15.0	17.0	16.5	16.5	84	15.0	10.3	14.5	10.0	14.5	9.7	13.4	9.5	12.4	171
	130	26			9.0	72	16.4	17.0	18.2	18.1	17.3	17.2	19.9	18.2	18.2	77	12.0	10.4	9.5	10.8	8.8	11.9	8.7	12.9	10.6	171
	170	30			12.0	88	18.5	19.0	19.4	18.0	19.0	19.4	19.2	19.5	19.5	70	16.0	16.5	14.8	11.6	14.0	12.9	14.0	12.9	13.0	169
	160	30	11536	70	14.0	87	19.6	20.0	20.2	19.5	20.0	19.4	20.3	20.5	20.5	53	17.8	11.0	12.4	10.8	11.2	11.4	11.3	11.4	10.8	169
Ave	158	27.6			11.3	85	16.84	17.1	17.64	18.08	17.66	18.24	19.06	18.36	18.36	74.4	14.46	11.98	11.84	10.6	11.14	10.9	11.48	10.58	11.48	170
16	170	28			13.0	90	30.3	30.8	31.2	30.0	31.8	31.0	31.6	29.5	32.4	72	15.5	9.8	13.8	9.0	11.0	9.5	11.4	8.5	10.3	300
60 Min	140	27			12.0	80	28.4	29.2	29.3	28.6	30.0	29.5	29.6	29.0	31.2	72	13.5	11.0	13.0	10.8	12.0	10.8	12.2	10.8	11.3	301
	175	25			12.0	92	31.6	31.5	32.8	31.4	33.8	32.5	33.2	31.0	34.4	67	12.8	12.3	12.8	12.2	12.0	13.2	11.8	13.0	10.6	302
	150	27			13.0	82	29.5	31.0	30.8	30.0	31.8	31.5	31.8	30.0	33.0	80	13.0	10.6	11.0	10.3	11.0	10.8	11.4	11.0	10.4	301
	165	25	15620	113	10.0	89	29.5	30.4	30.8	31.0	31.8	32.0	31.8	30.5	33.2	76	11.0	9.0	9.8	8.5	9.0	8.8	9.5	8.8	8.7	302
Ave	160	26.4			12.0	86.6	29.84	30.68	31.34	30.9	32.8	31.8	32.7	30.7	32.84	73.4	13.06	10.24	11.48	9.86	10.9	10.2	11.26	9.62	10.26	301

Time & Run #	High Press	Low Press	Wt Brine	Wt Ammonia	Comp T: NH_3 In	Comp T: NH_3 Out	Brine Temp In Cooler: No 29	28	27	26	25	24	23	22	21	Ammonia Temp In Cooler: 1A	1	2	3	4	5	6	7	8	9	R.P.M.
9	145	28			14	82	19.0	20.0	20.5	20.0	21.0	21.5	21.0	24.0	22.5	54	14.8	11.5	14.0	11.0	15.0	11.5	13.0	11.0	13.0	174
	130	25			11	75	18.8	20.0	20.5	20.0	21.5	22.0	22.0	22.5	23.3	80	13.0	14.0	12.5	14.0	12.0	13.0	12.0	12.0	11.0	174
	131	28			13	78	18.6	19.5	20.3	20.0	22.0	22.0	22.0	24.0	24.0	76	13.5	12.0	12.0	10.0	11.0	10.5	11.0	10.0	11.0	173
	152	24			8	84	18.0	19.0	20.0	20.0	22.0	22.0	22.5	24.2	25.0	80	10.0	9.0	8.5	9.0	8.0	8.5	8.0	8.0	7.8	173
120 min	152	25			9.5	84	18.0	19.0	20.2	20.2	22.2	22.0	23.0	24.5	25.2	74	12.0	9.0	9.5	8.0	9.5	8.5	9.0	8.0	9.4	174
	148	26			12	86	19.0	20.0	20.75	20.2	21.5	23.0	22.0	22.5	23.0	76	14.0	13.0	12.5	13.0	12.0	12.5	12.0	12.0	11.2	172
	150	29			14	84	19.8	20.2	21.2	20.4	21.75	22.0	22.1	23.0	23.0	86	16.0	14.6	14.5	14.0	14.0	14.0	14.0	14.0	13.2	172
	150	30			14	84	20.0	21.0	21.4	20.2	22.0	22.0	22.0	23.0	23.0	83	16.0	15.0	14.8	15.0	14.0	14.5	14.2	14.0	13.4	174
	148	30	10,624	99	14	84	19.8	20.5	21.5	19.5	22.2	21.0	22.0	21.7	23.5	78	16.0	14.8	14.5	12.8	14.0	14.2	14.0	14.0	13.2	172
	145	26.1			12.2	82	19.2	21.1	21.2	21	21.8	22.1	22.8	23.5	23.8	76.3	14	13.3	12.5	12.1	11.9	12.0	12.0	10.6	11.5	173
12	150	27			11.0	86	25.4	25.0	26.4	26.0	27.0	27.0	27.0	28.0	28.5	72	12.2	11.0	12.0	10.0	11.0	10.8	11.1	10.0	10.2	302
	143	27			10.0	78	24.4	24.5	25.8	24.0	26.5	26.0	26.0	27.0	27.8	78	10.8	10.0	10.0	9.0	9.5	9.0	9.8	9.0	8.8	301
	145	24			8.0	81	25.4	25.0	26.5	25.0	27.3	27.0	27.0	28.0	28.8	73	10.0	9.0	10.0	8.0	10.0	8.5	9.5	8.0	9.0	302
	144	25			8.0	80	24.6	25.0	25.8	26.0	27.0	26.8	26.9	28.0	28.5	70	8.0	9.0	8.0	8.0	8.0	9.0	8.0	8.0	6.2	301
120 min	147	24			7.5	82	24.4	24.5	25.4	25.0	26.0	26.0	26.0	27.5	28.0	74	9.0	8.0	8.8	7.5	8.0	8.0	8.5	8.0	8.0	302
	146	24			7.5	82	23.4	23.5	24.2	24.0	25.0	25.0	25.0	26.5	26.9	74	9.0	8.0	8.8	7.0	8.0	8.0	8.0	7.5	7.9	300
	150	26			10.5	82	27.4	27.5	28.4	27.0	29.4	29.4	29.0	31.0	31.5	72	12.0	11.0	12.0	10.0	11.0	10.8	11.1	11.0	10.8	301
	150	26			10.0	82	25.5	25.5	26.4	26.0	27.0	27.0	27.0	28.0	29.2	73	11.5	10.0	11.2	10.0	11.0	10.5	11.0	10.0	10.4	301
	142	24	22920	217.5	8.0	80	24.4	24.6	25.2	24.0	26.0	26.0	26.0	27.0	28.0	70	9.0	9.0	8.5	8.0	8.0	8.2	8.0	8.0	8.0	300
Ave	146.3	25.2			8.9	81.4	24.6	25.2	25.8	25.3	27.3	26.9	27.36	28.1	28.56	72.9	10.17	9.24	9.9	8.3	8.9	8.9	9.34	8.03	8.8	301
13	130	23			5.0	76	18.6	18.3	20.0	21.0	20.75	20.0	20.0	21.7	22.0	76	7.0	5.0	5.5	4.0	6.0	5.0	5.0	4.0	5.0	305
	135	24			8.0	79	19.3	20.0	20.8	20.0	21.2	20.0	20.6	21.9	21.8	64	9.4	5.3	7.6	5.8	7.5	8.4	5.6	9.0	10.0	296
	160	26			13.5	80	24.2	22.0	24.1	22.0	24.4	21.3	24.0	24.0	27.0	59	14.0	11.0	14.0	11.0	13.0	13.4	13.0	14.0	12.4	295
	154	24			8.0	83	20.7	21.0	21.9	21.0	22.4	23.0	21.2	22.8	23.9	74	8.0	6.0	7.4	6.8	6.2	7.0	7.0	6.9	6.4	295
120 min	155	26			10.0	86	20.4	20.0	21.3	21.5	21.8	22.0	21.3	22.1	22.6	77	11.4	10.9	10.5	10.2	10.0	10.8	10.4	10.4	9.8	295
	145	23			6.0	80	19.6	20.0	21.0	20.0	21.4	21.0	21.2	22.0	22.4	68	8.0	6.2	6.0	6.0	5.2	6.8	5.6	6.2	5.7	295
	154	24			7.0	84	18.8	19.0	20.0	19.5	20.8	21.0	21.0	21.5	22.0	78	7.5	8.0	7.0	7.0	6.0	8.0	7.5	8.0	6.0	295
	150	25			9.5	83	19.0	19.0	20.0	19.0	20.4	20.2	20.0	21.0	21.7	78	11.0	10.0	10.5	10.0	9.0	10.0	10.0	10.0	9.2	295
	150	26	23566	225	10.0	84	18.8	19.0	20.0	19.0	20.3	20.0	20.0	21.0	21.8	78	11.0	10.0	10.5	9.0	10.0	10.0	10.0	10.0	9.2	295
Ave	148	24.5			8.55	81.7	20.13	20.01	21.6	21.3	22.6	21.2	21.7	22.2	23.0	72.4	8.4	7.8	7.6	7.25	7.2	8.12	8.13	7.92	7.99	296

Time-Run #	High Press	Low Press	Wt Brine	Wt Ammonia	Comp T. NH3 In	NH3 Out	Brine Temp In Cooler No. 29	28	27	26	25	24	23	22	21	Ammonia Temp In Cooler 1A	1	2	3	4	5	6	7	8	9	R.P.M.
	#/□"	#/□"	#	#	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	RPM
14	152	27			12	84	19.9	21.0	21.7	21.0	22.2	22.0	22.0	22.0	23.0	72	14.0	10.0	12.0	9.0	11.0	9.0	11.0	18.0	11.0	174
	150	22			20	80	19.3	19.8	21.0	20.0	21.6	21.2	21.5	21.6	22.4	71	7.4	8.4	5.9	9.0	5.4	9.1	15.4	9.4	13.7	173
	152	26			11	82	18.5	19.8	20.0	19.6	20.5	20.3	20.0	20.8	21.3	75	13.0	12.7	12.0	12.0	11.4	12.4	11.6	12.0	10.8	173
	154	27			12	84	19.0	19.7	20.2	19.8	20.4	20.2	20.0	22.0	21.3	71	14.0	12.0	13.0	13.0	13.0	13.0	14.7	13.0	12.0	174
120 Min	148	28			13	81	19.5	20.0	20.5	19.2	20.5	20.8	20.4	21.4	21.5	77	14.8	13.4	14.0	13.2	14.2	13.3	13.4	13.1	12.9	172
	150	26			11	82	18.8	19.5	20.4	19.5	21.0	21.0	20.5	21.8	21.8	74	13.0	10.0	11.0	9.0	10.0	9.5	10.9	10.0	10.8	172
	150	23			9	82	17.8	19.0	19.8	18.0	20.0	20.0	20.0	20.0	21.0	71	9.0	9.0	7.2	9.0	8.0	9.5	7.0	10.0	7.4	173
	154	28	21513		13	83	18.0	18.0	19.2	18.0	19.8	19.5	19.5	20.0	20.5	72	13.0	13.0	12.0	12.0	12.0	12.5	11.8	12.0	11.0	172
	147	29		106	14	78	19.0	19.5	20.1	20.0	20.9	20.0	20.0	20.0	21.5	76	15.0	14.0	14.0	14.0	13.5	13.5	13.8	13.0	13.0	173
Ave	151	26.2			12.8	82	19.1	19.8	20.8	19.6	20.9	20.8	21.1	21.3	21.8	73	12.6	12.2	11.1	11.3	10.7	11.2	12.2	11.5	11.5	173
18	165	21			7	86	20.2	20.2	21.4	20.0	21.4	21.0	20.8	22.0	22.5	81	13.8	12.0	13.0	12.0	12.0	11.5	12.1	11.0	9.5	294
	160	23			10	80	20.8	21.4	22.0	20.8	22.6	22.0	21.9	22.5	23.0	72	11.2	11.0	11.5	14.0	11.0	14.5	11.7	14.2	11.4	300
	120	25			10	74	21.8	22.2	22.9	22.0	23.3	23.2	22.9	24.0	24.3	78	11.5	9.0	11.0	8.0	10.0	8.5	10.0	8.0	10.0	295
	155	23			8	83	21.6	21.8	22.5	22.0	23.0	22.5	22.5	23.4	24.0	76	8.0	8.0	8.0	7.0	8.0	8.0	7.5	8.0	7.0	296
120 Min	175	26			11	93	20.2	20.8	21.3	22.0	21.6	21.0	21.0	22.0	22.5	74	11.6	10.0	11.5	10.0	11.3	10.5	11.0	10.0	10.2	295
	200	21			5	102	19.4	20.0	20.8	22.0	21.0	20.3	20.0	21.2	21.5	76	12.0	14.0	13.0	14.0	12.0	14.5	12.9	14.0	10.0	294
	140	27	32063		12	79	20.0	20.2	21.0	20.0	21.0	21.0	20.2	21.8	22.0	75	13.0	11.0	12.0	10.0	11.5	11.0	11.8	10.5	11.4	300
	165	24			9	88	20.0	20.2	21.0	20.0	21.2	21.0	21.0	22.0	22.2	77	8.0	8.0	7.0	7.0	8.0	7.5	8.0	7.0	7.4	294
	125	23		221	7	78	19.0	20.0	20.4	20.0	20.8	20.5	20.0	21.5	21.9	78	8.0	7.0	7.0	8.0	7.0	6.5	6.9	6.0	6.2	295
Ave	156	23.7			8.8	86	20.5	20.9	21.98	22	22.19	21.4	21.84	22.45	22.8	75.7	11.8	11.2	11.24	9.8	10.1	12.9	10.4	9.96	9.63	295
19	135	22			19.0	103	19.0	21.0	20.2	19.0	20.5	20.0	20.0	21.0	21.1	74	11.0	14.0	11.0	14.0	10.0	14.0	11.0	14.0	10.4	
	150	30			18.5	82	20.0	22.0	21.2	20.0	21.2	21.25	20.0	22.0	22.0	68	16.5	14.0	15.5	14.0	15.0	14.0	15.0	14.0	14.4	
	143	29			14.3	80	21.0	21.0	22.0	22.0	22.2	22.0	22.0	22.2	22.8	68	16.0	13.0	14.5	12.0	14.0	12.3	14.0	12.0	13.8	
	168	28			9.0	76	20.6	21.0	21.8	20.0	22.0	22.0	22.0	22.8	21.8	67	11.0	12.0	10.0	11.5	10.0	11.0	10.0	12.0	12.0	
120 Min	152	28			13.9	84	20.8	20.5	21.8	20.0	22.0	21.8	22.0	22.5	22.8	71	15.0	14.0	13.5	12.0	13.0	13.0	13.0	12.5	12.2	
	152	23	34588		14.0	84	20.0	19.8	21.5	20.0	22.0	22.0	21.0	22.0	22.5	70	11.0	8.0	8.0	8.0	10.0	8.0	9.0	12.0	8.2	
	153	27			14.0	90	19.4	19.5	20.6	20.0	20.9	20.0	20.0	21.0	21.3	73	11.5	11.0	10.5	11.0	10.0	11.0	10.2	11.0	10.5	
	155	28			16.0	86	20.0	20.0	20.9	20.0	21.0	20.5	20.0	21.8	21.5	78	15.0	14.0	14.0	13.0	12.0	13.5	13.5	14.0	12.8	
	158	30		125	16.0	86	21.0	21.0	22.0	20.5	22.0	22.0	20.5	22.2	22.2	83	17.0	16.0	16.0	16.0	14.0	15.5	15.0	16.0	13.6	
Ave	152	27.2			15	85.6	20.4	20.8	21.8	21.2	21.5	21.5	21.5	22.1	22.2	72.4	13.8	13.7	12.6	12.6	11.7	12.5	12.3	12.3	13.1	

Time-Run #	High Press	Low Press	Wt Brine	Wt Ammonia	Comp T. NH₃ In	Comp T. NH₃ Out	Brine Temp In Cooler No 29	28	27	26	25	24	23	22	21	Ammonia Temp In Cooler 1A	1	2	3	4	5	6	7	8	9	R.P.M.
	#/□"	#/□"	#	#	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	RPM
17	170	24			8.0	94	26.5	26.5	27.5	26.5	28.2	27.5	27.0	26.25	29.0	83	11.0	5.0	8.2	4.0	7.8	5.2	7.5	6.0	9.0	302
	155	27			12.0	85	26.0	26.0	26.8	26.0	27.5	27.0	25.8	27.5	28.0	77	13.8	8.0	13.0	8.0	12.0	8.5	12.0	8.0	12.5	301
60 Min	150	25			9.0	85	24.8	25.0	25.8	25.0	26.2	26.5	25.8	28.0	27.3	69	13.0	13.0	13.0	12.0	12.0	12.4	12.5	12.0	11.0	302
	165	29			14.0	86	25.0	25.0	25.8	24.5	26.5	25.5	25.8	28.0	27.6	71	14.5	12.5	14.0	12.0	13.0	12.5	13.0	12.0	13.0	301
	155	27	17074	118	12.0	80	24.4	24.5	25.4	24.0	25.8	25.0	20.0	28.0	26.8	72	12.0	11.8	11.5	11.0	11.0	11.5	11.0	11.0	10.8	300
Ave	159	26.4			11.0	86	25.34	25.6	26.76	25.3	27.34	26.5	27.18	27.9	27.74	74.4	12.8	12.7	11.3	9.1	10.66	9.7	11.1	9.0	11.26	301
20	126	26			12.	76	12.4	14.2	14.2	14.0	14.3	14.0	13.3	14.4	14.5	63	11.5	9.8	10.1	9.7	10.3	8.8	11.6	10.0	11.0	171
	139	26			12	78	15.4	15.6	16.2	15.8	15.8	16.0	15.0	16.4	16.5	69	13.0	12.5	12.2	10.9	11.2	12.2	13.0	12.3	12.1	171
60 Min	150	27			13	82	17.3	18.0	18.2	18.1	18.2	18.0	17.5	18.4	18.4	76	14.5	12.4	13.4	12.6	13.0	12.5	12.8	12.4	12.8	171
	155	29			13	86	18.5	19.0	19.4	18.0	19.6	19.2	19.6	20.0	20.0	72	15.4	14.4	13.6	13.8	12.8	13.8	14.0	13.9	13.2	171
	160	30	15920	76	14	86	19.6	20.0	20.2	19.5	20.6	20.4	19.8	21.0	21.0	78	15.8	14.0	14.4	16.0	13.8	15.5	11.3	14.0	13.3	171
	146	27.6			12.8	81.6	16.84	17.1	17.64	18.08	17.5	17.02	17.74	18.54	18.28	71.6	14.04	13.42	12.72	12.8	11.92	12.56	12.54	11.72	12.28	171
25	125	27			12	70	16.1	16.5	17.2	16.0	17.2	17.1	16.0	17.3	17.5	54	13.0	11.0	13.0	11.0	13.0	11.0	12.0	12.0	10.8	171
	115	28			12	70	17.0	17.5	18.0	16.0	18.0	17.5	18.0	18.0	18.0	72	14.0	13.0	13.0	12.0	12.5	13.0	13.0	13.0	12.0	170
60 Min	130	28			12	76	18.6	19.0	19.4	18.0	19.5	19.0	19.5	19.7	19.8	76	14.0	14.0	12.5	14.0	12.0	14.3	12.3	14.0	11.8	172
	150	31			16	84	20.4	20.8	21.2	20.0	21.0	21.0	21.0	21.4	21.4	83	17.0	15.0	16.0	14.9	16.0	16.0	15.0	15.0	13.8	170
	142	32	18984	75	17	79.5	21.7	22.0	22.4	22.0	22.2	22.0	22.0	22.4	22.8	74	18.3	18.0	18.0	18.0	17.5	17.2	17.0	17.0	16.6	172
	133	29.2			13.8	75.9	19.0	16.86	17.64	19.4	19.6	18.8	18.0	20.22	20.1	71.8	15.26	15.0	14.5	14.2	13.6	14.3	13.9	13.4	12.4	171
22	165	23			10.0	110	26.8	26.0	27.8	26.0	28.6	27.0	28.0	27.8	28.8	77	9.2	11.0	6.8	11.0	8.0	11.0	8.0	11.0	7.5	295
	145	28			12.0	81	25.0	25.0	25.8	25.0	26.2	25.8	25.8	27.0	27.0	73	13.0	10.8	12.8	10.0	12.0	10.4	12.0	10.0	11.0	297
65 Min	140	25			8.0	79	23.5	24.0	24.5	24.0	25.0	24.5	25.0	26.0	26.0	76	9.5	8.0	9.0	7.5	8.0	7.5	8.0	7.5	8.2	300
	135	24			7.5	77	23.2	23.8	24.4	23.8	25.0	24.0	24.5	26.0	25.2	70	8.5	6.0	7.5	5.8	7.0	6.5	7.0	6.5	7.0	300
	165	25			8.0	86	23.5	24.0	24.4	24.0	25.0	24.5	24.5	26.0	25.8	66	9.8	7.0	8.9	6.0	8.0	7.0	8.0	7.0	8.0	300
	155	24	20501	106	7.0	84	23.4	24.0	24.6	24.0	25.0	25.0	25.0	26.5	25.8	66	7.8	5.0	6.0	4.0	6.0	4.4	5.8	6.0	6.0	300
	150	24.8			8.75	86.16	24.23	24.57	25.65	25.16	26.6	25.43	26.2	26.95	26.43	71.3	8.63	7.77	9.9	7.08	7.36	7.1	7.93	7.2	7.95	298.7

Time-Run #	High Press.	Low Press	Wt Brine	Wt Ammonia	Comp T.		Brine Temp In Cooler									Ammonia Temp In Cooler										R.P.M.
					NH_3 In	NH_3 Out	No. 29	28	27	26	25	24	23	22	21	1A	1	2	3	4	5	6	7	8	9	
	#/□"	#/□"	#	#	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	RPM
23	155	28			18	92	22.5	22.8	23.4	22.0	24.0	23.5	23.5	24.0	24.6	76	14.0	13.0	13.5	12.0	13.0	12.5	13.0	12.0	12.8	295
	155	30			14	85	22.5	23.0	23.4	22.0	23.9	23.5	23.0	24.0	24.6	79	14.0	12.0	13.5	12.0	13.0	12.0	13.0	12.0	12.2	297
	155	26			10	86	22.0	22.3	23.0	22.0	23.0	23.0	23.0	24.0	24.4	78	11.2	11.0	11.0	10.0	11.0	10.4	11.0	10.0	10.2	295
120 Min	145	25			8	81	22.4	22.8	22.5	21.5	22.9	22.5	22.0	23.5	23.9	82	10.2	9.0	9.8	8.0	10.0	8.5	9.3	8.5	8.8	300
	135	24			8	75	20.8	21.0	22.0	21.0	22.2	22.0	22.0	23.0	23.5	67	8.0	8.0	8.0	6.0	8.0	7.0	7.3	6.0	7.0	297
	180	25			8	70	20.0	20.3	21.2	21.0	21.5	21.0	21.5	22.0	22.7	70	9.0	8.0	8.5	8.0	9.0	8.0	8.0	8.0	8.0	300
	155	26			10	84	20.0	20.3	21.0	20.0	21.0	21.0	21.0	21.5	22.0	74	12.5	12.0	12.0	10.0	11.0	11.0	11.5	11.0	10.8	298
	170	27	37,573		10	86	20.6	21.0	21.6	20.0	21.8	21.2	21.0	22.1	23.0	77	11.0	10.0	10.5	9.0	10.0	9.5	10.0	9.0	9.6	295
	135	25		224.5	8	78	20.0	20.5	21.0	20.0	21.3	21.0	21.0	22.0	22.4	68	9.2	9.0	9.0	8.0	8.0	8.2	8.5	8.0	7.9	295
Ave	147	26.2			10.4	82	21.4	21.8	22.4	22.3	22.9	22.6	23.1	23.6	23.5	74.6	10.5	10.7	10.4	9.52	10.74	9.66	9.98	9.69	10.3	297
24	145	30			16.0	80	21.6	22.0	22.8	21.8	22.8	22.1	22.0	22.8	23.0	78	17.0	16.0	16.0	16.0	16.0	15.5	15.3	16.0	15.8	175
	140	26			13.0	78	21.6	22.0	22.9	22.0	23.0	24.0	22.0	23.0	23.5	69	14.0	9.0	11.0	8.0	10.0	8.0	10.0	8.0	10.6	175
	145	25			22.0	81	20.8	21.0	22.0	21.0	22.6	22.0	22.0	22.5	23.0	71	8.0	8.0	6.0	8.0	6.0	8.5	7.0	12.0	11.6	177
120 Min	150	18			24.0	92	19.8	20.0	20.8	20.0	21.0	20.5	20.0	21.5	22.0	68	11.0	8.0	9.0	8.0	9.0	8.5	9.0	8.0	13.8	175
	145	31			16.0	80	20.0	20.0	21.0	19.0	21.0	20.4	20.0	22.0	21.0	72	16.5	16.0	16.0	14.0	16.0	15.5	15.0	15.0	15.0	175
	160	31			17.0	87	21.0	21.5	22.0	21.0	22.0	22.0	21.0	22.5	22.1	72	17.0	16.0	16.5	16.0	16.0	16.2	16.2	16.0	15.0	176
	160	33	38,763		18.0	85	22.0	22.0	23.0	22.0	23.0	23.0	22.0	23.0	23.2	79	19.0	18.0	18.0	18.0	18.0	17.0	17.5	18.0	17.0	175
	140	27			12.0	78	22.0	22.2	23.1	22.0	23.8	23.2	23.0	24.0	23.9	74	14.0	13.0	11.8	13.0	11.0	12.5	11.0	12	11.1	175
	165	30		128.5	14.0	89	21.2	21.5	22.4	21.0	22.7	22.0	22.0	23.0	23.5	78	13.0	13.0	12.0	12.5	13.0	12.8	11.9	13	12.0	175
	147.7	28			16.9	83	21.3	21.6	22.7	21.2	22.4	22.3	22.3	22.9	23.0	73.4	14.4	13.8	12.9	12.8	12.5	12.7	12.5	12.3	13.6	175
6	155	25			9.0	87	28.5	29.0	30.2	30.0	32.0	32.0	33.0	34.0	35.0	72	10.0	12.0	9.5	8.0	9.0	7.5	9.0	8.0	9.2	300
	165	25			9.0	91	30.0	31.0	31.8	32.0	33.0	33.0	34.0	35.0	36.0	80	11.0	12.0	11.0	10.0	11.0	11.0	10.5	10.0	9.8	301
60 Min	160	27			11.0	87	30.0	31.0	31.5	31.0	33.0	33.0	34.0	35.5	36.1	72	13.5	12.0	13.0	12.0	12.5	12.0	12.5	12.0	12.2	300
	160	27			11.0	88	29.9	31.0	31.3	31.0	33.0	33.5	33.5	35.0	35.8	72	12.5	11.0	12.0	12.0	12.0	11.5	11.9	11.0	11.2	300
	150	26	7735	101.5	11.0	82	29.5	30.5	31.0	31.0	32.0	33.0	33.0	34.0	35.0	72	12.0	10.8	12.0	11.0	11.0	11.5	11.2	11.0	10.6	301
	158	26			10.2	87	29.58	30.7	30.76	31.1	33.1	33.1	32.8	34.9	35.6	73.6	11.8	10	10.9	10.2	11.1	10.4	10.9	9.5	10.6	300

Time-Run #	High Press	Low Press	Wt Brine	Wt Ammonia	Comp T: NH_3 In	Comp T: NH_3 Out	Brine Temp in Cooler: No 29	28	27	26	25	24	23	22	21	Ammonia Temp in Cooler: 1A	1	2	3	4	5	6	7	8	9	R.P.M.
	#/□"	#/□"	#	#	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	R.P.M
21	150	24			8	100	29.2	30.0	30.3	29.5	31.4	31.0	31.0	30.0	32.8	71.0	10.7	10.0	10.5	11.0	10.0	11.5	8.5	11.5	9.6	300
	152	27			12	83	30.8	31.0	31.8	32.0	32.8	33.0	33.0	34.0	34.7	76.0	7.0	8.0	6.0	6.0	6.0	7.0	10.0	7.0	7.0	302
	150	25			10	12.3	33.8	34.0	34.8	35.0	36.0	36.0	36.0	37.0	37.0	75.0	11.0	10.0	10.5	9.5	10.0	9.8	9.0	10.0	9.6	301
90 Min	165	25			10	13.0	34.0	34.5	35.1	35.0	36.1	36.0	36.0	37.0	38.0	71.0	10.0	10.0	9.0	10.0	8.0	10.0	9.6	10.0	8.2	302
	157	29			14	85	32.0	32.3	32.8	32.0	33.9	33.0	37.0	33.0	35.5	75.0	10.0	13.0	10.0	13.4	9.0	13.8	10.1	8.8	11.2	302
	150	25	24383		9	84	29.0	29.0	29.6	29.0	30.1	30.0	30.0	31.0	31.8	78.0	11.5	10.0	10.8	10.0	10.0	9.7	9.6	10.0	10.0	300
	158	26		185.5	10	86	30.0	31.0	31.0	31.0	32.0	32.0	32.0	32.5	33.0	74.0	11.0	10.0	10.0	9.0	10.0	9.5	10.0	9.5	9.5	301
	154.6	25.86			10.43	98.7	31.26	31.9	31.8	32.0	33.73	33.2	33.0	33.7	34.7	74.3	10.17	9.94	8.94	9.54	8.9	9.89	9.44	7.45	9.3	301

V Results of Condenser Tests

The results of the condenser tests are tabulated on page 44 and the observed data are shown on pages 74 to 81 inclusive. Items one to three of the result sheet are self explanatory. The ammonia saturation temperature in the condenser, item four, was taken as an average of the thermometer readings excluding thermometer 41 which indicated the temperature of the entering superheated ammonia. The reason for omitting ammonia thermometer number 41 is given in the discussion of item fifteen. The temperature difference between entering cooling water temperature and ammonia saturation temperature, item five, was obtained by subtracting entering water temperature from saturation ammonia temperature. The weight of brine circulated was taken directly from the observed data while the brine range, item seven, was obtained as the difference in temperature of the entering and leaving cooler brine. The tons of refrigeration from the cooler or total heat given up by the brine, item eight, was computed from the weight of brine circulated per hour, the brine range, and the brine specific heat.

The weight of ammonia circulated per hour, item nine, was obtained by direct weighing during the tests. This quantity was subject to three or four pounds variation due to the accumulation of ammonia in the different parts of the system. The tons of refrigerating effect produced in the condenser based on the weight of ammonia, item ten, was calculated by the following formula:

RESULT SHEET – CONDENSER TRANSFER TESTS – SERIES 2.

NO			1	2	3	4	5	6	7	8	9	10	11	12
1	Length of Run	Min	30	30	30	30	30	30	30	30	30	30	30	30
2	Water Temp Enter Cond	°F	61.1	61.5	60.3	59.9	60.3	60.3	59.3	60.8	60.3	59.6	59.35	61.25
3	Condenser Pressure Gage	#/□"	116.4	128.3	151.7	107	115	130	100	115	120	103.4	108.9	119.2
4	NH_3 Sat. Temp in Cond	°F	71	75.9	84.7	67	70.4	76.9	64	68.5	72.2	63.6	65.8	71
5	NH_3 Sat. Temp Less Ent. H_2O T.	°F	9.9	14.4	24.4	7.1	10.1	16.6	4.7	7.7	11.9	4.0	6.45	9.75
6	Wt Brine Circulated	#/Hr	10576	4674	5514	4422	5122	4672	4384	5230	7740	5164	6234	5558
7	Brine Range	°F	2.5	9.0	10.5	6.5	9.8	13.7	6.7	9.9	10.4	6.0	8.62	14.2
8	Cooler Refrigeration	Tons	1.655	2.608	3.598	1.792	3.118	4.075	1.828	3.221	5.00	1.921	3.340	4.93
9	Wt of Ammonia	#/Hr	38	59	99	35	71	102	30	62	123	44	70	46
10	Condenser Tonnage on NH_3	Tons	1.690	2.580	4.29	1.56	3.15	4.40	1.45	2.755	5.48	1.99	3.17	2.07
11	Wt Cooling Water Per Min	#/Min	43.2	42.9	41.3	79.0	81.7	83.2	121.6	120.7	122.9	182.8	190.7	188.2
12	Cooling Water	Gals/Min	5.18	5.14	4.95	9.48	9.80	9.97	14.6	14.49	14.75	21.9	22.9	22.6
13	Cooling Water Range	°F	8.8	13.0	21.9	5.5	8.1	12.5	3.1	5.6	7.4	2.4	4.04	6.05
14	Condenser Heat Transfer	BTU/Hr	22810	33490	54300	26080	39740	62410	22610	40,600	60800	26320	46220	68200
15	Condenser Heat Transfer	Tons	1.905	2.788	4.525	2.17	3.315	5.20	1.885	3.381	5.062	2.192	3.855	5.695
16	Mean Temp. Difference	°F	4.27	6.42	10.87	4.00	5.55	9.05	2.5	4.75	7.38	2.91	4.21	6.17
17	Heat Transfer Area	□'	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47
18	Coef Heat Trans.	BTU/°/□' Per Hr	206	197	188	246	272	257	342	323	313	342	415	418
19	Velocity Cond. Water	Ft/Min	1.114	1.105	1.065	2.039	2.11	2.145	3.135	3.111	3.168	4.715	4.920	4.865
20	Surface Coef Water	BTU/□'/sec/°	.278	.276	.275	.300	.302	.303	.330	.329	.331	.369	.373	.370
21	Steel Coef	"	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
22	Ammonia Film Coef	"	.0746	.0726	.0537	.0956	.109	.1029	.1502	.137	.1148	.1431	.1934	.1963
23	ΔT Water Surface	°F	.861	1.273	2.068	.912	1.380	2.159	.719	1.292	.1925	.748	1.296	1.931
24	ΔT Steel Wall	°F	.1995	.293	.474	.228	.374	.646	.1973	.3545	.532	.2395	.403	.595
25	ΔT Ammonia Film	°F	3.21	4.84	8.328	2.860	3.823	6.345	1.584	3.104	4.923	1.923	2.511	3.644

NO			13	14	15	16	17	18	19	20	21	22	23	24
1	Length of Run	Min	30	30	30	30	30	30	30	30	30	30	30	30
2	Water Temp Enter Cond	°F	68.8	70.1	69.6	71.1	69.1	70.82	70.9	69.8	70.6	70.1	69.7	69.8
3	Condenser Pressure Gage	#/□"	137	157.75	179.2	163	142	134.9	126.8	131.5	146	121.7	127	138.7
4	NH_3 Sat. Temp in Cond	°F	77.3	85.35	93.2	87.4	79.5	76.7	75.1	77	82.6	72.4	75.3	80.25
5	NH_3 Sat. Temp Less Ent. H_2O T.	°F	8.5	15.25	23.6	16.3	10.4	5.88	4.2	7.2	12.0	2.3	5.6	10.45
6	Wt Brine Circulated	#/Hr	4694	4560	5106	6818	6704	5882	5808	5854	5844	6936	5022	4872
7	Brine Range	°F	5.7	10.3	15.0	13.5	7.2	5.3	5.88	8.68	13.8	3.7	10.2	15.7
8	Cooler Refrigeration	Tons	1.672	2.93	4.780	5.75	3.012	1.941	1.931	3.16	5.06	1.592	3.190	4.770
9	Wt of Ammonia	#/Hr	34	40	104	108	77	43	44	63	95	40	73	152
10	Condenser Tonnage on NH_3	Tons	1.475	1.725	4.46	4.56	3.29	1.88	1.91	2.80	4.08	1.75	3.23	6.35
11	Wt Cooling Water Per Min	#/Min	43.6	43.5	42.05	93.5	80.2	85.6	129.0	127.5	122.4	187.3	184.8	183.1
12	Cooling Water	Gals/Min	5.24	5.23	5.05	11.2	9.64	10.25	15.5	15.31	14.7	22.5	22.15	22.0
13	Cooling Water Range	°F	7.85	13.72	21.37	12.4	8.15	4.6	3.0	4.9	8.2	1.7	4.1	5.9
14	Condenser Heat Transfer	BTU/Hr	20530	35850	53900	69000	39300	23400	23300	37400	60200	19,090	45400	64800
15	Condenser Heat Transfer	Tons	1.712	2.978	4.49	5.30	3.275	1.937	1.941	3.115	5.02	1.59	3.78	5.39
16	Mean Temp. Difference	°F	3.77	6.77	10.56	8.94	5.46	3.31	2.69	4.25	7.25	1.85	4.00	7.15
17	Heat Transfer Area	□'	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47
18	Coef Heat Trans.	BTU/°/□' Per Hr	206	200	192.5	294	272.5	270	350.5	332.5	313.5	389.5	429	342.5
19	Velocity Cond. Water	Ft/Min	1.124	1.122	1.085	2.41	2.140	2.209	3.355	3.289	3.155	4.830	4.762	4.72
20	Surface Coef Water	BTU/□'/sec/°	.277	.276	.271	.311	.302	.304	.334	.333	.332	.370	.369	.369
21	Steel Coef	"	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
22	Ammonia Film Coef	"	.0767	.0739	.0708	.1205	.1100	.1067	.1326	.1429	.1310	.1748	.1852	.1433
23	ΔT Water Surface	°F	.777	1.361	2.088	2.325	1.365	.808	.735	1.178	1.901	.542	1.288	1.84
24	ΔT Steel Wall	°F	.179	.313	.472	.602	.344	.2044	.2036	.327	.526	.166	.397	.566
25	ΔT Ammonia Film	°F	2.814	5.096	8.00	6.013	3.741	2.298	1.755	2.745	4.823	1.142	2.315	4.744

NO			25	26	27	28	29	30	31	32	33	34	35	36
1	Length of Run	Min	30	30	30	30	30	30	30	30	30	30	30	30
2	Water Temp Enter Cond	°F	80.1	83.3	81.6	82.8	80.72	81.52	91.7	79.8	81.5	80.45	89.02	89.98
3	Condenser Pressure Gage	#/□"	164	190	214.4	164	165.5	186	216	148.9	161.9	171.6	176.4	186
4	NH_3 Sat. Temp in Cond	°F	87.7	96.4	103	87	89	96	105	83.2	87.7	91	92.5	95.8
5	NH_3 Sat. Temp Less Ent. H_2O T.	°F	7.6	13.1	21.4	4.2	8.28	14.48	13.3	3.4	6.2	10.55	3.48	5.82
6	Wt Brine Circulated	#/Hr	3382	6532	6718	8910	3994	7882	7790	6296	6022	6370	6592	5752
7	Brine Range	°F	7.0	6.5	10.5	2.8	10.36	10	9.7	3.3	7.6	13.0	4.8	8.0
8	Cooler Refrigeration	Tons	1.469	2.64	4.43	1.558	2.57	4.94	4.74	2.90	2.853	5.22	1.684	2.882
9	Wt of Ammonia	#/Hr	38	69	89	30	59	102	106	36	60	80	36	36
10	Condenser Tonnage on NH_3	Tons	1.58	2.895	3.71	1.255	2.53	4.33	4.42	1.52	2.53	3.45	1.49	1.48
11	Wt Cooling Water Per Min	#/Min	40.7	36	38.6	82.4	84.7	82.75	81.5	127.8	124.7	126.9	125.2	124.7
12	Cooling Water	Gals/Min	4.89	4.32	4.63	9.91	10.16	9.94	9.8	15.35	14.98	15.23	15.02	15.00
13	Cooling Water Range	°F	6.88	11.86	19.4	3.57	6.48	11.6	10.65	2.72	4.32	7.35	2.28	3.80
14	Condenser Heat Transfer	BTU/Hr	16800	25600	44950	17650	32450	57600	52100	21500	32750	55950	17120	28420
15	Condenser Heat Transfer	Tons	1.398	2.132	3.74	1.472	2.745	4.795	4.340	1.730	2.698	4.66	1.426	2.37
16	Mean Temp. Difference	°F	3.19	5.46	9.01	2.16	4.46	7.85	7.17	2.11	3.70	6.56	2.00	3.62
17	Heat Transfer Area	□'	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47
18	Coef Heat Trans.	BTU/°/□' Per Hr	199	177.2	188	309	264.5	2.77	274.5	285	334.5	322	323.5	297
19	Velocity Cond. Water	Ft/Min	1.05	.929	.995	2.124	2.182	2.186	2.102	3.292	3.216	3.271	3.23	3.22
20	Surface Coef Water	BTU/□'/sec/°	.274	.272	.275	.302	.304	.304	.301	.333	.331	.332	.331	.332
21	Steel Coef	"	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
22	Ammonia Film Coef	"	.0872	.0634	.0682	.1334	.1136	.1127	.1113	.1851	.1444	.1362	.137	.1204
23	ΔT Water Surface	°F	.643	.988	1.715	.614	1.135	1.985	1.814	.679	1.027	1.764	.544	.899
24	ΔT Steel Wall	°F	.147	.224	.393	.154	.288	.502	.456	.188	.286	.488	.145	.248
25	ΔT Ammonia Film	°F	2.40	4.248	6.902	1.292	3.037	5.362	4.90	1.243	2.377	4.308	1.311	2.473

NO			37	38	39	40	41	42	43	44	45	46	47	48
1	Length of Run	Min	30	30	30	30	30	30	30	30	30	30	30	30
2	Water Temp Enter Cond	°F	90.50	81.4	80.85	80.8	88.6	89.25	89.4	91.3	93.1	93.62	93.18	90.12
3	Condenser Pressure Gage	#/□"	202.5	157.5	155.8	171.5	188.5	178	190	210	234	189.5	194.8	195.5
4	NH_3 Sat. Temp in Cond	°F	102.1	84.5	85.7	90.6	96.5	93.5	96	102.2	113.2	95.5	97.1	97.6
5	NH_3 Sat. Temp Less Ent. H_2O T.	°F	11.6	3.1	4.85	9.8	7.9	4.25	6.6	10.9	20.1	1.88	3.92	7.48
6	Wt Brine Circulated	#/Hr	6980	6652	5924	6362	5430	4878	5862	4580	6408	5350	4366	7550
7	Brine Range	°F	13.1	4.8	8.0	11.9	7.7	4.7	3.9	7.9	10.1	4.8	9.0	9.0
8	Cooler Refrigeration	Tons	5.28	1.721	2.96	5.202	2.548	1.422	1.435	2.26	4.04	1.60	2.45	4.24
9	Wt of Ammonia	#/Hr	82	38	28	42	31	34	33	56	98	30	56	103
10	Condenser Tonnage on NH_3	Tons	3.38	1.63	2.42	3.62	2.61	1.42	1.34	2.27	4.12	1.21	2.31	4.36
11	Wt Cooling Water Per Min	#/Min	123.65	185.2	188.6	180.8	86.5	81.0	40.2	45.0	45.9	192	187.5	192.2
12	Cooling Water	Gals/Min	14.84	22.45	22.65	21.7	10.25	9.7	4.83	5.4	5.52	23.1	22.5	23.1
13	Cooling Water Range	°F	8.2	1.95	3.00	5.55	6.32	3.30	5.8	9.92	18.4	1.33	2.52	4.20
14	Condenser Heat Transfer	BTU/Hr	60800	21650	38950	60200	32410	16050	18950	26800	50800	15850	28350	48450
15	Condenser Heat Transfer	Tons	5.07	1.806	2.83	5.02	2.702	1.337	1.16	2.23	4.23	1.28	2.36	4.04
16	Mean Temp. Difference	°F	7.06	2.00	3.37	6.45	4.25	2.36	2.75	4.56	8.62	1.07	2.5	4.85
17	Heat Transfer Area	□'	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47	26.47
18	Coef Heat Trans.	BTU/°/□' Per Hr	325.5	409	382	352	288	257	192	221	218	540	426	377
19	Velocity Cond. Water	Ft/Min	3.182	4.776	4.864	4.66	2.204	2.089	1.036	1.160	1.184	4.95	4.834	4.96
20	Surface Coef Water	BTU/□'/sec/°	.331	.368	.370	.363	.305	.301	.273	.274	.275	.373	.372	.373
21	Steel Coef	"	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2
22	Ammonia Film Coef	"	.1282	.1904	.1685	.1507	.1192	.1015	.0699	.0851	.0854	.3195	.2049	.1652
23	ΔT Water Surface	°F	1.925	.617	.961	1.739	1.114	.560	.536	1.026	1.938	.432	.799	1.361
24	ΔT Steel Wall	°F	.532	.189	.296	.526	.283	.141	.122	.234	.444	.134	.248	.423
25	ΔT Ammonia Film	°F	4.603	1.194	2.113	4.185	2.853	1.659	2.092	3.300	6.338	.504	1.453	3.066

$$Tc = \frac{W(H_1 - h_2)}{12000}$$

In which: Tc = Condenser tonnage

W = Weight of ammonia condensed

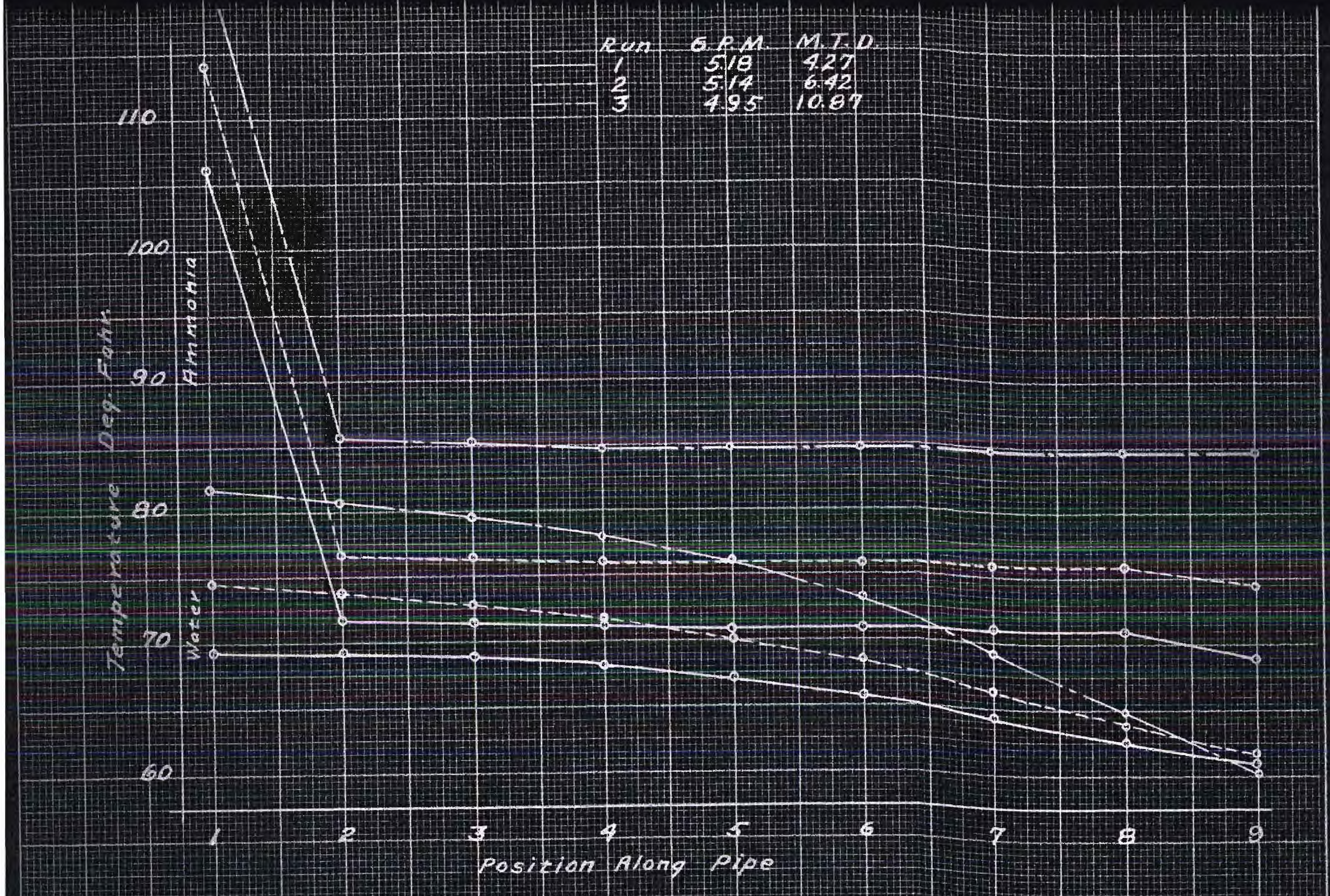
H_1 = Total heat per pound of superheated ammonia entering condenser

H_2 = Heat of the liquid ammonia leaving the condenser

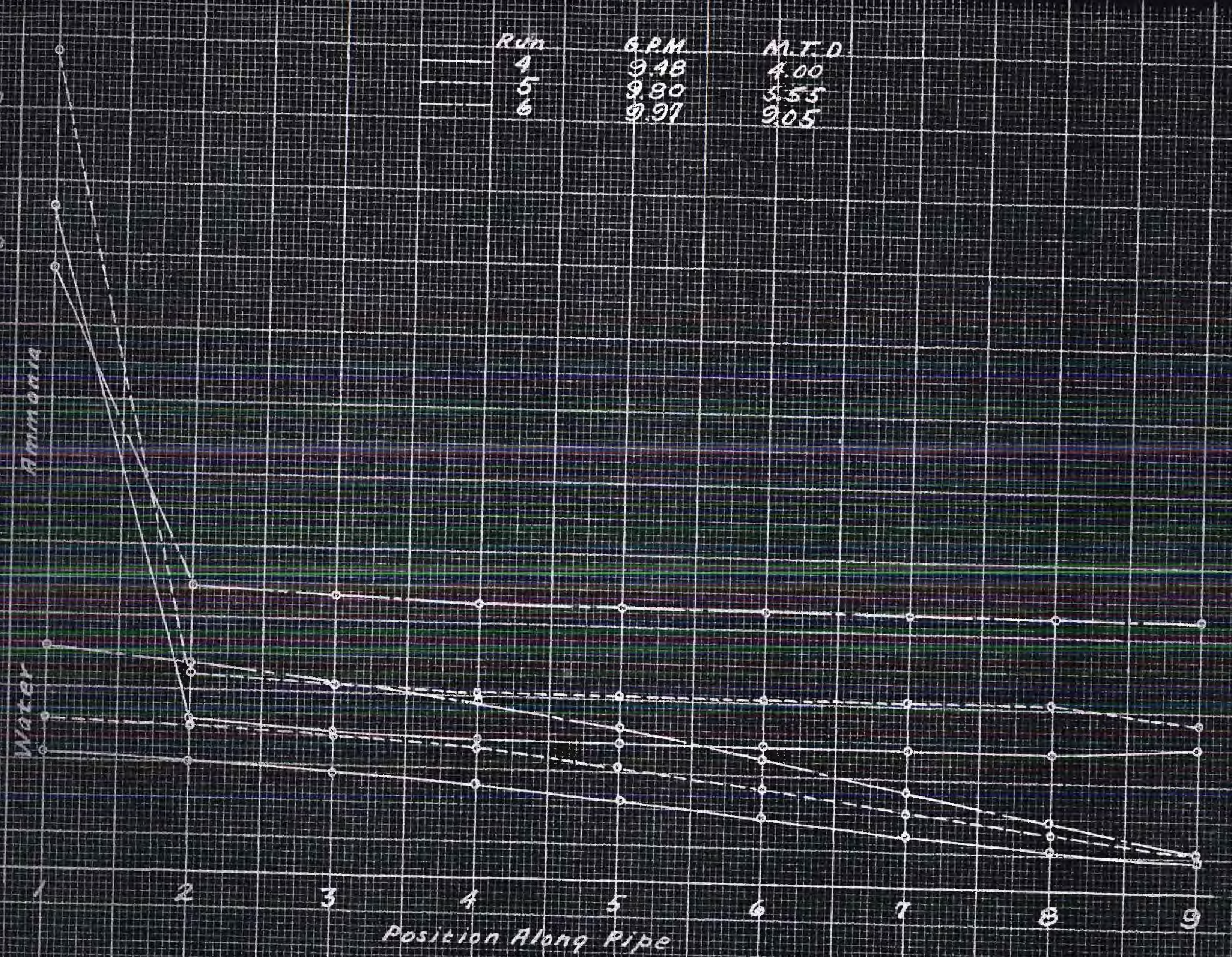
The weight of cooling water circulated per minute, item eleven, was obtained directly from the observed data by dividing the water circulated during a run by 30. The quantity of water in gallons per minute was computed by dividing item eleven by the weight of a gallon of water.

The condenser water range is the difference in temperature of the entering and leaving condenser water. By multiplying the pounds of water circulated per minute by 60 times the condensing water range, the total heat absorbed of the water resulted- item fourteen. The condenser tonnage, item fourteen, was obtained by dividing item fifteen by 12000.

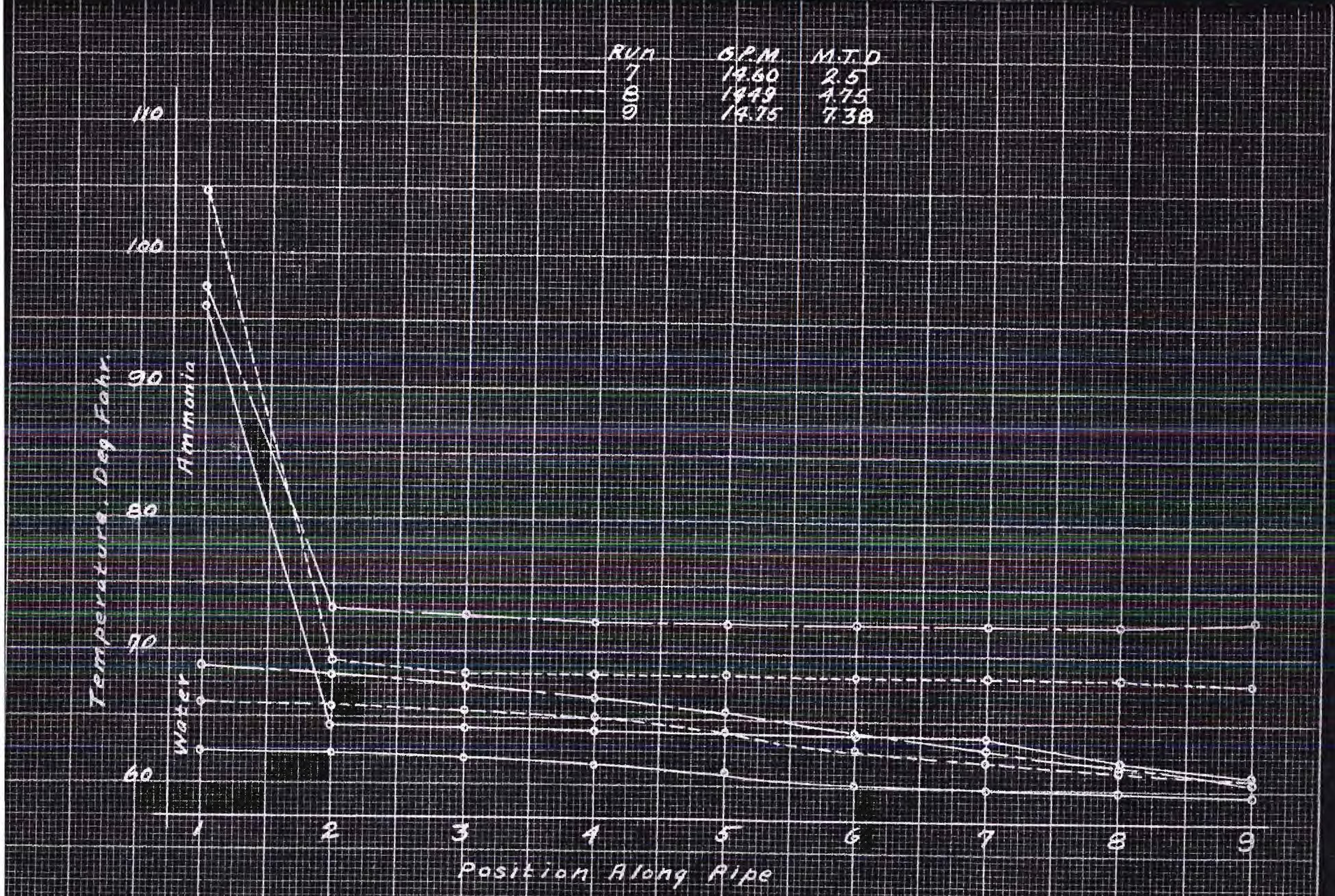
The mean temperature difference was determined by plotting actual temperatures of ammonia and water as ordinates, and position along the condenser pipe as abscissa. The curves for the forty-eight runs made are shown on pages 46 to 62 inclusive. By finding the inclosed area for a given run, the mean ordinate in degrees and the mean temperature difference could be computed.



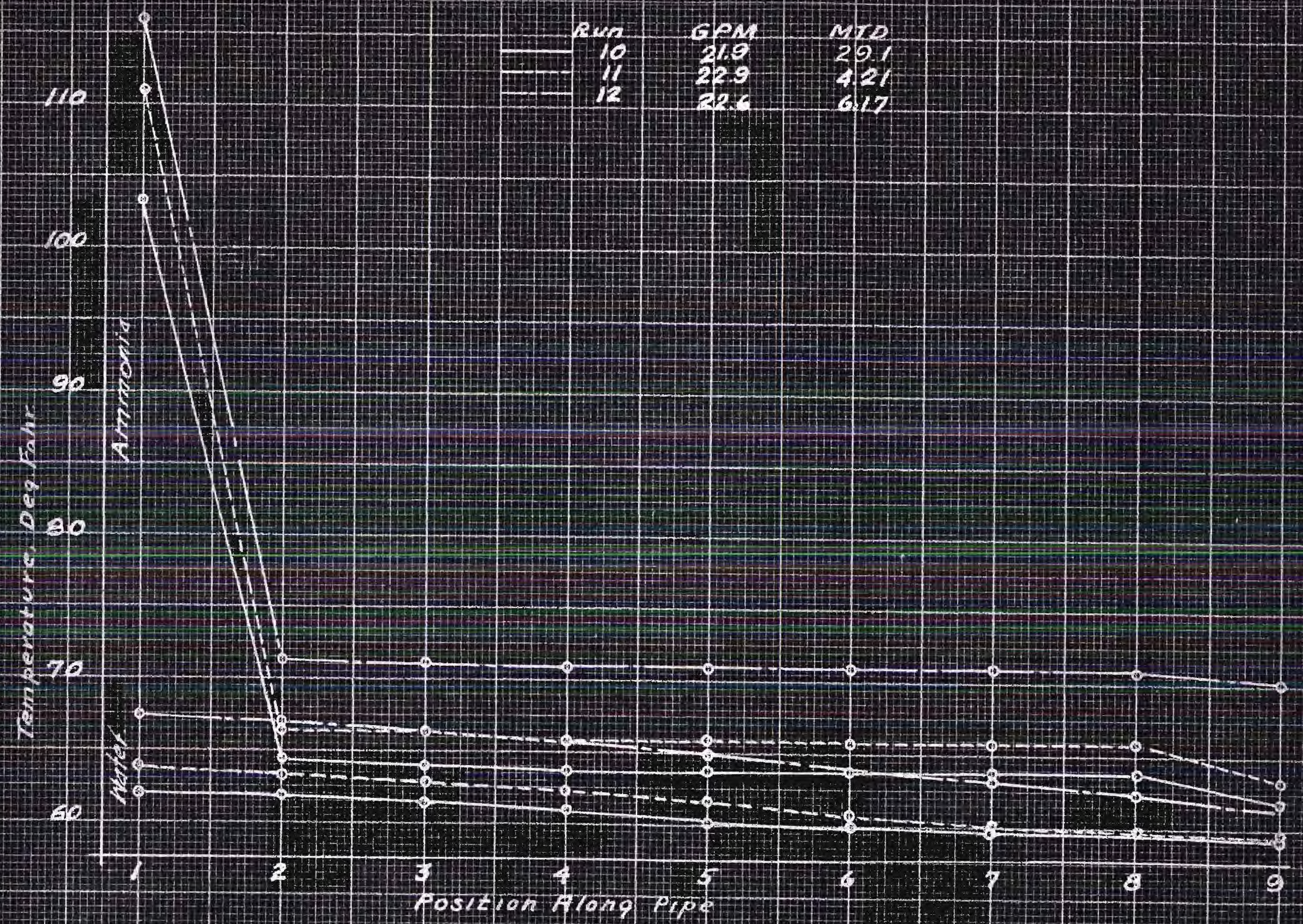
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS



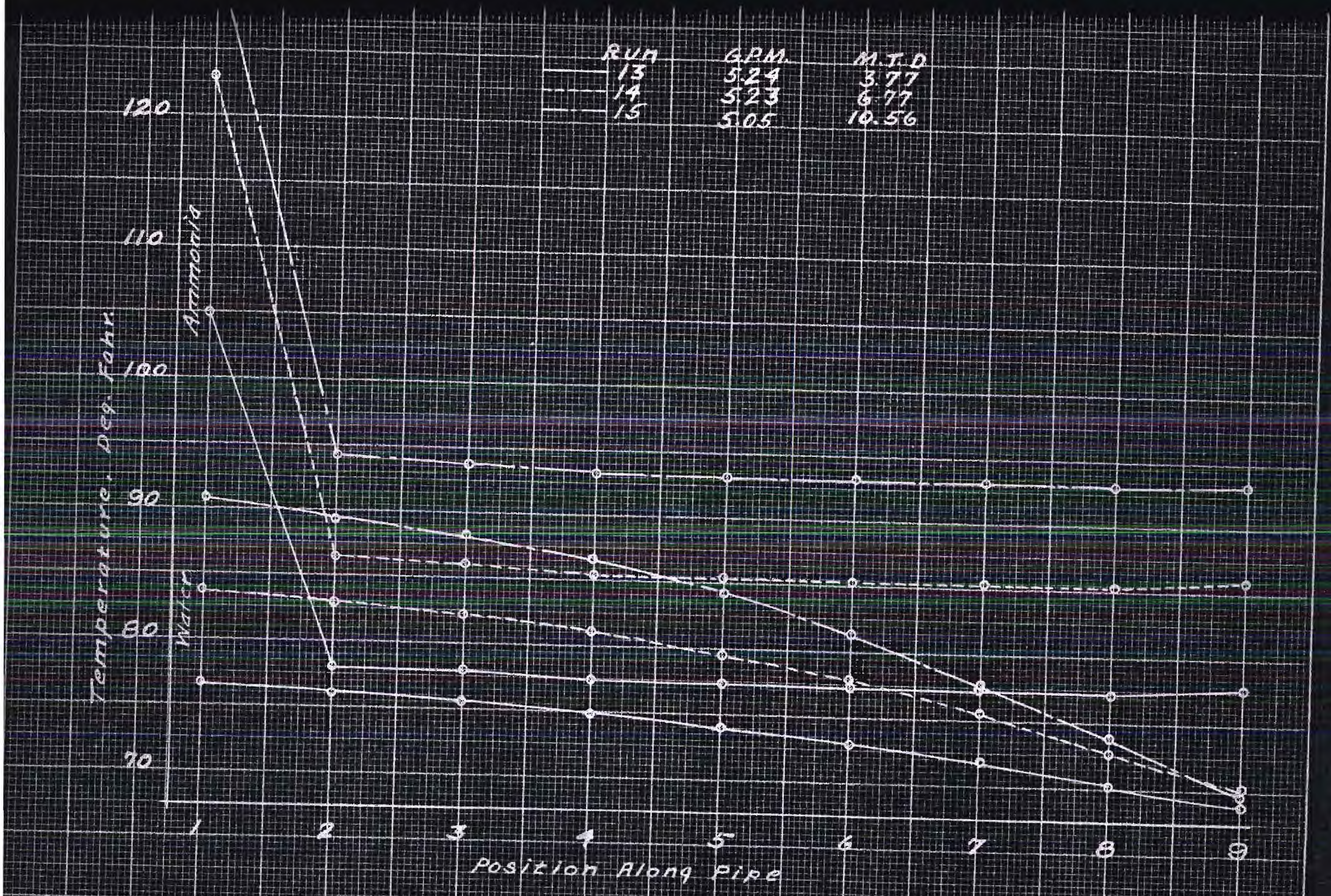
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS



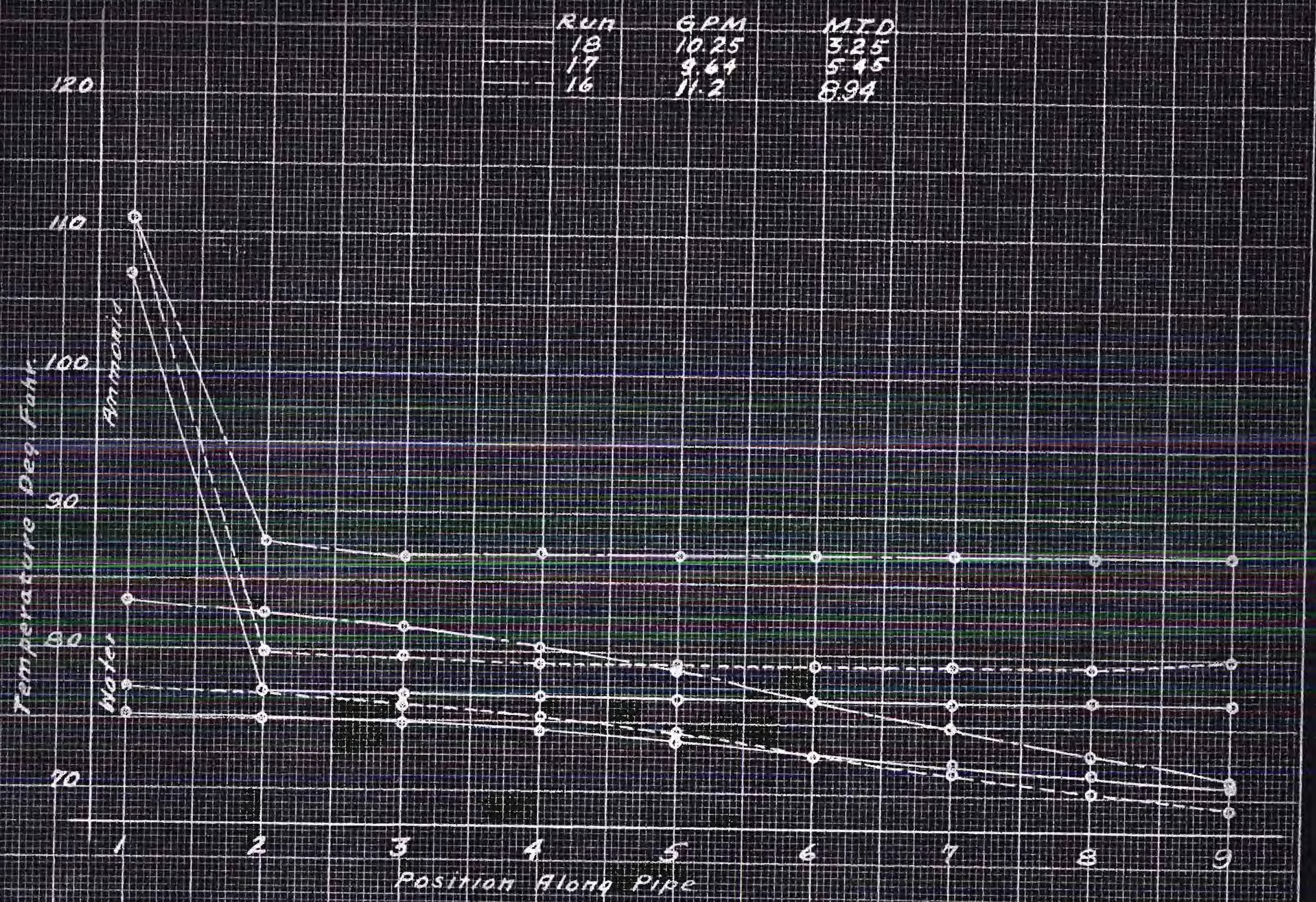
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS



ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS

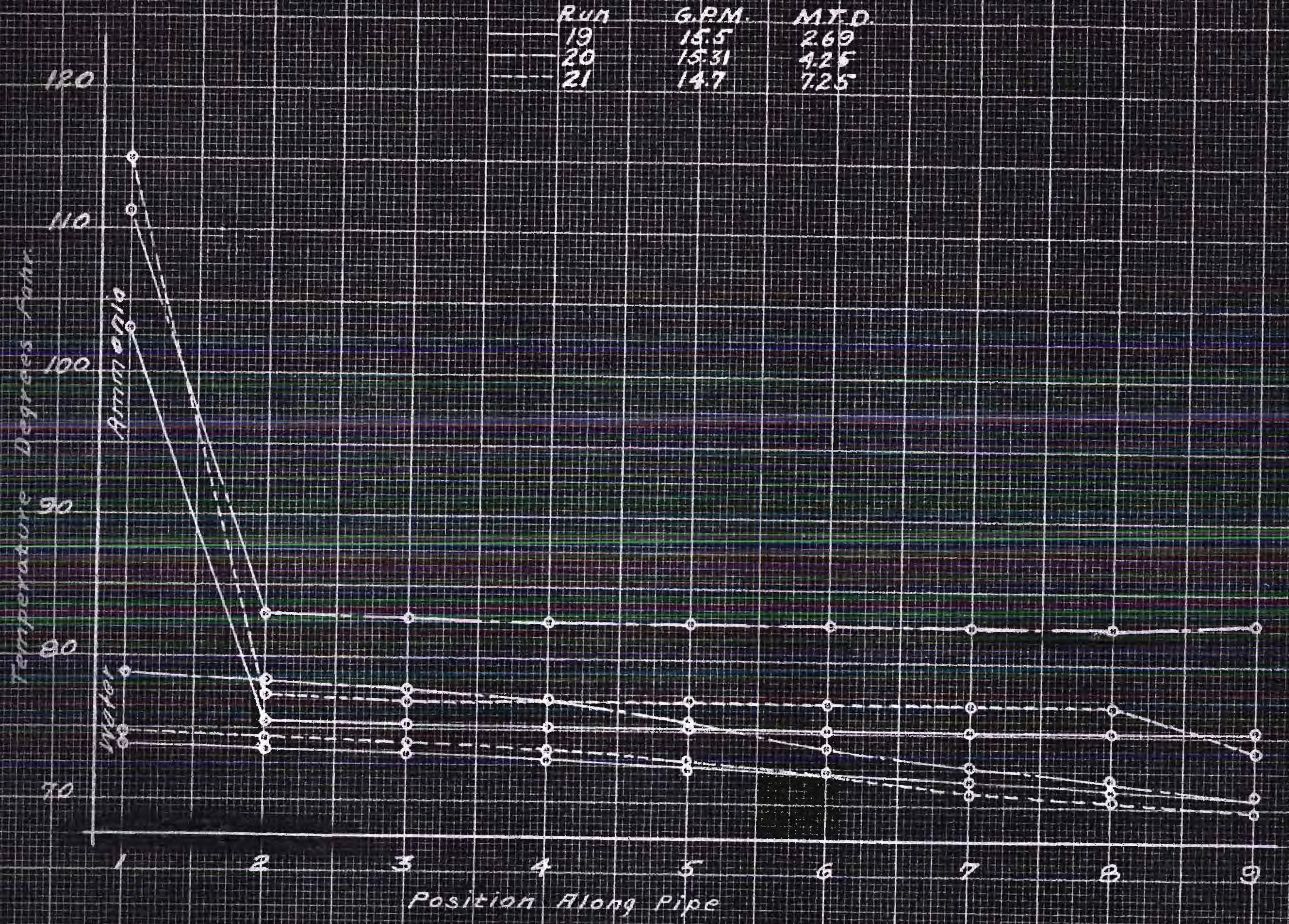


ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS

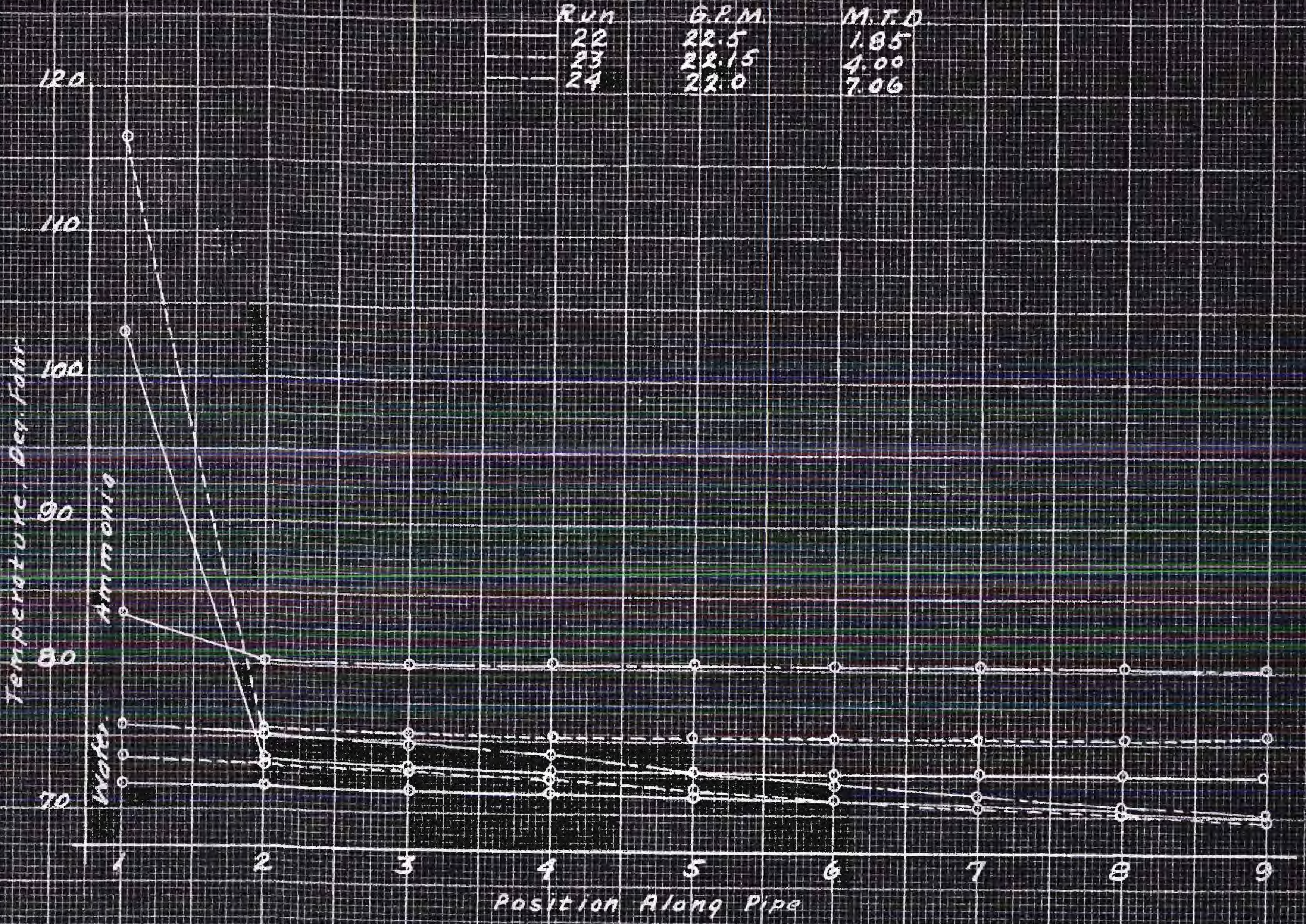


ACTUAL TEMPERATURE DIFFERENCE CURVES

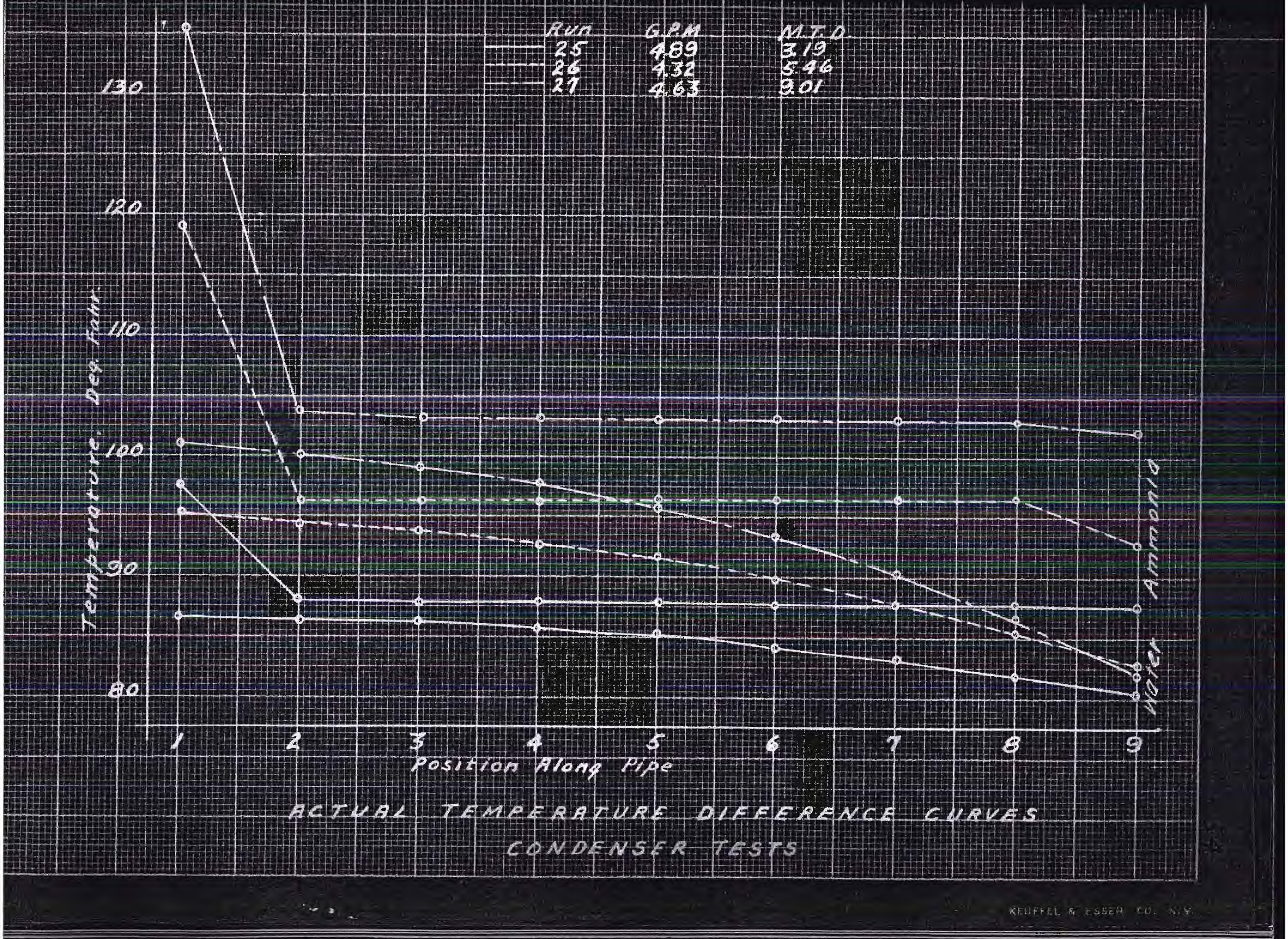
CONDENSER TESTS



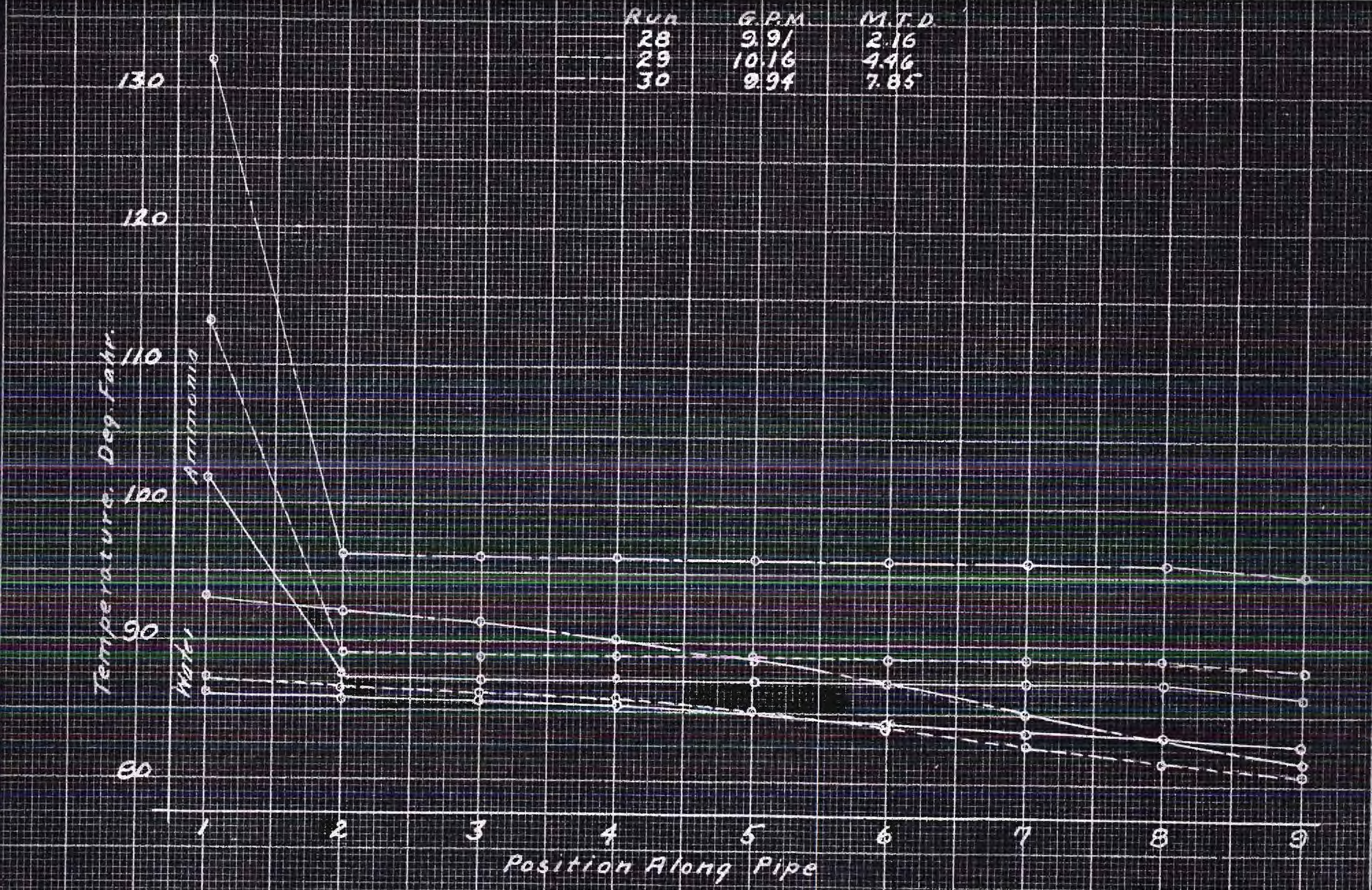
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS



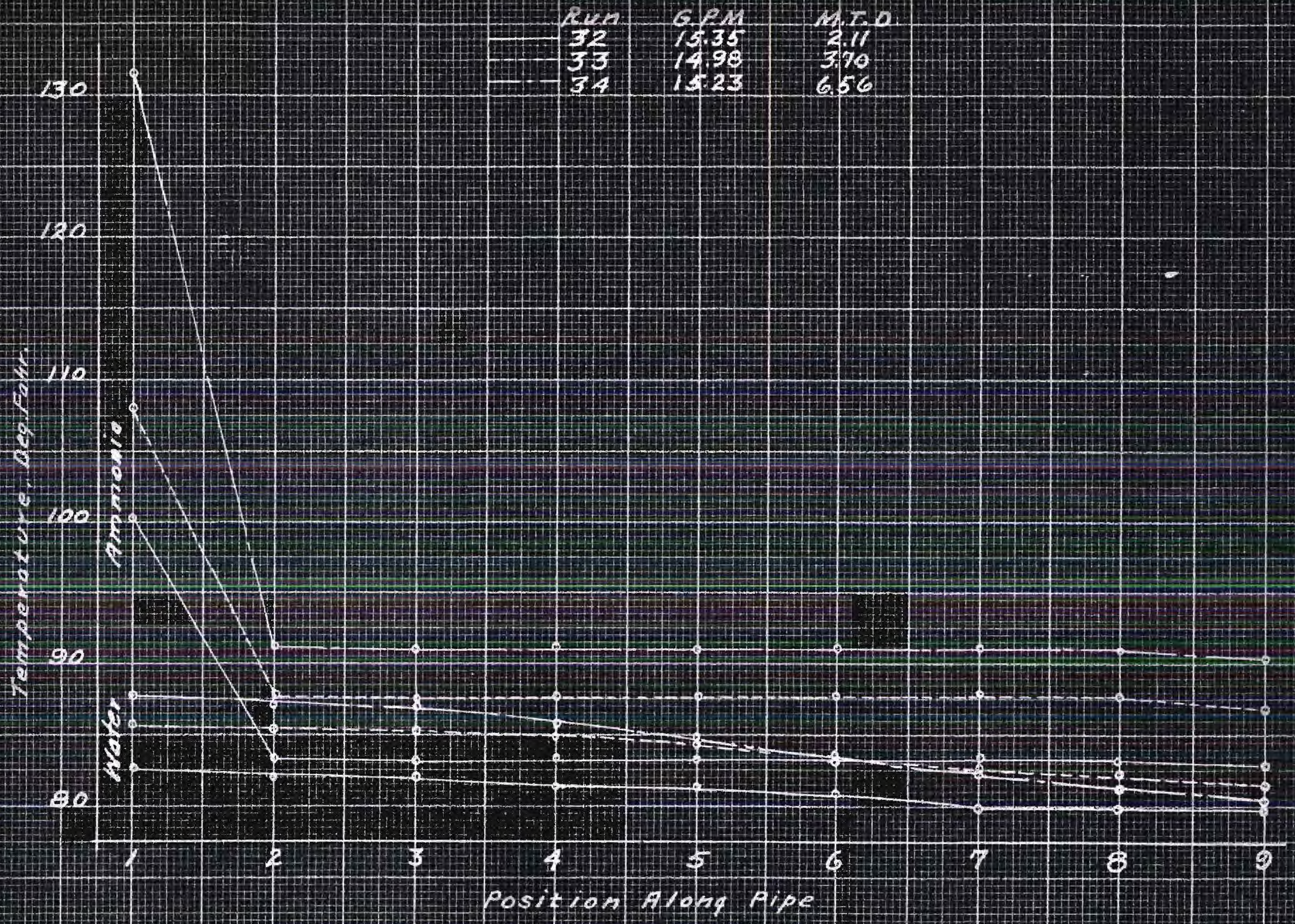
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS



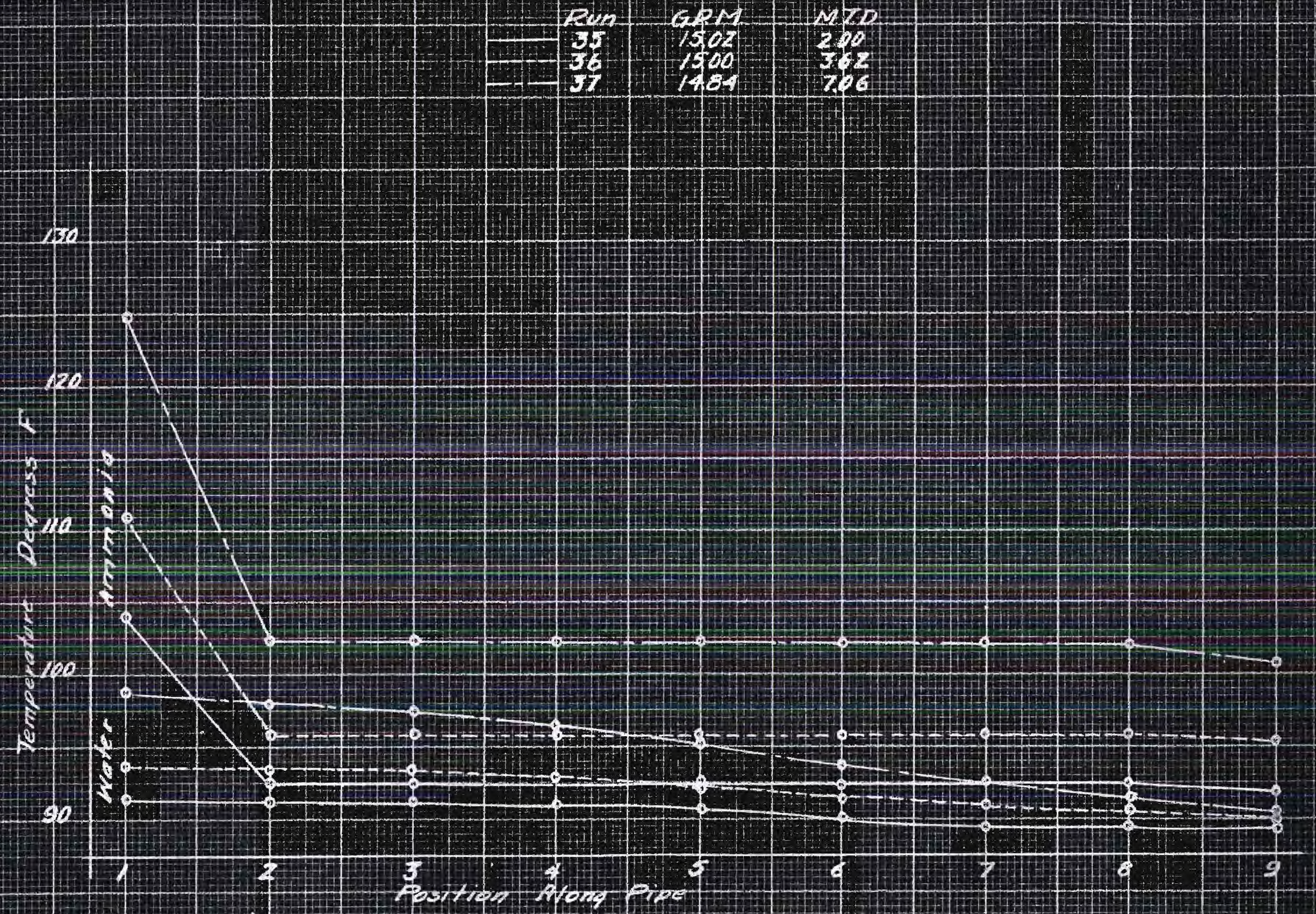
Run G.P.M M.T.D.
25 4.89 3.19
26 4.32 5.46
27 4.63 9.01
130
120
110
100
90
80
Temperature Deg. Fahr.
Ammonia
Water
1 2 3 4 5 6 7 8 9
Position Along Pipe
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS
KEUFFEL & ESSER CO. N.Y.



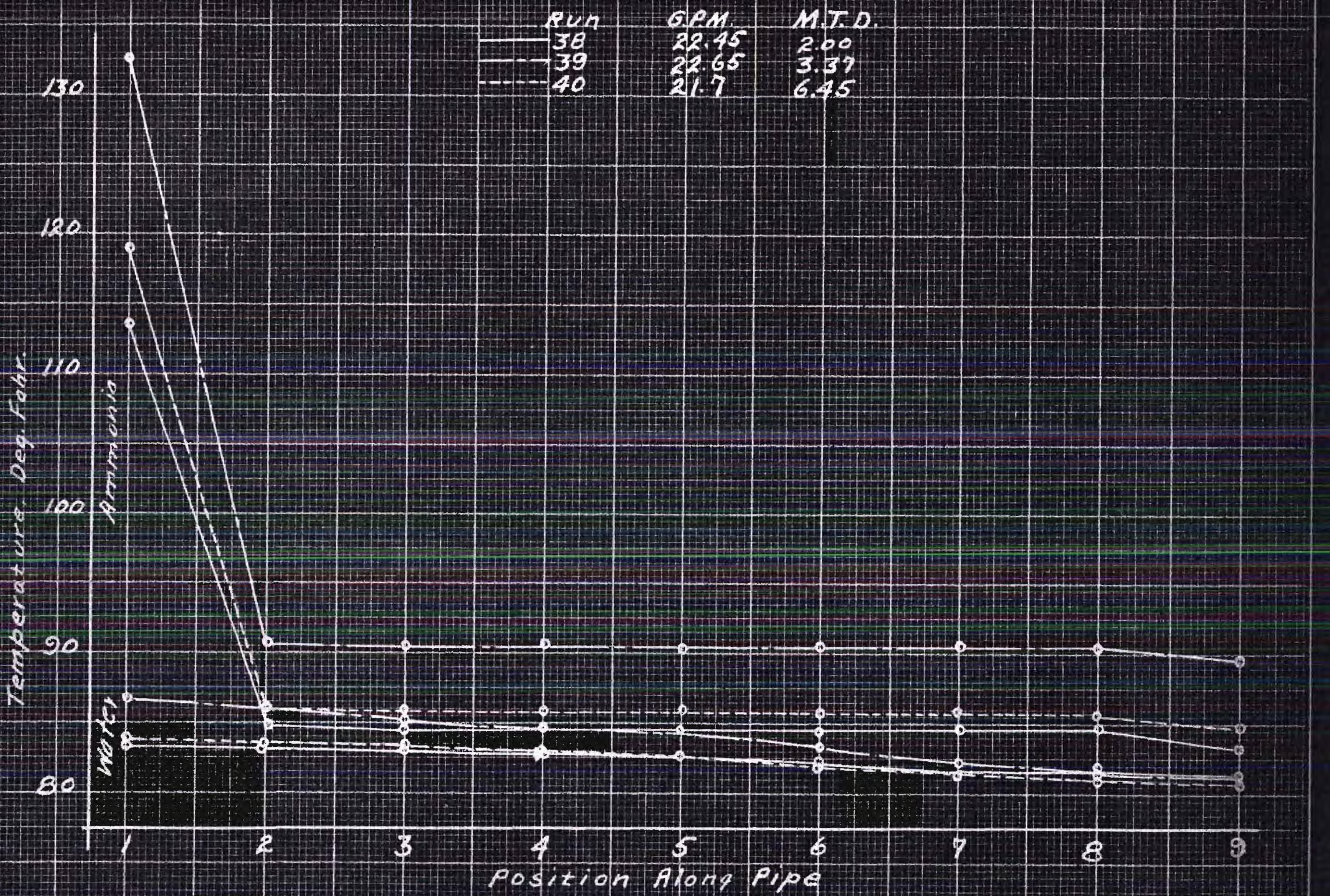
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS



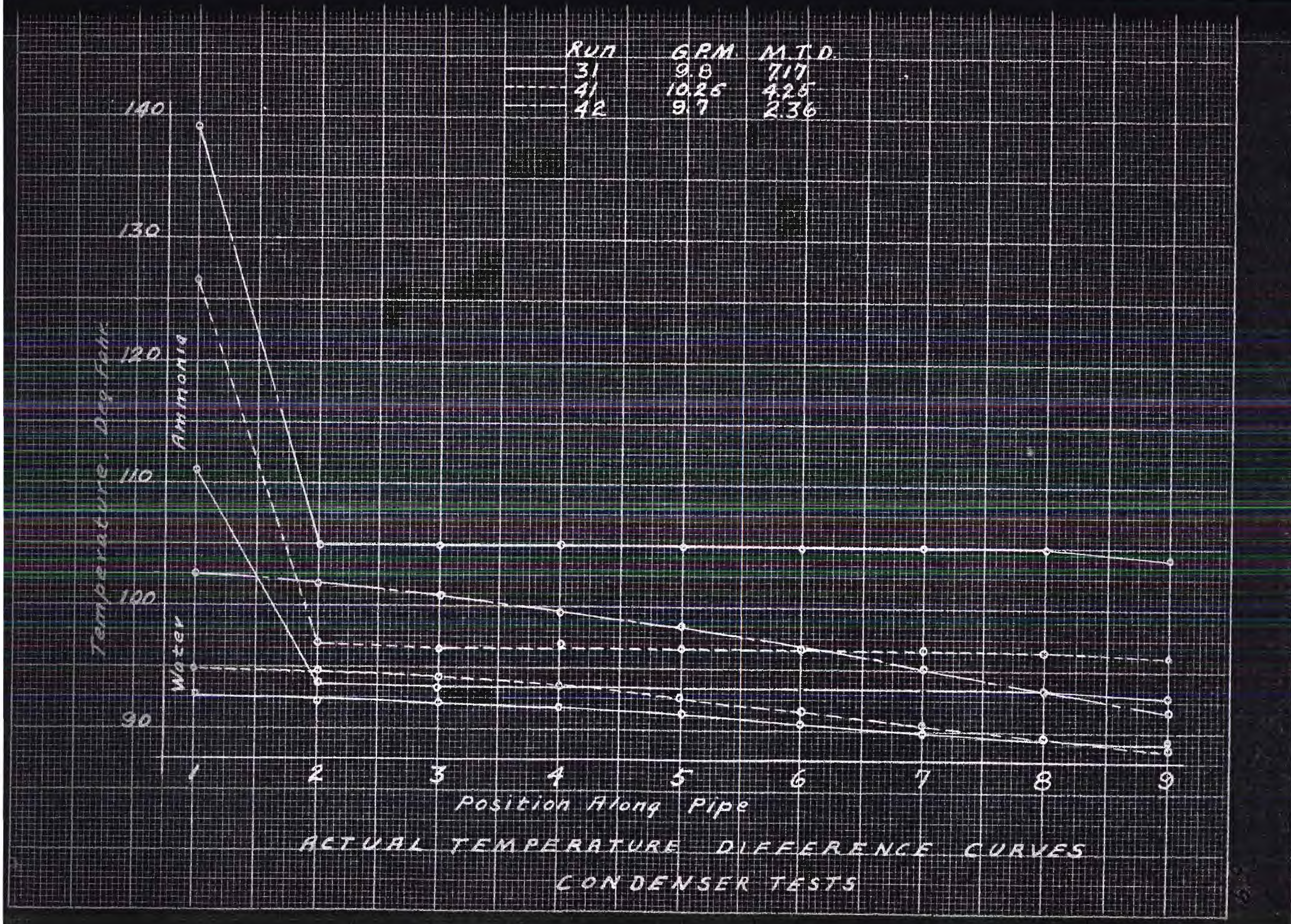
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS



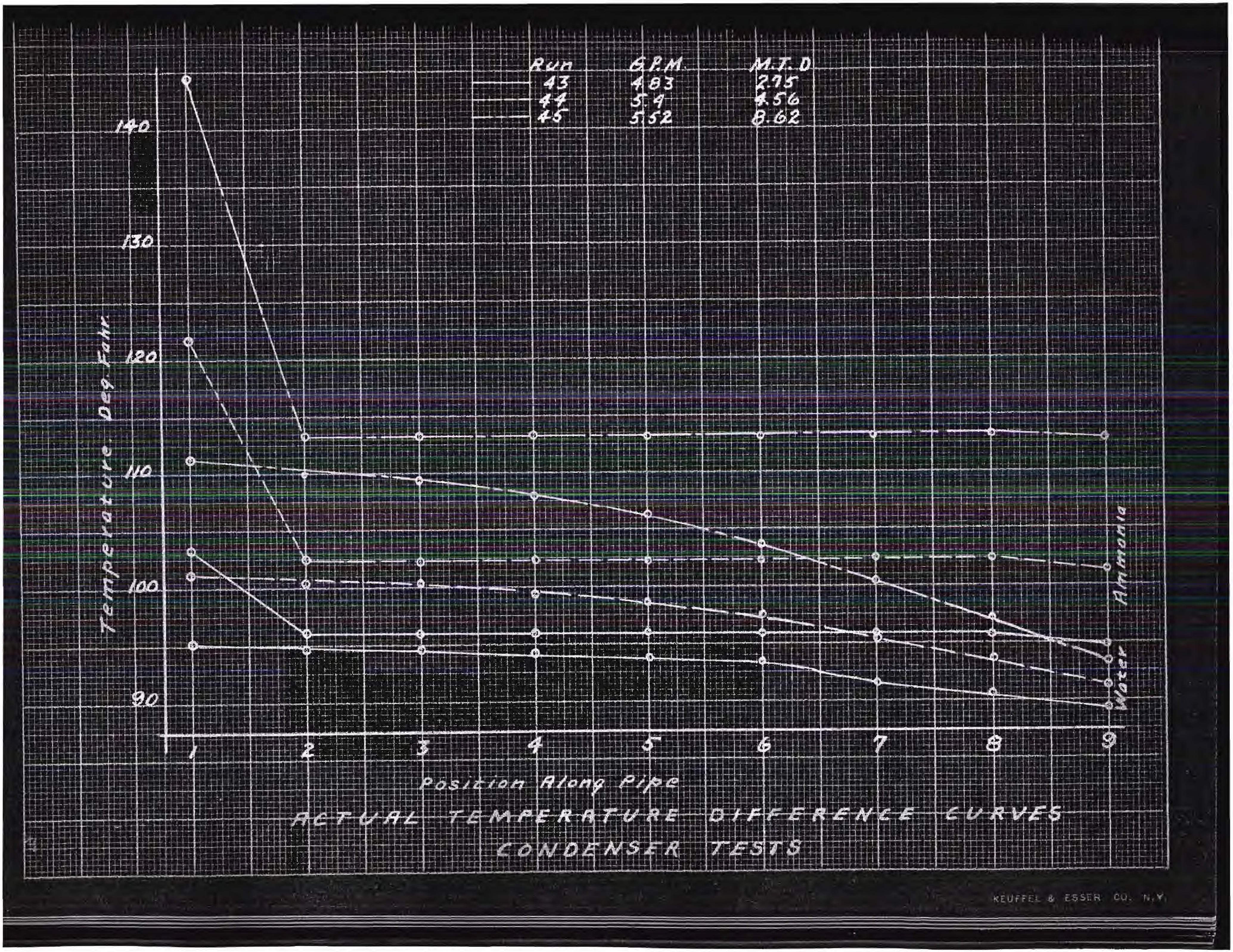
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS



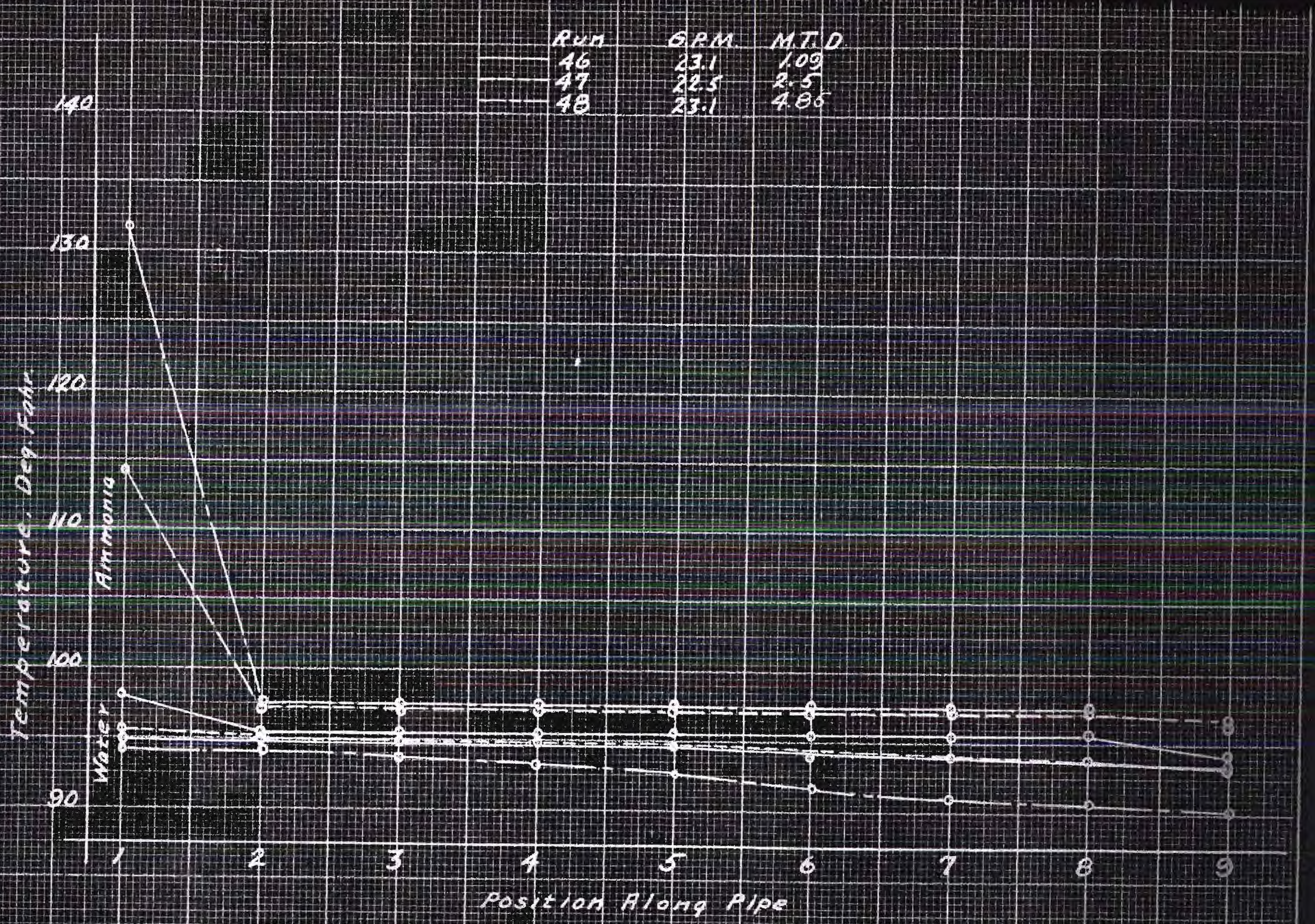
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS



Run G.P.M. M.T.D.
31 9.8 7.17
41 10.26 4.25
42 9.7 2.36
140
130
120
110
100
90
Temperature, Deg. Fahr.
Ammonia
Water
1 2 3 4 5 6 7 8 9
Position Along Pipe
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS
KEUFFEL & ESSER CO. N.Y.



Run G.P.M. M.T.D
43 4.83 2.75
44 5.4 4.56
45 5.52 8.62
140
130
120
110
100
90
Temperature Deg. Fahr.
Ammonia
Water
1 2 3 4 5 6 7 8 9
Position Along Pipe
ACTUAL TEMPERATURE DIFFERENCE CURVES
CONDENSER TESTS
KEUFFEL & ESSER CO. N.Y.



ACTUAL TEMPERATURE DIFFERENCE CURVES

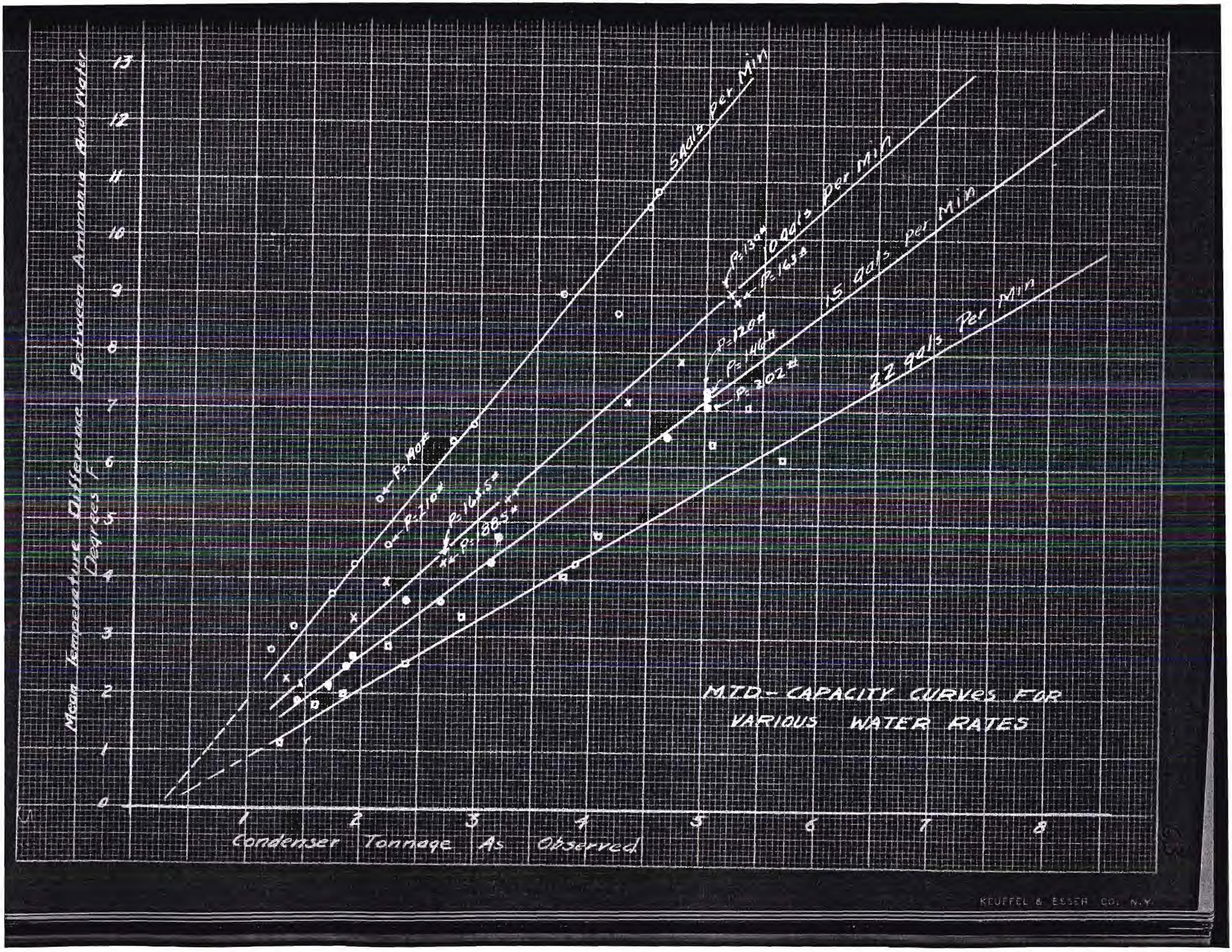
CONDENSER TESTS

In finding the area inclosed, the area added by the superheated ammonia was omitted because this was a variable quantity and it would be hard to account for in design and plant layout. Its effect on actual heat transfer is slight and did not show any inconsistencies by its omission. In actual practice, the saturation temperature is the predominating ammonia temperature and also the heat transfer area exposed to this temperature is most effective as is shown by the slope of the water temperature curves.

The set of curves shown on page 63 was obtained by plotting the mean temperature difference as ordinate and the condenser tonnage for a given water rate as abscissa. For a given quantity of water, there is a straight line relationship between the average mean temperature difference and the condenser tonnage. These curves tend to converge to a common point at zero mean temperature difference. Undoubtedly if runs were made at very low mean temperature difference, these curves would bend and pass through the origin, otherwise this would have to be explained as a heat leak.

Curve sheet page 65 shows the relation of condenser tonnage and quantity of water for a given mean temperature difference. This is a straight line relation except for low velocities - say below 100 feet per minute. This characteristic is also exhibited by steam condenser performances.

The heat transfer pipe area was taken as the actual area of pipe exposed to ammonia on one side and water on the other. This value was used as it is given by the manufacturer as the heat transfer area of the unit, and it seemed best from a commercial



Mean Temperature Difference Between Ammonia And Water
Degrees F
Condenser Tonnage As Observed
5 gals Per Min
10 gals Per Min
15 gals Per Min
22 gals Per Min
MTD - CAPACITY CURVES FOR
VARIOUS WATER RATES
KEUFFEL & ESSER CO. N.Y.

point of view. The area exposed to superheated ammonia gas tends to reduce heat transfer but this area is practically constant as shown by results of tests run at the University of Illinois,[17] and would not produce inconsistent results if not taken into account. Hence, in using this total area, a more nearly average value of coefficient of heat transfer for the work results and also, the results obtained in design would more nearly agree with actual operation conditions.

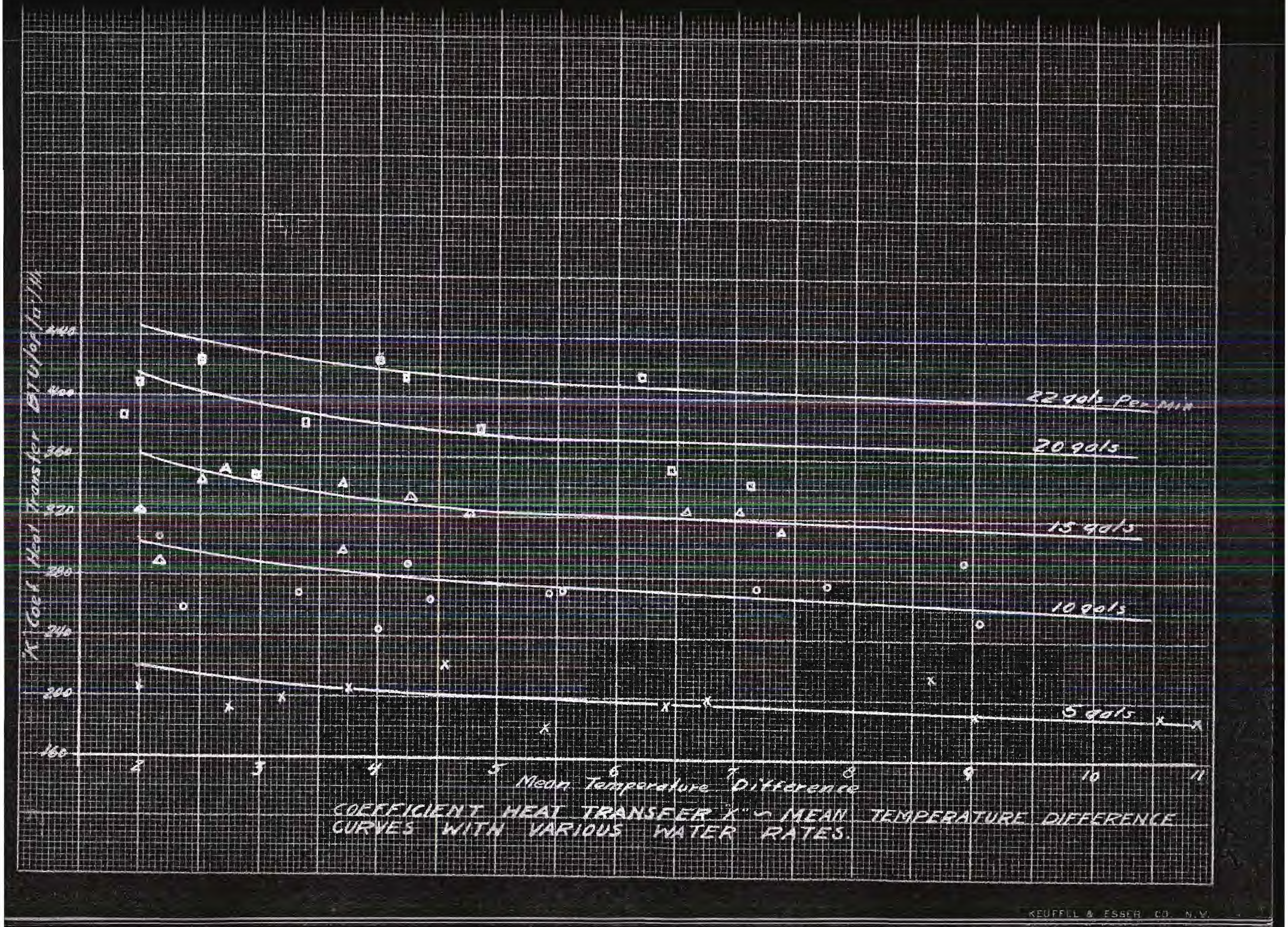
The coefficient of heat transfer "K", item eighteen, was calculated by dividing the total heat transfer per hour by the heat transfer area times the mean temperature difference. The values of K thus determined were plotted as ordinates and the mean temperature difference as abscissa for a given velocity of water. These curves appear on page 66. The value of K decreases as the mean temperature difference increases for a given quantity of cooling water as is shown.

The curves on page 65 show the relation between K and varying quantities of water for a given mean temperature difference. This relationship is a straight line except for velocities of cooling water less than 100 feet per minute.

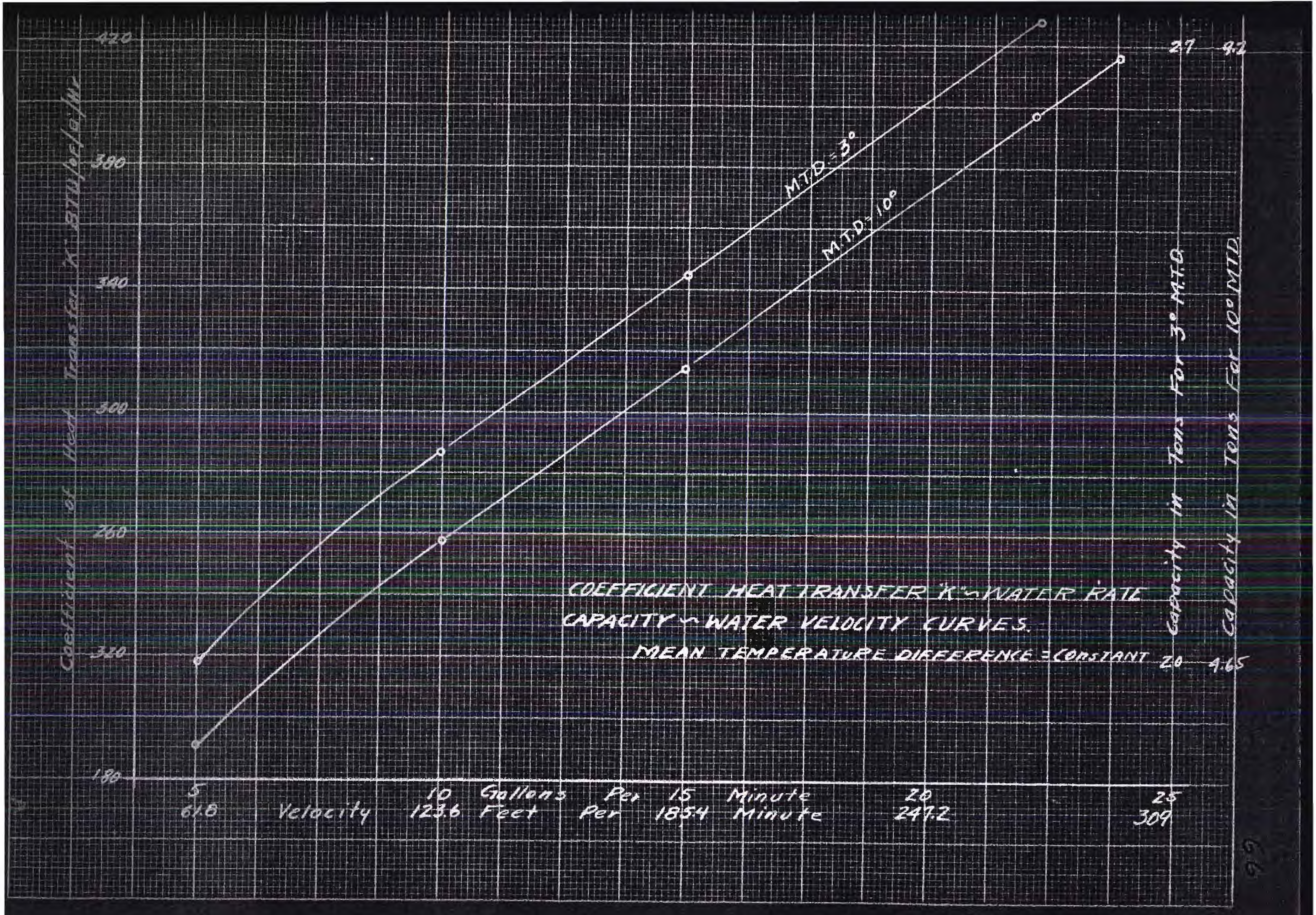
The mathematical relation of mean temperature difference and K is expressed by the equation:

$$K = \frac{C}{MTD^{.7}} \quad \text{for a given velocity}$$

[17] Kratz, A.P., Macintire, H.J., and Gould, R.E: Bulletin 171, December 1927, page 54.



COEFFICIENT HEAT TRANSFER "K" ~ MEAN TEMPERATURE DIFFERENCE CURVES WITH VARIOUS WATER RATES.



Coefficient of Heat Transfer K BTU/sq.ft./°F/Hr
420
380
340
300
260
320
180
M.T.D.=3°
M.T.D.=10°
COEFFICIENT HEAT TRANSFER "K" ~ WATER RATE
CAPACITY ~ WATER VELOCITY CURVES.
MEAN TEMPERATURE DIFFERENCE = CONSTANT
5 10 Gallons Per 15 Minute 20 25
61.8 Velocity 123.6 Feet Per 185.4 Minute 247.2 309
Capacity in Tons For 3° M.T.D.
Capacity in Tons For 10° MTD
2.7 9.2
2.0 4.65

In which: K = Coefficient of heat transfer BTU per degree per square foot per hour

C = A constant

MTD = Mean temperature difference, actual

When velocity is taken into account C varies with the velocity as:

$$C = 230 + V/1.22$$

In which: V = Velocity of water in feet per minute

K is then expressed as:

$$K = \frac{230 + \frac{V}{1.22}}{MTD^{.7}} \quad \text{and}$$

$$H = \frac{A\left(230 + \frac{V}{1.22}\right)MTD}{MTD^{.7}} = A\left(230 + \frac{V}{1.22}\right)(MTD)^{.3}$$

In which: H = Total heat transferred

A = Heat transfer area of pipe

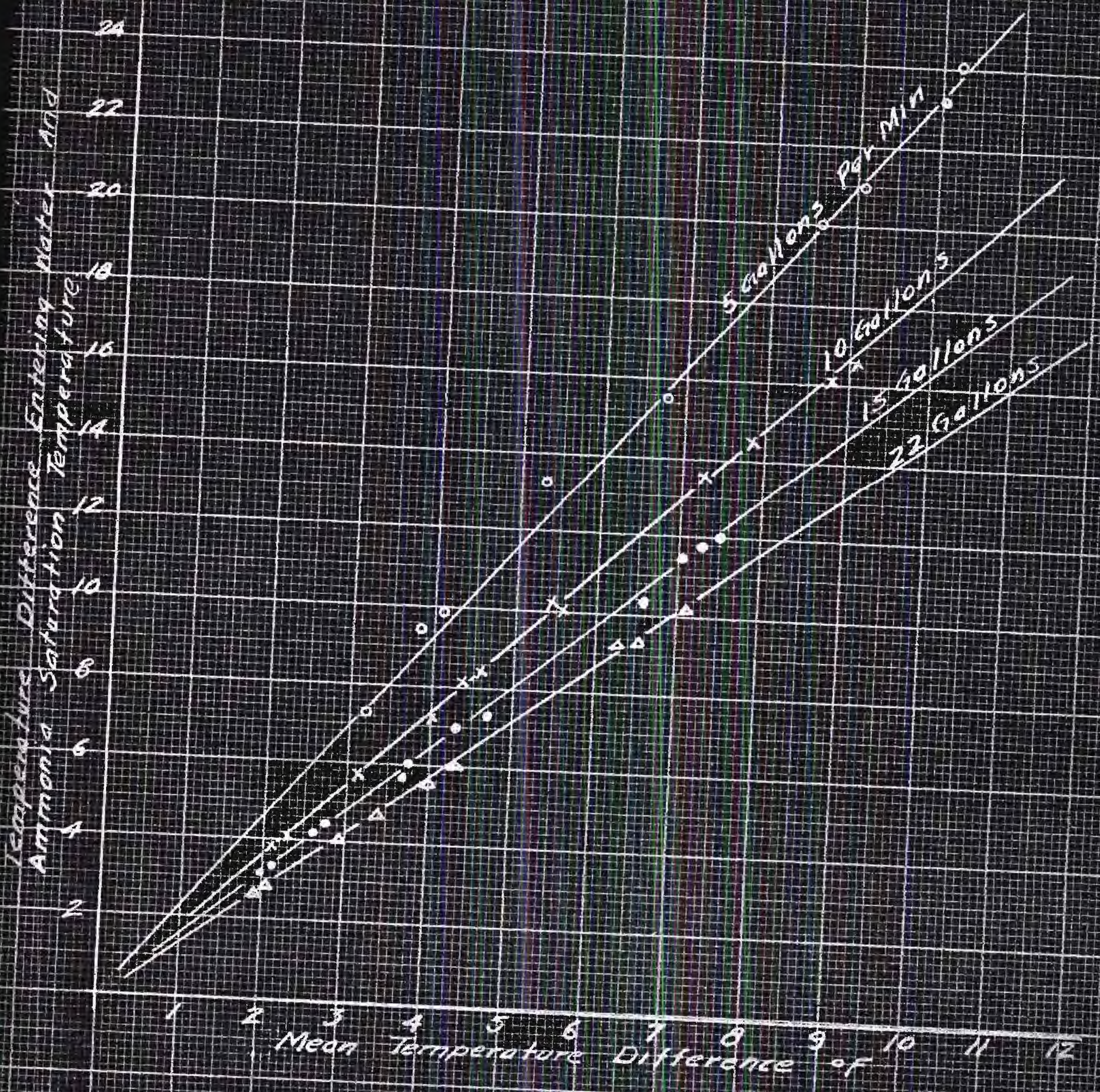
The equation checks the results obtained except for low velocities. The results then obtained are slightly high.

The surface coefficients, items twenty, twenty-one, and twenty-two, were calculated by the same method outlined in the cooler tests. They show the resistance to heat flow of the ammonia film to be two to three times as great as the resistance offered by the water surface film. The temperature drops, items twenty-three, twenty-four, and twenty-five, also bring this fact to light in a different way.

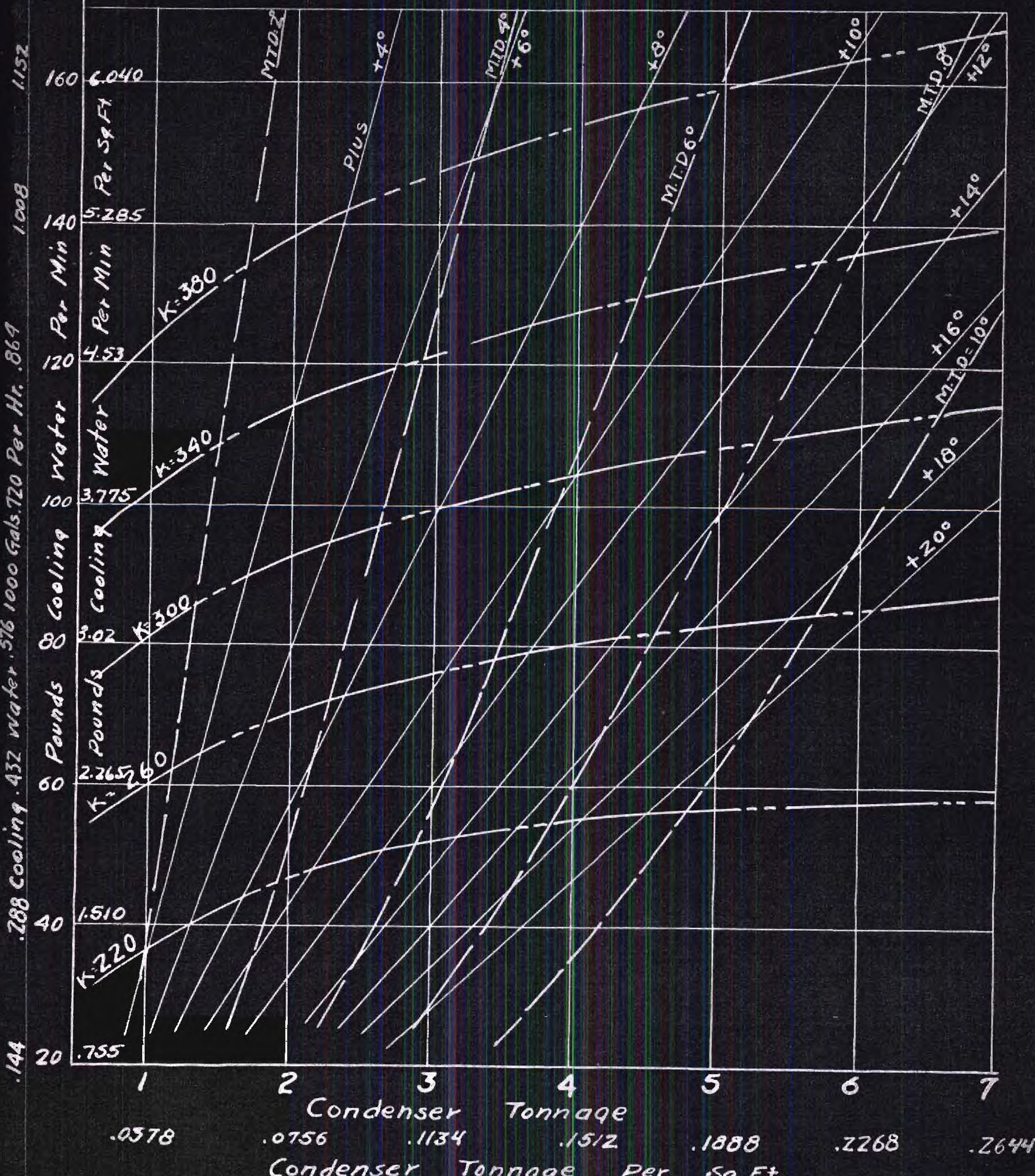
The curve on page 69 shows the relation between the mean temperature difference and the difference in temperature of the saturation temperature of ammonia and the entering water temperature. It is interesting to note that these curves are straight lines for a given quantity of water. These are called plus lines.

By plotting the mean temperature difference, condenser tonnage, plus lines, K, and velocity to a common set of coordinates- pounds of water per minute as ordinate and condenser tonnage as abscissa- the performance curves result. The performance curves are shown on page 70. These curves are used in design exactly as they were used for the cooler with the exception of the use of the plus lines. The use of these curves can best be explained by an example. It is desired to produce four tons condenser effect with 100 pounds of 70 degrees Fahrenheit cooling water per minute. It will be noticed that this point falls on the plus 10.5 line. The resulting saturation ammonia temperature will be 70 + 10.5 or 80.5 degrees Fahrenheit and the condenser pressure will be 154.3 pounds per square inch absolute. Special application of these curves are given in the next section of this paper, "Effects on Plant Operation".

A comparison of the results here obtained with the condenser tests of the University of Illinois will show the coefficient of heat transfer of the Illinois test to be high for a given quantity of water per square foot of heat transfer surface. This can be accounted for by the fact that the actual water velocity was greater and hence the surface conductance was great. However, when based on pounds of water per minute, the results of the University of



MEAN TEMPERATURE DIFFERENCE — AMMONIA SATURATION TEMPERATURE LESS ENTERING WATER TEMPERATURE.
DATA FOR PLUS LINES



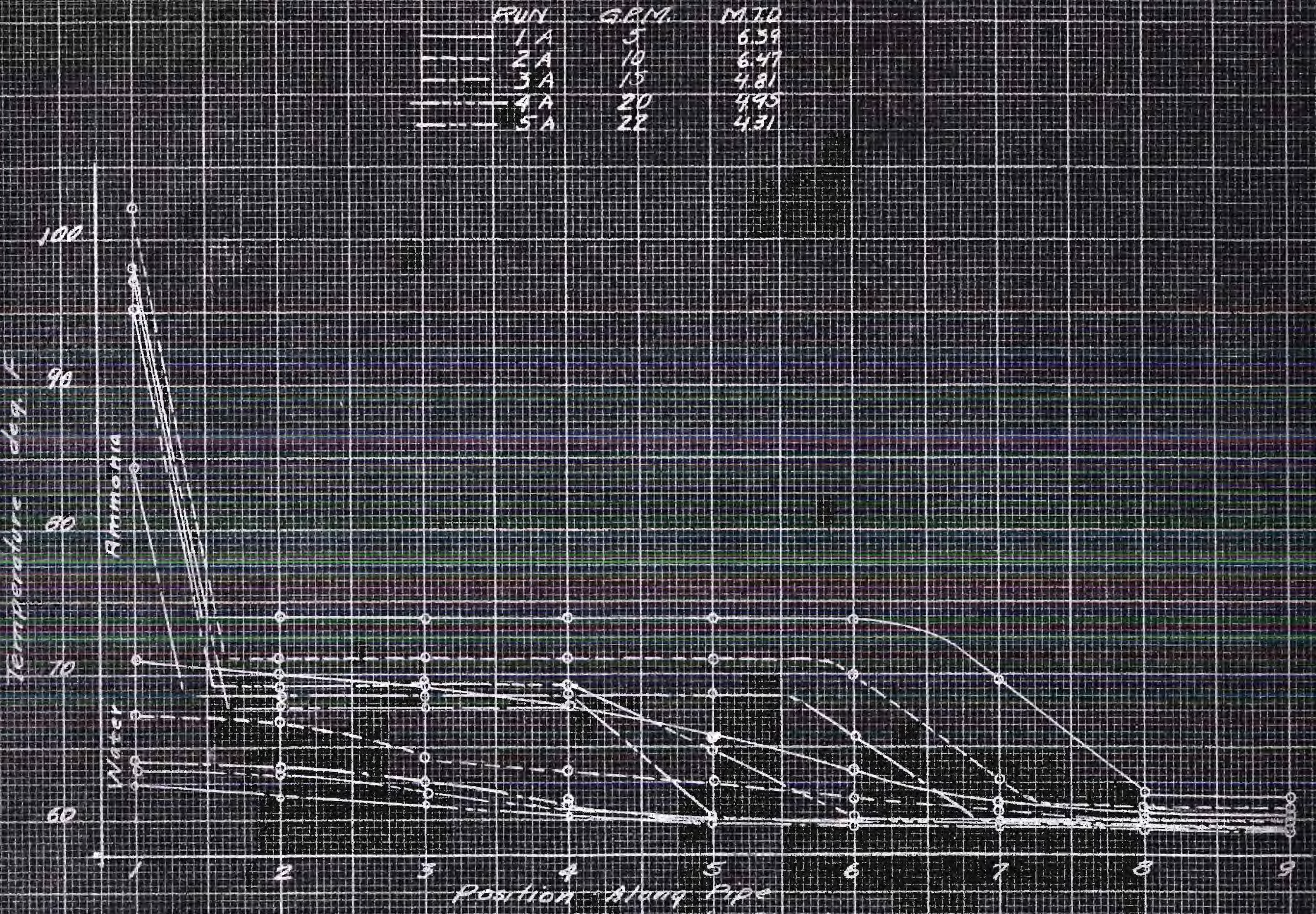
PERFORMANCE CURVES

1¼" X 2" Double Pipe Condenser 8 Pipes High

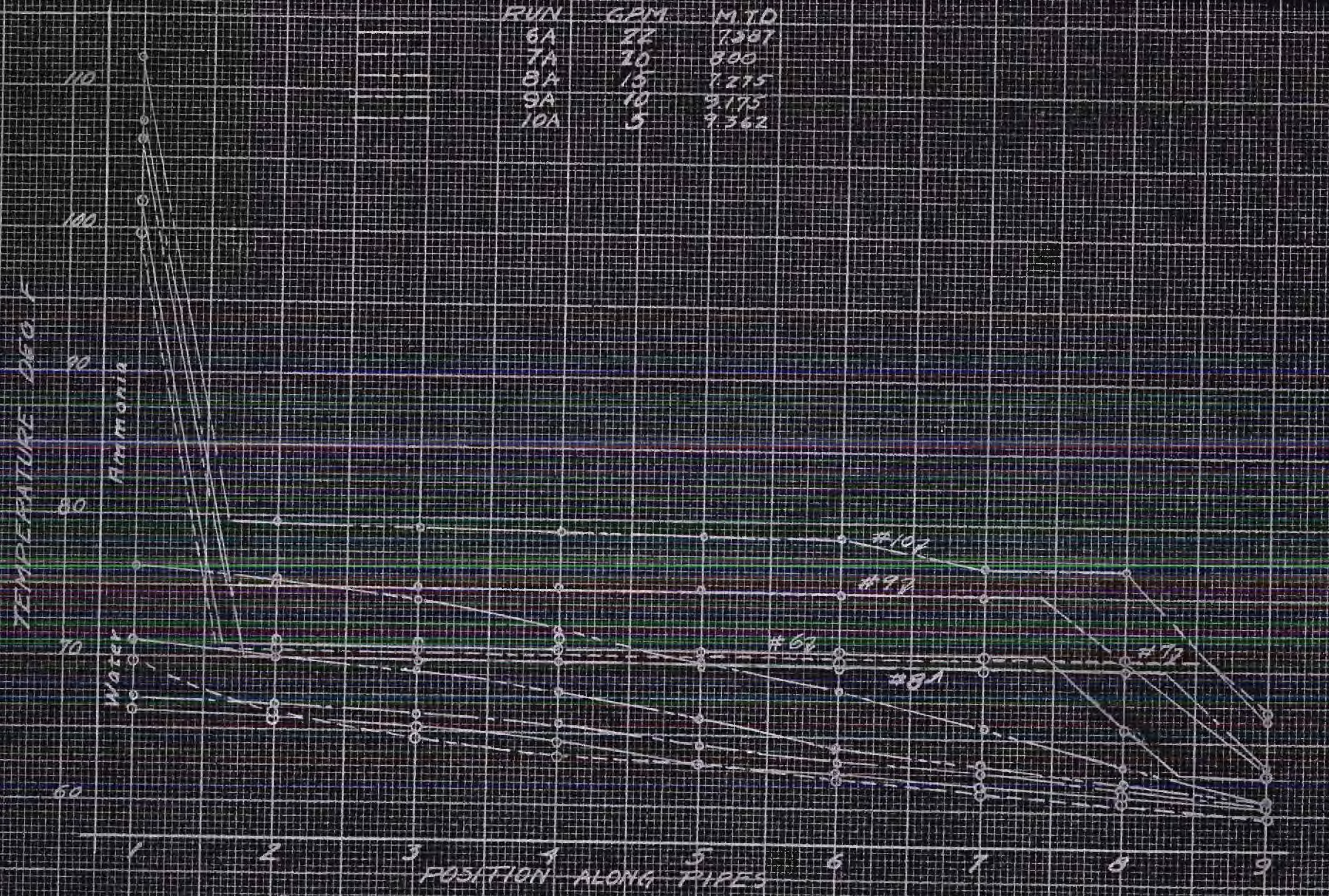
Illinois are low, i.e., for a given mean temperature difference. This can partially be explained by the fact that in the small condenser the water was in greater turbulance due to the closeness of the water return bends, and the greater the turbulance, the greater would be the conductance of the water film. The test at the University of Illinois did not go to a low enough velocity to show the decrease in the coefficient of heat transfer K due to velocity and hence do not show the tendency for the mean temperature difference line on the performance curves to bend toward the origin.

The presence of air in the condenser is very quickly detected by means of the thermometers in the ammonia vapor. Curve sheets pages 72 and 73 show the effect produced by air in the condenser. The most effective method of ridding the condenser of non condensible vapors is by purging the condenser near the liquid ammonia outlet. The effect produced on the performance is simply to cut down the heat transfer area.

The effect of pressure is best shown by the curves on page 63. On this set of curves four sets of points show that the M.T.D. required for a given capacity is lower for higher pressures. This effect is not large, perhaps making about 1/4° M.T.D. less per 50 pounds per square inch increase in pressure.



Curves Showing Effect of Air In Condenser.



Curves Showing Effect of Air In Condenser.

Time-Run#		Pressure		Weights			Brine		Condenser Ammonia Temps.									Condenser Water Temps.								
	Room Temp.	Discharge	Suction	Brine	Cond. Water	Ammonia	Temp-In	Temp-Out	41-In	42	43	44	45	46	47	48	49-out	51-out	52	53	54	55	56	57	58	59-In
	°F	#/□"	#/□"	lbs.	lbs.	lbs.	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
1	79	134	9				56	53	107	72	72.5	72	72	71.9	72	71.9	69	70.7	70.1	69.8	68.5	68	66.5	65.2	63.3	61.3
30 Min.	79	130	9.5				54	52	107.5	72	72.2	72	71.9	71.8	72	71.8	70	70.5	70	69.5	68.2	68	66.3	65.0	63.0	61.2
	79	129	9		1295		53	50.5	105.5	71	71.0	71	70.8	70.6	70.9	70.6	70	69.4	69	68.5	67.1	67	66.5	64.2	62	60.6
	79	128	9				52.5	50	105	70.5	70.8	70.2	70.2	70.1	70.0	70.1	68	69.1	68.8	68	67.0	66.7	66.1	64	62	60.4
	79	116.4	9.1	5288		19	53.8	51.3	106.2	71.97	71.6	71.0	71.02	70.9	70.92	70.9	69.1	69.92	69.4	69.0	68.0	67.2	65.5	64.5	62.5	61.07
2	79	144	18				53	44	111.5	77	77.2	77	77	77	77	77	77.5	75.1	74.8	73.8	72.3	71.2	69.5	67.5	65	62.1
30 Min.	79	145	17				52.8	44	114	77	77.3	77	77	77	77	77	77	76.2	74.9	73.9	72.4	71.5	69.8	67.8	65.1	62.3
	79	145	18		1288		50	41.2	116	76	76.7	76.3	76.8	76.2	76.8	76	76	74.7	74	73.1	71.7	70.9	69.0	66.9	64	61.1
	79	140	17				50	41.2	116	75	75	75	75	75	75	75	73.5	73	72.3	71.6	70	69.0	67.0	65.2	62	59.8
	79	128.3	17.5	2337		29.7	51.45	42.6	114.4	76.8	76.5	76	76.2	76.1	76.1	76.0	75.9	74.5	73.7	73.1	71.9	70.4	68.4	66.7	63.9	61.5
3	79	168	35				45	34	127	85	85.2	85	85.2	85	85.2	84.2	85.5	81.9	80.5	79.3	77	75.5	72	69	64.5	59.6
30 Min.	79	164	30				43.5	32.5	124	84	84.3	84	84	84	84	84	84	81.2	80.2	78.8	76.9	75	72	68.8	64.6	60.1
	80	167	29		1240		48.5	36.3	121	86.2	86.7	86.2	86.2	86.2	86.2	86.2	86	83.5	82.2	81	78.3	76.5	74	70.	65.3	60.4
	82	165	30				43.8	36	117	85	85.4	85	85	85	85	85	85	82.1	80.5	79.5	77.5	75.8	73	69.2	65	60.4
	80	151.7	31	2757		42.5	45.2	34.7	122	85.6	85.4	84.7	84.9	84.9	84.8	84.7	85.0	82.2	80.6	79.8	77.9	75.5	73.5	69.1	64.8	60.3
4	81	120	12				53.5	48	102	67.9	67.9	68	67.9	67.9	67.9	67.9	63.2	66	66.8	64.9	64	63.6	62.2	61.7	60.3	60.2
30 Min.	81	121	12				53	46	103.5	67.5	67.5	67.5	67.5	67.3	67.5	67.3	62	65.6	65.3	64.9	63.9	63.6	62	61.6	60.1	59.7
	80	119	10		2370		51.8	44.6	104	67	66.8	67	66.7	66.8	66.7	66.8	62	65	64.9	64	63.5	63	62	61.2	60.2	59.4
	79	119	10				50	44	104	66.8	66.8	66.8	66.7	66.9	66.9	66.7	62	65.2	65	64.2	63.5	63.1	62.1	61.4	60.7	59.6
	80.2	107	11	2211		17.5	52.1	45.6	103.4	67.9	67.2	67	67	67	66.9	67	62.2	65.4	64.9	64.6	64	63.2	61.7	61.4	60.2	59.9
5	82	128	20				48	38	109	70	70.4	70.1	70.1	70.2	70.1	70.2	70	68.2	68	67	66	65.3	64	63	61.9	60.1
30 Min.	83	130	20				46.3	37.5	112	71	71.2	71.2	71	71.1	71	71.1	70.1	68.9	68.7	67.7	66.7	65.9	64.7	63.2	62	60.2
	82	130	19		2450		44.6	35.7	116	69.7	70.4	70	70.8	70	70.8	70	69	68	67.2	67	65.2	65.2	63.8	62.9	61.2	60.1
	84	130	22				43.5	33	119	71	71.2	71.2	71	71	71	71	70.5	68.6	68.2	67.2	66.1	65.8	64	63	61.6	60.1
	82.8	115	20.5	2561		35.5	45.8	36	114	71	70.8	70.3	70.5	70.4	70.4	70.4	69	68.4	67.7	67.3	66.3	65.3	63.7	62.9	61.6	60.3
6	84	143	37				48	34	102	75.5	76	76	76	75.9	76	75.9	76	72.2	71.5	70.3	68.8	68	66	64.2	62	59.9
30 Min	84	140	34				54	40.3	91	75	75	75	75	74.9	75	74.9	74.5	71.4	70.9	69.7	68.1	67	65	63.6	61.5	59.4
	84	146	38		2500		60	48	99	76.8	76.6	77.2	76.4	77.2	76.2	77.2	76	72.9	72.7	70.5	69	68	66.8	64.4	62.7	60
	84	151	39				54	38.8	104	79	79	79	78.9	79	78.8	79	78	74.8	74	72.5	71	69	68	65.7	63.5	60.9
	84	130	37	2386		51	54	40.3	99	77.2	76.9	76.5	76.2	76.6	76.2	76.3	76	72.8	72	70.9	69.3	67.8	66.1	64.4	62.3	60.3

Time-Run No.	Room Temp	Pressure		Weights			Brine		Condenser Ammonia Temp's.									Condenser Water Temp's.								
		Discharge	Suction	Brine	Cond. Water	Ammonia	Temp-In	Temp-Out	41-In	42	43	44	45	46	47	48	49-out	51-out	52	53	54	55	56	57	58	59-In.
	°F	#/□"	#/□"	#	#	#	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
7 30 Min.	66	115	8				46.5	40	97	63.8	64.2	64	64	64	64.2	62	61.0	62.4	62.7	61.9	61	61	60.2	60	59.3	59.1
	66	114	8				47	40	95.6	63.5	63.8	64	63.7	64	64	62	61.0	62.1	62.2	61.5	61	61	60	59.8	59.1	59.1
	72	115	8		3645		47	40.8	95.6	64	64.3	64.1	64	64.2	64.1	63.9	61.0	62.5	62.8	62.0	61.2	61.1	60.5	60	59.2	59.2
	69	115	8				47	40	96	63.9	64.1	64	64	64	64	60.5	61.0	67.3	62.5	61.8	61	61	60	59.9	59.2	59.1
	68	100.0	8	2192		15	46.9	40.2	96	64.4	64.1	63.7	63.8	63.8	63.8	61.9	61.0	62.4	62.3	61.9	61.3	60.8	59.8	59.8	59.3	59.3
8 30 Min.	70	126	21				44.8	34.5	104	69	69.1	69	69	69	69.2	69	68	66.8	66.2	65.8	64.7	64.5	63.2	62.9	61.3	60.7
	65	124	18				44	35	104.5	67.5	67.9	68	68	68	68	67.9	67	65.7	65.5	65	64	63.9	63	62.2	61	60.4
	65	125	19		3620		43	33	105	68.5	68.8	69	69	69	69	69	69	66.5	66.3	65.5	64.6	64.2	63.5	62.8	61.7	60.7
	65	125	19				42	32	105.5	68	68.6	69	69	69	69	68.8	69	66.4	66.3	65.2	64.7	64.1	63.8	62.7	62	60.6
	66	110.5	19.2	2615		31	43.5	33.6	104.8	69.1	68.4	68.5	68.6	68.6	68.5	68.7	68.1	66.4	65.8	65.5	64.8	64	63	62.6	61.4	60.8
9 30 Min.	69	135	36				51	40.5	88	72.9	73.2	73.2	73	73.2	73.2	73	73.5	69.1	68.8	67.8	66.3	65.9	64.5	63	61.8	60.3
	70	135	35				54	43	94	72.8	73.1	73	73	73.1	73.1	73	73.5	69	68.5	67.4	66	65.5	64	63	61.5	60.1
	68	132	32		3680		55	44.5	100	72	72.2	72	72.3	72.5	72.5	72	73	68.4	67.9	67.0	65.5	65	63.9	62.9	61	60.1
	69	131	30				56.5	46	106	71	71.5	71.8	71.7	71.8	71.8	71.3	72	68	67.5	66.5	65.2	64.8	63.6	62.5	61	59.8
	69	120	31.2	3870		61.5	53.9	43.5	97	72.8	72.5	72.2	72.3	72.5	72.4	72.1	72.9	68.6	67.9	67.3	66.1	65.1	63.6	62.8	61.2	60.3
10 30 Min.	80	103.5	10				46	38.5	104	64	64.2	64	64	64	64.5	64	62	62.2	62.1	62	61	61.5	60.5	60.4	60	59.9
	80	103.5	10				44	38	103	63.5	63.8	63.6	63.4	63.8	64	63.8	62	61.9	61.9	61.6	61	61.1	60.1	60	59.8	59.6
	80	103.5	10		5480		43	38	103	63.5	63.9	64	63.9	64	64	64	62	62.1	62.1	62	61	61.2	60.5	60.3	59.9	59.7
	80	103	10				43.5	38	103	63.1	63.5	63.8	63.3	63.7	63.5	63.7	61.5	61.9	62	61.3	61	66.9	60.5	60	60	59.2
	80	101.4	10	2582		22	44.1	38.1	103.2	64.1	63.6	63.5	63.6	63.9	63.7	63.8	61.8	62.02	61.7	61.7	61.3	61	60	60.1	59.8	59.8
11 30 Min.	80	108	20				43	35	108	65.5	65.9	66	65.9	66.1	66	66.1	62	63.2	63.5	62.3	62	61.6	61.1	60.3	60	59.3
	80	109	22				42	33.8	111	65.8	66	66	66	66	66	66	62	63.3	63.5	62.8	62	61.9	61	60.8	60	59.2
	80	109	22		5720		40.8	32	113	65.9	66.2	66	66.5	66	66	66	66	63.6	63.6	63	62	62	61	61	60	59.7
	82	109.5	20				39.5	30	113	65.9	66.1	66	66	66	66	66	64	63.4	63.0	62.8	62	61.9	61.1	60.6	60	59.4
	80.5	105.9	21	3117		35	41.32	32.7	111	66.4	66.5	65.7	65.9	65.8	65.7	65.85	63.4	63.39	63.1	62.8	62.3	61.6	60.6	60.3	59.9	59.35
12 30 Min.	85	116	33				59.5	45	113	69.8	70.1	70	70	70	70	70	65	66.2	66.1	65	64.5	64	63.2	62	61.7	60.5
	85	120.5	33				58	44	115	71.5	71.6	72	71.7	71.8	71.8	71.8	72	67.9	67.6	66.9	66	65.3	64.5	63.8	63	61.9
	80	121	30		5650		58	44.5	117	71	71.6	71.5	71.7	71	72	71.5	72.2	67.8	67.3	66.9	65.7	65.4	64.5	63.9	63	62
	80	119.5	33				59.5	44.5	119	70.9	71.2	71	71	71.8	71.1	71	71.5	67.3	67	66	65.1	64.9	64	63	62.2	61.6
	82.5	116.2	32	2779		23	58.7	44.5	116	71.4	71.1	70.8	70.9	70.9	70.9	70.9	70.1	67.3	66.7	66.3	65.8	64.7	63.6	63.1	62.4	61.25

Time-Run No.	Room Temp.	Pressure: Discharge	Pressure: Suction	Weights: Brine	Weights: Cond. Water	Weights: Ammonia	Brine: Temp-In	Brine: Temp-Out	Condenser Ammonia Temp's: 41-In	42	43	44	45	46	47	48	49-Out	Condenser Water Temp's: 51-out	52	53	54	55	56	57	58	59-In
	°F	#/□"	#/□"	lbs.	lbs.	lbs.	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
13	82	140	9				54	48	108	78.6	79.2	79	79	78.8	79	78.8	78	77.8	77.1	76.9	75.6	75.2	74	73	71	69.2
30 Min	80	138	9				53	47	107	78	78.6	78	78	78	78.2	78	78	77.1	76.9	76.1	75.2	75	74	72.8	71	69.3
	80	136	7		1310		51.2	46	103	77	77.5	77	77	77	77	77	78	76.1	75.8	75.2	74.1	74	73	72	69.9	68.9
	75	134	7				50.5	45	101	76	76.8	76.5	76	76	76.8	76	77	75.6	75	74.9	73.7	73.3	72.2	71.2	69.3	68
	79	134	8	2347		17	52.2	46.5	105	78	78	77.3	77.3	77.3	77.4	77.3	77.7	76.7	75.9	75.8	75	74.2	72.9	72.1	70.2	68.8
14	82	163	27				55	44.8	123	88	88.6	88	88	88	88	88	88	85.9	85	84	82.5	81	79	76	73	69.5
30 Min	83	157	20				55	44.8	124	85	85.6	85	85	85	85.3	85	86	83.3	82.7	82	80	79.3	77.5	75.6	72.7	69.7
	82	155	20		1305		56	46	123	84.8	84.8	85	84.7	84.3	84.7	84.3	85	82.8	82.1	81.4	80	79.2	78	75.7	73	70.2
	82	156	20				54	43.5	122	85.4	85.4	85	85	85	85	85	85.5	83.3	82.9	82	80.8	79.5	78	76	73	70.2
	82.2	154.7	21.7	2280		20	55	44.8	123	86.4	86.1	85.4	85.5	85.4	85.4	85.4	86	83.8	82.9	82.4	81.1	79.3	77.7	75.7	72.8	70.1
15	83	182	44				70	51	134	95.6	95.6	96.2	95.3	96.5	95.5	92.5	93.9	93.6	92	89	88.5	84.8	83.2	78.2	74.1	69.1
30 Min	83	181	35				64	51	133	93.7	93.8	93	93.5	93	93	93	94	90.8	89.5	88.2	86	84.6	81.5	78.4	73.8	69.5
	82	177	34		1260		59.5	46	132	92.5	92.7	92	92	92	92.2	92	93	89.5	87.4	87	85.1	83.4	81	77.5	73.2	69
	78	177	34				66.6	42	133	93	92.5	92.5	92.5	92.6	92.5	93	93	90.0	89	87.6	86	84	82	78.1	74.5	70
	81.5	176.2	37	2553		52	62.5	47.5	133	94.3	93.6	93.1	93.1	93.3	93	92.8	93.2	91.0	89.2	88.1	86.7	84	81.5	78	73.8	69.6
16	81	167	45				69.5	54.5	96	88.5	89.4	89	89	89	89	89	89	85.1	84.2	83.3	81.4	80.5	78.2	77	74	72
30 Min	83	164	42				74	58.5	109	88	88.5	88	88	88	88	88	88	84.2	83.5	82.2	80.5	79.5	78	76	73.5	71.3
	82	161	40		2808		64.8	52.5	118	86	86.9	87	86.8	87	86.9	87	87	82.6	82	80.9	79	78	76.5	74.8	72.1	70.3
	82	159	38				60	49	121	86	89.2	86	86	86	86	86	86	82.2	81.5	80.2	79	77.9	76	74.1	72	69.9
	82	158.4	41.2	3409		54	67.1	53.6	111	87.7	86.7	87.2	87.2	87	87.2	87.3	87.4	83.5	82.5	81.6	80	78.8	76.8	75.4	72.8	70.8
17	83	142	24				57	49	103	80	80	80	80	80	80	80	79.8	77.8	77.5	76.5	75.5	75	73.8	72.5	70.8	69.5
30 Min	83	145	24				54.5	46.5	109	80	80.4	80	80	80	80.5	80	81	77.7	76.8	76.5	75.2	74.8	73.2	72	70.2	68.6
	83	141	22		2410		51	44	115	79	79.4	79.5	79.4	79.3	79.3	79.3	80	77.0	76.8	76	74.9	74	73	72	70.3	68.8
	83	140	20				48	42	116	78	78.7	78.5	78.7	78.5	78.8	78.5	79.5	76.5	76	75.2	74.2	73.8	72.8	71.5	69.9	68.6
	83	136.8	22.5	3352		38.5	52.6	45.4	111	79.8	79.6	79.2	79.3	79.2	79.3	79.3	80	77.3	76.5	76.2	75.2	74.2	72.8	71.9	70.2	69.1
18	80	132.5	11				46	41	109	76	76	76	76	76	76	76	75	74.6	74.7	74	73.5	73	72.6	71.6	71	69.9
30 Min	82	135	11				45	39.5	107	76.5	77	77	77	77	77	77	77	75.6	75.6	75	74.5	74	73.4	72.9	72	71.1
	82	136	11		2670		44	38.5	106	76.5	77.2	77	77	77.8	77	77	77.5	75.7	75.7	75	74.5	74	73.5	72.8	72	71.0
	82	136	11				43.2	38	106	76	76.9	77	76.9	77	76.9	77.8	77.5	75.4	75.4	74.8	74	73.9	73.1	72.5	71.8	70.5
	81.5	130	11	2941		21.5	44.5	39.2	107	76.8	76.8	76.5	76.5	76.7	76.4	76.7	76.7	75.4	75	74.8	74.4	73.5	72.8	72.3	71.6	70.8

Time-Run No.	Room Temp.	Pressure		Weights			Brine		Condenser Ammonia Temp's									Condenser Water Temps.								
		Discharge	Suction	Brine	Cond Water	Ammonia	Temp-In	Temp-out	41-In	42	43	44	45	46	47	48	49-out	51-out	52	53	54	55	56	57	58	59-In
	°F	#/□"	#/□"	lbs.	lbs	lbs	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
19	83	132	12				41	36	103	75	75.6	75.6	75.5	75.6	75.5	75.6	75	74.1	74.1	73.8	73.3	73	72.8	72	71.7	70.9
	82	132	12				42	36	103	75	75.6	75.5	75.5	75.5	75.5	75.5	76.5	74.1	74	73.8	73	73	72.6	72	71.5	71
30 Min.	82	132	12		3871		42	37	103	75	75.6	75.5	75.5	75.5	75.6	75.5	75.8	74	73.9	73.7	73	73	72.1	72	71.3	70.7
	81	131	11				43	37.5	103	74	74.9	75	74.9	74.8	75	74.8	75	73.4	73.3	73.0	72.3	72.1	71.8	71.2	70.8	70.2
	82	126.8	11.8	2904		22	42	36.6	103	75.4	75.4	75.1	75.1	75.2	75.1	75.1	75.2	73.9	73.5	73.7	72.7	72.4	72.3	71.7	71.2	70.9
20	82	138	20				45	36.5	115	77.5	78	78	78	78	78	78	73.5	75.2	75.2	74	73.8	73	72.8	71	71	70.3
	82	137	21				47	39	115	76.5	77.1	77	77	77	77	77	74.5	74.6	74.5	73.8	73	72.4	72	70.9	70	69.1
30 Min.	82	135	19		3823		49	40.8	115	76	76.6	76.6	76.6	76.6	76.6	76.6	74	74.1	74.0	73.2	72.8	72	72	70.7	70	69.2
	82	136	20				52	42	115	76.5	77	77.1	77	77	77	77	75	75	75.0	74	73.4	73	72.5	71.4	70.8	69.8
	82	130.5	20	2927		31.5	48.3	39.6	115	77.2	76.9	77	77	77	76.9	77	74.1	74.7	74.4	73.9	73.5	72.4	71.9	70.9	70.4	69.8
21	82	152	43				52	40	112	83	83.5	83	83.5	83	83.4	83	83.5	79.1	78.5	77.9	76.2	75.8	74.1	73.3	71.6	70.2
	85	145	30				56	43	104	80	80.6	80.4	80.5	80.5	80.5	80.5	81	76.9	76.5	75.8	74.7	74	73	72	70.5	69.3
30 Min.	84	150	35		3675		62	46	102	82.2	82.8	83	82.8	83	82.8	83	83	79.1	79	77.9	77.1	75.8	75.4	73.5	72.8	70.2
	88	153	37				63	48.5	117	84	84.2	84	84	84	84	84	84	80.2	80	79	77.8	76.9	76	74.5	73	71
	84.2	146	35.2	2922		47.5	58	44.4	111.2	83.0	82.8	82.3	82.5	82.4	82.4	82.4	82.8	78.8	78.2	77.9	76.2	75.2	74.2	72.7	71.9	70.6
22	83	126	10				45	41	103	72.5	72.2	72.2	72.8	72	72.8	72.2	73.5	71.2	71	71	70	70.8	70.2	70.0	69.5	69.3
	82	120.5	9.5				46	42	102	72	72.5	72.5	72.6	72.5	72.6	72.6	72.5	71.3	71.3	71	70.9	70.8	70.4	70	69.8	69.4
30 Min.	82	126.5	10		5620		45.2	42	104	74	73.8	74	73.8	74	73.8	74	73.5	72.9	73.1	72.1	71.9	71.9	71.4	71	70.8	70.4
	82	126	9.8				45.4	41.7	103	73.4	73.4	72.9	73	72.8	73	73.9	73.5	72	72	72	71.5	71.4	71	71	70.5	70.4
	82	121.7	9.8	3468		20	45.4	41.7	103	73.4	73.2	72.6	72.9	72.6	72.8	73.7	73.1	71.8	71.5	71.6	71.4	71.0	70.4	70.4	70.1	70.1
23	85	133	20				48.5	40	114	76	76.2	76.1	76	76.2	76.1	76.2	76.5	74	74	73.2	73	72.5	72	71.4	71	70.2
	85	133	20				50.2	40.8	116	75	75.9	75.9	75.9	75.8	75.9	75.8	75.5	75.4	73.3	72.9	72	72	71.5	71	70.4	69.8
30 Min.	85	131	20		5540		52.5	41	118	74	75	75	75	75	75	75	75	72.7	72.6	72	71.7	71	70.8	70	69.8	69.1
	85	131	20				53	42	119	75	75	75.2	75	75	75.5	75	76	72.9	72.9	72	71.8	71.3	71	70.2	69.9	69.1
	85	127	20	2511		36.5	51.1	40.9	116.8	75.6	75.5	75.3	75.3	75.3	75.2	75.2	75.7	73.8	72.9	72.6	72.4	71.5	70.9	70.6	70.2	69.7
24	81	142	41				53.3	36.5	90	79	79.6	79.5	79.7	79.1	79.8	79.5	80	75.2	74.3	74	72.8	72.8	71.5	71	69.7	69.2
	85	142	41				54.5	37	81	79.5	80	80	80	80	80	80	80	75.2	75.1	74.2	73.5	73	72.3	71.2	70.8	69.5
30 Min.	85	145	42		5500		57.5	41	81	80	80.8	81	80.8	80.8	80.8	80.8	80.5	76.2	76	75	74.1	73.7	73	72	71	70.2
	86	144	45				57.5	45.5	82	80	80.8	81	80.8	80.9	80.6	80.9	80.5	76.2	76	75	74.5	73.3	73	71.9	71.1	70
	84	138.7	42.2	2436		76	55.7	40.0	83.5	80.2	80.3	80.1	80.1	80	80	80.1	80.2	75.7	75.1	74.7	74	73.0	72.1	71.4	70.6	69.8

Time-Run No.	Room Temp.	Pressure		Weights			Brine		Condenser Ammonia Temp's									Condenser Water Temp's								
		Discharge	Suction	Brine	Cond Water	Ammonia	Temp-In	Temp-Out	41-In	42	43	44	45	46	47	48	49-Out	51-Out	52	53	54	55	56	57	58	59-In
	°F	#/□"	#/□"	lbs	lbs	lbs	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
25	85	160	10				44	38.2	97	86	86.4	85.9	86	85.4	86	86.4	87	85	84.6	84.2	83.3	83	82	81	79	77.6
30 Min.	85	157	10				43.5	38	97	85.9	85.5	85.5	85.2	85.8	85	85.8	85	84.2	84.1	83.9	83.5	82.8	82	81.3	80	78.5
	86	168	11		1220		43.5	35	98	90	90.4	89.9	89.9	90	89.9	90	90	89.1	89	88.3	88	87	87	85.6	84	82.3
	86	171	11				43	35	98	90.5	90.8	90.5	90.4	90.4	90.4	90.4	91	89.6	89.2	89	88.3	87.4	87	85.8	83.8	82.2
	85.5	159	10.5	1691		19	43.5	36.5	97.5	88.1	87.6	88.1	87.8	87.7	87.7	87.7	86.8	87	86.3	86.3	85.5	85.1	83.9	83.4	83.7	80.1
26	84.4	188	21				47	41	120.4	93.4	94.6	93.4	94	96.6	95	96	85	91.6	90.2	90	87.8	86.9	84.6	81.6	77.8	77.5
30 Min.	83.7	177	20				45	39	119	93.6	94	94	93.4	93.6	93.6	93.5	92	93	92.3	92	91.4	90	89.5	88.5	86.9	82.8
	83	196	23		1080		43	37	118	98.6	98.5	99	98.3	98.6	98.5	98.4	99	97.6	96.5	96.5	95.6	94.8	93.8	92	89.2	86.5
	88	200	23				43	35	118.6	99.7	100.1	99.6	99.7	99.8	99.8	99.6	100	98.5	97.4	97.1	96.4	95	94	92	89.5	86.5
	84.8	186	21.8	3266		34.5	44.5	38	119	96.3	96.2	96.4	96.2	96.4	96.6	96.6	92.6	95.2	93.9	93.9	92.6	91.8	89.9	87.5	85.5	83.3
27	90	204	38				57.5	43	135	101.6	101.2	101	101	101	100.5	101	100.5	98.5	98	96	95.5	92.8	91.5	89.5	84.4	78.8
30 Min.	90	216	38				48.5	40	137	104.8	104.6	104	104	104	103.5	104	104	101.8	101	99.5	98.5	95.8	94.5	90.5	87	81.4
	90	218.5	33		1158		47	38	137	104.8	105.1	104	104.5	104	105	104	105	102.4	101.5	100.5	99	97	95	92	88	82.5
	90	215	32.5				51	41	133	103.8	104	103.5	103.2	103.2	103.8	103.2	104	101.4	100.8	100	98.5	96.8	95	92	88	83.8
	90	210	35.4	3389		44.5	51	40.5	135.5	103.8	103.1	103.2	103	102.9	103.1	102.9	102	101.0	100	99	97.7	95.6	93.4	90	86.7	81.6
28	82	164	13				55	51	102	86	85.8	85.5	85.5	85.6	85.5	86.6	86	84.4	84.3	84.1	83.9	83.3	83	82.6	82	80.7
30 Min.	82	164	10				53	51	102	88.4	88.2	88	88	87.6	88	87.7	88.5	86.8	86.6	86.1	85.9	85.3	85	84.5	83.7	82.6
	82	164	10		2470		53.5	51	102	88	88	87.9	87.8	87.7	87.8	87.8	88.2	86.8	86.6	86.2	86	85.7	85.6	85	84.4	83.5
	82	165	9				54	51.5	101	88.4	88.4	88	88.1	88	88.1	88.1	88.5	87.3	87.2	87	87	86.2	86	85.8	85.	84.2
	82	162	10.5	4455		15	53.9	51.1	101.7	87.7	87	87.5	87.2	87	87.2	87.1	86.4	86.3	85.8	85.8	85.5	85.1	84.3	83.5	83.5	82.8
29	82	169	20				55.5	46.5	108	89.8	89.8	89.5	89.7	89.4	89.8	89.4	90.1	87.7	87.4	87	86	85.8	84.8	84	82.2	81.4
30 Min.	82	168.5	20				55	45	112	89.7	89.7	89.3	89.3	89.2	89.4	89.3	89.9	87.5	87.3	86.8	86	85	84.8	83.8	82	80.8
	83	166.5	20		2541		53.5	42.5	116	89.2	89.2	89	89	88.8	88.9	88.8	89.5	87	86.7	86	85.4	84.8	84.2	83	81.9	80.4
	83	165	18				53	41.5	116	88.6	88.8	88	88.5	88.6	88.9	88.7	89.2	86.6	86.2	86	85	84.8	84	83	81	80.3
	82.5	165.5	19.5	1997		29.5	54.3	43.9	113	89.4	88.8	89	88.9	88.8	88.9	88.9	88.3	87.2	86.5	86.5	85.4	85.1	83.9	82.5	81.6	80.7
30	84	189	40				63	53	129.7	96.2	96.7	96.2	96.3	96.1	96.4	96	96.5	92.9	92.1	91.2	90	88.8	87.8	85.9	83.6	81.3
30 Min.	84	190	40				65	55	132.4	96.4	97.3	96.6	96.8	96.1	97	96.7	97	93.6	92.4	91.8	90.3	89.3	88	86.2	83.6	81.7
	82	187	37		2480		64	55	133.6	95.8	96.2	95.7	96	95.6	96	95.5	96	92.8	91.8	91	90	88.6	87.6	86	83.6	81.5
	82	191	40				65	54	134.4	96.6	96.8	96.4	96.2	96.1	94	96.3	96.3	93.2	92.6	91.7	90.5	89	88	86	83.8	81.6
	83	186	39	3941		51	64.2	54.2	132	96.2	96.2	96.3	96.1	95.8	95.8	95.9	95.1	93.1	91.8	91.4	90	88.9	87.3	85	83.4	81.5

Time-Run No.	Room Temp.	Pressure		Weights			Brine		Condenser Ammonia Temp's.									Condenser Water Temp's.								
		Discharge	Suction	Brine	Cond Water	Ammonia	Temp-In	Temp-Out	41-In	42	43	44	45	46	47	48	49-Out	51-Out	52	53	54	55	56	57	58	59-In
	°F	#/□"	#/□"	lbs.	lbs.	lbs.	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
31	87	219	38				65	55	139	105.6	106.4	105	105.8	105	106	105	107	103	102	101.9	100	99.2	97.3	96.8	94	92.4
	88	217	36				64	55	139.4	104.8	105.3	104.6	104.8	104.7	104.9	104.7	105	102.2	101.3	100.5	99.6	98.7	97.2	96	93.4	91.6
30 Min	87	216	37		2442		63.5	53.5	139.6	104.6	105.2	104.8	104.6	104.7	104.8	104.6	105	102.2	101.2	100.7	99.6	98.2	97.3	95.9	92.7	91.5
	88	217	35				62.7	53	140	104.6	105.3	104.6	105	104.6	104.9	104.7	106	102	101	100.4	99.5	98	96.4	95.6	93.6	91.3
	87.5	216	36.5	3895		53	63.8	54.1	139	104.9	104.9	105.1	104.9	104.8	105	104.8	104.1	102.4	101.5	100.9	99.5	98.5	96.5	95.1	93.2	91.7
32	85	152.5	10				48	44.5	100.6	84	84.1	84	84	84	84	84	85	83.8	82.9	82.7	82.2	82	82	81.3	80.8	80.4
	85	152.5	10				47.8	43.8	100.3	84.1	84.4	84	84.2	84.1	84.2	84	85	82.9	82.9	82.8	82	82	81.6	81.5	80.6	80.3
30 Min.	84	148.5	10		3830		46.5	43	100.4	82.8	83.1	82.8	83	82.6	83	82.8	84	81.6	81.4	81.2	80.7	80.6	80.1	80	79.2	79
	83.5	150	10				46.5	42	100.6	82.9	82.9	82.8	83	82.9	83	82.9	83	81.8	81.8	81.6	81.3	81	81	80.5	80	79.6
	84.4	148.9	10	3148		18	46.7	43.4	100.4	83.4	83.2	83.5	83.3	83.2	83.4	83.2	82.8	82.5	81.8	82.1	81.3	81.4	80.6	79.8	80.0	79.8
33	85	164	18				50	43	103	87.8	87.7	88	87.5	87.5	87.5	87.8	88	85.8	85.9	85.3	85	84.5	84.1	83.5	82.9	81.9
	85	163	21				51.6	43.6	105.5	87.6	87.8	87.5	87.6	87.5	87.8	87.7	88	85.4	85.3	85	84.2	84	83.7	82.9	81.9	81
30 Min.	85	162.5	20		3740		52.9	45.2	106.5	87.4	87.7	87.3	87.5	87.4	87.5	87.4	88	85.3	85.3	84.8	84.4	83.9	83	82.8	82.1	81
	85	166	20				54.5	46.5	117	88.4	88.8	87.3	88.3	88.5	88.4	88.4	88.5	86.8	86.4	86	85.4	85	85	84.2	83.5	82.7
	85	161.9	19.8	3011		30	52.2	44.6	108	87.8	87.4	87.6	87.5	87.5	87.7	87.6	86.7	85.8	85.3	85.3	84.6	84.4	83.4	82.4	82.4	81.5
34	86	172.5	35				66	52.6	130	90.8	91.2	90.6	91.0	90.5	90.8	90.7	91.7	87.4	86.8	86.4	85.1	84.4	83.8	82.8	81.2	80
	86	175	35				71	58	131.5	91.4	91.7	91.5	91.3	91.1	91.3	91.4	91.5	88.1	87.5	87	85.9	85	84	83	81.4	80.4
30 Min.	86	175	35		3810		70	58	132	91.3	91.5	91.5	91.3	91.1	91.3	91.2	91.5	88	87.5	86.9	85.9	85	84.2	83	82	80.4
	86	174	35				62.5	53	132	91	91.6	91	91.2	91	91.3	91	91.6	87.8	87.3	86.9	86	85	84.5	83.2	81.8	81
	86	171.6	34.5	3185		40	67.4	54.4	131.4	91.1	90.9	91.3	91.0	90.7	91.1	90.9	90.1	87.8	86.9	86.8	85.5	84.9	83.5	82	81.4	80.5
35	87	182.5	11				55	50	107	94	94.2	94	94	94	94	94	95	92.8	93	92.5	93	92	92	91.8	91.2	90.5
	87	179	10				56	51	105	92.8	93.6	93	93.3	93	93.3	93	94	91.6	91.5	91.4	91	90.9	90.7	90.2	89.8	89.4
30 Min.	87	177	9.5		3760		57	52.5	102	91	91.8	91	91.5	91	91.5	91	92	90.2	90	90	89	89.7	89.5	89	88.2	87.8
	87	177	10				57.5	53	101.5	91.7	91.8	91.8	91.6	91.7	91.7	91.8	92	90.6	90.8	90	90.4	89.9	89.7	89.5	89.1	88.4
	87	176.4	10.1	2796		18	56.4	51.6	103.9	92.4	92.3	92.6	92.4	92.2	92.5	92.3	91.9	91.3	90.9	91	90.7	90.6	89.9	89.1	89.4	89.0
36	89	194	30				60	51	103	97.4	97.3	97	97	97.5	97	97.3	97.3	95	94.8	94.1	94	93	93	92.3	92	90.7
	89	184	22				59	51	111	95	95.9	95	95.5	95	95.5	95	95	93.4	93.4	93	92.7	92	91.6	91	90	89.2
30 Min.	89	186	20		3740		58.5	51	114	95.4	95.8	95.5	95.7	95	95.7	95.7	95.7	93.6	93	93.3	92.4	92.2	91.7	91.8	91	89.9
	89	192	20				58.5	51	116	96.2	96	95.6	96	95.8	96.1	96.1	96.1	94.1	94	93.4	93	92.5	92.2	91.8	91	90.1
	89	186	23	2876		18	59	51	111	96	95.6	95.9	95.8	95.6	96	96	95.8	93.8	93.4	93.5	92.8	92.4	91.5	90.7	90.8	90.0

Time-Run No.	Room Temp.	Pressure		Weights			Brine		Condenser Ammonia Temp's.									Condenser Water Temp's.								
		Discharge	Suction	Brine	Cond. Water	Ammonia	Temp-In	Temp-Out	41-In	42	43	44	45	46	47	48	49-Out	51-Out	52	53	54	55	56	57	58	59-In
	°F	#/□"	#/□"	lbs.	lbs.	lbs.	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
37	89	208	43				58.5	46	126	103	103.7	103	103	103	103	102.8	103.5	99.4	98.5	98	97.4	96	95.1	94.1	92.5	91
	90	208	43				70	54	123	103	103.2	103	102.8	102.8	102.9	102.7	102.5	99	98.5	97.8	96	95.5	94.3	93.5	91.5	90.3
30 Min.	90	206	40		3711		65	53	122	102.2	102.8	102	102.4	102.2	102.4	102	102.5	99	98.2	97.9	96.8	96	95	94	92.4	91.2
	87	204	39.5				63	51	128	100.9	101.3	100.5	100.8	100.6	101	100.7	101	97.4	97	96.1	95.4	94.2	93.5	92.4	91	89.5
	89	202.5	41.4	3240		41	64.1	51	124.8	102.3	102.2	102.2	102	102	102.2	101.9	101	98.7	97.7	97.5	96.2	95.4	93.9	92.5	91.7	90.5
38	88	146	10				61.5	56.5	118	82.4	82	82	82.5	81.8	82	82	82.5	80.4	80.3	80.2	79.9	79.8	79.5	79	78.8	78.5
	88	156	10				60.5	56	115	85.1	85	86	84.4	84.8	84.8	84.8	85	83.6	83.7	83.5	83.2	83	83	82.8	82.4	82
30 Min.	88	158	10		5556		59	54	111	85.9	86	86	85.9	85.5	85.9	85.8	86.5	84.5	84.5	84.3	84.1	84	83.8	83.5	83.2	82.8
	88	158	10				58	53.5	110	86.3	86.3	86	86	86	86	86	86.5	84.9	85	84.7	84.5	84	84.2	84	83.5	83.2
	88	152.5	10	2826		19	59.8	55	113.5	84.9	84.2	84.9	84.7	84.3	84.6	84.5	83.2	83.4	83	83.2	82.7	82.7	81.8	81.3	81.8	81.4
39	85	158	20				50	42	116	86.2	86.2	86	86.1	86	86	86	86.5	84.2	84	83.8	83.4	83	83	82.3	81.9	81.3
	85	156	20				53.5	45.5	119	85.9	85.8	85.9	85.8	85.9	86	86.8	86.5	83.8	83.6	83.5	83	82.9	82	82	81.2	80.6
30 Min.	86	159	20		5688		52	44	120	86	85.6	86	85.6	86	86.5	86	86.5	83.8	83.6	83	83	82.2	83	81.8	82	80.6
	85	158	20				51	43	121	86.8	86.9	85.9	86.9	85.8	86.9	85.8	86.5	83.6	83.7	83.1	83	82.6	82.5	82	81.8	80.9
	85	155.8	20	2962		28	51.6	43.6	119	86.0	86.3	86.0	85.7	86.7	86.8	85.7	84.8	83.9	83.3	83.4	82.9	82.7	82	81	81.5	80.9
40	92	176	39.5				57	44	135	91.2	91.2	91	90.9	91	90.8	91	91	86.9	86.7	85.9	85.2	84.5	84	82.9	82.2	81.1
	92	172	35				56	45	125	90.2	90.7	90	90.4	90	90.4	90	91	86.2	85.8	84.4	84.2	84	83.5	82.8	81.8	80.8
30 Min.	92	176	37		5424		56.5	44	135	91.2	91.2	91	91	91	90.7	91	91	87	86.8	86	85.5	84.6	84	83.3	82.4	81.5
	92	172	35				55	44	135	90.2	90.5	90	90	90	90	90	90.6	86.4	86	85.2	85	84	83.5	82.8	82.1	80.9
	92	171.5	36.6	3181		42	56.1	44.2	132.5	90.7	90.3	90.6	90.4	90.3	90.5	90.3	89.5	86.2	85.9	85	84.8	84.3	83.1	82.0	81.9	81.1
41	92	197	21				48.8	41	127	98.8	99.3	99	99	99	99	99	99.5	97.2	96.5	96.3	95.5	95	94.2	93.9	91.8	90.8
	92	196	21				47.5	39.6	127	98	98.2	98	98	98	98	98	99	96	95.6	95	94.5	93.4	93.2	92.5	90.6	89.6
30 Min.	92	187	19.5		2565		45	37.5	127	95.4	95.6	95.2	95.3	95.5	95.5	95.5	96	93.4	93	92.6	92	91	90.5	90	88	87.1
	92	186	19.5				43.5	36	125	95	95	95	94.8	94.8	94.6	94.8	95	93.1	92.8	92.2	91.8	91	91	89.6	88.5	87
	92	188.5	20.2	2715		31	46.2	38.5	126.5	96.8	96.4	96.9	96.6	96.6	96.7	96.6	96	94.9	94.1	94	93.3	92.6	91.4	90.5	89.6	88.6
42	92	182	10				41	36	113	94.2	94.3	94	94	94	94	94	94	93	93	92.6	92.3	91.8	91.7	91.3	90.6	89.6
	92	183	10				41	36	112	94.4	94.6	94.1	94.2	94.2	94.2	94.1	95	93.4	93.3	93	92.7	92.1	92	91.8	90.8	90.1
30 Min.	92	180	9.5		2430		40.5	36	111	93.2	93.7	93.7	93.6	93.6	93.8	93.7	94	92.4	92.2	92	91.6	91.1	91	90.9	89.6	89
	92	177	9.0				40	35.5	108	92.4	92.8	92	92.6	92	92.6	92	93	91.4	91.2	91.1	91.8	90.3	90.1	90	89	88.2
	92	178	9.6	2439		17	40.6	35.9	111	93.6	93.2	93.5	93.4	93.3	93.6	93.3	92.6	92.6	92.0	92.2	91.9	91.3	90.6	90	89.8	89.3

Time-Run No.	Room Temp	Pressure		Weights			Brine		Condenser Ammonia Temp's									Condenser Water Temp's								
		Discharge	Suction	Brine	Cond Water	Ammonia	Temp In	Temp Out	41-In	42	43	44	45	46	47	48	49-Out	51-Out	52	53	54	55	56	57	58	59-In
	°F	#/□"	#/□"	lbs.	lbs.	lbs	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F	°F
43	88	190	10				65.8	62.5	103	95.8	96.4	95.8	96	95.5	96	95.5	97	95.2	94.8	94.9	94	93.7	96.7	92	89.6	88.7
	88	187	10				65	62	103	95.3	95.4	95.0	95	95	95	95	95	94.2	94	93.8	93.7	92.8	92	91.5	90.6	88.7
30 Min	85	190	10		1206		64	60	104	96	96.4	96.0	96	96	96	96	96	96.2	95	94.8	94.6	93.8	93.5	92.3	91.6	89.5
	86	193	12				63	58	103	97	97.2	97.0	96.8	97	96.9	97	97	96.2	96	95.6	95.3	94.8	94.5	93.6	92.1	90.7
	87	185.5	10.5	2931		16.5	64.5	60.6	103.2	96	95.8	96.1	96	95.7	95.9	95.7	94.8	95.2	94.55	94.8	94.2	93.8	93.6	91.4	90.8	89.4
44	90	207	19.5				57.8	50	120	101.4	101.7	101	101	101.5	101.4	101.5	101.5	100	99.8	99	99	97.2	97	95.2	93.5	90.8
	91	208	20				57.0	49	121	102	102.3	102	102	102	102	102	102	100.7	100.1	99.8	99	98	97.2	95.6	93.8	90.9
30 Min	93	212	20.5		1350		56.5	48.5	122.5	103.2	103.4	103	103	103	103	103	103.2	101.8	101.2	100.9	100	99	98	96.7	94.1	92
	94	213	20				56	48	124	103.6	104	103.6	103.7	102.5	103.7	103.5	104	102.4	101.8	101.4	100.6	99.8	98.5	97	94.5	92.5
	92	207.5	20	2290		28	56.8	48.9	121.9	102.5	102.2	102.5	102.2	102.3	102.4	102.3	101.3	101.22	100.3	100.3	99.4	98.5	97.1	95.2	93.8	91.3
45	95	248	37.5				55	45	142	113	113.2	113	112.8	112.8	112.8	112.7	113	110.8	110	109	107.9	105.8	104	101	97.8	92.7
	96	251	37.5				55	45	146	113.8	114	113.5	113.5	113.5	113.5	113.5	114	111.6	110.5	109.9	108	106.5	105	102	98	93.5
30 Min	94	247	34		1377		55	46	149	113.2	113.6	113	113.2	112.8	113.2	113	114	111.5	110	109.8	108	106.4	104	101.8	97	93.3
	92	250	38				55	43.6	149	113.4	113	112.8	112.8	113	112.8	113	113	111	110	109	108	105.8	104	101.2	97.2	93
	94	248.7	36.7	3204		49	55	44.9	144.5	113.3	113.9	113.2	112.9	112.8	113	112.9	102.1	111.5	109.7	109.4	107.8	106.1	103.6	100.5	97.3	93.1
46	78	188	10				50	45	98	94.6	94.4	94.6	94.2	94.8	94.2	94.8	93	93.8	93.9	93.7	93.6	93.4	93.5	93.4	93.1	92.5
	78	191	12				50	45	98	96.2	97	96.5	96.6	96.5	96.6	96.5	97	95.6	95.5	95.4	95.2	95	95	95	94.6	94.2
30 Min	78	192	9.5		5760		52.5	47.5	98	96.4	97	96.8	96.7	96.8	96.7	96.8	97	96	95.9	95.9	95.8	95.6	95.6	95.5	95	94.6
	78	187	9				53	49	97	95	95.5	95	95	95	95	95	95	94.4	94.3	94.0	93.9	93.9	93.9	93.9	93.6	93.2
	78	188.5	10.1	2675		15	51.4	46.6	97	97.75	95.4	95.8	95.6	95.6	95.5	95.6	94.1	94.96	94.5	94.8	94.4	94.6	93.9	93.5	93.9	93.62
47	77	195	20				55	47	111	97.2	97.2	97	95.4	97	97	97.1	97.5	95.2	95.3	95	94.9	94.6	94.5	94.4	94	93.1
	80	198	20				55	45	113	98.4	98.6	98.4	98.2	98.3	98.2	98.4	99	96.2	96.1	96	96	95.2	95	95.1	94.7	93.7
30 Min	80	198	20		5625		55	46	117	98.2	98.2	98.7	98.6	98	98.6	98.7	99	97.2	96	96.5	95.9	95.8	95.2	95	94.3	94.4
	78	188	20				56	47	116	95.2	95.9	95.2	95.5	95.5	95.5	96	97	94.2	94.2	94	93.5	92.8	92.6	92.1	91.8	91.5
	79	189.4	20	2183		28	55.2	46.2	114.2	97.2	96.9	97.4	97.1	97	97.2	97.3	96.72	95.7	95	95.4	94.9	94.6	93.9	93.1	93.5	93.18
48	78	196	32				57.5	49	130	97.4	98.2	98	97.6	98	98	98	98	94.6	94.5	94	93.8	93	93	92.2	91.5	90.4
	76	195	35				58	49	133	97.6	97.8	97.5	97.5	97.6	97.7	97.6	98	94.2	93.6	93.6	93.3	92.2	91.8	91.2	90.7	90
30 Min	76	194	32		5766		57	48	133	97	97.6	97	97	97	97	97	97	94	93.8	93.3	93	92.5	92	92	90.8	90.1
	80	197	36				56.5	47	138	98	98.3	98	98	98	98	98	98	94.5	94.3	94	93.5	92.9	92.5	92	90.9	90
	77	191	33.8	3775		51.5	51.2	48.2	131.5	97.5	97.4	97.7	97.3	97.4	97.5	97.4	96.31	94.32	93.7	93.7	93.3	92.7	91.7	90.7	90.8	90.12

VI. Effects on Plant Operation

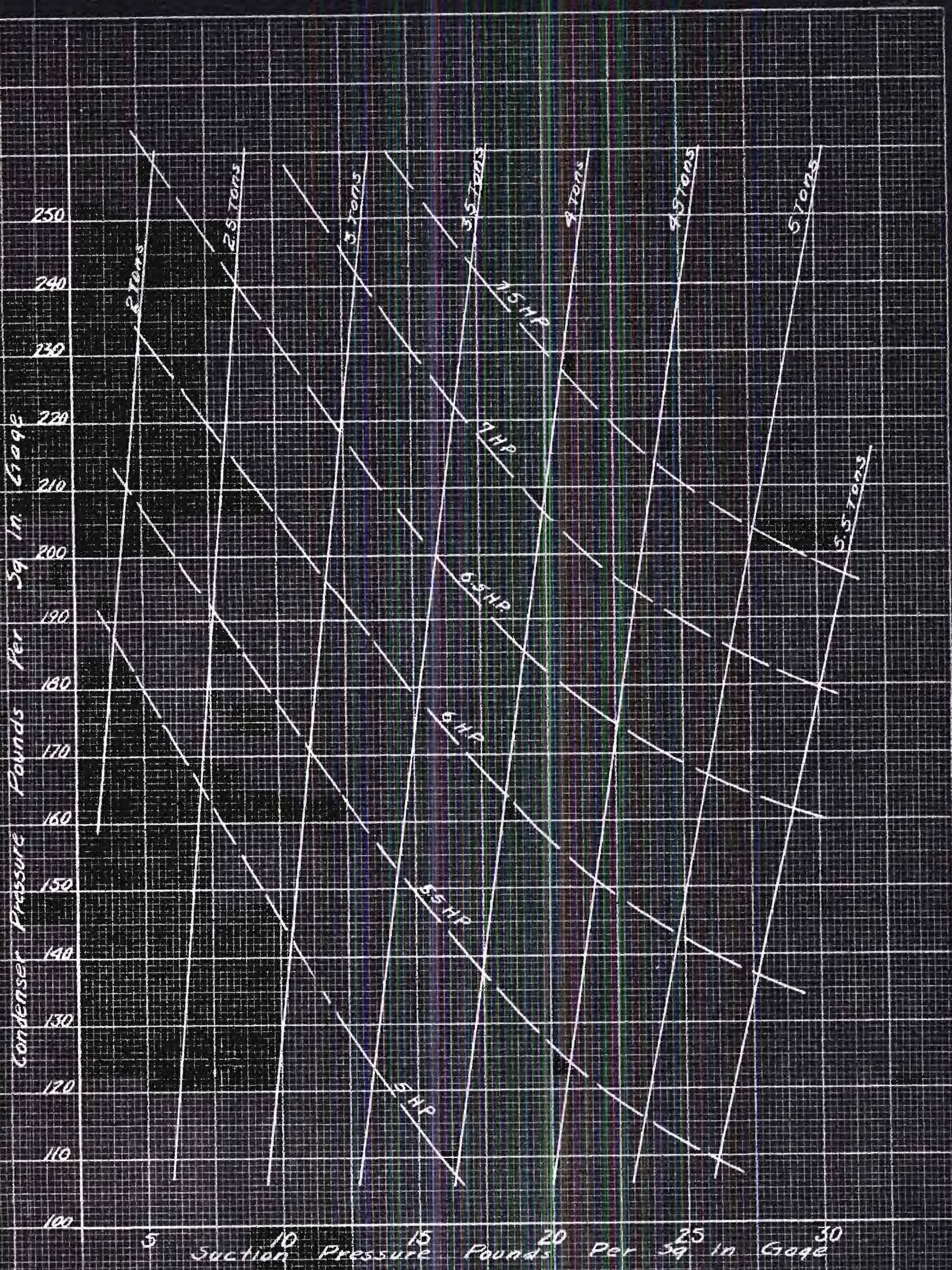
When considering the operation of a compression refrigeration system, it should be kept in mind that the system consists of three units, the cooler, the condenser, and the compressor. When in operation there is a definite relationship existing between each unit, depending upon the operating conditions. In order to produce a certain quantity and temperature of brine, a fixed maximum back pressure must not be exceeded. Also, if the compressor is to pump sufficient ammonia to produce the refrigerating effect in the cooler, it must work within certain pressure ranges or else it will not have a large enough capacity or else it will pump too large a quantity of ammonia. Also, the condenser must not only have a given quantity of water to condense the high pressure ammonia but it must do it at a reasonable pressure for the given condensing water temperature. Just how these relationships will balance themselves can be obtained by a study of the foregoing performance curves of the cooler and condenser, and of the performance curves of the compressor.

The performance curves of the compressor such as are needed in a study of this sort are shown on page 76. The curves are drawn from data taken during these tests and from data furnished by the Frick Company of Waynesboro, Pennsylvania. A brief summary of this data is shown on page 75. The values given for power by the Frick Company were higher than the power determined in these tests. Owing to the fact that the machine tested was new and in excellent working condition, more weight was given to the Frick data.

A study of plant operation can best be made by means of a prob-

Compressor Characteristic Data

Suction pressures	Discharge pressure	Capacity in tons.	Horse Power required
5	205	2.16	5.49
	195	2.19	5.4
	185	2.22	5.24
	175	2.24	5.1
	165	2.265	4.93
	155	2.288	4.82
10	205	2.785	6.00
	195	2.815	5.88
	185	2.858	5.69
	175	2.89	5.53
	165	2.908	5.34
	155	2.945	5.235
15	205	3.395	6.525
	195	3.435	6.34
	185	3.48	6.18
	175	3.52	5.98
	165	3.565	5.78
	155	3.6	5.62
20	205	4.04	7.05
	195	4.08	6.86
	185	4.12	6.61
	175	4.18	6.41
	165	4.23	6.19
	155	4.26	5.97
25	205	4.72	7.35
	195	4.77	7.14
	185	4.82	6.86
	175	4.88	6.68
	165	4.95	6.41
	155	4.99	6.19
30	205	5.29	7.66
	195	5.34	7.43
	185	5.40	7.16
	175	5.47	6.87
	165	5.54	6.63
	155	5.60	6.53
35	205	5.93	7.88
	195	5.99	7.63
	185	6.05	7.34
	175	6.14	7.07
	165	6.21	6.79
	155	6.28	6.44



CAPACITY-HORSEPOWER CURVES 4" X 4' FRICK COMPRESSOR
RPM = 300

lem. The necessary data would be as follows:

A = Two tons refrigeration of 25 degree brine with 4 degree range

B = Two tons refrigeration of 16 degree brine with 4 degree range

Cooling water temperature 75 degrees

Determine the pressure existing in the coolers, the amount of brine circulated in each case, the discharge pressure and the economical quantity of condensing water to use if power costs four cents per kilowatt hour and water costs ten cents per 1000 gallons.

Since we have two different temperatures of brine it will be necessary to use two coolers. By referring to the cooler performance curves, it will be necessary to circulate 140 pounds of brine per minute and to maintain a mean temperature difference of 13.4 degrees, using arithmetical mean temperature difference.

$25 + \frac{4}{2} = 27°$ average temperature

$27° - 13.4° = 13.6°$ or 41.5 pounds per square inch absolute cooler pressure

The necessary back pressure for the 16 degrees will be that pressure corresponding to an average temperature of 13.4 degrees less than the average temperature of the brine temperature.

$16 + \frac{4}{2} = 18°$ average brine temperature in cooler B

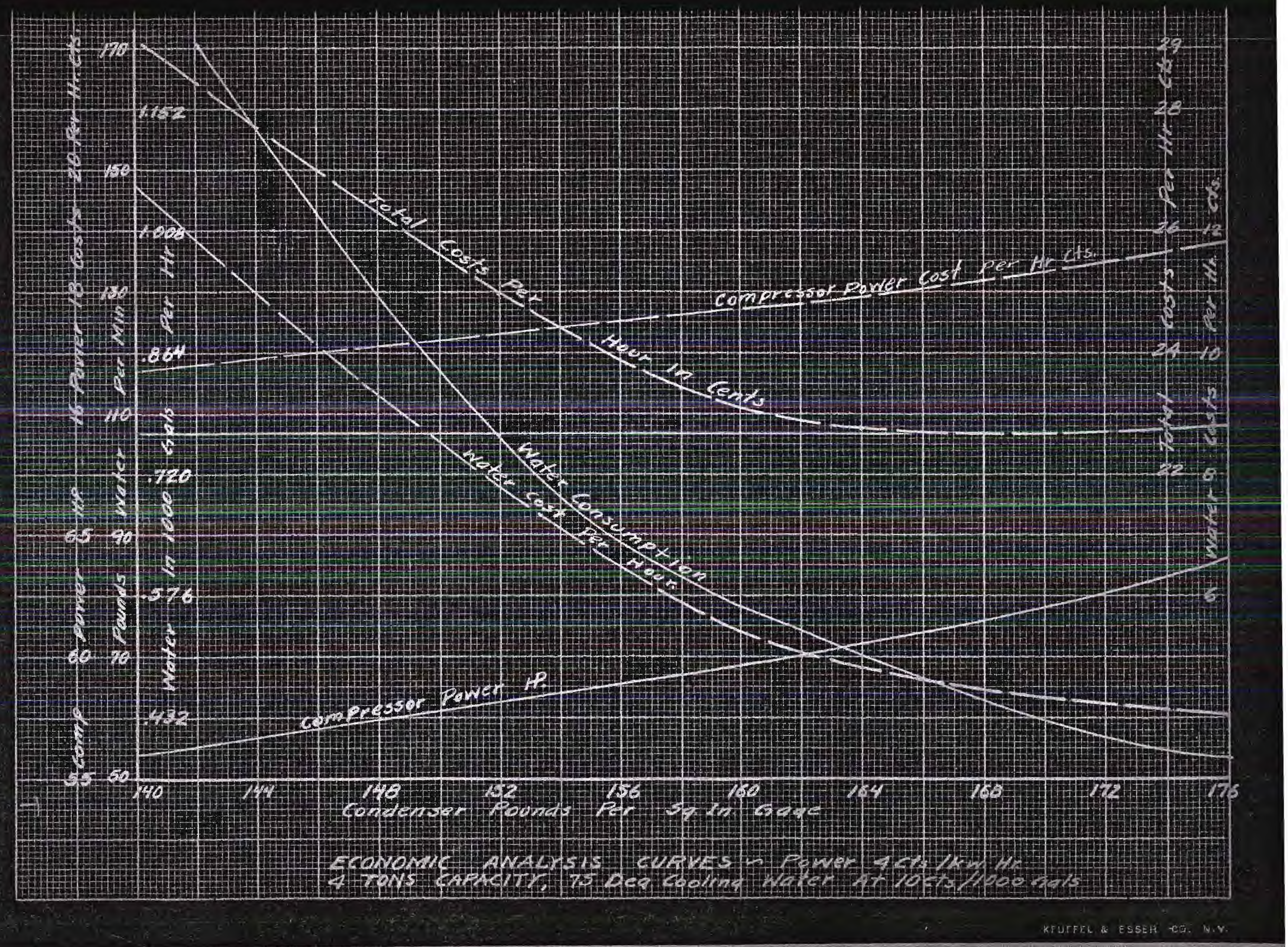
$18° - 13.4° = 4.6° = 34$ pounds per square inch absolute or 19.3 pounds per square inch gage pressure cooler B

Hence, both of the coolers will be operated from the same compressor. The back pressure maintained must not exceed 19.3 pounds per square inch gage. This lower pressure has no effect on the 25 degree brine cooler since only sufficient ammonia will be allowed to pass the expansion value to do the necessary cooling.

By referring to the performance curves of the compressor, we find that 19.3 pounds per square inch gage is higher than what is necessary for four ton capacity with condenser pressures less than 200 pounds per square inch gage.

The condenser performance curve shows the condenser to have a large enough capacity to handle four tons using 56 pounds of water and a pressure corresponding to 75° + 18° or 93° Fahrenheit - 175 pounds per square inch gage. The condenser would also have the four tons capacity using 180 pounds of water per minute and a condenser pressure corresponding to 75° + 7° = 82° - pressure of 143.6 pounds per square inch gage.

Plotting a curve showing the relationship of quantity of water and condenser pressure, the curves on page 79 result. By use of the performance curves for the compressor, the variation in power consumption for various head pressures for four tons capacity are plotted. By multiplying each quantity of water by its cost- ten cents per 1000 gallons and the power by its cost- four cents per kilowatt hour, then cost curves per hour for power and water are obtained. These two last curves are then added together and the lowest point on the curve, total costs per hour, is located. By referring to the lower axis it will be noticed that 168 pounds per square inch gage pressure is the most economical pressure for the conditions stated, also the water consumption should be 63 pounds per minute. The total cost of operation will be 22.7 cents per hour and the power consumed



Comp Power HP
Power Costs Per Hr Cts
Pounds Water Per Min
Water In 1000 Gals Per Hr
Total Costs Per Hr Cts
Water Costs Per Hr Cts
Total Costs Per Hour In Cents
Compressor Power Cost Per Hr Cts.
Water Consumption
Water Cost Per Hour
Compressor Power HP.
Condenser Pounds Per Sq In Gage
ECONOMIC ANALYSIS CURVES - Power 4 Cts/Kw Hr
4 TONS CAPACITY, 73 Deg Cooling Water At 10 Cts/1000 Gals
KEUFFEL & ESSER CO. N.Y.

will be 6.33 horse power.

By referring to the performance curves of the compressor at 168 pounds per square inch gage and four tons capacity, the suction or cooler pressure will be 18.25 pounds per square inch gage. This comes below the lowest pressure requirement for the coolers and is therefore okeh.

VII. Conclusions - Summary

Cooler Test Conclusions - Summary

1. There is little difference in the value of the arithmetical and logarithmetical mean temperature difference.

2. There is little difference between the actual mean temperature difference and the logarithmetical or arithmetical mean temperature difference.

3. The coefficient of heat transfer K varies inversely as the mean temperature difference raised to the .455 power.

4. The coefficient K varies directly as one-sixth of the velocity.

5. The total heat transfer varies as: $H = A(196 + V/6)(MTD)^{.545}$

6. The ammonia film resistance varies as the area exposed to ammonia gas.

7. The ammonia film resistance is eight to sixteen times that of the water film resistance

8. The maximum rotary of a 1 1/4 x 2 x 10' eight pipe condenser with a 10° mean temperature difference would be about 2 1/3 tons.

Condenser Test Conclusions - Summary

1. The condenser tonnage is a function of the water rate and the mean temperature difference.

2. The film surface coefficient of conductance varies as K varies and inversely as some function of the total quantity of heat transfer. The film thickness varies as some function of the weight of ammonia condensed per square foot.

3. Based on surface coefficients obtained by the University of Illinois, Bulletin No. 40, the ammonia surface coefficient increases as the water velocity increases.

4. The coefficient of heat transfer varies as the velocity divided by one and twenty-two hundredths.

5. The coefficient of heat transfer varies inversely as the mean temperature difference to the seven tenths power.

6. The most effective area is that which comes in contact with the coldest water.

7. There is little subcooling of the liquid when the condenser is properly purged.

8. An increase in pressure decreases the necessary mean temperature difference for a given capacity.

Plant Operation Conclusions - Summary

1. There is an economic minimum for the total cost of quantity of water and compressor power.

2. The relative cooler area to condenser area is approximately 2 1/2 to 1 when using double pipe units in commercial ranges.

3. Where high temperature cooling water is used, greater quantities of water are needed for economical operation.

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