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Tests of a York Refrigerating Machine

Mechanical Engineering

B. S.

1913

TESTS OF
A YORK REFRIGERATING MACHINE

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THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

MECHANICAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1913

UNIVERSITY OF ILLINOIS

May 31 1913

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Emmons Overmier, Ralph Roscoe Hawkins, and Lester Reginald Larsen

ENTITLED Tests of a York Refrigerating Machine

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

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TESTS OF A YORK REFRIGERATING MACHINE

Introduction

In this series of tests a piece of work was undertaken which, so far as was known, had not been done on this particular machine previous to this time. The main purpose was to determine the capacity of the ten ton York refrigerating machine in the Mechanical Laboratory, making correction for the radiation from the air into the brine and from air into the ammonia through the exposed pipe. Along with the main object, the performance of the various parts of the machine was determined, such as the steam consumption and the heat transmission to and from the brine in the different parts of its path.

A York catalog contains the capacities and horse powers for various suction and discharge pressures. Conditions in these tests were kept as near like those in the catalog as possible with the idea in mind of comparing the results obtained with those listed by the builder.

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CHAPTER I

Historical

Refrigerating machines may be divided into three classes as follows:

Class I - The refrigerator using a freezing mixture.

Class II - The refrigerator using air which is compressed, cooled and expanded. The low temperature produced during expansion is used to abstract heat.

Class III - The refrigerator using a volatile liquid of low boiling point.

Class I. The Freezing Mixture - This method of producing cold was known since 1762 and was and still is used by scientists in experimental laboratories. The refrigerating effect is produced by the absorption of the latent heat of fusion. When ice and sodium chloride are brought together, the heat necessary to combine and melt cannot be supplied fast enough by external radiation so the internal heat is used thus chilling the ice and chloride. Other mixtures have been used such as calcium chloride and water and ammonium nitrate and water.

Class II.- Air Machines - The first cold air machine of any note was invented by Gorrie in 1845. His machine worked on the closed cycle, more like the ordinary ammonia compression machines. The air was compressed, cooled and expanded. This expanded air was used to cool brine, which in turn was circulated in the ice tank or in the cold chamber.

In 1873, Gifford invented an open cycle machine. The expanded air was sent directly into the cold chamber.

In 1877, Bell - Coleman Company installed this system of refrigerating on trans-Atlantic ships for the preservation of meats. The Strathleven was the first ship to use artificial refrigeration to any extent. It carried thirty-four tons of frozen mutton from Australia to England.

Class III.- Evaporation of a Volatile Liquid - In 1755 Cullen invented a machine for making ice with the use of a vacuum. This system required a high vacuum in order to get any results, and hence a large volume, making it impracticable. The vacuum system was further developed , but the ice formed was porous and opaque and melted rapidly.

In 1834, Perkins invented a compression machine using ether. This was no commercial success as ether is too inflammable. The parts of his machine were, however, the same as those of the modern machine.

In 1873, Linde introduced the modern ammonia compression machine.

Other volatile liquids and gases have been tried such as CO_2 and SO_2, but NH_3 is by far the most successful.

The following table shows the pressure and volume ratios for the three vapors with upper temperature taken at 68° F. and lower as 14° F.

	NH_3	SO_2	CO_2
Suction pressure	41.5	14.75	385
Discharge pressure	124.0	47.61	826
Volume ($CO_2 = 1$)	4.4	12.00	1

CO_2 will take a small machine but such high pressure must be maintained. SO_2 is better as regards pressures, but a cylinder volume twelve times as large must be used. NH_3 strikes a mean in all respects.

CHAPTER II

Theory of Vapor Compression Refrigeration

Refrigeration by vapor compression consists essentially of the vaporization and absorption of heat by a liquid having a low boiling point. The system consists of a compressor cylinder, condenser, expansion valve and brine tank. The vapor after being compressed in the cylinder passes through a condenser consisting of pipes around which cooling water is passed. After the vapor has been cooled to the liquid state it flows into a tank and is allowed to pass out slowly through a needle valve into pipes surrounded by brine. Since the brine is at a higher temperature than the liquid, heat is given up by the brine to vaporize the liquid. The vapor then passes back to the compressor. The fluid circuit is divided into high and low pressure parts, the compressor and condenser being under high pressure and the brine cooling coil under low pressure.

The ideal cycle of refrigeration as indicated by the temperature entropy diagram, Fig. 1, consists of an adiabatic compression BC of the vapor; it is then cooled at constant pressure in the condenser to saturation, D, (providing point C represents a condition of superheat) and liquified at constant temperature T_2 as represented by line DE. From the liquified state, E, the fliud passes through the expansion valve, and receiving heat from the brine, vaporizes and expands at

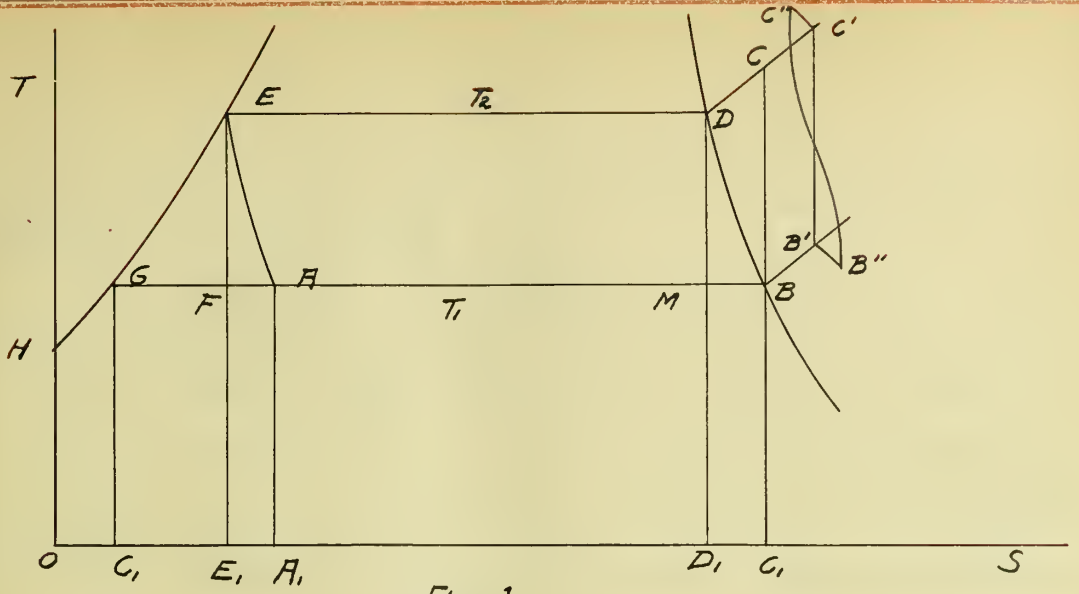


Fig. 1

constant temperature T_1 as represented by AB.

The heat given up by the brine is represented by the area A_1ABC_1.

The passage of the liquid through the expansion valve is an example of wiredrawing and the heat content remains constant before and after passing the valve. Hence, areas $OHGEE_1$ and $OHGAA_1$ are equal. Considering the area $OHGFE_1$ common to both, the area of the triangle GEF is equal to the area of the rectangle E_1FAA_1. Assuming an expansion through the valve at constant heat, the work that must be done is the difference between Q_1, the heat given up by the brine, and Q_2, the heat rejected to the condenser.

Q_2 = area $E_1C_1CDEE_1$

Q_1 = area $A_1ABC_1A_1$

Work = W = area $E_1C_1CDEE_1$ - area $A_1ABC_1A_1$

= area $BCDEE_1A_1AB$ = area BCDEGB

The Carnot efficiency is the ratio of the useful effect of operation to the energy expended = $\dfrac{Q_2 - Q_1}{Q_2} = \dfrac{T_2 - T_1}{T_2}$

Efficiency of refrigeration = $\dfrac{Q_1}{Q_2 - Q_1} \quad \dfrac{T_1}{T_2 - T_1}$. This ex-

pression is usually greater than one, and is commonly called the ideal coefficient of performance.

In actual performance the cycle does not follow that indicated above. Usually there is some superheat as indicated by the point B' and on account of wiredrawing as the vapor passes into the compressor there is a small drop in pressure and consequently a fall in temperature B'B". The extent of this fall in pressure may be determined by comparing the suction pressure just behind the inlet valve to the compressor, to that on the compressor-indicator diagram. This change is ordinarily negligible. Owing to the fact that the vapor is cooled during compression this part of the cycle is not adiabatic and the line B"C" curves to the left. Wiredrawing again causes a drop in pressure as the vapor passes the outlet valve of the compressor. This drop is indicated by C"C'.

Three vapors are commonly used for refrigeration, namely, NH_3, CO_2, and SO_2. The choice of these vapors depends upon the pressures and volumes necessary to obtain suitable temperatures. The upper temperature is governed by the cooling water temperature and the lower by that required for refrigeration. With an upper temperature of 60°F and a lower one of 14°F., the discharge pressure for NH_3 is about three times that for SO_2, but the specific volume of SO_2 is three times that of NH_3. The discharge pressure of CO_2 is about twenty times that of SO_2, but its specific volume is one-twelfth that of SO_2. Considering pressures and volumes and damage to metal due to corrosion, NH_3 is considered the best medium of refrigeration in most cases.

CHAPTER III

Description of Apparatus

1. The Plant - The following are the principal dimensions of the engine and compressor:

Engine: (1) Diameter of steam cylinder - - - - - - -11 1/2"
(2) Diameter of piston rod - - - - - - - - - - 1 7/8"
(3) Stroke - - - - - - - - - - - - - - - - - -10"
Compressor: (1) Diameter of ammonia cylinder - - - - 7 1/2"
(2) Stroke - - - - - - - - - - - - - - - -10"

The engine as shown in plate II, page 12, was of the double acting Corliss type with an automatic cut-off governor. A throttling calorimeter was fitted near the steam nozzle to determine the quality of the entering steam.

Plate II, page 12, shows the compressor, and plate III, page 13, shows the cylinder details. Ammonia is sucked into the cylinder on the up stroke and flows through the valve in the piston on the down stroke. It is then compressed and when the pressure is slightly greater than that in the condenser, the valve in the head opens and the gas passes into the condenser. The ammonia cylinder should have as little clearance as possible and in view of this fact, a false head has been devised as shown in plate III. This head is held down by means of springs, which give way only when liquid or other non-

compressible substance gets between the piston and the head. The cylinder is jacketed; water entering at the lower end and overflowing at the top. This is clearly shown in the diagrammatical sketch. plate I, page II.

After leaving the compressor, the ammonia passes into the condenser consisting of a number of coils. The ammonia flows in the inside pipe and cooling water circulates around this. These coils are shown at K in plate I. The ammonia receiver is located at R, plate I. H is the expansion valve and L the brine cooling coils. The ammonia flows in a pipe inside of the brine coil except at the end where it is exposed to the air.

The brine was taken from the ice tank, and pumped through the heating coil N and through the cooling coils L. O represents the circulating pump; E and F represent the weighing tanks. The condensate from the heating coil was weighed as was also the condensate from the engine. The condenser water was measured in cubic feet by the meter shown at M. The circulating pump was of the double acting duplex type.

2. Testing Instruments - The following is a list of the instruments used on the tests together with their location.

(a) Thermometers-

Steam calorimeter temp. - 0 to 300° F.

Ammonia temp. leaving condenser - 0 to 120° F.

Ammonia temp. entering brine coil -(-40) to (+40)° F.

Ammonia temp. leaving brine coil - 0 to 120° F.

Ammonia temp. leaving left cylinder - 0 to 220° F.

Ammonia temp. leaving right cylinder - 0 to 220° F.

Brine temp. leaving brine coil - 0 to 120° F.

Brine temp. leaving pump - 0 to 220° F.

Brine temp. entering pump - 0 to 220° F.

Water temp. entering condenser - 0 to 220° F.

Water temp. leaving condenser - 0 to 220° F.

Steam temp. entering heating coil - 0 to 300° F.

Water temp. leaving heating coil - 0 to 220° F.

Water temp. leaving left cylinder jacket - 0 to 220° F.

Water temp. leaving right cylinder jacket - 0 to 220° F.

Water temp. entering cylinder jackets - 0 to 220° F.

(b) Indicators-

Steam - Taber outside spring 100 lb.

Ammonia - Crosby inside spring 100 lb.

Ammonia - Star Brass outside spring 100 lb.

(c) Speed counter.

(d) 4 Platform scales.

(e) Water meter. Range - 0 - 99999 cubic feet.

(f) Salometer.

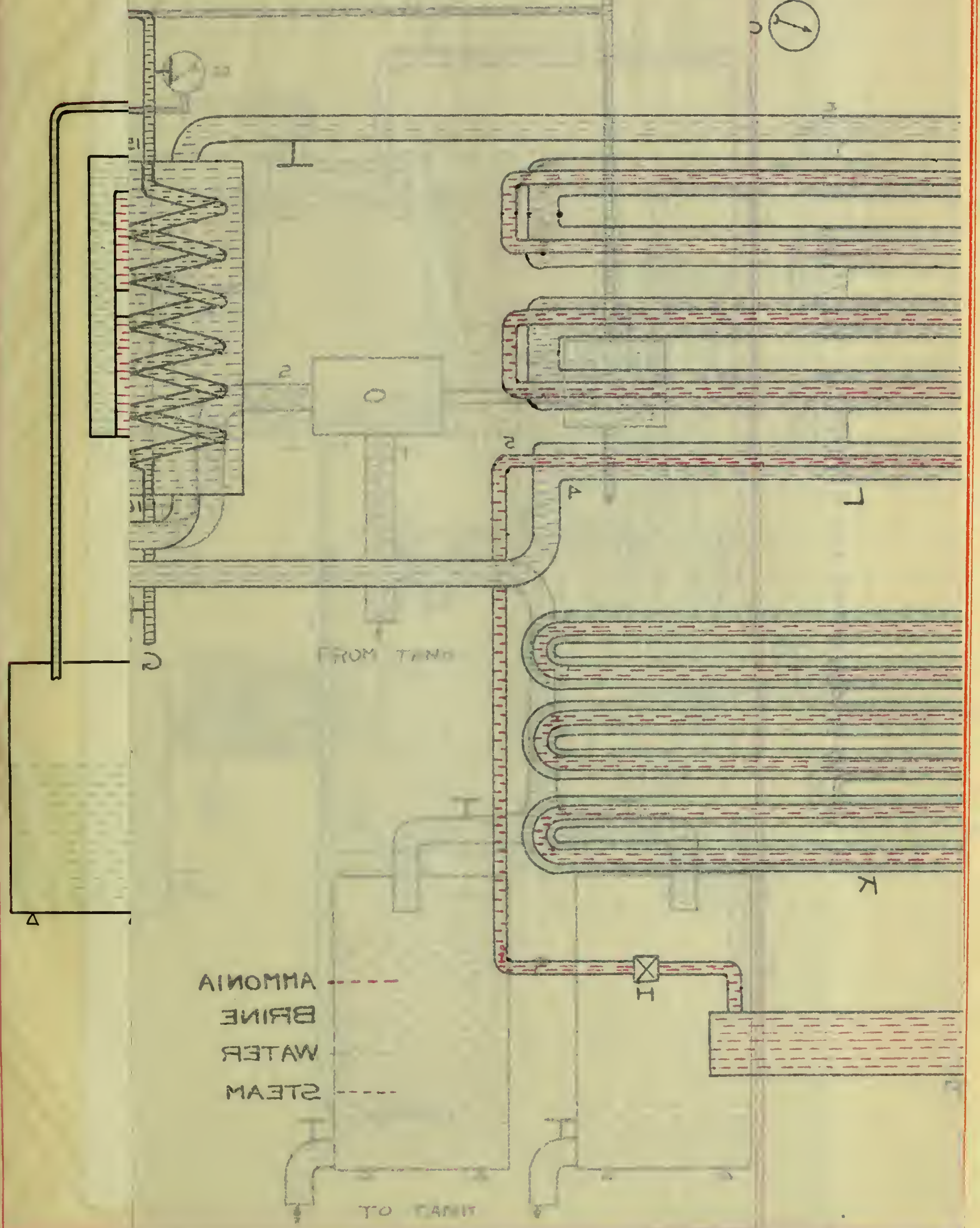


PLATE I.

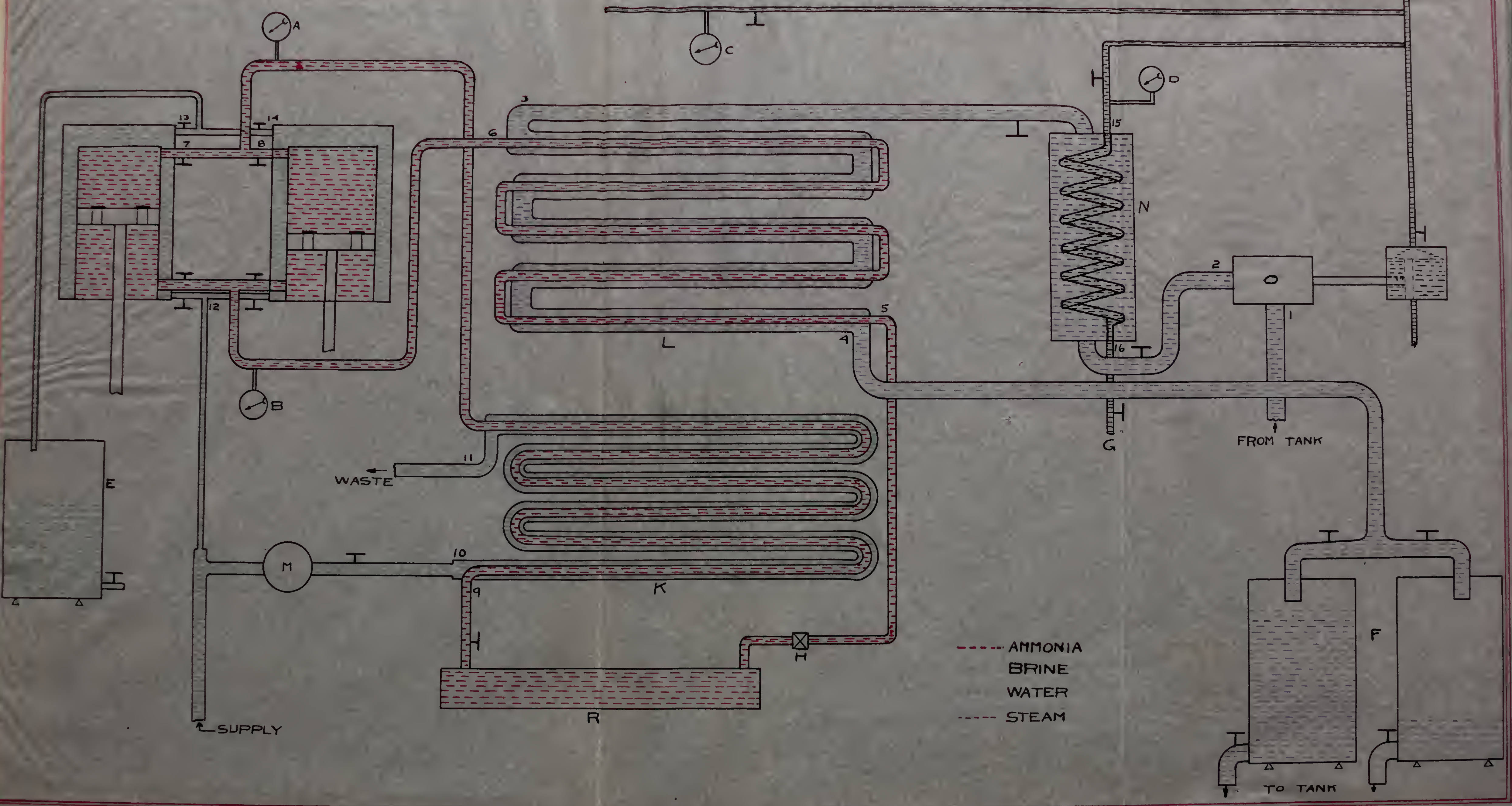
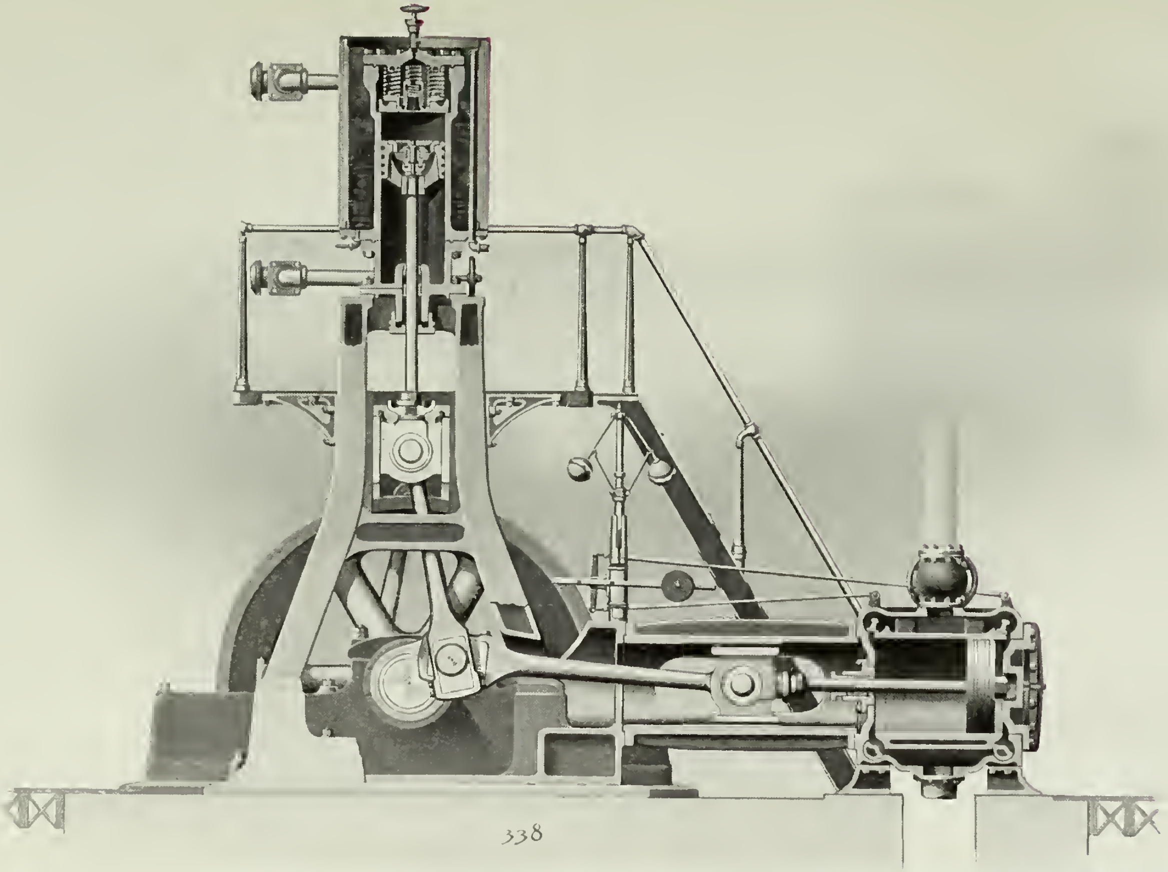
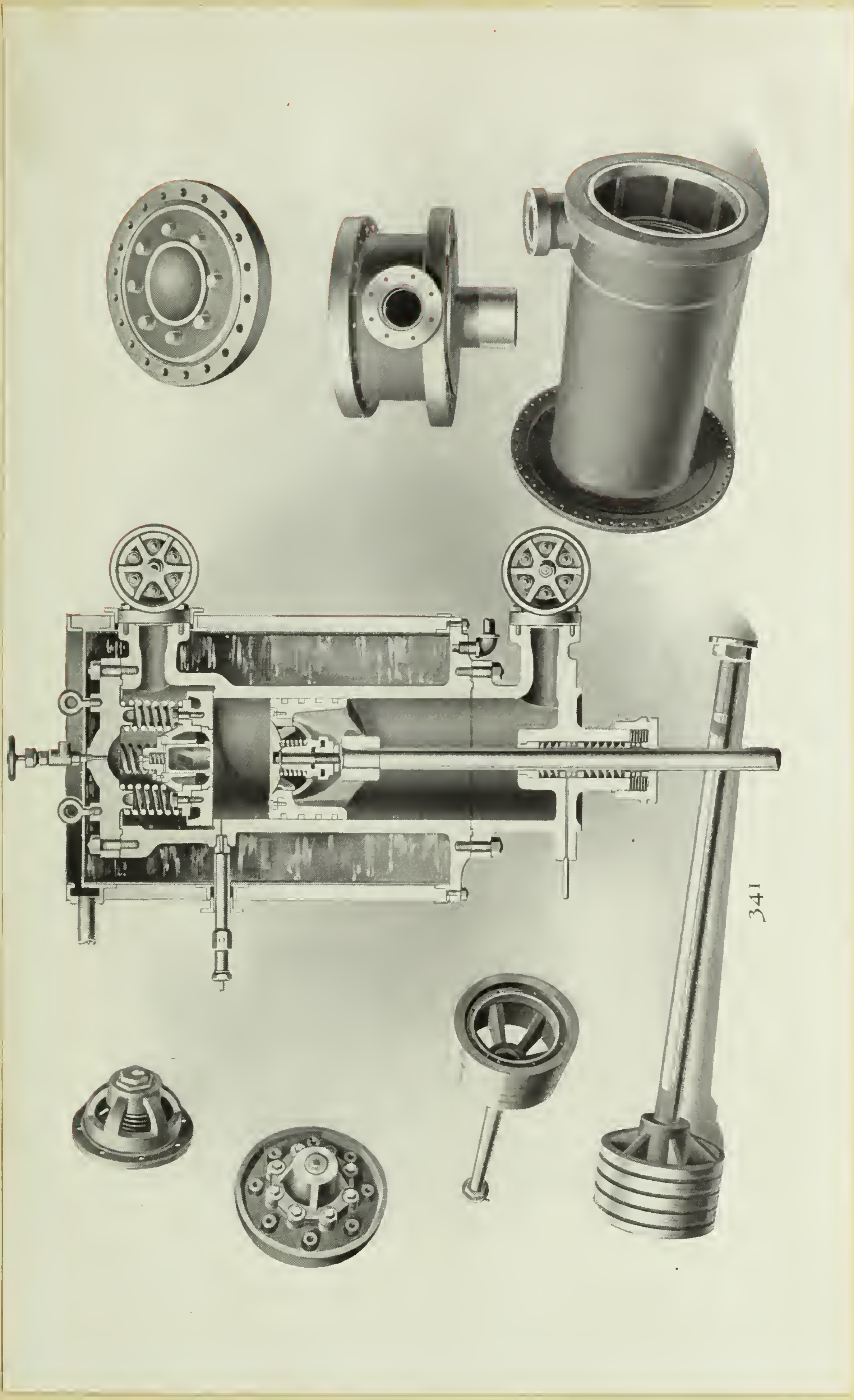

A
C
D
13
14
7
8
3
6
15
N
2
O
1
5
4
L
16
G
FROM TANK
B
12
11
WASTE
E
M
10
9
K
H
R
SUPPLY
F
TO TANK
AMMONIA
BRINE
WATER
STEAM

Plate II



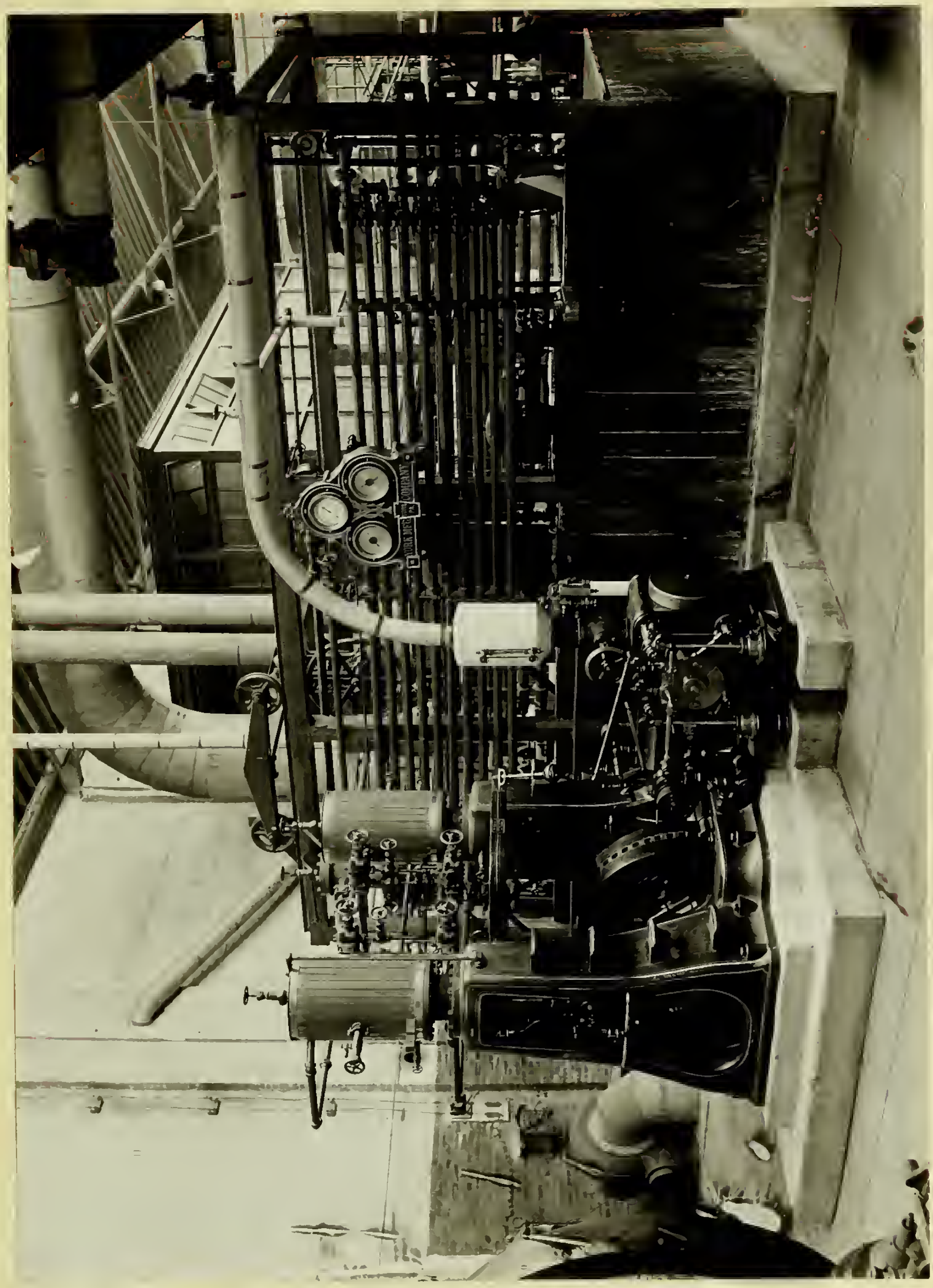
Longitudinal Sectional View of Machine.

Plate III



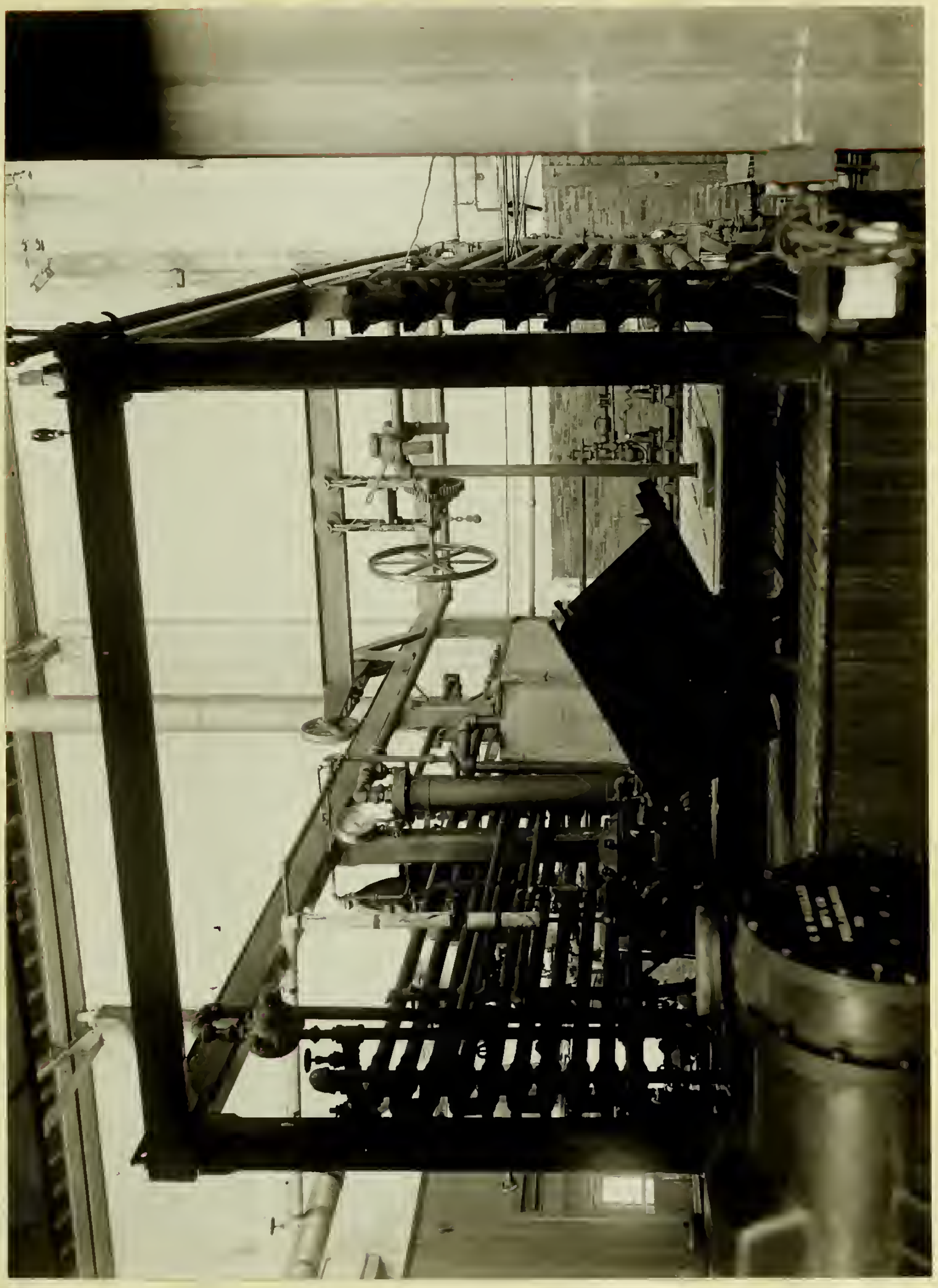
Compressor cylinder details

Plate IV



Elevation showing engine and condenser coils

Plate V



End view showing coils and brine tank

CHAPTER IV

Methods of Conducting Tests

Before starting this series of tests, all valves were packed, engine valves set, and all gages calibrated.

Pressures were changed, both suction and discharge. The suction pressure was varied by regulating the expansion valve; the more it was open, the greater the back pressure. The discharge pressure was varied by regulating the condenser water. With a given amount of ammonia going through the expansion valve, there will be a given weight pass through the cooling coils. If the temperature be high, the pressure will be high, since with a constant volume, the pressures are directly proportional to the temperatures. If a large amount of cooling water is used, it will absorb large quantities of heat from the ammonia, reduce its temperature and hence its pressure provided the weight of ammonia is kept constant.

The jacket water was weighed at E and temperatures taken at 12, 13, and 14.

The cubic feet of condenser water was read on the meter, also the inlet and outlet temperatures (10, 11) were taken.

Temperatures of the ammonia and brine were taken at various places in the system. The brine was weighed in the tanks F, and dis-

charged back to the tank underneath the platform shown in plates IV and V. pages 14 and 15 respectively.

The heating coil was used to give capacity enough to the system. Steam at a given pressure and temperature entered the coil and left at G in the condensed form. This condensate was weighed.

The work done by the ammonia consists of three parts; that accounted for by the drop in temperature of the brine in the cooling coils, the radiation of the air into the ammonia through the end pipes, and radiation into the brine coils. Some tests were run so near room temperature that no radiation by this latter means could take place. For radiation at lower temperatures, a separate test was run. All these radiation tests were run after the main tests. The brine was lowered in temperature to that of the test, and was circulated at the same rate. The ammonia was shut off and brine still circulated. Readings of the brine temperatures (inlet and outlet) were taken thus finding the rise, if any. This rise was due wholly to the radiation from the air into the brine. From the rate of circulation and the rise in temperature, the tonnage due to radiation was found.

The radiation to the ammonia pipes was a small matter. It was figured on the basis that, that for cast iron, 1.75 B.t.u. would be radiated per hour per square foot per degree difference in temperature. The room temperature was taken as one temperature, and the mean temperature of the ammonia entering and leaving the brine cooling coils was taken as the other temperature. The area of exposed surface was measured as accurately as possible.

When first starting the series of tests, four were run with cooling coils frosted, and no heating coil was used. It was found that at such low temperatures (3° or 4° above 0) very little capacity could be obtained. In a test under conditions of test No. 1 only 2.5 tons refrigeration per 24 hours could be obtained. The heating coil was then put in. The least amount of heat that could be added was enough to raise the temperature above 32° or even to 60°. The initial object was to run the brine at about 30°. Without the coil, the temperature went down to 3° or 4°, and with it, it went up above 32°. From this we concluded that the cooling coils did not afford enough capacity for the amount of brine circulated with just the heat taken up by the brine from the air, or the capacity of the compressor was greater than that of the coils.

Theoretical Capacities and Horse Powers for various suction and discharge pressures as given by the Builder's Catalog

Discharge press. lb. per sq. in. gage and corresponding temperatures	Suction press. lb. per sq. in. gage and corresponding temperatures					
	5 lb. = -17.5°		15.67 lb. = 0°		25 lb. = 11.5°	
	Cap.	H.P.	Cap.	H.P.	Cap.	H.P.
145 lb. = 82°	6.6	12.7	10.7	14.9	14.3	15.8
165 lb. = 89°	6.4	13.7	10.3	16.2	13.9	17.4
185 lb. = 95.5°	6.2	14.6	10.0	17.3	13.4	18.8
205 lb. = 101.4°	6.0	15.3	9.7	18.5	13.0	20.2

No.	
I	Numbe
2	Durat
3	Av. r
4	Atmos
5	Speci
6	Av. a
7	Av. a
8	Av. a
9	Av. a
IO	Av. r
II	Av. c
I2	Av. c
I3	Av. t
I5	Av. t
I6	Av. t
I7	Av.
I8	Av.
I9	Av.
20	Av.
21	Av.
22	Av. t

TESTS OF A YORK REFRIGERATING MACHINE Overmier Hawkins Larsen

CHAPTER V.

Results of Tests.

No.	Item												
I	Number of trial	I	2	3	4	5	6	7	8	9	I0	II	I2
2	Duration of trial (hr.)	2	2	2	I	2	2	2	2	2	2	2	2
3	Av. rev. per min.	88.2	88.7	88.2	88.5	88	88	88.4	88.8	88.2	88	88.5	88
4	Atmospheric press. (lb./sq.in.)	I4.3	I4.30	I4.3	I4.3	I4.5	I4.5	I4.3	I4.3	I4.68	I4.68	I4.3	I4.3
5	Specific heat of brine.	.789	.789	.789	.789	.789	.789	.789	.789	.789	.789	.789	.789
6	Av. abs. steam press. (lb./sq.in.)	I33.3	I32.I	II5.9	I4I	I4I.5	I4I.5	I43	I43.5	I45	I36.7	I44.4	I42.3
7	Av. abs. exhaust press. (lb./sq.in.)	I4.3	I4.3	I4.3	I4.3	I4.5	I4.5	I4.3	I4.3	I4.68	I4.68	I4.3	I4.3
8	Av. abs. ammonia press. entering compressor (lb./sq.in.)	20.I5	I8.6	I8.9	I9.3	29.84	29.96	29.86	29.I	39.78	40.0	39.6	39.I
9	Av. abs. ammonia press. leaving compressor (lb./sq.in.)	I59.3	I79.I	I96.3	2I7.6	2I9.5	202.7	I78.8	I58.7	I6I.48	I8I.48	200.8	2I9.5
I0	Av. room temp. (deg. F.)	72	85	85	72	70	70	76	85	80	80	78	85
II	Av. calorimeter temp. (deg. F.)	289.5	289	283.2	289.5	286.2	292.2	292.7	287.2	293.8	293.0	292.0	292.9
I2	Av. quality of steam. (Percent)	99.2	99.4	99.I	99.4	99.3	99.6	99.6	99.0	99.5	99.5	99.5	99.2
I3	Av. temp. of ammonia entering brine coil.(deg. F.)	I9.7	-I8.5	-20.6	-20.0	-2.34	-2.09	-0.69	-2.I0	II	II.7	II.6	I0.4
I5	Av. temp. of ammonia leaving brine coil.(deg. F.)	64.I	75.45	82.4	64.7	42.7	49.7	58.4	57.8	55.03	62.7	52.4	50.4
I6	Av. temp. of ammonia entering left compressor.(deg, F.)	205	2I0.4	2I2.7	2I0.2	208.4	204	208.I	207.2	284.7	200	209.3	2I4.4
I7	Av. temp. of ammonia entering right compressor.(deg. F.)	I96.5	263.3	207.6	208.6	2I0.7	205.8	206	20I.2	290.4	202	2II.9	2I6.7
I8	Av. temp. of ammonia leaving condenser. (deg. F.)	78.5	85.2	90.4	97.I	96.7	89.6	85.7	77.3	77.7	85.5	94	99.6
I9	Av. temp. of brine entering circulating pump. (deg. F.)	56.7	67	75.5	60.6	28.7	37.5	49.6	45.3	45.I	5I.3	47	46.2
20	Av. temp. of brine leaving circulating pump. (deg. F.)	58.2	67.2	75.6	6I.0	29.7	37.8	50.0	46.I	45.5	5I.5	47.6	46.6
2I	Av. rise in temp. of brine through pump. (deg. F.)	I.5	.2	.I	.4	I.0	.3	.4	.8	.4	.2	.6	.4
22	Av. temp. of brine entering heating coil. (deg. F.)	58.2	67.2	75.6	6I.0	29.7	37.8	50.0	46.I	45.5	5I.5	47.6	46.6

No.	
I	Num
23	Av.
24	Av.
25	Av.
26	Av.
27	Tot
28	Av.
29	Av.
30	Av.
3I	Av.
32	Av.
33	Av.
34	Av.
35	Av.
36	Av.
37	Av.
38	Av.
39	I.h
40	I.h
4I	I.h
42	I.h
43	I.h
44	I.h
45	Tot
46	Con
47	Wei
48	Wei

Tests of a York Refrigerating Machine. Results of Tests continued.

No.	Item												
1	Number of trial	1	2	3	4	5	6	7	8	9	10	11	12
23	Av. temp. of brine leaving heating coil. (deg. F.)	64.9	75.41	83.8	66.16	42	48.4	59.5	56.3	58.6	64.8	55	56.6
24	Av. rise in temp. of brine through heating coil. (deg. F.)	6.7	8.21	8.2	5.16	12.3	10.6	9.5	10.2	13.2	13.3	7.4	10.0
25	Av. temp. of brine entering brine cooling coil. (deg. F.)	64.9	75.41	83.80	66.16	42.0	48.4	59.5	56.3	58.6	64.8	55	56.6
26	Av. temp. of brine leaving brine cooling coil. (deg. F.)	59.3	69.9	78.5	62.2	31.3	39.6	50.5	45.6	45.7	52.3	46.3	45.4
27	Total drop in temp. of brine through cooling coil. (deg. F.)	5.6	5.51	5.3	3.96	10.7	8.8	9.5	10.7	12.9	12.53	8.75	11.2
28	Av. temp. of water entering cylinder jackets. (deg. F.)	64.3	64.3	65.8	66.9	67.2	64.9	64.1	65.3	65.4	65.3	65.85	65.1
29	Av. temp. of water leaving left jacket. (deg. F.)	83.2	76.6	79.0	90.0	88.3	86.0	81.4	98.9	80.5	84.1	88.9	81.4
30	Av. temp. of water leaving right jacket. (deg. F.)	82.8	83.6	88.9	88.2	86.3	84.4	81.2	86.5	82.0	87.1	91.9	81.0
31	Av.rise in temp. of water in jackets. (deg. F.)	18.7	15.8	18.1	22.2	20.1	20.3	17.2	27.4	15.8	20.3	24.5	16.1
32	Av. temp. of water entering condenser. (deg. F.)	63.6	63.7	64.8	65.6	66.9	64.5	67.7	64.4	80.4	64.3	52.44	64.3
33	Av. temp. of water leaving condenser. (deg. F.)	82.3	90.5	98.1	105.1	108.3	99.3	89.3	82.6	80.4	89.1	94.6	102.1
34	Av. rise in temp. of water through condenser. (dge. F.)	18.7	26.9	33.3	39.5	41.4	35.1	21.5	18.2	15.8	24.8	42.2	37.8
35	Av. m.e.p. of engine--H.E. (lb./sq.in.)	33.2	39.2	44.4	37.4	47.2	43.95	40.2	40.1	41.3	46.0	49.0	50.3
36	Av. m.e.p. of engine--C.E. (lb./sq.in.)	32.0	39.7	40.7	35.1	43.54	41.0	39.0	37.5	38.4	43.0	46.1	48.2
37	Av. m.e.p. of ammonia cylinders--left. (lb./sq.in.)	39.4	51.7	57.5	46.9	59.8	58.4	58.3	51.5	55.6	63.5	66.5	70.9
38	Av. m.e.p. of ammonia cylinders--right. (lb./sq.in.)	39.4	50.2	57.3	43.2	58.7	57.5	55.9	53.0	59.4	61.7	66.0	69.9
39	I.h.p. of engine--H.E.	7.68	9.02	10.2	8.7	10.9	10.2	9.3	9.3	9.56	11.6	11.4	11.55
40	I.h.p. of engine--C.E.	7.23	8.91	9.2	7.94	9.8	9.24	9.02	8.52	8.65	11.0	10.4	10.88
41	I.h.p. of engine--total.	14.91	17.92	19.44	16.64	20.7	19.38	18.32	17.52	18.21	22.6	21.8	22.43
42	I.h.p. of ammonia cylinders--left.	3.88	5.12	5.66	4.63	5.87	5.74	5.49	5.10	5.41	6.34	6.59	6.95
43	I.h.p. of ammonia cylinders--right.	3.88	4.97	5.65	4.27	5.76	5.65	5.51	5.25	5.85	6.06	6.54	6.86
44	I.h.p. of ammonia cylinders--total.	7.76	10.09	11.31	8.90	11.63	11.39	11.00	10.35	11.26	12.40	13.13	13.82
45	Total weight of condensate. (lb.)	1224	1300	1640	631	1428	1372	1360	1338	1385	1435	1511	1550
46	Condensate per hour. (lb.)	612	650	820	631	714	686	680	669	692	717	756	775
47	Weight of dry steam per hr. (lb.)	607	654	828	627	708	684	677	676	689	714	753	781
48	Weight of dry steam per engine i.h.p. hr. (lb.)	40.75	36.5	42.5	37.8	34.2	35.3	37	38.6	37.8	31.6	34.8	34.8

No.	
I	Num
49	Wei
50	Tot
5I	Tot
52	Tot
53	Tot
54	Bri
55	B.t
56	B.t
57	B.t
58	Jac
59	B.t
60	Con
6I	B.t
62	Tot
63	Tem
64	Tem
65	Abs
66	Con
67	Hea
68	Hea
69	Ton
70	Ton
7I	Ton
72	Med
73	Pla
	s

Tests of a York Refrigerating Machine. Results of tests continued.

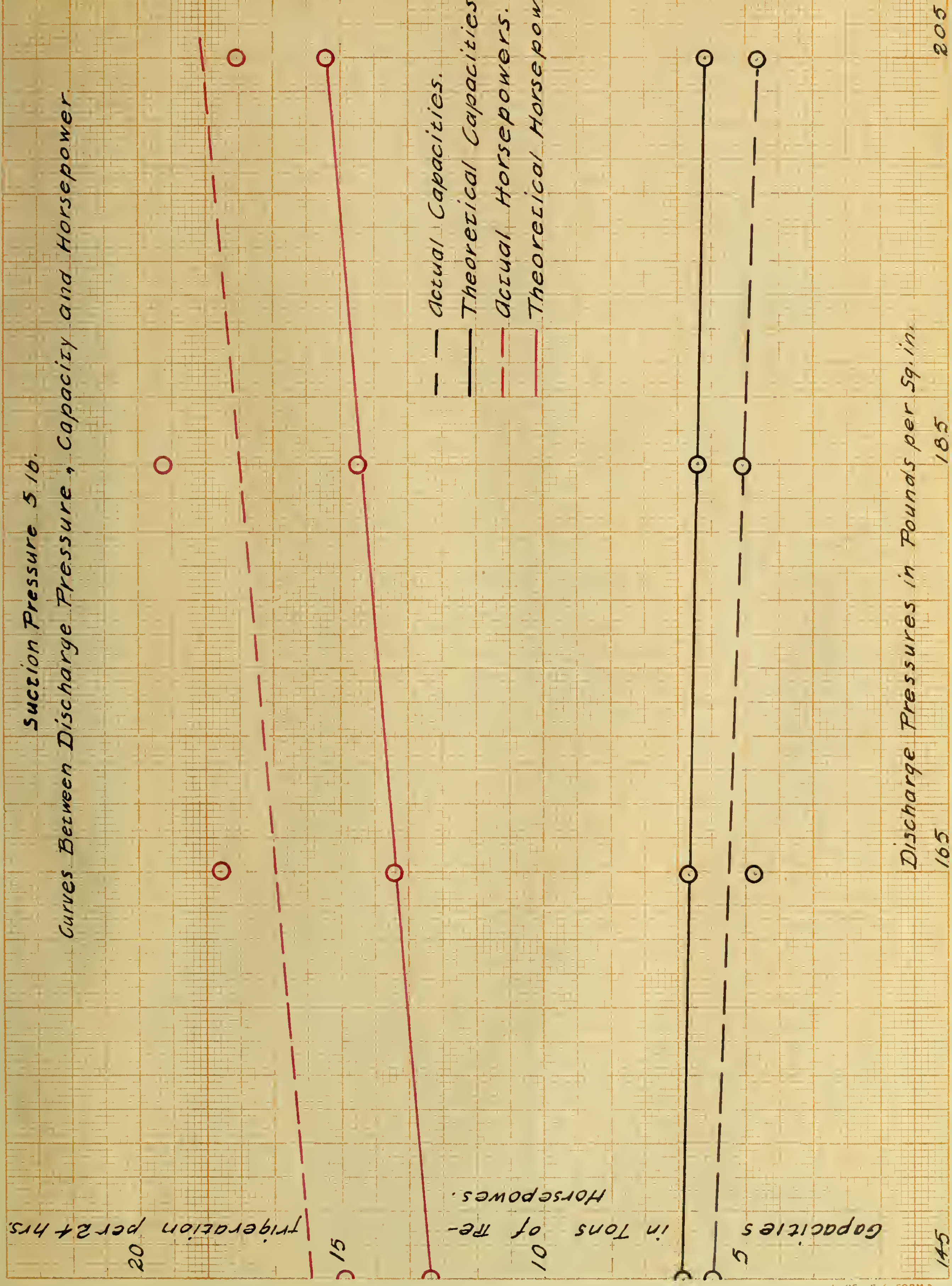
No.	Item												
1	Number of trial.	1	2	3	4	5	6	7	8	9	10	11	12
49	Weight of dry steam per ammonia i.h.p. hr. (lb.)	78.2	64.9	73.1	70.5	60.8	60.0	61.6	65.3	61.2	57.5	57.4	56.5
50	Total B.t.u. supplied in steam to engine per hr.	725000	771000	970000	749000	840000	812000	867500	801000	820000	854000	894000	926000
51	Total B.t.u. supplied in steam to engine per steam i.h.p. hr.	48650	43000	49900	45100	40600	42000	44100	45700	45000	37800	41000	41200
52	Total B.t.u. supplied in steam to engine per ammonia i.h.p. hr.	93400	76400	85700	84200	72100	71400	73400	77500	72900	68850	68100	67000
53	Total brine circulated. (lb.)	31209	26023	28461	18010	21576	24611	28467	23604	27492	24670	35492	28147
54	Brine circulated per hr. (lb.)	15604	13011	14230	18010	10788	12305	14233	11802	13750	12335	17746	14073
55	B.t.u. taken from brine per hr.	87400	56600	59600	56000	91100	85500	135400	99900	140450	154900	122700	124300
56	B.t.u. taken from brine per steam i.h.p. hr.	5860	3160	3060	3360	4400	4420	7385	5700	7705	6850	5630	5530
57	B.t.u. taken from brine per ammonia i.h.p. hr.	11260	5610	5260	6190	7890	7510	12310	9650	12490	12490	9340	9000
58	Jacket water per hr. (lb.)	932	1257	1269	1065	1356	1212	920	1374	795	1458	622	1228
59	B.t.u. absorbed by jacket water per hr.	17420	20000	2294	23650	27250	24260	15810	37650	12620	29600	15230	19760
60	Condenser water per hr. (lb.)	3415	3250	2206	1203	2040	2703	4460	11826	1656	5850	5110	5922
61	B.t.u. absorbed by condenser water per hr.	63900	87400	71250	47500	84500	94800	95950	216000	26180	145300	215500	224000
62	Total B.t.u. absorbed by jacket and condenser water per hr.	83120	107400	94910	71150	117500	119420	101760	253650	38800	174900	230730	243760
63	Temp. of steam entering heating coil. (deg. F.)	254.5	251	251	251	254	252.8	264	257.9	270.3	268	263	261.5
64	Temp. of steam leaving heating coil. (deg. F.)	78.5	85.77	92.60	77.5	55.0	59	79.2	67.9	80	85.9	72.5	76.5
65	Abs. press. of steam in heating coil. (lb./sq.in.)	14.55	14.55	14.55	14.55	13.27	15.00	16.3	14.55	16.68	16.68	15.30	15.3
66	Condensate from heating coil per hr. (Lb.)	81	72.5	77.5	74.0	110.0	110	95.5	83.3	127.5	152.5	100.0	66.5
67	Heat given by steam in coil to brine (including radiation). (B.t.u.)	91000	80800	87100	83080	126060	125540	107030	95600	143700	171300	117500	75000
68	Heat received by brine from steam per hr. (B.t.u.)	82600	84400	92100	73300	104700	103000	106080	95200	142800	129400	103600	111000
69	Tons refrigeration per 24 hr.	5.75	4.72	4.95	4.65	7.69	7.13	8.91	8.32	11.71	10.18	10.22	10.38
70	Tons refrigeration per steam i.h.p. hr.	.0132	.011	.0137	.0168	.0153	.0153	.0204	.0198	.0268	.0233	.0195	.0193
71	Tons refrigeration per ammonia i.h.p. hr.	.0213	.018	.0235	.0315	.0272	.0265	.0330	.0335	.0434	.0378	.0324	.0312
72	Mechanical efficiency. (percent)	52.1	56.2	58.2	52.5	57.3	58.8	60.0	59.1	61.7	55.0	62.0	61.5
73	Plant efficiency, B.t.u. taken from brine per B.t.u. supplied in steam. (percent)	12.06	7.34	7.89	7.55	10.84	11.95	16.75	11.46	17.12	18.12	13.7	13.43

No.	
1	Nu
74	Ri
75	Lo
76	Av
77	Sq
78	Te
79	He
80	Lo
81	To

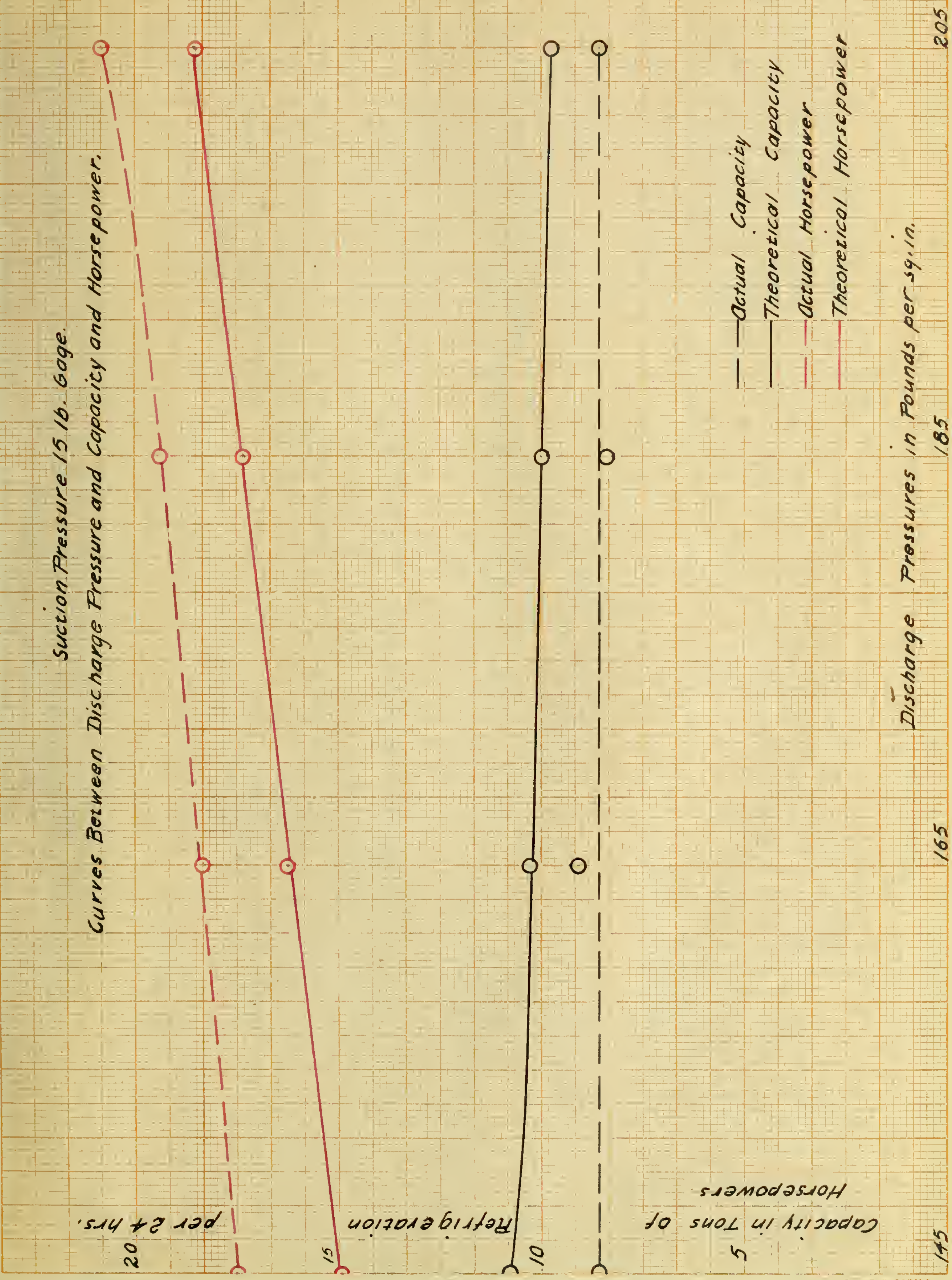
Correction for radiation

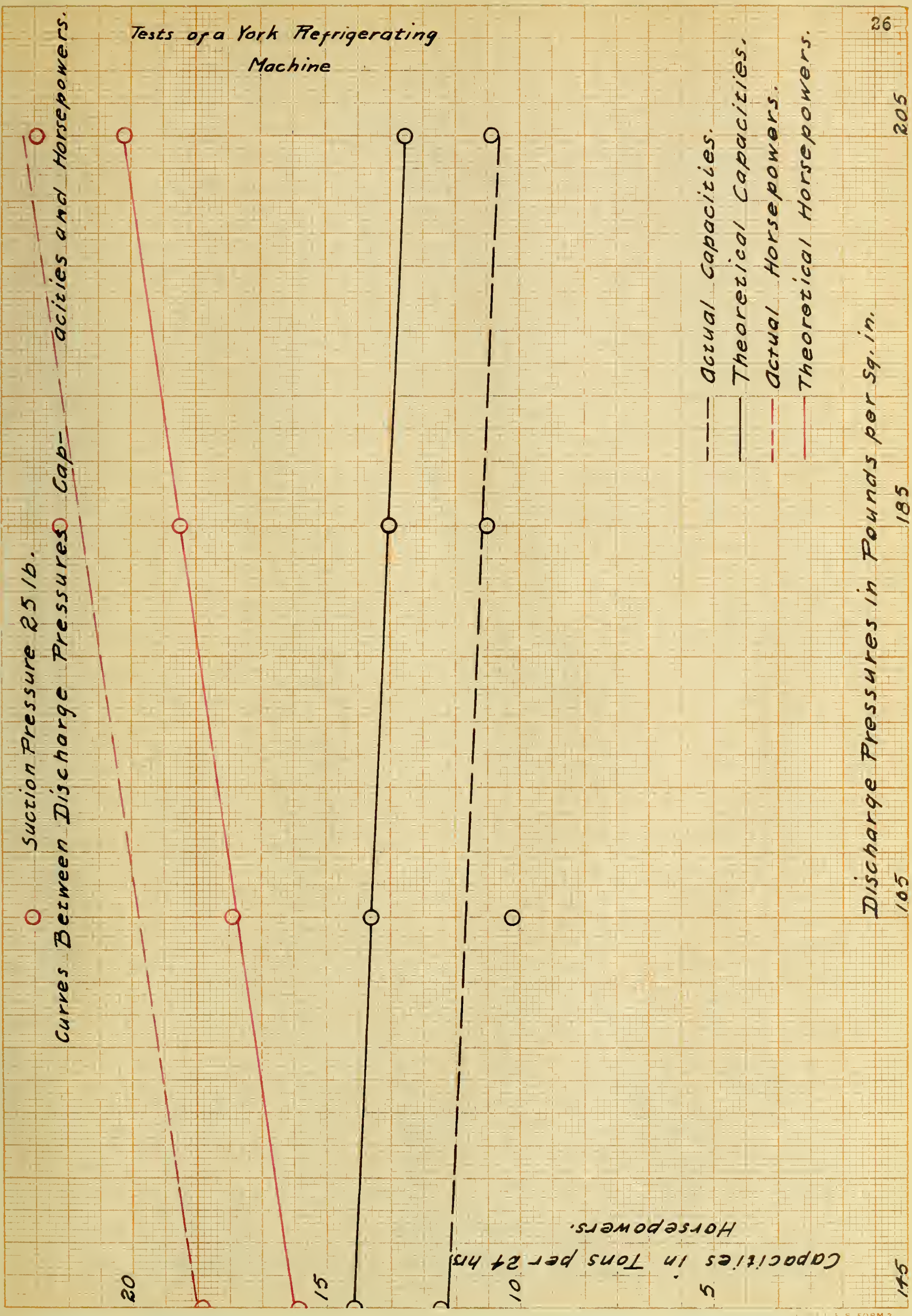
No.	Item												
1	Number of trial	I	2	3	4	5	6	7	8	9	I0	II	I2
74	Rise in temp. of brine in radiation test. (deg. F.)	0	0	0	0	I	I	.3	.35	.42	0	.5	.42
75	Loss in tons of refrigeration due to radiation to brine.	0	0	0	0	.9	I.03	.28I	.272	.379	0	.582	.388
76	Av.mean temp. of ammonia flowing through coils. (deg. F.)	22.2	28.47	30.90	22.40	20.I7	23.8I	25.70	27.85	33.0I	37.2	32.0	30.30
77	Sq. ft. of exposed ammonia pipe.	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9	6.9
78	Temp. difference between ammonia and outside air. (deg. F.)	49.8	56.53	54.I0	50.0	50	46	50.26	57.I5	47.0	42.8	48	54.7
79	Heat loss due to ammonia radiation per hr. (B.t.u.)	602	68I	654	603	603	555	606	69I	566	5I7	555	66I
80	Loss in tons of refrigeration due to radiation to ammonia.	.05	.0568	.0545	.0462	.0502	.0462	.0500	,0575	.0474	.0430	.0502	.055
8I	Total capacity in tons of refrigeration per 24 hr.	5.8	4.77	5.00	4.70	8.64	8.20	9.24	8.65	I2.I36	I0.22	I0.85	I0.80

Tests of a York Refrigerating Machine

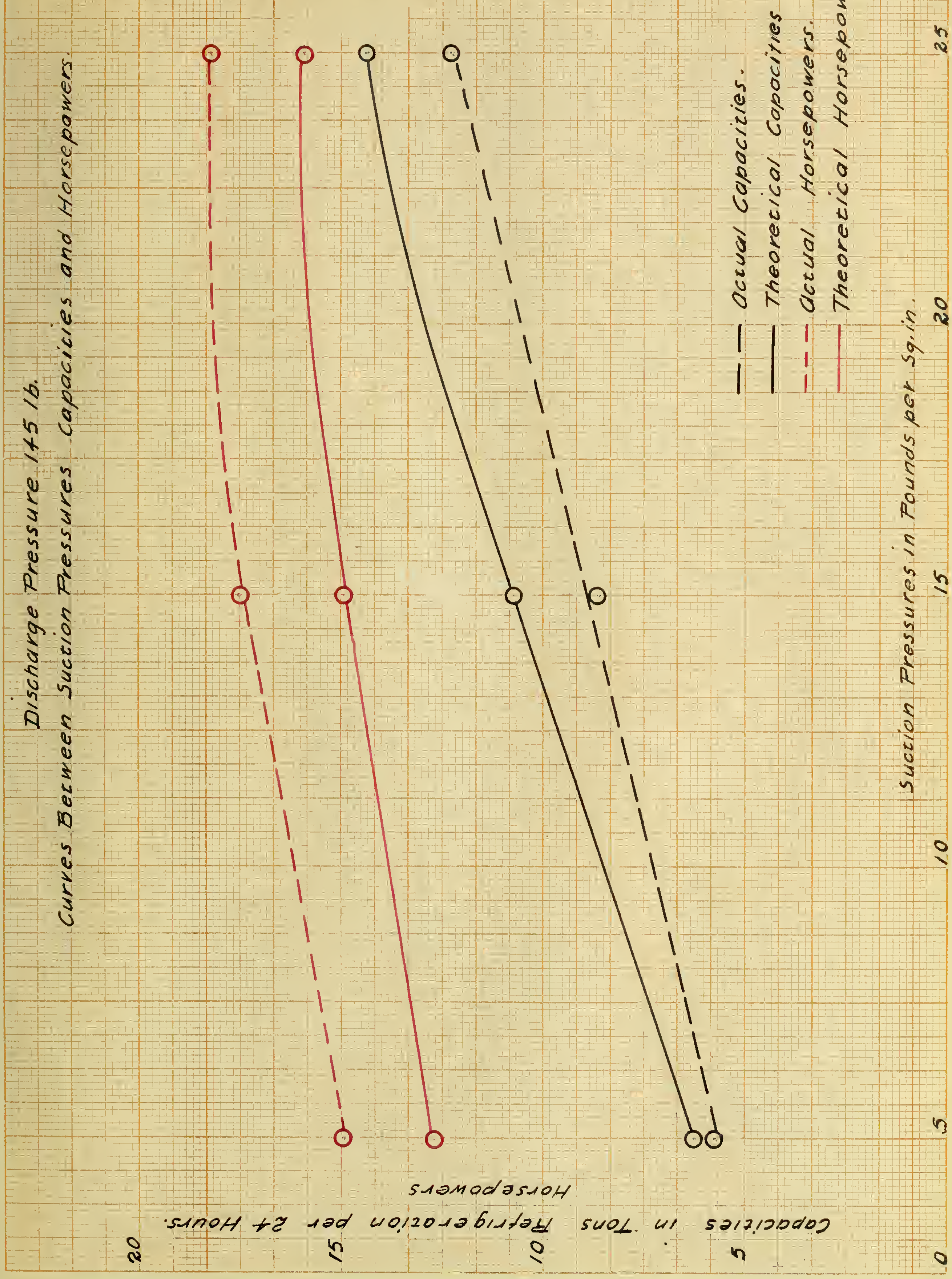


Tests of a York Refrigerating Machine.



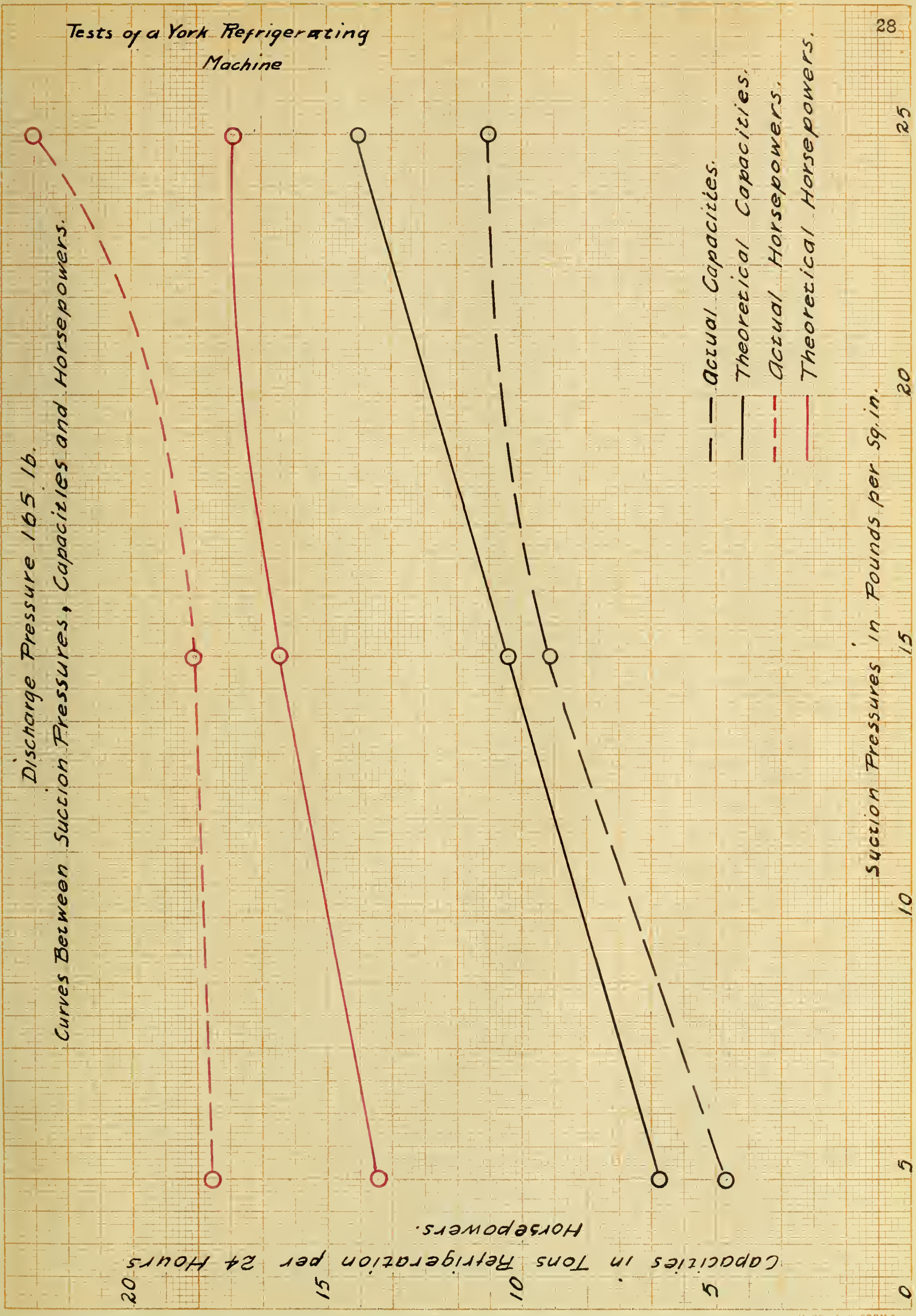

Tests of a York Refrigerating Machine
Suction Pressure 25 lb.
Curves Between Discharge Pressures Capacities and Horsepowers.
Actual Capacities.
Theoretical Capacities.
Actual Horsepowers.
Theoretical Horsepowers.
Discharge Pressures in Pounds per Sq. in.
145
165
185
205
Capacities in Tons per 24 hrs
Horsepowers.
5
10
15
20

Tests of a York Refrigerating Machine



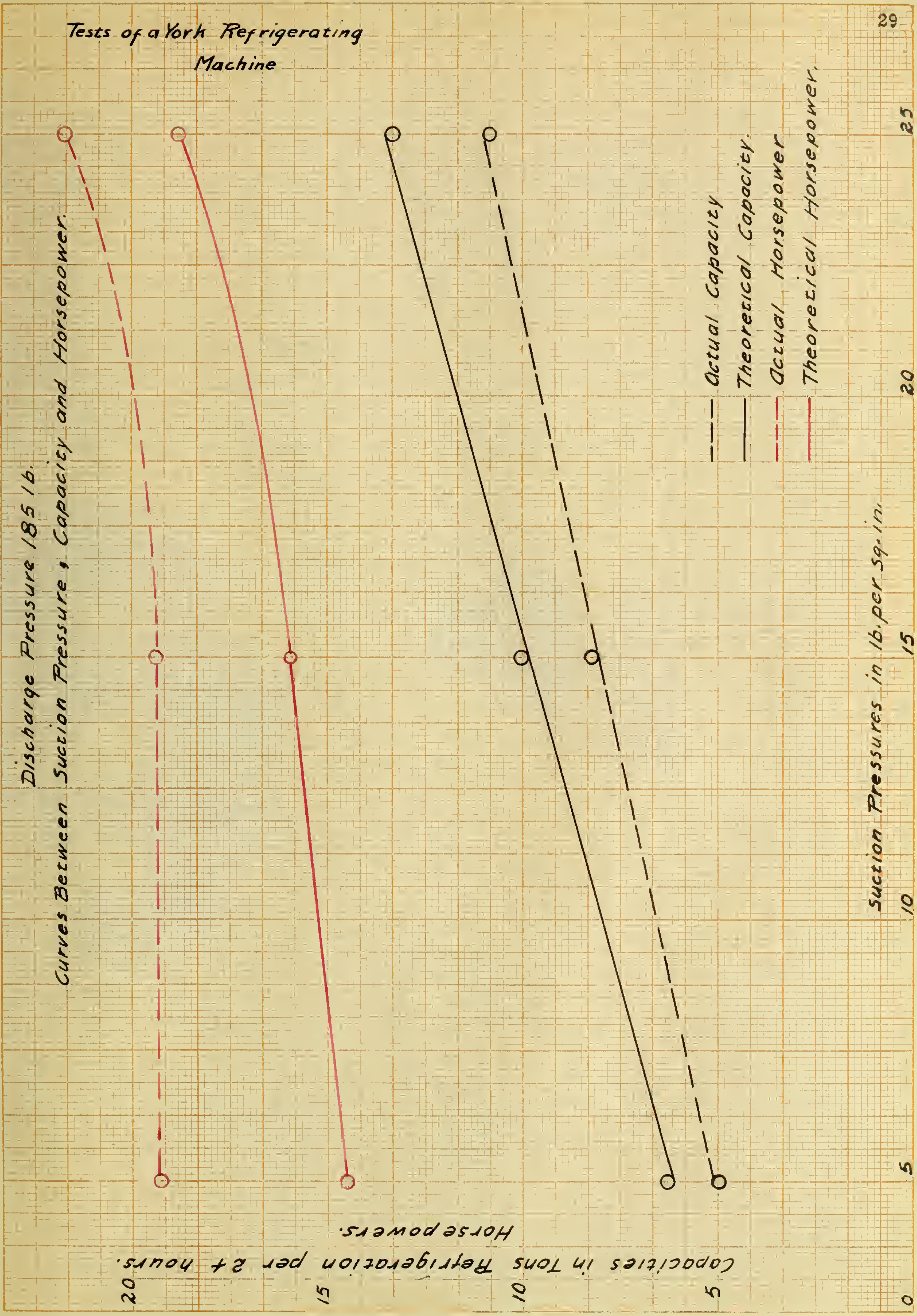
Discharge Pressure 145 lb.

Curves Between Suction Pressures Capacities and Horsepowers.



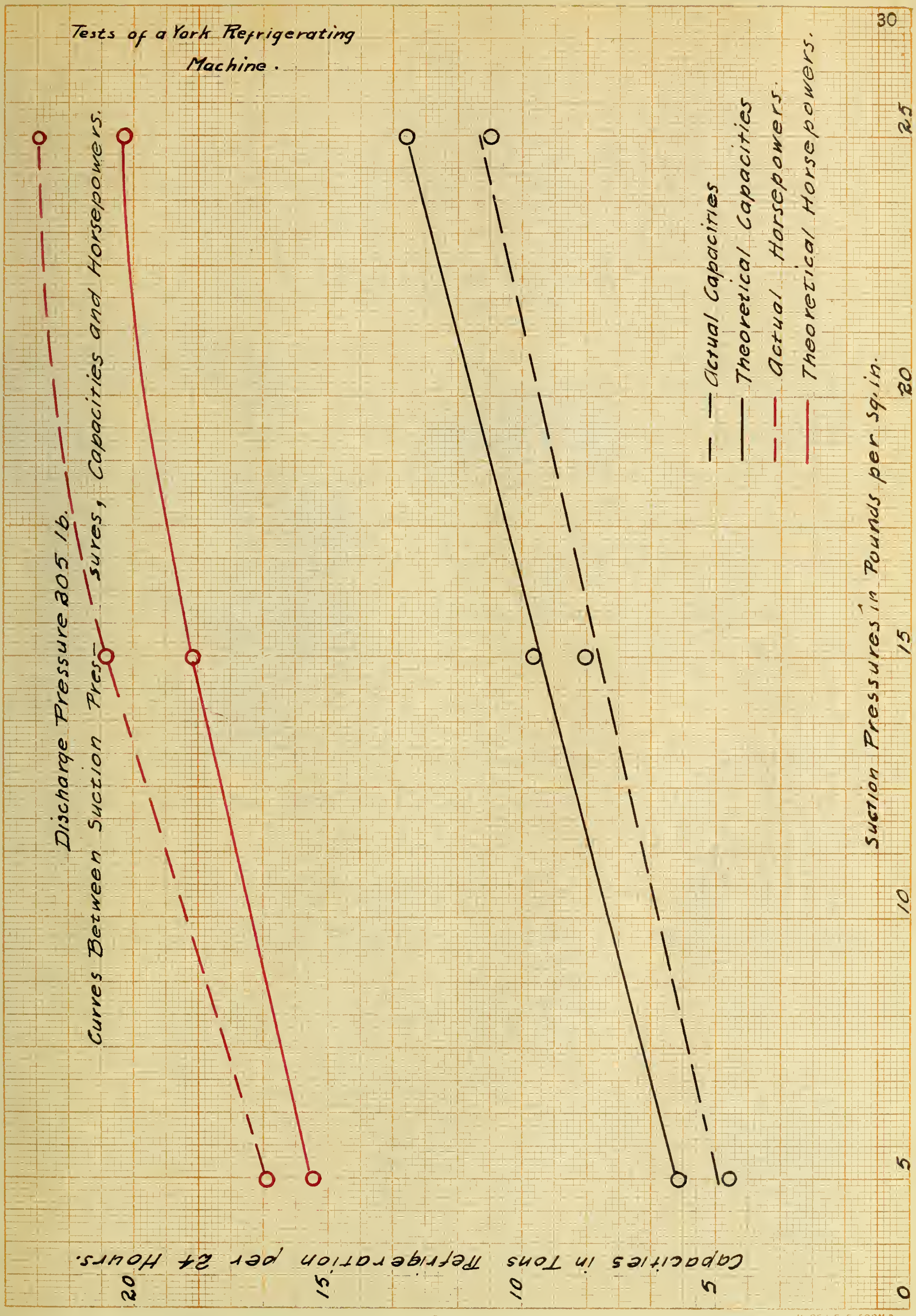
Tests of a York Refrigerating Machine

Tests of a York Refrigerating Machine



Discharge Pressure 185 lb.

Curves Between Suction Pressure, Capacity and Horsepower.



Tests of a York Refrigerating Machine.

U. OF I. S. S. FORM 3

CHAPTER VII

Discussion of Results

One notable thing about these tests is that the radiation of the air into the brine amounts to so much. From the result sheet it can be seen that there is about one ton lost for one degree rise in temperature of the brine through the cooling coil (in the radiation tests). With brine at 40°, one degree drop was noticed, and with brine at 60°, no drop was noticed. The temperature of the brine being so near the room temperature, the radiation was negligible.

The curves, on the whole, are very good, especially those of capacities. One test seems to be low in tonnage, namely, test No. 10, with suction at 25 lb. and discharge at 165 lb. This error was probably due to an inaccuracy in reading the thermometers. An error of one degree will make a difference of one and one-half tons in these tests.

CHAPTER VIII

Conclusions

From the curves it is seen that as the capacity decreases with a given suction pressure, the horse power increases. This has a theoretical basis. From the temperature entropy diagram under "Theory", it is seen that as the pressure increases, the latent heat decreases. The horse power is largely a function of the discharge pressure and the capacity a function of the latent heat of fusion, so the greater the horse power is, the smaller will be the capacity for a given suction pressure.

The curves show that more horse power than the rating was needed and less capacity than the rating was developed. It is interesting to note that in each case, the capacity developed lies between 83 and 85 percent of the rated capacity.

From the steam indicator cards, it is seen that, due to the extremely early cut-off, the Corliss engine used is by far too large for the system.

As above stated, the cooling coil capacity is not large enough for this size plant.

Generally speaking, with a given suction pressure, the capacity decreases as the first power of the increasing discharge pressure

(straight line with negative slope), and the horse power increases as the first power of the discharge pressure.

As the suction pressure increases, with constant discharge pressure, the capacity increases as the first power. No such conclusion can be drawn as to the horse power.

CHAPTER IX

Sample Calculations

No.

1. Test No. 9
2. Duration of trial = 2 hrs.
3. Av. rev. per min. = 88.2
4. Atmospheric pressure = 14.68 lb./sq. in.
5. Specific heat of brine = .789
6. Av. abs. steam press. = 144.98 lb./sq. in.
7. Av. abs. exhaust press. = 14.68 lb./sq. in.
8. Av. abs. ammonia press. entering compressor = 14.68 + 25.1 = 39.78 lb./sq. in.
9. Av. abs. ammonia press. leaving compressor = 14.68 + 146.8 = 161.48 lb./sq. in.
10. Av. room temperature = 80° F.
11. Av. calorimeter temperature = 293.8° F.
12. Av. quality of steam = .995 (From Mollier diagram)
13. Av. temp. of ammonia entering brine coil = 10° F.
15. Av. temp. of ammonia leaving brine coil = 55.03° F.
16. Av. temp. of ammonia leaving compressor - left = 284.7° F.
17. Av. temp. of ammonia leaving compressor -right = 290.4° F.
18. Av. temp. of ammonia leaving condenser = 77.7° F.
19. Av. temp. of brine entering circulating pump = 45.06° F.

20. Av. temp. of brine leaving circulating pump = 45.45° F.

21. Av. rise through pump = 45.45 - 45.06 = .39° F.

22. Av. temp. of brine entering heating coil = 45.45° F.

23. Av. temp. of brine leaving heating coil = 58.6° F.

24. Av. rise through coil = 58.6 - 45.45 = 13.15° F.

25. Av. temp. of brine entering cooling coil = 58.6° F.

26. Av. temp. of brine leaving cooling coil = 45.68° F.

27. Av. drop through cooling coil = 58.6 - 45.68 = 12.92° F.

28. Av. temp. of water entering cylinder jackets = 65.37° F.

29. Av. temp. of water leaving left jacket = 80.5° F.

30. Av. temp. of water leaving right jacket = 82° F.

31. Av. rise in jackets = $\frac{80.5 + 82}{2} - 65.37 = 15.8°$ F.

32. Av. temp. of water entering condenser = 64.6° F.

33. Av. temp. of water leaving condenser = 80.4° F.

34. Av. rise through condenser = 80.4 - 64.6 = 15.8° F.

35. Av. m.e.p. of engine - H.E. = 41.3 lb./sq. in.

36. Av. m.e.p. of engine - C.E. = 38.4 lb./sq. in.

37. Av. m.e.p. of left ammonia cycle = 55.6 lb./sq. in.

38. Av. m.e.p. of right ammonia cycle = 59.4 lb./sq. in.

39. I.h.p. of engine - H.E. = $\frac{41.3 \times 10 \times 104 \times 88.2}{12 \times 33000} = 9.56$

40. I.h.p. of engine - C.E. = $\frac{38.4 \times 10 \times 101.24 \times 88.2}{12 \times 33000} = 8.65$

41. I.h.p. of engine - total = 9.65 + 8.56 = 18.21

42. I.h.p. of ammonia cylinder - left =

$$\frac{55.6 \times 10 \times 44.3 \times 88.2}{12 \times 33000} = 5.41$$

43. I.h.p. of ammonia cylinder - right =

$$\frac{59.4 \times 10 \times 44.3 \times 88.2}{12 \times 33000} = 5.85$$

44. I.h.p. of ammonia cylinder - total = 5.85 + 5.41 = 11.26

45. Total condensate = 1385 lb.

46. Condensate per hour = 692.5 lb.

47. Dry steam per hour = 692.5 x .995 = 689 lb.

48. Dry steam per steam i.h.p. hour = 689 ÷ 18.21 = 37.82 lb.

49. Dry steam per ammonia i.h.p. hour = 689 ÷ 11.26 = 61.2 lb.

50. Total B.t.u. supplied in steam to engine per hour =
1182 x 692.5 = 820,000.

51. B.t.u. per steam i.h.p. hour = 820,000 ÷ 18.21 = 45,000

52. B.t.u. per ammonia i.h.p. hour = 820,000 ÷ 11.26 = 72,900

53. Total brine circulated = 27,492 lb.

54. Brine per hour = 27,492 ÷ 2 = 13,750 lb.

55. B.t.u. taken from brine per hour =
13,750.0 x .789 x 12.92 = 140,450

56. B.t.u. taken from brine per steam i.h.p. hour =
140,450 ÷ 18.21 = 7,705

57. B.t.u. taken from brine per ammonia i.h.p. hour =
140,450 ÷ 11.26 = 12,490

58. Jacket water per hour = 795 lb.

59. B.t.u. absorbed by jacket water per hour =
795 x 15.80 = 12,620

60. Water used in ammonia condenser per hour = 1656 lb.

61. B.t.u. absorbed by condenser water per hour =
1656 x 15.8 = 26,180

62. B.t.u. absorbed by jacket and condenser water per hour = 12.620 + 26,180 = 38.800

63. Temp. of steam entering heating coil = 270.3°

64. Temp. of steam leaving heating coil = 80°

65. Abs. steam pressure in heating coil = 16.68 lb./sq. in.

66. Heating coil condensate per hour = 127.5 lb.

67. Heat given by steam to brine = 127.5 x(1175 - 48) = 143.700 B.t.u.

68. Heat received by brine per hour = 13,750 x .789 x 13.15 = 142,800 B.t.u.

69. Tons refrigeration per 24 hours = 140.450 x 24 ÷ 288.000 = 11.71

70. Tons per steam i.h.p. hour = $11.71 \div \frac{18.21}{24} = \frac{.644}{24} = .0268$

71. Tons per ammonia i.h.p. hour = $11.71 \div \frac{11.26}{24} = \frac{1.04}{24} = .0434$

72. Mechanical efficiency = 11.26 ÷ 18.21 = 61.75 %

73. Plant efficiency = 140,450 ÷ 820,000 = 17.12 %

74. Rise in temperature in radiation test = .42°

75. Tons radiation to brine = $\frac{.42 \times 13{,}750 \times 24 \times .789}{288{,}000} = .379$

76. Av. temp. of ammonia through coils = (55.03 - 11) ÷ 2 = 33.01°

77. Sq. ft. of ammonia surface (exposed) = 6.9

78. Temp. difference between ammonia and outside air = 80 - 33 = 47°

79. Heat radiated through ammonia exposed surface = 1.75 x 6.9 x 47 = 566 B.t.u. per hour.

80. Tons refrigeration due to ammonia radiation

566 x 24 ÷ 288,000 = .0474

81. Total tons refrigeration per 24 hours =

11.71 + .379 + .0474 = 12.136

TEST NO. I.

Suction press. -- 5#.

Discharge press. -- 145#

Test No.I.

3/24/13
Time--4:50
Machine--York
Spring--100#

R.P.M.--88.2
M.E.P.--H.E.--30.5
--C.E.--32.5

H.E.

C.E.

Hawkins

Test No. I.

East ammonia cyl.

3/24/13
Time--4:50
Machine--York
Spring--100#
R.P.M.--88.2
M.E.P.--40

Larsen

Test No.I.

West ammonia cyl.

3/24/13
Time--4:50
Machine--York
Spring--100#
R.P.M.--88.2
M.E.P.40

Larsen

TEST NO. 3.

Suction press. -- 5#

Discharge press. -- 185#

Test No. 3.

3/24/13
Time--9:30
Machine--York
Spring--100#

R.P.M.--88.3
M.E.P.--H.E.--46.2
--C.E.--42.5

H.E.

C.E.

Larsen

Test No. 3.

East ammonia cyl.

3/24/13
Time--9:30
Machine--York
Spring--100#
R.P.M.88.3
M.E.P.--60

Overmier

Test No.3 .

West ammonia cyl.

3/24/13
Time--9:30
Machine--York
Spring--100#
R.P.M.--88.8
M.E.P.--58.8

Overmier

TEST NO. 4.

Suction press. -- 5#

Discharge press. -- 205#

Test no.4.

3/24/13
Time--8.25
Machine--York
Spring--100#

R.P.M.--88.5
M.E.P.--H.E.--37.5
--C.E.--34.3

Hawkins

Test No. 4 .

East ammonia cyl.

3/25/13
Time--8:25
Machine--York
Spring--100#
R.P.M.--88.5
M.E.P.--47.5

Larsen

Test No.4.

3/25/13
Time--8.25
Machine York
Spring--100#
R.P.M.--88.5
M.E.P.--43

West ammonia cyl.

Larsen

TEST NO. 5.

Suction press. -- I5#

Discharge press.-- 205#

Test No.5.

3/21/I3
Time--5:55
Machine--York
Spring--I00#

R.P.M.--88
M.E.P.--H.E.--47
--C.E.--45.7

H.E.

C.E.

Hawkins

Test No.5.

East ammonia cyl.

3/2I/I3
Time--5:55
Machine--York
Spring--I00#
R.P.M.--88
M.E.P.--60

Larsen

Test No.5.

West ammonia cyl.

3/21/I3
Time--5:55
Machine--York
Spring--I00#
R.P.M.--88
M.E.P.--66

Larsen

TEST NO. 6.

Suction press. -- 15#

Discharge press. -- 185#

Test No. 6.

3/21/13
Time--9:20
Machine--York
Spring--100#

R.P.M.--88
M.E.P.--H.E.--48
--C.E.--41

H.E.

C.E.

Overmier

Test No. 6.

East ammonia cyl.

3/21/13
Time--9:20
Machine--York
Spring--100#
R.P.M.--88
M.E.P.--59

Hawkins

Test No. 6.

West ammonia cyl.

3/21/13
Time--9:20
Machine--York
Spring--100#
R.P.M.--88
M.E.P.--59

Hawkins

TEST NO. 7.

Suction press. -- 15#

Discharge press. -- 165#

Test No. 7.

3/24/13
Time--1:25
Machine--York
Spring--100#

R.P.M.--88.4
M.E.P.--H.E.--41
--C.E.--40.2

H.E.

C.E.

Larsen

Test No.7.

East ammonia cyl.

3/24/13
Time--1:25
Machine--York
Spring--100#
R.P.M.--88.4
M.E.P.--56.3

Overmier

Test No. 7.

3/24/13
Time--1:25
Machine--York
Spring--100#
R.P.M.--88.4
M.E.P.--53.7

West ammonia cyl.

Overmier

Test No. 8.

Suction press.--15# Discharge press.--145#

Test No.8.

3/22/13
Time--1:15
Machine--York
Spring--100#

R.P.M.--88.8
M.E.P.--H.E.--42
--C.E.--39

H.E.

C.E.

Hawkins

Test No. 8.

East ammonia cyl.

3/22/13
Time--1:15
Machine--York
Spring--100#
R.P.M.--88.8
M.E.P.--53.7

Larsen

Test No.8.

3/22/13
Time--1:15
Machine--York
Spring--100#
R.P.M.--88.8
M.E.P.--55.3

West ammonia cyl.

Larsen

TEST NO. 9.

Suction press. -- 25# Discharge press. -- 145#

Test No.9.

3/22/13
Time--4:00
Machine--York
Spring--100#

R.P.M.--88.2
M.E.P.--H.E.--38.7
--C.E.--37.0

H.E.

C.E.

Overmier

Test No.9.

East ammonia cyl.

3/22/13
Time--4:00
Machine--York
Spring--100#
R.P.M.--88.2
M.E.P.--56.5

Hawkins

Test No. 9.

3/22/13
Time--4:00
Machine--York
Spring--100#
R.P.M.--88.2
M.E.P.--58.6

East ammonia cyl.

Hawkins

TEST NO. 10.

Suction press. -- 25#

Discharge press. --165#

Test No. 10.

3/22/13
Time--7:25
Machine--York
Spring--100#

R.P.M.--88
M.E.P.--H.E.--46.3
--C.E.--42.5

H.E.

C.E.

Larsen

Test No. 10.

East ammonia cyl.

3/22/13
Time--7:25
Machine--York
Spring--100#
R.P.M.--88
M.E.P.--62

Overmier

Test No. 10

3/22/13
Time--7:25
Machine--York
Spring--100#
R.P.M.**88
M.E.P.--61

West ammonia cyl.

Overmier

TEST NO. II.

Suction press. -- 25# Discharge press. -- 185#

Test No. II.

Machine--York
Spring--I00#
R.P.M.--88.5
M.E.P.--H.E.--50
--C.E.--45

3/24/I3
Time--I0:05

H.E. C.E.

Hawkins

Test No. II.

East ammonia cyl.

Machine--York.
Spring--I00#
R.P.M.--88.5
M.E.P.--69
3/24/I3
Time--I0:05

Larsen

TEST NO.II.

3/24/I3
Time--I0:05
Machine--York
Spring--I00#
R.P.M.--88.5
M.E.P.--67.3

West ammonia cyl.

Larsen

TEST NO. I2.

Suction press. -- 25# Discharge press. -- 205#

Test No. I2.

3/24/I3
Time--I0:50
Machine--York
Spring--I00#
R.P.M.--88
M.E.P.--H.E.--50.9
--C.E.--47.7

H.E. C.E.

Overmier

Test No. I2.

East ammonia cyl.

3/24/I3
Time--I0:50
Machine--York
Spring--I00#
R.P.M.--88
M. E. P.--70.4

Hawkins.

Test No. I2

West ammonia cyl.

3/24/I3
Time--I0:50
Machine--York
Spring--I00#
R.P.M.--88
M.E.P.--7I

Hawkins