Kreisinger

Heating by Reversed Cycles

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HEATING BY REVERSED CYCLES

...BY...

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

HENRY KREISINGER

ENTITLED HEATING BY REVERSED CYCLES

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

OF Bachelor of Science in Mechanical Engineering

L. P. Breckenridge

HEAD OF DEPARTMENT OF Mechanical Engineering

Contents.

Heating by Reversed Cycles.

What Heating by Reversed Cycles Means.

In the case of a direct heat engine a current of heat flows from a hot body into a cold body, and part of the heat is converted into mechanical energy. An engine running under these conditions is said to operate on a direct cycle. This process may be reversed. If mechanical energy is supplied, and the engine is run in the reversed direction, heat will flow from the cold body into the hot body. An engine which thus consumes mechanical energy and makes heat available, is said to operate on a reversed cycle. If this heat, made available by the reversed engine, is used for heating purposes, the reversed engine may be called a heating machine, and the heating system using such heating

machines is called Heating by Reversed Cycles.

The operation of a direct and reversed heat engine may be shown very clearly by means of cycles on the temperature-entropy plane. Taking the simple Carnot's rectangular cycle, let M and N (Fig. 1) be the cycles of a direct and reversed engine respectively.

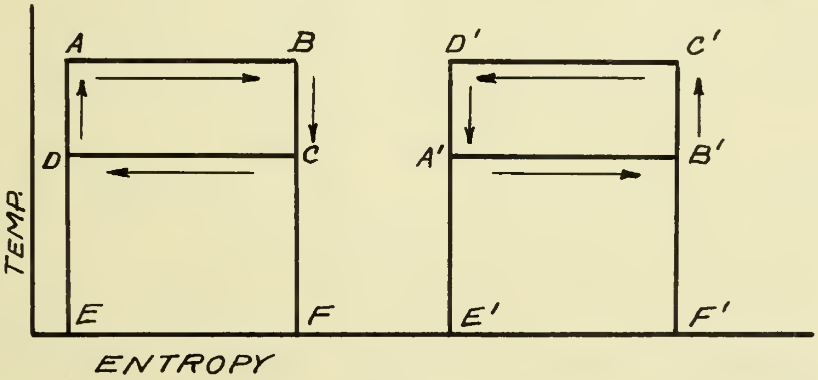


Fig 1.

Area ABFE represents the heat supplied to the direct engine. The heat ABCD is converted into mechanical energy, and the heat CDEF is rejected or passed to the atmosphere or condensor. If the reversed engine N is supplied with the mechanical energy A'B'C'D', the reversed engine or heating machine takes the heat A'B'F'E' from the atmosphere, and together with

the mechanical energy trasformed into heat, will make the heat C'D'E'F' available for heating purposes.

Thus it is seen that heating by reversed cycles is not merely changing the mechanical energy into heat as it is ordinarily done with electrical energy. A much larger quantity of heat is made available by the use of the reversed cycle than is the heat equivalent of the mechanical energy expended. Nor does it mean that any heat energy is created. The heating machine takes the heat at a lower temperature from the atmosphere, and lifts it to a higher temperature level. To illustrate the process Prof. Reeve uses the following analogy.

"A man wishes to fill a land-locked basin lying some few feet above the sea-level with water, and has as a means with which to work, a small stream falling from a mill-pond situated ten times as high as the basin above the sea. He might, in the first place, simply let the stream flow into the basin,

which it would eventually fill. This would correspond to the ordinary direct method of heating buildings. But if his small water power were extremely valuable, or if time were valuable also, he might hasten matters by letting the small stream in its fall into the basin, drive a water wheel. By attaching to this water wheel a pump piped to lift water from the sea, and to discharge it into the basin, it is plain that the latter would be filled much more quickly and at a much less cost of mill-pond water. If the basin were 10 feet and the small mill-pond 100 feet above the sea-level, respectively, the basin would be filled in the second case in one-tenth of the time, or with one-tenth as much water drawn from the mill-pond, as compared with the first case".

In Prof. Reeve's illustration the quantity of water that can be pumped into the basin, with a given quantity of water from the mill-pond depends upon the hight of the basin above the sea level.

For small heights this quantity will be large, and for large heights small. The same is true with the heating machine. The quantity of heat which the heating machine makes available with a given mechanical energy, depends upon the temperature level to which the heat is lifted; for low temperatures this quantity will be large, while for high temperatures it will be very small. Fig. 2 shows three cycles in which the mechanical energy expended is the same, but the quantities of heat made available by the heating machine vary greatly. CDEF is much larger in cycle C than in cycle B.

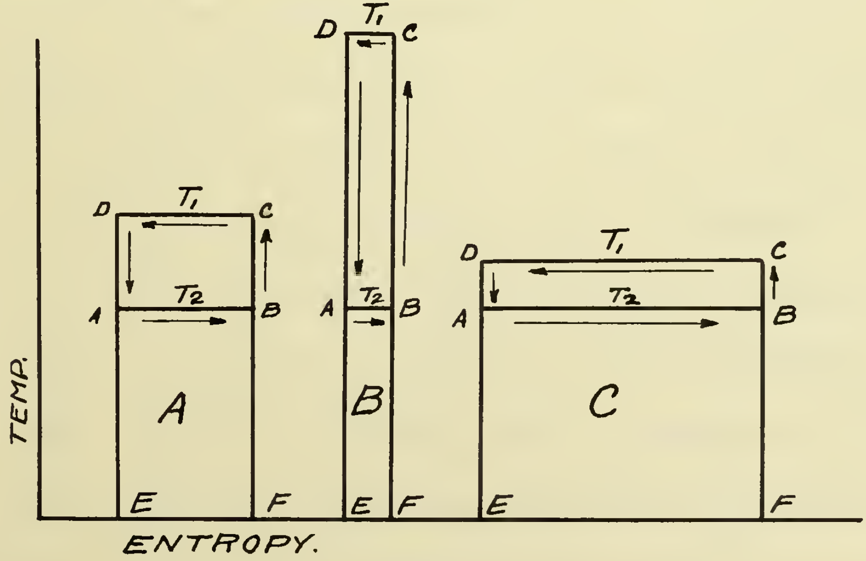


Fig 2.

The Advantage of Heating by Reversed Cycles.

A better utilization of fuel is one advantage of heating by reversed cycle. It is not hard to imagine a direct engine operating on a cycle having a form like B (Fig. 2), and running a heating machine which operates on a cycle like C. With the original small quantity of heat CDEF in cycle B, at high temperature T_1, we obtain the large quantity of heat CDEF in cycle C, at a lower temperature T_1. This advantage applies to both, local and central heating systems. Of course in local heating systems the complicated and expensive apparatus would be a disadvantage. But, if the coal were very expensive it would perhaps pay to install a steam boiler, and a heating machine run by a steam engine which would take steam from the boiler. Both, the exhaust steam from the steam engine and the heat made available by the heating machine could be used for heating purposes. The bad

economy in our present heating system lies in that we develope the heat at high furnace temperature, and let it fall down to the low-temperature of the radiator, or room to be heated, without letting it do any work. This in Prof. Reeve's illustration is parallel to letting the mill-pond water fall into the basin without letting it run the pump and help to fill the basin.

In central heating service the system of heating by reversed cycle might prove more efficient than any of our present heating systems. It would certainly be more efficient than direct heating by electricity. It could be perhaps operated more successfully for much longer distances than hot water or steam heating from central stations. In the case of reversed cycle heating from central station, the direct engine operating on a cycle like B (Fig. 2) would be placed at the central station located in a place where a large quantity of coal could be conveniently stored.

The mechanical energy developed by the direct engine would be trasformed into electricity and transmitted by wires to large commercial buildings where electric motors would be used for running a heating machine operating on cycle C (Fig. 2). Of course there would be losses due to transformation and trasmission of energy, and also due to imperfections of the cycles.

Practical Cycles.

So far only the rectangular Carnot cycle, which is the most efficient, has been used for illustrations. In reality this cycle can not be attained, as no medium used in direct and reversed heat engines is known to follow the rectangular cycle. The form of a cycle varies with the medium. Gasses in general follow the Joule cycle shown in Fig. 5., and vapors like water and ammonia follow the vapor cycle shown in Fig. 7. These are the two cycles

most commonly met with in practice. Their efficiency increases as they approach the rectangular cycle.

Requirements of the Medium.

The substance best fitted for medium to be used in heating machines should fulfill the following requirements.

(a) In order to give high efficiency its cycle must approach the rectangular cycle.

(b) If it is a vapor it must be volatile at low temperature, and at about the atmospheric pressure.

(c) At high temperatures the pressure must not be too high.

(d) If compound or mixture, the constituents must not separate by evaporation or liquefaction.

(e) It must have no effect on metals of which the machine is built, nor on the lubricants used in cylinder.

(f) It must be non-explosive.
(g) It must be without injurious physiological effects on the attendants.
(h) It should not be too costly to buy.
(j) It must be sufficiently dense as not to require an excessively large compressive cylinder.

The Efficiency of the Reversed Cycle.

The efficiency of the reversed cycle is the heat made available by the reversed engine, divided by the energy expended, both being expressed in the same units. In the Carnot and vapor cycle the efficiency depends directly on the upper temperature T_1, and the lower temperature T_2. It will be shown later that in the Joule cycle it depends on the ratio of the pressures $\frac{P_2}{P_1}$ only. The upper temperature of the cycle T_1, is set by the temperature of the radiator which the warming machine is to

supply with heat. However, by increasing the radiating surface of the radiator, its temperature, and consequently the upper temperature T_1 may be lowered at will. The lower temperature T_2 is fixed by the temperature of the atmosphere, which of course can not be controlled. In order that the heat should flow from the medium into the carrier used in the radiator, the temperature of the medium must be raised by compression a few degrees above the temperature of the radiator. For the same reason the medium must be cooled by expansion below the temperature of the atmosphere. It is evident then, that with radiators having large radiating surface and low temperature, the reversed cycle is more efficient. This feature will be discussed later more thoroughly.

Let us now try various cycles for different values of T_1, having T_2 fixed by the atmosphere at 0°F., or 460.8°F. abs.

The Limiting Case. — Carnot Cycle.

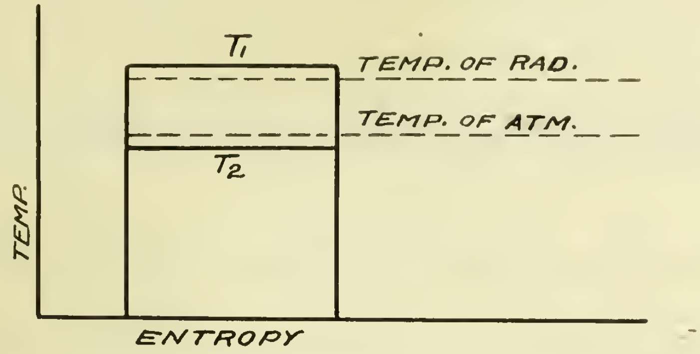


Fig. 3

The expression for efficiency of Carot cycle is.

$$E = \frac{T_1}{T_1 - T_2}$$

T_1 = const. = 460.8°F. abs.

For T_1 = 650.8°F. abs. E = 3.41
" T_1 = 620.8°F. abs. E = 3.864
T_1 = 600.8°F. abs. E = 4.3
T_1 = 580.8°F. abs. E = 4.83
T_1 = 560.8°F. abs E = 5.6
T_1 = 550.8°F. abs. E = 6.1

The efficiencies in the above cases state that the heating machine, if it could be operated on rectangular cycle would make from 3.41 to 6.1 times as much heat available than if the mechanical energy were merely changed into heat. Or 3.41 to 6.1 times

as much heat than an electric current would at the same expense.

The Joule Cycle.– Air as Medium.

The first medium which suggests itself for the use in heating machines is air. It can be easily handled, has no effect on the metals and lubricants, does not cost anything, and under favorable conditions the Joule cycle comes fairly near to the rectangular cycle. The diagram in figure 4 shows the principal parts of a heating machine using air as medium.

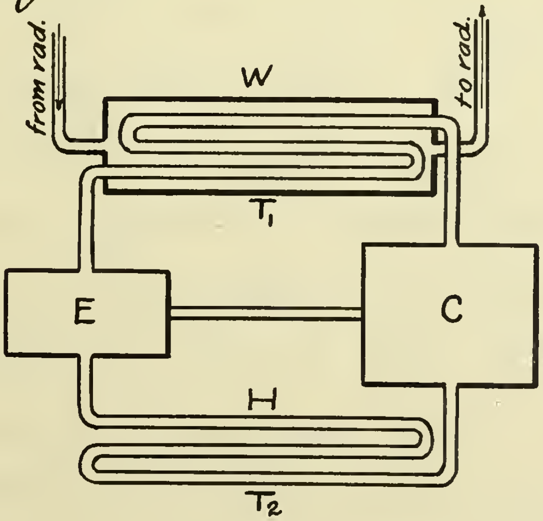


Fig. 4.

The compressing cylinder C takes in the air at the temperature T_2 from the coil H; by compressing it adiabaticaly raises its temperature to T_1, and then discharges it into the coil W. Water circulating around this coil trasmits the heat from the compressed air to the radiator. The air is thus reduced in volume at constant pressure P_1. It is then expanded adiabaticaly in the expansion cylinder E, and passed at a temperature much below T_2 into the coil H. Owing to the low temperature of the expanded air in coil H, the heat of the atmosphere around H flows into the air and expands it at constant pressure. Then the air is again taken into the compresing cylinder and a new cycle is started. In this manner a constant current of heat is made to flow from the atmosphere into the carrier and the radiator. The four thermodynamics process are shown in the cycle of Fig. 5. FA represents adiabatic compression in C, AB

represents abstraction of heat at constant pressure P_1 in W, BE represents adiabatic expansion in E, and EF represents the taking in heat at constant pressure P_2.

The following is a general analysis of the Joule cycle when the heating machine is using air as medium.

Let Q = required quantity of heat per stroke.
N = number of strokes per minute.
P_1 = upper pressure in lb. abs.
P_2 = lower " " " "
T_1 = upper temperature in F.° abs.
T_2 = lower " " " "
M = weight of air per stroke lb.
C_p = specific heat of air at constant pressure = .237

$$K = \frac{\text{spec. heat of air at const. pres.}}{\text{spec. heat of air at const. vol.}} = 1.41$$

E = efficiency
W = work done per stroke.
H.P. = required horse power to drive heating machine.

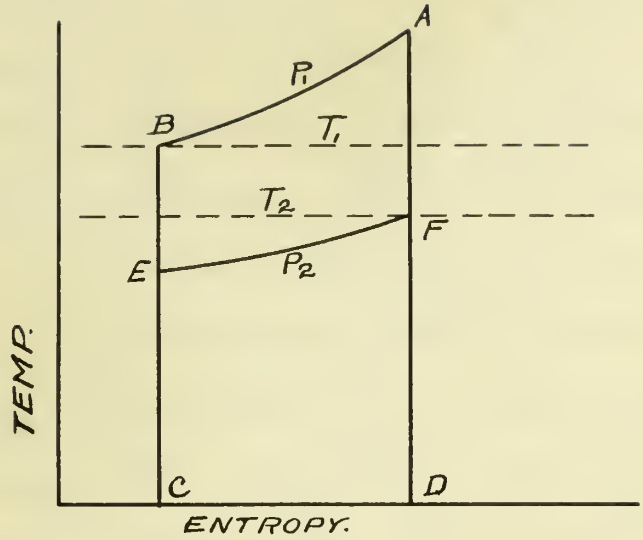


Fig. 5

For given P_1 and P_2, T_1 and T_2.

$$T_A = \left(\frac{P_1}{P_2}\right)^{\frac{K-1}{K}} T_2\,, \quad T_E = \left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} T_1$$

$$M = \frac{Q}{C_p(T_A - T_1)}$$

Heat taken from atmosphere $= MC_p(T_2 - T_E)$

$$W = MC_p\,[T_A - T_1 - T_2 + T_E]$$

$$H.P. = \frac{778NW}{33000}$$

$$E = \frac{MC_p(T_A - T_1)}{MC_p[(T_A - T_1) - (T_2 - T_E)]} = \frac{T_A - T_1}{(T_A - T_1) - (T_2 - T_E)}$$

Or, $\frac{1}{E} = 1 - \frac{T_2 - T_E}{T_A - T_1}$

Since $\frac{T_2}{T_A} = \left(\frac{P_2}{P_1}\right)^{.29} = \frac{T_E}{T_1}$

$\frac{1}{E} = 1 - \left(\frac{P_2}{P_1}\right)^{.29}$ or, $E = \frac{1}{1 - \left(\frac{P_2}{P_1}\right)^{.29}}$

The last expression for E shows that the efficiency of the Joule cycle depends only on the pressure ratio $\frac{P_2}{P_1}$ and not on the temperatures. To increase the efficiency increase the pressure ratio $\frac{P_2}{P_1}$.

The expression for M shows that the advantage gained by making T_1 lower is decreasing the weight of air per stroke, and consequently the volume of the compressive cylinder.

The values in table I to VI were calculated on the basis of

$Q = 1000$ B.T.U.

$N = 120$, for various values of P_1, P_2 and T_1, the value of T_2 being taken constant at 460.8°F abs. Any horizontal line gives the conditions under which a warming machine must be operated to give the required 1000 B.T.U. per stroke. A large cylinder volume is the objectionable feature of air. The best results are obtained for $P_2 = 100$ or 200 lb. This high initial pressure necessarily makes the upper pressure very high. However, as air has no odor, the leakage resulting

from such high pressures would not perhaps be troublesome

The heating effect of a heating machine delivering 1000 B.T.V. per stroke is equivalent to a direct heating from a steam boiler of a little over 200 boiler horse power. For such small heating effect the H.P. required to run the heating machine as given in the tables will seem too large. But if we consider that our boiler horse power definition is an old one, and that a 200 H.P. boiler will furnish steam for a good modern steam engine of 400 to 500 H.P., the results in the table are not so discouraging.

The Vapor Cycle.— Ammonia as Medium.

Anhydrous ammonia, which is used as a medium in refrigerating machinery very extensively, can also be used to advantage in heating machines, if the upper temperature is not taken too high. Fig. 6 shows

diagrammatically the operation of a heating machine using ammonia as a medium.

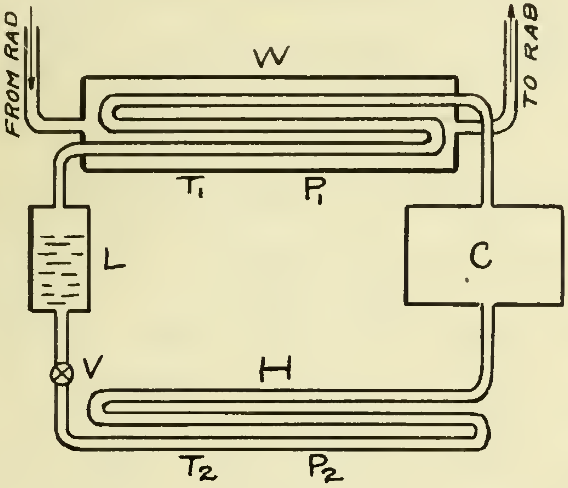


Fig. 6.

The compressor C takes in the saturated ammonia vapor from the coil H at the atmospheric temperature T_2 and pressure P_2, the latter being different from the pressure of the atmosphere. It It compresses it adiabaticaly to pressure P_1 and temperature T_A (Fig. 7); the vapor is now superheated. From the compressor the vapor is discharged into the coils W where the water abstracts the heat from it and transmits it to the radiators. In the coils W the ammonia is first reduced to saturated vapor; then as the

abstraction of heat is going on, the vapor is gradually condensing and trickles into the liquid reservoir L. From the reservoir the liquid ammonia is passed through the expansion valve V into the coils H. As soon as the pressure is reduced, the liquid vaporizes taking the heat necessary for vaporization from the atmosphere at the temperature T_2. From the coils H the vapor is again taken into the compression cylinder and a new cycle is started. Thus by a continuous repetition of the cycles a constant current of heat is made to flow from the atmosphere at the low temperature T_2, into the carrier and the radiator at a higher temperature T_1.

The thermodynamic processes are shown in the vapor cycle (Fig. 7). FA represents adiabatic compression in the cylinder C, AB is the abstraction of the heat ABKH from the superheated vapor at constant pressure P_1, BC is the abstraction of the heat BCGK during the condensation, CDE is the process of passing the ammonia

liquid through the expansion valve, and EF is the process of taking in the heat EFJK from the atmosphere during the vaporization.

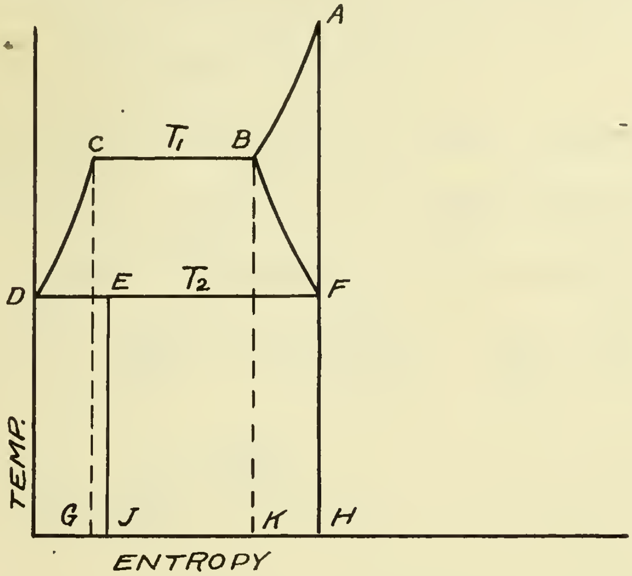


Fig. 7.

The following is a general analysis of the vapor cycle when the heating machine is using ammonia as a medium.

Let Q = required quantity of heat per stroke
N = number of strokes per minute
P_1 = upper pressure in lb. abs.
P_2 = lower " " " "
T_1 = upper temperature in F.° abs.
T_2 = lower " " " "
r_1 = heat of vaporization at T_1
r_2 = " " " " T_2

C_p = specific heat of ammonia vapor at constant pressure.

C_q = specific heat of liquid ammonia.

m = constant analogous to κ for air

M = weight of ammonia per stroke in pounds

W = work done per stroke.

H.P. = horse power required to run the heating machine.

E = efficiency of cycle.

Then $T_A = \left(\frac{P_1}{P_2}\right)^{\frac{m-1}{m}} T_2$

$$Q = HACG = M\left[C_p(T_A - T_1) + r_1\right]$$

$$M = \frac{Q}{C_p(T_A - T_1) + r_1}$$

$$W = M\left[C_p(T_A - T_1) + r_1 + C_q(T_C - T_D) - r_2\right]$$

$$H.P. = \frac{778NW}{33000}$$

$$E = \frac{C_p(T_A - T_1) + r_1}{C_p(T_A - T_1) + r_1 + C_q(T_C - T_D) - r_2}$$

This problem is worked out for the six different values for T_1 as in the case of Carnot cycle, T_2 being taken as constant

at 460.8°F. abs., and the various quantities are given in table VII. The same basis was taken as in the air problem, that is,

$$Q = 1000 \text{ B.T.U. and } N = 120.$$

The values for P_1, P_2, r_1, and r_2 were taken from Woods tables of "Properties of the Saturated Vapor of Ammonia". For $T_1 = 650.8°F$ the values for P_1 and r_1 were computed by formulas given in Wood's Thermodynamics.

$$\log P = 6.2469 - \frac{2200}{T} \qquad (p. 326)$$

$r = 555.5 - .613t - .000219t^2$, where t is temperature above zero Fahrenheit.

(p. 332)

The following values were also taken from Wood's Thermodynamics.

$$C_p = .50836$$

$$C_q = 1.00$$

$$m = 1.292, \qquad \frac{m-1}{m} = .225$$

In table VII any horizontal line gives the condition under which a heating machine using ammonia as a medium, must be operated. The efficiency of the ammonia cycle comes very near to that of the Carnot Cycle. The cylinder volume is small, but for

higher values of T_1 the upper pressure P_1 is too high, which fact forbids the use of ammonia as a medium. Under such high pressures it would be impossible to prevent leakage. Leakage of ammonia even in the most minute amounts, would be always troublesome, on account of its penetrating and unpleasant odor. However, for the two lowest values of T_1 the pressure P_1 is tolerably low, so that if great care were exercised leakage could be prevented. It is also in these two cases, that the efficiency of the cycle is very encouraging.

Sulphur Dioxide as Medium.

Sulphur dioxide which is sometimes used as a medium in refrigerating machinery and waste heat engines, could also be used as a medium in heating machines. It has the same objectionable feature as ammonia, in that it has a very strong and disagreeable odor; its vapor is even more dangerous to

life when inhaled than that of ammonia. Its pressure is not so high for high temperatures, and therefore it may be expected that its volume will be larger to produce the same heating effect as ammonia. It may be stated here that it is impossible to get a medium that would give the required heating effect with a low pressure and a small cylinder volume at the same time. The work that is to be done is the product of pressure and volume, and is fixed. So that by decreasing the pressure we necessarily get a large volume.

The cycle of sulphur dioxide is essencially the same as that of ammonia, and the same general analysis can be used for computing the various values. In table VIII any horizontal line gives the conditions under which a heating machine must be operated when using sulphur dioxide as a medium. For the calculation of the values given in this table the same basis was taken as for the first two media, that is,

$Q = 1000$ B.T.U., and $N = 120$.

Little has been done towards determining experimentaly the properties of saturated vapor of sulphur dioxide for high temperatures. The values ordinarily given in tables are computed by means of a formula which is based on a few experimental values determined at low temperature. The values given for r in Wood's tables of "Properties of Saturated Vapor of Sulphur Dioxide" disagree among themselves, and give absurd results when applied to problems in heating by reversed cycle. The same is true of the values in Peabody's table.

In computing table VIII, the following values were used.

The values of pressure were taken as determined experimentaly by Mr. D. D. Mohler, and presented by Mr. E. F. Miller before the American Society of Mechanical Engineers in paper No. .010, in December 1903.

$C_p = .15482$ – Wood's Thermodynamics p. 357.
$C_q = .40$ " " " "

$\frac{m-1}{m} = .22$ – Peabody

$r_2 = 165.05$ – Woods experimental value

The values of r_2 were determined from the following relation.

Entropy DC + Entropy CB + Entropy BA = Entropy DF. (Fig. 7.)

$$C_q \log_\epsilon \frac{T_C}{T_D} + \frac{r_1}{T_1} + C_p \log_\epsilon \frac{T_A}{T_B} = \frac{r_2}{T_2}$$

Assuming the values for C_p, C_q, $\frac{m-1}{m}$ and r_2 to be correct as given above, the values for r_1 were computed from the given equation. The assumption was made because specific heat is easier to determine than latent heat.

Plates.

Plate I. gives the pressures of saturated vapor of ammonia and sulphur dioxide plotted on temperature as abscissa. The curves show that the pressure increases very rapidly for high temperatures.

Plate II. gives the efficiencies of the four cycles, plotted on the upper temperature T_1 as abscissa. The curve of effi-

ciency of the Carnot cycle runs the highest; next to it is the efficiency of ammonia, and then sulphur dioxide. These three curves should meet for $T_1 = T_2$. All three curves rise very rapidly as T_1 approaches T_2. The efficiency curves of air at constant $\frac{P_1}{P_2}$ are parallel to the axis of abscissa, for, as has been shown the efficiency is constant when $\frac{P_1}{P_2}$ is constant. The meeting point A of the air curve with the Carnot cycle curve shows for what value of T_1 the Joule cycle immerges into the Carnot cycle. For this point the weight of air per stroke would have to be equal to infinity.

Plate III. gives the cylinder volumes plotted on the upper temperature T_1 as abscissa. The curves show that the volumes of ammonia and sulphure dioxide are very nearly constant, while the volume of air decreases rapidly for high values of T_1, and slowly for low values. Only the cases having high initial pressure could be plotted; in other cases the volumes are too large and the points come off the paper.

The Possibilities of Heating by Reversed Cycles.

Before heating by reversed cycles can be put successfully into practice, the high first cost of its installation must be justified by a high efficiency. It has been shown before that the high efficiency of the reversed cycle can be only attained by making the upper temperature low as possible. If T_1 could be taken about 560°F. abs., ammonia could be used as a medium; this would insure an efficiency of 4.5 or 5. In our present steam heating system the temperature is above 212°F., and in the hot water system about 180°F. Now, the question is, can we make the temperature of our radiators as low as 95°F.? If we use such low temperature, the velocity of radiation will be reduced and we must provide a large radiating surface, in order that the same quantity of heat should be radiated in a given time as before.

A similar case in hydrolics will

perhaps make this point clearer.

Suppose it is required to fill a tank with water from a reservoir located at some hight above the tank. The reservoir is constantly kept full of water by a steam pump. If we have only a small pipe to take the water from the reservoir down into the tank, the velocity of the water must be very high in order that a required quantity of water can be delivered in a given time. This high velocity of water requires the reservoir to be very high above the level of the tank. If however, we provide a large main, only a small difference in levels will be required to deliver the same quantity of water as before. If in both cases the same results can be obtained, why not to take the second case, and save the work of pumping the water the extra hieght to produce the necessary velocity head through the small pipe?

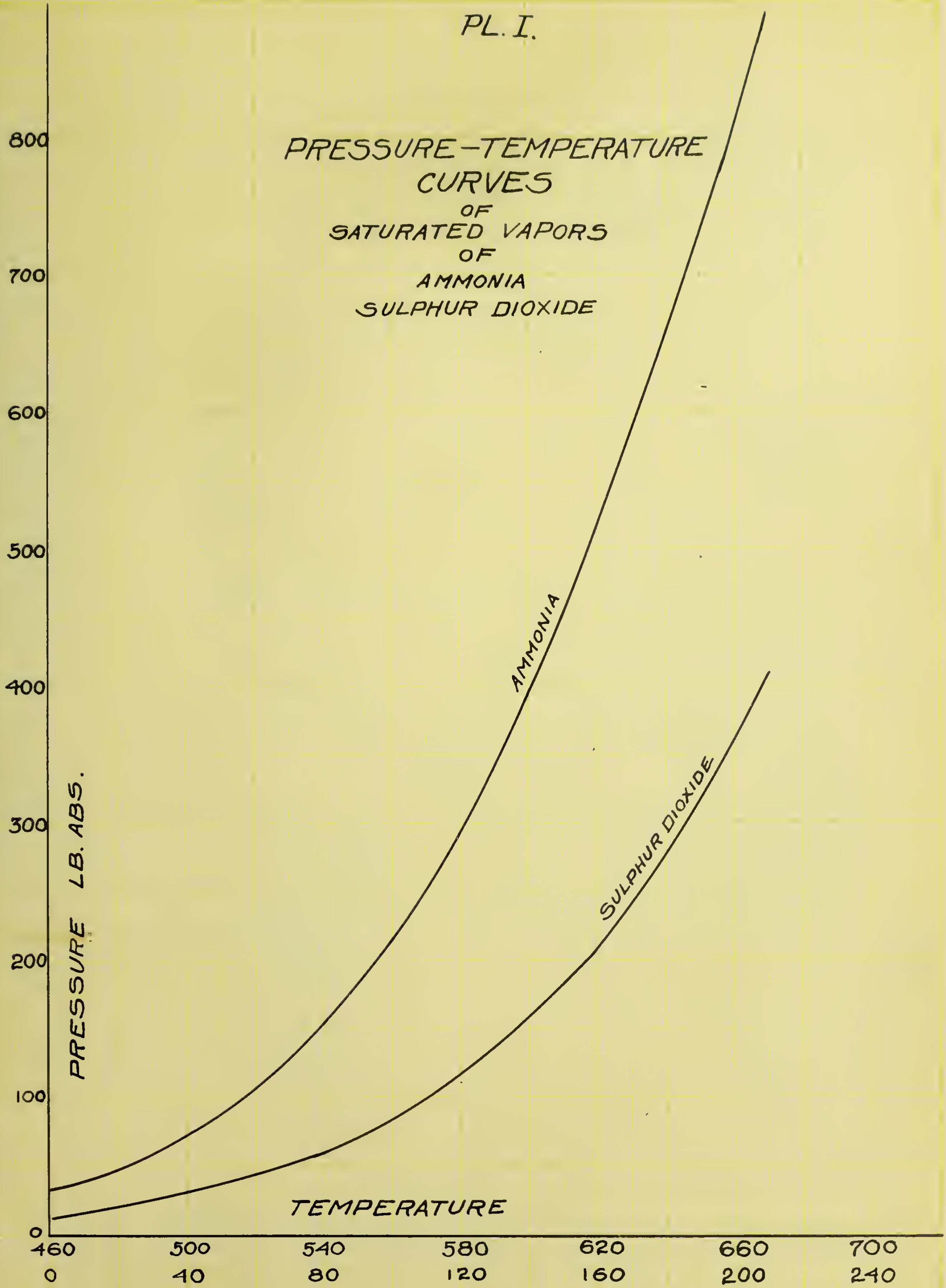
Returning to our heating system, why should we pump the heat 100 or more degrees above the temperature level of the room, and then let it fall down through

a small radiating surface? Why not to use a large radiating surface and pump the heat only a few degrees above the temperature level of the room, thus saving ourselves the work of pumping the heat the extra 100 degrees?

In the present form of radiators it would be difficult to increase the radiating surface sufficiently, without ~~without~~ making the radiators to take up much room. The problem could be solved in another way. Why not do away with radiators altogether, and make the walls and perhaps the floor of heat conducting material and use them for radiators? How much more comfortable it would be in such a room: the temperature would be more uniform, there being no intense heat radiated from one corner and a chill in another; we could then lean against the radiator without the fear of blistering. Of course this would require a change in building construction, and the remodeling of our present buildings.

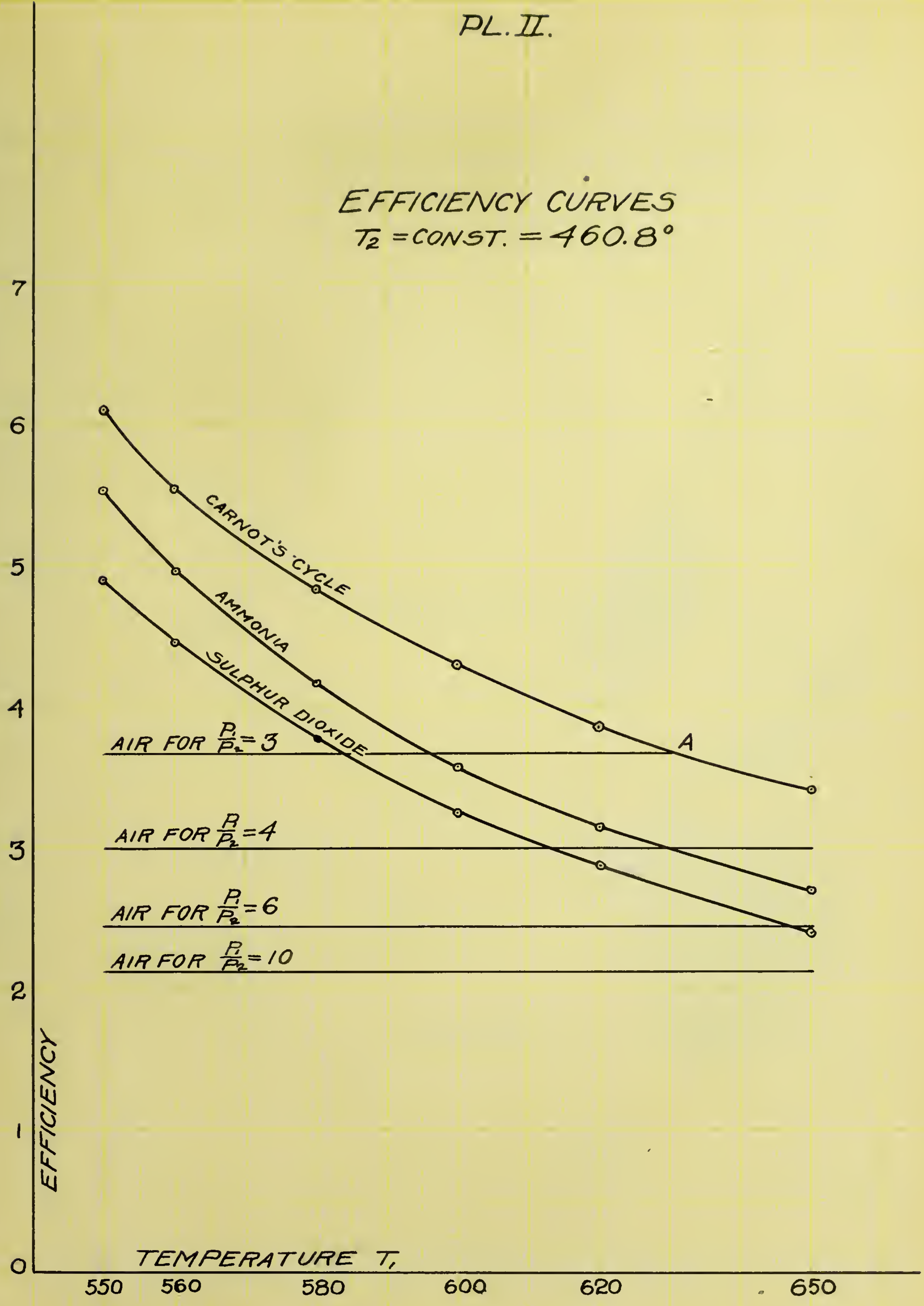
But, if we think of the development of our modern fire proof buildings we shall admit that such changes are possible.

PL. I.



PRESSURE-TEMPERATURE CURVES OF SATURATED VAPORS OF AMMONIA SULPHUR DIOXIDE

PL. II.



EFFICIENCY CURVES
T_2 = CONST. = 460.8°

PL. III.

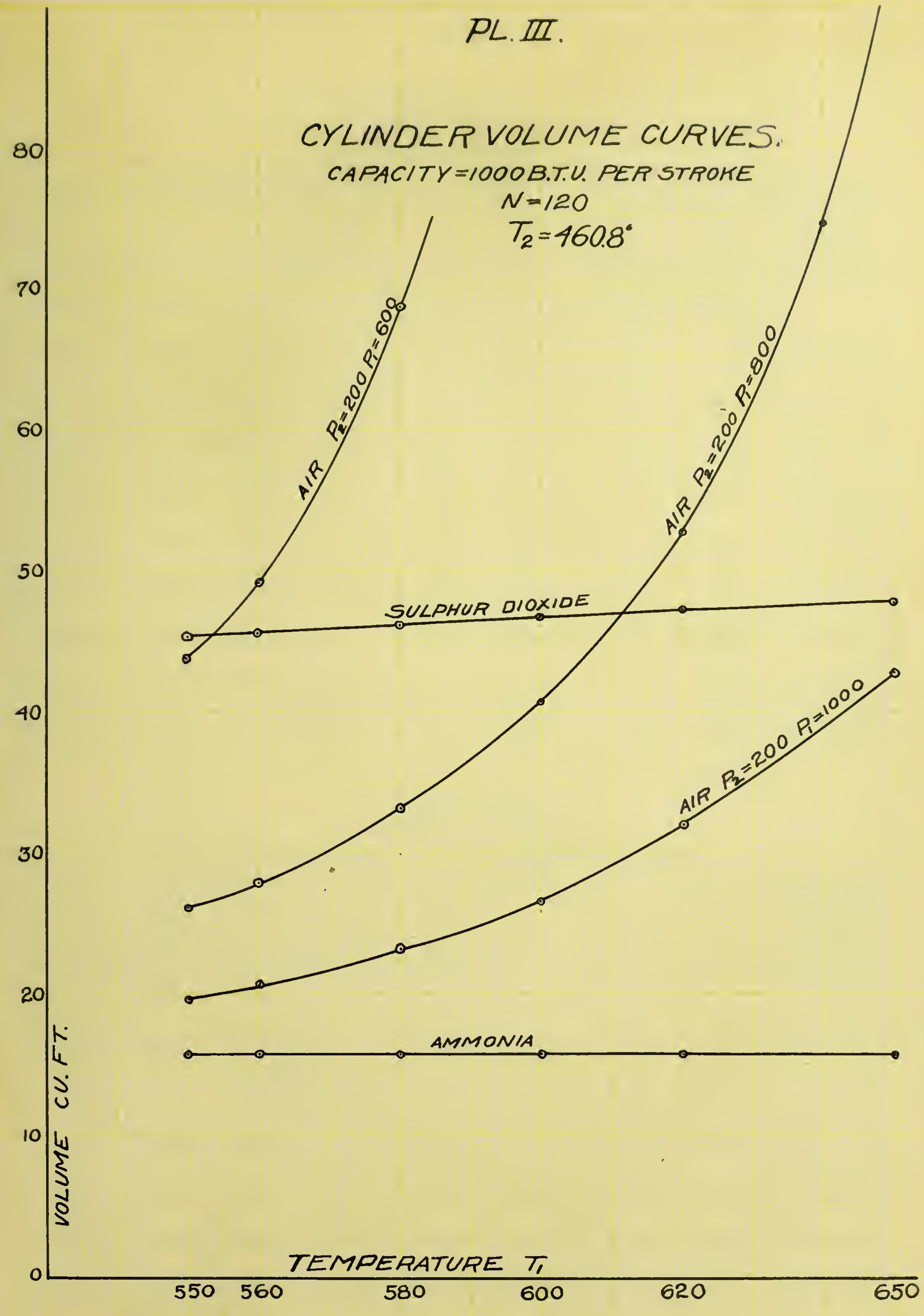

CYLINDER VOLUME CURVES.
CAPACITY = 1000 B.T.U. PER STROKE
N = 120
$T_2 = 460.8°$
AIR $P_2 = 200$ $P_1 = 600$
AIR $P_2 = 200$ $P_1 = 800$
AIR $P_2 = 200$ $P_1 = 1000$
SULPHUR DIOXIDE
AMMONIA
VOLUME CU. FT.
TEMPERATURE T_1
0
10
20
30
40
50
60
70
80
550
560
580
600
620
650

TABLE I.

AIR AS MEDIUM

$T_1 = 650.8°F. ABS.$ $T_2 = 460.8°F. ABS.$

T_A F.°ABS.	T_E F.°ABS.	P_1 LB.ABS.	P_2 LB.ABS.	M LB.	E	H.P.	VOL. CU.FT.	SIZE OF CYL. DIA.X ST. FT.
803.	373.	100	14.7	27.65	2.35	1195	320.0	
982.5	305.	200	14.7	12.7	1.89	1490	147.0	5X7.5
1108.	271.	300	14.7	9.45	1.72	1625	109.1	4.5X6.9
1200.	249.8	400	14.7	7.2	1.63	1740	88.6	4X7.1
689.	436.	400	100	112.0	3.00	995	188.0	5X9.6
775.	387.	600	100	33.9	2.47	1150	57.8	3.5X6
841.	356.4	800	100	22.2	2.21	1280	37.8	3X5.3
899.	334.	1000	100	16.9	2.15	1390	29.0	3X4.2
689.	436.	800	200	112.0	3.00	995	94.0	4.5X5.8
735.	410.	1000	200	50.1	2.66	1124	42.6	3.5X4.4

TABLE II.

AIR AS MEDIUM

$T_1 = 620.8°F. ABS.$ $T_2 = 460.8°F. ABS.$

T_A F.°ABS.	T_E F.°ABS.	P_1 LB.ABS.	P_2 LB.ABS.	M LB.	E	H.P.	VOL. CU.FT.	SIZE OF CYL. DIA.X ST. FT.
803.	336.	100	14.7	23.15	2.35	1210	267.5	6X9.5
982.5	290.5	200	14.7	11.65	1.89	1500	134.0	5X6.8
689.	416.	400	100	62.0	3.00	973	105.4	4.5X6.6
775.	369	600	100	27.35	2.47	1145	46.5	3.5X4.8
841.	340	800	100	19.1	2.21	1270	32.4	3X4.5
899.	318.5	1000	100	15.1	2.15	1378	25.8	3X3.7
689.	416.	800	200	62.0	3.00	973	52.6	3.5X5.5
735.	389.	1000	200	36.9	2.66	1055	31.9	3X4.6

TABLE III.

AIR AS MEDIUM
$T_1 = 600.8°$ F. ABS. $T_2 = 460.8°$ F. ABS.

T_A F.° ABS.	T_E F.° ABS.	P_1 LB. ABS.	P_2 LB. ABS.	M LB	E	H.P.	VOL. CU. FT.	SIZE OF CYL. DIA X ST. FT.
657.	421.	50	14.7	75.3	3.34	827	870	
803.	344.5	100	14.7	20.84	2.35	1205	241	6 X 8.6
982.5	281.	200	14.7	11.03	1.89	1495	128	5 X 6.5
689.	401.	400	100	47.9	3.00	915	81.0	4.5 X 4.9
775.	356.5	600	100	24.2	2.47	1135	41.2	3.5 X 4.3
841	328.	800	100	17.45	2.21	1265	29.9	3 X 4.25
899	308.	1000	100	14.15	2.15	1380	24.1	3 X 3.4
689	401.	800	200	4.79	3.00	915	40.7	3.25 X 4.7
735	377	1000	200	31.4	266	1050	26.7	3 X 3.8

TABLE IV.

AIR AS MEDIUM
$T_1 = 580.8°$ F. ABS. $T_2 = 460.8°$ F. ABS.

T_A F.° ABS.	T_E F.° ABS.	P_1 LB. ABS.	P_2 LB. ABS.	M LB	E	H.P.	VOL. CU. FT.	SIZE OF CYL. DIA X ST. FT.
657.5	417.	50	14.7	63.4	3.34	970	734.	
803.	333.	100	14.7	19.0	2.35	1200	220.	6 X 78
633.	422.	300	100	80.8	3.65	753	137.3	5 X 7
689	388.5	400	100	38.9	3.00	945	66.0	3.5 X 6.8
734.5	364.	500	100	27.4	2.66	1050	47.0	3.25 X 5.5
775.	345.	600	100	21.7	2.47	1147	36.8	3 x 5.2
633.	422.	600	200	80.9	3.65	753	68.6	3.5 X 7.1
689	388.5	800	200	38.9	3.00	945	33.1	3 X 4.7

TABLE V.

AIR AS MEDIUM

$T_1 = 560.8$°F. ABS. $T_2 = 460.8$°F. ABS.

T_A F.° ABS.	T_E F.° ABS.	P_1 LB. ABS.	P_2 LB. ABS.	M LB.	E	H.P.	VOL. CU. FT.	SIZE OF CYL. DIA.×ST. FT.
615	420	40	14.7	77.8	4.01	705	900	
657.5	393	50	14.7	43.7	3.34	854	506	8 X 10.1
803.	322	100	14.7	17.4	2.35	1210	201	5.5X8.5
601.	430	250	100	105	4.28	660	178	5.5X7.5
633.	408	300	100	58.5	3.65	757	99.5	4.5X5.9
689.	375	400	100	33.95	3.00	935	55.1	3.5X5.3
734.5	353	500	100	24.3	2.66	1070	41.0	3 X 5.8
601	430	500	200	105.	4.28	660	89.5	4.5X5.3
633	408	600	200	58.5	3.73	757	49.2	3.5X5.7

TABLE VI.

AIR AS MEDIUM.

$T_1 = 550.8$°F. ABS. $T_2 = 460.8$°F. ABS.

T_A F.° ABS.	T_E F.° ABS.	P_1 LB. ABS.	P_2 LB. ABS.	M LB	E	H.P.	VOL. CU. FT.	SIZE OF CYL. DIA.×ST. FT.
615	412.5	40	14.7	65.9	4.01	701	760	
657.5	387.	50	14.7	39.6	3.24	874	458	7.5X10.5
803	316	100	14.7	16.74	2.35	1210	192	5.5X8.1
601	422	250	100	84.1	4.27	644	144	5.X7.3
633	400.5	300	100	51.4	3.65	756	87.5	4X6.9
689	368.5	400	100	30.6	3.00	939	52.	3.5X5.5
734.5	346.5	500	100	23.0	2.66	1070	39.	3 X 5.5
601	422.	500	200	84.1	4.27	644	71.5	4 X 5.9

TABLE VII.

AMMONIA AS MEDIUM.

T_1 F.°ABS.	T_2 F.°ABS.	T_A F.°ABS.	P_1 LB.ABS.	P_2 LB.ABS.	M LB.	E	H.P.	VOL. CU.FT.	SIZE OF CYL. DIA.X.ST. FT.
650.8	460.8	944	729.3	30.37	1.724	2.7	1050	15.57	2.25X3.8
620.8	460.8	870	514.4	30.37	1.73	3.15	896	15.68	2.25X3.8
600.8	460.8	820	392.2	30.37	1.735	3.58	792	15.75	2.25X3.8
580.8	460.8	766	293.5	30.37	1.742	4.17	677	15.78	2.25X3.8
560.8	460.8	715	215.14	30.37	1.75	4.97	570	15.82	2.25X3.8
550.8	460.8	689	18.28	30.37	1.76	553	516	15.88	2.25X3.8

TABLE VIII.

SULPHUR DIOXIDE AS MEDIUM.

T_1 F.°ABS.	T_2 F.°ABS.	T_A F.°ABS.	P_1 LB.ABS.	P_2 LB.ABS.	M LB	E	H.P.	VOL. CU.FT.	SIZE OF CYL. DIA.X.ST. FT
650.8	460.8	976	314.3	10.3	6.55	2.4	1184	47.65	3.5X4.9
620.8	460.8	893	209.5	10.3	6.43	2.84	998	47.2	3.5X4.9
600.8	460.8	839	157.6	10.3	6.35	3.24	871	46.6	3.5X4.9
580.8	460.8	785	116.08	10.3	6.27	3.76	750	46.05	3.5X4.9
560.8	460.8	731	84.38	10.3	6.20	4.45	637	45.6	3.5X4.8
550.8	460.8	705	71.2	10.3	6.16	4.89	578	45.3	3.5X4.8