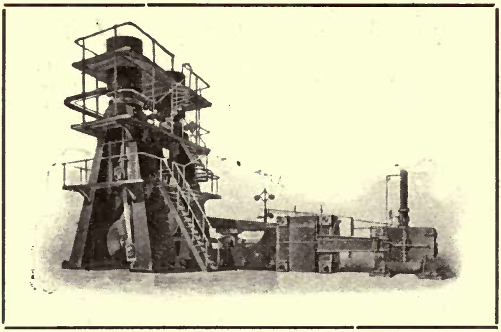
Indicating The Refrigerating Machine



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INDICATING

THE

REFRIGERATING MACHINE

THE APPLICATION OF THE INDICATOR TO THE AMMONIA COMPRESSOR AND STEAM ENGINE, WITH PRACTICAL INSTRUCTIONS RELATING TO THE CONSTRUCTION AND USE OF THE INDICATOR AND READING AND COMPUTING INDICATOR CARDS

BY

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BOSTON, MASS.

CHICAGO
H. S. RICH & CO.
1899

Press of
ICE AND REFRIGERATION,
CHICAGO.

PREFACE.

Often while plotting the adiabatic curve on an indicator card taken from an ammonia compressor, I have wished to shorten the time required and simplify the process. This led to working out the constants in Table No. 1. Having these constants, Table No. 2 naturally suggested itself to still further simplify the work. In addition to this I have added such other matter as seemed pertinent to a work of this character, hoping to place before the reader all necessary references for one who may have to work up indicator cards taken from an ammonia compressor. If my reader appreciates the value of the adiabatic curve after looking through this work, and learns to use Table No. 2, I feel that my aim will have hit the mark.

G. T. V.

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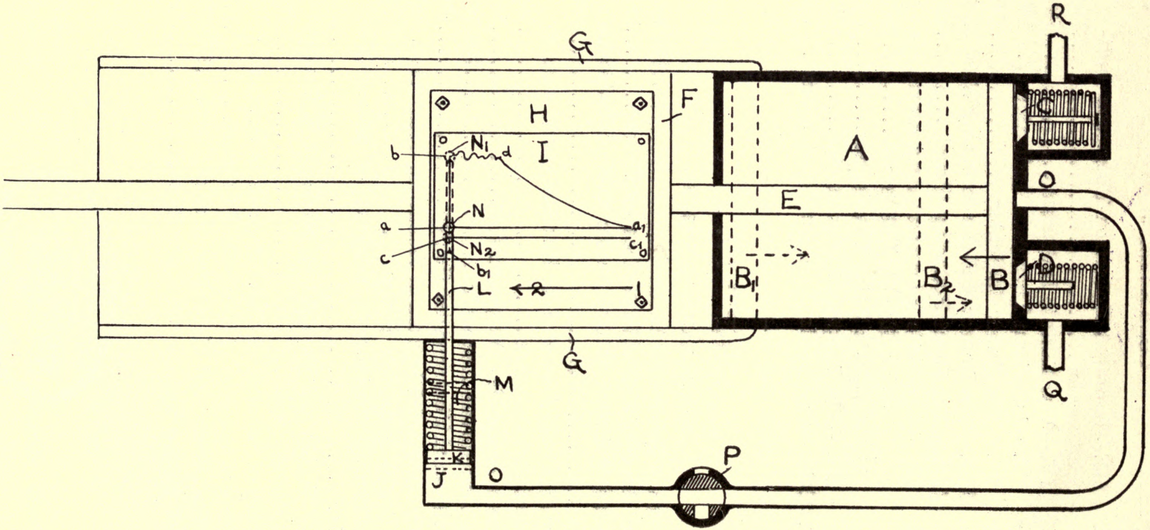

Fig 1a

INDICATING

THE

REFRIGERATING MACHINE

PART I.

INDICATING THE AMMONIA COMPRESSOR.

CHAPTER I.

THE ELEMENTARY INDICATOR.

For the convenience of those who are not familiar with the principle of the indicator, but may wish to look through this book, I will give an elementary description of the principles involved. I sincerely hope that thus I may be able to bring this work understandingly before those who are interested in or own compressors, but who have not had a technical education.

In Fig. 1*a*, shown on opposite page, let *A* be the compressor cylinder; *B* the piston; *C* the suction valve; *D* the discharge valve; *E* the piston rod; *F* the cross-head; *G G* cross-head guides; *H* a board made fast to the cross-head; *I* a piece of paper called an indicator card blank, which is tacked to board *H*; *J* a small cylinder, having piston *K* and piston rod *L*, compression spring *M*; *N* pencil carried by piston rod *L*; *O O* pipe leading from cylinder *A* to cylinder *J*; *P* cock that may connect cylinders *A* and *J*, or shut off *A* from *J*, at the same time leaving cylinder *J* open to the atmospheric pressure.

Now we will suppose pencil *N* to press against paper *I*, and cross-head *F* to move in the direction 1, 2. Evidently the pencil *N* will trace the straight line $a a_1$ on paper *I*. Now whatever pressure exists in cylinder *A* must also be in cylinder *J*, being transmitted through the pipe *O O*. Suppose now the pencil *N* at position *c* representing atmospheric pressure in cylinder *A*, then allow pressure in cylinder *A* to gradually increase, the cross-head *F* remaining fixed in position. It is evident that this pressure will move piston *K*, compress spring *M* and trace the line *c b* with pencil *N*. Then if the pressure in cylinder *A* is reduced the piston *K* will return to its original position by virtue of spring *M*. Now suppose spring *M* to be so constructed that one pound per square inch pressure in cylinder *A* will compress it .01 of an inch and that 100 pounds per square inch will compress it one inch; it will be evident that every .01 of an inch of line *a b* represents one pound per square inch pressure in cylinder *A*. If *a b* is .75 inches long, then the pressure in cylinder *A* is seventy-five pounds.

If cock *P* is so turned as to open cylinder *J* to the air, when the cross-head *F* moves, it will cause pencil *N* to trace line $c c_1$, called the atmospheric line. All vertical distances above this line will represent pressures above the atmosphere. All vertical distances below this line will represent pressures below the atmosphere. The pressure of the atmosphere is 14.7 pounds per square inch. Should a perfect vacuum be found in cylinder *A*, then pencil *N* would go to b_1, b_1 representing to scale, by its vertical distances from line $c\,c_1$, 14.7 pounds per square inch pressure. Now it should be clear that any variation of pressure in cylinder *A* will either raise or lower pencil *N* in relation to line $c\,c_1$, and that any motion of the cross-head *F* will move the paper so that the pencil *N* will vary its horizontal distance from line $b\,b_1$. As the cross-head *F* moves with the same motion as that of piston *B* it is evident that all points at a horizontal distance from line $b\,b_1$ represent different positions of piston *B*, and all vertical distances from line $c\,c_1$ represent pressures in cylinder *A* on piston *B* at these positions.

Now let us see how the indicator pencil will act under an actual test. Let us suppose that piston *B* has just started in the direction of the full arrow. Then pencil *N* at point *a* shows the beginning of piston's stroke and pressure *c a*, which is the back pressure (gauge). As the piston *B* moves forward the gas flows into cylinder *A* through suction valve *C* at the constant back pressure from the expansion chamber through pipe *R*, and the pencil traces the line $a\,a_1$.

Now the piston *B* having reached the end of its stroke, B_1, starts back in the direction of the dotted arrow. In doing this it begins to compress the gas in the cylinder *A*, thus closing suction valve *C;* and as the pressure in cylinder *A* becomes more and more, the pencil traces the curved line $a_1\,d$ (the compression curve). When the piston reaches the position, B_2, corresponding with the pencil point *d*, the pressure in cylinder *A* is a little greater than that transmitted by pipe *Q* from condenser to the discharge valve *D*. From this position the piston discharges the gas past the discharge valve to the end of the stroke, the pencil in the meanwhile tracing the wavy, peaked line, *d b*. The reason for the unevenness of this line is the chattering of the discharge valve *D*. The piston *B* now having reached its original position, starts to go back in the other direction (that of the full arrow) again. Now the discharge valve *D* closes, due to the condenser pressure, and the pressure in cylinder *A* falls to that due to the suction or back pressure. As this change takes place while the piston *B* is changing its motion from forward to backward, the cross-head moves only a very small amount, and a nearly vertical line, *b a*, is traced by the pencil *N*.

We have now followed the pencil through its travels, and the resulting diagram, $a\ a_1\ d\ b\ a$, is the desired indicator diagram. This same explanation can apply to a steam card by going around the diagram the other way; $b\ d\ a_1\ a\ b$ will be a steam engine card, except that the line *b d* will be more smooth, the line $d\ a_1$ will represent the expansion line, *d* the point of cut-off, and $a_1\ a$ the exhaust line. The practical forms of indicators, such as are used to-day, do not differ in principle from this elementary form; they differ only in detail. The card *I* is carried on an oscillating drum, which is oscillated by a cord from the cross-head. The pencil is carried by a straight line multiplying device. Another chapter gives full description of the various standard makes of indicators, so I will not go farther into the subject of the construction of the indicator at this point.

CHAPTER II.

THE VALUE OF INDICATING A COMPRESSOR.

In this chapter I will try to demonstrate the value of indicating an ammonia compressor, of doing it regularly, and knowing how to correctly interpret the meaning of the indicator card. I have known men who were well up on indicator practice, and who are intelligent engineers, to let a compressor run for months, when a very little knowledge of such methods as I hope to set forth would have saved a great amount of worry in regard to the quality of work being done, and a good many hundred dollars of expense on coal bills.

All competent engineers know the names of the various lines and are familiar with the general appearance of the indicator card. They know that the admission line is parallel to the atmospheric line. The compression line rises in an easy curve to the discharge line. The discharge line is usually wavy or peaked, due to the vibration of the discharge valves. The admission and discharge lines should be joined by a nearly vertical line. The card should have a square heel. We know that this square heel indicates the amount of clearance.

In Fig. 1 the card has a square heel at *a*, consequently you say, "The clearance is small." If the card had been like Fig. 2, you would say, "Very bad; too much clearance," and you would overhaul your compressor and make the clearance what it should be. How many engineers

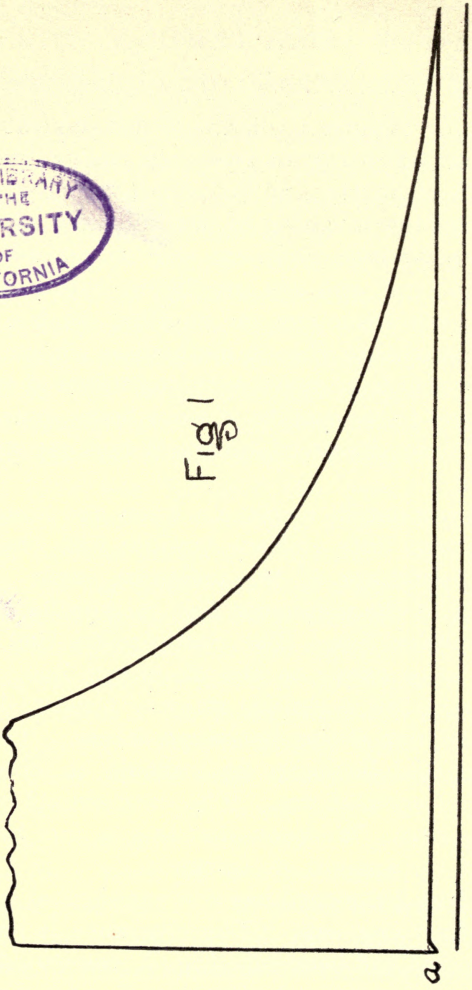

Fig 1

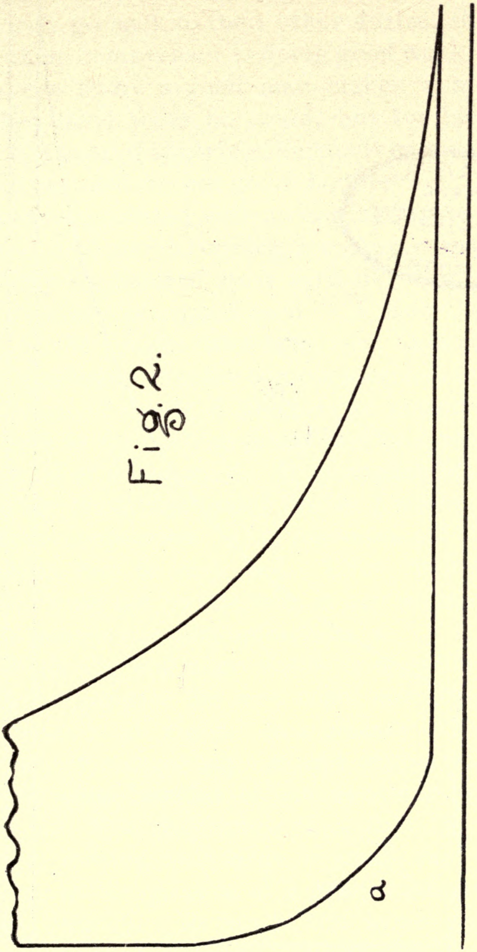

Fig. 2.

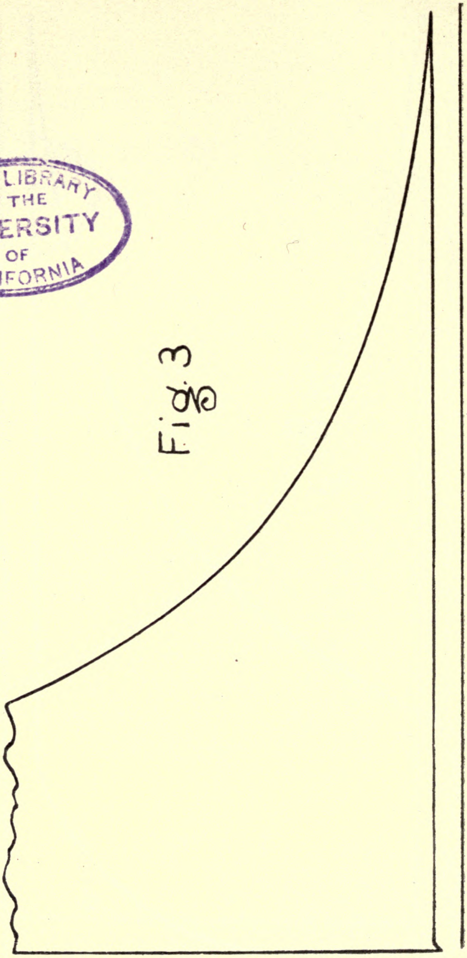

Fig 3

go any farther than this? They take a card like Fig. 1, look at it, see that it has a good square heel, and say, "This is a good card." As a result they go back to their other duties, thinking that their compressor is doing good work. Here is where many a good man makes a mistake. He has done what he could, but for lack of a practical way of applying thermodynamic reasoning to his card he can go no farther.

I am acquainted with an engineer who knows a great deal about running a compression plant. One day he handed me a card like Fig. 3. He said, "Here is a good card." I took the card, applied the simple rules to it, that I am about to give, and found that the compressor was in a very bad way. I doubt if there is an engineer who can look at the card as given in Fig. 3, and say it is a good or a bad card. It is impossible to tell whether the compression line is good or bad by a simple inspection. One may notice if the compression line is very bad. Even then I think there would not be one man in a great many that could pass a valuable opinion on it.

What the engineer needs is a guide, something to compare his card with; something that he knows is all right. In a picture or diagram the way of comparing size and proportion is by having some familiar object, as a man, for comparison. You may know then that the bridge you are looking at is large or small, that you are looking at the picture of a great cathedral or a small church. In much the same way it is necessary to have your comparison on an indicator card.

This comparison or guide is the *adiabatic*

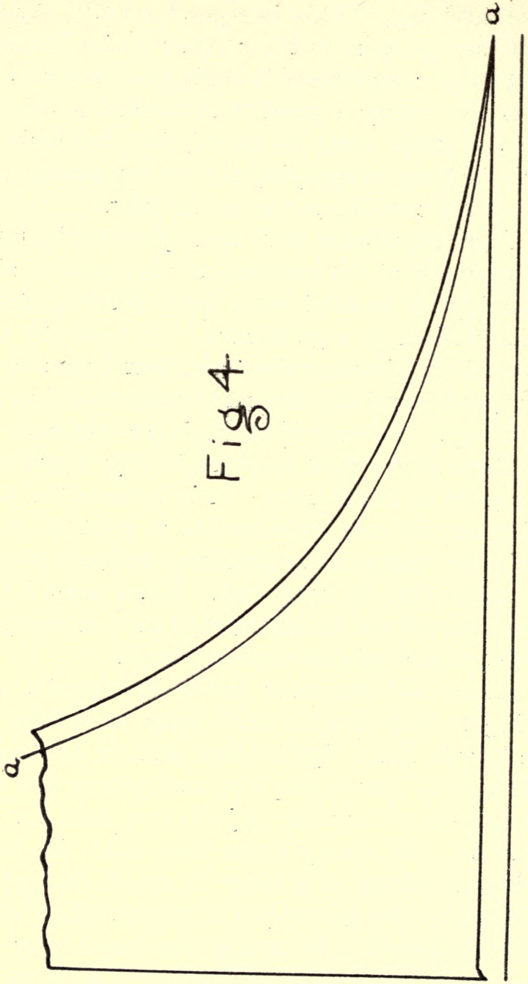

Fig 4.

line. The isothermal line is interesting, and also serves as a guide, but it is a poor guide. One cannot draw sound conclusions in all cases from the isothermal line's relation to the compression curve, as traced by the indicator pencil. The adiabatic line is the true guide. The calculation of this adiabatic line necessitates the use of logarithms in calculating the fractional powers of numbers. This may be difficult for some engineers to do. Even our best engineers will find that it is no small matter to figure the adiabatic line for an indicator card. They can do it easily enough, no doubt, but it will take much more valuable time than they usually have to devote to it. Consequently, I believe that if I set forth a simple and practical way of obtaining this line, engineers will, by using this method, be able to get much better work out of their machines. The owners of plants will also save money that is needlessly wasted at present.

I reproduce Fig. 3 here in Fig. 4, having drawn the adiabatic line *a a* on the card. This card, that looked so good to my friend the engineer, is now shown to be very bad. I told him that probably the cylinder gasket between the discharge port and the cylinder was blown out. (The reasoning for this will be given later.) Upon an examination of the compressor this was found to be the case. The machine, I am sorry to say, had been running for a long time in this condition. Being a large machine, it had needlessly wasted a good deal of money while thus running.

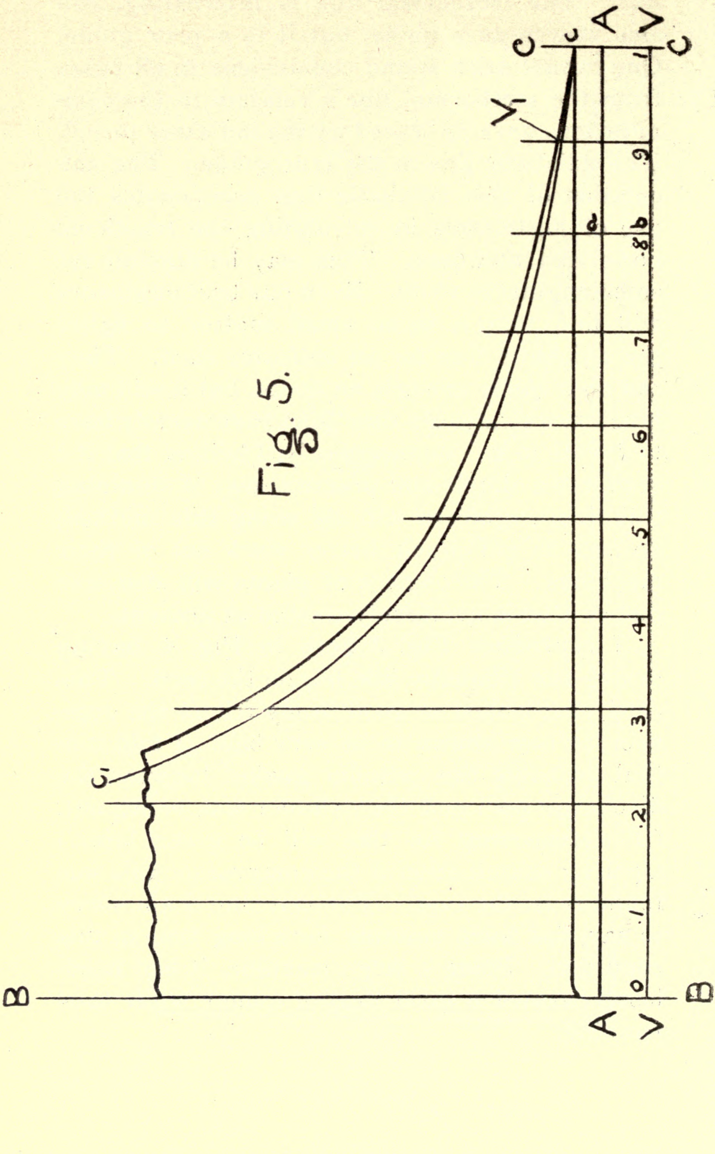

Fig. 5.

CHAPTER III.

THE ADIABATIC CURVE.

An adiabatic line is a curve that represents the adiabatic expansion or compression of a gas or vapor. Adiabatic expansion or compression is the expansion or compression of a gas or vapor, without loss or gain of heat. It is expressed by $p v^{\frac{c_p}{c_v}} = p_1 v_1^{\frac{c_p}{c_v}}$ where $p =$ initial pressure, $v =$ initial volume, $p_1 =$ final pressure, $v_1 =$ final volume, $c_p =$ specific heat at constant pressure, $c_v =$ specific heat at constant volume. $\frac{c_p}{c_v}$ is called the ratio of specific heats; for ammonia gas it is $\frac{.508}{.3913} = 1.3$ $\therefore$ $p v^{1.3} = p_1 v_1^{1.3}$. That is, the initial pressure times the 1.3 power of the initial volume is equal to the final pressure times the 1.3 power of the final volume, p and p_1 being absolute pressures.

In Fig. 5 the atmospheric line *A A* is the line drawn by the indicator pencil when the indicator cock is so turned that the atmospheric pressure is on both sides of the indicator piston. Measure off perpendicular to and below *A A* the distance *a b*, equal to the atmospheric pressure, 14.7 pounds, using the same scale as that of the indicator spring. Draw a line through *b* parallel to *A A*. This line is the vacuum line *V V*. Draw lines *B B* and *C C*, perpendicular to the atmospheric line *A A*, and tangent to or touching the extreme right and left hand portions of the diagram. I disregard the clearance, as being too small to appreciably affect the results to be obtained. All pressures must be measured at right angles from the vacuum line $V V$. The pressures are then the true or absolute pressures.

Now divide line $V V$ into ten equal parts. The point where the right hand end of the diagram cuts the line $C C$ at c is the point of the beginning of the compression. The vertical distance from c to $V V$ is the absolute back pressure when measured on the same scale as that of the indicator spring.

Let $p =$ the absolute back pressure, as measured from the vacuum line $V V$ to c. At the beginning of the compression, as the cylinder is full of gas, v can be called 1. The most convenient point from which to draw the adiabatic line will be from the point of the beginning of compression, or where $v = 1$. Now as $1^{1.3} = 1$, we have $p \times 1 = p_1 v_1{}^{1.3}$ or $p_1 = \frac{p}{v_1{}^{1.3}}$; p_1 is the ordinate (or vertical distance from $V V$) of any point, V_1, on the adiabatic line for a corresponding abscissa (or horizontal distance on $V V$ from $C C$), p being the absolute back pressure under consideration, and v_1 varying from 1 to 0.

The divisions of $V V$ are now marked, as shown on Fig. 5, viz.: .9, .8, .7, .6, .5, .4, .3, .2, .1 and 0. These points on $V V$ indicating that the volume at these points is either .9, .8, .7 to .1 or 0, as the case may be.

$.1^{1.3}$ = the number which = 1.3 × logarithm of .1.

Log. .1 = 9.000000 − 10
1.3 multiply by 1.3
11.700000 − 13
−3 +3 add and subtract 3
8.700000 − 10 = log. of .05
$\therefore$ $.05 = .1^{1.3}$

$$
\begin{array}{rl}
\text{Log. } .2 = 9.301030-10 & \\
1.3 & \text{multiply by 1.3} \\
\hline
27903090 & \\
9301030 & \\
\hline
12.0913390-13 & \\
-3 \qquad\qquad +3 & \text{add and subtract 3} \\
\hline
9.0913390-10 = \text{log of } .123 & \\
\therefore\ .123 = .2^{1.3} &
\end{array}
$$

In like manner:

TABLE NO. 1.

$.1^{1.3} = .050$
$.2^{1.3} = .123$
$.3^{1.3} = .209$
$.4^{1.3} = .304$
$.5^{1.3} = .406$
$.6^{1.3} = .514$
$.7^{1.3} = .629$
$.8^{1.3} = .748$
$.9^{1.3} = .871$

Now, having the values of $.1^{1.3}$ to $.9^{1.3}$ we can find values for $p_{.1}$, $p_{.2}$, $p_{.3}$ to $p_{.9}$, by substituting the corresponding values of $v_{.1}$, $v_{.2}$ to $v_{.9}$ in formula $p_1 = \frac{p}{v_1^{1.3}}$

$$p_{.9} = \frac{p}{v_{.9}^{1.3}}$$

$$p_{.8} = \frac{p}{v_{.8}^{1.3}}$$

$$p_{.7} = \frac{p}{v_{.7}^{1.3}}$$

$$p_{.6} = \frac{p}{v_{.6}^{1.3}}$$

$$p_{.5} = \frac{p}{v_{.5}^{1.3}}$$

$$p_{.4} = \frac{p}{v_{.4}^{1.3}}$$

$$p_{.3} = \frac{p}{v_{.3}^{1.3}}$$

$$p_{.2} = \frac{p}{v_{.2}^{1.3}}$$

$$p_{.1} = \frac{p}{v_{.1}^{1.3}}$$

TABLE NO. 2.

ADIABATIC CONSTANTS.

p.	15	16	17	18	19	20	21	22	23	24
p.9	17.2	18.4	19.5	20.6	21.8	22.9	24.1	25.2	26.4	27.6
p.8	20.0	21.4	22.7	24.3	25.4	26.7	28.1	29.4	30.7	32.1
p.7	24.9	25.4	27.0	28.6	30.2	31.8	33.4	35.0	36.5	38.1
p.6	29.2	31.1	33.1	35.0	36.9	38.6	40.8	42.8	44.7	46.7
p.5	37.0	39.5	41.8	44.4	46.8	49.3	51.8	54.3	56.7	59.2
p.4	49.3	52.7	56.8	59.2	62.5	65.8	69.1	72.4	75.7	79.0
p.3	71.7	76.5	81.3	86.1	90.8	95.6	100.3	105.2	110.0	114.8
p.2	122.0	130.0	138.2	146.3	154.5	162.7	170.6	178.9	187.0	195.1
p.1	300.0	320.0	340.0	360.0	380.0	400.0	420.0	440.0	460.0	480.0
p.	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**
p.9	28.7	29.8	31.0	32.1	33.2	34.4	35.6	36.7	37.9	39.0
p.8	33.4	34.7	36.1	37.4	38.8	40.1	41.4	42.8	44.1	45.4
p.7	39.7	41.3	42.8	44.5	46.2	47.7	49.3	50.8	52.4	54.0
p.6	48.7	50.6	52.5	54.4	56.4	58.3	60.3	62.2	64.2	66.2
p.5	61.7	64.2	66.6	69.1	71.5	74.0	76.4	78.8	81.4	83.8
p.4	82.3	85.5	88.8	92.2	95.4	98.5	102.0	105.2	108.6	111.8
p.3	119.6	124.2	129.0	133.9	138.7	143.4	148.2	153.0	157.8	162.5
p.2	203.2	211.4	219.4	227.8	235.8	244.0	252.0	260.0	268.2	276.3
p.1	500.0	520.0	540.0	560.0	580.0	600.0	620.0	640.0	660.0	680.0
p.	**35**	**36**	**37**	**38**	**39**	**40**	**41**	**42**	**43**	**44**
p.9	40.2	41.3	42.5	43.6	44.7	45.9	47.1	48.2	49.3	50.5
p.8	46.8	48.1	49.4	50.8	52.1	53.4	54.8	56.1	57.4	58.8
p.7	55.6	57.2	58.8	60.4	62.0	63.6	65.2	66.7	68.3	69.8
p.6	68.0	70.0	71.9	73.8	75.8	77.8	79.7	81.6	83.6	85.5
p.5	86.3	88.7	91.2	93.7	96.2	98.7	101.0	103.5	106.0	108.3
p.4	115.1	118.4	121.7	125.0	128.2	131.6	135.0	138.1	141.5	144.7
p.3	167.3	172.1	177.0	181.6	186.5	191.2	196.0	200.8	205.8	213.0
p.2	284.7	292.7	300.7	309.0	317.0	325.0	333.4	341.2	349.2	357.8
p.1	700.0	720.0	740.0	760.0	780.0	800.0	820.0	840.0	860.0	880.0
p.	**45**	**46**	**47**	**48**	**49**	**50**	**51**	**52**	**53**	**54**
p.9	51.7	52.7	53.9	55.1	56.2	57.4	58.5	59.7	60.8	62.0
p.8	60.2	61.5	62.8	64.1	65.4	66.8	68.1	69.4	70.8	72.1
p.7	71.5	73.1	74.7	76.3	77.8	79.5	81.0	82.6	84.2	85.8
p.6	87.5	89.4	91.4	93.3	95.2	97.2	99.1	101.0	103.0	105.0
p.5	110.8	113.2	115.8	118.2	120.5	123.0	125.6	128.0	130.6	133.0
p.4	148.0	151.3	154.6	158.0	161.2	164.5	167.7	171.0	174.3	177.6
p.3	215.0	220.0	224.8	229.5	234.2	239.0	243.8	248.6	253.5	258.1
p.2	366.0	374.0	382.0	390.0	398.0	407.0	414.0	422.0	432.0	438.0
p.1	900.0	920.0	940.0	960.0	980.0	1000.0	1020.0	1040.0	1060.0	1080.0
p.	**55**	**56**	**57**	**58**	**59**	**60**				
p.9	63.2	64.3	65.4	66.6	67.7	68.8				
p.8	73.5	74.8	76.1	77.5	78.8	80.1				
p.7	82.4	89.0	90.5	92.2	93.7	95.3				
p.6	107.0	108.9	110.8	112.8	114.8	116.8				
p.5	135.5	138.0	140.4	142.8	145.2	147.7				
p.4	181.0	184.2	187.5	190.7	194.0	197.3				
p.3	263.0	267.8	272.4	277.2	282.0	287.0				
p.2	447.0	466.0	463.0	472.0	480.0	487.0				
p.1	1100.0	1120.0	1140.0	1160.0	1180.0	1200.0				

If now we give a value of 15 to p=fifteen pounds absolute back pressure, and substitute for $v_{.9}^{1.3}$ to $v_{.1}^{1.3}$ their values as given in table No. 1 we will have:

$$p_{.9} = \frac{15}{.871} = 17.2$$
$$p_{.8} = \frac{15}{.748} = 20.0$$
$$p_{.7} = \frac{15}{.629} = 24.9$$
$$p_{.6} = \frac{15}{.514} = 29.2$$
$$p_{.5} = \frac{15}{.406} = 37.0$$
$$p_{.4} = \frac{15}{.304} = 49.3$$
$$p_{.3} = \frac{15}{.209} = 71.7$$
$$p_{.2} = \frac{15}{.123} = 122.0$$
$$p_{.1} = \frac{15}{.050} = 300.0$$

In like manner $p_{.9}$ to $p_{.1}$ can be found for any other value of p. These values have been calculated and are given in Table No. 2, up to p=60 pounds, advancing by increments of one pound.

To plot the adiabatic line by means of Table No. 2: Find in the horizontal line with p the number corresponding to the absolute back pressure on your card. Then in the same vertical column that contains your absolute back pressure, and opposite $p_{.9}$ find the value of $p_{.9}$. Lay this off on line .9 (Fig. 5) from $V V$ to the same scale as that of your indicator spring. Do the same for $p_{.8}$ $p_{.7}$ to $p_{.1}$. You then have a series of points through which you draw the smooth curve $c_1 c$ (Fig. 5). This line $c_1 c$ is the adiabatic line.

If the ammonia gas were compressed from point c (Fig. 9) up to the condenser pressure in a perfectly tight and non-conducting cylinder without loss or gain of heat, then the adiabatic line would be the curve traced by the indicator pencil. Now if there is no leakage past the valves or piston, this adiabatic line will in all ammonia compressors, as used to-day, almost overlie the compression line of the card for its whole length (see Fig. 9).

The water jacket does not seem to affect the compression line to any great extent. The jacket of water may affect the relative positions of the adiabatic and compression curves, during the latter one-fourth or one-fifth of the stroke (when the gas is very hot); then the adiabatic line will be seen to be slightly above the compression line (see Fig. 9). *If the compression line of the card does not follow very nearly the adiabatic you can make up your mind that something is wrong in connection with the piston, valves or gaskets of the compressor.* This is, of course, assuming that the indicator is properly connected; that the pipe leading from the cylinder to the indicator is short and of small bore, say ⅛-inch diameter, and that this pipe is well insulated from the cooling effect of water in the jacket. One thing is certain, *the compression curve can never lie above the adiabatic line if the compressor is working properly.* I will take up and discuss the conclusions that can be drawn from the different relations of the adiabatic and compression lines as soon as I have indicated how to draw the isothermal line on the indicator card.

CHAPTER IV.

THE ISOTHERMAL CURVE.

If there is no leakage to or from the cylinder during compression, and if the cylinder walls, head and piston are perfect conductors of heat, surrounded by a suitable cooling medium, then the temperature of the gas will remain constant during its compression, and we will have the isothermal line traced by the indicator pencil. No ammonia compressor is running to-day that will give a compression line like this on the indicator card. I doubt very much if an ammonia compressor will ever be built that will give a card where the compression line will approach it in any great degree. There is such a great amount of heat generated during compression that about all that can be hoped for is to prevent too great an accumulation of heat in the metals of the cylinder. This is all that I believe is accomplished by the water jacket, even in the best compressors built.

The isothermal line is more easily calculated than the adiabatic. It is represented by the formula $p\,v = p_1 v_1$. That is, the initial pressure times the initial volume is equal to the final pressure times the final volume. Taking v as 1, then $p \times 1 = p_1 \times v_1$ or $p_1 = \frac{p}{v_1}$. Now take values of v_1 from .9 to .1 as we did in the case of the adiabatic line; then as p represents the back pressure in pounds absolute, the different values of p_1, as $p_{.9}$ $p_{.8}$ $p_{.7}$ to $p_{.1}$, will be found by dividing the absolute back pressure p by the

TABLE NO. 3.

ISOTHERMAL CONSTANTS.

p.	15	16	17	18	19	20	21	22	23	24
p.9	16.7	17.8	18.9	20.0	21.1	22.2	23.3	24.5	25.6	26.7
p.8	18.7	20.0	21.2	22.5	23.7	25.0	26.2	27.5	28.7	30.0
p.7	21.4	22.8	24.3	25.7	27.1	28.6	30.0	31.4	32.8	34.3
p.6	25.0	26.7	27.3	30.0	31.7	33.4	35.0	36.7	38.4	40.0
p.5	30.0	32.0	34.0	36.0	38.0	40.0	42.0	44.0	46.0	48.0
p.4	37.5	40.0	42.5	45.0	47.5	50.0	52.5	55.0	57.5	60.0
p.3	50.1	53.4	56.7	60.1	63.4	66.7	70.1	73.4	76.7	80.1
p.2	75.0	80.0	85.0	90.0	95.0	100.0	105.0	110.0	115.0	120.0
p.1	150.0	160.0	170.0	180.0	190.0	200.0	210.0	220.0	230.0	240.0

p.	25	26	27	28	29	30	31	32	33	34
p.9	27.8	28.9	30.0	31.1	32.2	33.3	34.4	35.6	36.7	37.8
p.8	31.2	32.5	33.7	35.0	36.2	37.5	38.7	40.0	41.2	42.5
p.7	35.7	37.1	38.6	40.0	41.4	42.8	44.3	45.7	47.2	48.6
p.6	41.7	43.4	45.0	46.7	48.3	50.0	51.7	53.4	55.0	56.7
p.5	50.0	52.0	54.0	56.0	58.0	60.0	62.0	64.0	66.0	68.0
p.4	62.5	65.0	67.5	70.0	72.5	75.0	77.5	80.0	82.5	85.0
p.3	83.4	86.7	90.1	93.4	96.7	100.1	103.4	106.7	110.1	113.4
p.2	125.0	130.0	135.0	140.0	145.0	150.0	155.0	160.0	165.0	170.0
p.1	250.0	260.0	270.0	280.0	290.0	300.0	310.0	320.0	330.0	340.0

p	35	36	37	38	39	40	41	42	43	44
p.9	38.9	40.0	41.2	42.3	43.4	44.5	45.6	46.7	47.8	48.9
p.8	43.7	45.0	46.2	47.5	48.7	50.0	51.2	52.5	53.7	55.0
p.7	50.0	51.4	52.8	54.3	55.7	57.2	58.6	60.0	61.4	62.8
p.6	58.4	60.0	61.7	63.4	65.0	66.7	68.4	70.0	71.7	73.4
p.5	70.0	72.0	74.0	76.0	78.0	80.0	82.0	84.0	86.0	88.0
p.4	87.5	90.0	92.5	95.0	97.5	100.0	102.5	105.0	107.5	110.0
p.3	116.7	120.1	123.4	126.7	130.1	133.4	136.7	140.1	143.4	146.7
p.2	175.0	180.0	185.0	190.0	195.0	200.0	205.0	210.0	215.0	220.0
p.1	350.0	360.0	370.0	380.0	390.0	400.0	410.0	420.0	430.0	440.0

p.	45	46	47	48	49	50	51	52	53	54
p.9	50.0	51.2	52.3	53.4	54.5	55.6	56.7	57.8	58.9	60.0
p.8	56.2	57.5	58.7	60 0	61.2	62.5	63.7	65.0	66.2	67.5
p.7	64.3	65.7	67.2	68.5	70.0	71.4	72.8	74.3	75.7	77.2
p.6	75.0	76.7	78.4	80.0	81.7	83.4	85.0	86.7	88.4	90.0
p.5	90.0	92.0	94.0	96.0	98.0	100.0	102.0	104.0	106.0	108.0
p.4	112 5	115.0	117.5	120.0	122.5	125.0	127.5	130.0	132.5	135.0
p.3	150.0	153.4	156.7	160.0	163.4	166.7	170.0	173.4	176.7	180.0
p.2	225.0	230.0	235.0	240.0	245.0	250.0	255.0	260.0	265.0	270.0
p.1	450.0	460.0	470.0	480.0	490.0	500.0	510.0	520.0	530.0	540.0

p.	55	56	57	58	59	60				
p.9	61.2	62.3	63.4	64.5	65.6	66.7				
p.8	68.7	70.0	71.2	72.5	73.7	75.0				
p.7	78.5	80.0	81.4	82.8	84.3	85.7				
p.6	91.7	93.4	95.0	96.7	98.4	100.0				
p.5	110.0	112.0	114.0	116.0	118.0	120.0				
p.4	137.5	140.0	142.5	145.0	147.5	150.0				
p.3	183.4	186.7	190.1	193.4	196.7	200.1				
p.2	275.0	280.0	285.0	290.0	295.0	300.0				
p.1	550.0	560.0	570.0	580.0	590.0	600.0				

volume $v_{.9}$, $v_{.8}$ to $v_{.1}$. Let $p = 15$ pounds absolute; then

$$p_{.9} = \frac{15}{.9} = 16.7$$
$$p_{.8} = \frac{15}{.8} = 18.7$$
$$p_{.7} = \frac{15}{.7} = 21.4$$
$$p_{.6} = \frac{15}{.6} = 25.0$$
$$p_{.5} = \frac{15}{.5} = 30.0$$
$$p_{.4} = \frac{15}{.4} = 37.5$$
$$p_{.3} = \frac{15}{.3} = 50.1$$
$$p_{.2} = \frac{15}{.2} = 75.0$$
$$p_{.1} = \frac{15}{.1} = 150.0$$

In like manner $p_{.9}$ to $p_{.1}$ can be found for any other value of p. These values have been calculated, and are given in Table No. 3, up to sixty pounds.

To plot the isothermal line by means of Table No. 3, proceed the same as explained in regard to the adiabatic line. Fig. 6 shows a card upon which this has been done.

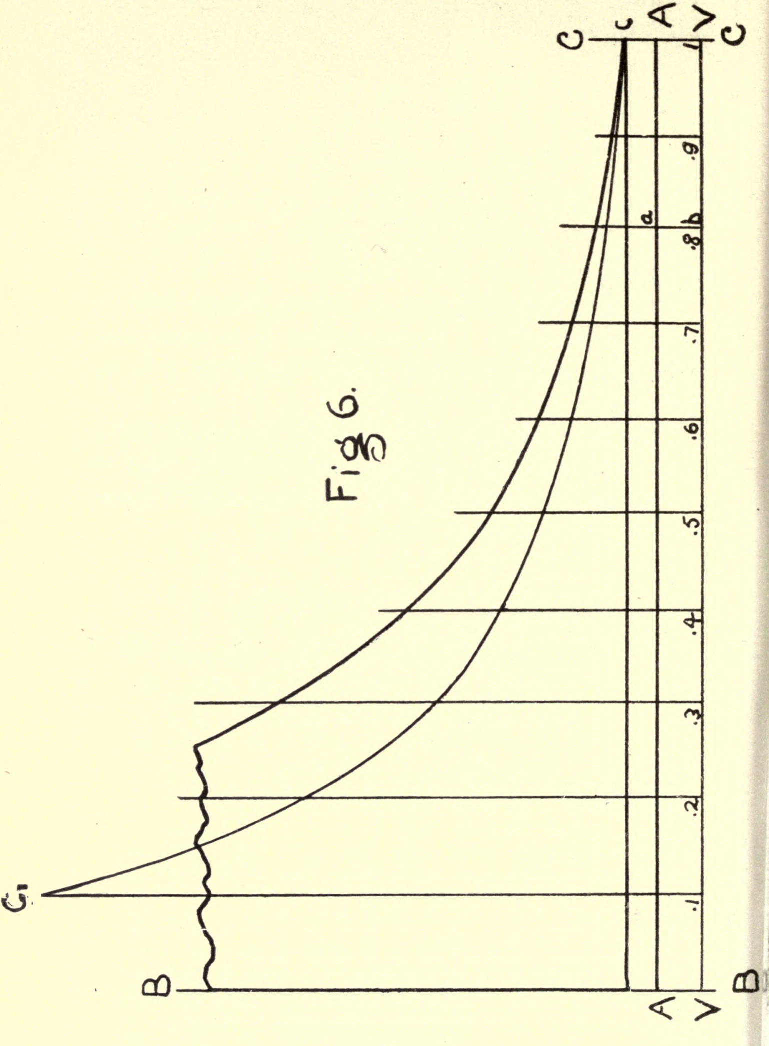

Fig 6.

CHAPTER V.

DISCUSSION OF THE ADIABATIC AND ISOTHERMAL CURVES.

Now, let us discuss the conclusions that may be drawn by inspecting a card having these adiabatic and isothermal lines drawn on it. First, let us discuss the adiabatic line. Take the card shown by Fig. 7. Here is seen that the compression line is above the adiabatic line. Something is wrong; what is it? Let us consider what conditions could exist that would cause this condition of affairs. It is evident that the pressure in the cylinder increases faster than could be caused by the action of the piston. The same conditions that cause the compression line to lie above the adiabatic line during compression will cause the cylinder to be cheated out of part of its full charge of gas from the suction pipe. The reason is that the high pressure gas from the condenser is leaking into the cylinder, either through leaky discharge valves, their gaskets or the cylinder head gasket between the cylinder and the discharge port. Therefore, we pump much less gas than we should. It also takes more power to run the compressor, as will be evident from the increased area of the diagram. It will not take long for a compressor to waste enough coal to buy a first-class indicator, if this condition of affairs is allowed to go on for any great length of time.

In large machines the loss will be very great.

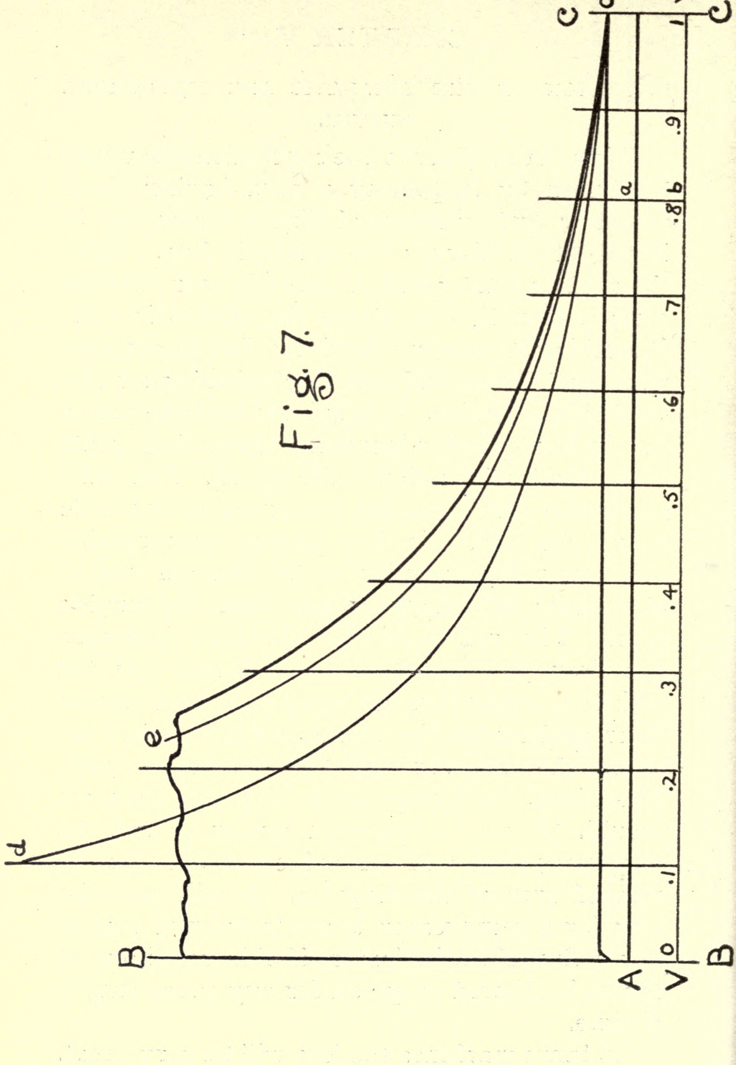

Fig. 7.

The engineer should take off the cylinder head and examine the cylinder head gasket. If it looks bad, replace it with a new one. Try the valves with the fingers, and see that no scale or foreign matter has attached itself to the valve or its seat. Also examine the valve cage gaskets. After having done all that you can to remedy the trouble, by a careful examination, replace the cylinder head, and connect a pressure gauge to the indicator connection. Allow the condenser pressure to act upon the outer faces of the discharge valves. If the pressure, as shown by the gauge, remains the same or increases very slowly you have remedied the difficulty. Otherwise, if the pressure increase rapidly, you have not.

In nine cases out of ten the engineer will find upon his first careful examination of the gaskets and valves that the gasket is defective, or that there is some foreign substance in the valve seat. It may be that the valves need regrinding. This is a point that is rather difficult to determine by a mere inspection, hence the pressure gauge test.

Now let us examine the card as shown by Fig. 8. Here the compression line is some little distance below the adiabatic line *e c*. It approaches the isothermal line *d c*. Some engineers might thoughtlessly say: "What a fine card! how efficient the water jacket must be!" etc. But, as I said before, compressors "are not built that way." By apparently being so good the card gives ample evidence of a very bad state of affairs within the compressor.

Let us see what conditions could give this

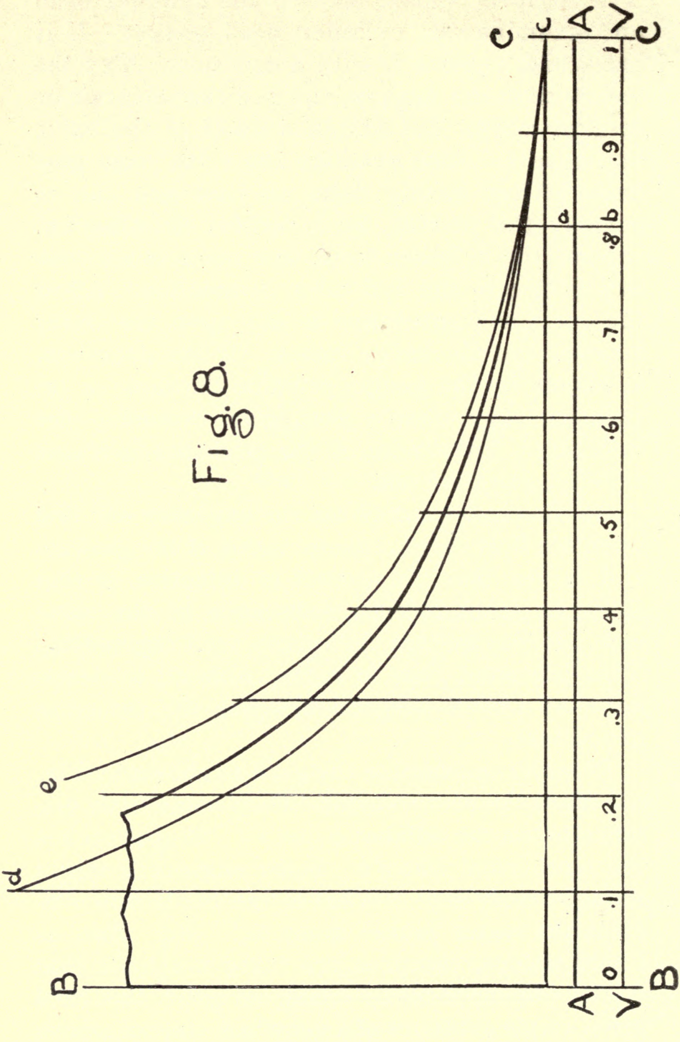

Fig. 8.

result. It is evident that the pressure is not as great at any point on the curve as it should be. What is the cause of this? Some of the gas has leaked out of the cylinder, either by leaky suction valves or their gaskets. The cylinder head gasket may be defective between the suction port and the cylinder, or you may have a leaky piston. It is evident that a sort of rubber ball action is going on in the cylinder. Part of the gas is compressed and expanded between the suction pipe and the cylinder, in place of being discharged into the condenser. The gas is in part pumped over and over again, thereby cutting down the capacity of the machine. Remove the cylinder head, examine the gaskets and valves. Do all that you can by a careful inspection to make good the trouble. Then replace the cylinder head and connect a pressure gauge to the indicator connection. Compress the gas in the cylinder so as to have a high pressure. Note the pressure on the gauge. If it does not decrease, or if it decreases very slowly, you have remedied the trouble. If it decreases rapidly, either the valves need regrinding, the piston needs new rings or the cylinder should be rebored, or all these troubles may exist at once. After having had the valves reground if the pressure test, as indicated above, still shows a rapidly decreasing pressure, you would better call in the agent for your machine, and let him decide whether the piston rings or the boring of the cylinder are at fault.

Fig. 9 shows the relations of the compression curve and adiabatic line, *e c*, that your compressor should give if in perfect condition. It has prob-

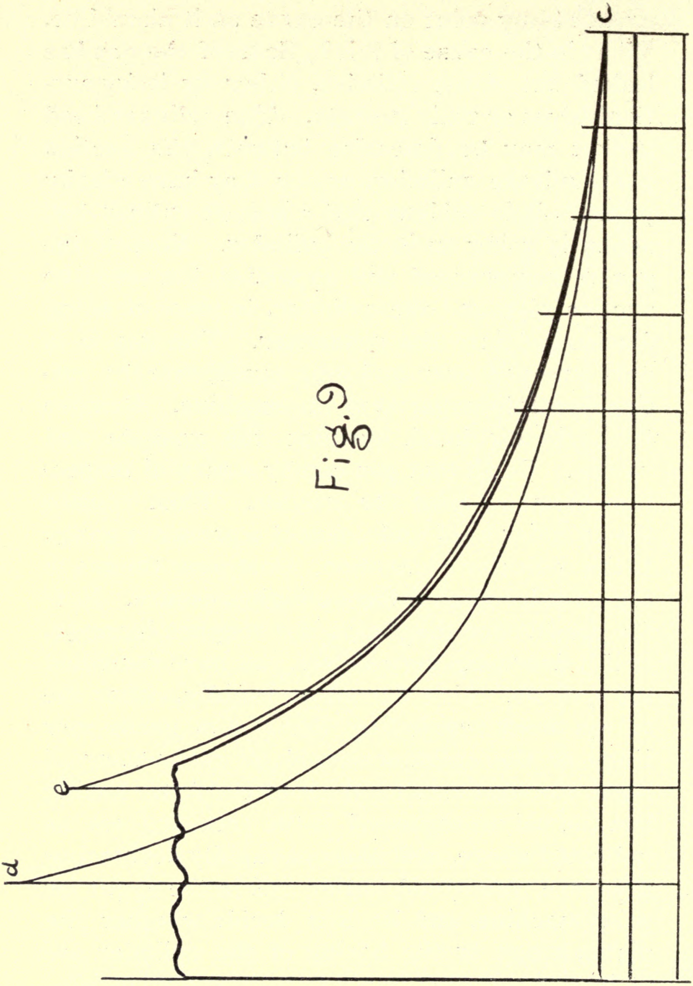

Fig 9

ably occurred to you while reading the above that you might do all of your testing with a pressure gauge, in place of bothering with an indicator. This is true, in a way. Engineers who do not own an indicator may make all the above tests in regard to leaky valves, etc., by connecting a pressure gauge to the indicator cock and proceeding as explained above.

The indicator card is a valuable permanent record of what your compressor is doing. It should be taken every week, dated and filed away for future reference. A steel indicator is preferred for ammonia work. However, you may use your composition indicator without fear of damage if you keep it well oiled, and thoroughly clean it as soon as you have finished your test.

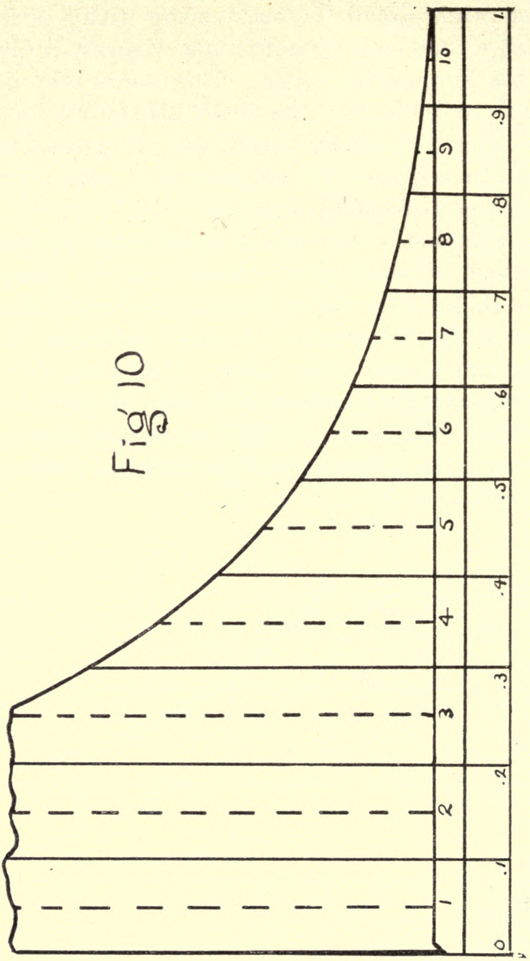

Fig 10

CHAPTER VI.

FINDING THE HORSE POWER OF AN INDICATOR CARD.

To obtain the horse power, or work of compression, represented by the indicator card it is convenient to have a planimeter, and thus measure the area of the card. Then divide the area thus found by the length of the card in inches, and multiply the result by the scale of the spring used. The result is the mean effective pressure, expressed as M. E. P. The mean effective pressure is the average pressure of the gas in the cylinder from the beginning of suction to the end of discharge.

I will not go into the method of using the planimeter, as it is fully explained in the instructions that are furnished with each instrument, and also in Parts II and III of this book. If you are not fortunate enough to own a planimeter, and cannot borrow one, you can obtain the M. E. P. as follows: In Fig. 10 you should already have your card divided into ten equal spaces, $v_1 v_{.9}$, $v_{.8} v_{.7}$, etc. All that is necessary is to find the average heights of these areas that are included between the vertical lines as $v_{.9} v_{.8}$ and the admission and compression or discharge lines. Divide each of these spaces, $v_1 v_{.9}$ to $v_{.1} v_0$, into two equal parts, and draw through these divisions the dotted lines as shown, which are numbered 1, 2 to 10.

Measure the length of each line from the admission line to where it cuts the compression or discharge curve, using the same scale as that of the indicator spring used. Add together these lengths and divide the result by 10. The quotient is then the average height or the M.E.P.

Having the M.E.P., the horse power is readily found by the following simple formula:

$$\text{H. P.} = \frac{n \times l \times a \times (\text{M.E.P.})}{33{,}000}$$

Where n=strokes (not revolutions) per minute.
l=length of stroke in feet.
a=area of piston in square inches.
M. E. P.=mean effective pressure.

Every engineer should know the constant for his compressor.

It is evident that in the above formula $\frac{l \times a}{33{,}000}$ is constant for all conditions or tests. This value, $\frac{l \times a}{33{,}000}$, is the constant for your compressor, and is indicated by C. Therefore the horse power is

$$\text{H. P.} = C \times n \times (\text{M. E. P.})$$

The horse power of the steam engine is obtained in the same way. Only remember that whereas your compressor may have been single-acting, as is assumed for the above formula, your engine is double-acting; therefore you should multiply your strokes by 2, and your engine constant is approximately $\frac{2l \times a}{33{,}000.}$ This is also the constant for a double-acting compressor. In a double-acting compressor or a steam engine the area of one side of the piston must have deducted from it the area of the piston rod, thus giving the effective area of the piston. The true constant for that side of the piston will then be $\frac{l \times (a - a_1)}{33{,}000}$, a_1 being the area of the piston rod in square inches. The difference between the H. P. of the steam engine and that of the compressor is the friction of the machine.

CHAPTER VII.

ACTUAL DISPLACEMENT OF A COMPRESSOR.

The actual displacement of the compressor should be known. We know that the compressor does not pump the weight of gas that it should, as figured from its theoretical displacement, the reason being, as stated by Prof. Denton, that the gas is rarefied during suction by coming in contact with the hot walls of the cylinder.

It is evident that if the gas is rarefied the weight of a given volume of gas would be less after rarefaction than before. Consequently our compressor may vary in its actual capacity from 70 per cent to 90 per cent of the theoretical capacity, these two figures, 70 per cent and 90 per cent, being extreme cases that are rarely if ever reached. The common value of the actual capacity is from 75 per cent to 80 per cent of the theoretical capacity.

My theory in regard to this rarefaction is that as the gas enters the cylinder through the narrow annular openings between the hot valves and their seats, it is superheated and thus rarefied. There is only a brief interval between the end of compression and the beginning of suction. When suction begins the cylinder head and valves are at their maximum temperature. Consequently I could think of no better way of heating a gas than that of forcing it through these narrow annular openings, having hot metal surfaces to pass by. The head and valves should be cooled by some means other than the gas to be pumped.

The gas should arrive at the cylinder as near the temperature of the boiling point of the liquid ammonia, due to its back pressure, as possible. Every degree of superheating cuts down the actual capacity of the compressor. It is well known that a gas will expand $\frac{1}{461}$ of its volume at 0° F. for every degree of increase of its temperature. The suction pipe to a compressor should be thoroughly insulated. The vapor from the expansion coils should not be used for any cooling purpose whatsoever. Cooling the liquid ammonia by means of the return vapor is poor practice. To be sure, it is an advantage to have the ammonia arrive at the expansion valve as cold as possible, but it is more disadvantageous to warm up the vapor than not to cool down the liquid with it.

It will be evident how poor the gas is in cooling power when it is remembered that one pound of vapor only has a cooling effect of .5 British thermal units for every degree F. that it warms up; while a pound of the liquid ammonia has while vaporizing a cooling effect of 555 B. T. U., on an average, or over one thousand times as much. (*Cool the liquid ammonia by any other available means, but not by the return ammonia vapor.*)

If the expansion coils or receptacle are practically built, if the coils are not too long, you will have no trouble with liquid ammonia coming over to your machine. Should you be unfortunate enough to have a brine tank or expansion coils that will squirt the liquid in the form of a spray over to the compressor, you would better put a separator in your suction pipe or else get a more efficient brine tank or expansion coils.

The talk about where the frost line should or should not stop on the suction pipe is all bosh. The frost should go right up to and around the compressor cylinder if it is uninsulated. But better still, the suction pipe and the cylinder should be thoroughly insulated from the effect of heat from outside sources. It is necessary to know the temperature of the boiling point of the ammonia in your expansion coils, and also the temperature of the gas at the suction entrance to your compressor. So long as the temperature of the gas at the compressor is 5° or 10° F. above that of the boiling ammonia, there will be no danger of getting liquid over to your machine.

I would not let the gas get colder than 10° above that of the boiling point of the ammonia. Probably there are hundreds of plants that cannot follow this advice because they have squirting expansion coils. But the time is not far distant when these plants will throw aside their squirting coils and substitute expansion devices which do not tend to squirt the liquid ammonia like an atomizer. The liquid ammonia should be allowed to boil in such a vessel that there is ample room for the vapor to escape without dragging along some of the liquid with it. I have tried both kinds, squirting coils and proper expansion vessels, and I would not take an ordinary coil brine tank for a gift unless I could use it for some other purpose than for a brine tank.

Now to determine the actual displacement of your compressor. If you use the brine system this can readily be done. Get the specific gravity of your brine by means of a hydrometer. If you do not own a hydrometer, weigh equal volumes of your brine and water. Divide the weight of the brine by that of the water. The result is the specific gravity of your brine. Now look up in the tables (see Part IV) the corresponding specific heat. Take several readings of the temperature of your brine to tank and also of brine from tank. Average the readings of the inlet brine and also average those of the outlet brine. Subtract the results. This is of course the number of degrees that you have cooled your brine through.

Find the weight of brine circulated per minute by your pump. To do this, multiply the strokes of your pump per minute by the length of stroke in inches by the piston area in square inches, and divide the result by 1,728; this gives the cubic feet pumped per minute; multiply this by the weight of a cubic foot of your brine, to obtain the weight pumped per minute. If your pump is in good condition you should multiply this result by .95, .95 being the probable actual capacity of your brine pump.

Having now the weight in pounds of the brine pumped per minute, multiply this weight by the degrees F. change in temperature of your brine in the brine tank, and multiply this result by the specific heat of your brine. Now, divide the above result by 200, and your final answer is the tons of refrigeration that you are doing per twenty-four hours.

One ton refrigeration in twenty-four hours $= 2{,}000 \times 142$ B. T. U.; 142 B. T. U. is the latent heat of liquefaction of ice. $2{,}000 \times 142 = 284{,}000$

B. T. U. per twenty-four hours $= \frac{284,000}{1,440} = 200$, nearly, B. T. U. per minute. Twenty-four hours $= 1,440$ minutes. Expressed in the form of a formula, the above will read:

$$\frac{(t - t_1) \times s \times w}{200} = R.$$

$R =$ tons refrigeration per twenty-four hours.

$t =$ temperature warm brine; $t_1 =$ temperature cold brine.

$s =$ specific heat of brine.

$w =$ weight of brine circulated per minute.

Now, turn to your ammonia tables (see Part IV) and find the weight of a cubic foot of vapor of ammonia at the back pressure at which you are running. Also look up the latent heat of vaporization at this pressure, and the boiling point of the liquid ammonia. Take the temperature of your liquid ammonia just before it enters the expansion valve. If your liquid pipe is insulated, as it should be, this temperature will be about the same as that of the water coming from your condenser.

Subtract the boiling point of the ammonia from this temperature. As the specific heat of liquid ammonia is 1, this gives the number of B. T. U. that the liquid must be cooled to bring it to the boiling point. As this has to come from the heat of vaporization, we subtract it from the heat of vaporization, leaving as a result the available cooling effect in B. T. U. of one pound of liquid ammonia under our conditions. Expressed in the form of a formula, the above becomes—

$$\frac{R \times 200}{r - (t_2 - t_3)} = \frac{200\ R}{r - t_2 + t_3} = W$$

r = heat of vaporization.

t_2 = temperature of ammonia at expansion valve.

t_3 = temperature of ammonia at boiling point.

W = pounds of ammonia circulated per minute.

Take the theoretical displacement in cubic feet of your compressor per minute $= D$; multiply this by the weight of a cubic foot of vapor of ammonia at the back pressure you are using (see Part IV for tables). The result is the theoretical number of pounds of ammonia pumped by your compressor $= W_1$. Then D_1 = the actual capacity of your compressor; $D_1 = \frac{W}{W_1}$.

EXAMPLES.

No. 1.—Required the horse power of card (see Fig. 10).

The compressor has two single-acting cylinders, each twelve inches in diameter, stroke= eighteen inches; forty revolutions per minute; scale of spring, 40.

Solution.—Measure height of lines 1, 2, 3 to 10, with a 40 scale. They measure 88, 88, 88, 58, 35, 22, 13, 7, 4, 1. The sum of these figures is 404. Dividing by 10, the result is 40.4 = M. E. P.

The constant for this compressor is

$$C = \frac{l \times a}{33,000} = \frac{1.5 \times 113}{33,000} = .00514$$

$$\text{H. P.} = C \times n \times \text{M. E. P.}$$

$$\therefore \text{H. P.} = .00514 \times 40 \times 40.4 = 8.3.$$

As there are two cylinders, we must obtain also the horse power of the other card; if it is the same as this card, then the horse power of both cylinders is $8.3 \times 2 = 16.6$.

If the horse power of the steam engine is 20, then $20 - 16.6 = 3.4 =$ friction of machine $= \frac{3.4}{20}$, 17 per cent of that of the steam cylinders.

This is very good. The friction will usually be about 20 per cent.

No. 2.—Required the refrigeration per day.

Brine pumped per minute = 667 pounds.

Change in temperature of brine = 3° F. = $t - t_1$.

Specific heat of brine = .8.

$$\text{Then } R = \frac{(t-t_1) \times s \times w}{200} = \frac{3 \times .8 \times 667}{200} = 8 \text{ tons.}$$

No. 3.—Required the actual capacity of the compressor, the theoretical capacity being 100 per cent.

Temperature of liquid ammonia to expansion valve = 70° F.; $r = 572$, $t_3 = -28$ for an absolute back pressure of fifteen pounds.

$R = 8$, $r = 572$, $t_2 = 70°$ F., $t_3 = -28°$ F.

$$\therefore W = \frac{R \times 200}{r - t_2 + t^3} = 3.018 \text{ pounds per minute.}$$

The theoretical displacement of the compressors is $\frac{113 \times 18 \times 2 \times 40}{1{,}728} = 94$ cubic feet per minute.

The weight of a cubic foot of vapor of ammonia at 15 pounds absolute is .056 pounds $\therefore 94 \times .056 =$ 5.26 pounds $= W_1$ the theoretical capacity of the compressor $\therefore \frac{W}{W_1} = D_1 = \frac{3.018}{5.26} = 57.4$ per cent = the actual capacity of the compressor. This is too small, consequently you should find out by your adiabatic line where the trouble is.

CHAPTER VIII.

SPECIAL FAULTS AS SHOWN BY CARDS.

Fig. 11 shows a card when the suction valve has too strong a spring or a valve that is inclined to stick to its seat. (See distorted heel at *a*.)

Fig. 12 shows a card where the line *a a* is drawn to scale at a vertical distance above the atmospheric line *A A*, equal to the suction pressure in the suction pipe. This shows that the suction valve spring is too strong.

Fig. 13 shows a card where the line *b b* has been drawn by connecting the indicator to the suction pipe and line *a a* by connecting the indicator to the discharge pipe. These lines should be about as shown on the card. The lines *a a* and *b b* can best be laid off to scale above *A A*, corresponding to the pressures in these pipes, as shown by the pressure gauge, although they may be drawn by the indicator pencil if the suction and discharge pipes are tapped and connected to the indicator.

Fig. 14 shows a card with a line, *a a*, drawn to scale at a distance above line *A A* equal to the pressure in the discharge pipe. This indicates too stiff discharge valve springs.

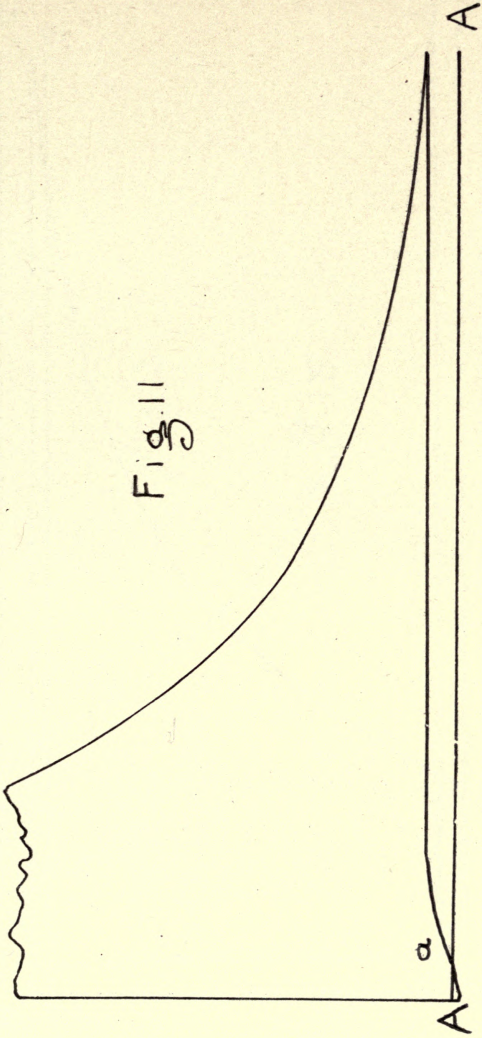

Fig. 11

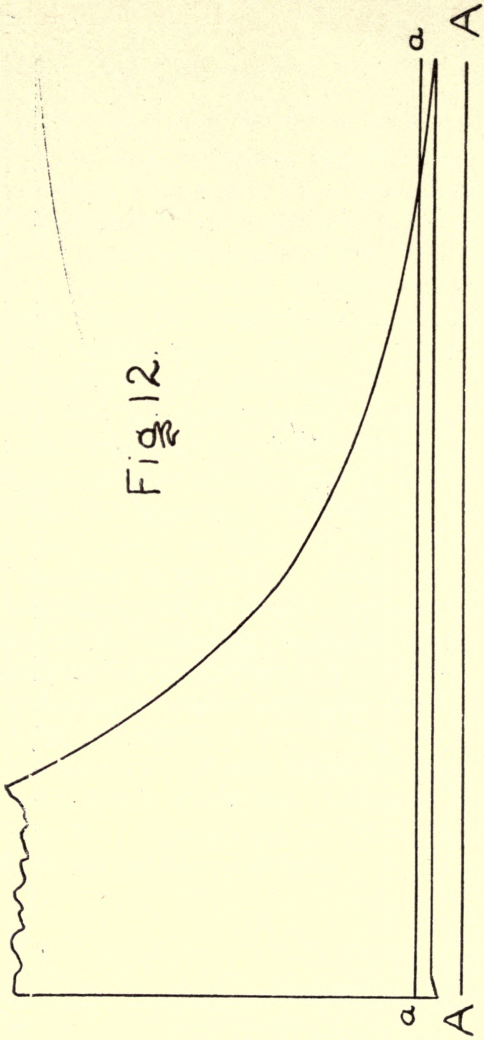

Fig 12.

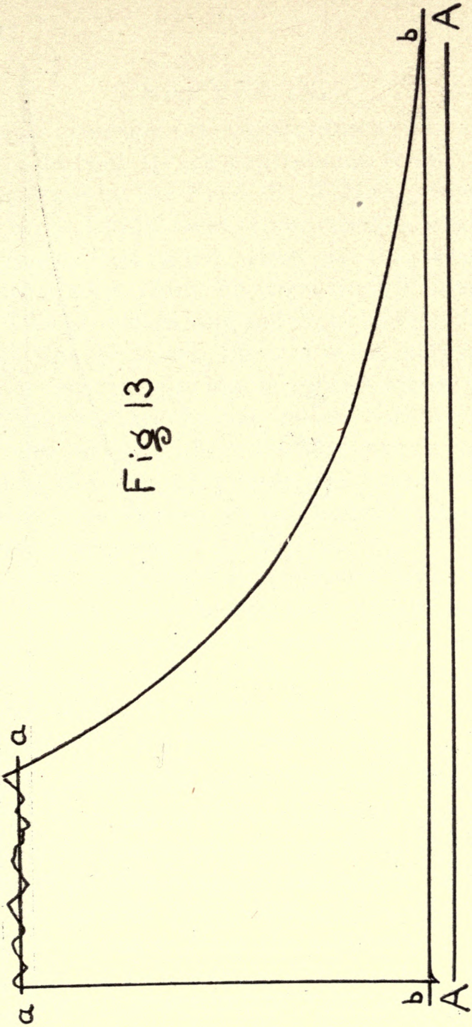

Fig 13

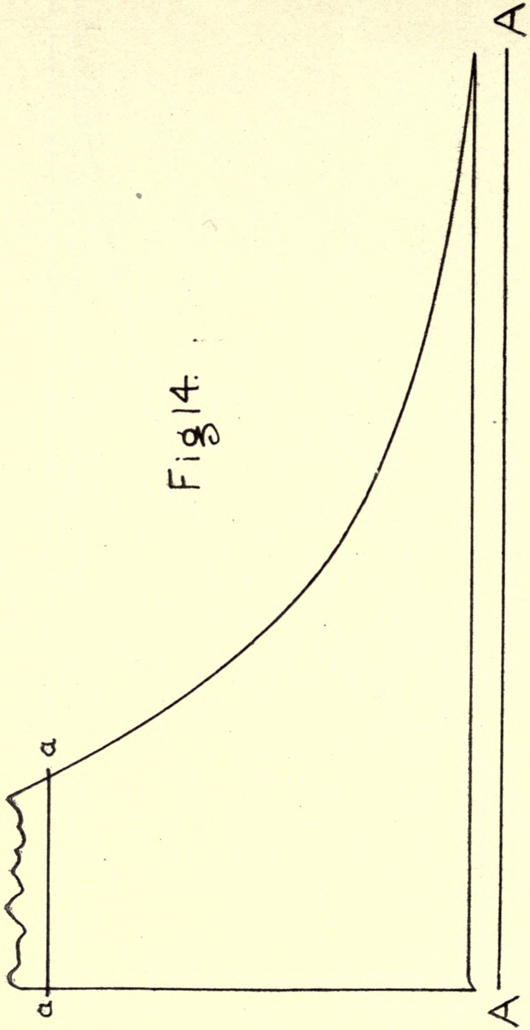

Fig 14.

CHAPTER IX.

WET COMPRESSION SYSTEM INDICATING.

Figs. 15 and 16 are reproduced from cards furnished me by the Fred W. Wolf Co., from an 18×30 inch Linde (wet compression system) compressor, that were taken at the Western Cold Storage Co. plant, on November 9, 1898, on which I have drawn the adiabatic line *c d*, isothermal line *a d* and the curve of saturation *b d*. The scale of spring for these cards is 60. These diagrams were given me as representative cards, and seem to show that my reasoning, as applied to the dry compression or water jacket machines, also applies to the wet compression machines, particularly in Fig. 16.

The wet compression machines differ from the dry compression machines in that the former injects liquid ammonia into the cylinder before compression to take up the heat of compression, while the latter surrounds the cylinder with a water jacket for the same purpose.

THE CURVE OF SATURATION.

If the ammonia in the cylinder at the beginning of compression is a saturated vapor, and if this condition (the state of saturation) is maintained throughout compression, then there will be a different curve from the adiabatic and isothermal traced by the indicator pencil. This is called the curve of saturation. Any point on this curve has its ordinate or vertical distance from *V V* equal to the pressure in the cylinder, and its abscissa or horizontal distance from *d V* equal

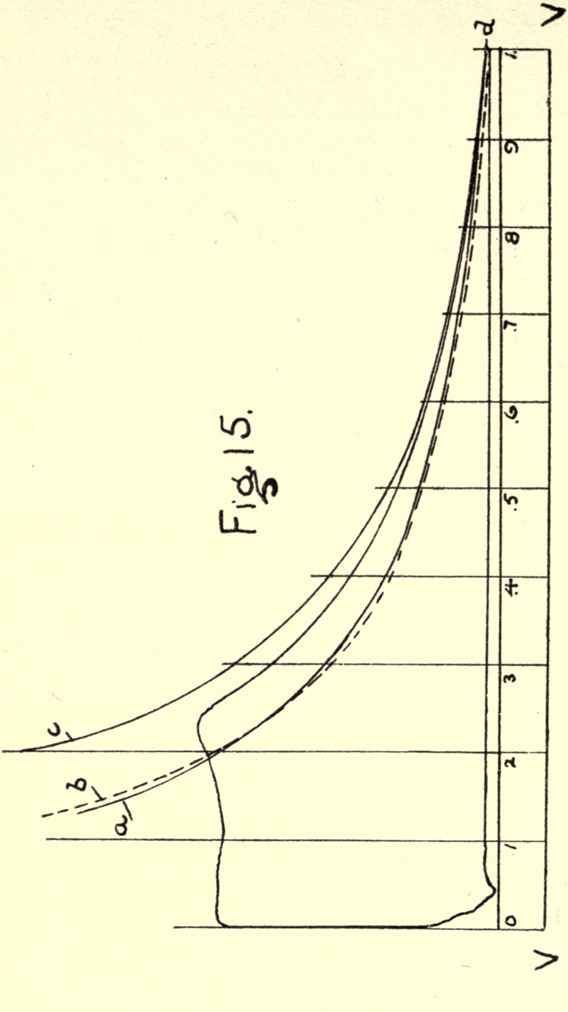

Fig. 15.

to the relative volume in cylinder, the initial or (cylinder full) volume being 1. The ordinate being obtained by looking up in a table of the properties of saturated vapor of ammonia the pressure corresponding to the weight of a cubic foot of vapor at this point, this weight being the product of the relative volume at this point and the weight of a cubic foot of vapor at the absolute back pressure of the card. Curves *b d*, Figs. 15 and 16, are curves of saturation. This curve can be readily determined, approximately, from the tables of the properties of saturated vapor of ammonia in the following manner:

Find from the tables the volume in cubic feet per pound of the vapor at the absolute back pressure of the card. Multiply this value by .9, .8, .7, .6, .5, .4, .3, .2, .1, and note from the tables the absolute pressures corresponding to these new volumes. These pressures are points on the curve of saturation for values, .9, .8, .7, .6, .5, .4, .3, .2, .1 of v.

For example, let the absolute back pressure be twenty-one pounds per square inch. We find from the tables that the number of cubic feet of vapor per pound at this pressure is approximately 12.834. Then it follows that—

12.834×.9=11.55	cu. ft. per lb.	= 23.5	lbs. per sq. inch
12.834×.8=10.27	"	= 26.5	"
12.834×.7= 8.98	"	= 31 0	"
12.834×.6= 7.70	"	= 35.8	"
12.834×.5= 6.42	"	= 43.0	"
12.834×.4= 5.13	"	= 54.6	"
12.834×.3= 3.85	"	= 59.7	"
12.834×.2= 2.57	"	=113.7	"
12.834×.1= 1.28	"	=232.0	"

Laying off these values of pressures found on the vertical lines to scale at volumes $v_{.9}$, $v_{.8}$, $v_{.7}$,

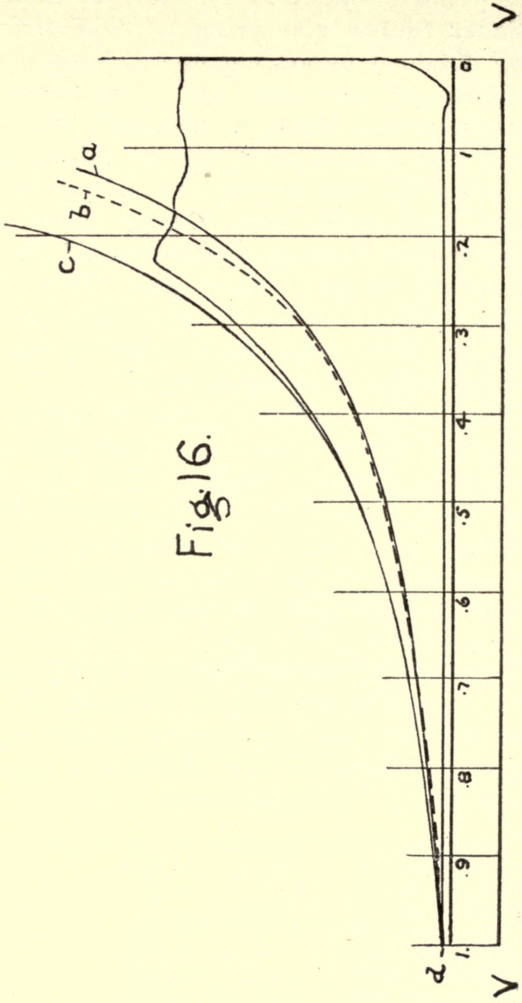

Fig. 16.

$v_{.6}$, $v_{.5}$, $v_{.4}$, $v_{.3}$, $v_{.2}$, $v_{.1}$, from the vacuum line, we have the desired points on the curve of saturation.

LIMITS OF COMPRESSOR.

From the above it follows that the adiabatic curve will be traced when no heat is taken from or given to the gas during compression. The isothermal curve will be drawn if the gas is maintained at the same temperature that it has at the beginning of compression. Theoretically, the gas should be quite cold at the beginning of compression, say from 10° below 0° F. to 10° above 0° F. It will be seen that compressors using water jackets could *never maintain this line unless they had jacket water as cold or colder than these temperatures of gas at the beginning of compression.* As the jacket water usually ranges anywhere from 50° F. to 100° F., it is clear that no heat can be taken from the compressed gas until it has reached this temperature.

This will explain why the actual curve of compression follows the adiabatic curve part of the way, and then tends toward the isothermal curve. Where the actual compression curve leaves the adiabatic, is the point of the stroke where the jacket water is just beginning to "get in its work." Therefore, if any one shows you a card from a water jacketed dry compressor that approaches the isothermal line for the first half of the stroke, you would better make up your mind that the card is wrong.

It will be seen in Figs. 15 and 16 that the curve of saturation *b d* follows very closely the isothermal curve. In wet compression machines this curve (the curve of saturation) is aimed at by injecting enough liquid ammonia into the cylinder to take up the heat of compression. If this works as well practically as it does by theory, then the curve of saturation is possible, and therefore quite a reduced area of card is obtained, indicating less power required to compress the ammonia.

As it is not my desire to compare the relative merits of the wet and dry compressors, I will only add that to be fair when comparing one with the other the question should be thoroughly investigated as to whether there are factors that enter into the value of each machine other than those shown by the indicator cards, and also to note that cards 15 and 16, which are taken as representative cards of the wet compression system, are almost identical with what is obtained from dry compression machines, particularly Fig. 16.

CHAPTER X.

INSTRUCTIONS FOR CONNECTING INDICATOR TO MACHINE.

In regard to connecting the indicator to the compressor and arranging for the drum motion, I refer the reader to Chapters II and III of Part II; how to take the diagrams, to Chapter IV, Part II. I advise the use of a reducing wheel, as explained in Chapters VII and VIII, Part III.

The reducing wheel will be found very accurate and simple, and can be used with any of the indicators described. Most of the indicator manufacturers have these reducing wheels in stock, specially adapted to their particular make of indicator.

In making the ammonia connection with the compressor cylinder, I advise the use of a ½-inch pipe connection, made from a solid piece of iron or steel, having a hole ⅛ inch diameter drilled through it. The reason for using so small a bore is to reduce the clearance as much as possible. This connection can be capped when not in use, or, better still, fitted with a ½-inch cock, in which the hole in the plug has been bushed down to ⅛ inch diameter. I advise the use of Coffin's averaging instrument for obtaining the mean effective pressure of cards. This instrument gives you the mean effective pressure direct without the intermediate steps of calculation necessary with the common planimeter, and also a neat board upon which to measure the card.

INDICATING
THE
REFRIGERATING MACHINE

Part II.

INDICATING THE STEAM ENGINE.*

CHAPTER I.

THE STEAM ENGINE INDICATOR.

The steam engine indicator, invented by James Watt, and long kept secret, was for many years after its secret became known, strangely neglected by most makers and users of steam engines.

The earlier forms of the instrument, which preceded that invented by Richards, were so imperfect and so ill adapted to engines running at other than very low speeds, that their indications were often misleading, more often unintelligible, and seldom of much value beyond revealing the point of stroke at which the valves opened and closed—a most valuable service, alone worth the cost of an indicator, but only a small part of the service to be obtained from a really good instrument.

The general principles, on which the best type of steam engine indicator is designed, may be briefly stated as follows:

A piston of carefully determined area is nicely fitted into a cylinder so that it will move

*Reprinted by courtesy of Crosby Steam Gage and Valve Co. from their book on indicator practice.

up and down without sensible friction. The cylinder is open at the bottom and fitted so that it may be attached to the cylinder of a steam engine and have free communication with its interior, by which arrangement the under side of the piston is subjected to all the varying pressures of the steam acting therein. The upward movement of the piston—due to the pressure of the steam—is resisted by a spiral spring within the cylinder, of known elastic force. A piston rod projects upward through the cylinder cap and moves a lever having at its free end a pencil point, whose vertical movement bears a constant ratio to that of the piston. A drum of cylindrical form and covered with paper is attached to the cylinder in such a manner that the pencil point may be brought in contact with its surface, and thus record any movement of either paper or pencil. The drum is given a horizontal motion coincident with and bearing a constant ratio to the movement of the piston of the engine. It is moved in one direction by means of a cord attached to the crosshead, and in the opposite direction by a spring within itself.

When this mechanism is properly adjusted and free communication is opened with the cylinder of a steam engine in motion, it is evident that the pencil will be moved vertically by the varying pressure of steam under the piston; and as the drum is rotated by the reciprocating motion of the engine, if the pencil is held in contact with the moving paper during one revolution of the engine a figure or diagram will be traced representing the pressure of steam in the cylinder, the upper line showing the pressure urging the piston forward, and the lower the pressure retarding its movement on the return stroke.

To enable the engineer to more correctly interpret the nature of the pressures, the line showing the atmospheric pressure is drawn, which indicates whether the pressure at any part is greater or less than that of the atmosphere.

From such a diagram may be deduced many particulars which are of supreme importance to engine builders, engineers and the owners of steam plants.

WHAT IS THE GOOD OF AN INDICATOR?

This question was asked by a young engineer who had come to examine and purchase an indicator, with a view to rendering his services of greater value to his employer, by a knowledge and use of that instrument. His question was overheard by the proprietor of a large establishment, who took occasion to reply as follows:

"I will tell you what good an indicator did at our works. Our steam engine was not giving sufficient power for our business, and we expected to be obliged to procure a larger one. A neighbor suggested that we have our engine indicated to see if we were getting the best service obtainable from it. This was done, and the result was, that when the valves were properly adjusted and other slight changes made, we had *ample power*, and the improved condition of the engine made a reduction in our coal bills during the following year of $500."

Another case: An expert engineer was called to indicate several locomotives just completed by one of our prominent locomotive builders, who had in use a large Corliss engine, which had been running only a few months. When the locomotives were indicated, the proprietor proposed that the indicator be applied to the Corliss engine, the engineer of which remarked: "Guess you 'll find her all right, as she 's running fine."

The first card showd that *nearly all the work was being done at one end of the cylinder.* The valves were changed and a great improvement was apparent in the running of the engine, while the actual consumption of coal was reduced from an average of 3,370 pounds per day, before the change was made, to 2,338 pounds afterward.

These two instances are valuable in showing "the good of an indicator."

Items of Information to be Obtained by the Use of the Indicator.—The arrangement of the valves for admission, cut-off, release and compression of steam.

The adequacy of the ports and passages for admission and exhaust; and when applied to the steam chest, the adequacy of the steam pipes.

The suitableness of the valve motion in point of rapidity at the right time.

The quantity of power developed in the cylinder, and the quantity lost in various ways: by wire drawing, by back pressure, by premature release, by mal-adjustment of valves, leakage, etc.

It is useful to the designers of steam engines in showing the distribution of horizontal pressures at the crank pin, through the momentum and inertia of the reciprocating parts, and the angular distribution of the tangential component of the horizontal pressure; in other words, the rotative effect around the path of the crank.

Taken in combination with measurements of feed water and the condensation and measurement of the exhaust steam, with the amount of fuel used, the indicator furnishes many other items of importance when the economical generation and use of steam are considered.

For every one of these purposes it is important that the diagram traced by the indicator should truly represent the path of the piston and the pressure exerted on both sides of the piston at every point of that path.

INDICATOR DIAGRAMS.

The degree of excellence to which steam engines of the present time have been brought is due more to the use of the indicator than to any other cause, as a careful study of indicator diagrams taken under different conditions of load, pressure, etc., is the only means of becoming familiar with the action of steam in an engine, and of gaining a definite knowledge of the various changes of pressure that take place in the cylinder.

An indicator diagram is the result of two movements, namely: a horizontal movement of the paper in exact correspondence with the movement of the piston, and a vertical movement of the pencil in exact ratio to the pressure exerted in the cylinder of the engine; consequently, it represents by its length the stroke of the engine on a reduced scale, and by its height at any point, the pressure on the piston at a corresponding point in the stroke. The shape of the diagram depends altogether upon the manner in which the steam is admitted to and released from the cylinder of the engine; the variety of shapes given from different engines, and by the same engine under different circumstances, is almost endless, and it is in the intelligent and careful measurement of these that the true value of the indicator is found, and *no one at the present day can claim to be a competent engineer who has not become familiar with the use of the indicator, and skillful in turning to practical advantage the varied information which it furnishes.*

A diagram shows the pressure acting on one side of the piston only, during both the forward and return stroke, whereon all the changes of pressure may be properly located, studied and measured. To show the corresponding pressures on the other side of the piston, another diagram must be taken from the other end of the cylinder. When the three-way cock is used, the diagrams from both ends are usually taken on the same paper, as in Fig. 9.

ANALYSIS OF THE DIAGRAM.

The names by which the various points and lines of an indicator diagram are known and designated are given below, and their significance fully explained. (See Fig. 1.)

The closed figure or diagram, *C D E F G H*, is drawn by the indicator, and is the result of one indication from one side of the piston of an engine. The straight line *A B* is also drawn by the indicator, but at a time when steam connection with the engine is closed, and both sides of the indicator piston are subjected to atmospheric pressure only.

The straight lines *O X*, *O Y* and *J K*, when required, are drawn by hand as explained below, and may be called reference lines.

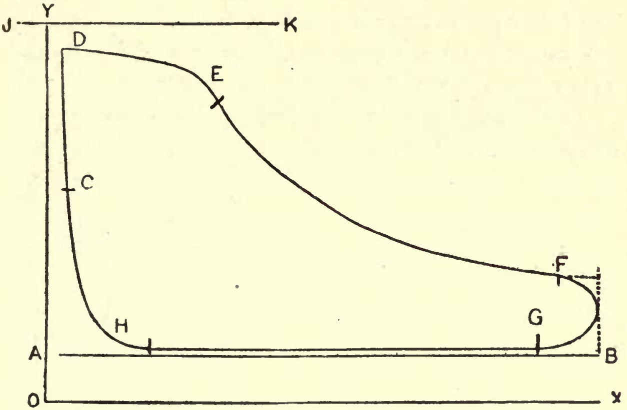

FIG. 1.

DIAGRAM LINES EXPLAINED.

The admission line C D shows the rise of pressure due to the admission of steam to the cylinder by the opening of the steam valve. If the steam is admitted quickly when the engine is about on the dead center this line will be nearly vertical.

The steam line D E is drawn when the steam valve is open and steam is being admitted to the cylinder.

The point of cut-off E is the point where the admission of steam is stopped by the closing of the valve. It is sometimes difficult to determine the exact point at which the cut-off takes place. It is usually located where outline of diagram changes its curvature from convex to concave.

The expansion curve E F shows the fall in pressure as the steam in the cylinder expands behind the moving piston of the engine.

The point of release F shows when the exhaust valve opens.

The exhaust line F G represents the loss of pressure which takes place when the exhaust valve opens at or near the end of the stroke.

The back pressure line G H shows the pressure against which the piston acts during its return stroke. On diagrams taken from non-condensing engines it is either coincident with or above the atmospheric line, as in Fig. 1. On cards taken from a condensing engine, however, it is found below the atmospheric line, and at a distance greater or less according to the vacuum obtained in the cylinder.

The point of exhaust closure H is the point where the exhaust valve closes. It cannot be located very definitely, as the change in pressure is at first due to the gradual closing of the valve.

The compression curve H C shows the rise in pressure due to the compression of the steam remaining in the cylinder after the exhaust valve has closed.

The atmospheric line A B is a line drawn by the pencil of the indicator when its connections with the engine are closed and both sides of the piston are open to the atmosphere. This line represents on the diagram the pressure of the atmosphere, or zero of the steam gauge.

REFERENCE LINES EXPLAINED.

The zero line of pressure, or line of absolute vacuum *O X*, is a reference line, and is drawn by hand $14\frac{7}{10}$ pounds by the scale, below and parallel with the atmospheric line. It represents a perfect vacuum, or absence of all pressure.

The line of boiler pressure J K is drawn by hand parallel to the atmospheric line and at a distance from it, by the scale equal to the boiler pressure shown by the steam gauge. The difference in pounds between it and the line of the diagram *D E* shows the pressure which is lost after the steam has flowed through the contracted passages of the steam pipes and the ports of the engine.

The clearance line O Y is another reference line drawn at right angles to the atmospheric line and at a distance from the end of the diagram equal to the same per cent of its length as the clearance bears to the piston travel or displacement. The distance between the clearance line and the end of the diagram represents the volume of the clearance and waste room of the ports and passages at that end of the cylinder.

DERANGED VALVE MOTION.

Fig. 2 shows two diagrams, one from each end of the cylinder of a single-valve high pressure engine. This valve admits the steam over its ends and exhausts inside. The derangement is caused by the valve stem being too long; consequently, at the back end the diagram shows that the steam was admitted late, cut off early, exhausted early and the exhaust valve closed late, so that there is little or no compression.

The diagram at the crank end shows the opposite defects, viz.: Steam is admitted too soon and carried too far on the stroke, the exhaust valve is opened too late and closed too soon to get the steam well out of the cylinder, causing excessive back pressure—even greater than the boiler pressure as shown by the loop at the top.

To remedy this derangement, the valve stem should be shortened by the screw threads at one end. It may then be found that the steam valve

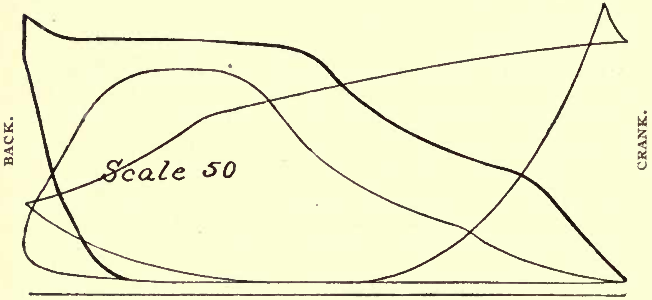

FIG. 2.

opens a little too late at both ends, and it will therefore be necessary to turn the eccentric ahead on the shaft until both diagrams resemble the figures shown in the heaviest lines.

UNITS OF MEASUREMENT AND TECHNICAL TERMS.

All substances of whatever nature are measurable, and their measurements are referable to some established unit, to be properly expressed and dealt with. An intimate knowledge of some of these is indispensable to the engineer; a few are here briefly defined:

The unit of linear measurement is the inch or one-twelfth part of a foot.

The unit of superficial measurement is the square inch.

The unit of solid measurement is the cubic inch.

The unit of fluid pressure is the pound avoirdupois, consisting of 7,000 grains.

The unit of elasticity, or the pressure exerted by elastic fluids, is, for popular use, one pound on one square inch.

The unit of work or power is one pound lifted twelve inches, or in other words, one pound of force acting through one foot of distance, and is called the foot-pound.

Horse Power.—The standard used for measuring the power of a steam engine is the horse power. It was originally determined by James Watt from experiments made on London dray horses. It is considerably above the power of an ordinary horse and is now simply an arbitrary standard. It is equal to 33,000 foot-pounds exerted during one minute of time, or 550 foot-pounds during one second. As a foot-pound is the amount of work done in raising one pound through the distance of one foot, an equivalent amount of work would be raising half a pound two feet, or twelve pounds one inch.

Indicated horse power is the horse power of an engine as found by the use of a steam engine indicator, and is thus expressed: I. H. P.

Net horse power is the indicated horse power of an engine, less the horse power which is consumed in overcoming its own friction.

Wire drawing, as applied to steam, is the reducing of its pressure, due to its flowing through restricted or crooked pipes and passages.

Absolute pressure is pressure reckoned from absolute vacuum; in other words, it is the pressure of any fluid as shown by a pressure gauge, with the weight or pressure of the atmosphere added thereto.

Initial forward pressure in a cylinder is the pressure acting on the piston at or near the beginning of the forward stroke.

Terminal forward pressure is the pressure above the line of perfect vacuum that would exist at the end of the stroke if the steam had not been released earlier. It may be found by continuing the expansion curve to the end of the diagram, as in Fig. 1 at *F*, or it may be taken at the point of release. This pressure is always measured from the line of perfect vacuum, hence it is the absolute terminal pressure.

Mean effective pressure is the average of all the steam pressure which acts on one side of the piston to move it forward, less all the steam pressure which acts on the other side of the piston to retard it. It is expressed thus: M. E. P.

Piston displacement is the space in the cylinder swept through by the piston in its travel. It is reckoned in cubic inches, and is found by multiplying the net area of the piston in inches, by the length of stroke in inches, allowance being made for the piston rod.

Clearance is all the waste room or space at either end of the cylinder, between its head and the piston when on a dead center, including the counterbore and the ports, up to the face of the closed valves.

Sensible heat is the temperature of any body, as air, water or steam, which may be measured by the thermometer.

Specific heat is the quantity of heat required to raise one unit of weight of the substance through one degree of temperature, measured in thermal units. When the pressure remains constant Regnault found the specific heat for superheated steam to be 0.4805 of a thermal unit.

The unit of heat, or thermal unit, is the quantity of heat required to raise the temperature of one pound of water from 62° to 63° F.

Mechanical Equivalent of Heat.—It has been found by experiment that if one pound of pure water at 62° F. be raised to 63° F., that energy is exerted equivalent to lifting 778 pounds one foot high, or one pound 778 feet high. This energy is called the mechanical equivalent of one thermal unit of heat, and it is usually designated by the letter *J* and its reciprocal, or $\frac{1}{778}$, by *A*.

Saturated Steam.—When steam is formed in a closed vessel in contact with its own liquid, it is said to be saturated, and it will have a certain definite pressure and density corresponding to each different temperature. If, at the same time, the steam contains no liquid in suspension, it is said to be dry and saturated.

Superheated Steam.—If, after all the liquid has been converted into steam, more heat be added, the temperature will rise and the steam is said to be superheated, because its temperature will be greater than that corresponding to saturated steam of the same pressure. The amount of superheating will vary according to the conditions under which it occurs—that is to say, whether the volume of the containing vessel varies or remains constant.

CHAPTER II.

HOW AND WHERE TO ATTACH THE INDICATOR.

The indicator should be attached close to the cylinder whenever practicable, especially on high speed engines. If pipes must be used they should not be smaller than half an inch in diameter, and as short and direct as possible; if long pipes are needed they should be slightly larger than half an inch, and covered with a non-conducting material.

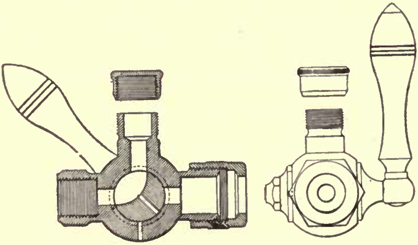

FIG. 3.

Diagrams should be taken from both ends of the cylinder of an engine. If the diagram from one end is satisfactory it is not safe to assume that one taken at the other end will be equally so; it is often otherwise, owing to the varying conditions usually found; the lengths of thoroughfares, the points of valve opening and closing, and the lead, are variable and should be carefully adjusted to secure the best results, and this can only be done through the instrumentality of an indicator.

When only one indicator is employed, it is generally attached to a three-way cock (Fig. 3), which is located midway in the line of pipe, connecting the holes at either end of the cylinder; by this arrangement diagrams can be taken from either end simply by turning the handle of the three-way cock. In such a case, the second diagram should be taken as quickly as possible after the first, so as to be under like conditions of speed, pressure and load.

The indicator can be used in a horizontal position, but it is more convenient to take diagrams when it is in a vertical position, and this can generally be obtained, when attaching to a vertical engine, by using a short pipe with a quarter upward bend. No putty or red lead should be used in making any joints, as particles of it may be carried by the steam into the indicator, and great harm result therefrom; if a screw fits loosely, wind into the threads a little cotton waste, which will make a steam tight joint. *The indicator should never be set so as to communicate with thoroughfares where a current of steam will flow past the orifice leading to the indicator, as the diagrams taken under such conditions would be of no practical value.*

The cylinders of most modern steam engines are drilled and tapped for the indicator and have plugs screwed into the holes, which can readily be removed and the proper indicator connections inserted. But when this is not the case, the engineer should be competent to do it under the directions here given.

When drilling holes in the cylinder the heads should be removed if convenient, so that one may know the exact position of the piston, the size of ports and passages, and be able to remove every chip or particle of grit which might otherwise do harm in the cylinder or be carried into the indicator and injure it. When the heads cannot be taken off, it can be arranged so that a little steam may be let into the cylinder, when the drill has nearly penetrated its shell, so that the chips may be blown outward, care being taken not to scald the operator.

Each end of the cylinder should be drilled and tapped for one-half-inch pipe thread. The holes must always be drilled into the clearance space, at points beyond the range of the piston when at the end of the stroke, so as not to be obstructed by it, and away from steam passages, to avoid strong currents of steam. By placing the engine on a dead center, it is easy to tell how much clearance there is, and the hole should be drilled into the middle of this space; the same process should be repeated at the other end of the cylinder.

On horizontal engines the most common practice is to drill and tap holes in the side of the cylinder at each end, and insert short half-inch pipes with quarter upward bends, into which the indicator cocks may be screwed; on some horizontal engines it may be more convenient to drill and tap into the top of the cylinder at each end, and screw the cocks directly into the holes. On vertical engines, for the upper end of the cylinder the cock may be screwed into the upper head or cover, and for the lower end, into the side of the cylinder, after drilling and tapping the necessary hole. It is preferable to drill the holes in the sides of a cylinder rather than the heads, because the former gives better results and requires less pipe and fittings.

Before deciding just where to drill the holes it is wise to consider all the conditions of the case and devise the whole plan for indicating the engine.

Sometimes a drum motion can be erected more advantageously in one place or position in the engine room than another, or one kind may be better adapted for a given place than another. Again, the type of engine and position of the steam chest, the kind of cross-head and the best means for attaching to it, the position of the eccentric, its rods and connections, all should be taken into account when determining the best places to drill the cylinder and locate the indicator, in order to secure a proper connection with the reducing motion, a perfectly free passage for steam to the indicator and the most convenient access to the instrument for taking diagrams.

CHAPTER III.

THE DRUM MOTION.

The motion of the paper drum may be derived from any part of the engine which has a movement coincident with that of the piston. In general practice and in a large majority of cases the cross-head is chosen as being the most reliable and convenient part, and for this purpose it is drilled and tapped for an iron stud or pin to be screwed into it. This stud should be long enough, in most cases, to reach about six inches beyond the outer surface of the cylinder. The movement of the cross-head must be reduced from whatever it actually is, to about three inches, or the length of the diagram to be taken, and this reduced motion must be in exact ratio to the motion of the piston.

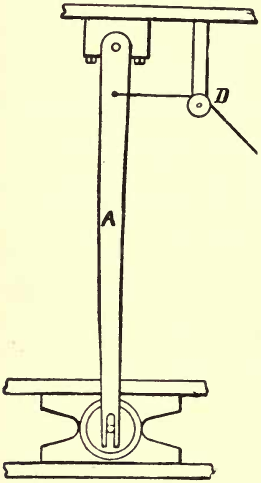

FIG. 4.

To obtain this reduced motion a variety of means may be employed, any one of which calls forth the ingenuity and skill of the engineer. The reducing lever in some one of its various forms is easily made, and can be adapted to suit almost any conditions.

The slotted lever (Fig. 4) is a common form of this device, and answers very well for large and quick running engines. It should be made of straight grained pine, one inch or more in thickness, about six inches wide at the top, where there is a hole for a bolt, and tapering to four inches at the bottom, where there is a slot about six inches long and of the same width as the diameter of stud in the cross-head, which gives it a vibrating motion. This lever is suspended by a bolt from the ceiling or from a truss or frame overhead prepared for that purpose, in such a manner as to permit it to swing edgewise and parallel with the guides. It must hang plumb when the stud in the cross-head is in the slot and the piston is at mid-stroke; in this position the slot should extend an inch or more above the stud, for play.

To find the point at which to attach the cord, divide the length of the lever by the length of the piston stroke, and multiply the quotient by the required length of the diagram, and the product will be the proper distance from the pivot to the point of attachment.

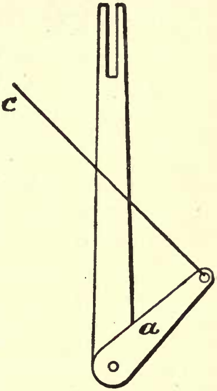

FIG. 5.

The slotted lever with a cord arm, which can be set at any desired angle to the main lever, is shown in Fig. 5. This is a convenient device when it is found necessary to attach the reducing motion to the floor, which may be done by fastening down with lag screws or bolts a suitable piece of timber, to which the lever is pivoted, so that it will vibrate edgewise with the movement of the engine. It may also be attached overhead in the same manner as the plain slotted lever. The lever must stand plumb when the piston is at mid-stroke, at which time the cord arm, *a*, must be fixed at such an angle as to have the cord, *c*, draw at right angles to its longitudinal axis, and in the plane of its vibration; the direction of the cord may have any necessary angle with horizontal line, but it must be at right angles with the cord arm at mid-stroke. The point of attachment for the cord is found by the same arithmetical rule as given for Fig. 4.

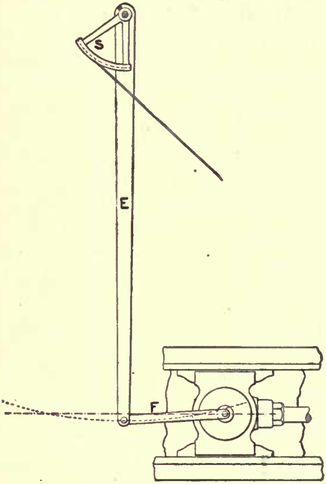

FIG. 6.

The Brumbo pulley, shown in Fig. 6, is another form of reducing lever, and one more generally used by engineers, especially on locomotives. It can be quickly and cheaply made, and can be used on almost any engine. The swinging lever, *E*, is a strip of pine board three or four inches wide, and at least one and a half times as long as the piston stroke. It is suspended by a bolt or screw from a frame or truss overhead, constructed for that purpose, and is connected at its lower end by the wooden link, *F*, of convenient length (say about one-half the length of stroke) to the usual stud or pin attached to the cross-head. The sector, *S*, also made of wood, with a groove in its lower circular edge for the cord to run in, is screwed to the upper end of the pendulum, so that its center will exactly coincide with the center of the bolt on which it swings. The radius of the sector, which is necessary to give the proper motion to the drum to obtain the desired length of the diagram, can be found as follows: Divide the length of the lever by the length of the piston stroke, and multiply the quotient by the length of the diagram desired, and the product will be the required radius, all the terms being expressed in inches. For example: If the lever is thirty inches long and the piston stroke twenty inches, and we wish to obtain a diagram three inches long, we have 30 inches ÷ 20 inches = 1½ inches; 1½ inches × 3 inches = 4½ inches, the radius required to give a 3-inch diagram.

When the conditions are favorable, the lever should be hung so that it will swing in a vertical plane, parallel with the guides and in line with the indicator, as this arrangement is the most simple, and the use of guide pulleys is avoided. It is not absolutely necessary, however, that the lever shall swing in a vertical plane, but it may swing in a plane at any angle thereto, where the conditions require it. In such cases, a man's ingenuity and inventive faculty must aid him. A link made of a thin strip of steel, that will twist a little, is in some cases very convenient.

When the cross-head is at mid-stroke the lever must hang plumb, and the pin which connects its lower end to the link must be as much below the line of motion of the stud in the cross-head *H*, as it sweeps above that line at either end of the stroke. See cut for illustration of this point, which is important. The cord must lead from the sector in about the same plane with its swing. Carrying pulleys should be avoided whenever possible, but whatever number is necessary should be firmly placed. The swinging arm of the guide pulley on the indicator should always be adjusted in the direction from which the cord is received. Some engines are furnished with a drum motion of this kind, made of steel with nicely fitted joints, which can be readily attached to the engine, and are very convenient to use.

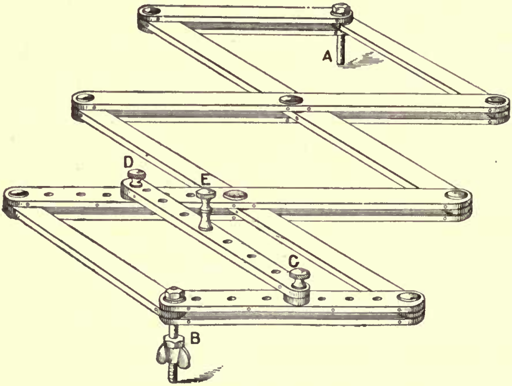

Fig. 7.

The pantograph, illustrated in Fig. 7, is another style of reducing motion. Although theoretically it gives a perfect motion, owing to its many joints it may soon become shaky and give erroneous results, unless it is very nicely made and carefully used. When the indicator is applied to the side of the cylinder the pantograph works in a horizontal plane. The pivot end *B* rests on a post or other support set opposite to the middle of the guides, and the working end *A* receives motion from the cross-head—to which it is attached by a suitable iron with a hole drilled in it for the stud A to work in. By adjusting the support for the pivot end to the proper height and at a proper distance from the guides, the cord may be carried directly from the pin E to the indicator without the need of carrying pulleys.

The reducing wheel is another device for giving the proper motion to the paper drum. Although old in principle, and as formerly made not highly approved by experienced engineers, this style is now coming into more general use, and the superior manner in which it is designed and constructed seems to warrant this change—especially on short-stroke engines which require only a short cord. Its portability and convenience of application also tend to make it a favorite, especially with young engineers. It is usually clamped to the frame of the engine, in a direct line from the indicator to the stud in the cross-head, thus avoiding the need of guide pulleys. This is considered the only practical drum motion for an oscillating engine.

Whatever drum motion mechanism is used, its accuracy can be easily tested in the following manner: Lay off on the guides, points at one-quarter, one-half and three-quarters of the stroke. Connect the indicator with the drum motion in the same manner as for taking diagrams. When the cross-head is on either dead center, touch the pencil to the paper and make a vertical mark, and in the same way make vertical marks when the cross-head reaches each successive quarter point on the guides. If the marks are exactly at fourths on the card, the motion of the cross-head has been accurately reduced.

The directions here given for constructing and arranging drum motions are general; special cases may require modification of the forms and special adaptation of the means here described, all of which call forth the ingenuity and skill of the engineer.

Fig. 8 X shows a pantograph device at mid-stroke. This is made of bar iron nicely riveted together. The indicator cord may be attached at *b*. The end *a* is attached to a pin on the cross-head. The fixed fulcrum is at *c*. *a*, *b* and *c* must always lie in the same straight line, and *e d*, *b n*, parallel and equal to *f g*. Also, *a f* : *n f* = stroke of piston to length of indicator diagram.

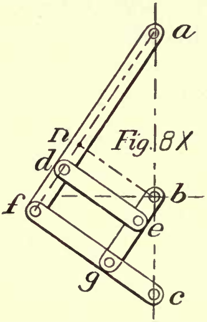

Fig. 8X

Fig. 8 Y is a device used at the Massachusetts Institute of Technology. *f* is a rod moving in a slide parallel to the piston rod. Link *b d* is attached to *f*, and link *a e* to the cross-head. *a*, *b* and *c* must always lie in the same straight line. *ae*:*bd* and *ec*:*cd* = stroke of piston to length of indicator diagram. The cord is hooked on a pin at *g*; it is well to have a pin for each indicator used.

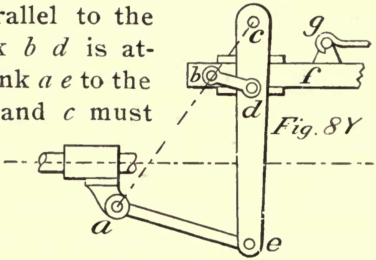

Fig. 8Y

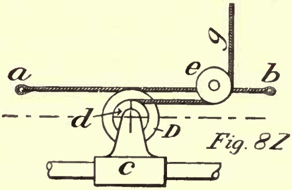

Fig. 8Z

Fig. 8 Z is a device by Armand Stévart for long strokes. *a* and *b* are fixed ends of cord wrapped around pulley *D*. Indicator cord is attached to small pulley *d* and passes around guide pulley *e*. *D* and *d* are attached to cross-head. Dia. $D \div$ dia. $d =$ stroke piston $\div$ the difference between stroke of piston and length of card.

CHAPTER IV.

HOW TO TAKE DIAGRAMS.

When the indicator has been placed in position and a correct drum motion obtained, it is next necessary to adjust the length of the cord so that the drum will not strike the stops at either extreme of its rotation. Find about the length of cord required and make a loop at the end, so that when the hook on the short piece of cord connected with the indicator is hooked in, the cord will be a little too long. Take up the extra length by tying knots in the cord until the drum rotates without striking either stop. This method may seem rather primitive, but it has been adopted by many of our best engineers after trying the various devices for shortening the cord.

The paper or card should be wrapped smoothly around the drum; have the two lower edges come evenly together as they meet after being passed under the clip; when in this position, the paper may be slipped down as far as the shoulder in the clip; a little practice will enable one to do this with facility.

After the cord is adjusted and a paper wrapped on the drum, open the indicator cock and allow the piston to play until the instrument has been thoroughly warmed by the steam, then gently press the pencil on the paper by the wooden handle. After the pencil has remained on the paper during one or more revolutions, draw it back, close the cock and again gently press the pencil on the paper and take the atmospheric line.

The pressure of the pencil on the paper can be adjusted by screwing the handle in or out, so that when it strikes the stop there will be just enough pressure on the pencil to give a distinct fine line. The line should not be heavy, as the friction necessary to draw such a line is sufficient to cause errors in the diagram.

After the diagram has been taken disconnect the cord, to avoid any unnecessary wear on the drum.

On locomotives and engines, the speed of which is so great that it is difficult to hook in the loop, arrangements can easily be made so this will not have to be done. At the further end of the arc on the Brumbo pulley insert an ordinary screw eye. Drive another screw eye firmly into a small hole drilled in the center of the end of the bolt on which the bar swings. The cord from the indicator can then be carried through the eye at the end of the arc, and then through the eye in the end of the bolt and back to some convenient point near the instrument where it can be easily reached by the operator. Connect the cord with the instrument and draw it through the eyes until the drum will not strike the stops at its extreme positions. Then at the point of the cord just before the eye at the end of the arc, tie a small ring. When the cord is drawn taut by the operator, the ring stops the cord when it has been drawn through just enough to give the proper motion to the drum. As soon as the diagram and atmospheric line have been taken, slacken the cord and the drum will stop. This arrangement is very convenient on locomotives, as the cord can be drawn taut with one hand while the diagram is taken with the other.

Make notes on the card of as many of the following facts as possible: The day and hour of taking the diagram; the kind of engine from which the diagram is taken, which end of the cylinder and which engine, if one of a pair; the diameter of the cylinder, the length of the stroke, the diameter of the piston rod, the number of revolutions per minute and the position of the throttle; the atmospheric pressure; the steam pressure at the boiler and at the engine, by the gauge; the vacuum by the gauge on condenser and the temperature of the feed at the boiler; if the engine is compound, the pressure in the receiver; the scale of the spring used in the indicator; the volume of the clearance at each end of the cylinder, and what per cent of the piston displacement each of these volumes is. (Directions for ascertaining the volume of the clearance and what per cent that volume is of the piston displacement, are given on pages 97 to 100.)

It is often useful to make notes of special circumstances of importance, such as a description of the boiler, the diameter and length of the steam and exhaust pipes, the temperature of the feed water, the quantity of water consumed per hour, etc.

On a locomotive, note the time of passage between mile posts in minutes and seconds, from which, when the diameter of the drivers is known, the number of revolutions per minute may be calculated. Note also the position of the throttle and the link, the size of the blast

Engine............ *Hour*............ *No.*............

Date............ *Condition* .... *Cyl.*............ *End*............

Diam. Cyl............. *Stroke*............ *Diam. Pist. Rod*............ *Throttle*............ *Revs.*............

Press. by Gauge	
Boiler	....
At Engine	....
Vacuum	....
Atmos. Press.	....
Area	....
Length	....
Av'ge Height	....
M. E. P.	....
I. H. P.	....

Indicator cards, printed as here shown, with blank spaces for writing in the data usually required with a diagram, are now commonly used. This form is very convenient for mounting in a book.

orifice, the weight of the train, and the gradient.

On diagrams from marine engines, note, in addition to the general facts, the speed of the ship in knots per hour, the direction and force of the wind, the direction and state of the sea, the diameter and pitch of the screw, the kind of coal, the amount consumed, and the ashes made per hour.

CHAPTER V.

HOW TO FIND THE POWER OF AN ENGINE.

To find the power actually exerted within the cylinder of a steam engine, it is necessary to ascertain separately three factors and the product of their continued multiplication. These factors are: The net area of the piston, designated by the letter *a;* the mean velocity or speed of the piston, designated by *s;* and the mean effective pressure urging the piston forward, designated by M. E. P.

The Piston Area.—This, at the back end, is the same as the area of cross-section of the cylinder; at the crank end it is the same, less the area of cross-section of the piston rod. These areas may be found from their diameters in a table of the areas of circles, or be computed by multiplying the square of the diameter in inches by the approximate number 0.7854.

The Mean Piston Speed.—The mean of the constantly varying speed of the piston is found by multiplying twice the length of the stroke measured in feet, by the number of revolutions of the crank shaft per minute, which should be carefully ascertained by taking the mean of many countings, or the readings of a speed counter during a considerable time. The mean piston speed will be expressed in terms of feet per minute.

The Mean Effective Pressure.—There are several approximate methods for computing the mean effective pressure, one of which is to divide the diagram into ten equal parts, as shown in Fig. 9. Then through the points of division draw lines, which are called ordinates, at right angles to the atmospheric line. The mean heights or pressures of the small areas thus formed are indicated by the dotted lines midway between the ordinates.

The mean effective pressure of the whole (of each) diagram may now be found by measuring (on the dotted lines) the mean pressure in each of the small areas with the scale corresponding to the spring used in taking the diagram.

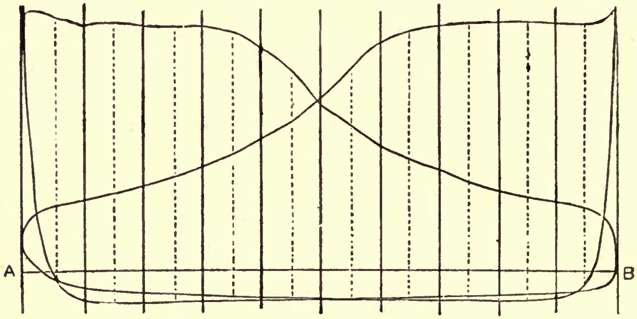

FIG. 9.

Diagrams from Hartford engine. Cylinder, 16×24 inches. Boiler pressure, 87 pounds. Vacuum per gauge, 23½ inches. 130 revolutions per minute.

The sum of these mean pressures, divided by 10, the number of divisions, will give the mean effective pressure sought, in pounds per square inch.

If a diagram has many irregularities of outline, it may be necessary to divide it into twenty equal divisions to insure a correct measurement of the pressures; in such a case we divide the sum of the pressures by 20 instead of 10. In other cases, when irregularities occur only in a part of a diagram, it is only necessary to subdivide one or more of the ten divisions to insure greater accuracy in that part; in such a case we must measure the pressure in each subdivision and divide their sum by 2 to get the mean pressure of that division. (See Fig. 11 for a full illustration of this method.)

If the scale is not at hand the heights of the divisions may be pricked or marked off on a strip of paper, one after the other continuously until all are measured; then the distance from the end

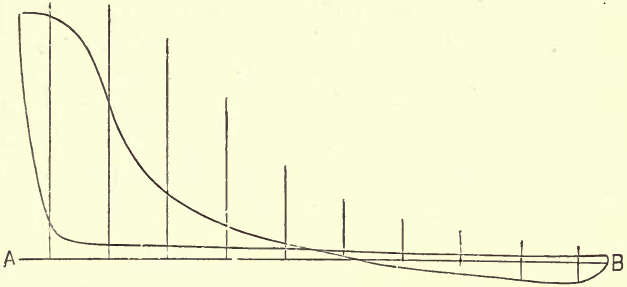

FIG. 10.

of the strip to the last mark will represent the sum of all the measurements, which can be measured in inches with an ordinary rule. This quantity, divided by the number of divisions in the diagram—or diagrams, if there are two—and multiplied by the scale of the spring used, will give the average of mean effective pressure, the same as by the other method.

When there is a loop in the diagram, as in Fig. 10, the area inclosed in the loop should be subtracted from the other part, as it represents loss of efficiency.

The quickest and most accurate method for measuring the diagram and finding the mean effective pressure is by the use of Amsler's Polar planimeter. With careful manipulation, the planimeter will give the exact area of a diagram in square inches and decimal parts thereof, to hundredths of a square inch, and the tedious process of dividing the diagram into equal parts and measuring their average pressures or heights, with the liability of making errors, is avoided.

Measure the diagram with the planimeter, as directed in Chapter VII. Divide the number of square inches area thus found by the length of the diagram, expressed in inches and decimals, and the result will be the average height of the diagram. Multiply this average height by the scale corresponding to the spring used in taking the diagrams, and the result will be the mean effective pressure. It is better to multiply first and divide afterward, to avoid troublesome fractions. (A description of the planimeter and full directions for its use on indicator diagrams are given in Chapter VII, Part II, and Chapters X and XI, Part III.)

Fig. 11 illustrates two diagrams divided first into ten equal spaces, and then each end space subdivided so as to more accurately measure those parts of each in which the greatest irregularities occur. Observe that the pressures or heights of the subdivisions of each end space are measured, and the sum of these measurements divided by 2 to get the mean pressure or height of that one of the ten spaces.

The pressures of Diagram No. 1, as measured by the scale, are set in a column on the left,

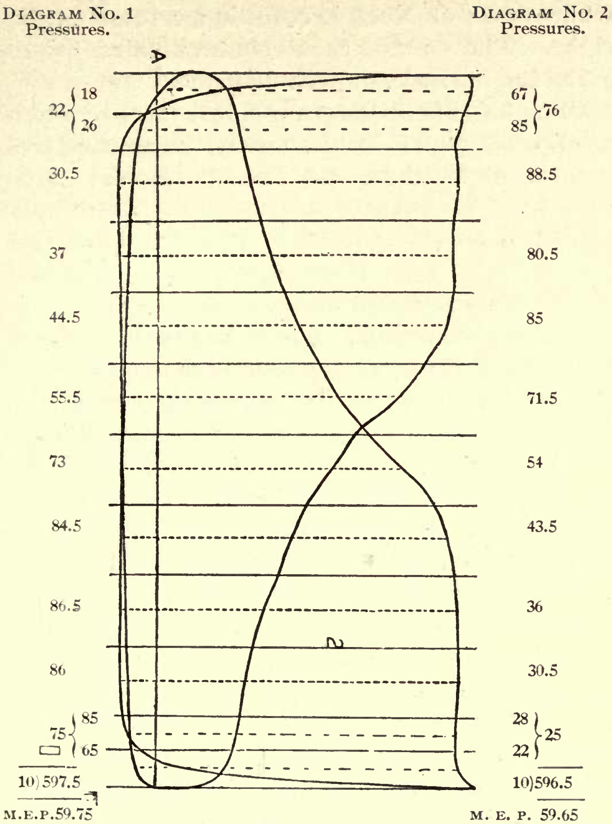

Fig. 11.

Heights of Divisions Measured on a Strip of Paper.

Diagram No. 1.		Diagram No. 2.
10) 11.95 in.	Divide by 10	10) 11.93 in.
1.195		1.193
50	Multiply by proper scale.	50
M.E.P. 59.750		M. E. P. 59.650

Planimeter Measurements.

Diagram No. 1.		Diagram No. 2.	
Square inches,	4.42	Square inches,	4.46
Length,	3.72	Length,	3.73
Average height,	1.188	Average height,	1.195
M. E. P.	59.4 lbs.	M. E. P.	59.75 lbs.

while those of No. 2 are set in a column on the right. The sum of each column divided by 10 gives the M. E. P. of that diagram.

The heights of Diagram No. 1, marked off on a slip of paper continuously, measure 11.93 inches, while those of No. 2 measure 11.95 inches; these quantities, divided by 10 and multiplied by 50, give the M. E. P. of each diagram respectively, and if accurately measured, will be the same as found by the scale.

These diagrams, when measured by the planimeter, give results which are substantially the same as found by the approximate methods. These results are given at the bottom of page 93 with Fig. 11.

Having now obtained, by one of the several methods given above, our three factors mentioned at the beginning of this chapter, viz.:

a = mean net area of piston in square inches.

s = mean speed of piston in feet per minute.

p = mean effective pressure in pounds on each square inch of the piston—the product of their continued multiplication will give the indicated power of the engine in foot-pounds per minute; and this product divided by 33,000, which is the conventional number of foot-pounds in one horse power, will give a quotient equal to the indicated power of the engine in indicated horse power, commonly designated by the initial letters I. H. P.

$$\text{Thus: I. H. P.} = \frac{a \times s \times p}{33{,}000} \text{ or } \frac{a\ s\ p}{33{,}000}$$

When there are a number of diagrams taken from the same engine to be worked up, the calculations may be simplified by multiplying the area of the piston by twice the length of the stroke, and dividing the result by 33,000. This gives the "constant of the engine," that is, the power that would be developed at one revolution per minute with one pound mean effective pressure. Multiply this constant by the number of revolutions per minute, and then by the mean effective pressure, and the product will be the I. H. P.

If the number of revolutions is the same for several diagrams, as is frequently the case with stationary engines, the calculation may be still further simplified by multiplying the "constant of the engine" by the number of revolutions per minute. This will give the "horse power constant," or the horse power developed per pound M. E. P. Multiply the horse power constant by the M. E. P., and the product will be the indicated horse power (I. H. P.).

CHAPTER VI.

THE HYPERBOLIC CURVE.

This curve is frequently applied to indicator diagrams for the purpose of comparing it with the expansion curve as drawn by the indicator, and if it coincides very nearly, this fact may generally be taken as evidence tending to show that the steam and exhaust valves of the engine are properly closed and the piston tight.

Without going into any discussion regarding condensation and re-evaporation in steam engine cylinders, it is a well known fact that indicator diagrams, taken from large engines, properly made and in good order, show expansion curves which are close approximations to the hyperbola.

Before this curve can be drawn, it is necessary to ascertain the capacity of the clearance or waste room; that is, all the space between the cylinder heads and the piston at each dead center, including the counterbore and the ports up to the face of the closed valves.

There are several ways of finding this: One, by direct calculation from sectional drawings, when accurate drawings can be obtained; another, by putting the engine at dead center with valves closed, and then filling the clearance space with water, which has been carefully weighed in a convenient vessel, then weighing what is left; and the difference between the weight of the whole and the remainder is the weight of water required to fill the clearance space. From this the number of cubic inches occupied by the water may be computed. At ordinary temperatures (60° to 75° F.), for all practical purposes, we may call the weight of one cubic inch of water 0.036 pounds, and 27.8 cubic inches of water equal to one pound. Then the number of pounds of water, divided by 0.036 or multiplied by 27.8, will give the number of cubic inches. If accurate scales for weighing the water are not at hand, it can be carefully measured in a quart or pint measure, and the number of cubic inches found directly. A gallon contains 231 cubic inches, a quart 57.75 and a pint 28.875 cubic inches.

The volume of the clearance will rarely be alike at the two ends of the cylinder, therefore the number of cubic inches in the clearance at each end must be divided by the net area of the piston at its own end; that is, the number of cubic inches in the clearance at the end nearest the crank must be divided by the number of square inches in the cross-section of the cylinder, less the number of square inches in the cross-section of the piston-rod; and the number of cubic inches in the clearance at the end farthest from the crank must be divided by the number of square inches in the cross-section of the cylinder. The quotient in each case will be the length of clearance at the respective ends of the cylinder, expressed in inches.

It is convenient to have the length of the clearance expressed as a fraction of the piston displacement or stroke of the piston. To obtain this fraction, divide the number of cubic inches in volume of clearance by the number of cubic inches in the volume swept through by the piston at each end separately, taking care to allow for the volume occupied at one end by the piston rod, and the quotient will be the decimal fraction that the clearance space is of the volume swept through by the piston. In this instance (Fig. 12) it is found to be .16 inches.

Fig. 12 illustrates a good method for locating points in the hyperbola through which the curve may be drawn.

First, draw the zero line *V*, at the proper

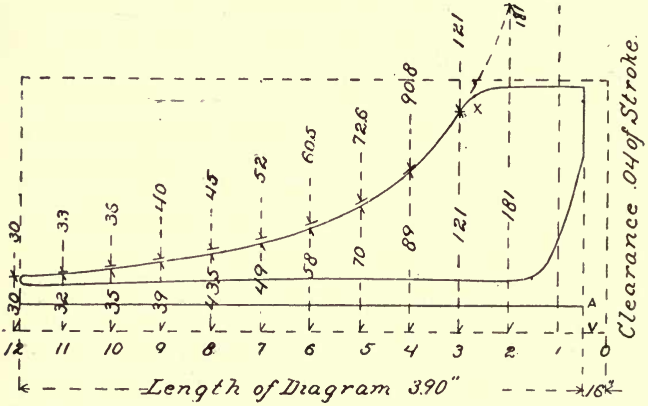

FIG. 12.

distance, viz., $14\frac{7}{10}$ pounds by the scale below and parallel with the atmospheric line; next, draw the clearance line *O*, as computed, .16 of an inch from the end of the diagram; next, locate the point of cut-off *X*, and draw the perpendicular line number 3 through it; next, divide the space between this line and the clearance line into three equal parts; then, taking one of these parts for a measure, point off, on the vacuum line, equal spaces toward the left hand until one or more falls beyond the end of the diagram as shown, and erect perpendicular lines from each point. These lines are called ordinates and numbered consecutively 1, 2, 3, 4, etc., beginning with the one next to the clearance line. It is well to bear in mind the fact that vertical distance on a diagram represents pressure, and horizontal distance volume.

In this case we have started the hyperbola from the point of cut-off *X*, and its course is indicated by the short lines drawn through the ordinates a little above the actual curve, with their calculated pressures written above; the actual pressures of the expansion curve are written below it. The properties of the hyperbola are such, that if the distance of the point *X* from the clearance line *O* be multiplied by the height of *X* from the zero line *V*, the height of any other point in the curve can be found by dividing this product by its distance from the clearance line. And on this principle we proceed to locate points on the ordinates through which our hyperbola will run.

We find the pressure at the point of cut-off to be 121 pounds, with a volume which we call 3, because there are three spaces or volumes between it and the clearance line. Then, $121 \times 3 = 363$, which is our dividend for all the other volumes. Therefore the height at which the hyperbola will cut ordinate 4 will be determined by dividing 363 by 4, which is 90.8 (it is unnecessary to carry the division beyond one decimal), and of ordinate 5, 72.6; of ordinate 6, 60.5; and so on to the end. At ordinate 12 we find that the hyperbolic and the actual curves practically coincide. In like manner we may extend the curve to the right: $363 \div 2 = 181$ pounds, which would be the pressure if the steam were compressed up to two volumes. If desired, the hyperbolic curve can be started just before the point of release, and projected in the opposite direction by the same method.

Instead of using figures, which stand for pressures or volumes of steam, to locate the hyperbola, as in this instance, the distances from the base and perpendicular lines of any point may be expressed in inches and decimal parts, with the same result.

A quick way to draw the hyperbola is to take the whole distance between ordinate 3 and the clearance line as a measure, and set off equal spaces to the left, as before directed. Then we would have but four ordinates, and would number them as follows: 1 at 3d, 2 at 6th, 3 at 9th and 4 at 12th. At 1 we would have a pressure of 121 pounds; at 2, 121 pounds $\div 2 = 60.5$; at 3, 121 pounds $\div 3 = 40$; and at 4, 121 pounds $\div 4 = 30$.

As a general rule, the near approximation of the expansion curve to the theoretical or hyperbolic curve may be taken as evidence of good conditions, but should not be accepted for a certainty, unless all the known facts and conditions tend in the same direction.

GEOMETRIC METHOD OF FINDING THE HYPERBOLA.

The hyperbola may be found by following the directions given below, in connection with Fig. 13. *A* is the atmospheric line; *Z* the zero line, or line of no pressure; *B* the line of boiler pressure, and *C* the clearance line. Locate the first point in the hyperbola at the point of release, *X*, and draw the vertical line, *X E*. Then draw diagonal line *E H*; then, from *X*, draw horizontal

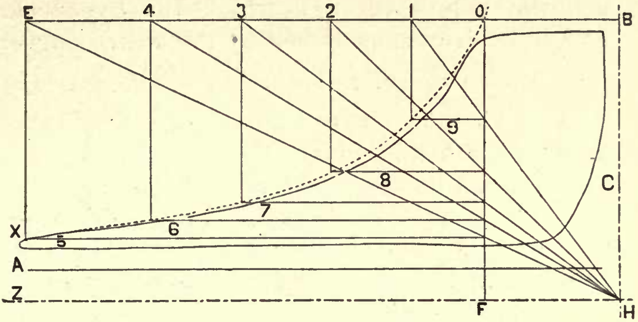

FIG. 13.

line 5 to its intersection with *E H*, through which draw vertical line, *F O*. Now, mark off points between *O* and *E*, as 1, 2, 3, 4—exact spacing is unnecessary—and from these points draw diagonal lines to *H*, and vertical lines down to, or

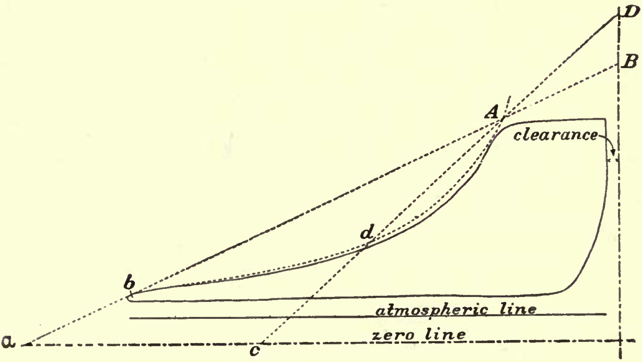

FIG. 14.

a little below, the actual curve. Now, draw horizontal lines 6, 7, 8 and 9 from the points of intersection in the line *F O*, of the diagonal lines

H 4, *H* 3, *H* 2 and *H* 1, respectively; and the points where these lines cross the vertical lines, 1, 2, 3 and 4, in connection with points *X* and *O*, are the points through which the hyperbola should be drawn, as shown by the dotted curve.

ANOTHER METHOD OF FINDING THE HYPERBOLA.

Fig. 14, shown on preceding page, illustrates another method of finding the hyperbola.

Through the point of release *b* draw any line, as *a B*, and make *A B* equal to *a b*. Then draw any other line, as *c D*, and make *c d* equal to *A D*; then *d* will be a point in the hyperbola passing from *b* to *A*, as shown by the dotted curve. By drawing a number of lines through *A* and following the same method, we can find as many points in the hyperbola.

CHAPTER VII.

AMSLER'S POLAR PLANIMETER, WITH DIRECTIONS FOR USING IT ON INDICATOR DIAGRAMS.

Fig. 15 represents the No. 1 planimeter. It is the simplest form of the instrument, having but one wheel, and is designed to measure areas in square inches and decimals of a square inch. The figures on the roller wheel *D* represent units, the graduations on the wheel represent tenths, and the vernier gives the hundredths.

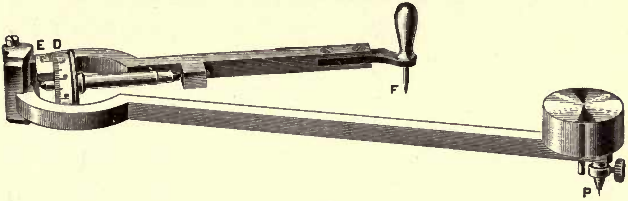

FIG. 15.

Directions for Measuring an Indicator Diagram with a No. 1 Planimeter.—Care should be taken to have a flat, even, unglazed surface for the roller wheel to travel upon. A sheet of dull finished cardboard serves the purpose very well.

Set the weight in position on the pivot end of the bar *P*, and after placing the instrument and the diagram in about the position shown in the cut (Fig. 16), press down the needle point so that it will hold its place; set the tracer point at any given point in the outline of the diagram, as at *F*, and adjust the roller wheel to zero. Now follow the outline of the diagram carefully with the tracer point, moving it in the direction indicated by the arrow, or that of the hands of a watch, until it returns to the point of beginning. The result may then be read as follows: Suppose we find that the largest figure on the roller wheel *D* that has passed by zero on the vernier *E*, to be 2 (units), and the number of graduations that have also passed zero on the vernier to be 4 (tenths), and the number of the graduation on the vernier which exactly coincides with a

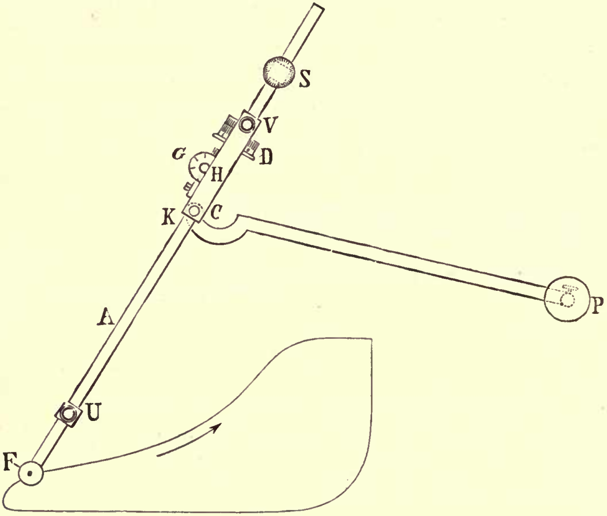

FIG. 16.

graduation on the wheel to be 8 (hundredths), then we have 2.48 square inches as the area of the diagram. Divide this by the length of the diagram, which we will call 3 inches, and we have .8266 inches as the average height of the diagram. Multiply this by the scale of the spring used in taking the diagram, which in this case is 40, and we have 33.06 pounds as the mean effective pressure per square inch on the piston of the engine.

When there is a loop in the diagram (see Fig. 10), caused by the steam expanding below the back pressure line when the engine is non-condensing, its outline should be traced in the same way as directed for a plain diagram, as the principle on which the planimeter works is such that the area of the loop will be subtracted from the main part of the diagram, and the reading of the instrument when the measurement is completed will be the correct net area sought.

When one has become familiar with the use of the planimeter it is not necessary always to set the wheels at zero, as required in the foregoing directions, but their reading as they stand just before beginning to trace a diagram may be noted down, and this quantity subtracted from the reading when the tracing is completed. The difference between the two readings is the area sought.

The use of Amsler's Polar planimeter in the measurement of indicator diagrams enables one to measure ten cards with it in the time which would be required to measure one card by any other method, and it insures the utmost accuracy in the work.

The planimeter is a precise and delicate instrument, and should be handled and kept with great care, in order that it may be depended upon to give correct results. After using it should be wiped clean with a piece of soft chamois skin.

INDICATING

THE

REFRIGERATING MACHINE

PART III.

CONSTRUCTION OF INDICATORS.

INTRODUCTION.

MANUFACTURERS' DESCRIPTION OF INDICATORS, PLANIMETERS, REDUCING WHEELS AND COFFIN'S AVERAGING INSTRUMENT, ETC.

The author is indebted to the various indicator manufacturers for the following cuts and descriptions of their instruments. The indicators are described as "Steam Engine Indicators," but the descriptions, of course, apply equally as well to ammonia compressor indicators, the only difference being that for compressor indicating most manufacturers make an indicator of steel, aluminum or composition metal, to resist the action of ammonia. In all other particulars the indicators are the same.

I recommend that the reader send for the catalogues and price lists of these instruments. The catalogues will be mailed free of charge, and many of them are quite valuable as treatises on indicator practice.

CHAPTER I.

THE CROSBY INDICATOR.

The Crosby Indicator is designed and constructed to meet the exacting requirements of modern engineering. During the last few years, under the keen search and exhaustive tests of eminent engineers, the practice in this department of science has undergone important changes, tending to establish more correct methods and thereby to reach more accurate results; especially is this true in the use and scope of the indicator, so that the work done with this instrument in former times seems coarse and crude when compared with the more exact attainment of the present.

Educators in the scientific schools of both Europe and America have seen the importance of more exact knowledge and instruction in the technical sciences; and the great achievements of recent years in the construction of buildings, ships, armaments and machines attest the thoroughness with which research in these departments has been prosecuted; in none has there been greater progress made than in those of mechanical and steam engineering.

A knowledge of these facts has kept the manufacturer of the steam engine and ammonia compressor indicator on the alert. Within a recent time, the Crosby indicator has, without any great change in its outward appearance, received important improvements. Slight changes in design, a more perfect mechanical construction due to the use of improved and specialized machinery, and a careful selection of metals for the different parts, have all contributed to this favorable result.

The movements of piston and pencil point are perfectly parallel; the movement of the pencil point is also exactly parallel with the axis of the drum.

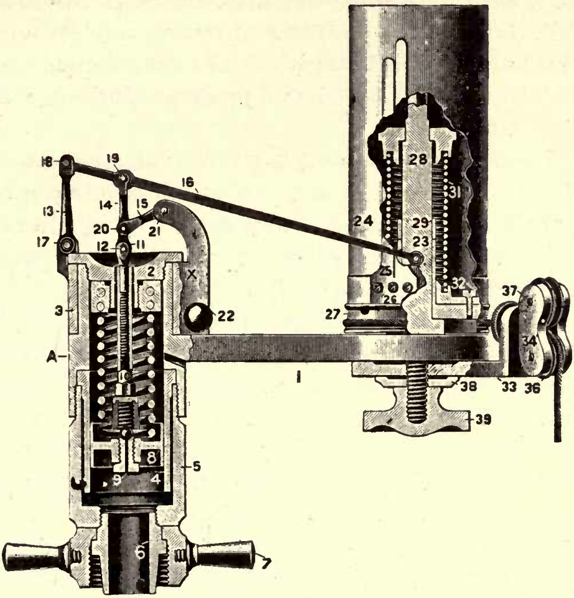

FIG. 1.

The rating of the springs by the newly constructed testing apparatus, which embodies all the valuable aids to exactness which have yet been discovered, is nearer perfection than could have been attained, or even expected, until within a very recent time.

DESCRIPTION OF THE INDICATOR.

The illustration shows the design and

arrangement of the parts of the Crosby steam engine indicator.

Part 4 is the cylinder proper, in which the movement of the piston takes place. It is made of a special alloy, exactly suited to the varying temperatures to which it is subjected, and secures to the piston the same freedom of movement with high pressure steam as with low; and as its bottom end is free and out of contact with all other parts, its longitudinal expansion or contraction is unimpeded, and no distortion can possibly take place.

Between parts 4 and 5 is an annular chamber, which serves as a steam jacket; and being open at the bottom, can hold no water, but will always be filled with steam of nearly the same temperature as that in the cylinder.

The piston 8 is formed from a solid piece of the finest tool steel. Its shell is made as thin as possible consistent with proper strength. It is hardened to prevent any reduction of its area by wearing, then ground and lapped to fit (to the ten-thousandth part of an inch) a cylindrical gauge of standard size. Shallow channels in its outer surface provide a steam packing, and the moisture and oil which they retain act as lubricants, and prevent undue leakage by the piston.

The piston rod 10 is of steel and is made hollow for lightness. It is connected with the piston by a screw at its lower end. When these parts are connected, be sure to screw the rod into the slotted socket as far as it will go; that is until the upper edge of the socket is set firmly against the bottom of the channel formed in the under side of the shoulder of the piston rod. This is very important, as it insures a correct alinement of the parts and a free movement of the piston within the cylinder.

The swivel head 12 is screwed into the upper end of the piston rod, more or less according to the required height of the atmospheric line on the diagram. Its head is pivoted to the piston rod link of the pencil mechanism.

The cap 2 rests on top of the cylinder, and holds the sleeve and all connected parts in place. The smooth portion of the cap which fits into the top of the cylinder serves as a guide by which all the moving parts are adjusted and kept in correct alinement.

The sleeve 3 surrounds the upper part of the cylinder and supports the pencil mechanism. The arm X is an integral part of it. The handle for adjusting the pencil point is threaded through the arm, and in contact with a stop screw in the plate may be delicately adjusted to the surface of the paper on the drum. It is made of hard wood in two sections; the inner one may be used as a lock nut to maintain the adjustment.

The pencil mechanism is designed to afford sufficient strength and steadiness of movement, with the utmost lightness; thereby eliminating, as far as possible, the effect of momentum, which is especially troublesome in high speed work. Its fundamental kinematic principle is that of the pantograph. The fulcrum of the mechanism as a whole, the point attached to the piston rod and the pencil point are always in a straight line. This gives to the pencil point a movement exactly parallel with that of the piston. The pencil lever, links and pins are all made of hardened steel; the latter—slightly tapering—are ground and lapped to fit accurately, without perceptible friction or lost motion.

Springs.—In order to obtain a correct diagram, the height of the pencil of the indicator must exactly represent in pounds per square inch the pressure on the piston of the steam engine at every point of the stroke; and the velocity of the surface of the drum must bear at every instant a constant ratio to the velocity of the piston. These two essential conditions have been attained to a great degree of exactness in the Crosby indicator by a very ingenious construction and nice adaptation of both its piston and drum springs, and have proved satisfactory.

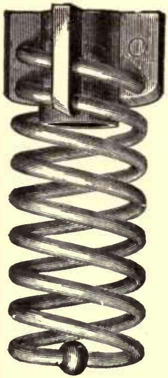

FIG. 2.

The piston spring is of unique and ingenious design, being made of a single piece of the finest spring steel wire, wound from the middle into a double coil, the spiral ends of which are screwed into a brass head having four radial wings with spirally drilled holes to receive and hold them securely in place. Adjustment is made by screwing them into the head more or less until exactly the right strength of spring is obtained, when they are there firmly fixed. This method of fastening and adjusting removes all danger of loosening coils, and obviates all necessity for grinding the wires.

The foot of the spring—in which lightness is of great importance, it being the part subject to the greatest movement—is a small steel bead, firmly "staked" on to the wire. This takes the place of the heavy brass foot used in other indicators, and reduces the inertia and momentum at this point to a minimum, whereby a great improvement is effected. This bead has its bearing in the center of the piston, and in connection with the lower end of the piston rod and the upper end of the piston screw (both of which are concaved to fit) it forms a ball-and-socket joint which allows the spring to yield to pressure from any direction without causing the piston to bind in the cylinder.

The drum spring in the Crosby indicator is a short spiral.

If the conditions under which the drum spring operates be considered, it will readily be seen that at the beginning of the stroke, when the cord has all the resistance of the drum and spring to overcome, the spring should offer less resistance than at any other time; in the beginning of the stroke in the opposite direction, however, when the spring has to overcome the inertia and friction of the drum, its energy or recoil should be greatest.

These conditions are fully met in the Crosby indicator; its drum spring being a short spiral, having no friction, a quick recoil, and being scientifically proportioned to the work it has to do.

The drum and its appurtenances, except the drum spring, are similar in design and function to like parts of other indicators, and need not be particularly described. All the moving parts are designed to secure sufficient strength with the utmost lightness, by which the effect of inertia and momentum is reduced to the least possible amount.

From the design of the Crosby indicator as above set forth—the conformation and purpose of its several parts—it will be seen that every opportunity to improve the instrument has been taken. Add to this the fact that only the most skillful workmen of long training in the art are employed, and that every part is made to a standard size by modern specialized machinery, with tools perfectly adapted to their work, and it will be admitted that the proper means have been taken to produce a first-class indicator. We believe this object has been accomplished.

All Crosby indicators are changeable from right hand to left hand instruments if occasion requires.

The Crosby indicator is ordinarily made with a drum one and one-half inches in diameter, this being the correct size for high speed work, and answering equally well for low speeds. If, however, the indicator is to be used only for low speeds, and a longer diagram is preferred, it can be furnished with a 2-inch drum.

The Crosby indicator in a special design is made to indicate extremely high pressures. Instruments of this design have been used with perfect success in the testing of ordnance and for other explosive effects.

When desired the Crosby indicator is made of steel, to resist the action of ammonia.

A detent attachment is furnished with the instrument when required.

Every part of the Crosby indicator is perfectly adapted to its particular function, also to its relation to all the other parts, in size, proportion and material. Its small size and light weight serve to protect it from accident, and so contribute to its durability and to the facility with which it can be handled.

Full particulars for the proper care and handling of the Crosby indicator accompany each instrument. They are manufactured only by the Crosby Steam Gage and Valve Co., Boston, Mass.

CHAPTER II.

THE BACHELDER ADJUSTABLE SPRING INDICATOR.

Since the introduction of the Bachelder indicator to the public some years ago it has been materially improved, both in design and detail of construction.

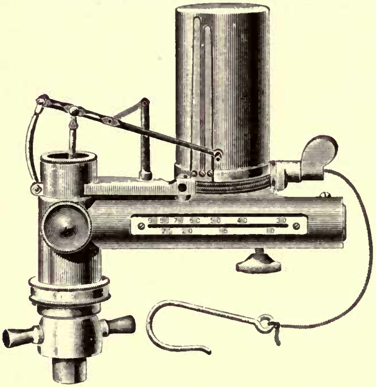

FIG. 3.

The flat spring is no longer an experiment, but an established success as to accuracy and durability. The downward motion of the spring being the same as the upward, a correct record is shown of a condensing or low pressure cylinder of a compound engine.

DESCRIPTION OF THE INDICATOR.

The special features of this instrument consist of the T shaped hollow case, and adjustable flat spring. The cylinder, being separate from the case proper, is screwed to the lower end, where it is held by a small set screw. By turning this screw one-half of a turn the cylinder can be unscrewed; then to remove the piston, take out the screw at the piston end of the spring, and at the connection with pencil lever. These are the only parts necessary to remove for cleaning. The flat steel spring works in the horizontal body of the case, one end being rigidly secured by means of a taper steel screw, and the other attached to the connecting rod between the piston and pencil lever. The change of spring is made by removing the screw that connects it to the piston rod, and the one which holds it in the case. The range of the high pressure spring is so great that a change is only necessary when using on a compound or triple

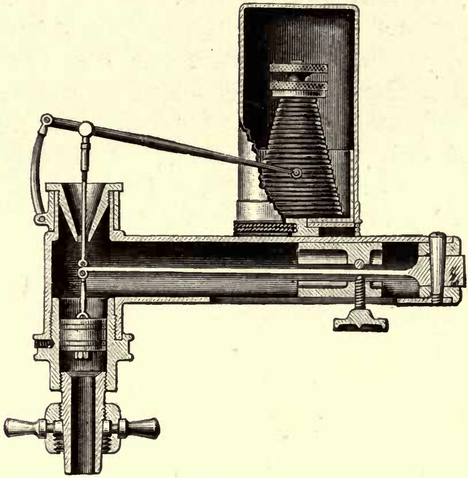

FIG. 4.

expansion engine. Connection is made to the piston with a ball and socket joint. Access can be had to the piston for oiling or removing, by unscrewing knurled cap on face of instrument.

A split bushing in the case is provided with a longitudinal recess for the reception of the spring. In the upper side of the bushing a hardened steel pin is inserted. The lower side of the case has a longitudinal slot, through which a set screw passes and through the lower side of the bushing, directly opposite the steel pin, so that when the screw is tightened, the spring is held rigidly between it and the steel pin. To change from one scale to another, loosen the set screw and slide the bushing along until the mark on projecting block is opposite the scale required, then tighten the screw. The scales are marked on the face of the case, the upper one being for high pressure, and the other for low pressure. The parallel motion is of the latest improved design, is entirely accurate and free from lost motion or friction. The height of atmospheric line is adjustable by means of a swivel in connecting rod near the pencil lever. With this brief description and a reference to the accompanying cuts, the general principle will be readily understood.

Each indicator is furnished with two flat springs, which are equivalent to eleven spiral springs.

The low pressure springs have the scales of 10, 15, 20 and 25. The high pressure springs have the scales of 30, 40, 50, 60, 70, 80 and 90, so that cards of proper height can be taken at any pressure up to 175 pounds. A special instrument for ammonia use, or for higher pressures than the above is furnished when required.

The Bachelder indicator is manufactured only by John S. Bushnell, successor to Thompson & Bushnell, 120 and 122 Liberty street, New York City.

CHAPTER III.

IMPROVED ROBERTSON-THOMPSON INDICATOR.

The improved Robertson-Thompson indicator, which has just been placed on the market, is unusually heavy, but as a result of most careful experiment this weight is so perfectly distributed that the best results may be attained at speeds far in excess of any met with in actual practice. One of the most serious errors in ordinary indicator work is caused by flexure of the arm which carries the drum, particularly when the cord is carried above or below the instrument. In this manner an error of 10 per cent is easily possible, particularly if the instrument is being used with a high pressure spring. For instance, with an 80 spring it would require a movement of but one-eightieth of an inch to show an error of one pound. In many cases weakness at this point will account for the curious features often noticed at the junction of the admission and steam lines on the diagram. The drum carrying arm of the improved Robertson-Thompson indicator is so stiff that no error from this cause is possible.

DESCRIPTION OF THE INDICATOR.

The cylinder is steam jacketed, and by its construction the possibility of the piston being cramped as a result of external strains is precluded. The area of this cylinder is exactly one-half inch, and each spring is suitable for twice the pressure stamped on it; for instance, a 60 spring may be used for a pressure of 120 pounds or less. The coupling is reamed to ¼-inch area, and with each instrument an extra ¼-inch piston is furnished. With this piston each spring may be used for pressures four times as great as the number stamp thereon, so that with a 60 spring 240 pounds may be safely indicated. This extra piston is of special value for hydraulic and gas engine work. The pistons are made of steel, but phosphor bronze will be substituted if preferred.

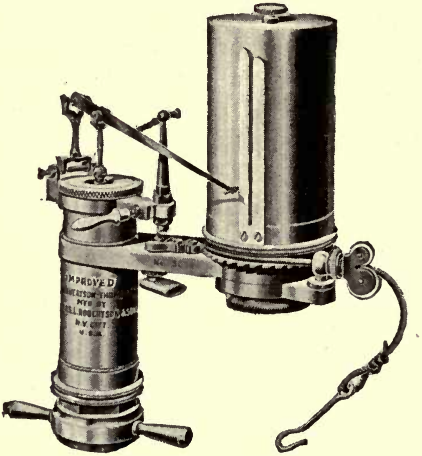

FIG. 5.

The piston springs are standardized by the most approved testing apparatus, in connection with a mercury column. To guarantee against pressure above the piston, a large relief opening has been provided, the outlet being a neat swivel elbow, by means of which the "blow" may be discharged in any direction, at the will of the operator. Each instrument is provided with a detent or stop motion.

In Fig. 6 a new device is shown for adjusting

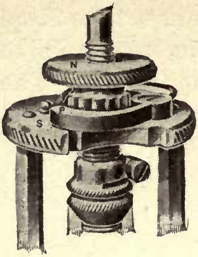

FIG. 6.

the tension of the drum spring. By rotating the knurled head *S*, to the right the spring may be tightened as much as desired, and securely held by pawl *P;* the ratchet wheel *N* is securely attached to the shaft by means of a left hand thread. Thus the tendency of the drum spring is to tighten the ratchet nut more firmly. By pressing the thumb into the recess in the spring winder *S*, the pawl is released, when the tension may be diminished to any desired amount. This ratchet wheel has sixteen teeth, which provide for the adjustment of the spring to a nicety. Drum springs are of the clock type, but spiral form will be furnished if preferred. Cone bearings are provided to take up all wear of the drum spindle. The parallel movement is made of tool steel, highly polished and richly blued. All bearings are wide and perfectly fitted.

In Fig. 7 the pencil mechanism is shown in three positions, which will give a perfect idea of the manner in which an absolutely correct straight line is obtained. This movement forms a perfect pantograph, so that the pencil movement is exactly proportional to that of the piston, the ratio being 5 to 1.

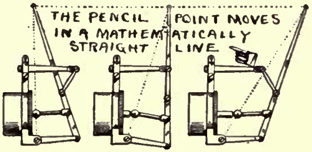

FIG. 7.

All moving parts are worked down to the lightest weight consistent with durability. For comparison it may be stated that the drum weight is but one and one-fourth ounces, and the pencil lever twenty-five grains.

By special order, the instrument will be fitted with the improved Victor reducing wheel, which comprises a patent cord feeding device. The manufacturers are James L. Robertson & Sons, No. 204 Fulton street, New York city.

CHAPTER IV.

THE BUFFALO INDICATOR.

The Buffalo indicator is of standard size, and well made throughout. It is handsome in design and finish, all working parts being accurately fitted and carefully tested. The working parts are few, and of such light weight that a quick response to the steam pressure is always insured. A new style double coil spring of high tension is used, which insures correct diagrams. The piston is ½-inch area, provided with water grooves. The piston rod is made of $\frac{3}{16}$-inch steel, hollow at the upper end, threaded to receive a swivel head (which permits of the adjustment of the pencil to suit weak or strong vacuum springs), and turned smaller at the lower, to reduce its weight.

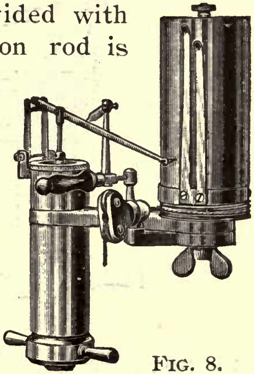

FIG. 8.

The parallel motion is secured by a link attached to and governing the pencil lever direct. The screws of this link are made free from any appreciable loss motion, and will remain so indefinitely. It is made of "tool steel," and will trace a correct vertical line within its limit of three inches. The arm, link and uprights are made of $\frac{3}{16} \times \frac{1}{32}$-inch steel, the uprights being held together by small bars $\frac{3}{32}$-inch diameter, one-half inch long, the ends of which are turned smaller, and threaded to receive the ⅛-inch hex nut, which fastens the uprights against the shoulder. The lower bar is centered at the proper angle to fit the pivot screws, and permit of very fine adjustment. Bearings of the link are one-fourth inch long. The entire movement is carefully blued. The movement of the pencil coincides with that of the piston at all times, and is acknowledged to be the most accurate made. The rosewood handle that swings the pencil

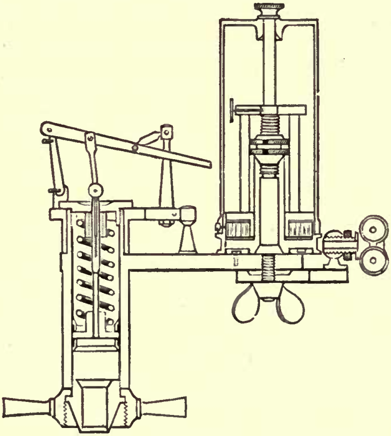

FIG. 9.

movement can be screwed in or out against the stop post so as to get the required pressure of lead or wire upon the card.

For ordinary use, drums 1.75 inches diameter, three and one-half inches high—two inches when specified—are furnished. They are made from special drawn telescope tubing, turned as thin as is consistent with ordinary usage, and supported at the top by a bearing one-half inch long. The barrel, which carries the drum, it will be noticed by reference to the cut, is very light, and is provided with adjustable cone bearings. The drum spring is a flat coil of the clock pattern, and can be adjusted for any speed met in practice, by unscrewing the thumb screw, turning to the quarter, then tighten as shown. The arm which carries the guide pulleys can be adjusted to allow the cord to run in any direction without the aid of carrying pulleys. The drum cord will not climb from one coil to another, and can be adjusted to any angle by means of the guide pulleys.

The indicator is made almost entirely of brass, highly polished and nickeled; but for ammonia a special composition is used. Each indicator is sent out in a polished mahogany box, fitted with a metal plate, to which the indicator is attached by means of the coupling and plug.

CHAPTER V.

AMERICAN THOMPSON INDICATOR.

The American Thompson improved indicator was patented by J. W. Thompson, August 31, 1875, and July 12, 1881.

The radical improvements, as made in the old style Thompson indicator, consist of lightening the moving parts, substituting steel screws in place of taper pins, using a very light steel link instead of a large brass one, reducing the weight of the pencil lever, also weight of squares on trunk of piston and lock nut on end of spindle, and increasing the bearing on connection of parallel motion. By shortening the length and reducing the actual weight of the paper cylinder just one-half, and by shortening the bearing on spindle, also lowering the spring casing to a nearer plane to that in which the cord runs, we have reduced the momentum of the paper cylinder to a very small amount. All of these improvements have lessened the amount of friction, which was heretofore very small, but is now reduced to a minimum.

The parallel movement of pencil is secured by a link attached to and governing the lever direct. The pivots of this link are made free from any appreciable lost motion, and will remain so indefinitely; but if any such lost motion should exist, it will affect the integrity of the parallel movement only to an extent equal to it. The parallel movement will be affected only by the play in the pivots of the link, and not in any degree or manner by the play of any other parts.

The force required to guide the lever in its parallel movement is received on the pivots of the link alone, where the friction it causes is practically inappreciable.

With the slot and roller device this guiding force is received on several rapidly moving surfaces, multiplied in amount by leverage. The same is true to a considerable extent of the plan of attaching the link to the connecting rod.

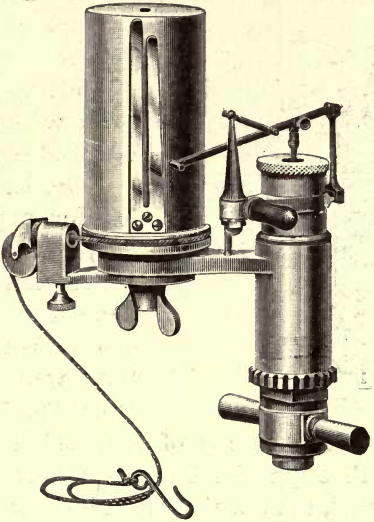

FIG. 10.

The Paper Cylinder Movement.—It is so constructed that the tension of the coiled drum spring within the paper cylinder can be increased or decreased, for different speeds of engines. As little or as much of the spring can be taken up or let out as desired, thereby providing for fine adjustments.

For high speeds the instrument will give accurate results for all practical purposes, without any special adjustments further than to give sufficient tension to keep the cord taut at all points.

When exceptionally accurate work is desired, the length of the diagram may be carefully measured, and compared with the length of a line traced on the paper when the engine is working slowly. If the diagram is found to differ in length from this line, vary the tension of the spring till they agree. The paper cylinder, or "drum," is now made with covered top.

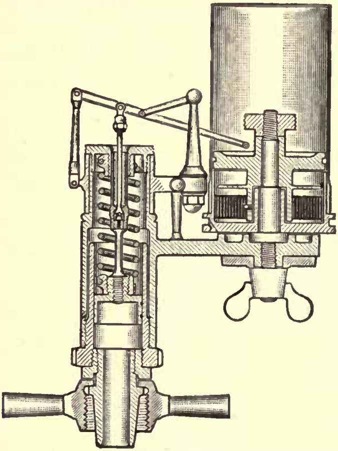

Fig. 11.

The leading pulley for paper cylinder, the latest improvement in the American Thompson improved indicator, was patented June 26, 1883, and consists (see Fig. 10) of a wheel which leads the cord through the hole, in contact with the scored wheel, over which the cord can be run to any possible angle, to connect with the motion wherever it may be, or of whatever kind.

The pulley works in a sleeve which rotates in the stand according to the adjustments required, and which is held in its position, where adjusted by the thumb screw, which acts as a binding screw working in the groove on the sleeve. By this it is held in any position that may be chosen, and yet is free to revolve the moment the binding screw is loosened, without any possibility of interfering with the motion by means of scarring the sleeve or disturbing the particles of metal on surface. It also gives all the desired freedom of motion and facility of adjustment.

By means of the set screw, the stand which carries the wheel can be adjusted to run the cord to any possible angle within a range of 360°.

In the double-pulley arrangement, as used in other indicators, the range of adjustment is limited, and in some cases the cord cannot be made to run in a number of certain directions, except in a grating, rough and uneven manner.

In this improved swivel pulley the use of carrying pulleys is done away with, and from the fact that, no matter what the angle of deflection may be, or what direction it may be necessary to take the cord, it will work smoothly; for the pulley face and the face of the groove on the paper cylinder are always in the proper position, one with the other, to take the cord to the motion, wherever that may be arranged.

In high speed, short stroke electric light engines great range of adjustment is very important; for considerable trouble is experienced sometimes upon engines running 350 and 360 revolutions per minute, in arranging the cords so as to use independent arcs, and in making such connections with reference to right lines, that no distortion of diagrams should be given.

It is provided with a "stop motion" (see Fig. 10), which is so arranged that the horn handle screw can be screwed up against the post or stop placed midway between paper cylinder and steam cylinder so as to regulate the pressure of pencil lead upon the paper.

The best and finest quality of steel wire is used in making our springs; and they are all wound on a mandrel and tempered in the most careful manner by the oldest and most experienced workmen in the business.

All springs are wound on mandrels from four to four and one-half threads to the inch, and thereby give more wire to each spring, and a consequent less strain, than if wound, as in springs of other indicators, on mandrels two to three threads to the inch.

Whatever grinding is done to lighten a spring amounts to very little; in fact, at the most it is

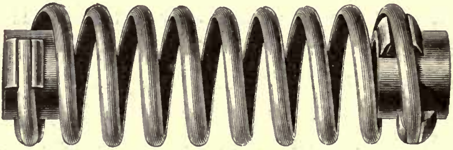

FIG. 12.

never ground to cause more than one to three pounds difference in 100 pounds; and, when the sensitiveness of the spring is considered, very little grinding will produce this result.

All springs made are scaled, providing for vacuum; and the capacity of any spring can be ascertained by the following general rule: Multiply scale of spring by 2½, and subtract 15, and the result will be the limit of pounds steam pressure to which spring should be subjected. Example: 40-pound spring × 2½ = 100 — 15 = 85 pounds pressure, capacity of a 40-pound spring.

To adapt the American Thompson improved indicator to all pressures, springs are made to any desired scale. The following are the most generally used: 8, 10, 12, 16, 20, 24, 30, 32, 40, 48, 50, 56, 60, 64, 72, 80, 100. For pressures from 65 to 85 pounds, a 40-pound spring is best adapted; for, as 40 pounds pressure on a 40-pound spring will raise pencil one inch, 80 pounds pressure on the same spring will raise pencil about two inches, which is the usual height of a diagram.

All the springs are scaled providing for vacuum, but close experiments have shown that, from the fact that springs compress and elongate in unlike proportions, the regular pressure springs vary about one pound in fifteen, or about 6⅔ per cent. A special vacuum spring is made with regular thread, scaled for vacuum only.

The detent motion, as applied to the American Thompson indicator, consists of a pawl mounted on a stud, combined with a spring and ratchet, by the use of which the paper cylinder can be stopped and a change of cards made without unhooking or disconnecting the indicator cord.

By moving the pawl so as to catch in the teeth of the ratchet on base of paper cylinder, the latter is held stationary as the engine completes its stroke. The cord, being entirely free, runs loosely with the motion of the engine, but the paper cylinder being stationary, the cards can be changed without the least disturbance of adjustments. By throwing the pawl out of the ratchet the paper cylinder is released, and immediately resumes its stroke with the engine, but care must be taken not to allow the paper cylinder, by force of its spring, to return to the stop with a thump; this can easily be done by simply holding the cord slightly with the thumb and finger until the beginning of the next stroke. This device obviates the change of adjustments, and is particularly valuable to amateurs and others not familiar with the use of the indicator. It is also valuable to users of the indicator on very quick running electric light engines, and in all cases where the circumstances are such that the disconnection of the connecting cord must cause the operator considerable trouble and the loss of valuable time.

All American Thompson improved indicators are provided with a piston .798-inch diameter = ½-inch area, which, with the 100-pound spring, provides for indicating pressure up to 250 pounds.

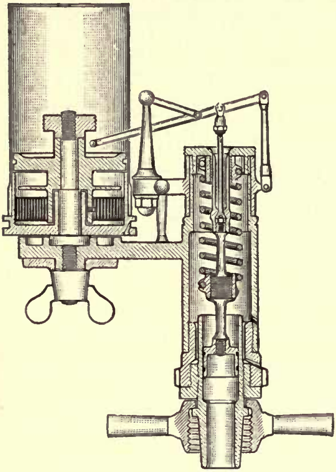

FIG. 13.

When pressure above that is to be indicated, an extra piston is furnished of .564-inch diameter = ¼-inch area, which, when substituted for the ½-inch area piston, doubles the capacity of each spring, thereby adapting the indicator for indicating pressures up to 500 pounds.

From the above it will be seen that when an indicator is furnished with the regular ½-inch area piston, and an extra ¼-inch area piston in addition, the instrument can be used to indicate all pressures from 0 to 500 pounds.

This indicator is constructed of steel for ammonia compressor work.

CHAPTER VI.

THE TABOR INDICATOR.

The special peculiarity of the Tabor indicator lies in the means employed to communicate a straight line movement to the pencil. This and other features of the instrument are shown in the appended cuts, and these are so clear that little explanation is needed. A stationary plate containing a curved slot is firmly secured in an upright position to the cover of the steam cylinder. This slot serves as a guide and controls the motion of the pencil bar. The side of the pencil bar carries a roller which turns on a pin, and this fitted so as to roll freely from end to end of the slot with little lost motion. The curve of the the slot is so adjusted and the pin attached to such a point, that the end of the pencil bar, which carries the pencil, moves up and down in a straight line, when the roller is removed from one end of the slot to the other. The curve of the slot just compensates the tendency of the pencil point to move in a circular arc, and a straight-line motion results.

The pencil mechanism is carried by the cover of the outside cylinder. The cover proper is stationary, but a nicely fitted swivel plate, which extends over nearly the whole of the cover, is provided, and to this plate the direct attachment of the pencil mechanism is made. By means of the swivel plate, the pencil mechanism may be turned so as to bring the pencil into contact with the paper drum, as is done in the act of taking a diagram.

The pencil mechanism is attached to the swivel by means of the vertical plate containing the slot, which has been referred to, and a small standard placed on the opposite side of the swivel for connecting the back link. The slotted plate is backed by another plate of similar size, which serves to receive the pressure brought to bear on the pencil bar when taking diagrams, and to keep the pencil bar in place. The pencil mechanism consists of three pieces: The pencil bar, the

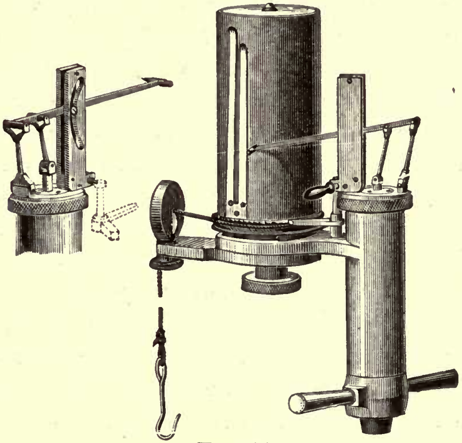

FIG. 14.

back link and the piston rod link. The two links are parallel with each other in every position they may assume. The lower pivots of these links and the pencil point are always in the same straight line. If an imaginary link be supposed to connect the two in such a manner as to be parallel with the pencil bar, the combination would form an exact pantograph. The slot and roller serve the purpose of this imaginary link.

The connection between the piston and the pencil mechanism is made by means of a steel piston rod. At the upper end, where it passes through the cover, it is hollow and has an outside diameter measuring three-sixteenths of an inch. At the lower end it is solid and its diameter is reduced. It connects with the piston through a ball and socket joint. The socket forms an independent piece, which fits into a square hole in the center of the piston, and is fastened by means of a central stem provided with a screw, which passes through the hole and receives a nut applied from the under side. The nut has a flat sided head, so as to be readily operated by the fingers. A number of shallow grooves are cut upon the outside of the piston, to serve as a so called water packing.

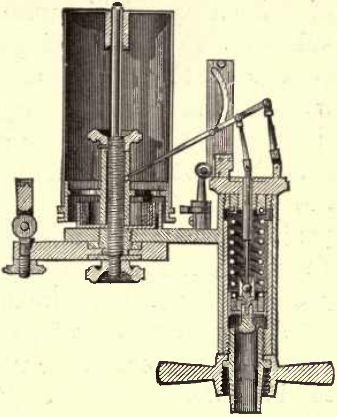

FIG. 15.

Purchasers of indicators have many important points to consider carefully before buying an instrument of such precision as an indicator should be, to be reliable. One of the most important features of an indicator is the parallel motion. It is one that has engrossed the attention of leading engineers and inventors for the past quarter of a century: that the correctness of the parallel motion of the Tabor indicator is such that at all times and at every point on a diagram within the reach of the pencil point, the extreme end of the pencil bar will record a vertical travel or movement of just five times that of the indicator piston.

The springs used in the Tabor indicator are of the duplex type, being made of two spiral coils of wire with fittings, as shown in the cut. The springs are so mounted that the points of connection of the two coils lie on opposite sides of the fitting. This arrangement equalizes the side strain on the spring, and keeps the piston central in the cylinder, avoiding the excessive friction caused by a single coil spring forcing the piston against the side of the cylinder. The thread by which the spring is attached is cut on the inside of the fitting, and suitable threaded projections on the under side of the cover and on the upper side of the piston, respectively, are provided for its attachment.

The springs are adjusted under steam pressure, and are, consequently, correct only when used for steam engines. If required for water or other purposes, either special springs should be obtained that are adjusted with reference to the required use, or the springs should be tested at the time, and the actual scale of the spring determined. It should be borne in mind that a spring becomes impaired by continued use, and its scale changes. For important work, therefore, the accuracy of the spring should always be tested by comparison on the spot with a reliable steam gauge, employing, as nearly as possible, the conditions under which the instrument was used. For steam work, they may be tested by attaching to the main steam pipe, for this purpose, a half-inch pipe fitted with a globe valve, a tee for the attachment of the indicator, another tee for the steam gauge, and finally a small drip valve. By keeping the drip valve slightly open and regulating the globe valve, any desired pressures in the apparatus can be secured.

The maximum safe steam pressures above atmosphere, to which the various springs made for the indicator can be subjected, are given in the following table:

FIG. 16.

Scale of Spring.	Maximum Safe Pressure to Which a Spring can be Subjected.
8	10
10	15
12	20
16	28
20	40
24	48
30	70
32	75
40	95
48	112
50	120
60	140
64	152
80	180
100	200
120	240
150	290

The paper drum turns on a vertical steel shaft, secured at the lower end to the frame of the indicator. The drum is supported at the bottom by a carriage, which has a long vertical bearing on the shaft. It is guided at the top by the same shaft, which is prolonged for this purpose, the drum being closed in at the top and provided with a central bearing. The drum is held in place by a close fit, in the usual manner, and is easily removed by the hand when desired. Stops are provided on the inside of the drum at the bottom, with openings in the outside of the carriage to correspond, so as to prevent the drum from slipping. These are so placed that the position of the drum may be changed so as to take diagrams in the reverse position of the pencil mechanism, when so desired. The drum is made of thin brass tubing, so as to be extremely light. Suitable strength is obtained by leaving a ring of thicker metal at the bottom and by employing the closed top. Steel clips are attached to the drum for holding the paper.

The drum carriage projects below the lower end of the drum, where it is provided with a groove for the reception of the driving cord. This groove has sufficient width for two complete turns of the cord. The drum spring, by which the backward movement of the drum is accomplished, consists of a flat spiral spring of the watch spring type, placed in a cavity under the drum carriage encircling the bearing. It is attached at one end to the frame below, and at the other end to the drum carriage. In its normal position the drum carriage is kept against a stop by means of the pull of the spring. The lower hub of the drum carriage rests directly on the spring case, while the opposite hub is in contact with a knurled thumb nut, screwed and pinned to the drum stud, in a position to just give a slight amount of end motion to the drum carriage. This thumb nut also serves as a convenient means of regulating the tension of the drum spring, as by loosening the nut that screws the spring case to the arm of the instrument, said thumb nut can be turned in either direction until the desired tension is obtained, and then again tightening the nut.

A simple form of carrier pulley serves to operate the driving cord from any direction. A single pulley is mounted within a circular perpendicular plate, the center of which coincides with the center of the driving cord. This center also coincides with the circumference of the pulley. The plate can be turned about its center so as to swing the pulley into any desired angular position, and thereby lead the cord off in any desired direction. The plate is held by a circular frame, which serves also as a clamp, and the pulley is fixed in position by the use of the same nut which secures the frame to the pulley arm.

Some of the prominent features in the design and construction of the Tabor indicator, which are noticeable to one handling the instrument, may be mentioned:

The instrument is attached by means of a coupling having but one thread. It is simple, like a common pipe coupling, and is operated by simply turning it in the proper direction, without exercising that care which the use of couplings having double threads requires.

The indicator cock has a stop which limits its range in either direction to full open or closed, and also has holes provided for the release of all steam that may remain between the indicator piston and cock after operating.

The pressure of the pencil on the paper drum is regulated by means of a screw, which passes through a projection on the slot plate, and strikes against a small stop provided for the purpose, which stands on the frame. This screw is operated by a handle, which is of sufficient size to be readily worked by the fingers, and which also serves as a handle for turning the pencil mechanism back and forth, as is done in the act of taking diagrams. The handle may be introduced and worked from either side, so as to use the pencil mechanism on either side of the paper drum.

The end of the pencil bar is shaped in the form of a thin tube for the reception of the pencil lead or metallic marking point. The tube is split apart on the side and yields to the slight pressure required to introduce the pencil, which can be introduced from either side, so as to mark on either side of the paper drum desired.

The outside of the instrument in all its parts, excepting the pencil bar and links composing the pencil mechanism, is nickel plated. The pencil mechanism is made of steel, hardened and drawn to a spring temper, with blue finish.

Some of the dimensions of the parts in the instrument of standard size are as follows:

Diameter of piston	0.7978	inches.
Diameter of paper drum	2.063	"
Stroke of paper drum..............	5.5	"
Height of paper drum..............	4.	"
Number of times pencil mechanism multiplies piston motion	5.	"
Range of motion of pencil point....	3.25	"

A result of the care in designing and constructing these instruments is a reduction of friction to the least possible amount.

CHAPTER VII.

THE IMPROVED VICTOR REDUCING WHEEL.

Recent improvements in the Victor reducing wheel make it near absolute perfection. Every part is made of the material best suited to the work, and each joint is so admirably fitted that its lightness, accuracy and durability are only equaled by the convenience and facility with which it may be applied to any indicator, stroke or speed. It has no gears, therefore no grating action. The cord wheel revolves on a polished spindle. The wheel is stationary, and the guide pulley is moved across its face a distance equal to the thickness of the cord for each revolution, so that the cord will wind evenly, coil to coil, no matter in what direction it is led.

The improved Victor aluminum reducing wheel is made in two patterns, large and small. The only difference in these patterns lies in the diameter of the main cord wheel. The large pattern is especially intended for strokes of four feet and over, and will give perfect satisfaction on strokes of eight feet. There are several in use on high speed engines, but for this work the smaller size is recommended, and guaranteed to operate perfectly to any speed met with in practice.

Both patterns are carried in stock, with special arms *D*, Fig. 17, to fit all makes of indicators.

A feature of the Victor wheel is its extreme simplicity, and the facility with which it may be taken apart for cleaning and replacing springs.

By actual timing the instrument has been taken apart, a spring replaced and assembled, ready for use in three minutes.

One of the most important features in a reducing wheel is smooth running. In fact, without it an accurate diagram cannot be secured. After many experiments the arrangement employed in the improved Victor, a heavy, braided linen cord, which connects the small pulley *E* to the spring case *F*, Fig. 17, was adopted.

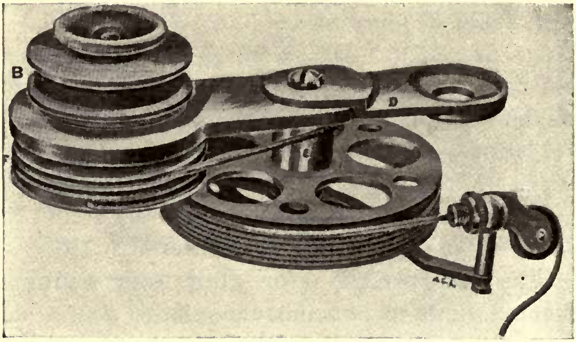

FIG. 17.

This method transmits the power of the spring without friction, and as the cord is always under a uniform tension, all stretch is soon eliminated. When worn out it may be replaced in a moment and without cost.

The spring case, *F*, is made of aluminum, and is deeply grooved, so that the intermediate cord can never ride, and is perfectly guided at all times.

The freedom from friction, which is one of the most pleasing and noticeable features of the Victor wheel, insures its operation with much less spring tension than others, which means longer life of the spring.

The cord wheel revolves on a polished steel spindle, so that a nice fit may be made and maintained, even after years of ordinary use.

The improved Victor wheel is provided with bushings for all strokes. These bushings, *B*, are quickly changed.

It is manufactured by James L. Robertson & Son, 204 Fulton street, New York city.

CHAPTER VIII.

THE IDEAL REDUCING WHEEL.

The object of the reducing wheel is to reduce accurately the motion of an engine cross-head to that required for a paper drum of an indicator, and to give the required length of diagram regardless of the engine stroke. If either the indicator or reducing motion is not correct, the cards are useless and deceptive, hence the first step toward obtaining the true state of affairs in a steam cylinder is an indicator that will show both the true pressure, or vacuum, and a correct reducing motion by which diagrams can be taken, so that an intelligent engineer can interpret them, adjust the valves and figure the power developed.

The Ideal reducing wheel is made of aluminum, brass and steel, combining strength and lightness, two essential features, together with first-class workmanship.

The wheel or drum, from which the cord passes to the cross-head is only two and three-quarters inches in diameter, and is made of aluminum. The coil spring for the take-up is in a case two and one-quarter inches in diameter, and connected by a 3 to 1 gear with the cord wheel spindle, so that while the light aluminum cord wheel makes three revolutions, the spring makes but one. The spring can be adjusted to any desired tension, to keep the cord taut on return stroke. The cord wheel revolves on a steel screw, the thread of which is the same pitch as the cord, so that when the cord is drawn out the wheel travels as it revolves. By this means the cord is wound smoothly on the drum and passes straight through the guide pulley.

To use the reducing wheel on the indicator, remove the carrier pulley from the indicator, and put the wheel on in place of it. Pass the drum cord around the small disk through the hole and under the holder, being careful to see that the cord is wound around the bushing or disk from the left, as shown in Fig. 18. Before attaching hook see that cord on the wheel and indicator is taut at shortest part of the stroke, and that it will

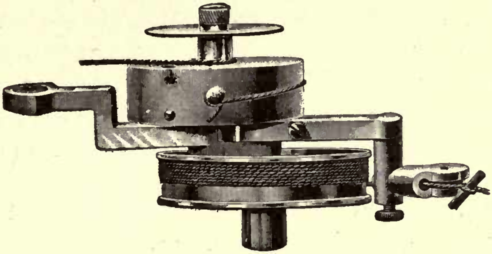

FIG. 18.

pull out a little further than the longest part of stroke. The reducing wheel can be used in any place where it is most convenient, bearing in mind that the cord from it to the cross-head should run in a straight line. In unhooking the cord, allow it to return slowly until the stop reaches the guide pulley.

Bushings of various sizes are furnished so that cards can be taken from any length of stroke up to seventy-two inches.

The Ideal reducing wheel is manufactured only by John S. Bushnell, successor to Thompson & Bushnell, 120–122 Liberty street, New York city.

CHAPTER IX.

SARGENT'S ELECTRICAL ATTACHMENT FOR STEAM ENGINE INDICATORS.

In making elaborate tests of power plants, it has heretofore been necessary to employ as many assistants as there were indicators used, but the difficulty of securing simultaneous action on their part is so great that satisfactory work is rarely obtainable, and more certain means to that end are now considered necessary.

Mr. Frederick Sargent, M.E., invented and patented an electrical device applicable to an indicator, by means of which any number of instruments can be operated and diagrams taken at the same instant of time, simply by closing an electric circuit.

Fig. 19 shows a Crosby indicator fitted with a Sargent electrical attachment.

For the purpose of illustrating the manner of operating the attachment, assume that it is desirable to procure simultaneous diagrams from a compound engine, taking cards from the ends of each cylinder. Attach the indicators to the engine and arrange the drum motion in the usual manner. On each indicator secure the electrical attachment to its plate. Make the connections with the battery, having all of the several magnets and the circuit closer in series. Place the paper upon the drum and bring the pencil arm into such a position as will allow the latch to drop into the screw eye.

Press the armature firmly against the magnet and adjust the marking point to the paper in the usual manner. The sleeve handle must be unscrewed enough to allow the full operation of the armature. The circuit should be closed and the armature tension springs adjusted, so that the connected attachment will work simultaneously. Everything should now be in readiness to take diagrams. Connect the drum motions, open the indicator cocks, and as soon as desirable close

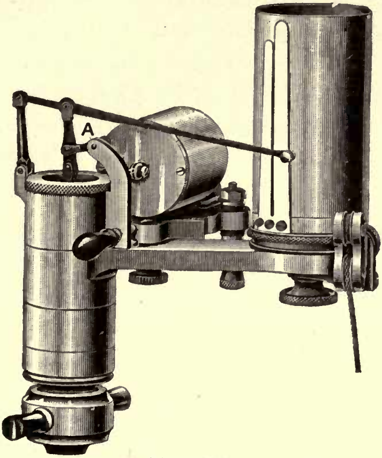

FIG. 19.

the circuit, and instantly all of the pencils will be brought against the papers and will remain there as long as the circuit is kept closed.

In order to put on new papers, disengage the drum motions, lift the latch and swing the pencil arm out of the way.

The amount of battery power required will vary with circumstances and will range from one to two or more cells of a No. 2 Sampson battery, or its equivalent.

The battery for operating the attachment is inclosed in a neat hardwood box with a suitable handle for carrying it, and is sealed so as to prevent slopping. It is very compact and portable, being at the same time extremely active, long lived and especially adapted to open circuit work.

The connections to the indicator attachments can be made with the battery without opening the box, the binding posts being on the outside. This battery, with a quantity of suitable wire for making connections, is furnished with the attachment. The Sargent electrical attachment is manufactured by the Crosby Steam Gage and Valve Co., Boston, Mass.

CHAPTER X.

AMSLER'S POLAR PLANIMETER, WITH DIRECTIONS FOR USING IT ON INDICATOR DIAGRAMS.

Fig. 20 represents the No. 1 planimeter. It is the simplest form of the instrument, having but one wheel, and is designed to measure areas in square inches and decimals of a square inch. The figures on the roller wheel *D* represent units, the graduations on the wheel represent tenths, and the vernier gives the hundredths.

The use of Amsler's polar planimeter in the measurement of indicator diagrams enables one

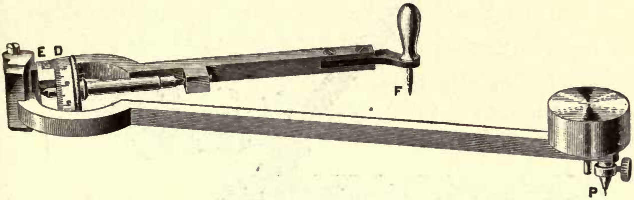

FIG. 20.

to measure ten cards with it in the time which would be required to measure one card by any other method, and it insures the utmost accuracy in the work.

The planimeter is a precise and delicate instrument, and should be handled and kept with great care, in order that it may be depended upon to give correct results. After using, it should be wiped clean with a piece of soft chamois skin.

The Amsler polar planimeter is manufactured by the Crosby Steam Gage and Valve Co., Boston, Mass.

CHAPTER XI.

THE LIPPINCOTT PLANIMETER.

The accompanying engraving, Fig. 21, represents a new form of planimeter.

It will be noticed that the wheel has a knife edge, and is free to move on its shaft, so that there can be no slipping on the surface upon which it moves, giving the same results when used upon the roughest table as upon the finest paper.

As the rotary movement of this wheel does not register, it is apparent that the accuracy of

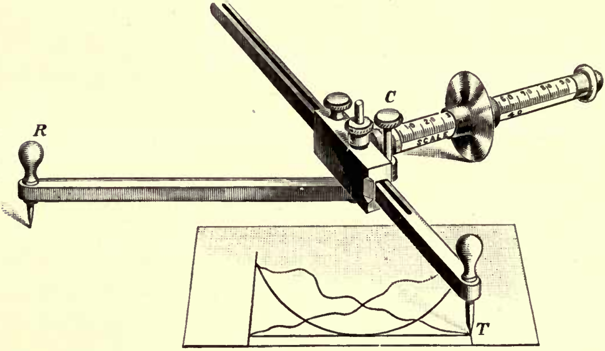

FIG. 21.

the instrument will not be affected by any reduction of the diameter of the wheel or injury to the knife edge. This is one of the most important points to be considered in the selection of a planimeter. It is evident, however, that this claim is only made possible by taking the reading from the hub and not from the edge of the wheel. The possibility of a vitiated reading on account of the knife edge coming in contact with separate scale, is also avoided thereby.

With the Lippincott planimeter the sliding is done entirely upon the shaft, and as this shaft is made of glass it is practically frictionless.

The pivot screw is made hollow, and by means of a small knob a sharp point may be protruded for convenience in setting to the card length, while a small spiral spring normally holds it in a protected position after the setting operation has been completed.

It will thus be seen that any bending in the tracer point would be compensated for in every setting, and could therefore occasion no error. This is a most important improvement, and guarantees initial and continued accuracy.

Inside the glass shaft is placed the scale, which is printed upon specially prepared paper, so that the greatest contrast and legibility may be insured. The ends of this shaft are then hermetically sealed under a partial vacuum, so that the scale can never become discolored or affected by the atmosphere.

The plates employed in printing these scales are engine divided and mathematically correct.

Three of these scale tubes are provided with the instrument, each containing two different graduations, so that the mean effective pressure may be read direct, without computation, for the following indicator springs: 6, 8, 10, 12, 16, 20, 24, 30, 32, 40, 50, 60, 80, 100, 120 and 150. For instance, if it is required to ascertain the M. E. P. of a card taken with an 80 spring, insert a tube containing a 40 scale, and mentally double the reading; or if special accuracy is desired, trace the diagram twice, without stopping, and the reading will be correct for an 80-pound spring.

The correct reading for a 20 spring may be had from a 40 scale also, and in like manner other scales may be used with different springs, which is more desirable than to encumber the case with a number of useless scale tubes.

Any special graduation will be furnished to order.

To use the instrument, select a tube containing a scale corresponding to spring used in taking the card, and insert same in the clamp, as in Fig. 21, after which the clamp screw is to be tightened sufficiently to prevent the tube from being easily moved.

Loosen the set screw, and adjust the points to the exact length of the card. The set screw should then be firmly tightened, so that the tracer bar cannot be moved in the frame block.

Having fastened the card upon the table with thumb tacks, place the instrument with radial bar at right angles to the tracer bar. After this move the tracer point down to point *T*. The left hand edge of the wheel hub may then be set at zero, either by moving the radial point *R* to the right or left, or by moving the wheel on the shaft. After the instrument is properly placed, the tracer point should trace the line of the diagram to the left, in the direction taken by the hands of a watch, noting carefully that the wheel does not strike at either end of the shaft in making the circuit.

If a reading is desired in square inches, use a 40 scale and set the points four inches apart.

The points may also set five inches apart and a 50 scale used, or six inches and a 60 scale. The latter is preferable in taking the area of large figures.

Use no oil on any part of the instrument, and keep the glass tube perfectly clean with tissue paper, or clean chamois skin. The wheel should slide with perfect freedom from one end of the tube to the other.

This instrument is packed in a fine morocco velvet lined case, with nickel trimmings, and every one is guaranteed perfectly accurate. It is manufactured by James L. Robertson & Sons, 204 Fulton street, New York city.

CHAPTER XII.

THE COFFIN AVERAGING INSTRUMENT FOR CALCULATING INDICATOR DIAGRAMS.

When the mean effective pressure on a large number of diagrams is desired, time and labor may be saved by the employment of an averaging instrument or planimeter, an instrument designed to measure the areas of irregular figures. It is operated by moving a tracer, with which it is fitted, over the line of the diagram, and it records the area upon a graduated wheel.

In using the Coffin averager, the grooved metal plate, *I*, is first connected to the board upon which the apparatus is mounted, in the position shown in the cut, being held in place by a thumb-screw applied from the back side. The indicator card is then placed under the clamps *C* and *K*, which may be sprung away from the board a sufficient amount to allow the card to be introduced, and the card is moved toward the left into such a position that the atmospheric line is near to and parallel with the lower edge of the stationary clamp, *C*, while the extreme left hand end of the diagram is even with the perpendicular edge of the clamp. The movable clamp, *K*, which is fastened at the bottom to a sliding plate, is then moved toward the left, till the vertical beveled edge just touches the extreme right hand end of the diagram. The diagram shown in the cut represents the proper location which should exist when these preliminary adjustments have been completed. The slide at the bottom of clamp *K* fits closely, so that the application of a slight pressure with the thumb or finger is required to displace it.

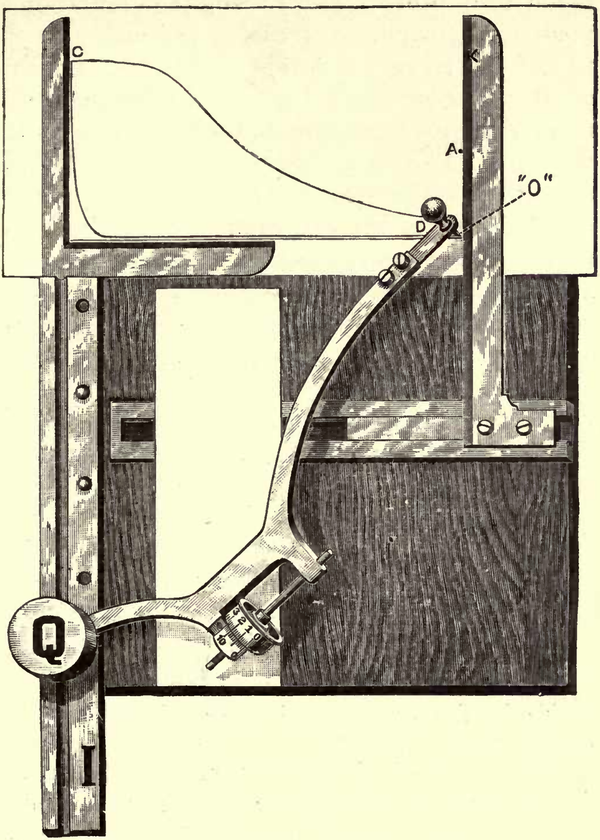

FIG. 22.

The beam of the instrument is next placed on the board, with the pin at the lower end resting in the groove, *I*, and the weight, *Q*, applied to the top of the pin so as to keep it securely in place.

The tracer, *O*, is moved to the right hand end of the diagram and set at the point *D*, on the line of the diagram, where the clamp *K* and the diagram touch each other. Here a slight indentation is made in the paper by pressing the finger on the top of the tracer, and this serves as a starting point. The graduated wheel is next turned so as to bring its zero mark to the zero mark on the vernier. The instrument is now ready for operation. The tracer, *O*, is carefully moved over the line of the diagram, in the direction of motion of the hands of a watch, and continued till a complete circuit is made and the tracer finally reaches the starting point, *D*. Keeping an eye on the wheel, the tracer is now moved upward by sliding it along the edge of the clamp *K*, until the reading on the wheel returns to zero. Another light indentation is made in the paper to mark the new position which the tracer occupies. This point is represented at *A* in the cut. The instrument is now moved away, the clamp pushed back, and the distance between the two points, *D* and *A*, is measured by employing a scale corresponding to the number of the spring used in the indicator. The distance thus found is the mean effective pressure, expressed in pounds per square inch of piston.

The Coffin planimeter determines the desired result without computation, but it may be used also for determining the area inclosed by the diagram. This area is given by the reading on the graduated wheel, when the circuit of the diagram has been made and the tracer reaches the starting point, *D*. The wheel has fifteen main divisions, each of which represents one square inch of area. Each division has five sub-divisions, each sub-division representing one-fifth, or two-tenths, of a square inch of area. The vernier scale enables the sub-divisions to be read in fiftieths, each of these fiftieths, therefore, representing two-one-hundredths of a square inch. Having obtained the area in this manner, the mean effective pressure may be computed by dividing the number of the spring representing the pressure per inch in height by the length of the diagram (inches) and multiplying the quotient by the area (square inches). In first placing the indicator card under the clamps, care must be observed that the ends of the diagram set a little away from the edge of the clamp, so as to allow for one-half the diameter of the tracer, and to bring the center of the tracer over the center of the line of the diagram.

PART IV.

MISCELLANEOUS TABLES.

PROPERTIES OF SATURATED AMMONIA.

CALCULATED FROM THE ORIGINAL FORMULA OF PROF. DE VOLSON WOOD, BY GEORGE DAVIDSON, M.E.

Computed especially for and originally published in *Ice and Refrigeration* for December, 1894.

Temperature.		Pressure, Absolute.		Gauge Pressure, Pound per Sq. Inch.	Heat of Vaporization, Thermal Units. h.	Volume of Vapor per Pound, Cubic Feet. v.	Volume of Liquid per Pound, Cubic Feet. v_1	Weight of Vapor in Pounds per Cubic Foot. w	Weight of Liquid in Pounds per Cubic Foot. w_1	Temperature. Degrees F.
Degrees F. t.	Absolute. T.	Pounds per Sq. Foot. P.	Pounds per Sq. Inch. p.							
—40	420.66	1539.90	10.69	—4.01	579.67	24.388	.02348	.0410	42.589	—40
39	1	1584.43	11.00	—3.70	579.07	23.735	.02351	.0421	42.535	39
38	2	1630.03	11.32	—3.38	578.42	23.102	.02354	.0433	42.483	38
37	3	1676.71	11.64	—3.06	577.88	22.488	.02357	.0444	42.427	37
36	4	1724.51	11.98	—2.72	577.27	21.895	.02359	.0457	42.391	36
—35	425.66	1773.43	12.31	—2.39	576.68	21.321	.02362	.0469	42.337	—35
34	6	1823.50	12.66	—2.04	576.08	20.763	.02364	.0482	42.301	34
33	7	1874.73	13.02	—1.68	575.48	20.221	.02366	.0495	42.265	33
32	8	1927.17	13.38	—1.32	574.89	19.708	.02368	.0507	42.213	32
31	9	1980.78	13.75	—0.95	574.39	19.204	.02371	.0521	42.176	31
—30	430.66	2035.69	14.13	—0.57	573.69	18.693	.02374	.0535	42.123	—30
29	1	2091.83	14.53	—0.17	573.08	18.225	.02378	.0549	42.052	29
28	2	2149.23	14.92	+0.22	572.48	17.759	.02381	.0563	42.000	28
27	3	2207.94	15.33	+0.63	571.89	17.307	.02384	.0577	41.946	27
26	4	2267.97	15.75	+1.05	571.28	16.869	.02387	.0593	41.893	26
—25	435.66	2329.34	16.17	+1.47	570.68	16.446	.02389	.0608	41.858	— 25
24	6	2392.09	16.61	1.91	570.08	16.034	.02392	.0624	41.806	24
23	7	2456.23	17.05	2.35	569.48	15.633	.02395	.0640	41.754	23
22	8	2520.45	17.50	2.8	568.88	15.252	.02398	.0656	41.701	22
21	9	2588.77	17.97	3.27	568.27	14.875	.02401	.0672	41.649	21
—20	440.66	2657.23	18.45	+3.75	567.67	14.507	.02403	.0689	41.615	—20
19	1	2727.17	18.94	4.24	567.06	14.153	.02406	.0706	41.563	19
18	2	2798.62	19.43	4.73	566.43	13.807	.02409	.0725	41.511	18
17	3	2871.61	19.94	5.24	565.85	13.475	.02411	.0742	41.480	17
16	4	2946.17	20.46	5.76	565.25	13.150	.02414	.0760	41.425	16
—15	445.66	3022.31	20.99	+6.29	564.64	12.834	.02417	.0779	41.374	—15
14	6	3100.07	21.53	6.83	564.04	12.527	.02420	.0798	41.322	14
13	7	3179.45	22.08	7.38	563.43	12.230	.02423	.0818	41.271	13
12	8	3260.52	22.64	7.94	562.82	11.939	.02425	.0838	41.237	12
11	9	3343.29	23.22	8.52	562.21	11.659	.02428	.0858	41.186	11
—10	450.66	3427.75	23.80	+9.10	561.61	11.385	.02431	.0878	41.135	—10
9	1	3513.97	24.40	9.70	560.99	11.117	.02434	.0899	41.084	9
8	2	3601.97	25.01	10.31	560.39	10.860	.02437	.0921	41.034	8
7	3	3691.75	25.64	10.94	559.78	10.604	.02439	.0943	41.000	7
6	4	3783.37	26.27	11.57	559.17	10.362	.02442	.0965	40.950	6
—5	455.66	3876.85	26.92	12.22	558.56	10.125	.02445	.0988	40.900	— 5
4	6	3972.62	27.59	+12.89	557.94	9.894	.02448	.1011	40.845	4
3	7	4069.48	28.26	13.56	557.33	9.669	.02451	.1034	40.799	3
2	8	4168.70	28.95	14.25	556.73	9.449	.02454	.1058	40.749	2
1	9	4269.90	29.65	14.95	556.11	9.234	.02457	.1083	40.700	1
0	460.66	4373.10	30.37	+15.67	555.50	9.028	.02461	.1107	40.650	0
+1	1	4478.32	31.10	16.40	554.88	8.825	.02463	.1133	40.601	+ 1
2	2	4485.60	31.84	17.14	554.27	8.630	.02466	.1159	40.551	2
3	3	4694.96	32.60	17.90	553.65	8.436	.02469	.1186	40.502	3
4	4	4806.46	33.38	18.68	553.04	8.250	.02472	.1212	40.453	4

* For values at temperatures higher than 100° F. see Wood's table on page 163.

PROPERTIES OF SATURATED AMMONIA.

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Computed especially for and originally published in *Ice and Refrigeration* for December, 1894.

Temperature.		Pressure, Absolute.		Gauge Pressure, Pound per Sq. Inch.	Heat of Vaporization, Thermal Units. h.	Volume of Vapor per Pound, Cubic Feet. v.	Volume of Liquid per Pound, Cubic Feet. v_1	Weight of Vapor in Pounds per Cubic Foot. w	Weight of Liquid in Pounds per Cubic Foot. w_1	Temperature. Degrees F.
Degrees F. t.	Absolute. T.	Pounds per Sq. Ft. P	Pounds per Sq. Inch. p.							
+5	465.66	4920.11	34.16	+19.46	552.43	8.070	.02475	.1240	40.404	+5
6	6	5035.95	34.97	20.27	551.81	7.892	.02478	.1267	40.355	6
7	7	5153.99	35.79	21.09	551.19	7.717	.02480	.1296	40.322	7
8	8	5274.28	36.63	21.93	550.58	7.553	.02483	.1324	40.274	8
9	9	5396.83	37.48	22.78	549.96	7.388	.02486	.1353	40.225	9
+10	470.66	5521.71	38.34	+23.64	549.35	7.229	.02490	.1383	40.160	+10
11	1	5649.48	39.23	24.53	548.73	7.075	.02493	.1413	40.112	11
12	2	5778.50	40.13	25.43	548.11	6.924	.02496	.1444	40.064	12
13	3	5910.52	41.04	26.34	547.49	6.786	.02499	.1474	40.016	13
14	4	6044.96	41.98	27.28	546.88	6.632	.02502	.1507	39.968	14
+15	475.66	6182.00	42.94	+28.24	546.26	6.491	.02505	.1541	39.920	+15
16	6	6321.24	43.90	29.20	545.63	6.355	.02508	.1573	39.872	16
17	7	6463.24	44.88	30.18	545.01	6.222	.02511	.1607	39.872	17
18	8	6607.77	45.89	31.19	544.39	6.093	.02514	.1641	39.777	18
19	9	6754.90	46.91	32.21	543.74	5.966	.02517	.1676	39.729	19
+20	480.66	6904.68	47.95	+33.25	543.15	5.843	.02520	.1711	39.682	+20
21	1	7057.15	49.01	34.31	542.53	5.722	.02523	.1748	39.635	21
22	2	7211.33	50.09	35.39	541.90	5.605	.02527	.1784	39.572	22
23	3	7370.27	51.18	36.48	541.28	5.488	.02529	.1822	39.541	23
24	4	7530.96	52.30	37.60	540.66	5.378	.02533	.1860	39.479	24
+25	485.66	7694.52	53.43	+38.73	540.03	5.270	.02536	.1897	39.432	+25
26	6	7860.89	54.59	39.89	539.41	5.163	.02539	.1937	39.386	26
27	7	8030.16	55.76	41.06	538.78	5.058	.02542	.1977	39.339	27
28	8	8202.38	56.96	42.26	538.16	4.960	.02545	.2016	39.292	28
29	9	8377.56	58.17	43.47	537.53	4.858	.02548	.2059	39.246	29
+30	490.66	8555.74	59.42	+44.72	536.91	4.763	.02551	.2099	39.200	+30
31	1	8736.96	60.67	45.97	536.28	4.668	.02554	.2142	39.115	31
32	2	8921.26	61.95	47.25	535.66	4.577	.02557	.2185	39.108	32
33	3	9108.71	63.25	48.55	535.03	4.486	.02561	.2229	39.047	33
34	4	9299.32	64.58	49.88	534.40	4.400	.02564	.2273	39.001	34
+35	495.66	9493.07	65.92	+51.22	533.78	4.314	.02568	.2318	38.940	+35
36	6	9690.04	67.29	52.59	533.13	4.234	.02571	.2362	38.894	36
37	7	9890.75	68.68	53.98	532.52	4.157	.02574	.2413	38.850	37
38	8	10093.91	70.09	55.39	531.89	4.068	.02578	.2458	38.789	38
39	9	10300.88	71.53	56.83	531.26	3.989	02582	.2507	38.729	39
+40	500.66	10511.16	72.99	+58.29	530.63	3.915	.02585	.2554	38.684	+40
41	1	10724.95	74.48	59.78	529.99	3.839	.02588	.2605	38.639	41
42	2	10942.18	75.99	61.29	529.36	3.766	.02591	.2655	38.595	42
43	3	11162.93	77.52	62.82	528.73	3.695	.02594	.2706	38.550	43
44	4	11387.21	79.08	64.38	528.10	3.627	.02597	.2757	38.499	44
+45	505.66	11615.12	80.66	+65.96	527.47	3.559	.02600	.2809	38.461	+45
46	6	11846.64	82.27	67.57	526.83	3.493	.02603	.2863	38.417	46
47	7	12081.80	83.90	69.20	526.20	3.428	.02606	.2917	38.373	47
48	8	12320.71	85.56	70.86	525.57	3.362	.02609	.2974	38.328	48
49	9	12563.36	87.25	72.55	524.93	3.303	.02612	.3027	38.284	49
+50	510.66	12809.91	88.96	+74.26	524.30	3.242	.02616	.3084	38.226	+50
51	1	13080.21	90.70	76.00	523.66	3.182	.02620	.3143	38.167	51
52	2	13314.43	92.46	77.76	523.03	3.124	.02623	.3201	38.124	52
53	3	13572.52	94.25	79.55	522.39	3.069	.02626	.3258	38.080	53
54	4	13834.64	96.07	81.37	521.76	3.012	.02629	.3220	38.037	54

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Degrees F. *t*.	Absolute. *T*	Pounds per Sq. Foot. *P*.	Pounds per Sq. Inch. *p*.							
+55	515.66	14100.74	97.92	+83.22	521.12	2.958	.02632	.3380	37.994	+55
56	6	14370.92	99.80	85.10	520.48	2.905	.02636	.3442	37.936	56
57	7	14645.18	101.70	87.00	519.84	2.853	.02639	.3505	37.893	57
58	8	14923.98	103.64	88.94	519.20	2.802	.02643	.3568	37.835	58
59	9	15206.28	105.60	90.90	518.57	2.753	.02646	.3632	37.793	59
+60	520.66	15493.09	107.59	+92.89	517.93	2.705	.02651	.3697	37.736	+60
61	1	15784.23	109.61	94.91	517.29	2.658	.02654	.3762	37.678	61
62	2	16079.67	111.66	96.96	516.65	2.610	.02658	.3831	37.622	62
63	3	16379.51	113.75	99.05	516.01	2.565	.02661	.3898	37.579	63
64	4	16683.75	115.86	101.16	515.37	2.520	.02665	.3968	37.523	64
+65	525.66	16992.50	118.03	+103.33	514.73	2.476	.02668	.4039	37.481	+65
66	6	17305.70	120.18	105.48	514.09	2.433	.02671	.4110	37.439	66
67	7	17623.45	122.38	107.68	513.45	2.389	.02675	.4189	37.383	67
68	8	17945.89	124.62	109.92	512.81	2.351	.02678	.4254	37.341	68
69	9	18272.81	126.89	112.19	512.16	2.310	.02682	.4329	37.285	69
+70	530.66	18604.53	129.19	+114.49	511.52	2.272	.02686	.4401	37.230	+70
71	1	18941.00	131.54	116.84	510.87	2.233	.02689	.4479	37.188	71
72	2	19282.21	133.90	119.20	510.22	2.194	.02693	.4558	37.133	72
73	3	19628.32	136.31	121.61	509.58	2.153	.02697	.4645	37.079	73
74	4	19979.22	138.74	124.04	508.93	2.122	.02700	.4712	37.037	74
+75	535.66	20335.16	141.22	+126.52	508.29	2.087	.02703	.4791	36.995	+75
76	6	20696.00	143.72	129.02	507.64	2.052	.02706	.4873	36.954	76
77	7	21061.85	146.26	131.56	506.99	2.017	.02710	.4957	36.900	77
78	8	21432.82	148.84	134.14	506.34	1.995	.02714	.5012	36.845	78
79	9	21808.85	151.45	136.75	505.69	1.952	.02717	.5123	36.805	79
+80	540.66	22190.15	154.10	+139.40	505.05	1.921	.02721	.5205	36.751	+80
81	1	22576.51	156.78	142.08	504.40	1.889	.02725	.5294	36.696	81
82	2	22968.88	159.50	144.80	503.75	1.858	.02728	.5382	36.657	82
83	3	23365.38	162.26	147.56	503.10	1.827	.02732	.5473	36.603	83
84	4	23767.81	165.05	150.35	502.45	1.799	.02736	.5558	36.549	84
+85	545.66	24175.61	167.88	+153.18	501.81	1.770	.02739	.5649	36.509	+85
86	6	24588.92	170.75	156.05	501.15	1.741	.02743	.5744	36.456	86
87	7	25007.80	173.66	158.96	500.50	1.714	.02747	.5834	36.407	87
88	8	25432.16	176.61	161.91	499.85	1.687	.02751	.5927	36.350	88
89	9	25862.14	179.59	164.89	499.20	1.660	.02754	.6024	36.311	89
+90	550.66	26297.88	182.62	+167.92	498.55	1.634	.02758	.6120	36.258	+90
91	1	26739.88	185.69	170.99	497.89	1.608	.02761	.6219	36.219	91
92	2	27186.56	188.79	174.09	497.24	1.583	.02765	.6317	36.166	92
93	3	27639.43	191.94	177.24	496.59	1.558	.02769	.6418	36.114	93
94	4	28098.26	195.13	180.43	495.94	1.534	.02772	.6518	36.075	94
+95	555.66	28563.00	198.35	+183.65	495.29	1.510	.02776	.6622	36.023	+95
96	6	29033.86	201.62	186.92	494.63	1.486	.02780	.6729	35.971	96
97	7	29510.69	204.94	190.24	493.97	1.463	.02784	.6835	35.919	97
98	8	29993.52	208.29	193.59	493.32	1.442	.02787	.6934	35.881	98
99	9	30482.52	211.68	196.98	492.66	1.419	.02791	.7047	35.829	99
+100	560.66	30977.78	215.12	+200.42	492.01	1.398	.02795	.7153	35.778	+100

WOOD'S TABLE OF PROPERTIES OF SATURATED VAPOR OF AMMONIA.

Temperature		Pressure Absolute.							
Degree F.	Absolute.	Lbs. per Sq. Ft.	Lbs. per Sq. In.	Heat of Vaporization, Thermal Units.	External Heat. Thermal Units.	Internal Heat. Thermal Units.	Volume of Vapor per Lb Cu. Ft	Volume of Liquid per Lb Cu Ft	Weight of a Cu Ft of Vapor, Pounds
— 40	420.66	1540.9	10.69	579.67	48.23	531.44	24.37	.0234	.0410
— 35	425.66	1773.6	12 31	576.69	48.48	528.21	21.29	.0236	.0467
— 30	430.66	2035.8	14.13	573.69	48.77	524.92	18.66	.0237	0535
— 25	435.66	2329.5	16.17	570.68	49 06	521.62	16.41	.0238	.0609
— 20	440.66	2657.5	18.45	567.67	49.38	518.29	14.48	.0240	.0690
— 15	445.66	3022.5	20.99	564.64	49.67	514 97	12.81	0242	.0779
— 10	450.66	3428.0	23.77	561.61	49.99	511.62	11.36	.0243	.0878
— 5	455.66	3877.2	26.93	558.56	50.31	508.25	10.12	.0244	.0988
0	460.66	4373.5	30.37	555.50	50.68	504.82	9.04	0246	.1109
+ 5	465.66	4920.5	34.17	552.43	50.84	501.59	8.06	0247	.1241
+ 10	470.66	5522.2	38.55	549.35	51.13	498.22	7.23	0249	.1384
+ 15	475.66	6182.4	42.93	546.26	51.33	494.93	9.49	.0250	.1540
+ 20	480.66	6905.3	47.95	543.15	51.61	491.54	5.84	.0252	.1712
+ 25	485.66	7695.2	53.43	540.03	51.80	488.23	5.26	.0253	.1901
+ 30	490.66	8556.6	59.41	536.92	52.01	484.91	4 75	.0254	.2105
+ 35	495.66	9493.9	65.93	533.78	52.22	481.56	4.31	.0256	.2320
+ 40	500.66	10512	73.00	530.63	52.42	478.21	3 91	.0257	.2583
+ 45	505.66	11616	80.66	527.47	52.62	474.85	3.56	.0260	.2809
+ 50	510.66	12811	88.96	524.30	52.82	471.48	3.25	.0260	.3109
+ 55	515.66	14102	97.93	521.12	53.01	468.11	2.96	.0260	.3379
+ 60	520.66	15494	107.60	517.93	53.21	464.72	2.70	.0265	.3704
+ 65	525.66	16993	118.03	514.73	53.38	461.35	2 48	.0266	.4034
+ 70	530.66	18605	129.21	511.52	53.57	457.85	2.27	.0268	.4405
+ 75	535.66	20336	141.25	508.29	53.76	454.53	2 08	.0270	.4808
+ 80	540.66	22192	154.11	504.66	53 96	450.70	1.91	.0272	.5262
+ 85	545.66	24178	167.86	501 81	54.15	447 66	1.77	.0273	.5649
+ 90	550.66	26300	182.8	498.11	54.28	443.83	1.64	.0274	.6098
+ 95	555.66	28565	198.37	495.29	54.41	440.88	1.51	.0277	6622
+100	560.66	30980	215.14	491.50	54.54	436.96	1.39	.0279	.7194
+105	565.66	33550	232.98	488.72	54.67	434.08	1.289	.0281	.7757
+110	570.66	36284	251.97	485.42	54.78	430.64	1.203	.0283	.8312
+115	575.66	39188	272.14	482.41	54.91	427.40	1.121	.0285	.8912
+120	580.66	42267	293.49	478.79	55.03	423.75	1.041	.0287	.9608
+125	585.66	45528	316.16	475.45	55.09	420.39	.9699	0289	1.0310
+130	590.66	48978	340.42	472.11	55.16	416.94	.9051	.0291	1.1048
+135	595.66	52626	365.16	468.75	55.22	413.53	.8457	.0293	1.1824
+140	600.66	56483	392.22	465.39	55.29	410.09	.7910	.0295	1.2642
+145	605.66	60550	420.49	462.01	55.34	406.67	.7408	.0297	1.3497
+150	610.66	64833	450.20	458.62	55.39	402.23	.6946	.0299	1.4396
+155	615.66	69341	481.54	455.22	55.43	399 79	.6511	0302	1.5358
+160	620.66	74086	514.40	451.81	55.46	396.35	.6128	.0304	1.6318
+165	625.66	79071	549.04	448.39	55.48	392.94	.5765	.0306	1.7344

The critical pressure of ammonia is 115 atmospheres, the critical temperature at 130° F. (Dewar), critical volume .00482 (calculated).

TABLE OF AMMONIA GAS (SUPER-HEATED VAPOR). TEMPERATURE IN DEGREES F.

Press. p in Lbs. Abso.	0	5	10	15	20	25	30	35	40	45
	No. of Cu. Ft., *v*, Approximately Contained in 1 Lb. of Gas.									
15	18.81	19.05	19.20	19.48	19.68	19.87	20.06	20.25	20.544	20.74
16	17.56	17.85	18.09	18.24	18.43	18.52	18.81	18.90	19.20	19.44
17	16.60	16.70	16.96	17.08	17.28	17.48	17.66	17.85	18.09	18.31
18	15.54	15.84	15.93	16.12	16.32	16.51	16.70	16.89	17.08	17.32
19	14.78	14.97	15.16	15.26	15.45	15.64	15.84	15.93	16.12	16.36
20	14.01	14.25	14.40	14.49	14.68	14.88	14.97	15.16	15.36	15.58
21	13.34	13.53	13.63	13.82	14.01	14.11	14.30	14.40	14.59	14.80
22	12.76	12.86	13.05	13.15	13.34	13.44	13.63	13.72	13.92	14.12
23	12.19	12.28	12.48	12.57	12.76	12.86	13.05	13.15	13.34	13.54
24	11.71	11.80	11.90	12.09	12.19	12.38	12.48	12.57	12.76	12.96
25	11.23	11.34	11.42	11.61	11.71	11.80	11.90	12.09	12.19	12.38
26	10.75	10.84	11.04	11.13	11.23	11.32	11.52	11.61	11.71	11.85
27	10.36	10.46	10.56	10.75	10.84	10.94	11.04	11.23	11.32	11.45
28	9.98	10.08	10.17	10.36	10.46	10.56	10.65	10.75	10.84	10.94
29	9.60	9.69	9.79	9.98	10.08	10.17	10.27	10.36	10.46	10.57
30	9.2120	9.30	10.46	9.60	9.69	9.79	9.98	10.08	10.17	10.27
31	8.84	9.12	9.21	9.31	9.40	9.50	9.60	9.69	9.80	9.91
32	....	8.83	8.93	9.02	9.12	9.21	9.31	9.40	9.50	9.61
33	....	8.54	8.64	8.73	8.83	8.91	9.02	9.11	9.21	9.31
34	....	8.25	9.35	8.49	8.54	8.64	8.73	8.83	8.92	9.02
35	....	.....	8.16	8.25	8.35	8.44	8.54	8.64	8.64	8.75
36	....	.....	7.87	7.96	8.06	8.16	8.26	8.35	8.44	8.55
37	....	.....	7.68	7.67	7.87	7.96	8.06	8.16	8.26	8.36
38	....	....	7.48	7.58	7.68	7.77	7.77	7.87	7.96	8.05
39	....	.....	......	7.39	7.48	7.48	7.58	7.68	7.77	7.87
40	....	.....	.....	7.20	7.29	7.39	7.39	7.48	7.58	7.68
41	....	.....	.....	7.00	7.10	7.20	7.20	7.29	7.39	7.49
42	....	.....	....	6.81	6.91	7.00	7.10	7.10	7.20	7.30
43	....	.....	......	......	6.72	6.81	6.91	7.00	7.08	7.16
44	....	.....	......	......	6.52	6.62	6.72	6.81	6.91	7.10
45	....	...	......	.....	6.43	6.52	6.62	6.62	6.72	6.82

TABLE SHOWING REFRIGERATING EFFECT OF ONE CUBIC FOOT OF AMMONIA GAS AT DIFFERENT CONDENSER AND SUCTION (BACK) PRESSURES IN B. T. UNITS.

Temperature of Gas in Degrees F.	Corresponding Suction Pressure, Lbs. per sq. in.	Temperature of the Liquid in Degrees F.								
		65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresp'g. Condenser Pressure (gauge), lbs. per sq. in.								
		103	115	127	139	153	168	184	200	218
	G. Pres.									
—27°	1	27.30	27.01	26.73	26.44	26.16	25.87	25.59	25.30	25.02
—20°	4	33.74	33.40	33.04	32.70	32.34	31.99	31.64	31.30	30.94
—15°	6	36.36	36.48	36.10	35.72	35.34	34.96	34.58	34.20	33.82
—10°	9	42.28	41.84	41.41	40.97	40.54	40.10	39.67	39.23	38.80
— 5°	13	48.31	47.81	47.32	46.82	46.33	45.83	45.34	44.84	44.35
0°	16	54.88	54.32	53.76	53.20	52.64	52.08	51.52	50.96	50.40
5°	20	61.50	60.87	60.25	59.62	59.00	58.37	57.75	57.12	56.50
10°	24	68.66	67.97	67.27	66.58	65.88	65.19	64.49	63.80	63.10
15°	28	75.88	75.12	74.35	73.59	72.82	72.06	71.29	70.53	69.76
20°	33	85.15	84.30	83.44	82.59	81.73	80.88	80.02	79.17	78.31
25°	39	95.50	94.54	93.59	92.63	91.68	90.72	89.97	88.81	87.86
30°	45	106.21	105.15	104.09	103.03	101.97	100.91	99.85	98.79	97.73
35°	51	115.69	114.54	123.39	112.24	111.09	109.94	108.79	107.64	106.49

TABLE GIVING NUMBER OF CUBIC FEET OF GAS THAT MUST BE PUMPED PER MINUTE AT DIFFERENT CONDENSER AND SUCTION PRESSURES, TO PRODUCE ONE TON OF REFRIGERATION IN TWENTY-FOUR HOURS.

Temperature of Gas in Degrees F.	Corresponding Suction Pressure, Lbs. per sq. in.	Temperature of the Gas in Degrees F.								
		65°	70°	75°	80°	85°	90°	95°	100°	105°
		Corresp'g. Condenser Pressure (gauge), lbs. per sq. in.								
		103	115	127	139	153	168	184	200	218
	G. Pres.									
—27°	1	7.22	7.3	7.37	7.46	7.54	7.62	7.70	7.79	7.88
—20°	4	5.84	5.9	5.96	6.03	6.09	6.16	6.23	6.30	6.43
—15°	6	5.35	5.4	5.46	5.52	5.58	5.64	5.70	5.77	5.83
—10°	9	4.66	4.73	4.76	4.81	4.86	4.91	4.97	5.05	5.08
— 5°	13	4.09	4.12	4.17	4.21	4.25	4.30	4.35	4.40	4.44
0°	16	3.59	3.63	3.66	3.70	3.74	3.78	3.83	3.87	3.91
5°	20	3.20	3.24	3.27	3.30	3.34	3.38	3.41	3.45	3.49
10°	24	2.87	2.9	2.93	2.96	2.99	3.02	3.06	3.09	3.12
15°	28	2.59	2.61	2.65	2.68	2.71	2.73	2.76	2.80	2.82
20°	33	2.31	2.34	2.36	2.38	2.41	2.44	2.46	2.49	2.51
25°	39	2.06	2.08	2.10	2.12	2.15	2.17	2.20	2.22	2.24
30°	45	1.85	1.87	1.89	1.91	1.93	1.95	1.97	2.00	2.01
35°	51	1.70	1.72	1.74	1.76	1.77	1.79	1.81	1.83	1.85

ANHYDROUS AMMONIA.

Ammonia is a compound of one volume of nitrogen with three volumes of hydrogen, and is therefore represented by the chemical formula NH_3. It contains by weight 82.35 per cent nitrogen and 17.65 per cent hydrogen. Its molecular weight is 17.

Ammonia is a colorless gas possessing a very characteristic pungent smell. It is much lighter than air, having a specific gravity (air 1) of 0.586, one liter of gas weighing, at the normal temperature and pressure, 0.76193 grams. By mechanical pressure and cooling, it is converted from a gaseous to a liquid state (liquid anhydrous ammonia) which boils under the ordinary atmospheric pressure at $28\frac{6}{10}°$ below zero, or $240\frac{1}{2}°$ lower than the boiling point of water under the same conditions. One pound of the liquid at 32° will occupy 21.017 cubic feet of space when evaporated at the atmospheric pressure. The specific heat of ammonia gas, as determined by Regnault (capacity for heat), is 0.50836. Its latent heat of evaporation is about 560 thermal units at 32° Fahrenheit, at which temperature one pound of the liquid, evaporated under a pressure of fifteen pounds per square inch, will occupy twenty-one cubic feet.

TESTING ANHYDROUS AMMONIA.

Usually ammonia manufacturers sell their goods subject to the condition and agreement, on the part of the purchaser, that a sample be drawn from each cylinder upon arrival and subjected to a test before emptying the contents, no reclamation being allowed on account of deficiency in quality or strength after a cylinder has been emptied or partly emptied. Therefore it is important that the consumer satisfy himself of the purity of the ammonia before drawing off the contents of the cylinder.

EVAPORATION TEST.

Any dealer in chemical supplies will furnish an 8-ounce, flat bottom, wide neck, Bohemian glass boiling flask (in case of breakage it is well to have several of these). Fit in the neck a stopper having a ¼-inch vent hole punctured through for escape of the gas. Insert in this hole a short glass tube. Procure a piece of ⅜-inch iron pipe, threaded at one end; bend the pipe to such a shape that the threaded end can be connected with the cylinder valve; put the wrench on the valve of the cylinder and open it gently; allow a little of the ammonia gas to escape at first in order to purge the pipe and valve, then draw into the test flask from 2½ to 4 ounces of the liquid ammonia. When this is accomplished, remove the test flask at once, and insert in the neck the stopper with vent tube, then place it in such a position as will allow a small stream of water to flow over the sides of the flask. Under these conditions the ammonia will boil quickly and soon evaporate. Any residue remaining in the flask indicates impurities. Care is necessary in drawing off the sample, as a very little moisture in the test flask or in the pipe, or a brief exposure to the atmosphere, will at once affect it.

COMPARISONS OF THERMOMETER SCALES, SHOWING RELATIVE INDICATIONS OF THE CELSIUS, FAHRENHEIT AND REAUMUR THERMOMETER SCALES.

In the United States and England the Fahrenheit scale is generally used; in France and in all scientific investigations and treatises, the Celsius scale is uniformly used; and in Germany the Reaumur scale is the one generally adopted.

C.	F.	R.	C.	F.	R.	C.	F.	R.
100°	212.0°	80.0°	53°	127.4°	42.4°	6°	42.8°	4.8°
99	210.2	79.2	52	125.6	41.6	5	41.0	4.0
98	208.4	78.4	51	123.8	40.8	4	39.2	3.2
97	206.6	77.6	50	122.0	40.0	3	37.4	2.4
96	204.8	76.8	49	120.2	39.2	2	35.6	1.6
95	203.0	76.0	48	118.4	38.4	1	33.8	0.8
94	201.2	75.2	47	116.6	37.6	Zero	32.0	Zero
93	199.4	74.4	46	114.8	36.8	1	30.2	0.8
92	197.6	73.6	45	113.0	36.0	2	28.4	1.6
91	195.8	72.8	44	111.2	35.2	3	26.6	2.4
90	194.0	72.0	43	109.4	34.4	4	24.8	3.2
89	192.2	71.2	42	107.6	33.6	5	23.0	4.0
88	190.4	70.4	41	105.8	32.8	6	21.2	4.8
87	188.6	69.6	40	104.0	32.0	7	19.4	5.6
86	186.8	68.8	39	102.2	31.2	8	17.6	6.4
85	185.0	68.0	38	100.4	30.4	9	15.8	7.2
84	183.2	67.2	37	98.6	29.6	10	14.0	8.0
83	181.4	66.4	36	96.8	28.8	11	12 2	8.8
82	179.6	65.6	35	95.0	28.0	12	10.4	9.6
81	177.8	64.8	34	93.2	27.2	13	8.6	10.4
80	176.0	64.0	33	91.4	26.4	14	6.8	11.2
79	174.2	63.2	32	89.6	25.6	15	5.0	12.0
78	172.4	62.4	31	87.8	24.8	16	3.2	12.8
77	170.6	61.6	30	86.0	24.0	17	1.4	13.6
76	168.8	60.8	29	84.2	23.2	18	...	14.4
75	167.0	60.0	28	82.4	22.4	19	2.2	15.2
74	165.2	59.2	27	80.6	21.6	20	4.0	16.0
73	163.4	58.4	26	78.8	20.8	21	5.8	16.8
72	161.6	57.6	25	77.0	20.0	22	7.6	17.6
71	159.8	56.8	24	75.2	19.2	23	9.4	18.4
70	158.0	56.0	23	73.4	18.4	24	11.2	19.2
69	156.2	55.2	22	71.6	17.6	25	13.0	20.0
68	154.4	54.4	21	69.8	16.8	26	14.8	20.8
67	152.6	53.6	20	68.0	16.0	27	16.6	21.6
66	150.8	52.8	19	66 2	15.2	28	18.4	22.4
65	149.0	52.0	18	64.4	14.4	29	20.2	23.2
64	147.2	51.2	17	62.6	13.6	30	22.0	24.0
63	145.4	50.4	16	60.8	12.8	31	23.8	24.8
62	143.6	49.6	15	59.0	12.0	32	25.6	25.6
61	141.8	48.8	14	57.2	11.2	33	27.4	26.4
60	140.0	48.0	13	55.4	10.4	34	29.2	27.2
59	138.2	47.2	12	53.6	9.6	35	31.0	28.0
58	136.4	46.4	11	51.8	8.8	36	32.8	28.8
57	134.3	45.6	10	50.0	8.0	37	34.6	29.6
56	132.8	44.8	9	48.2	7.2	38	36.4	30.4
55	131.0	44.0	8	46.4	6.4	39	38.2	31.2
54	129.2	43.2	7	44.6	5.8	40	40.0	32.0

MEAN PRESSURE OF DIAGRAM OF AMMONIA COMPRESSOR.

Reprinted from the Catalogue of the De La Vergne Refrigerating Machine Co.

Condenser Pressure.		103	115	127	139	153	168	184	200	218
Condenser Temperature.		65°	70°	75°	80°	85°	90°	95°	100°	105°
Refrigerator Pressure.	Refrigerator Temperature.									
4	—20°	41.46	43.91	46.34	48.77	51.23	53.68	56.11	58.54	60.99
6	—15°	42.72	45.38	47.90	50.74	53.40	56.08	58.86	61.40	64.08
9	—10°	44.40	47.38	50.33	53.29	56.25	59.20	62.16	65.14	68.09
13	— 5°	45.86	49.15	52.42	55.70	58.97	62.25	65.53	68.81	72.08
16	0°	46.94	50.56	54.16	57.78	61.40	65.00	68.62	72.22	75.84
20	5°	47.74	51.73	55.70	59.68	63.67	67.66	71.62	75.61	79.61
24	10°	48.04	52.40	56.77	61.13	65.51	69.86	74.24	78.59	82.97
28	15°	47.88	52.67	57.44	62.23	67.02	71.81	76.60	81.39	86.18
33	20°	47.08	52.30	57.53	62.75	67.98	73.23	78.46	83.68	88.91
39	25°	45.06	51.34	57.05	62.75	68.46	74.17	79.88	85.58	91.29
45	30°	43.16	49.71	55.92	62.14	68.35	74.56	80.77	86.98	93.19
51	35°	40.52	47.26	54.02	60.76	67.52	74.28	81.02	87.78	94.52

PROPERTIES OF SATURATED STEAM.

Total pressure per square inch.	Temperature in Fahrenheit degrees.	Total heat, in Fahrenheit degrees, from water at 32° F.	Latent heat, Fahrenheit degrees.	Density, or weight of one cubic foot.	Volume of one pound of steam.	Relative volume or cubic feet of steam from one cubic foot of water.
Lbs.	Fahr.	Fahr.	Fahr.	Lbs.	Cubic Feet	Rel. Vol.
1	102.1	1112.5	1042.9	.0030	330.36	20600
2	126.3	1119.7	1025.8	.0058	172.08	10730
3	141.6	1124.6	1015.0	.0085	117.52	7327
4	153.1	1128.1	1006.8	.0112	89.62	5589
5	162.3	1130.9	1000.3	.0138	72.66	4530
6	170.2	1133.3	994.7	.0163	61.21	3816
7	176.9	1135.3	990.0	.0189	52.94	3301
8	182.9	1137.2	985.7	.0214	46.69	2911
9	188.3	1138.8	981.9	.0239	41.79	2606
10	193.3	1140.3	978.4	.0264	37.84	2360
11	197.8	1141.7	975.2	.0289	34.63	2157
12	202.0	1143.0	972.2	.0314	31.88	1988
13	205.9	1144.2	969.4	.0338	29.57	1844
14	209.6	1145.3	966.8	.0362	27.61	1721
14.7	212.0	1146.1	965.2	.0380	26.36	1642
15	213.1	1146.4	964.3	.0387	25.85	1611
16	216.3	1147.4	962.1	.0411	24.32	1516
17	219.6	1148.3	959.8	.0435	22.96	1432
18	222.4	1149.2	957.7	.0459	21.78	1357
19	225.3	1150.1	955.7	.0483	20.70	1290
20	228.0	1150.9	952.8	.0507	19.72	1229
21	230.6	1151.7	951.3	.0531	18.84	1174
22	233.1	1152.5	949.9	.0555	18.03	1123
23	235.5	1153.2	948.5	.0580	17.26	1075
24	237.8	1153.9	946.9	.0601	16.64	1036
25	240.1	1154.6	945.3	.0625	15.99	996
26	242.3	1155.3	943.7	.0650	15.38	958
27	244.4	1155.8	942.2	.0673	14.86	926
28	246.4	1156.4	940.8	.0696	14.37	895
29	248.4	1157.1	939.4	.0719	13.90	866
30	250.4	1157.8	937.9	.0743	13.46	838
31	252.2	1158.4	936.7	.0766	13.05	813
32	254.1	1158.9	935.3	.0789	12.67	789
33	255.9	1159.5	934.0	.0812	12.31	767
34	257.6	1160.0	932.8	.0835	11.97	746
35	259.3	1160.5	931.6	.0858	11.65	726
36	260.9	1161.0	930.5	.0881	11.34	707
37	262.6	1161.5	929.3	.0905	11.04	688
38	264.2	1162.0	928.2	.0929	10.76	671
39	265.8	1162.5	927.1	.0952	10.51	655
40	267.3	1162.9	926.0	.0974	10.27	640
41	268.7	1163.4	924.9	.0996	10.03	625
42	270.2	1163.8	923.9	.1020	9.81	611
43	271.6	1164.2	922.9	.1042	9.59	598
44	273.0	1164.6	921.9	.1065	9.39	585
45	274.4	1165.1	920.9	.1089	9.18	572
46	275.8	1165.5	919.9	.1111	9.00	561
47	277.1	1165.9	919.0	.1133	8.82	550
48	278.4	1166.3	918.1	.1156	8.65	539
49	279.7	1166.7	917.2	.1179	8.48	529
50	281.0	1167.1	916.3	.1202	8.31	518
51	282.3	1167.5	915.4	.1224	8.17	509
52	283.5	1167.9	914.5	.1246	8.04	500
53	284.7	1168.3	913.6	.1269	7.88	491
54	285.9	1168.6	912.8	.1291	7.74	482
55	287.1	1169.0	912.0	.1314	7.61	474
56	288.2	1169.3	911.2	.1336	7.48	466

PROPERTIES OF SATURATED STEAM.—CONT.

Total pressure per square inch.	Temperature in Fahrenheit degrees.	Total heat, in Fahrenheit degrees, from water at 32° F.	Latent heat, Fahrenheit degrees.	Density, or weight of one cubic foot.	Volume of one pound of steam.	Relative volume or cubic feet of steam from one cubic foot of water.
Lbs.	Fahr.	Fahr.	Fahr.	Lbs.	Cubic Feet	Rel. Vol.
57	289.3	1169.7	910.4	.1364	7.36	458
58	290.4	1170.0	909.6	.1380	7.24	451
59	291.6	1170.4	908.8	.1403	7.12	444
60	292.7	1170.7	908.0	.1425	7.01	437
61	293.8	1171.1	907.2	.1447	6.90	430
62	294.8	1171.4	906.4	.1469	6.81	424
63	295.9	1171.7	905.6	.1493	6.70	417
64	296.9	1172.0	904.9	.1516	6.60	411
65	298.0	1172.3	904.2	.1538	6.49	405
66	299.0	1172.6	903.5	.1560	6.41	399
67	300.0	1172.9	902.8	.1583	6.32	393
68	300.9	1173.2	902.1	.1605	6.23	388
69	301.9	1173.5	901.4	.1627	6.15	383
70	302.9	1173.8	900.8	.1648	6.07	378
71	303.9	1174.1	900.3	.1670	5.99	373
72	304.8	1174.3	899.6	.1692	5.91	368
73	305.7	1174.6	898.9	.1714	5.83	363
74	306.6	1174.9	898.2	.1736	5.76	359
75	307.5	1175.2	897.5	.1759	5.68	353
76	308.4	1175.4	896.8	.1782	5.61	349
77	309.3	1175.7	896.1	.1804	5.54	345
78	310.2	1176.0	895.5	.1826	5.48	341
79	311.1	1176.3	894.9	.1848	5.41	337
80	312.0	1176.5	894.3	.1869	5.35	333
81	312.8	1176.8	893.7	.1891	5.29	329
82	313.6	1177.1	893.1	.1913	5.23	325
83	314.5	1177.4	892.5	.1935	5.17	321
84	315.3	1177.6	892.0	.1957	5.11	318
85	316.1	1177.9	891.4	.1980	5.05	314
86	316.9	1178.1	890.8	.2002	5.00	311
87	317.8	1178.4	890.2	.2024	4.94	308
88	318.6	1178.6	889.6	.2044	4.89	305
89	319.4	1178.9	889.0	.2067	4.84	301
90	320.2	1179.1	888.5	.2089	4.79	298
91	321.0	1179.3	887.9	.2111	4.74	295
92	321.7	1179.5	887.3	.2133	4.69	292
93	322.5	1179.8	886.8	.2155	4.64	289
94	323.3	1180.0	886.3	.2176	4.60	286
95	324.1	1180.3	885.8	.2198	4.55	283
96	324.8	1180.5	885.2	.2219	4.51	281
97	325.6	1180.8	884.6	.2241	4.46	278
98	326.3	1181.0	884.1	.2263	4.42	275
99	327.1	1181.2	883.6	.2285	4.37	272
100	327.9	1181.4	883.1	.2307	4.33	270
101	328.5	1181.6	882.6	.2329	4.29	267
102	329.1	1181.8	882.1	.2351	4.25	265
103	329.9	1182.0	881.6	.2373	4.21	262
104	330.6	1182.2	881.1	.2393	4.18	260
105	331.3	1182.4	880.7	.2414	4.14	257
106	331.9	1182.6	880.2	.2435	4.11	255
107	332.6	1182.8	879.7	.2456	4.07	253
108	333.3	1183.0	879.2	.2477	4.04	251
109	334.0	1183.3	878.7	.2499	4.00	249
110	334.6	1183.5	878.3	.2521	3.97	247
111	335.3	1183.7	877.8	.2543	3.93	245
112	336.0	1183.9	877.3	.2564	3.90	243
113	336.7	1184.1	876.8	.2586	3.86	241

PROPERTIES OF SATURATED STEAM.—CONT.

Total pressure per square inch.	Temperature in Fahrenheit degrees.	Total heat, in Fahrenheit degrees, from water at 32° F.	Latent heat, Fahrenheit degrees.	Density, or weight of one cubic foot.	Volume of one pound of steam.	Relative volume or cubic feet of steam from one cubic foot of water.
Lbs.	Fahr.	Fahr.	Fahr.	Lbs.	Cubic Feet	Rel. Vol.
114	337.4	1184.3	876.3	.2607	3.83	239
115	338.0	1184.5	875.9	.2628	3.80	237
116	338.6	1184.7	875.5	.2649	3.77	235
117	339.3	1184.9	875.0	.2652	3.74	233
118	339.9	1185.1	874.5	.2674	3.71	231
119	340.5	1185.3	874.1	.2696	3.68	229
120	341.1	1185.4	873.7	.2738	3.65	227
121	341.8	1185.6	873.2	.2759	3.62	225
122	342.4	1185.8	872.8	.2780	3.59	224
123	343.0	1186.0	872.3	.2801	3.56	222
124	343.6	1186.2	871.9	.2822	3.54	221
125	344.2	1186.4	871.5	.2845	3.51	219
126	344.8	1186.6	871.1	.2867	3.49	217
127	345.4	1186.8	870.7	.2889	3.46	215
128	346.0	1186.9	870.2	.2911	3.44	214
129	346.6	1187.1	869.8	.2933	3.41	212
130	347.2	1187.3	869.4	.2955	3.38	211
131	347.8	1187.5	869.0	.2977	3.35	209
132	348.3	1187.6	868.6	.2999	3.33	208
133	348.9	1187.8	868.2	.3020	3.31	206
134	349.5	1188.0	867.8	.3040	3.29	205
135	350.1	1188.2	867.4	.3060	3.27	203
136	350.6	1188.3	867.0	.3080	3.25	202
137	351.2	1188.5	866.6	.3101	3.22	200
138	351.8	1188.7	866.2	.3121	3.20	199
139	352.4	1188.9	865.8	.3142	3.18	198
140	352.9	1189.0	865.4	.3162	3.16	197
141	353.5	1189.2	865.0	.3184	3.14	195
142	354.0	1189.4	864.6	.3206	3.12	194
143	354.5	1189.6	864.2	.3228	3.10	193
144	355.0	1189.7	863.9	.3250	3.08	192
145	355.6	1189.9	863.5	.3273	3.06	190
146	356.1	1190.0	863.1	.3294	3.04	189
147	356.7	1190.2	862.7	.3315	3.02	188
148	357.2	1190.3	862.3	.3336	3.00	187
149	357.8	1190.5	861.9	.3357	2.98	186
150	358.3	1190.7	861.5	.3377	2.96	184
155	361.0	1191.5	859.7	.3484	2.87	179
160	363.4	1192.2	857.9	.3590	2.79	174
165	366.0	1192.9	856.2	.3695	2.71	169
170	368.2	1193.7	854.5	.3798	2.63	164
175	370.8	1194.4	852.9	.3899	2.56	159
180	372.9	1195.1	851.3	.4009	2.49	155
185	375.3	1195.8	849.6	.4117	2.43	151
190	377.5	1196.5	848.0	.4222	2.37	148
195	379.7	1197.2	846.5	.4327	2.31	144
200	381.7	1197.8	845.0	.4431	2.26	141
210	386.0	1199.1	841.9	.4634	2.16	135
220	389.9	1200.3	839.2	.4842	2.06	129
230	393.8	1201.5	836.4	.5052	1.98	123
240	397.5	1202.6	833.8	.5248	1.90	119
250	401.1	1203.7	831.2	.5464	1.83	114
260	404.5	1204.8	828.8	.5669	1.76	110
270	407.9	1205.8	826.4	.5868	1.70	106
280	411.2	1206.8	824.1	.6081	1.64	102
290	414.4	1207.8	821.8	.6273	1.59	99
300	417.5	1208.7	819.6	.6486	1.54	96

MEAN EFFECTIVE PRESSURE OF DIAGRAM OF STEAM CYLINDER.

Cut-off at		1/10	1/9	1/8	1/7	1/6	1/5	1/4	3/10	1/3	2/5	1/2	3/5	2/3	7/10	3/4
Apparent Ratio of Expansion.		10	9	8	7	6	5	4	3.33	3	2.5	2	1.67	1.5	1.43	1.33
M. E. P. per Lb. Initial.		.330	.355	.385	.421	.465	.523	.596	.661	.699	.776	.846	.906	.937	.949	.964
Initial Pressure.																
Gauge	Absolute															
25	39.7	13.11	14.09	15.28	16.71	18.46	20.72	23.68	26.24	27.77	30.43	33.61	35.96	37.20	37.69	38.27
30	44.7	14.76	15.87	17.21	18.82	20.79	23.33	26.67	29.54	31.27	34.26	37.84	40.49	41.88	42.44	43.00
35	49.7	16.41	17.64	19.13	20.92	23.11	25.94	29.65	32.85	34.77	38.10	42.07	45.02	46.57	47.19	47.91
40	54.7	18.07	19.42	21.06	23.03	25.44	28.55	32.63	36.15	38.26	41.93	46.31	49.55	51.25	51.94	52.73
45	59.7	19.72	21.19	22.98	25.12	27.76	31.16	35.62	39.46	41.76	45.76	50.54	54.08	55.94	56.68	57.55
50	64.7	21.37	22.97	24.91	27.23	30.09	33.77	38.60	42.76	45.26	49.59	54.77	58.61	60.62	61.43	62.07
55	69.7	23.02	24.74	26.83	29.34	32.31	36.38	41.58	46.07	48.76	53.43	59.00	63.15	65.31	66.18	67.19
60	74.7	24.67	26.52	28.75	31.45	34.74	38.99	44.56	49.37	52.26	57.26	63.24	67.67	69.99	70.92	72.01
65	79.7	26.32	28.29	30.68	33.55	37.06	41.59	47.55	52.67	55.75	61.09	67.47	72.20	74.68	75.67	76.83
70	84.7	27.97	30.07	32.60	35.66	39.39	44.20	50.53	55.98	59.25	64.92	71.70	76.73	79.36	80.42	81.64
75	89.7	29.62	31.84	34.53	37.76	41.71	46.81	53.51	59.28	62.75	68.76	75.94	81.26	84.05	85.17	86.27
80	94.7	31.28	33.62	36.45	39.87	44.04	49.42	56.50	62.59	66.25	72.59	80.17	85.79	88.73	89.91	91.28
85	99.7	32.93	35.39	38.38	41.97	46.36	52.03	59.48	65.89	69.74	76.42	84.40	90.32	93.42	94.66	96.10
90	104.7	34.58	37.17	40.30	44.08	48.69	54.64	62.46	69.20	73.24	80.26	88.63	94.84	98.10	99.41	100.92
95	109.7	36.23	38.94	42.23	46.18	51.01	57.25	65.44	72.50	76.74	84.09	92.87	99.37	102.79	104.15	105.74
100	114.7	37.88	40.72	44.15	48.20	53.34	59.86	68.43	75.81	80.24	87.92	97.10	103.90	107.47	108.90	110.56
110	124.7	41.18	44.27	48.00	52.50	57.98	65.08	74.39	82.41	87.23	95.59	105.26	112.96	116.84	118.39	120.20
120	134.7	44.49	47.82	51.85	56.71	62.64	70.30	80.36	89.02	94.23	103.25	114.04	122.02	126.21	127.89	129.84
130	144.7	47.79	51.37	55.70	60.92	67.29	75.52	86.32	95.63	101.22	110.91	122.50	131.08	135.58	137.38	139.48
140	154.7	51.09	54.92	59.55	65.13	71.94	80.74	92.29	102.24	108.22	118.58	130.96	140.14	144.95	146.88	149.12
150	164.7	54.39	58.47	63.40	69.34	76.59	85.96	98.26	108.85	115.21	126.26	139.43	149.20	154.32	156.37	158.76
160	174.7	57.70	61.02	67.25	73.55	81.24	91.17	104.22	115.46	122.21	133.91	147.89	158.25	163.69	165.87	168.40
170	184.7	61.00	65.57	71.10	77.76	85.89	96.39	110.19	122.07	129.20	141.90	156.36	167.31	173.06	175.37	178.04
180	194.7	64.30	69.12	74.95	81.97	90.54	101.61	116.15	128.68	136.20	149.24	164.82	176.37	182.43	184.86	187.67
190	204.7	67.60	72.67	78.79	86.18	95.19	106.83	122.12	135.29	143.19	156.91	173.29	185.43	191.80	194.35	197.32
200	214.7	70.91	76.22	82.64	90.39	99.84	112.05	128.08	141.90	150.19	164.57	181.85	194.94	200.71	203.85	206.95
210	224.7	74.21	79.78	86.49	94.60	104.49	117.27	134.05	148.51	157.19	172.24	190.22	203.55	210.54	213.34	216.59
220	234.7	77.51	83.32	90.34	98.81	109.14	122.48	140.02	155.12	164.18	179.90	198.68	212.61	219.91	222.83	226.23
230	244.7	80.81	86.87	94.19	103.02	113.79	127.70	145.98	161.72	171.18	187.57	207.15	221.66	229.28	232.33	235.87

The M. E. P. for any initial pressure not given in the table can be found by multiplying the (absolute) given pressure by the M. E. P. per pound of initial, as given in the third horizontal line of the table.

HEAD OF WATER AND EQUIVALENT PRESSURE IN POUNDS PER SQUARE INCH.

Head in ft.	Press.	Head in ft.	Press.	Head in ft.	Press.	Head in ft.	Press.	Head in ft.	Press.
1	0.43	41	17.75	81	35.08	121	52.41	161	69.74
2	0.86	42	18.19	82	35.52	122	52.84	162	70.17
3	1.30	43	18.62	83	35.95	123	53.28	163	70.61
4	1.73	44	19.05	84	36.39	124	53.71	164	71.04
5	2.16	45	19.49	85	36.82	125	54.15	165	71.47
6	2.59	46	19.92	86	37.25	126	54.58	166	71.91
7	3.03	47	20.35	87	37.68	127	55.01	167	72.34
8	3.46	48	20.79	88	38.12	128	55.44	168	72.77
9	3.89	49	21.22	89	38.55	129	55.88	169	73.20
10	4.33	50	21.65	90	39.98	130	56.31	170	73.64
11	4.76	51	22.09	91	39.42	131	56.74	171	74.07
12	5.20	52	22.52	92	39.85	132	57.18	172	74.50
13	5.63	53	22.95	93	40.28	133	57.61	173	74.94
14	6.06	54	23.39	94	40.72	134	58.04	174	75.37
15	6.49	55	23.82	95	41.15	135	58.48	175	75.80
16	6.93	56	24.26	96	41.58	136	58.91	176	76.23
17	7.36	57	24.69	97	42.01	137	59.34	177	76.67
18	7.79	58	25.12	98	42.45	138	59.77	178	77.10
19	8.22	59	25.55	99	42.88	139	60.21	179	77.53
20	8.66	60	25.99	100	43.31	140	60.64	180	77.97
21	9.09	61	26.42	101	43.75	141	61.07	181	78.40
22	9.53	62	26.85	102	44.18	142	61.51	182	78.84
23	9.96	63	27.29	103	44.61	143	61.94	183	79.27
24	10.39	64	27.72	104	45.05	144	62.37	184	79.70
25	10.82	65	28.15	105	45.48	145	62.81	185	80.14
26	11.26	66	28.58	106	45.91	146	63.24	186	80.57
27	11.69	67	29.02	107	46.34	147	63.67	187	81.00
28	12.12	68	29.45	108	46.78	148	64.10	188	81.43
29	12.55	69	29.88	109	47.21	149	64.54	189	81.87
30	12.99	70	30.32	110	47.64	150	64.97	190	82.30
31	13.42	71	30.75	111	48.08	151	65.49	191	82.77
32	13.86	72	31.18	112	48.51	152	65.84	192	83.13
33	14.29	73	31.62	113	48.94	153	66.27	193	83.60
34	14.72	74	32.05	114	49.38	154	66.70	194	84.03
35	15.16	75	32.48	115	49.81	155	67.14	195	84.47
36	15.59	76	32.92	116	50.24	156	67.57	196	84.90
37	16.02	77	33.35	117	50.68	157	68.00	197	85.33
38	16.45	78	33.78	118	51.11	158	68.43	198	85.76
39	16.89	79	34.21	119	51.54	159	68.87	199	86.20
40	17.32	80	34.65	120	51.98	160	69.31	200	86.63

TABLE SHOWING PROPERTIES OF SOLUTION OF SALT.

(Chloride of Sodium.)

1 Percentage of Salt by Weight.	2 Pounds of Salt per Gallon of Solution.	3 Degrees on Salometer at 60° F.	4 Weight per Gallon at 39° F.-4° C.	5 Specific Gravity at 39° F.-4° C.	6 Specific Heat.	7 Freezing Point, Fahrenheit.
1	0.084	4	8.40	1.007	0.992	30.5
2	0.169	8	8.46	1.015	.....	29.3
2.5	0.212	10	8.50	1.019	.....	28.6
3	0.256	12	8.53	1.023	.....	27.8
3.5	0.300	14	8.56	1.026	.....	27.1
4	0.344	16	8.59	1.030	.....	26.6
5	0.433	20	8.65	1.037	0.960	25.2
6	0.523	24	8.72	1.045	.....	23.9
7	0.617	28	8.78	1.053	.....	22.5
8	0.708	32	8.85	1.061	.....	21.2
9	0.802	36	8.91	1.068	.....	19.9
10	0.897	40	8.97	1.076	0.892	18.7
12	1.092	48	9.10	1.091	.....	16.0
15	1.389	60	9.26	1.115	0.855	12.2
20	1.928	80	9.64	1.155	0.829	6.1
24	2.376	96	9.90	1.187	.....	1.2
25	2.488	100	9.97	1.196	0.783	.5
26	2.610	.....	10.04	1.204	.....	—1.1
29	.....	.....	.....	.....	.....	—4.7

To determine the weight of one cubic foot of brine, multiply the values given in column 4 by 7.48.

To determine the weight of salt to one cubic foot of brine, multiply the values given in column 2 by 7.48.

PROPERTIES OF SOLUTION OF CHLORIDE OF CALCIUM.

Percentage by Weight.	Specific Heat.	Spec. Grav. at 60° F.	Freezing Point, Degrees F.	Freezing Point, Deg. Cels.
1	0.996	1.009	31	— 0.5
5	0.964	1.043	27.5	— 2.5
10	0.896	1.087	22	— 5.6
15	0.860	1.134	15	— 9.6
20	0.834	1.182	— 1.5	—14.8
25	0.790	1.234	—21.8	—22.1

DIAMETERS, AREAS AND CIRCUMFERENCES OF CIRCLES.

Diam. Inches.	Circumf. Inches.	Area Sq. In.	Diam Inches.	Circumf. Inches.	Area. Sq. In.	Diam. Inches.	Circumf. Inches.	Area. Sq. In.
1	3.14159	0.78540	4	12.5664	12.566	8	25 1327	50.265
1/16	3.33794	0.88664	1/16	12.7627	12.962	1/8	25 5224	51.849
1/8	3.53429	0.99402	1/8	12.9591	13.364	1/4	25.9181	53.456
3/16	3.73064	1.1075	3/16	13.1554	13.772	3/8	26.3108	55.088
1/4	3.92699	1.2272	1/4	13.3518	14.186	1/2	26.7035	56.745
5/16	4.12334	1.3530	5/16	13.5481	14.607	5/8	27.0962	58.426
3/8	4.31969	1.4849	3/8	13.7445	15.033	3/4	27.4889	60.132
7/16	4.51604	1.6230	7/16	13.9408	15.466	7/8	27.8816	61.862
1/2	4.71239	1.7671	1/2	14.1372	15.904	9	28.2743	63.617
9/16	4.90874	1.9175	9/16	14.3335	16.349	1/8	28.6670	65.397
5/8	5.10509	2.0739	5/8	14.5299	16.800	1/4	29.0597	67.201
11/16	5.30144	2.2365	11/16	14.7262	17.257	3/8	29.4524	69.029
3/4	5.49779	2.4053	3/4	14.9226	17.721	1/2	29.8451	70.882
13/16	5.69414	2.5802	13/16	15.1189	18.190	5/8	30.2378	72.760
7/8	5.89049	2.7612	7/8	15.3153	18.665	3/4	30.6305	74.662
15/16	6.08684	2.9483	15/16	15.5116	19.147	7/8	31.0232	76.589
2	6.28319	3.1416	5	15.7080	19.635	10	31.4159	78.540
1/16	6.47953	3.3410	1/16	15.9043	20.129	1/4	32.2013	82.516
1/8	6.67588	3.5466	1/8	16.1007	20.629	1/2	32.9867	86.590
3/16	6.87223	3.7583	3/16	16.2970	21.135	3/4	33.7721	90.763
1/4	7.06858	3.9761	1/4	16.4934	21.648	11	34.5575	95.033
5/16	7.26493	4.2000	5/16	16.6897	22.166	1/4	35.3429	99.402
3/8	7.46128	4.4301	3/8	16.8861	22.691	1/2	36.1283	103.87
7/16	7.65763	4.6664	7/16	17.0824	23.221	3/4	36.9137	108.43
1/2	7.85398	4.9087	1/2	17.2788	23.758	12	37.6991	113.10
9/16	8.05033	5.1572	9/16	17.4751	24.301	1/4	38.4845	117.86
5/8	8.24668	5.4119	5/8	17.6715	24.850	1/2	39.2699	122.72
11/16	8.44303	5.6727	11/16	17.8678	25.406	3/4	40.0553	127.68
3/4	8.63938	5.9396	3/4	18.0642	25.967	13	40.8407	132.73
13/16	8.83573	6.2126	13/16	18.2605	26.535	1/4	41.6261	137.89
7/8	9.03208	6.4918	7/8	18.4569	27.109	1/2	42.4115	143.14
15/16	9.22843	6.7771	15/16	18.6532	27.688	3/4	43.1969	148.49
3	9.42478	7.0686	6	18.8496	28.274	14	43.9823	153.94
1/16	9.62113	7.3662	1/8	19.2423	29.465	1/4	44.7677	159.48
1/8	9.81748	7.6699	1/4	19.6350	30.680	1/2	45.5531	165.13
3/16	10.0138	7.9798	3/8	20.0277	31.919	3/4	46.3385	170.87
1/4	10.2102	8.2958	1/2	20.4204	33.183	15	47.1239	176.71
5/16	10.4065	8.6179	5/8	20.8131	34.472	1/4	47.9093	182.65
3/8	10.6029	8.9462	3/4	21.2058	35.785	1/2	48.6947	188.69
7/16	10.7992	9.2806	7/8	21.5984	37.122	3/4	49.4801	194.83
1/2	10.9956	9.6211	7	21.9911	38.485	16	50.2655	201.06
9/16	11.1919	9.9678	1/8	22.3838	39.871	1/4	51.0509	207.39
5/8	11.3883	10.321	1/4	22.7765	41.282	1/2	51.8363	213.82
11/16	11.5846	10.680	3/8	23.1692	42.718	3/4	52.6217	220.35
3/4	11.7810	11.045	1/2	23.5619	44.179	17	53.4071	226.98
13/16	11.9773	11.416	5/8	23.9546	45.664	1/4	54.1925	233.71
7/8	12.1737	11.793	3/4	24.3473	47.173	1/2	54.9779	240.53
15/16	12.3700	12.177	7/8	24.7400	48.707	3/4	65.7633	247.45

DIAMETERS, AREAS AND CIRCUMFERENCES OF CIRCLES.—CONTINUED.

Diam. Inches.	Circumf. Inches.	Area. Sq. In.	Diam. Inches.	Circumf. Inches.	Area. Sq. In.	Diam. Inches.	Circumf. Inches.	Area. Sq. In.
18	56.5487	254.47	32	100 531	804 25	46	144.513	1661.9
¼	57 3341	261.59	¼	101.316	816.86	¼	145.299	1680.0
½	58.1195	268 80	½	102.102	829.58	½	146 084	1698.2
¾	58.9049	276.12	¾	102 887	842.39	¾	146 869	1716 5
19	59.6903	283.53	33	103 673	855.30	47	147 655	1734 9
¼	60 4757	291.04	¼	104.458	868.31	¼	148.440	1753.5
½	61.2611	298.65	½	105 243	881.41	½	149.226	1772.1
¾	62.0465	306.35	¾	106.029	894.62	¾	150.011	1790.8
20	62.8319	314.16	34	106.814	907.92	48	150.796	1809 6
¼	63.6173	322.06	¼	107.600	921.32	¼	151.582	1828.5
½	64.4026	330.06	½	108.385	934.82	½	152.367	1847.5
¾	66.1880	338.16	¾	109.170	948.42	¾	153.153	1866.5
21	65.9734	346.36	35	109.956	962.11	49	153.938	1885.7
¼	66.7588	354.66	¼	110.741	975.91	¼	154.723	1905.0
½	67.5442	363.05	½	111.527	989.80	½	155.509	1924.2
¾	68.3296	371.54	¾	112.312	1003.8	¾	156.294	1943.9
22	69.1150	380.13	36	113.097	1017.9	50	157.080	1963.5
¼	69.9004	388.82	¼	113.883	1032.1	¼	157.865	1983.2
½	70.6858	397.61	½	114.668	1046.3	½	158.650	2003.0
¾	71 4712	406.49	¾	115.454	1060.7	¾	159.436	2022.8
23	72.2566	415.48	37	116.239	1075.2	51	160.221	2042.8
¼	73.0420	424.56	¼	117.024	1089.8	¼	161.007	2062.9
½	73.8274	433.74	½	117.810	1104.5	½	161.792	2083.1
¾	74.6128	443.01	¾	118.596	1119.2	¾	162.577	2103.3
24	75.3982	452.39	38	119.381	1134.1	52	163.363	2123.7
¼	76.1836	461.86	¼	120.166	1149.1	¼	164.148	2144.2
½	76.9690	471.44	½	120.951	1164.2	½	164.934	2164.8
¾	77.7544	481.11	¾	121.737	1179.3	¾	165.719	2185.4
25	78.5398	490.87	39	122.522	1194.6	53	166.504	2206.2
¼	79.3252	500.74	¼	123.308	1210.0	¼	167.290	2227.0
½	80.1106	510.71	½	124.093	1225.4	½	168.075	2248.0
¾	80.8960	520.77	¾	124.878	1241.0	¾	168.861	2269.1
26	81.6814	530.93	40	125.664	1256.6	54	169.646	2290.2
¼	82.4668	541.19	¼	126.449	1272.4	¼	170.431	2311.5
½	83.2522	551.55	½	127.235	1288.2	½	171.217	2332.8
¾	84.0376	562.00	¾	128.020	1304.2	¾	172.002	2354.3
27	84.8230	572.56	41	128.805	1320.3	55	172.788	2375.8
¼	85.6084	583.21	¼	129.591	1336.4	¼	173.573	2397.5
½	86.3938	593.96	½	130.376	1352.7	½	174.358	2419.2
¾	87.1792	604.81	¾	131.161	1369.0	¾	175.144	2441.1
28	87.9646	615.75	42	131.947	1385.4	56	175.929	2463.0
¼	88.7500	626.80	¼	132.732	1402.0	¼	176.715	2485.0
½	89.5354	637.94	½	133.518	1418.6	½	177.500	2507.2
¾	90.3208	649.18	¾	134.303	1435.4	¾	178.285	2529.4
29	91.1062	660.52	43	135.088	1452.2	57	179.071	2551.8
¼	91.8916	671.96	¼	135.874	1469.1	¼	179.856	2574.2
½	92.6770	683.49	½	136.659	1486.2	½	180.642	2596.7
¾	93.4624	695.13	¾	137.445	1503.3	¾	181.427	2619.4
30	94.2478	706.86	44	138.230	1520.5	58	182.212	2642.1
¼	95.0332	718.69	¼	139.015	1537.9	¼	182.998	2664.9
½	95.8186	730.62	½	139.801	1555.3	½	183.783	2687.8
¾	96.6040	742.64	¾	140.586	1572.8	¾	184.569	2710.9
31	97.3894	754.77	45	141.372	1590.4	59	185.354	2734.0
¼	98.1748	766.99	¼	142.157	1608.2	¼	186.139	2757.2
½	98.9602	779.31	½	142.942	1626.0	½	186.925	2780.5
¾	99.7456	791.73	¾	143.728	1643.9	¾	187.710	2803.9

DIAMETERS, AREAS AND CIRCUMFERENCES OF CIRCLES.—CONTINUED.

Diam. Inches.	Circumf. Inches.	Area. Sq. In.	Diam. Inches.	Circumf. Inches.	Area. Sq. In.	Diam. Inches.	Circumf. Inches.	Area. Sq. In.
60	188.496	2827.4	74	232.478	4300.8	88	276.460	6082.1
¼	189.281	2851.0	¼	233.263	4329.9	¼	277.246	6116.7
½	190.066	2874.8	½	234.049	4359.2	½	278.031	6151.4
¾	190.852	2898.6	¾	234.834	4388.5	¾	278.816	6186.2
61	191.637	2922.5	75	235.619	4417.9	89	279.602	6221.1
¼	192.423	2946.5	¼	236.405	4447.4	¼	280.387	6256.1
½	193.208	2970.6	½	237.190	4477.0	½	281.173	6291.2
¾	193.993	2994.8	¾	237.976	4506.7	¾	281.958	6326.4
62	194.779	3019.1	76	238.761	4536.5	90	282.743	6361.7
¼	195.564	3043.5	¼	239.546	4566.4	¼	283.529	6397.1
½	196.350	3068.0	½	240.332	4596.3	½	284.314	6432.6
¾	197.135	3092.6	¾	241.117	4626.4	¾	285.100	6468.2
63	197.920	3117.2	77	241.903	4656.6	91	285.885	6503.9
¼	198.706	3142.0	¼	242.688	4686.9	¼	286.670	6539.7
½	199.491	3166.9	½	243.473	4717.3	½	287.456	6575.5
¾	200.277	3191.9	¾	244.259	4747.8	¾	288.241	6611.5
64	201.062	3217.0	78	245.044	4778.4	92	289.027	6647.6
¼	201.847	3242.2	¼	245.830	4809.0	¼	289.812	6683.8
½	202.633	3267.5	½	246.615	4839.8	½	290.597	6720.1
¾	203.418	3292.8	¾	247.400	4870.7	¾	291.383	6756.4
65	204.204	3318.3	79	248.186	4901.7	93	292.168	6792.9
¼	204.989	3343.9	¼	248.971	4932.7	¼	292.954	6829.5
½	205.774	3369.6	½	249.757	4963.9	½	293.739	6866.1
¾	206.560	3395.3	¾	250.542	4995.2	¾	294.524	6902.9
66	207.345	3421.2	80	251.327	5026.5	94	295.310	6939.8
¼	208.131	3447.2	¼	252.113	5058.0	¼	296.095	6976.7
½	208.916	3473.2	½	252.898	5089.6	½	296.881	7013.8
¾	209.701	3499.4	¾	253.684	5121.2	¾	297.666	7051.0
67	210.487	3525.7	81	254.469	5153.0	95	298.451	7088.2
¼	211.272	3552.0	¼	255.254	5184.9	¼	299.237	7125.6
½	212.058	3578.5	½	256.040	5216.8	½	300.022	7163.0
¾	212.843	3605.0	¾	256.825	5248.9	¾	300.807	7200.6
68	213.628	3631.7	82	257.611	5281.0	96	301.593	7238.2
¼	214.414	3658.4	¼	258.396	5313.3	¼	302.378	7276.0
½	215.199	3685.3	½	259.181	5345.6	½	303.164	7313.8
¾	215.984	3712.2	¾	259.967	5378.1	¾	303.949	7351.8
69	216.770	3739.3	83	260.752	5410.6	97	304.734	7389.8
¼	217.555	3766.4	¼	261.538	5443.3	¼	305.520	7428.0
½	218.341	3793.7	½	262.323	5476.0	½	306.305	7466.2
¾	219.126	3821.0	¾	263.108	5508.8	¾	307.091	7504.5
70	219.911	3848.5	84	263.894	5541.8	98	307.876	7543.0
¼	220.697	3876.0	¼	264.679	5574.8	¼	308.661	7581.5
½	221.482	3903.6	½	265.465	5607.9	½	309.447	7620.1
¾	222.268	3931.4	¾	266.250	5641.2	¾	310.232	7658.9
71	223.053	3959.2	85	267.035	5674.5	99	311.018	7697.7
¼	223.838	3987.1	¼	267.821	5707.9	¼	311.803	7736.6
½	224.624	4015.2	½	268.606	5741.5	½	312.588	7775.6
¾	225.409	4043.3	¾	269.392	5775.1	¾	313.374	7814.8
72	226.195	4071.5	86	270.177	5808.8	100	314.159	7854.0
¼	226.980	4099.8	¼	270.962	5842.6			
½	227.765	4128.2	½	271.748	5876.5			
¾	228.551	4156.8	¾	272.533	5910.6			
73	229.336	4185.4	87	273.319	5944.7			
¼	230.122	4214.1	¼	274.104	5978.9			
½	230.907	4242.9	½	274.889	6013.2			
¾	231.692	4271.8	¾	275.675	6047.6			

TABLE OF PISTON SPEEDS.—FEET PER MINUTE

Stroke in Inches.	REVOLUTIONS PER MINUTE.																								
	50	60	75	80	90	100	120	125	140	150	160	170	180	200	225	240	250	275	300	320	325	350	360	375	400
6	50	60	75	80	90	100	120	125	140	150	160	170	180	200	225	240	250	275	300	320	325	350	360	375	400
7	58	70	87	93	105	117	140	146	163	175	187	198	210	233	262	280	292	321	350	373	379	408	420	437	467
8	67	80	100	107	120	133	160	167	187	200	213	227	240	267	300	320	333	367	400	427	433	467	480	500	533
9	75	90	112	120	135	150	180	187	210	225	240	255	270	300	337	360	375	412	450	480	487	525	540	562	600
10	83	100	125	133	150	167	200	208	233	250	267	283	300	333	375	400	417	458	500	533	542	583	600	625	667
11	92	110	137	147	165	183	220	229	257	275	293	312	330	367	412	440	458	504	550	587	596	642	660	687	733
12	100	120	150	160	180	200	240	250	280	300	320	340	360	400	450	480	500	550	600	640	650	700	720	750	800
14	117	140	175	187	210	233	280	292	303	350	373	397	420	466	525	560	583	642	700	747	758	817	840	875	933
15	125	150	187	200	225	250	300	312	350	375	400	425	450	500	562	600	625	687	750	800	812	875	900	937	1000
16	133	160	200	213	240	267	320	333	373	400	427	453	480	533	600	640	667	733	800	853	867	933	960	1000	1067
18	150	180	225	240	270	300	360	375	420	450	480	510	540	600	675	720	750	825	900	960	975	1050	1080	1125	1200
20	167	200	250	267	300	334	400	417	467	500	533	587	600	667	750	800	833	917	1000	1067	1083	1167	1200	1250	1333
22	193	220	275	293	330	367	440	458	513	550	587	623	660	733	825	880	917	1008	1100	1173	1192	1233	1320	1375	1467
24	200	240	300	320	360	400	480	500	560	600	640	680	720	800	900	960	1000	1100	1200	1280	1300	1400	1440	1500	1600
26	217	260	325	347	390	433	520	542	607	650	693	733	780	867	975	1040	1083	1192	1300	1360	1408	1517	1560	1625	1731
28	233	280	350	373	420	467	560	583	653	700	746	793	840	933	1050	1120	1166	1283	1400	1494	1516	1634	1680	1750	1866
30	250	300	375	400	450	500	600	625	700	750	800	850	900	1000	1125	1200	1250	1375	1500	1600	1624	1750	1800	1874	2000
36	300	360	450	480	540	600	720	750	840	900	960	1020	1080	1200	1350	1440	1500	1650	1800	1920	1950	2100	2160	2250	2400
40	333	400	500	533	600	667	800	833	933	1000	1066	1133	1200	1333	1500	1600	1666	1834	2000	2134	2166	2334	2400	2500	2666
42	350	420	525	560	630	700	840	875	980	1050	1120	1190	1360	1400	1575	1680	1749	1926	2100	2241	2274	2451	2520	2625	2799
48	400	480	600	640	720	800	960	1000	1120	1200	1300	1260	1440	1600	1800	1920	2000	2200	2400	2560	2600	2800	2880	3000	3200
54	450	540	675	720	810	900	1080	1125	1260	1350	1440	1530	1620	1800	2025	2160	2250	2475	2700	2880	2925	3150	3240	3375	3600
60	500	600	750	800	900	1000	1200	1250	1400	1500	1600	1700	1800	2000	2250	2400	2500	2750	3000	3200	3248	3500	3600	3748	4000
66	550	660	825	880	990	1100	1320	1375	1540	1650	1761	1869	1980	2199	2475	2640	2751	3024	3300	3519	3576	3699	3960	4125	4401
72	600	720	900	960	1080	1200	1440	1500	1680	1800	1920	2040	2160	2400	2700	2880	3000	3300	3600	3840	3900	4200	4320	4500	4800

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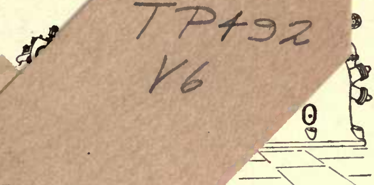

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