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The measurement of compressed air and its consumption in rock drills

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THE MEASUREMENT OF COMPRESSED AIR AND ITS CONSUMPTION IN ROCK DRILLS.

by

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A

THESIS

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INTRODUCTION.

The object of this thesis is to investigate the measurement of compressed air and to determine its consumption in rock drills. Our intention at first was to run more exhaustive tests on the drills, but due to the large amount of work necessary in rigging up the apparatus and computing results, we found it necessary to curtail our work to representative types of the hammer and the piston machines. We regret being unable to give more complete data in regard to the drills, but hope to point out fields for future work since, with the increased facilities now at hand, such work may be more satisfactorily carried out.

The articles on the Venturi tube with a Manometer, the Venturi Tube Meter, and the "Weighted Door" Meter were taken from Compressed Air, Vol.16, page 6255, 1911.

PART I.

THE MEASUREMENT OF COMPRESSED AIR.

As the use of compressed air increases, it becomes more and more necessary to be able to measure the actual volumes of air which are compressed and delivered by different machines so that their volumetric efficiencies and actual economies may be accurately determined, and also in the use of air by different apparatus, or in specific operations, it is equally desirable to know the volumes of air employed. The filling of small tanks may do for laboratory investigations on small compressors and for tests of short duration, but the method is of limited application at the best.

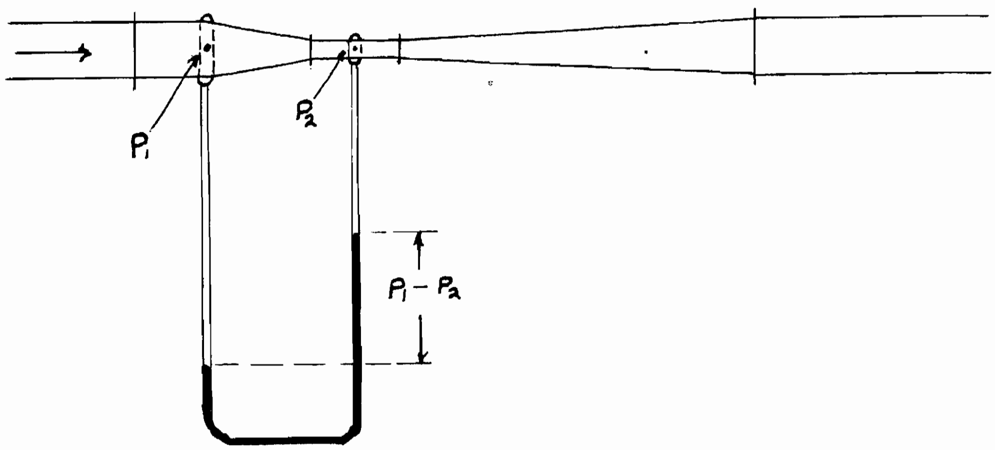
What is wanted is an apparatus which can be connected to compressed air piping wherever desired and which will give a continuous and permanent record of air passing through at whatever pressure, reporting the same, for uniformity and convenience, in volumes of free air. There are several machines on the market which guarantee to do this, their advertisements appearing in the technical journals.

However, none of these instruments, to our knowledge, have proven themselves to be of practical value. The difficulty being in constructing an apparatus which will accurately record varing temperatures, velocities, and pressures.

The only practical meters so far evolved are those which take instantaneous readings, giving the amount of air going through at any instant. Of this type may be mentioned the following: The simple orifice and manometer; the Venturi tube meter with a manometer; the Venturi tube meter with inverted bell and recording device; the "Weighted Door" meter.

A simple orifice and manometer meter will be described later, as it was the type used in the following experiments.

The Venturi Tube with a Manometer.



This meter effects the measurement of air in essentially the same manner as the orifice meter, but owing to the long tapering case on the down-stream side, the formation of eddies are avoided, and a very much larger proportion of the pressure drop ($P_1 - P_2$) is recovered. This discharge formula for the Venturi tube is of the form:

$$Q = KA\sqrt{\frac{P_1\ (P_1 - P_2)}{T_1\ (N^2 - 1)}}$$

Where (K) is a numerical constant.

A_1, the cross sectional area of the air main.

P_1 and T_1, the absolute pressure and temperature of the air at the Venturi tube.

$(P_1 - P_2)$, the drop in pressure between the full diameter and the throat.

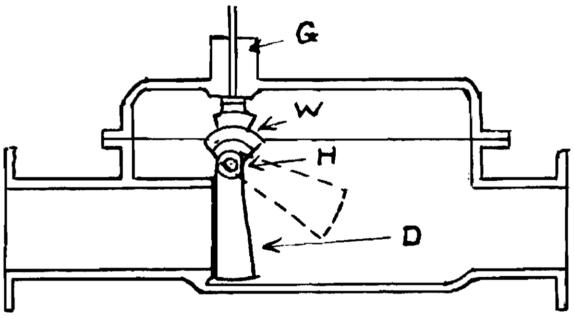
N is the ratio of the area of the up-stream to that of the throat and is called the throat ratio.

The value of the coefficient R was determined experimentally on the calibration plant in South Africa for all diameters of Venturi tubes between 3" and 20", and for all throat ratios that commonly occur in practice. These meters are now used to a large extent in measuring coal gas for town supply.

The Venturi Tube Meter.

In the Venturi tube meter with inverted bell, the difference of pressure $(P_1 - P_2)$ is measured by means of a light inverted bell immersed in an oil seal, the throat pressure P_2 acting on the under side of the bell and the up-stream pressure (P_1) on the outside. An increase of flow causes the bell to sink. The weight of the bell is taken by a carrying float made of vulcanite and slate (in order to compensate for changes in temperature) which is always immersed in mercury. The amount of movement of the bell is determined by a shaped float, the bell descending until the difference in pressure $(P_1 - P_2)$ is balanced by the buoyancy of the immersed portion of the shaped float. The bell carries a rack by means of which its motion is transmitted to a wheel and from thence through a gland to a can placed outside the bell chamber. Owing to the shaped float being long and tapering, the arrangement is extremely sensitive at low values of $(P_1 - P_2)$ giving an inch of motion when $(P_1 - P_2)$ changes by 1-1000th pound per square inch and being perfectly sensitive to variations of pressure of less than 1-10,000th pounds per square inch.

<u>The "Weighted Door" Meter</u>.



This type of meter is now being adopted for the larger sized mains on the Rand and consists of a weighted door, D, swumg on horizontal hinges,H, placed in the air main. The motion of the door, which is a measure of the flow passing, is transmitted out through the top of the meter case by means of two bevel wheels, W, and the gland shown. The weighted door thus replaces the orifice and manometer, or the Venturi tube, and the oil sealed bell. Although this instrument looks and actually is extremely simple, mechanically, it is somewhat difficult to manufacture. Felt protected roller bearings are used to carry the weighted door, and dash pots are provided on each side of the meter to damp down the oscillations of the door. Then in addition, although it is possible to design the meters so that the body casting is of the correct size, it is impossible to calculate the discharge for each position of the door before hand. Each meter, therefore, has to be calibrated; but when this is done, the measurement of the air is simple and easy. These meters have a greater range than either the orifice or the Venturi tube meters and it is possible, by suitably shaping the cavity,to measure down to 1-100th of the full flow. With a manometer it is difficult to measure less than 1/8 the full flow. Another advantage of this type of meter is the ease with which its capacity may be changed. All that has to be done is to alter the loading of the door and put a new change wheel in the counter train.

The Excelsior Airometer.

The Excelsior Airometer is a highly advertised machine that has come out in the past year. The manufacturers describe their machine as follows:

"The Excelsior Airometer is a simple, reliable, and accurate air meter. It measures in cubic feet the amount of free air used in the cylinder consumption of compressed air. Simplicity, durability, and accuracy are the dominant features of the Excelsior Airometer, it being guaranteed not to vary more than 3% from its original standard in five years. It is the only meter that automatically compensates for variations in pressure, that shows on its dial the exact amount of air that has passed through it irrespective of pressures, and that does not require careful attention to keep in condition."

"The airometer is built upon the principle that in the cylinder consumption of compressed air, the speed of air passage is dependent upon the pressure; and that the number of cubic feet of air used is in direct proportion to the speed the air body assumes when filling the cylinder. It consists of a series of turbines and deflecting discs, arranged alternately within a casing. The shaft upon which the turbines are mounted extends throughout the length of the meter, and is connected by worm gears with a series of decimated gears, which are connected to a series of decimal dials, from which the meter reading is taken. The deflecting discs are stationary in the casing, and around the outer edge are bored a series of holes, which have their axial line at an angle of 45 degrees across the axial line of the meter. Between the discs are compartments where the turbines are mounted on the shaft. The vanes of these turbines are set so that they face the axial line of the orifices at right angles. The air is admitted to the meter, and passing through the orifices, impinges in turn on the vanes of all the turbines before passing out."

Such is the manufacturer's description and we admit it sounds very impressive, but,on close analysis, it will be seen that no account is taken of the temperature which often will be quite different from that at the compressor. Also the inertia and lubrication of the turbines has much to do with the spped at which they revolve with a given pressure.

The airometer was calibrated by means of the orifice method. Air being furnished by a two stage compressor of 100 cubic feet of free air per minute at 100 lb. gage pressure. The pressure was varied from 60 lb. to 110 lb.

The air was first run through the airometer and thence to the orifice drum between which and the airometer was inserted a pressure gage and a thermometer. The pressure gage was calibrated by means of a Crosby gage tester and all pressure readings corrected. The orifice was a standard orifice cut in No.14 copper plate and inserted at the end of a sheet iron drum 8' long by 2' diameter. A thermometer gland and a gland for the manometer tube were near the orifice end. The difference in pressure was kept below 6" of water by means of the size of the orifice and by regulating the flow of air with a valve placed on the main just before entering the drum. 1.5", 1.75", and 2.35" orifices were used. The orifice coefficients used were those determined at McGill University by methods and apparatus described in Trans. Am. Soc. Mech. Eng., Vol.27, Dec., 1905, and in Compressed Air, Sept., 1906, p.4187.

Five minute runs were taken at varying pressures, an attempt being made to take them every 5 lbs., but the compressor could not always be run steady enough. Readings were taken every minute on the meter, the two thermometers, and on the manometer.

Time of from five to ten minutes was always allowed at the close of each run for the meter to adjust itself to a pressure 5 lbs. higher.

The quantity of air was determined as follows: (taken from Art.20 of Harris' "Compressed Air").

Let P_a air pressure in lbs.per sq. in. inside drum.

$Q =$ Wt. of air passing per second.

$W =$ Wt. of cubic foot of air in lbs.

Let $d =$ Diam. of orifice in inches.

$Z =$ Pressure as read on water gage in inches.

$t =$ Abs. temperature Fahr. inside the drum.

$c =$ Experimental coefficient.

Where changes of density and temperature can be neglected, the theoretic velocity through the orifice is $V = \sqrt{2gh}$ Where h is the head of air of uniform density, that would produce the pressure Z.

Hence $h = Z/12 \times \frac{62.5}{Wa}$; therefore

$V \sqrt{2g\ Z/12 \times \frac{62.5}{Wa}}$. But $Q = Wa \times aV$, where $a =$ area of orifice in sq. ft. $= \frac{\pi d^2}{4 \times 144}$

Inserting these values and putting Wa under the radical there results

$$Q = \frac{d^2}{4 \times 144} \sqrt{2g\ Z/12 \quad \frac{62.5\ Wa^2}{Wa}}$$

But $Wa = \frac{P^1a}{53.17\ t}$

$$\therefore\ Q = .0136\ d^2 \sqrt{Z/t\ P^1a} = .1632\ d^2 \sqrt{Z/t\ Pa}$$

where Pa is in lbs. per sq. in.

Inserting the experimental coefficient c, we have

$Q = .1632\ cd^2 \sqrt{Z/t\ P^1a}$ lbs. per second, from which the volume may be obtained by dividing the weight of a cubic foot of free air at the temperature desired.

P. GAGE	METER	T_1 METER DEG.C	T_2 ORIFICE DEG.C	Z	VOL. BY ORIFICE Vo	VOL. BY METER Vm	K
70	136	46.5	36.0	2.30	101	116	.872
73	139	47.5	37.1	2.44	103	118	.873
75	140	48.8	38.0	2.50	103	119	.865
76	139	50.5	39.2	2.54	105	117	.899
78	104	53.0	39.9	1.71	85	87	.977
79	103	53.8	40.5	1.73	86	86	1.00
80	104	54.4	41.2	1.76	87	87	1.00
83	105	56.6	43.5	1.93	96	87	1.10
84	105	55.1	42.5	1.93	96	87	1.10
85	106	55.8	42.8	1.94	96	88	1.09
87	101	57.9	43.6	1.97	97	89	1.09
88	101	57.4	43.4	1.96	97	89	1.09
93	86	58.8	44.9	1.75	86	71	1.21
94	88	59.0	45.0	1.75	86	72	1.19
95	88	59.2	45.2	1.78	87	72	1.21
96	88	59.9	45.8	1.79	87	72	1.21
97	78	60.6	46.2	1.68	85	64	1.33
98	77	60.4	46.0	1.71	85	63	1.35
103	77	61.5	47.6	1.80	87	64	1.36
108	70	63.1	48.0	1.64	83	57	1.45

Our experiments, of which the above set is characteristic, show that a straight line formula cannot be developed for the relation between the meter reading and the actual volume of free air passed. However, it may be possible that the relation takes the form of a curve represented by the equation $Vo = KV_m^n$ from which a log constant might be derived. But, even if this be true, the meter would have no advantage over the simple and inexpensive orifice meter since correct values could be determined for a constant pressure only as (K) varies with the pressure. Therefore, in view of the above facts, we feel justified in condemning the Excelsior Airometer as an automatic registering meter.

The High Pressure Orifice Meter.

The high pressure orifice meter used was built in the laboratory after the designs of Professor Harris. The principle of this meter is that a current of air passing through an orifice has a diminished pressure on the down-stream side; this diminished pressure is proportional to the velocity of the air current and hence to the quantity of air passing. So then if the temperature be known and the orifice calibrated for known capacities a formula may be derived for computing the weight of air passing per second. This may be done in the same manner as was the formula for the low pressure orifice.

The meter consists essentially of two sections of iron pipe 6 inches in diameter, one section being 3 feet long and the other 2 feet long. Each section has a heavy flange screwed on one end and a cap screwed on the other which is bored and threaded to take the pipe line. The longer section is the up-stream end and contains a screen for diffusing the current of air so as to have an equal velocity in the cross section of the pipe before reaching the orifice. A standard orifice of No.14 copper plate with a gasket on either side is placed and centered between the two flanges which were then bolted together. Holes were bored in the pipe for the insertion of the thermometer gland and the gage tubes. The thermometer gland was put in the upstream section while the gage tubes were six inches on either side of the orifice.

To measure the difference in pressure, a differential water gage was used and connected to the tubes on either side of the orifice. Later it was found necessary to move the downstream tube closer to the cap end in order to avoid the eddies which occur just past the orifice. All the final readings were taken with this new arrangement.

Calibration.

The low pressure orifice with its known coefficients was used in calibrating; it being fastened on to the downstream end by means of nipples and a union. All the air passing through the high pressure orifice therefore passed through the low pressure orifice. The relative sizes of orifice to use were calculated as follows:

$$Q = .1632\ C_1\ d_1^2 \sqrt{\frac{Z_1}{T_1} Pa} = .1632\ C_2\ d_2^2 \sqrt{\frac{Z_2}{T_2} r\ Pa}$$

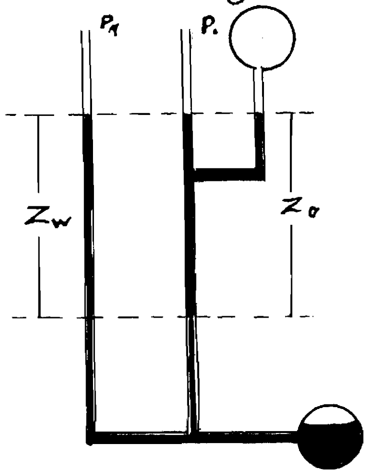
Cancelling out the constant values we have

$$d_2^4 = \frac{C_1}{C_2}\, d_1^4\, \frac{Z_1}{T_1}\, \frac{T_2}{Z_2}\, \frac{1}{r}$$ and assuming

$C_1 = C_2$, $Z_1 = Z_2$, and $T_1 = T_2$ we get $d_2^4 = \frac{d_1^4}{r}$ from which

$d_2 = \frac{d_1}{\sqrt[4]{r}}$; r being the ratio pressure and the absolute pressure in the mains.

Instead of using the ordinary manometer on the low pressure drum, as we did in the case of the airometer, we used an oil differential gage designed by Professor Harris and built in the laboratory. This gage is almost 5 times as sensitive as the ordinary water gage; its sensibility depending on the specific gravity of the oil used. We used kerosene with a specific gravity of .807. The method of determining this and of converting the readings into inches of water is given below.



P_1 = Pressure inside drum.

Zw = Inches of water.

Zo = " " Oil.

WZw = Weight of water column.

OZo = " " oil " .

Then $Pa + WZw = P_1 + OZo$ and $\frac{P_1 - Pa}{W} = \text{head} = Zw - \frac{O}{W} Zo$ which is the general equation. If Zw = Zo, the head in inches of water $= (1 - \frac{O}{W})Zo$, $\frac{O}{W}$ being the specific gravity of the oil.

$\frac{O}{W}$ may be determined as follows:

Introduce oil and water as shown and have atmospheric pressure on the top of each column then $Pa + WZw = Pa + OZo$ from which $\frac{O}{W} = \frac{Zw}{Zo}$

Readings on the pressure gage, the differential water gage, the oil gage, and the two thermometers were taken as near simultaneously as possible and recorded.

The coefficient c was determined as follows:
Since the same weight of air passes through both orifices per second,

$$Q = .1632\ c_1\ d_1^2 \sqrt{z^1/T_1\ Pa} = .1632\ c_2 d_2^2 \sqrt{z^2/T_2\ \ P_2}$$

and $$c_2 = \frac{c_1 d_1^2 \sqrt{z^1/T_1\ \ Pa}}{d_2^2 \sqrt{z^2/T_2\ \ \ P_2}}$$

$$= \frac{c_1 d_1^2}{d_2^2} \sqrt{\frac{z_1\ T_2}{z_2\ T_1} x \frac{Pa}{P_2}}$$

P_2 being the absolute pressure in the mains.

In the set of readings given below $d_1 = 2.012$ inches, $d_2 = 1.0$ inches, and $c_1 = .600$, the temperatures are absolute Fahrenheit and the pressures are corrected to absolute pressures.

CALIBRATION OF HIGH PRESSURE ORIFICE.

P.ABS.	T_1 ABS.	T_2 ABS.	Z_2	Z_1 OIL	Z_1 WATER	C_2
81	542.4	537.9	7.9	12.7	2.45	.562
91	544.2	537.9	4.9	9.95	1.92	.595
103	540.6	538.8	4.0	9.90	1.91	.619
113	538.8	538.8	4.65	12.00	2.32	.605
111	539.0	537.9	8.50	21.4	4.13	.602
97	536.1	535.2	13.85	28.6	5.52	.584
85	533.9	533.4	9.70	20.3	3.92	.631
66	536.1	533.4	9.80	13.7	2.64	.581
75	535.2	535.3	2.55	4.7	0.91	.628
103	537.9	536.1	2.30	5.70	1.10	.613
112	539.7	537.0	2.30	6.15	1.19	.618

Averaging the above results we obtained a value of .603 for c_2 which agrees with the constant obtained for the low pressure orifice.

PART II.

THE CONSUMPTION OF AIR BY ROCK DRILLS.

We have found that the efficiency of a rock drill as regards to air consumption and depth of hole drilled per unit of time is a variable quantity and depends on the following factors:

(1) The size of the cylinder.

(2) The valve mechanism. This effects the efficiency in that it regulates the number of blows per minute and the cut off. Some types are too slow in reversing the stroke and others cushion the blow.

(3) The method of delivering the power to the cutting edge. All the older types have the drill fastened to a reciprocating piston. A later type, and one proving superior in many respects, is the hammer drill. In this type a reciprocating hammer strikes the head of a revolving bit. Hollow steel may be used with this type of machine through which a jet of water or an air blast may be used to force out the cuttings.

(4) The manner of using the air in the cylinder. In the rock drill as used today, air is taken during the full stroke; it being impossible to construct a drill which will use air expansively and have a variable cut off which is necessary in rock drills. Also the weight of the drill would be unduly increased and the mechanism would be too delicate for the rough treatment allotted to a rock drill.

(5) The air pressure used. The piston drill operates to best advantage on pressures from 70-85 lbs. at the drill; higher pressures cause too much jar and vibration. With the hammer type higher pressures may be used, the hammer drill working to best advantage with pressures from 90-105 lbs.

(6) The hardness and mineralogical character of the rock. In hard rock the drill bits will wear and lose gage rapidly. If the rock contains mica, selvage, or other soft material, the hole will gum up and stick the drill if care is not taken to keep the hole clean. The same is true of soft rock which drills rapidly. Again slips and fractures are liable to turn the hole and fichure the drill.

(7) The character of the bits used. The correct type of bit is yet unsolved; personal opinion and experience at present governing the types used. The steel used and the correct temper are the most important since, if the bit does not hold its gage and cutting edge, no type will do much work.

(8) The personal equation. An experienced drill runner will get more inches of hole than an inexperienced man and likewise a man with experience in a certain kind of rock will do more than one who has not had experience in that rock, other conditions being equal. Much depends on keeping the drill doing its maximum work. In the case of the piston machine this consists in keeping the ports clean, in running with the throttle wide open as much as possible, in keeping the stroke maximum without hitting the front head, in keeping the hole lined up to prevent friction on the

sides, and in keeping the working parts well lubricated.

With due regard to the above considerations, a good rock drill must be simple in construction, must be portable, must be durable, all parts should be easy of access so that repairs may be quickly made, and the machine should be constructed so that steel may be easily and quickly changed. Again it must be capable of withstanding hard usage at the hands of a not overly intelligent and often savage miner.

The drills used in the test were the following:

TYPE	DIAM.CYL.	LGTH.STROKE	FEED	WGT.
Sullivan 5	2 1/4 in.	5 in.	18 in.	145 lb.
Leyner No.7	2 1/2 in.	2 3/4 in.	30 in.	125 lb.

These drills were mounted on a standard column set in a frame work of 12 x 12 in. timbers designed by Professor Forbes. The frame work was made rigid by being set in a concrete foundation and braced by knee braces and tie rods. The method of construction and manner of setting up may be seen by referring to the inserted photograph.

All the drilling was done in blocks of Missouri granite 4 x 4 x 3 feet. This granite is chiefly feldspars and quartz and is very hard so that the sharpening and tempering of the steel was a large item and took a large percentage of our time.

The bits used were the ordinary cross bits and were sharpened on a Leyner sharpener and swaged down on an anvil. High carbon tool steel was used for the Sullivan drill and the standard Leyner steel for the Leyner drill. It was found necessary to temper the steel as hard as it would stand up without breaking. This temper was found to be a light straw and even then the bit wore so rapidly that a set of steel would drill but one hole.

Air was furnished from a two stage 100 cu. ft. compressor through recievers of 200 cu. ft. capacity, a 2-inch pipe line, and another receiver of 50 cu. ft. capacity. The pressure was varied from 60-105 lbs.

The air was measured by means of the high pressure orifice meter, described on preceding pages, which was connected to the receiver and the hose leading to the drills. All readings were taken with the throttle wide open and an attempt was made to take them with the machine working to maximum efficiency. However, the factors mentioned entered in here and caused the consumption to vary greatly. For consumption only the maxima were taken since the others were of no value. The volume was computed as per formula derived for the orifice, $Q = .1632\ c\ d^2 \sqrt{Z/T\ P}$ per second, from which the volume was derived as follows:

Let $V =$ cu. ft. free air min.

$W =$ Wt. in lbs. of a cu. ft. of free air at temperature desired.

$$\text{then } V = \frac{60 \times .1632\ c\ d^2 \sqrt{Z/T\ P}}{W}$$

W for the following computations was taken at 60 degrees Fahrenheit and 14.1 lb. atmospheric pressure and $= .07329$.

Air Consumption of Sullivan Drill.

P.GAGE	P.ABS.	T DEG.C.	T ABS.F.	Z	V
59	71	25.0	537	3	51
65	77	20.0	526	3.5	57
69	81	20.0	528	3.8	61
73	85	20.0	528	4.1	65
74	86	17.0	523	4.0	65
75	87	17.0	523	4.5	70
78	90	17.0	523	4.9	74
80	92	17.0	523	4.9	75
82	94	20.5	529	5.2	77
83	95	25.0	537	5.5	79
85	97	21.0	530	5.3	79
88	100	24.0	535	5.6	82
90	102	21.0	530	6.6	90
93	105	23.0	533	6.6	92

Air Consumption of Leyner Drill.

P.GAGE	P.ABS.	T DEG.C.	T DEG.G.	Z	V
74	86	28.0	543	7.4	86
77	89	27.5	542	7.4	88
80	92	28.0	543	7.8	92
83	95	33.0	552	8.2	95
85	97	28.5	544	8.6	99
89	101	28.0	543	9.0	104
91	103	34.0	554	9.0	104
93	105	29.0	545	9.3	107
94	106	33.0	552	9.1	106
100	112	33.0	552	10.1	114

The volumes in the foregoing tables check up closely with the volumes a s computed from the piston displacements and published in the manufacturers catalogues. From them it will be seen that the air consumption varies directly with the pressure and if the drills could be run steady enough there is no doubt that a curve could be plotted for each drill showing the volume of air per minute, the pressure, and the inches of rock drilled providing an even temper and uniform gage be maintained on the steel. Such a curve would be valuable in testing the relative values of different styles of bit, the relative efficiencies of different machines, and also the most economical pressure to use for each type.

Our results and observations show that the Leyner drill with 1/4 inch larger cylinder consumes from 25-30 per cent more air than the Sullivan and drills, in the granite used, from 1 1/2 to 2 times as fast as the Sullivan. The only advantage we have found with the piston machine is that it is easier to start a hole with, but after the hole is started the personal equation does not count for as much with the hammer machine as it does with the piston machine. In the hammer machine the only essential is to keep the bit against the rock and keep it revolving; while with the piston machine the length of the stroke should be kept uniform and as near maximum as possible.