THESIS INVESTIGATION

ON THE SUBJECT OF

"THE INVESTIGATION AND SELECTION OF A VENTURI MIXING TUBE TO OBTAIN, WITH THE MINIMUM FUEL PRESSURE, THE PROPER PROPORTION OF KEROSENE VAPOR AND AIR FOR COMBUSTION IN A STANLEY STEAM CAR."

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Bachelor of Science

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INTRODUCTION

The recent enormous growth of the automotive industry and the increase of motor car transportation has confronted the country with the serious problem of providing sufficient fuel for the propulsion of motor driven vehicles. The economically available supply of high grade fuel which a few years ago was estimated would last for nearly a hundred years, has been reduced to a point where an imminent shortage threatens. At the present rate of consumption, unless vast new oil fields are quickly discovered, motor car transportation will be seriously hampered within a very few years. Already the effect of the shortage has been felt in a marked reduction of the quality of gasolene and an increase in its price.

Numerous attempts have been made to adapt the present motor cars for the use of a low grade of mineral, animal, or vegetable fuel oil. None of them have shown any indication that they would prove successful. It is evident that unless new fuel oil is discovered, such an adaptation must shortly be made. This is a difficult problem in the case of the internal combustion engines, but the steam power plant is readily adaptable to the use of low grade fuels.

Steam motor cars have been built since early in the history of the automobile and, though they have never held a predominant position in the automotive industry, their development has been comparable with that of the gasolene car. They have now reached a state of improvement where their operation, in many ways, is much more satisfactory than that of gasolene cars and their disadvantages slight. The unfamiliarity of the average automobile repair man with the steam car mechanism and the lack of service stations, however, prevent this type of car from becoming at present a serious competitor of the gasolene car.

The steam automobile, as represented by the Stanley Steam Car, consists of two main units; the engine and the boiler. The engine is a two cylinder, horizontal, double-acting, single-expansion steam engine with Stevenson link valve gear. It is geared directly to the differential. The boiler is a straight tube, vertical, fire tube boiler with welded tubes, tested to two thousand pounds persquare inch hydrostatic pressure and operating at 200 to 600 pounds. The fuel is burned directly beneath the boiler. Since it is not necessary to force the charge into the cylinder and burn it there in a small fraction of a second, automatic burners may readily be devised which will handle all manner of low grade fuels -- gases, liquids, and solids. At the present time the fuel used is kerosene. The mixture of air and kerosene vapor necessary for proper combustion is obtained by directing a jet of the vapor into the mouth of a straight mixing tube which discharges into the burner. The jet of vapor entering the tube draws in with it a quantity of air of about eighteen times its own volume. The vapor is produced by passing the kerosene through a heating coil above the burner. In order to produce the proper jet, however, it has been found necessary to carry a pressure of one hundred and twenty-five to one hundred and forty pounds per square inch on the fuel. This pressure is maintained by a pump geared to the rear axle. In the progress of the car's development it has become desirable to reduce this pressure, not for the saving in power required by the pump (this would be negligible), but for the sake of simplicity of design and operation. To this end the investigation outlined in this thesis has been carried out.

FORMER RESEARCH

Mr. Lambkin, of the Stanley Steam Carriage Company, has conducted a series of tests on this problem of obtaining proper mixtures for combustion and used, instead of straight tubes, several Venturi tubes of different dimensions. In his tests he substituted air for kerosene vapor, and this air passing into the Venturi tubes at high velocity, drew in larger quantities of air. He was able to compute the amount of air discharged from the nozzle. The Venturi tube discharged into a tank in which were cut small holes of various sizes so that an exit for the gases might be made of proper dimensions to give the desired back pressure.

He was able to compute the volume of air discharged from the nozzle, as well as to determine the volume of air emitted from the tank by calculation from the size of the opening and the pressures.

He did not feel, however, that the results of these tests were comprehensive enough and he wished to have further investigation made both for the purpose of checking his results, and of obtaining additional data.

OBJECT OF THIS INVESTIGATION

The object of the tests run in connection with this thesis is to determine which of the Venturi tubes originally used by Mr. Lambkin in his tests is best adapted to give at minimum fuel pressure the mixture of one part of fuel vapor to eighteen parts of air which they have selected for the proper proportion. It is also the purpose of this investigation to recommend, on the basis of the results found, modifications of any of these tubes to accomplish the same end.

APPARATUS

The Venturi tubes to be tested are shown in Figure 1. The gas from the nozzle enters the tube at the smaller end which is flared and in a car would be exhausted from the larger end of the tube directly into the burner. The throat has a straight bore while the contour from the throat to the exit of the tube has a straight taper.

In the tests run in connection with this thesis, carbon dioxide was used instead of kerosene vapor because it was more readily available and because the proportions of carbon dioxide and air could be more easily and accurately determined. Consultation with Professor C. W. Berry confirmed our belief that the physical properties of the two vapors were suf-

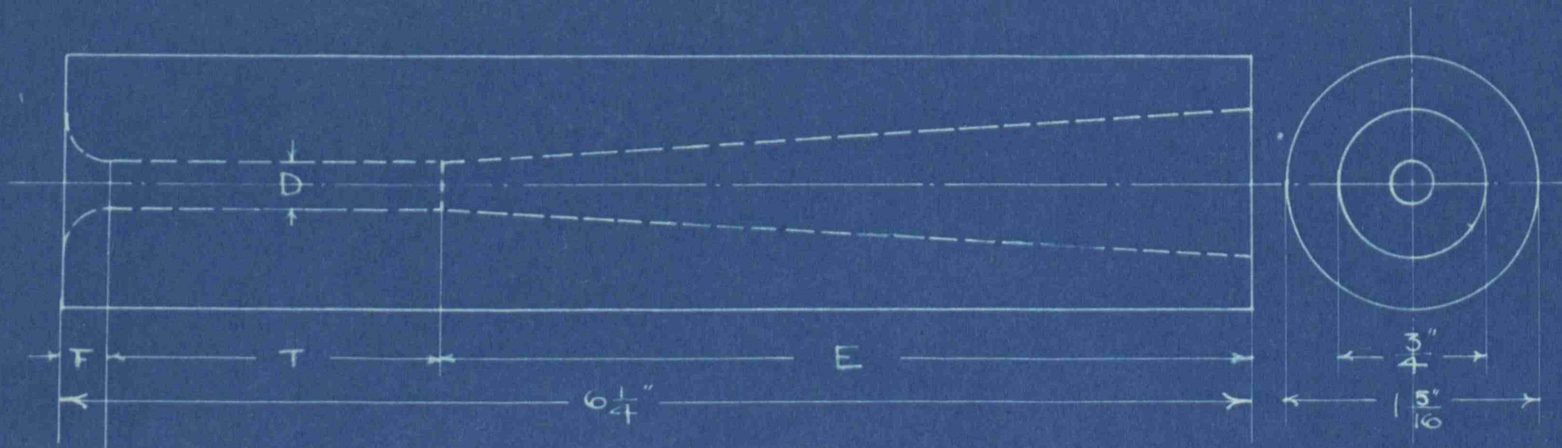

Figure 1

Original Venturi Tube Dimensions

D	F	T	E
3/16"	3/16	1 13/16"	4 1/4"
1/4"	3/16"	2 1/16"	4"
5/16"	1/4"	2 1/2"	3 1/2
3/8"	1/4"	3"	3"
7/16"	1/4"	3 3/4"	2 1/4"

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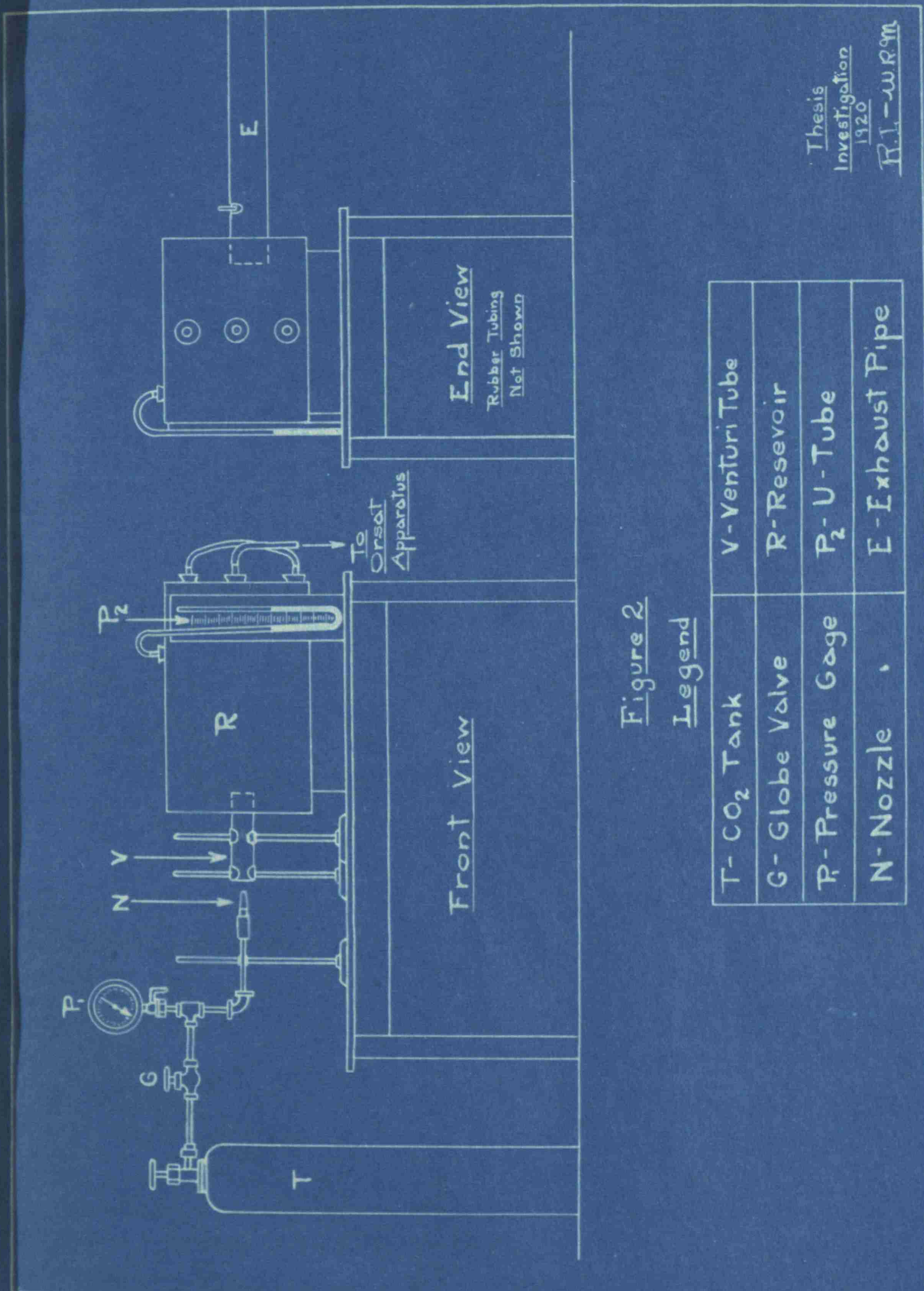
ficiently similar to permit such substitution, and that the reults obtained would be substantially correct.

The general arrangement of the apparatus is shown in the sketch in Figure 2. The carbon dioxide was stored in tanks under about one thousand pounds pressure. The fluid was conducted through a globe valve by which close regulation to the desired pressure could be obtained. The gas then passed through the nozzle and into the Venturi tube which was supported by test tube holders. One end of the tube was inserted into a five gallon tank through a rubber gasket, making the joint air tight.

The tank was provided with four small and two large openings. Three of the small openings were used for withdrawing samples of the gases to be analyzed and the fourth to make a connection with a U-tube containing water, by means of which the back pressure in the tank could be determined. Through one large opening the Venturi tube discharged into the reservoir, and the other, about four inches in diameter, was cut for the insertion of an exhaust pipe which led the carbon dioxide and air out of the run.

The exhaust pipe was equipped with a damper so that the back pressure in the reservoir could be adjusted.


E
End View
Rubber Tubing Not Shown
To Orsat Apparatus
P2
R
P1
N
V
G
T
Front View
Figure 2
Legend
T - CO2 Tank
G - Globe Valve
P1 - Pressure Gage
N - Nozzle
V - Venturi Tube
R - Resevoir
P2 - U - Tube
E - Exhaust Pipe
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An Orsat apparatus was used for determining the proportion of carbon dioxide in the mixture.

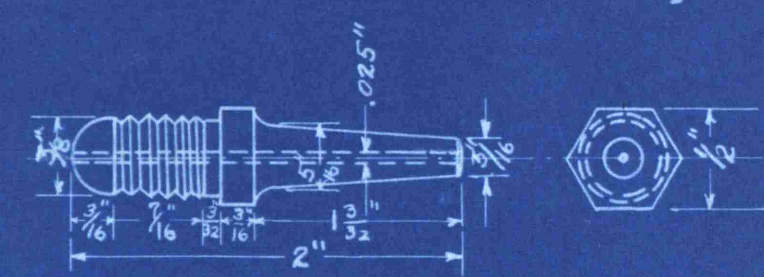
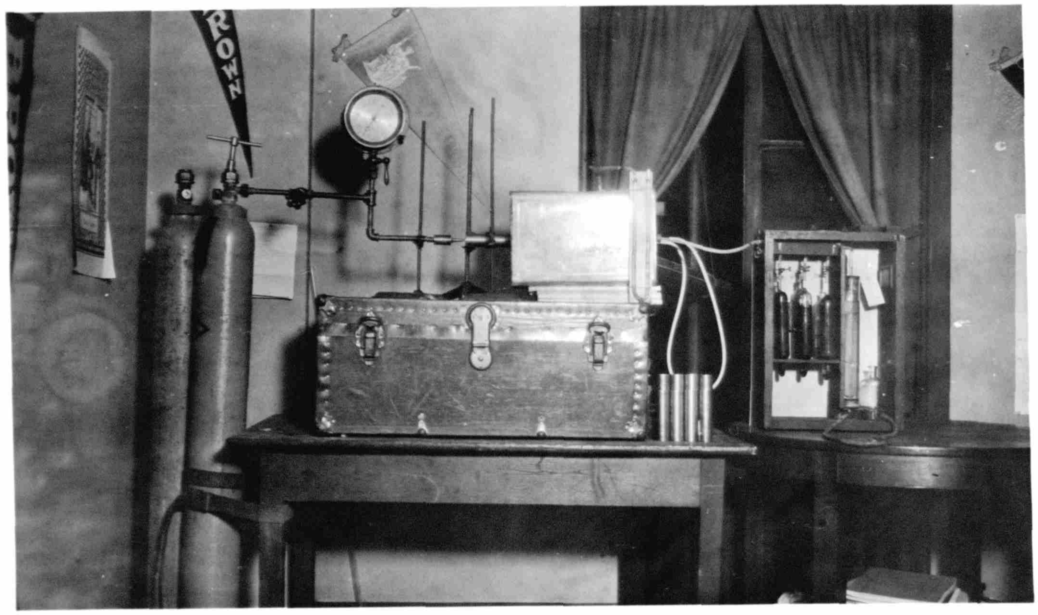


Figure 3
Nozzle for Discharging
Carbon Dioxide
Scale: Full Size

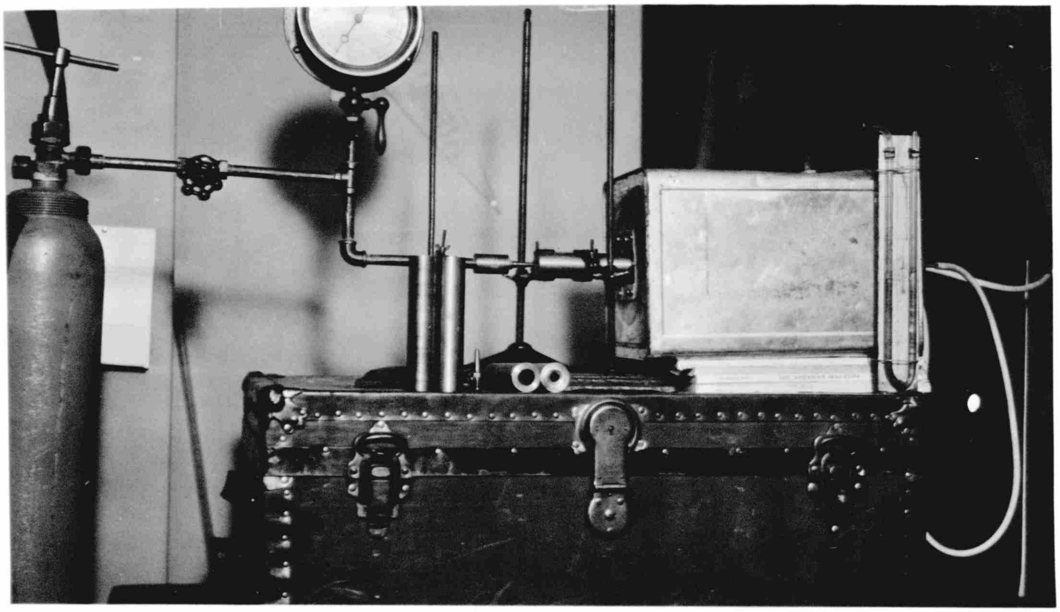
The nozzle shown in Figure 3 which was used in these tests for discharging the carbon dioxide into the Venturi tube is the type employed for oxy-acetylene welding. The size of the opening of this nozzle is .025" diameter.



FRONT VIEW OF APPARATUS

This shows the general arrangement of the appartus used in the investigation. Two tanks of carbon dioxide, each under a pressure of one thousand pounds pressure, were used in the tests.

Inasmuch as it was desirable to hold the initial pressure constant while each sample was being taken, and as the regulation of the valves to give this constant reading was difficult, it was found impossible for the man who controlled this pressure to read the back pressures at the same time. Consequently the U-tube which is shown in front was later moved to the end of the reservoir where it could be easily read by the man making the analysis of the mixture.

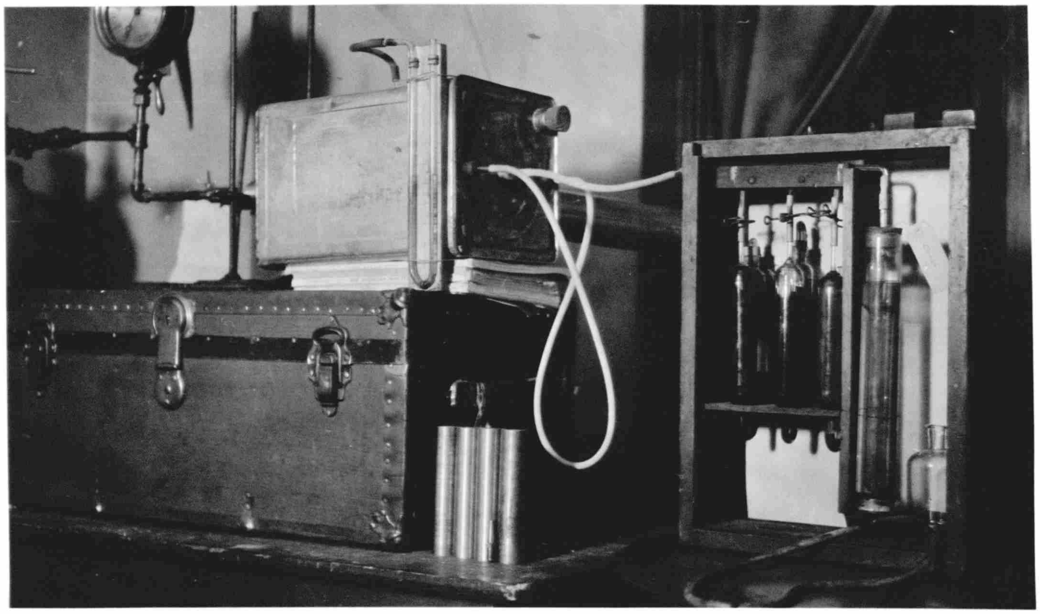


VIEW SHOWING NOZZLE AND TUBE IN POSITION

The arrangement for the entrance of the Venturi tube into the reservoir is shown clearly in this view. A rubber gasket was used so as to make an air tight joint.

The nozzle was equipped with standard machine threads so that a special union had to be made in order to couple the piping and the nozzle.

One nozzle and one tube are shown in position while four tubes and one nozzle are shown near the apparatus. The nozzle on the right lying on the trunk shows the entrance end while the one on the left shows the exit.



DETAILS OF RESERVOIR AND ORSAT APPARATUS

This view shows the arrangement of the tubes for obtaining samples from the reservoir. The middle rubber cork was fitted with a straight glass tube which entered the reservoir. The other two were fitted with glass tubes bent at right angles inside the reservoir so that they could be moved and samples taken from any part of the tank.

When it was desired to take temperature readings the thermometer was inserted in one of the rubber corks after removing the glass tubing.

A small part of the exhaust pipe which conducted the gases out of the room is also shown in this photograph.

METHOD OF TESTING

The apparatus was set up as shown in Figure 2. The carbon dioxide pressure at the nozzle was indicated at the pressure guage. Any desired pressure was maintained by manipulation of the globe valve between the guage and the tank. The nozzle directed a jet of gas into the small end of the Venturi tube. This jet carried with it through the tube and into the reservoir a large volume of air which became thoroughly mixed with the carbon dioxide by the turbulence in the reservoir. The pressure in the tank was indicated by the difference in the water levels in the U-tube, on which a scale was provided reading directly to tenths of an inch. Tubes were provided at one end of the tank through which samples of the mixture in the tank might be taken from different points for analysis in the Orsat apparatus.

Since the present fuel mixing system on the Stanley Steam Car employs a fuel pressure of nearly one hundred and forty pounds, it was thought advisable to run tests with a series of pressures up to and including that pressure. Accordingly, in all tests the nozzle pressures were varied by ten pound increments from one hundred and forty pounds to zero, and samples of the mixture were analyzed for each pressure. All tests were started at one hundred and forty pounds because the increased volume of gases entering at that pressure more quickly established a uniform mixture in the reservoir.

A number of dampers were constructed and tested in an effort to maintain a constant back pressure in the reservoir by varying the opening in the exhaust pipe. It was found in tests, however, that the variations of back pressure under extreme changes of tubes and nozzle pressures were so marked that it was practically impossible to construct a damper to permit an accurate adjustment of back pressure. Consequently it was decided to maintain the opening in the exhaust pipe constant and to read the back pressure in the reservoir directly from the U-tube under all conditions of tests.

Because of the difference in density of air and carbon dioxide, some doubt was at first entertained as to the uniformity of the mixture within the reservoir. However, tests made taking samples from various parts of the tank showed such close accordance of results that it was considered sufficient to take samples from only one point. The center of one end of the reservoir was selected as the point at which the samples could be most conveniently taken.

The manipulation of the Orsat apparatus was standardized with regard to the length of time required for the absorption of the carbon dioxide by the potassium hydroxide. It was found that, for the small per centages of carbon dioxide obtained in these tests, one minute and a half was sufficient time for the complete absorption of the carbon dioxide. Accordingly the sample was left in the pipette containing potassium hydroxide for that length of time for each analysis.

It was thought desirable to investigate the changes in temperature in the reservoir under different conditions. A series of tests run to determine these temperatures showed variations in temperatures so slight that their effect upon the results would be negligible, since calculations would be based on absolute temperatures and the maximum variation in the tank was only 2.2 degrees. The results of these tests are appended.

Inasmuch as the large number of variables in pressures, distances, and tube dimensions prohibited tests under all conditions, at the suggestion of Mr. Lambkin, of the Stanley Company, we ran a series of tests with one tube, varying the distance, L, Figure 1, between the tube and the nozzle, to determine the approximate distance at which the best results could be obtained. A study of the curves plotted from the results of these tests showed that with a distance, L, of 1/4" the best consistent results were secured. Consequently all further tests were run with this value of L.

Under the conditions thus determined tests were run on all tubes, varying the nozzle pressure from one hundred and forty pounds to zero by increments of ten pounds. For each pressure the back pressure in the tank, in inches of water, and the carbon dioxide content as determined by the Orsat apparatus in per cent, were recorded. Curves were plotted of carbon dioxide content in per cent against nozzle pressure in pounds per square inch. Further tests were made on modifications of two of the tubes. It was desired to determine the effect on the carbon dioxide content of shortening the exit taper of the Venturi tube. One half inch was cut from the exit end of the quarter inch tube and a test run to investigate its operation. Results were obtained and plotted as in previous tests. It was desired also to ascertain the effect of shortening the throat of the Venturi tube. The long throats with which these tubes were made were suspected of introducing considerable friction loss and reducing appreciably the amount of air admitted with the carbon dioxide. To corroborate this suspicion the throat of the 5/16" tube was cut down to 1/2" reproducing, as nearly as possible, the original flare at entrance. This tube was tested as before and the data recorded and plotted.

Since several tubes gave the desired mixture at low pressures a method of comparison was sought to determine which of these tubes might be used most advantageously. To this end it was suggested that we compute efficiencies for each tube at all pressures. For a known quantity of carbon dioxide flowing through the nozzle the input to the tube may be readily calculated. The output, however, is very indefinite. Under the best conditions of use the output would be very small and the efficiency of the tube, if calculated by that means, insignificant. We have, therefore, abandoned the idea of attempting any efficiency calculations for the tubes. To obtain comparative data on these tubes we have computed the work done per pound of air in compressing the air from atmospheric conditions to the back pressure in the reservoir corresponding to nozzle pressures for all conditions of tests. In computing this work we have considered adiabatic compression as most nearly corresponding with the actual conditions. Although an isothermal compression ismore efficient than the adiabatic the conditions under which this compression occurs are more nearly adiabatic than isothermal. Consequently the following formula was employed in computing the work of compression:

$$W = 144 P_a V_a \frac{n}{n-1}\left[\left(\frac{P_2}{P_a}\right)^{\frac{n-1}{n}} - 1\right] \text{ foot pounds.}$$

Where:

W = work per # of air

P_a = atmospheric pressure

P_2 = back pressure in the reservoir

V_a = volume of one pound of air at atmospheric conditions

n = 1.4 for air

Curves were plotted of work per pound of air against nozzle pressures for all tests.

DISCUSSION OF CURVES

Figures 4, 6, 8, and 10 are the results of tests carried out to determine the most desirable distance, L, Figure 1, between the nozzle and the tube. Since the main purpose of the investigation is to study the action of the tubes at low pressures the low pressure portions of these curves were considered chiefly in comparison. Comparison of these curves is well shown on the Composite Plot, Figure 22. Though curve No. 8 indicates a lower carbon dioxide content than does curve No. 10 at the lower pressures, both show per centages too high to give the proportions desired. Values of L of over 3/8", then, are undesirable. Curves Nos. 4 & 6 closely approximate the proper per centages at pressures of from ten to forty pounds. At these pressures there is very little difference in per centages with variations of the distance L under 1/4". The Curve No. 6, where L is equal to 1/4", indicates lower carbon dioxide content at low pressures than does Curve No. 4. Because of this fact it was decided to run tests on other tubes at this distance.

The effect of using the tube of larger throat diameter, 5/16", is shown by Curve No. 14 on the same Figure. This test gave approximately the desired carbon dioxide per centage at pressures of from ten to twenty pounds.

Tubes of larger throat diameter (Curves No. 18 & 20) gave proportions of carbon dioxide much lower than that desired. It was necessary to carry a nozzle pressure of 78# with a 3/8" tube (Curve No. 18) and 120# with the 7/16" tube (Curve No. 20) to obtain the ratios of carbon dioxide and air of 1 : 18. This explains the necessity of carrying a fuel pressure of 140# with the straight mixing tube now employed for this purpose on the Stanley Steam Car.

A test was run to study the effect of shortening the tapered exit of the Venturi tube. For this purpose the 1/4" tube was cut down 1/2" at this end, reducing the length of the taper from 4" to 3-1/2" and the diameter of the exit from 3/4" to 5/8". The results of this test are plotted in Figure 12. Comparing this curve with Figure 6, it will be seen that the carbon dioxide per centage is greater throughout the whole pressure range. Evidently the reduction of the tapered length permitted insufficient expansion of the mixture within the tube. For our purposes, then, the further reduction of the length of the tube tapers was undesirable.

To determine the effect of reducing the length of throat in the tube the 5/16" tube was cut down at the entrance end, reducing the throat length from 2-1/2" to 1/2". The entrance flare was reproduced as nearly as possible. Figure 16 is a curve plotted from the results of a test on this modified tube. The per centages of carbon dioxide for corresponding pressures are noticeably lower for this curve than in the curve on Figure 14 for the unaltered tube. Undoubtedly the reduction of throat length has so reduced the frictional losses as to permit the passage of a greater proportion of air.

Considerable irregularity will be noted in the work curves. Since the work performed is directly dependent upon the back pressure in the reservoir and none of the pressures recorded exceeded one inch of water, slight errors in back pressure reading involved considerable variation in the results. Disturbances within the reservoir at different pressures are also probably responsible for irregularities in the back pressure readings. In several of the curves such as Figure 15, the points were found to follow a series of nearly parallel straight lines, suggesting that the above conditions possibly existsin those cases.

The first four work curves, Figures 5, 7, 9, & 11, were plotted from results of tests on the same tube with varying values of L. A comparison of these curves shows the work per pound of air varying inversely with the distance from the nozzle tip to the tube.

With increased tube diameters, the work performed per pound of air increases, as shown by Figures 15, 19, 21, & 23.

Figure 13 (by comparison with Figure 11) indicates that a reduction of the taper length and consequently a reduction of the expansion of the gases within the tube results in a reduction of the work performed in the tube.

The work performed in the 5/16" tube with reduced throat (Figure 17) is substantially the same as that in the unaltered 5/16" tube (Figure 15).

CONCLUSIONS

1. Reduction of pressure at the nozzle causes a reduction in the carbon dioxide per cent in the mixture.

2. The air proportion in the mixture and the work of compression per pound of air increase with an increase of throat diameter of the Venturi tube for given nozzle pressures.

3. Reduction of the taper length raises the carbon dioxide per centage in the mixture.

4. Reduction of the throat length reduces the carbon dioxide per centage in the mixture.

RECOMMENDATIONS

On the basis of the results of these tests we recommend, for providing the required mixture of kerosene vapor and air on the Stanley Steam Car, one of the following tubes:

A 1/4" tube similar to that used in tests but with throat length reduced to 2". The tube with the 2-1/2" throat gave values a little above the proper proportion. This throat reduction should bring the proportion to approximately the desired value. The nozzle to be placed 1/4" from the tube entrance. Fuel pressure 10 #/sq. in.

The 5/16" tube with a very slightly reduced throat length. Carbon dioxide per centage recorded with a 5/16" tube was .1% high. The distance from nozzle tip to tube to be 1/4" and the fuel pressure 10 #/sq. in.

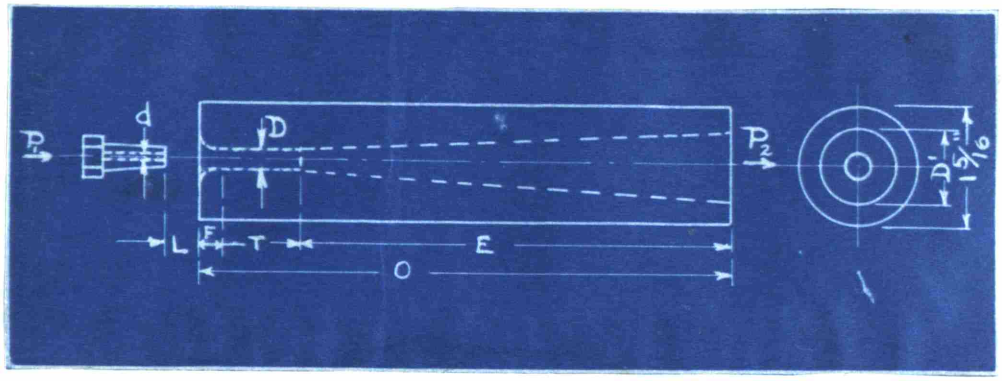
DATA ON CARBON DIOXIDE PERCENTAGE

UNITS:

P_1 equals nozzle pressure (#/sq. in.)

P_2 equals back pressure (ins. of H_2O)

CO_2 equals carbon dioxide content (%)



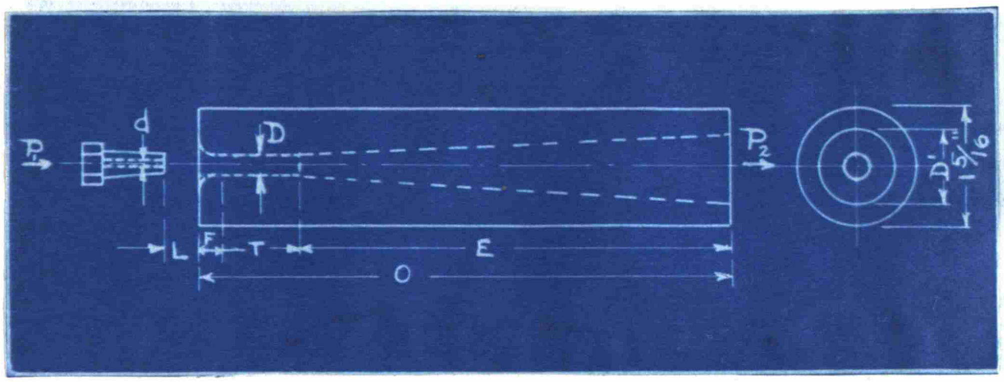
d - .025" T - 2-1/16"

D - 1/4" F - 3/16"

L - 1/8" O - 6-1/4"

E - 4"

Run No.	P_1	P_2	CO_2
1	140	.35	10.4
2	130	.30	10.0
3	120	.25	9.6
4	110	.25	9.0
5	100	.20	8.6
6	90	.20	8.3
7	80	.18	7.8
8	70	.15	7.3
9	60	.15	6.8
10	50	.12	6.4
11	40	.08	6.1
12	30	.05	5.7
13	20	.05	5.6
14	10	.02	5.3



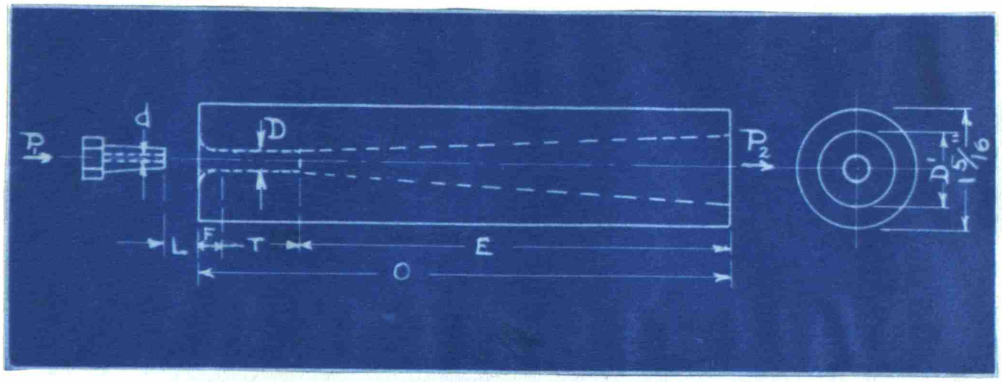
d - .025" T - 2-1/16"

D - 1/4" F - 3/16"

L - 1/4" O - 6-1/4"

E - 4"

Run No.	P_1	P_2	CO_2
1	140	.36	11.4
2	130	.30	11.0
3	120	.28	10.5
4	110	.28	9.8
5	100	.25	9.3
6	90	.22	8.7
7	80	.20	8.2
8	70	.20	7.4
9	60	.20	6.8
10	50	.17	6.3
11	40	.13	6.0
12	30	.09	5.6
13	20	.05	5.4
14	10	.02	5.4



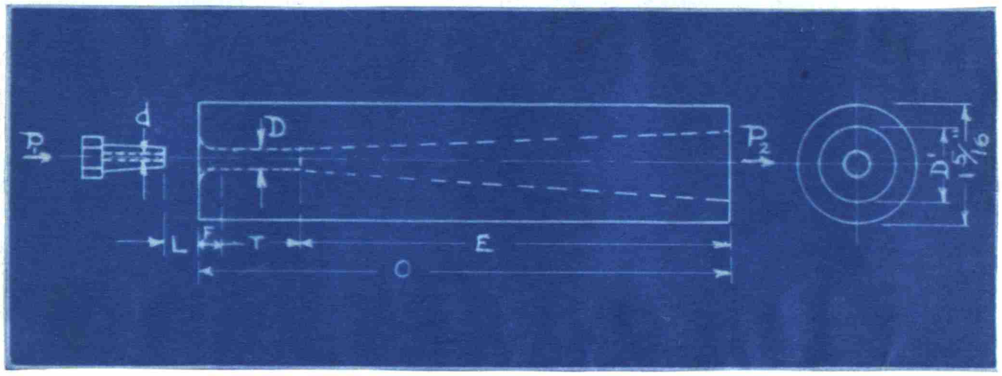
d - .025"   T - 2-1/16"

D - 1/4"   F - 3/16"

L - 3/8"   O - 6-1/4"

E - 4"

Run No.	P_1	P_2	CO_2
1	140	.32	11.9
2	130	.30	11.2
3	120	.28	10.8
4	110	.26	10.2
5	100	.24	9.7
6	90	.22	9.2
7	80	.20	8.4
8	70	.18	7.8
9	60	.16	7.4
10	50	.12	6.8
11	40	.10	6.4
12	30	.08	6.2
13	20	.05	5.9
14	10	.00	5.8



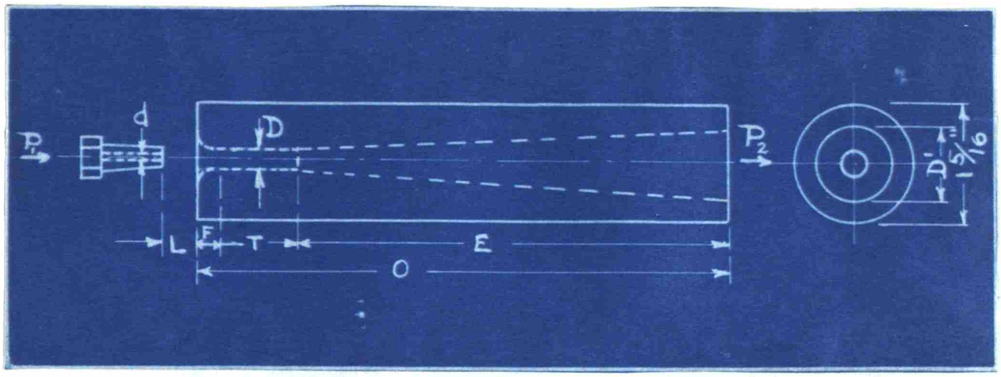
d - .025" T - 2-1/16"

D - 1/4" F - 3/16"

L - 1/2" O - 6-1/4"

E - 4"

Run No.	P_1	P_2	CO_2
1	140	.22	10.8
2	130	.21	10.2
3	120	.20	9.8
4	110	.20	9.4
5	100	.20	9.0
6	90	.19	8.8
7	80	.17	8.1
8	70	.15	7.8
9	60	.12	7.2
10	50	.10	7.0
11	40	.08	6.7
12	30	.05	6.3
13	20	.02	6.4
14	10	.00	6.4



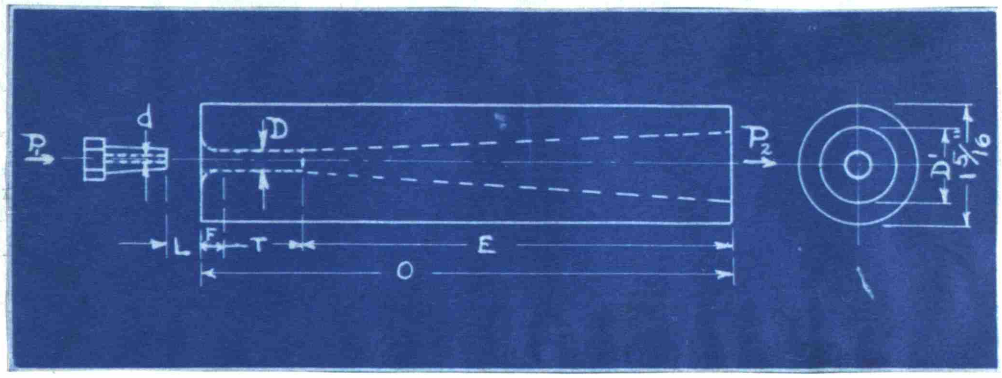
d - .025 T - 2-1/16"

D - 1/4" F - 3/16"

L - 1/4" O - 5-3/4"

E - 3-1/2"

Run No.	P_1	P_2	CO_2
1	140	.25	11.0
2	130	.20	11.0
3	120	.18	10.6
4	110	.15	10.2
5	100	.15	9.6
6	90	.15	9.2
7	80	.13	8.6
8	70	.10	8.4
9	60	.10	8.0
10	50	.08	7.6
11	40	.08	7.2
12	30	.06	6.6
13	20	.02	6.4
14	10	.00	6.2



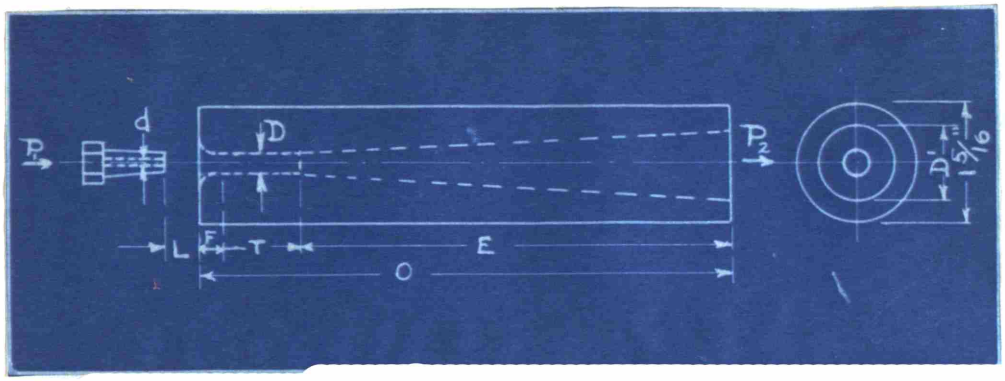
d - .025" T - 2-1/2"

D - 5/16", F - 1/4"

L - 1/8" O - 6- 1/4"

E - 3-1/2"

Run No.	P_1	P_2	CO_2
1	140	.55	10.0
2	130	.50	9.4
3	120	.45	8.6
4	110	.45	8.2
5	100	.40	8.0
6	90	.40	7.4
7	80	.35	7.0
8	70	.30	6.8
9	60	.25	6.6
10	50	.25	6.2
11	40	.20	5.8
12	30	.15	5.5
13	20	.10	5.4
14	10	.05	5.4



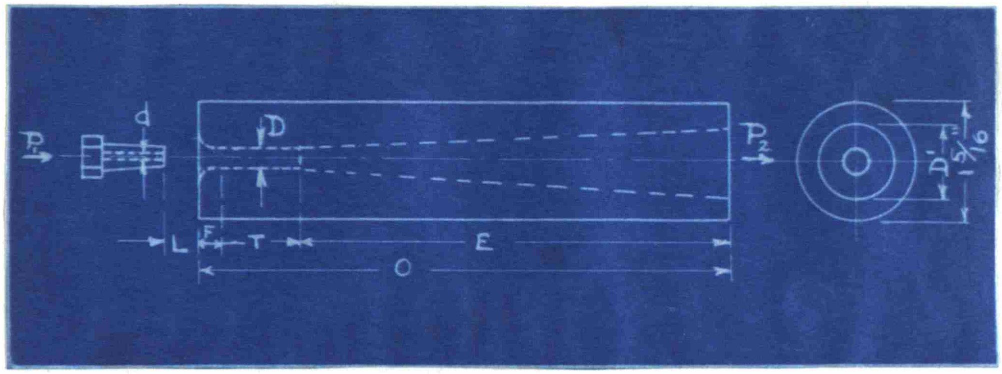
d - .025"   T - 1/2"

D - 5/16"   F - 1/8"

L - 1/4"   O - 4-1/8"

E - 3-1/2"

Run No.	P_1	P_2	CO_2
1	140	.46	7.2
2	130	.50	6.8
3	120	.50	6.5
4	110	.45	6.3
5	100	.38	6.0
6	90	.35	5.7
7	80	.30	5.3
8	70	.28	5.0
9	60	.22	4.8
10	50	.20	4.6
11	40	.15	4.3
12	30	.14	4.0
13	20	.08	3.8
14	10	.06	3.8



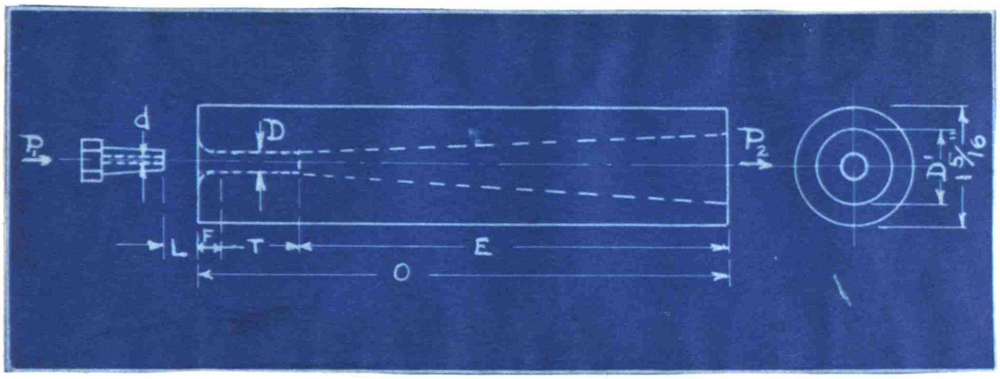
d - .025"   T - 3"

D - 3/8"   F - 1/4"

L - 1/4"   O - 6-1/4"

E - 3"

Run No.	P_1	P_2	CO_2
1	140	.75	7.0
2	130	.70	7.0
3	120	.65	6.8
4	110	.60	6.5
5	100	.55	6.2
6	90	.50	5.9
7	80	.45	5.4
8	70	.40	5.0
9	60	.35	4.6
10	50	.30	4.4
11	40	.20	4.2
12	30	.15	4.0
13	20	.10	3.9
14	10	.05	3.7



d - .025"

D - 7/16"

L - 1/4"

E - 2-1/4"

T - 3-3/4"

F - 1/4"

O - 6-1/4"

Run No.	P_1	P_2	CO_2
1	140	.90	6.0
2	130	.85	5.8
3	120	.80	5.6
4	110	.80	5.4
5	100	.60	5.2
6	90	.60	5.2
7	80	.55	4.8
8	70	.50	4.7
9	60	.45	4.4
10	50	.40	4.0
11	40	.30	3.8
12	30	.20	3.6
13	20	.10	3.4
14	10	.05	3.4

PROPORTIONS OF CARBON DIOXIDE AND AIR WITH CORRESPONDING PER CENTAGES OF CO_2

CO_2 to Air	% CO_2
1 : 18	5.27
1 : 17	5.56
1 : 16	5.88
1 : 15	6.25
1 ; 14	6.67
1 : 13	7.15
1 : 12	7.70
1 : 11	8.34
1 : 10	9.09
1 : 9	10.00
1 : 8	11.10
1 : 7	12.50

WORK PER POUND OF AIR

P_1 equals nozzle pressure (#/sq/in.)

P_2 equals back pressure (in. of H_2O)

Work in ft/ lbs. per lb. of air.

SEE FIGURE 5

d - .025" T - 2-1/16"

D - 1/4" F - 3/16"

L - 1/8" O - 6-1/4"

E - 4"

Run No.	P_1	P_2	Work
1	140	.35	25.12
2	130	.30	21.45
3	120	.25	17.74
4	110	.25	17.74
5	100	.20	14.10
6	90	.20	14.10
7	80	.18	12.74
8	70	.15	10.71
9	60	.15	10.71
10	50	.12	8.72
11	40	.08	6.04
12	30	.05	4.68
13	20	.05	4.68
14	10	.02	1.47

SEEEFIGURE 7

d - .025" T - 2-1/16"

D - 1/4" F - 3/16"

L - 1/4" O - 6-1/4"

E - 4"

Run No.	P_1	P_2	Work
1	140	.36	25.83
2	130	.30	21.45
3	120	.28	19.95
4	110	.28	19.95
5	100	.25	17.74
6	90	.22	15.51
7	80	.20	14.10
8	70	.20	14.10
9	60	.20	14.10
10	50	.17	12.09
11	40	.13	9.39
12	30	.09	6.71
13	20	.05	4.68
14	10	.02	1.47

SEE FIGURE 9

d - .025" T - 2-1/16"

D - 1/4" F - 3/16"

L - 3/8" O - 6-1/8"

E - 4"

Run No.	P1	P2	Work
1	140	.32	23.76
2	130	.30	21.45
3	120	.28	19.95
4	110	.26	18.48
5	100	.24	17.02
6	90	.22	15.51
7	80	.20	14.10
8	70	.18	12.74
9	60	.16	11.38
10	50	.12	8.72
11	40	.10	7.38
12	30	.08	6.04
13	20	.05	4.68
14	10	.00	0.00

SEE FIGURE 11

d - .025" T - 2-1/16"

D - 1/4" F - 3/16"

L - 1/2" O - 6-1/4"

E - 4"

Run No.	P_1	P_2	Work
1	140	.22	15.51
2	130	.21	14.75
3	120	.20	14.10
4	110	.20	14.10
5	100	.20	14.10
6	90	.19	13.39
7	80	.17	12.09
8	70	.15	10.71
9	60	.12	8.72
10	50	.10	7.38
11	40	.08	6.04
12	30	.05	4.68
13	20	.02	1.47
14	10	.00	0.00

SEE FIGURE 13

d - .025"   T - 2-1/16"

D - 1/4"   F - 3/16"

L - 1/4"   0 - 5-3/4"

E - 3-1/2"

Run No.	P_1	P_2	Work
1	140	.25	17.74
2	130	.20	14.10
3	120	.18	12.74
4	110	.15	10.71
5	100	.15	10.71
6	90	.15	10.71
7	80	.13	9.39
8	70	.10	7.38
9	60	.10	7.38
10	50	.08	6.04
11	40	.08	6.04
12	30	.05	4.68
13	20	.02	1.47
14	10	.00	0.00

SEE FIGURE 15

d - .025"　　T - 2-1/2"

D - 5/16"　　F - 1/4"

L - 1/8"　　O - 6-1/4"

E - 3-1/2"

Run No.	P_1	P_2	Work
1	140	.55	39.17
2	130	.50	35.50
3	120	.45	32.12
4	110	.45	32.12
5	100	.40	28.80
6	90	.40	28.80
7	80	.35	25.12
8	70	.30	21.45
9	60	.25	17.74
10	50	.25	17.74
11	40	.20	14.10
12	30	.15	10.71
13	20	.10	7.38
14	10	.05	4.68

SEE FIGURE 17

d - .025" T - 1/2"

D - 5/16" F - 1/8"

L - 1/4" O - 4-1/8"

E - 3-1/2"

Run No.	P_1	P_2	Work
1	140	.46	32.80
2	130	.50	35.50
3	120	.50	35.50
4	110	.45	32.12
5	100	.38	27.32
6	90	.35	25.12
7	80	.30	21.45
8	70	.28	19.95
9	60	.22	15.51
10	50	.20	14.10
11	40	.15	10.71
12	30	.14	10.05
13	20	.08	6.04
14	10	.06	5.62

SEE FIGURE 19

d - .025"   T - 3"

D - 3/8"   F - 1/4"

L - 1/4"   O - 6-1/4"

E - 3"

Run No.	P_1	P_2	Work
1	140	.75	53.87
2	130	.70	50.25
3	120	.65	46.52
4	110	.60	42.90
5	100	.55	39.17
6	90	.50	35.50
7	80	.45	32.12
8	70	.40	28.80
9	60	.35	25.12
10	50	.30	21.45
11	40	.20	14.10
12	30	.15	10.71
13	20	.10	7.38
14	10	.05	4.68

<u>SEE FIGURE 21</u>

d - .025"   T - 2-3/4"

D - 7/16"   F - 1/4"

L - 1/4"   O - 6-1/4"

E - 2-1/4"

Run No.	P_1	P_2	Work
1	140	.90	64.30
2	130	.85	60.62
3	120	.80	57.00
4	110	.80	57.00
5	100	.70	50.25
6	90	.60	42.90
7	80	.55	39.17
8	70	.50	35.50
9	60	.45	32.12
10	50	.40	28.80
11	40	.30	21.45
12	30	.20	14.10
13	20	.10	7.38
14	10	.05	4.68

WORK OF COMPRESSION PER POUND OF AIR FOR CORRESPONDING BACK PRESSURES

P_2	W'#	P_2	W'#
.02	1.47	.26	18.48
.05	4.68	.28	19.95
.08	6.04	.30	21.45
.09	6.71	.32	22.76
.10	7.38	.35	25.12
.12	8.72	.36	25.83
.13	9.39	.40	28.80
.15	10.71	.45	32.12
.16	11.38	.50	35.50
.17	12.09	.55	39.17
.18	12.74	.60	42.90
.19	13.39	.65	46.52
.20	14.10	.70	50.25
.21	14.75	.75	53.87
.22	15.51	.80	57.00
.24	17.02	.85	60.62
.25	17.74	.90	64.30

DATA ON RESERVOIR TEMPERATURES

UNITS:

P_1 equals nozzle pressure (#/sq.in.)

T_2 equals temperature in the reservoir (^oF)

D - 1/4" L - 1/4"

P_1	T_2
140	66.8
130	66.6
120	66.5
110	66.5
100	66.5
90	66.6
80	66.6
70	66.7
60	66.8
50	66.9
40	67.0
30	67.0
20	67.1
10	67.1

D - 5/16" L - 1/4"

P_1	T_2
140	68.5
130	68.4
120	68.4
110	68.4
100	68.4
90	68.3
80	68.3
70	68.4
60	68.4
50	68.4
40	68.4
30	68.4
20	68.4
10	68.4

D - 3/8" L- 1/4"

P_1	T_2
140	68.5
130	68.5
120	68.5
110	68.5
100	68.5
90	68.5
80	68.5
70	68.5
60	68.6
50	68.6
40	68.7
30	68.7
20	68.7
10	68.7

D - 7/16" L - 1/4"

P_1	T_2
140	68.6
130	68.6
120	68.6
110	68.6
100	68.5
90	68.5
80	68.5
70	68.5
60	68.5
50	68.5
40	68.5
30	68.5
20	68.5
10	68.5

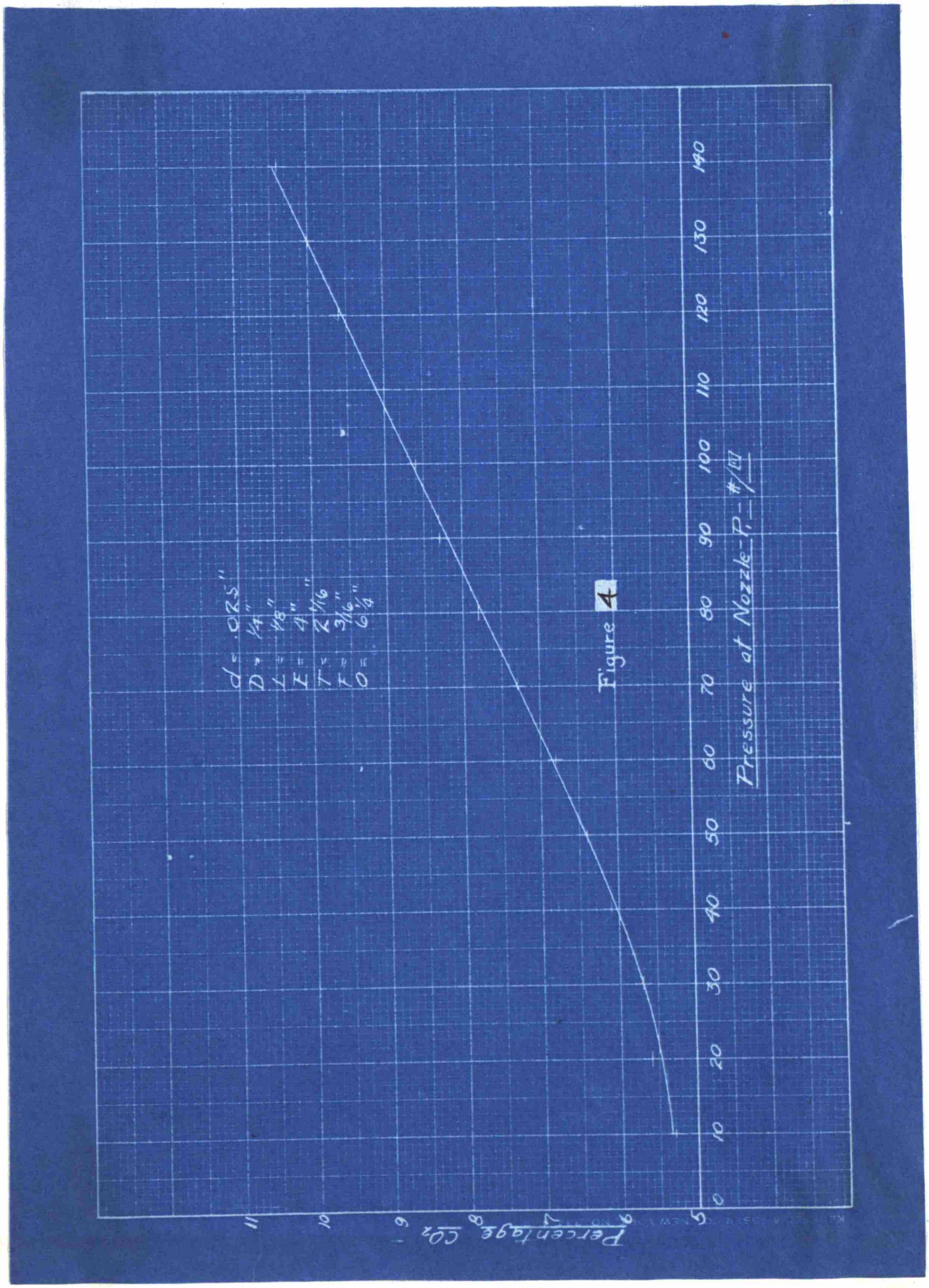

d = .025"
D = 1/4"
L = 1/8"
E = 4"
T = 2 1/16"
F = 3/16"
O = 6 1/4"
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure at Nozzle-P,- #/□"
5
6
7
8
9
10
11
Percentage CO_2

Figure 4

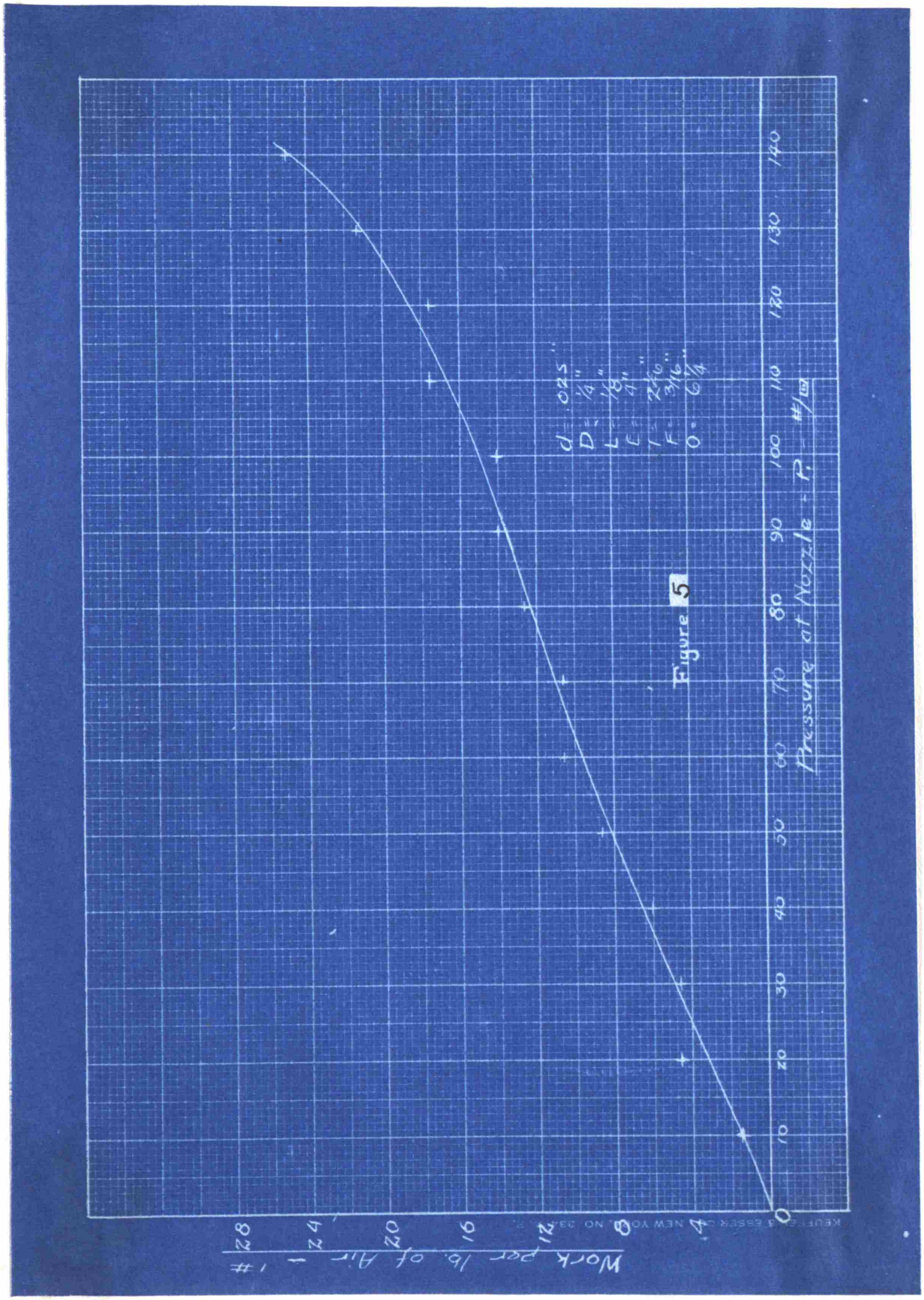

d = .025"
D = 1/4"
L = 1/8"
E = 4"
T = 7/16"
F = 3/16"
O = 6 1/4"
Pressure at Nozzle - P - #/□"
Work per lb. of Air - '#
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
4
8
12
16
20
24
28

Figure 5

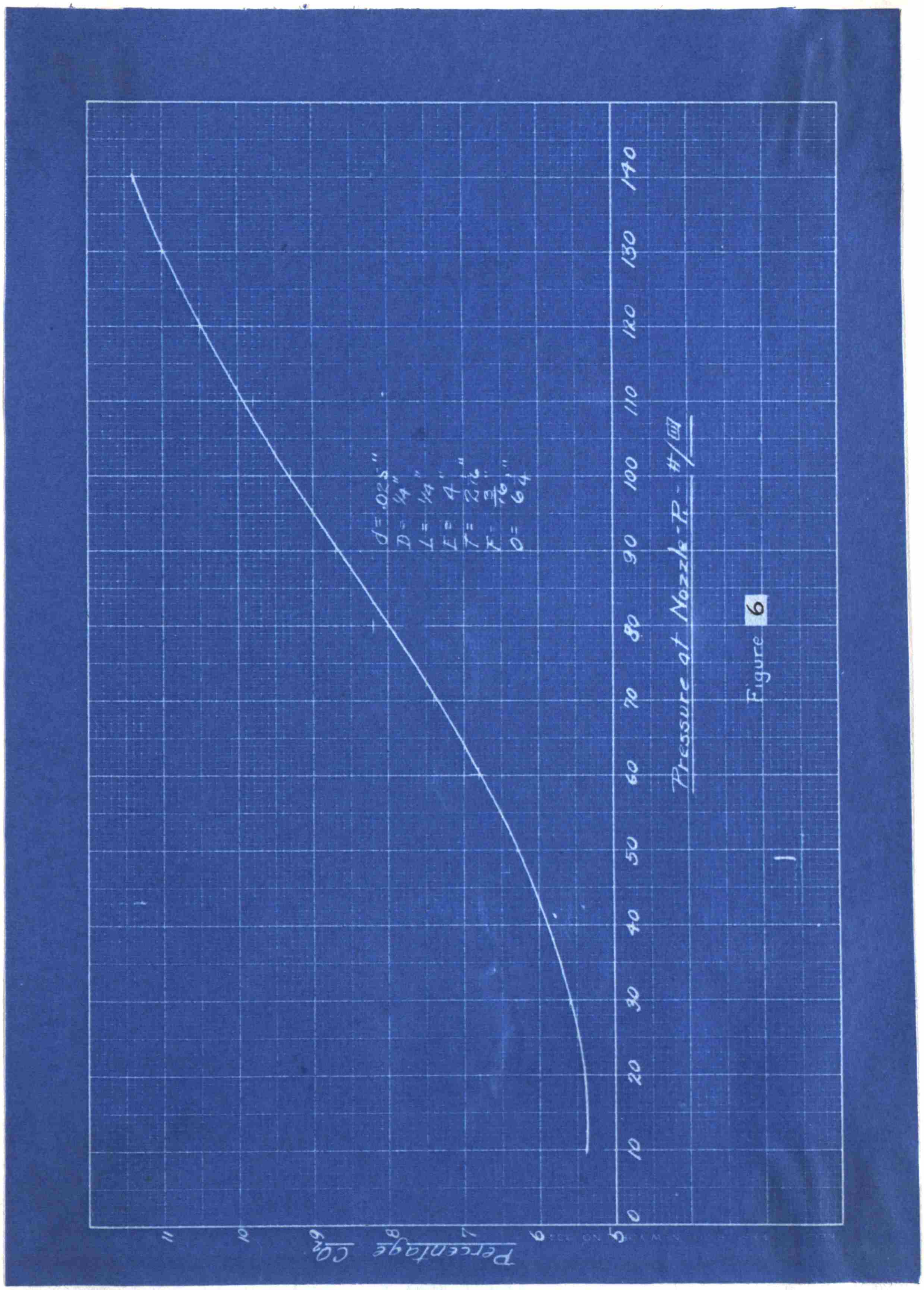

Percentage CO2
Pressure at Nozzle - P - #/□"
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
5
6
7
8
9
10
11
d = .025"
D = 1/4"
L = 1/4"
E = 4"
O = 64

Figure 6

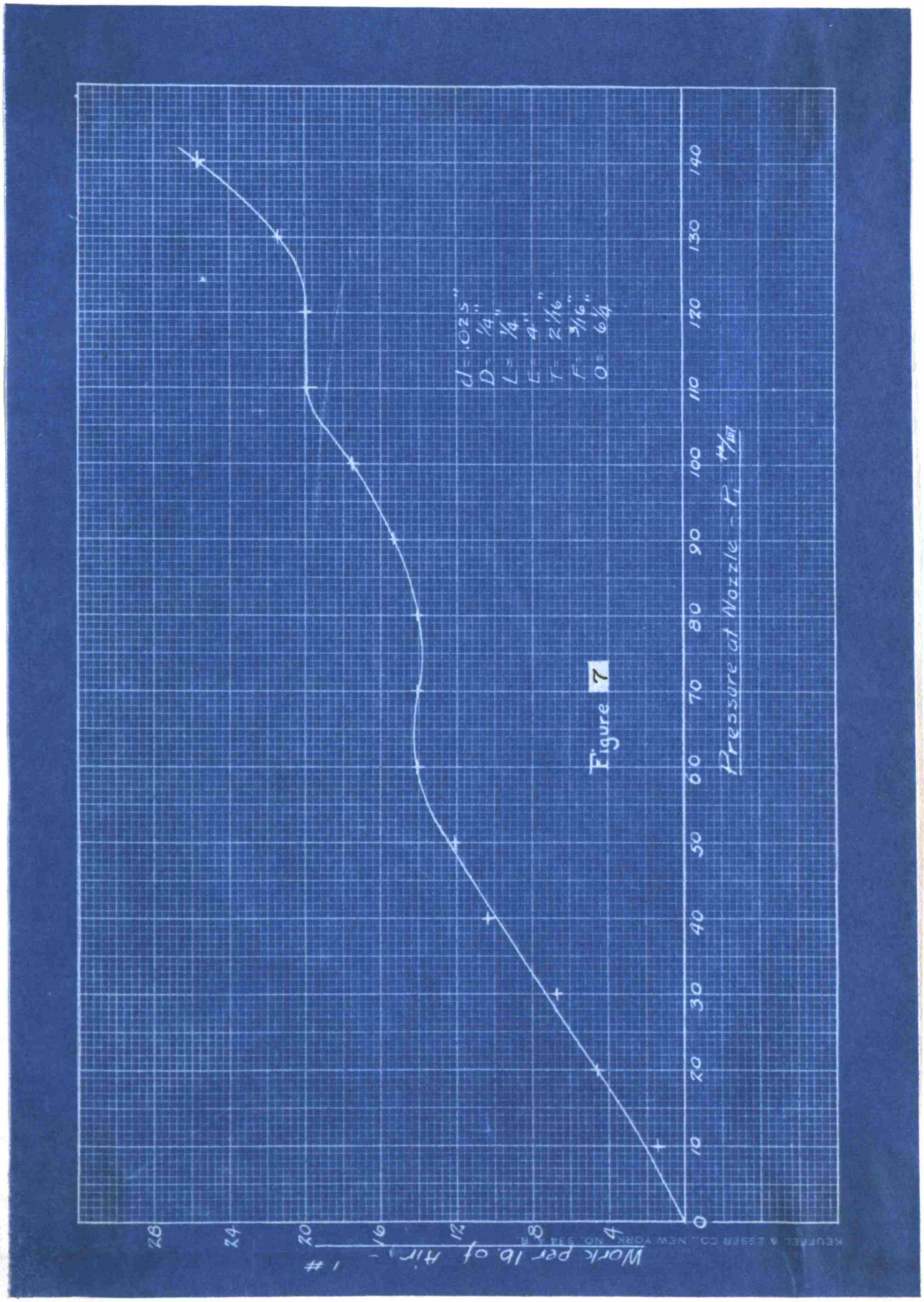


Figure 7
Pressure at Nozzle - P1
Work per lb. of Air
d = .025"
D = 1/4"
L = 1/4"
E = 4"
T = 2 1/16"
F = 3/16"
O = 6 1/4
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
4
8
12
16
20
24
28
KEUFFEL & ESSER CO., NEW YORK

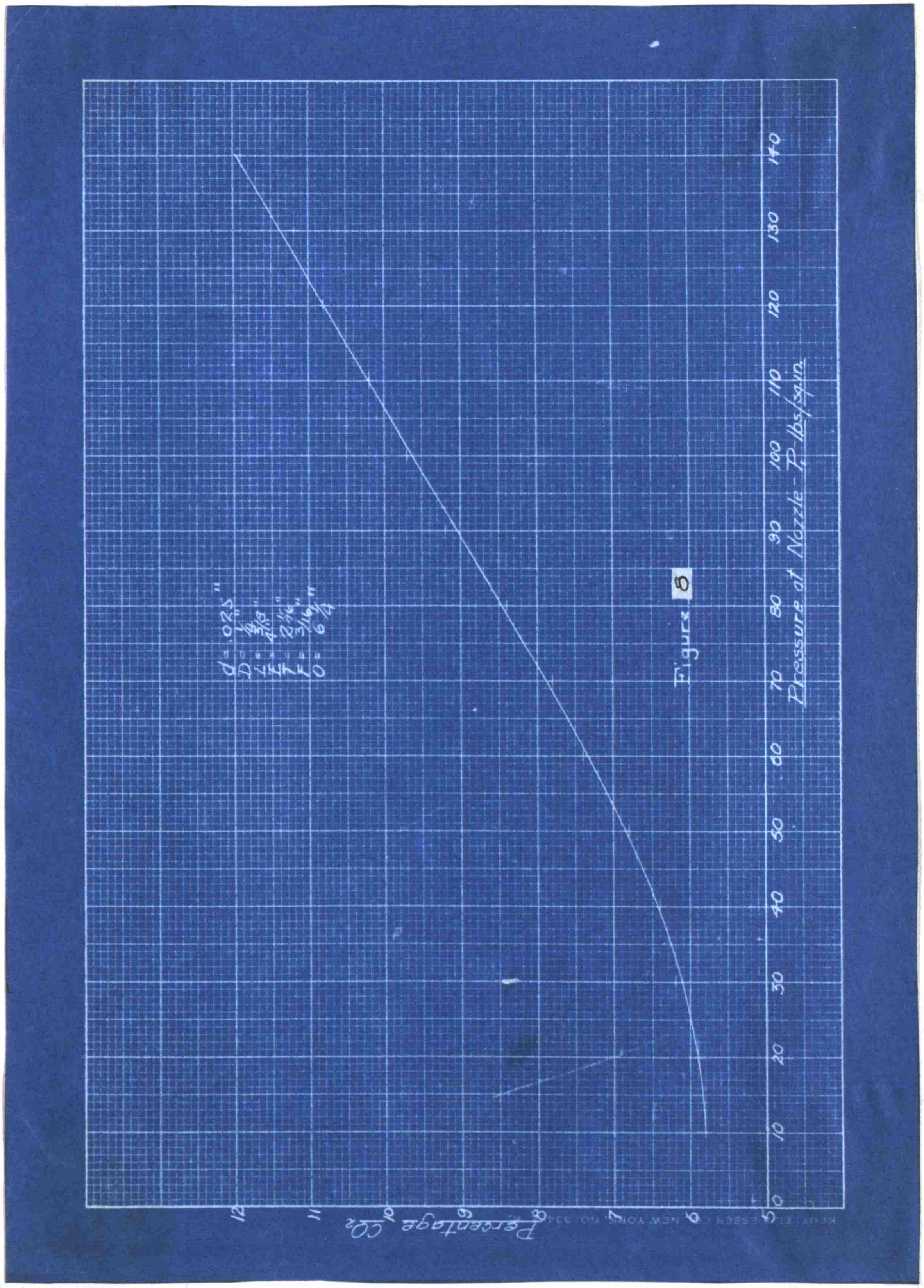
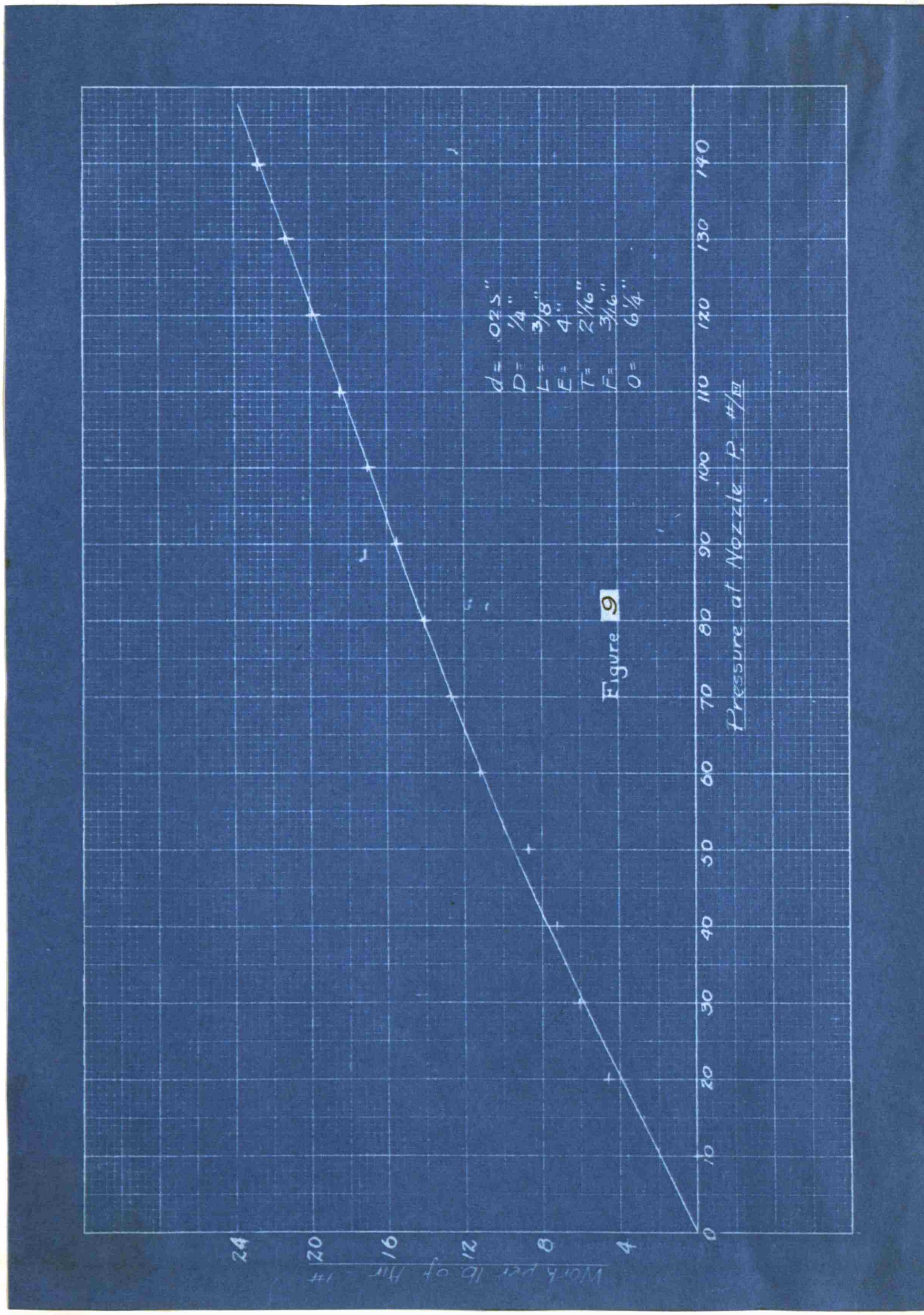


Figure 8
Pressure at Nozzle - P. lbs/sq.in.
Percentage CO_2
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
5
6
7
8
9
10
11
12
d = .025"
D = 1/8"
KEUFFEL & ESSER CO. NEW YORK NO. 334



d = .025"
D = 1/4"
L = 3/8"
E = 4"
T = 2 1/16"
F = 3/16"
O = 6 1/4"
Pressure at Nozzle p #/□"
0 10 20 30 40 50 60 70 80 90 100 110 120 130 140
Work per lb of Air - 1#
4 8 12 16 20 24

Figure 9

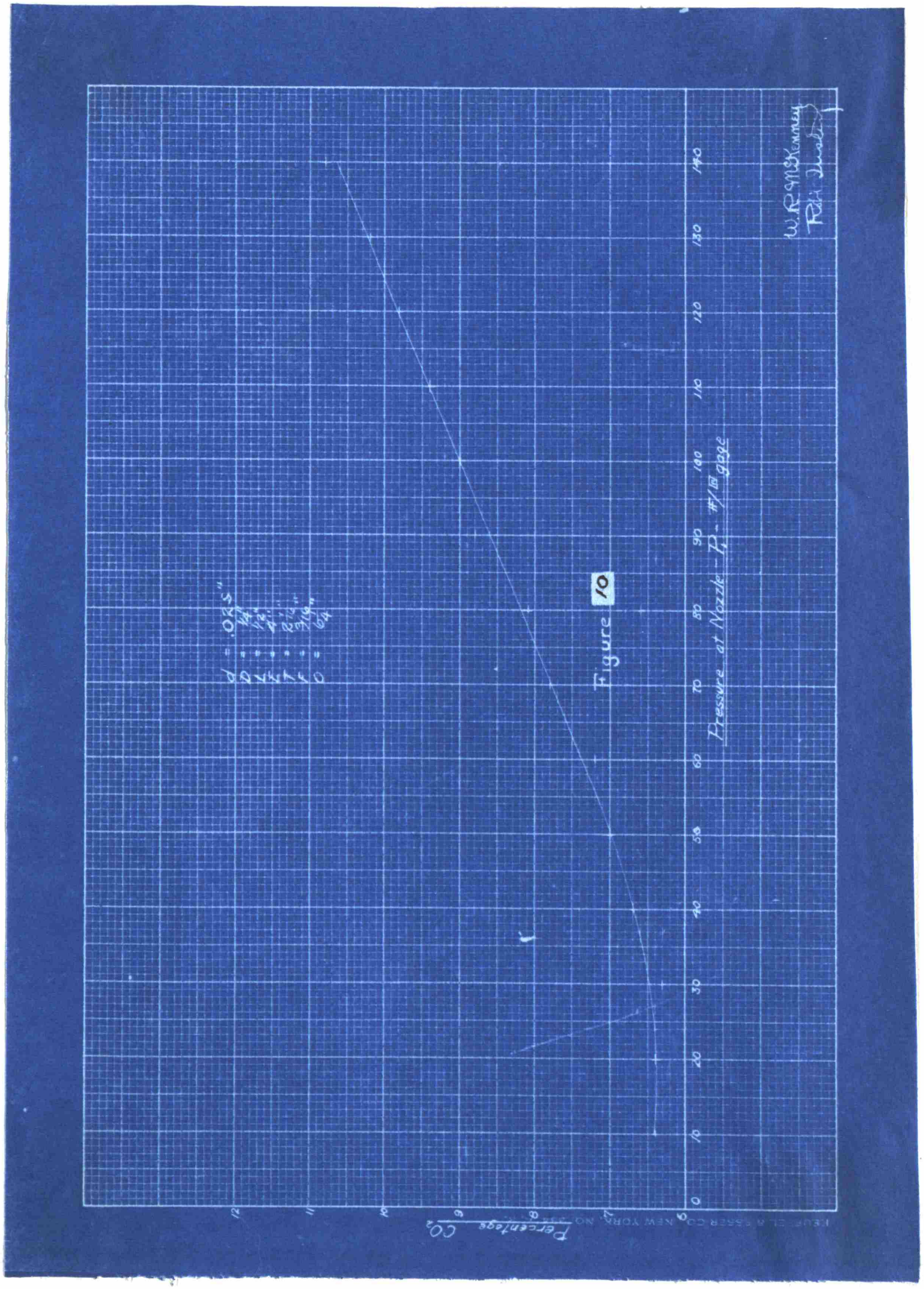
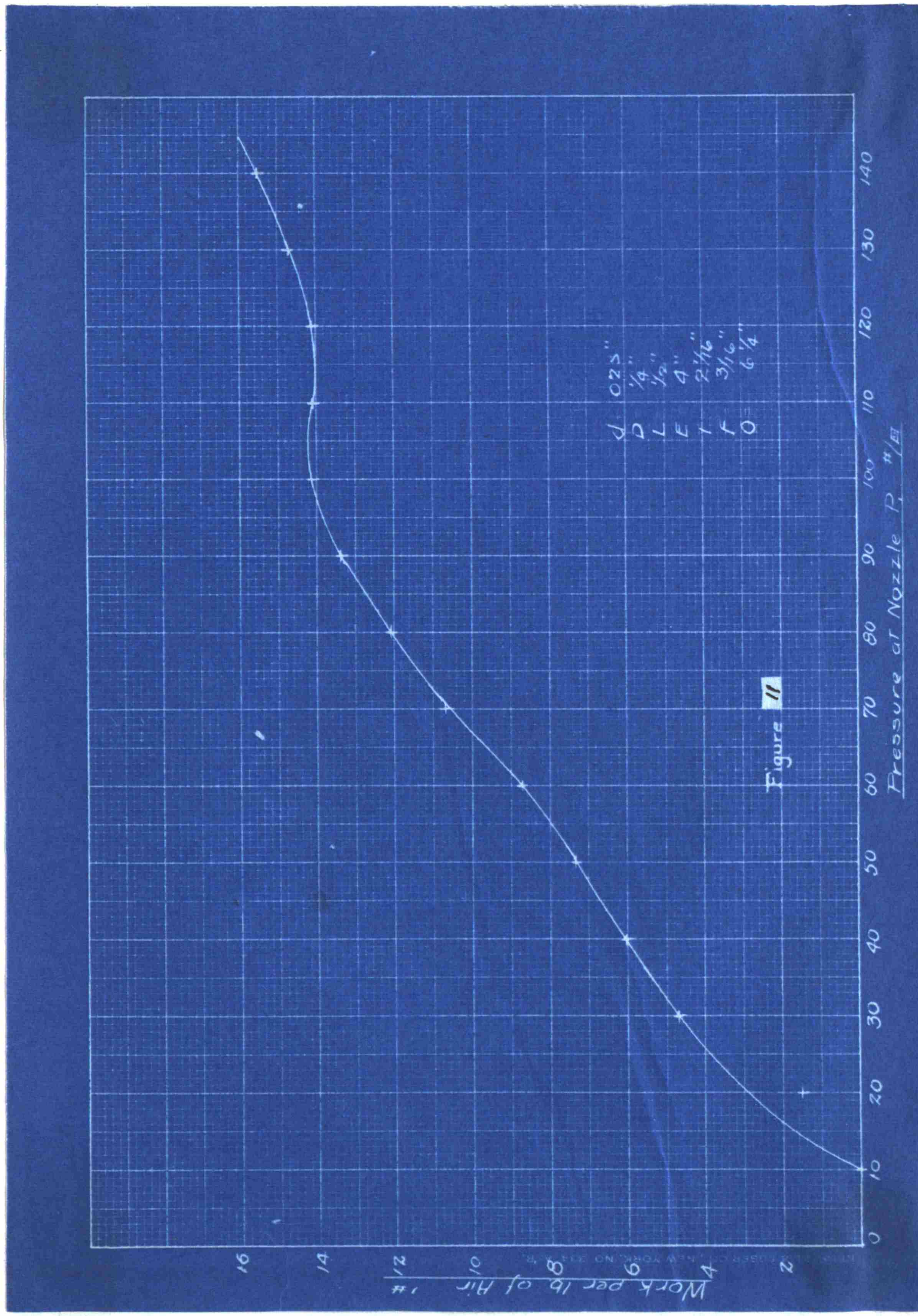


Figure 10
Pressure at Nozzle - P1 - #/□" gage
Percentage CO2
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
6
7
8
9
10
11
12


Pressure at Nozzle P, #/□"
Work per lb of Air '#
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
2
4
6
8
10
12
14
16
d .025"
D 1/4"
L 1/2"
E 4"
l 2 1/16"
f 3/16"
O 6 1/4"
Figure 11

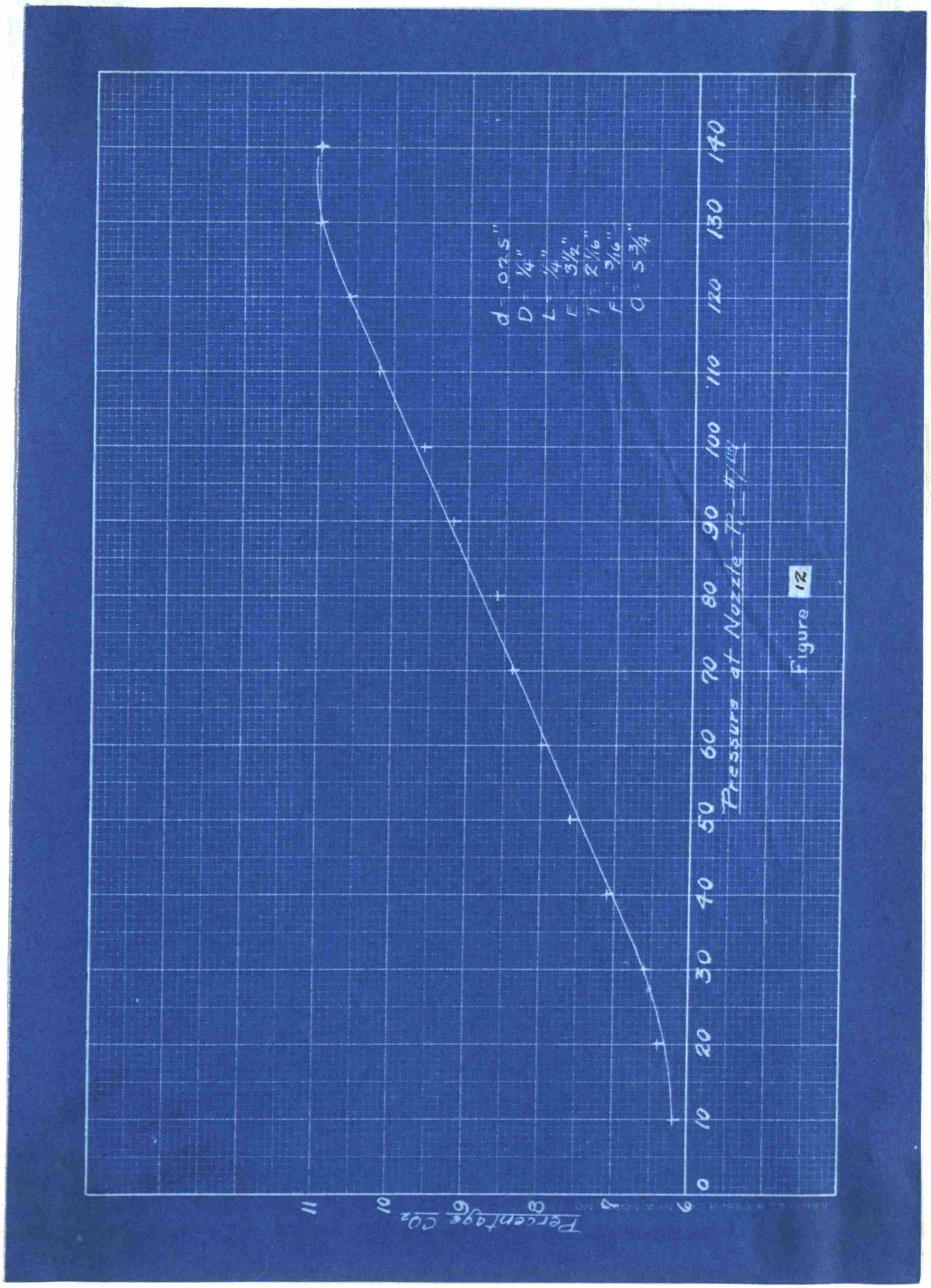

Percentage CO_2
6
7
8
9
10
11
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure at Nozzle
d - .025"
D - 1/4"
L - 1/4"
E - 3 1/2"
T - 2 1/16"
F - 3/16"
O - 5 3/4"

Figure 12

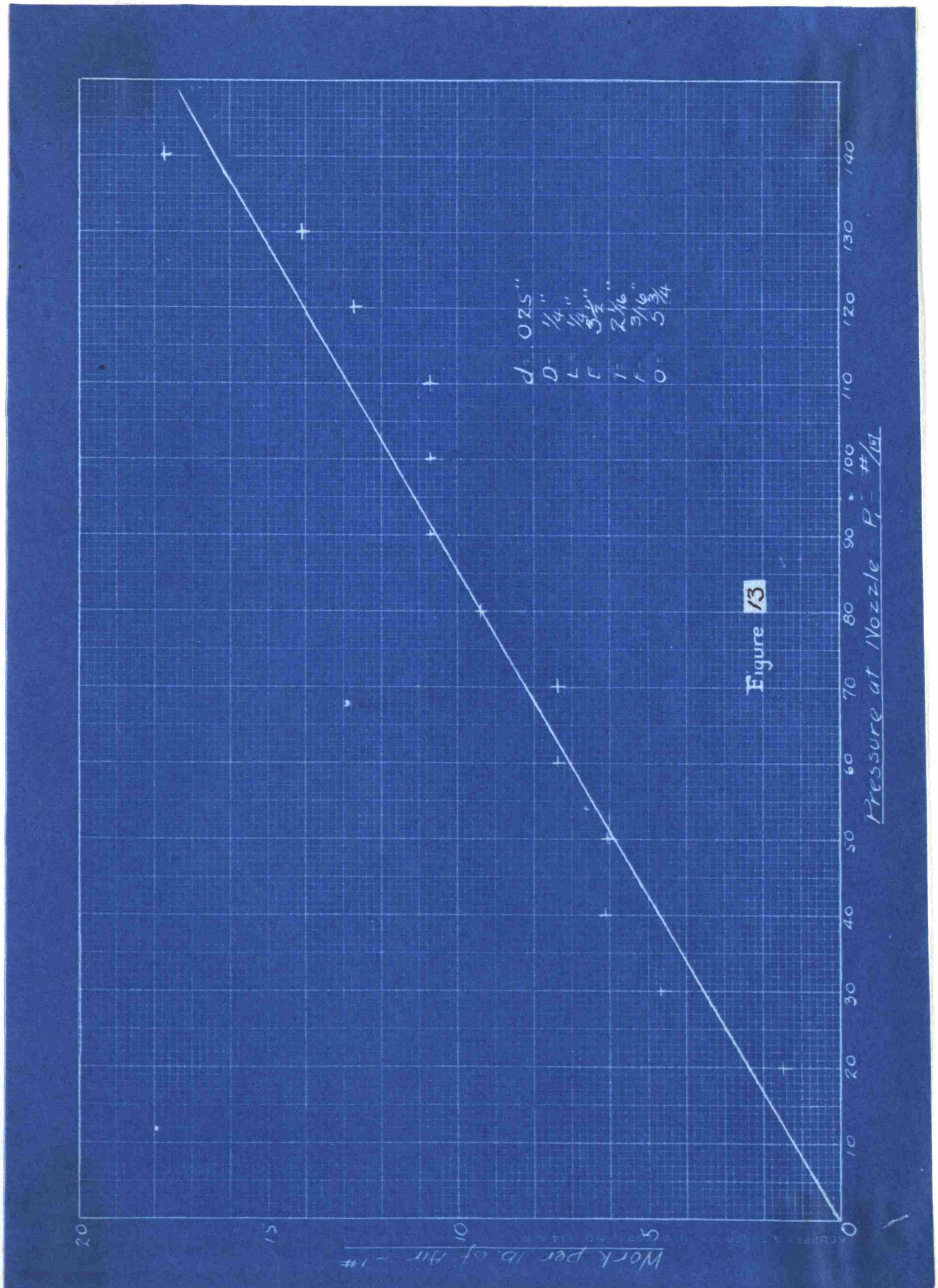

Pressure at Nozzle
Work per lb. of Air
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
5
10
15
20

Figure 13

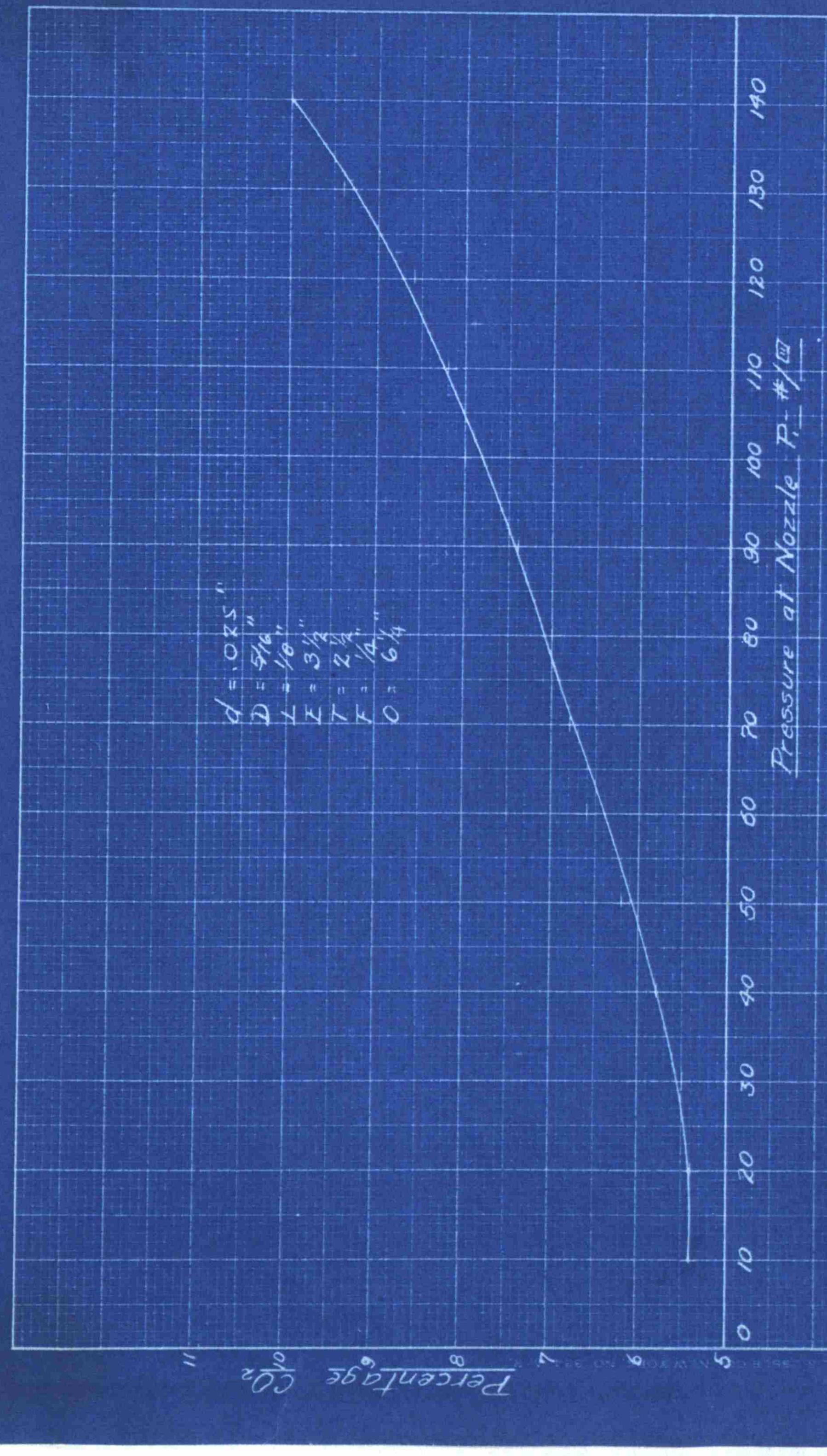
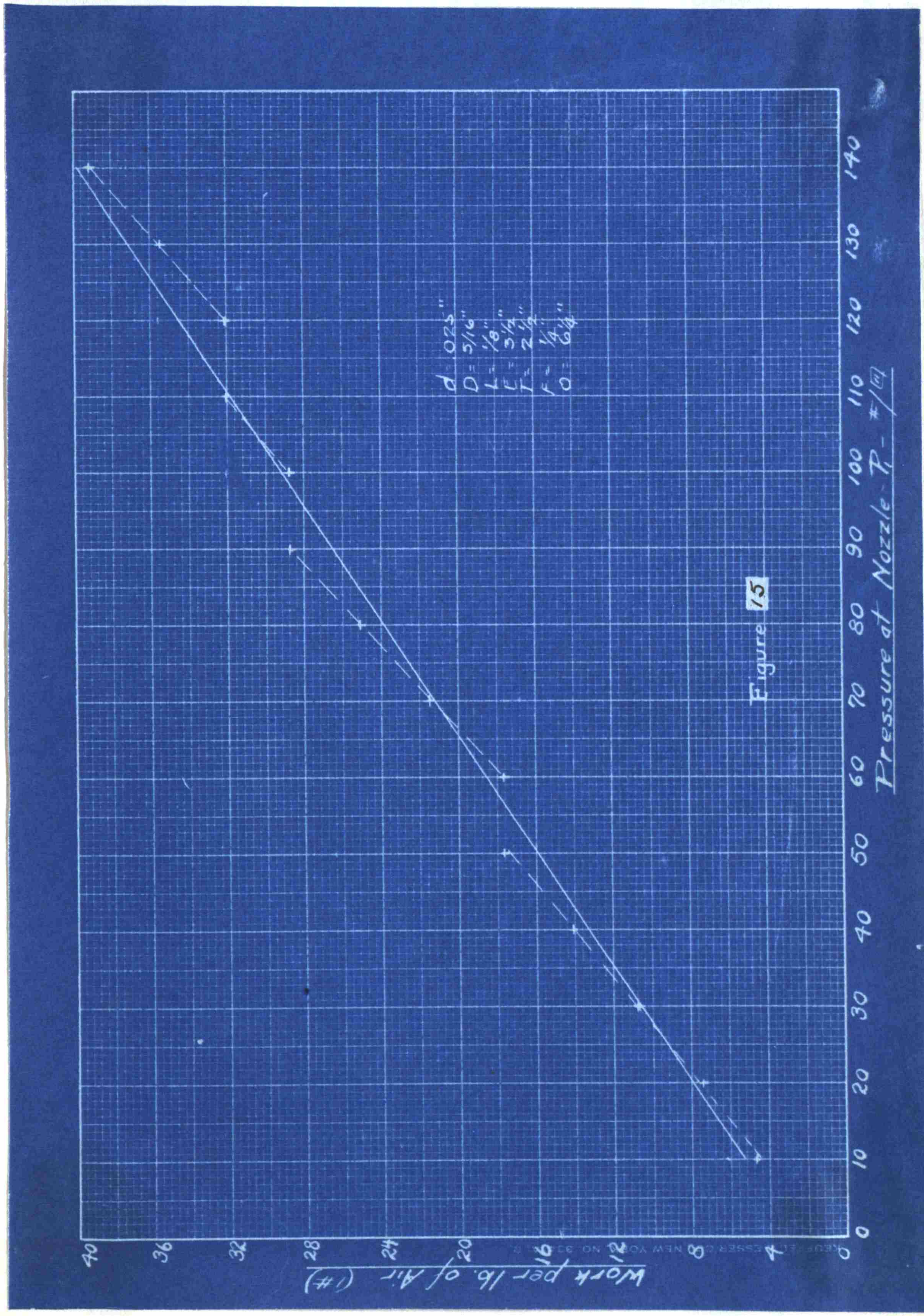
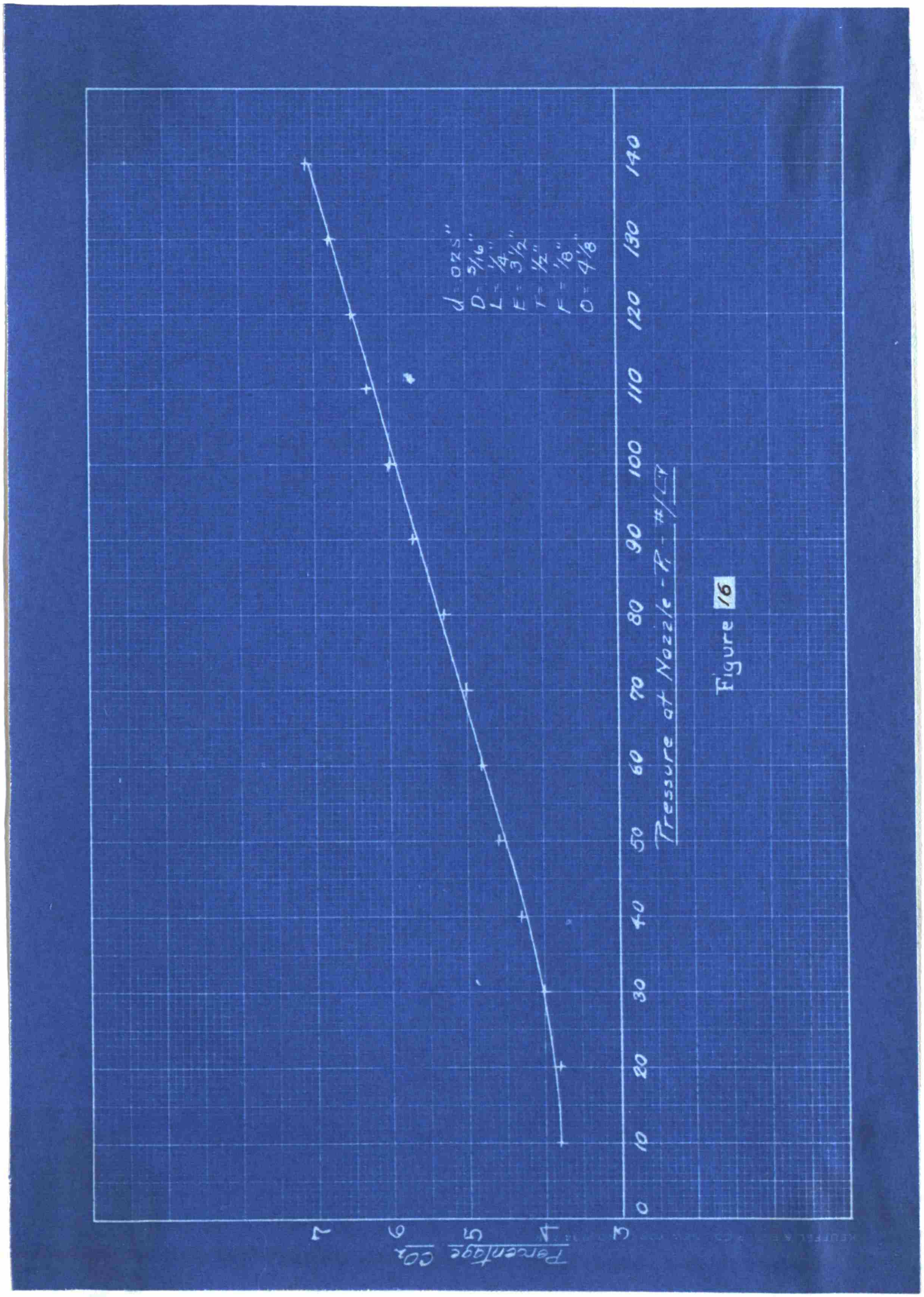

d = .025"
D = 5/16"
L = 1/8"
E = 3 1/2"
T = 2 1/2"
F = 1/4"
O = 6 1/4
Pressure at Nozzle P_1 - #/□"
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Percentage CO_2
5
6
7
8
9
10
11

Figure 14


d = .023"
D = 5/16"
L = 1/8"
E = 3 1/4"
T = 2 1/2"
F = 1/4"
O = 6 1/4"
Figure 15
Pressure at Nozzle P₁ - #/□"
Work per lb. of Air (#)
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
4
8
12
16
20
24
28
32
36
40



d = .025"
D = 5/16"
L = 1/4"
E = 3 1/2"
T = 1/2"
F = 1/8"
O = 4 1/8"
Pressure at Nozzle - P - #/□"
Percentage CO_2
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
3
4
5
6
7

Figure 16

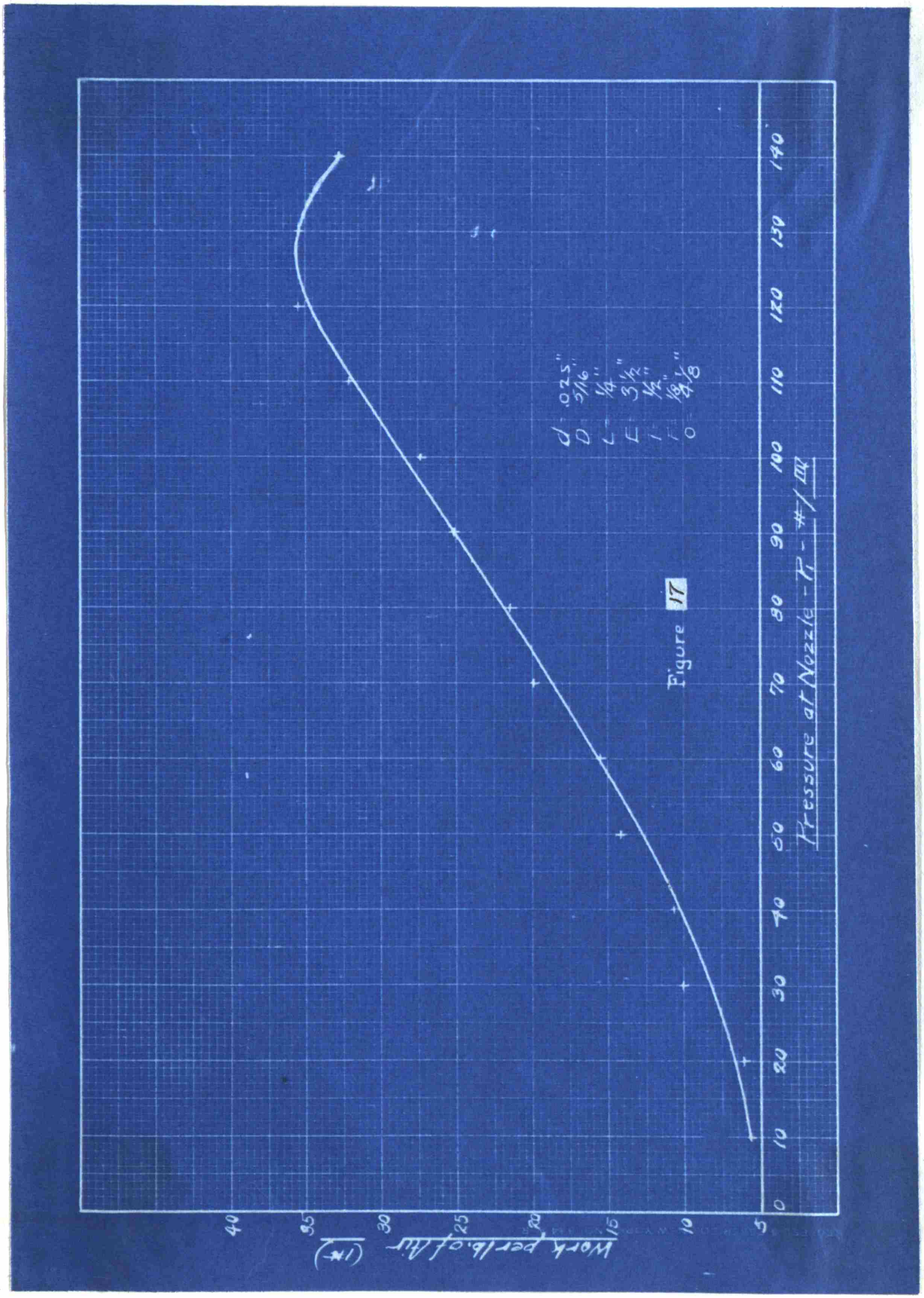


Figure 17
Pressure at Nozzle
Work per lb. of Air
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
5
10
15
20
25
30
35
40

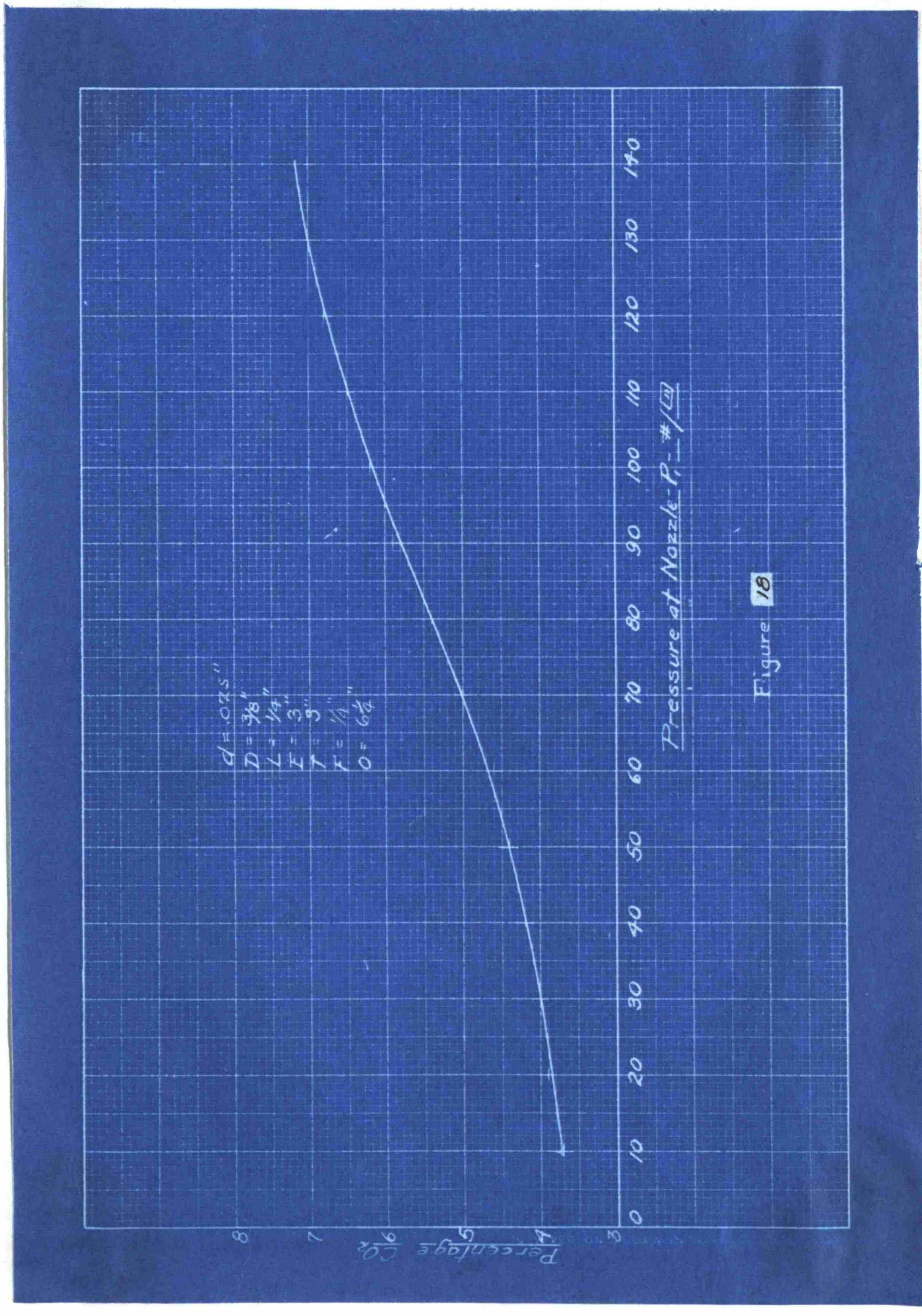

d = .075"
D = 3/8"
L = 1/4"
E = 3"
T = 3"
F = 1/16"
O = 6 1/4"
Percentage CO2
Pressure at Nozzle - P1 - #/□"
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
3
4
5
6
7
8

Figure 18

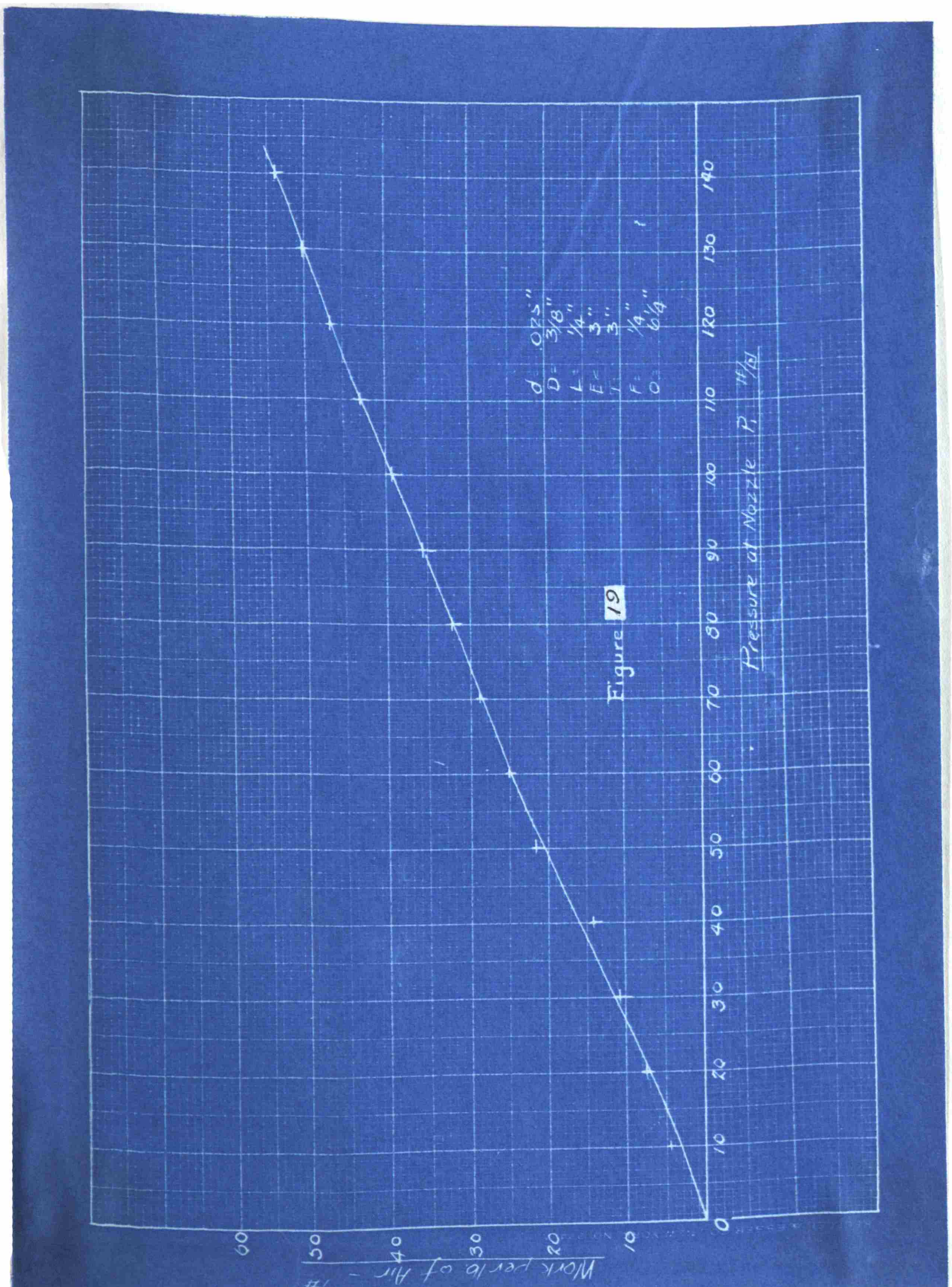


Figure 19
d = .025"
D = 3/8"
L = 1/4"
E = 3"
l = 3"
F = 1/4"
O = 6 1/4"
Pressure at Nozzle P₁ #/□"
Work per lb of Air - ft#
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140

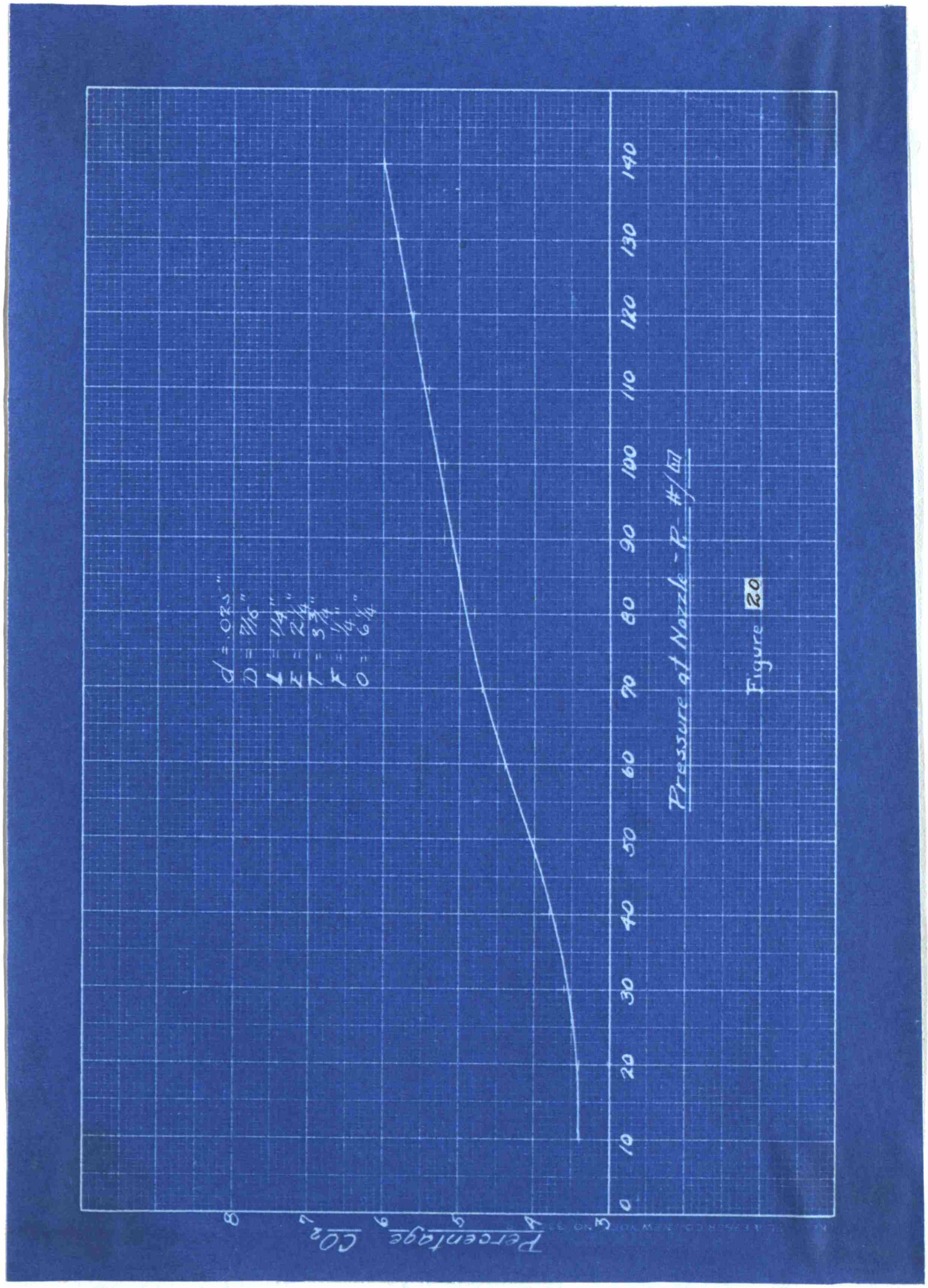

d = .025"
D = 7/16"
Percentage CO2
3
4
5
6
7
8
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
Pressure at Nozzle - P - #/□"

Figure 20

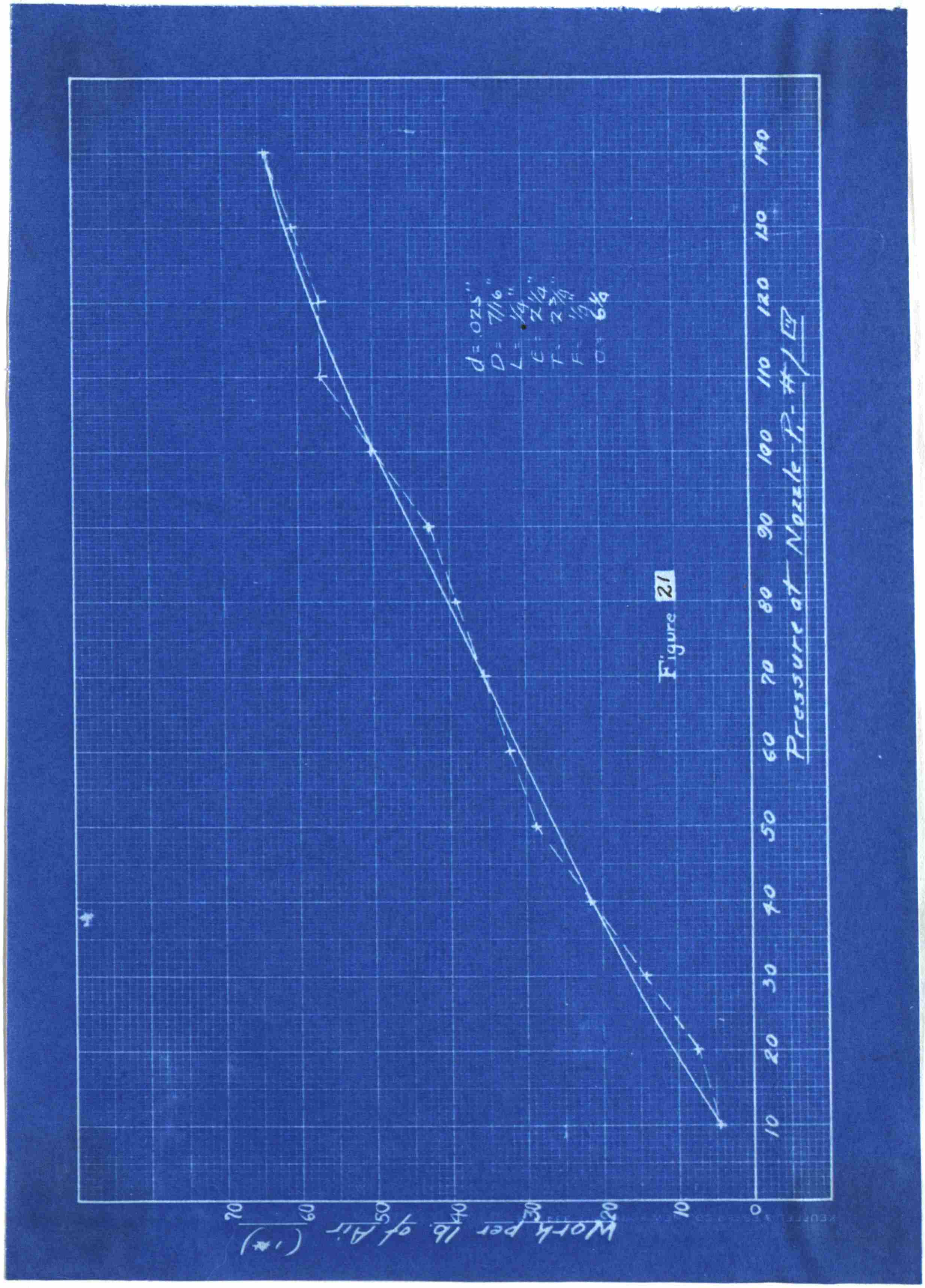
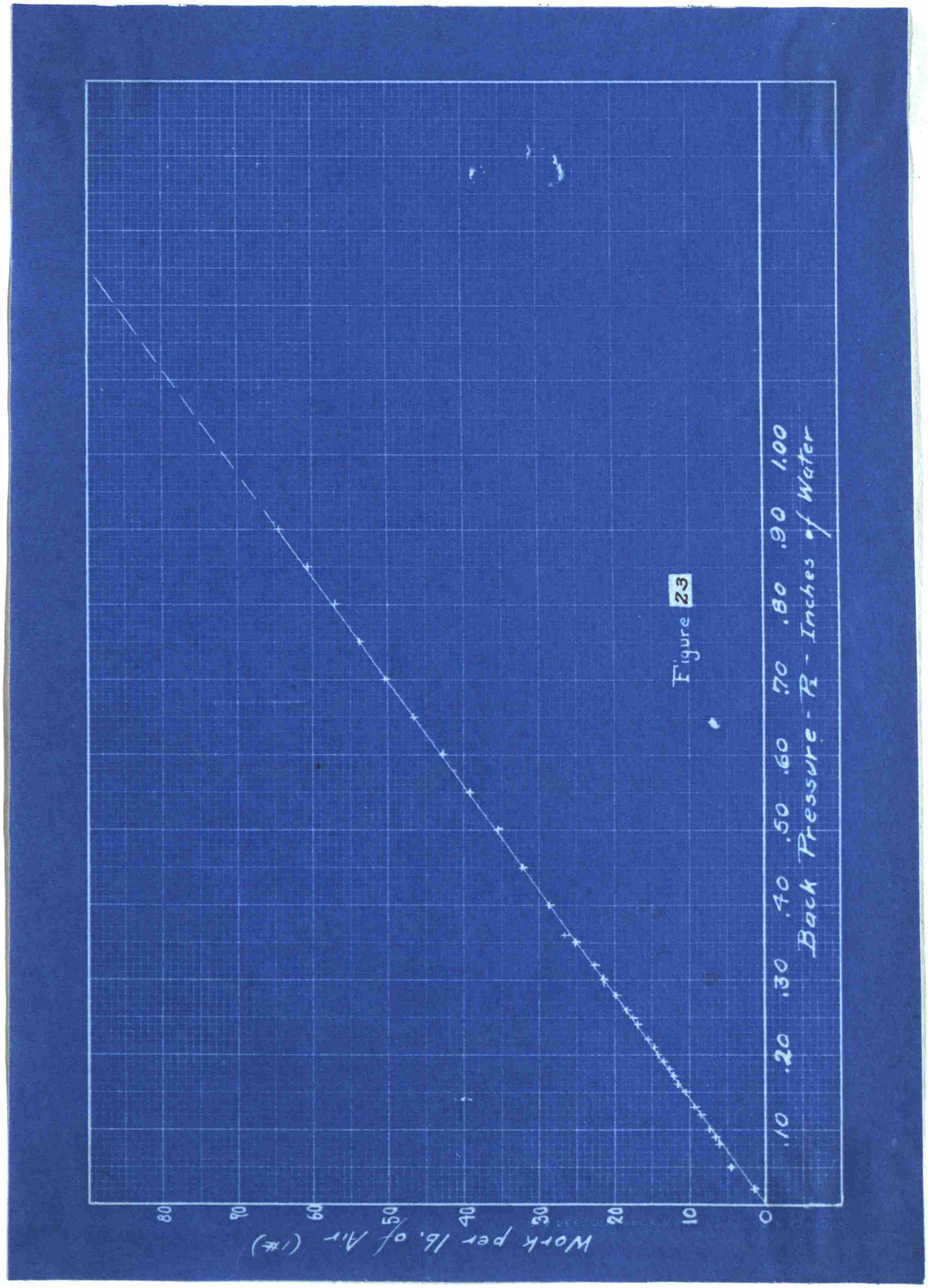
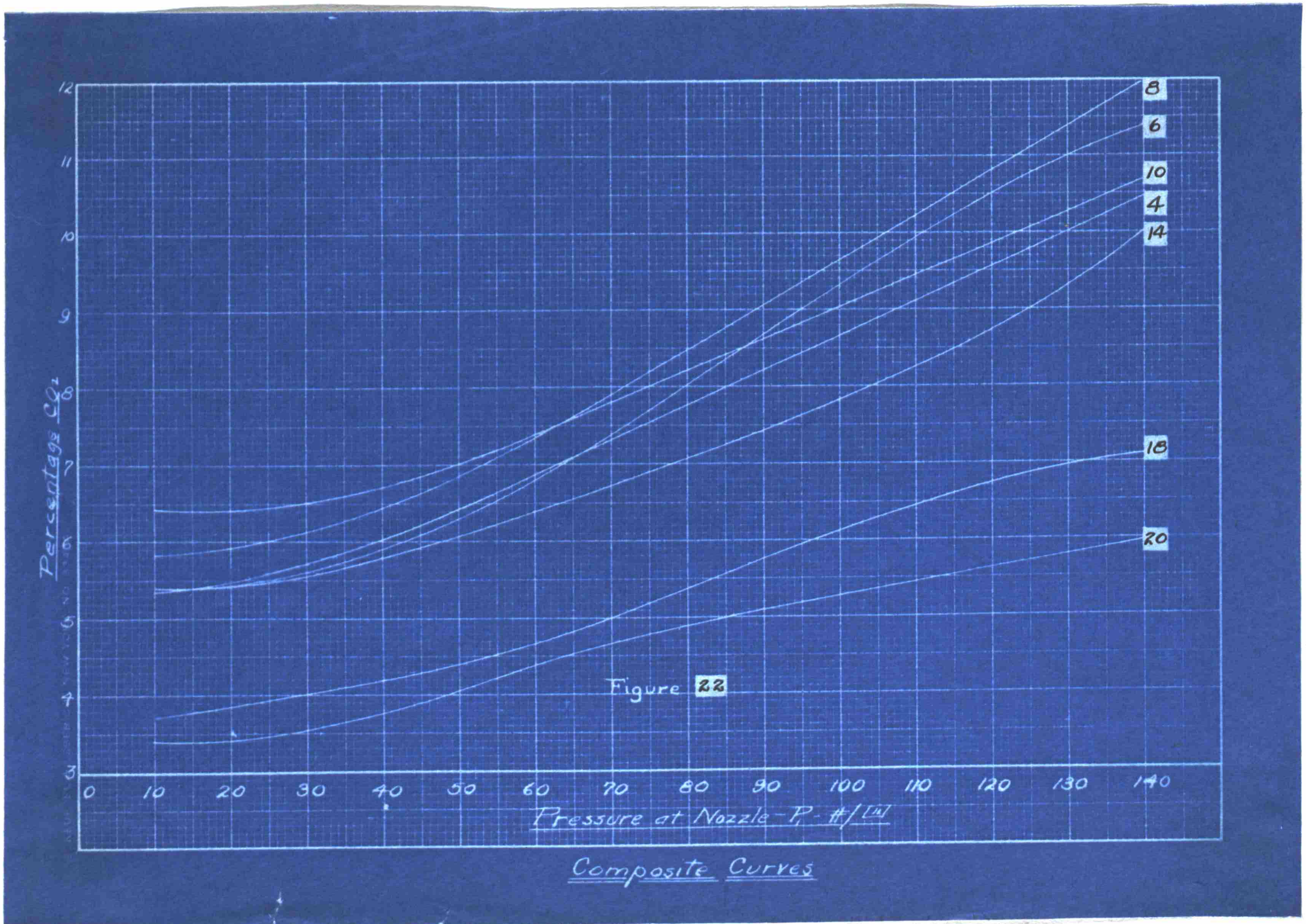


Figure 21
Pressure at Nozzle - P1 - #/□"
Work per lb. of Air
10
20
30
40
50
60
70
80
90
100
110
120
130
140
0
10
20
30
40
50
60
70


0
10
20
30
40
50
60
70
80
.10
.20
.30
.40
.50
.60
.70
.80
.90
1.00
Back Pressure - P1 - Inches of Water
Work per lb. of Air
Figure 23



Numbers on curves refer to figure numbers of curves