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**THE EFFECT OF WATER INJECTION
ON THE INDICATOR CARD**

**ROBERT F. WADSWORTH
NED GARRETT
MAYO M. FITZHUGH, JR.**

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THE EFFECT OF WATER INJECTION
ON THE INDICATOR CARD

by

Lieutenant Commander Robert F. Wadsworth, U.S.N.
Lieutenant Commander Ned Garrett, U.S.N.
Lieutenant Mayo M. FitzHugh, Jr., U.S.N.

Submitted in Partial Fulfillment of
the Requirements for the Degree of
Master of Science
in
Aeronautical Engineering
from the
Massachusetts Institute of Technology
1947

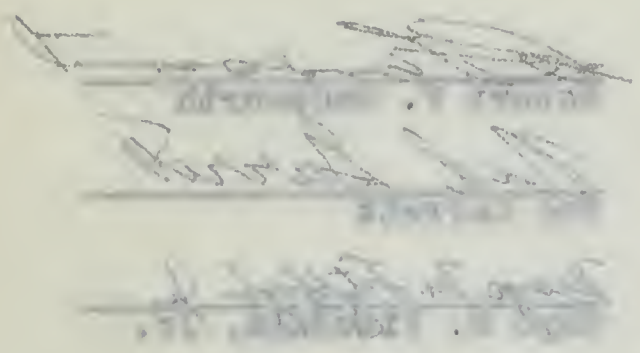
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Thesis
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Submitted in partial fulfillment of
the requirements for the degree of
Master of Science
in
Mathematical Engineering
The
Massachusetts Institute of Technology
1917



Signature of author:

Department of Mathematical Engineering, MIT, 1917.

Signature of instructor in charge
of research:

Signature of Chairman of Department
Committee on Graduate Studies:

Cambridge, Massachusetts,
23 May 1947.

Professor Joseph S. Newell,
Secretary of the Faculty,
Massachusetts Institute of Technology,
Cambridge, Massachusetts.

Dear Sir:

A thesis entitled "The Effect of Water Injection
on the Indicator Card" is herewith submitted in partial
fulfillment of the requirements for the degree of Master
of Science in Aeronautical Engineering.

Washington, D.C.
July 1957

Dr. J. Edgar Hoover,
Director,
Federal Bureau of Investigation,
Washington, D.C.

Dear Sir:

I have the honor to acknowledge the receipt of your letter of July 10, 1957, in which you advised that you had received a copy of the report of the Commission on the Assassination of President Kennedy, dated July 10, 1957, and that you had forwarded a copy of the same to the Bureau of Investigation.

Sincerely,
[Signature]

[Signature]
[Signature]
[Signature]

ACKNOWLEDGMENT

The authors wish to express their appreciation of the assistance rendered by Professor C. F. Taylor, Associate Professor A. R. Rogowski, Assistant Professor P. M. Ku, Assistant Professor W. A. Leary, Mr. J. C. Livengood, Mr. C. H. Kano, and Mr. J. L. Fardy.

CONFIDENTIAL

The subject was born [redacted] at [redacted] and is now residing at [redacted].
The subject was employed by [redacted] from [redacted] to [redacted].
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SUMMARY

This investigation was made to determine the effects of manifold water injection on the indicator diagrams and from these diagrams to calculate engine performance.

In carrying out this study, four runs were made. The first three were made at inlet pressures of 31", 20" and 45" of mercury and with a constant spark advance set for best power with no water injected, all other conditions being held constant. From these runs it was determined that the indicated mean effective pressure and the volumetric efficiency decreased with an increase in water rate, while the indicated efficiency remained substantially constant up to the point where the engine commenced to miss. With an increase in inlet pressure it was possible to inject more water before the engine misfired.

The fourth run was made at an inlet pressure of 31" of mercury but with the spark set at best power for each water rate used. From this run it was found that because of partial elimination of time losses, the indicated mean effective pressure decreased with an increase in water rate but not as much as in previous runs, while the indicated efficiency showed a slight increase. The volumetric efficiency dropped the same as in the previous run because the inlet conditions were not changed.

RESULTS

This investigation was made to determine the effects of various concentrations of sodium chloride on the growth of *Staphylococcus aureus* in a nutrient broth medium. The results are shown in the following table.

In carrying out this study, four different concentrations of sodium chloride were used, namely, 0%, 2%, 4%, and 8%. The 0% concentration was the control, and the other three were experimental. The results are shown in the following table.

The indicated results show that the growth of *Staphylococcus aureus* is inhibited by the addition of sodium chloride to the medium. The inhibition is more pronounced at higher concentrations of sodium chloride.

It is concluded that the growth of *Staphylococcus aureus* is inhibited by the addition of sodium chloride to the medium. The inhibition is more pronounced at higher concentrations of sodium chloride.

The results of this study are shown in the following table. The growth of *Staphylococcus aureus* is inhibited by the addition of sodium chloride to the medium. The inhibition is more pronounced at higher concentrations of sodium chloride.

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INTRODUCTION

The demand for higher engine outputs, greater than those allowable from detonation limited engines, has led to much investigation of the effect of water injection on detonation suppression and on overall engine performance. Most of these investigations have centered on the effect of water on detonation, and on the allowable increase in power which can be drawn from the engine after the suppression of detonation.

The purpose of this investigation has been to examine the effect of manifold water injection on the indicator card, and by use of data obtained from the indicator card to evaluate the indicated performance of the internal combustion engine. While much published data on water injection effects are available, very few experiments relating the effects of water injection to the indicator card have been conducted.

This study was conducted in the Sloan Automotive Laboratory at Massachusetts Institute of Technology by Lieut. Comdr. R. F. Wadsworth, U.S.N., Lieut. Comdr. N. Garrett, U.S.N., and Lieut. M. M. FitzHugh, U.S.N. Professor W. A. Leary, of the M.I.T. staff, was supervisor.

INTRODUCTION

The purpose of this investigation has been to examine the effect of limited water intake on the individual's ability to perform his normal work. It is well known that the body is able to function for a limited period of time without water, but the exact limits of this ability are not known. This study was designed to determine the effect of limited water intake on the individual's ability to perform his normal work.

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This study was conducted in the Department of Physiology at the University of California, Los Angeles. The subjects were ten young men, aged 20 to 30, who were in good health and had no known medical conditions. They were divided into two groups of five. One group was given unlimited water to drink, and the other group was given a limited amount of water to drink. The results of the study are presented in the following tables.

DESCRIPTION OF APPARATUS

The test equipment included: A Coordinating Fuel Research (CFR) engine delivering power to a dynamometer; a high speed MIT engine indicator and MIT diagram converter; an American Bosch fuel injector pump for water injection; and instruments for measuring air, fuel, water and engine speed. Fuel was vaporized in a heated vaporization tank; water was injected by a Bendix injection nozzle into the intake manifold. A schematic diagram of the engine set-up is shown in Fig. 1.

Engine

A standard 4-cycle one-cylinder CFR engine No. 469373 made by Waukesha Motor Co. was used. The bore was 3.25 in. in diameter, the stroke 4.50 in. and the displacement 37.33 cubic in. The compression ratio could be varied from 4 to 10 but was set for 6.63 for this investigation. The standard CFR engine is fully described in the CFR Handbook, 1944 edition (reference 1).

Dynamometer

A 5-hp motor-generator set made by the Star Electric Motor Co. was used as a motor to turn over the CFR engine for starting and motoring and as a generator to absorb the power delivered while the engine was firing.

Introduction

The first objective of this study is to determine the effect of the proposed changes on the overall performance of the system. The second objective is to identify the areas where the most significant improvements can be made. The third objective is to develop a plan of action to address these areas. The fourth objective is to monitor the progress of the implementation and make adjustments as needed. The fifth objective is to evaluate the results of the implementation and determine if the objectives have been met.

Background

The current system has been in operation for several years and has shown a steady decline in performance. This decline is due to a number of factors, including increasing data volume, aging hardware, and inefficient software. The proposed changes are designed to address these issues and improve the system's performance. The changes include upgrading the hardware, optimizing the software, and implementing new data management techniques. The expected results of these changes are a 20% increase in system throughput, a 15% reduction in error rates, and a 10% decrease in maintenance costs.

Methodology

The methodology used in this study is a combination of qualitative and quantitative methods. Qualitative methods include interviews with system users and experts, and focus groups. Quantitative methods include performance testing, data analysis, and cost-benefit analysis. The data collected from these methods will be used to evaluate the impact of the proposed changes and to develop a plan of action.

MIT Indicator

The high speed indicator is shown schematically in Figs. 4 and 5. A description of this instrument is included in references 2 and 8.

Converter

The diagram converter was merely a linkage device to convert the pressure versus crank angle diagram of high speed indicator to a pressure versus volume diagram.

Water Injection

The American Bosch fuel injection pump was used to inject water and was mounted on the half time shaft of the engine. Distilled water flowed by gravity from a two gallon tank into a water rotometer and then into the suction side of the pump. The pump also had a built-in surge tank and a centrifugal booster pump which gave a very smooth flow reading. A lock screw adjustment was used to give very fine control of water rate. A Standard Bendix (No. 135026, Serial 42) fuel injection nozzle was used for water injection into the manifold. The nozzle was set to open at 500 lbs. per sq. in. at which a fine spray in a 45 degree cone was attained.

Fuel System

The gasoline used in this experiment was standard 100 octane leaded aviation gasoline. This gasoline was taken from the mains of the Sloan lab-

THE ENGINE

The engine is a four cylinder, four stroke, petrol engine of 1000 cc capacity. It is fitted with a carburettor and a water pump. The engine is mounted on a cast iron base.

THE TRANSMISSION

The transmission is a manual gearbox with four forward gears and one reverse gear. It is fitted with a clutch and a handbrake. The gearbox is mounted on a cast iron base.

THE AXLES

The front axle is a rigid axle with a coil spring suspension. The rear axle is a semi-rigid axle with a leaf spring suspension. The axles are fitted with 12 inch diameter wheels and 1.5 inch wide tyres.

The steering is a rack and pinion type. The front suspension is a coil spring type. The rear suspension is a leaf spring type. The vehicle is fitted with a steering wheel and a gear shift lever.

THE BODY

The body is a simple, box-like structure. It is fitted with a front windscreen and side windows. The body is supported by a chassis.

oratory and passed through a fuel pump into a bubble separation tank, through the fuel rotometer and into the heated vaporizing tank. By a combination of two needle valves between the vaporizing tank and fuel rotometer accurate control of fuel flow was assured. A schematic diagram of the fuel system is shown in Fig. 7.

Detonation Detection

Detonation was detected by a Draper detonation pickup and a Dumont oscillograph No. 722. This equipment was only used to test for detonation at high manifold pressures. Most of the runs in this investigation were made below the incipient detonation level.

Air System

Air to the vaporizing tank was taken either from the laboratory high pressure main or from the test room at atmospheric pressure. A Worthington air compressor, driven by a 75 hp Wagner Electric Motor, supplied the high pressure air. When the air was drawn from the high pressure main, it was led to a regulator and a regulator valve through a .515 inch calibrated orifice into a surge tank through a throttle valve, a check valve, and into the vaporizing tank as shown in Fig. 1.

Speed Control

Speed control was measured with a tachometer supplemented by a strobotac for finer adjustments. A drop wire rheostat in the shunt field of the dynamometer was employed for speed control.

Ignition

The ignition wiring diagram is shown in Fig. 6.

General Remarks

The country was visited with a purpose
by the author in the year 1880.
It was found that the land was
very fertile and well adapted for
agriculture.

Location

The location of the place is
very good.

The climate is very pleasant
and the soil is very fertile.
The water is very pure and
the air is very fresh.
The people are very friendly
and the customs are very
interesting. The place is
very well situated for
commerce and industry.
The government is very
efficient and the laws are
very well enforced. The
education is very good and
the people are very intelligent.
The place is very well
governed and the people are
very happy. The place is
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The place is very well
governed and the people are
very happy.

PRELIMINARY PROCEDURE

Prior to commencement of this experiment, it was necessary to spend considerable time in testing and connecting up the apparatus as shown in Fig. 1. In order to simulate aircraft sea level operating conditions, it was decided to use 100 octane fuel, a fixed compression ratio, and water injection into the manifold.

A special manifold was designed, as shown in Fig. 3. The nozzle was aimed as close as practicable toward the inlet valve. Two thermometers were placed in this manifold. One was mounted before the nozzle, and one between the nozzle, and the inlet valve. The thermometer located after the nozzle was shielded to keep the water spray off the mercury bulb.

It was also necessary to calibrate the fuel and water rotometers for at least two different room temperatures 10 degrees apart so that interpolations could be made in between the curves at various temperatures. The method of calibration in every case consisted essentially of weighing the amount of liquid which passed through the rotometer in a measured interval of time, during which the rotometer setting was maintained at a constant level. Calibration curves were made from the data of tables I and II and plotted in Figs. 8 and 9. After completion of the final runs, the water rotometer was recalibrated with the engine

EXPERIMENTAL PROCEDURE

Type of measurement of the material. It was necessary to have a certain amount of the material in the form of a powder. The apparatus used for this purpose is shown in Fig. 1. The material was placed in a special container and the weight of the material was measured. The material was then placed in a special container and the weight of the material was measured. The material was then placed in a special container and the weight of the material was measured.

A special method was designed, as shown in Fig. 2. The results were shown as a plot of the material weight in grams versus the material weight in grams. The material was then placed in a special container and the weight of the material was measured. The material was then placed in a special container and the weight of the material was measured. The material was then placed in a special container and the weight of the material was measured.

It was also necessary to measure the material weight. The material was then placed in a special container and the weight of the material was measured. The material was then placed in a special container and the weight of the material was measured. The material was then placed in a special container and the weight of the material was measured. The material was then placed in a special container and the weight of the material was measured. The material was then placed in a special container and the weight of the material was measured.

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running at normal operating temperatures so that all water readings taken during the runs were within one degree of the calibrated temperature.

The air induction system was tested for leaks at 48 inches of mercury and checked until there was less than .4 inches per minute pressure drop. Computations showed this leakage to be well below one percent of the air used by the engine.

At first, it was thought that water injection timing would have little effect because it was injected into the manifold. The inlet valve opened at 14 degrees after top center and closed 234 degrees after top center. For the runs for which data is presented, the injector nozzle started injection at 36 degrees after top center and completed injection 79 degrees after top center for the high water rates. This allowed 155 degrees for the water to mix with the charge and to insure that all the water would be taken into the cylinder on each stroke. Several runs were made with the injection timed 360 degrees from this, that is, allowing the water to accumulate in the manifold near the intake valve while the intake was closed. Little or no differences were noted in the indicator card for the two timing conditions. A valve timing diagram is shown in Figure 2.

Due to the shape of the shrouded inlet valve, the spark plug was shifted on the opposite side of the cylinder from the normal position to prevent the water from

measured at several operating temperatures so that all water readings taken during the tests were within one degree of the indicated temperature.

The air handling system was tested for load at 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, 2200, 2300, 2400, 2500, 2600, 2700, 2800, 2900, 3000, 3100, 3200, 3300, 3400, 3500, 3600, 3700, 3800, 3900, 4000, 4100, 4200, 4300, 4400, 4500, 4600, 4700, 4800, 4900, 5000, 5100, 5200, 5300, 5400, 5500, 5600, 5700, 5800, 5900, 6000, 6100, 6200, 6300, 6400, 6500, 6600, 6700, 6800, 6900, 7000, 7100, 7200, 7300, 7400, 7500, 7600, 7700, 7800, 7900, 8000, 8100, 8200, 8300, 8400, 8500, 8600, 8700, 8800, 8900, 9000, 9100, 9200, 9300, 9400, 9500, 9600, 9700, 9800, 9900, 10000.

At first, it was thought that water injection into the engine would have little effect because it was believed that the water would evaporate as it entered the combustion chamber and thus reduce the engine temperature. However, the injection of water into the engine has been found to increase the engine temperature and to increase the engine output. This is due to the fact that the water injected into the engine is heated by the combustion products and thus increases the temperature of the combustion products. This increase in temperature results in a higher density of the combustion products and thus a higher output from the engine.

Several tests were run with the injection of water into the engine at various rates and at various temperatures. The results of these tests are shown in Figure 1. It is seen that the injection of water into the engine results in a higher engine temperature and a higher engine output. This is due to the fact that the water injected into the engine is heated by the combustion products and thus increases the temperature of the combustion products. This increase in temperature results in a higher density of the combustion products and thus a higher output from the engine.

For the purpose of the present study, the water injection system was tested at the following conditions: (1) 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200, 1300, 1400, 1500, 1600, 1700, 1800, 1900, 2000, 2100, 2200, 2300, 2400, 2500, 2600, 2700, 2800, 2900, 3000, 3100, 3200, 3300, 3400, 3500, 3600, 3700, 3800, 3900, 4000, 4100, 4200, 4300, 4400, 4500, 4600, 4700, 4800, 4900, 5000, 5100, 5200, 5300, 5400, 5500, 5600, 5700, 5800, 5900, 6000, 6100, 6200, 6300, 6400, 6500, 6600, 6700, 6800, 6900, 7000, 7100, 7200, 7300, 7400, 7500, 7600, 7700, 7800, 7900, 8000, 8100, 8200, 8300, 8400, 8500, 8600, 8700, 8800, 8900, 9000, 9100, 9200, 9300, 9400, 9500, 9600, 9700, 9800, 9900, 10000.

grounding out the plug. Runs were made, however, in both positions and practically no differences were observed in the indicator card for equal water rates. The engine stopped running at lower water rates in every case when the spark plug and shrouded inlet valve were placed in the designed operating condition.

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PROCEDURE

The following set of conditions was adopted as standard:

Inlet temperature - 160 degrees F (read at vaporizing tank before water injection nozzle)

Oil temperature - 150 degrees F

Jacket temperature - 212 degrees F

Engine speed - 1200 rpm

Fuel-air ratio - .0782

Compression ratio - 6.63

Exhaust pressure - 32" Hg.

Spark advance - Three sets of runs were made with best power spark advance set without water injection for each inlet pressure of 45", 31" and 20" Hg. One run was made with a variable spark advance, best power being set for each water/fuel ratio used for inlet pressure of 31" Hg.

A warm-up period of one and one-half hours was required as a daily routine prior to making recorded runs. At least twenty minutes were allowed to elapse between points for steady conditions. The engine was brought as near as possible to the standard temperatures by using steam to heat the oil tank and inlet air before starting. An electric air heater was used for finer control of inlet temperatures when necessary.

APPENDIX

The following are of conditions and results as

observed:

1.000	-	100	100
1.000	-	100	100
1.000	-	100	100
1.000	-	100	100
1.000	-	100	100
1.000	-	100	100
1.000	-	100	100
1.000	-	100	100

and the results of the experiments are as follows:

The first series of experiments was conducted at a pressure of 20" Hg. and a temperature of 20° C. The results of these experiments are as follows:

The second series of experiments was conducted at a pressure of 20" Hg. and a temperature of 40° C. The results of these experiments are as follows:

The third series of experiments was conducted at a pressure of 20" Hg. and a temperature of 60° C. The results of these experiments are as follows:

The fourth series of experiments was conducted at a pressure of 20" Hg. and a temperature of 80° C. The results of these experiments are as follows:

The fifth series of experiments was conducted at a pressure of 20" Hg. and a temperature of 100° C. The results of these experiments are as follows:

After steady operating conditions were attained, an indicator card was taken without water injection while all conditions were held constant. This was repeated for several water rates up to the point where the engine began to miss. These runs were made at inlet pressures of 45", 31" and 20" of mercury, the spark advance in each case being set for best power with no water and then being held constant for the remainder of the run. At 45" of mercury inlet pressure heavy detonation was encountered. After the first indicator card was taken with no water, the water rate was increased until only incipient detonation occurred. The remainder of this run was made in the same manner as the 31" and 20" of mercury inlet pressure runs.

After completion of the above runs, an additional run was made under the same conditions as the run made with an inlet pressure of 31" of mercury, except that the spark advance was adjusted to best power for each new water rate. It was found that the best power setting could be approximated by measuring the difference in degrees after top center between the pressure peaks of the indicator cards taken with no water and cards taken at successive water rates for the preceding run made at constant spark advance and at 31" of mercury inlet pressure. Finer adjustment was then made by noting with the strobotac any effect of small spark timing adjustment on the engine speed. It was found that in each case of varying water rate, the

After about twenty minutes were elapsed,
 an attempt was made to start the engine
 with all conditions were held constant. This was the
 second and second water taken up in the water tank
 the engine began to start. About two and a half
 minutes at 157, 117 and 207 at intervals, the water
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After completion of the first run, at 157
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best power spark advance occurred at a point which caused all the indicator cards of this run to peak at approximately the same number of degrees after top center as shown in Fig. 13.

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The following text is extremely faint and illegible. It appears to be a series of paragraphs or a list of items, but the content cannot be discerned.

PRESENTATION OF RESULTS

Results are presented in the form of diagrams and performance curves as follows:

Figures 10, 11, 12, and 13: Pressure versus crank-angle diagrams. Cards taken with the same inlet pressures are superimposed upon each other. The diagrams were traced directly from the cards obtained from the MIT High Speed Indicator. They show the effect of water injection into the intake manifold.

Figures 14, 15, 16, and 17: Pressure-volume diagrams presented in the same way as above. These diagrams were converted from the pressure versus crank-angle cards. This operation was perhaps the largest source of error.

Figure 18: Indicated mean effective pressure versus water/fuel ratio for different inlet pressures.

Figure 19: Indicated efficiency versus water/fuel ratio for different inlet pressures.

Figure 20: Volumetric efficiency versus water/fuel ratio for different inlet pressures.

Figure 21: Indicated mean effective pressure, efficiency, and volumetric efficiency versus water/fuel ratio for 31" of mercury inlet pressure with constant spark advance and with best power spark advance. These curves show the effect of partial elimination of time losses in the process.

Figure 22: Best power spark advance versus water/fuel ratio.

Figure 23: Rate of pressure rise versus water/fuel ratio for different inlet pressures.

EXPERIMENTAL RESULTS

The results of the experiment are shown in the following table:

TABLE I

TABLE I. Results of the experiment. The first column shows the number of trials, the second column shows the number of correct responses, and the third column shows the percentage of correct responses. The data are as follows:

TABLE II. Results of the experiment. The first column shows the number of trials, the second column shows the number of correct responses, and the third column shows the percentage of correct responses. The data are as follows:

TABLE III. Results of the experiment. The first column shows the number of trials, the second column shows the number of correct responses, and the third column shows the percentage of correct responses. The data are as follows:

TABLE IV. Results of the experiment. The first column shows the number of trials, the second column shows the number of correct responses, and the third column shows the percentage of correct responses. The data are as follows:

TABLE V. Results of the experiment. The first column shows the number of trials, the second column shows the number of correct responses, and the third column shows the percentage of correct responses. The data are as follows:

TABLE VI. Results of the experiment. The first column shows the number of trials, the second column shows the number of correct responses, and the third column shows the percentage of correct responses. The data are as follows:

DISCUSSION OF RESULTS

Effect on Area of P-V Diagrams and Indicated Efficiency

Fig. 19 shows that the indicated efficiency remains very nearly constant for increasing water/fuel ratio without change in spark advance. However, the area under the pressure-volume diagram (Fig. 14, 15, 16, 17) which was used to compute the indicated mean effective pressure (Fig. 18) and efficiency (Fig. 19) apparently shows a marked decrease in magnitude as the water/fuel ratio increases. This apparent decrease is caused by the greatly reduced flame speed and a large area loss generally associated with time loss. It will be noted, however, that there is a considerable increase in area on the expansion stroke. It is this compensating area which keeps the efficiency constant, or nearly so. As the water/fuel rate increases, the time loss area increases, but there is a corresponding increase in the area under the expansion curve.

Part of the increase in area may be accounted for in the following manner (Appendix II). Suppose that a normal Fuel-Air cycle is considered. For any point on the expansion line there will be found a certain pressure. Consider now that another process is carried out in which the compression stroke is identically the same as before. Now, instead of burning at constant volume, let the burning take place at a changing volume. By constructing a pressure-volume diagram for a standard fuel-air cycle, the area under

EXHIBIT 1

Letter to the Honorable Earl Browder, Washington, D.C.

Dear Mr. Browder:

I am writing you in connection with the charges against you which were made public in the New York Times on June 17, 1938.

I am sure that you are aware of the fact that the charges against you are completely unfounded.

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the new burning line may be computed and the new internal energy of the gases in the cylinder may be found. It will be found that since the gases have done less work up to the new point, the pressure and the temperature at the same volume point will be higher than the pressure and temperature on the original pressure-volume diagram. Expanding from this point isentropically gives a higher expansion curve, and therefore some additional area, which compensates in part for the time loss involved in the constant volume burning.

The rest of the increase in the compensating area is due entirely to the effect of the addition of water to the charge. The mean cylinder temperatures are lower throughout the cycle and the dissociation of the charge, including the water, is decreased with the temperature decrease (R. Wiebe,⁴). This leads to a higher percentage of CO_2 and H_2O in the products of combustion, and an increased amount of heat obtained from the fuel. The same author has constructed theoretical fuel-air-water charts and shows an increase in efficiency with water/fuel rate. This agrees well with the results of this investigation, since it was found that with spark advance adjusted to eliminate the time losses as much as possible, the actual indicated efficiency increased (Fig. 21). The theoretical increase in efficiency was greater, since the time losses were not entirely eliminated in the actual engine process.

The first thing I noticed when I stepped out of the car was the smell of the sea. It was a salty, bracing scent that seemed to fill the air. I took a deep breath, feeling the cool breeze against my face. The sun was shining brightly, and the water was a deep, shimmering blue. I could see the whitecaps in the distance, and the sound of the waves crashing against the rocks was a constant, rhythmic hum. I felt a sense of peace and freedom that I had never experienced before. It was as if the world had been put on hold, and I was the only one who had stepped out of the pause.

The view of the harbor was truly breathtaking. The water was a deep, shimmering blue, and the whitecaps in the distance were a constant, rhythmic hum. I could see the white cliffs of the mountains in the distance, and the sound of the waves crashing against the rocks was a constant, rhythmic hum. I felt a sense of peace and freedom that I had never experienced before. It was as if the world had been put on hold, and I was the only one who had stepped out of the pause.

As I walked along the shore, I noticed the small boats bobbing in the water. Some were fishing boats, and some were pleasure boats. The fishermen were busy with their work, and the pleasure boats were out for a day of fun in the sun. I saw a group of children playing in the sand, and a man fishing from a pier. The scene was a picture of a peaceful, idyllic life.

The harbor was a beautiful sight, and I was lucky to see it. The water was a deep, shimmering blue, and the whitecaps in the distance were a constant, rhythmic hum. I could see the white cliffs of the mountains in the distance, and the sound of the waves crashing against the rocks was a constant, rhythmic hum. I felt a sense of peace and freedom that I had never experienced before. It was as if the world had been put on hold, and I was the only one who had stepped out of the pause.

In the end, the harbor was a beautiful sight, and I was lucky to see it. The water was a deep, shimmering blue, and the whitecaps in the distance were a constant, rhythmic hum. I could see the white cliffs of the mountains in the distance, and the sound of the waves crashing against the rocks was a constant, rhythmic hum. I felt a sense of peace and freedom that I had never experienced before. It was as if the world had been put on hold, and I was the only one who had stepped out of the pause.

Kuhring (6), in a test of a Jaguar aircraft engine, noted a decrease in cylinder temperature when water is added. A decrease in heat transfer to the cooling water was noted in the present investigation, but the cooling water temperatures were held constant by varying the rate of coolant flow.

Effect on Volumetric Efficiency

The volumetric efficiency (Figs. 20 and 21) dropped off with an increase in water rate because the water was injected into the manifold, and the water and water vapor displaced some of the air which would have entered the cylinder. For this investigation the inlet conditions used in calculating the volumetric efficiency are defined by the pressure and temperature of the air and fuel vapor in the mixing tank.

Effect on Indicated Mean Effective Pressure

The indicated mean effective pressure (Figs. 18 and 21) dropped with increasing water/fuel ratios mainly because the volumetric efficiency was reduced. The expression stating that IMEP varies directly with $e_{g_i}(\overline{P}_c \eta_i)$ shows that if inlet conditions are kept constant, the fuel-air ratio remains constant, the same fuel is used, and, as in this case, the indicated efficiency remains substantially constant, then the indicated mean effective pressure is proportional to volumetric efficiency and should be expected to decrease.

On the other hand, had the water been injected into the cylinder after the valves were closed, there would be no change in volumetric efficiency and the indicated mean effective pressure would increase, as has been shown by several other investigations (10).

Effect on Compression Stroke

The bulge in the compression line (Figs. 10, 11 and 12) at high water rates is very likely caused by liquid water impinging on the hot cylinder surfaces and transferring heat from them. This water flashes to steam, and the heat added to the charge increases the sensible energy of the system and causes a pressure rise in the cylinder. At the lower water rates it is likely that not enough liquid water gets into the cylinder to cause a noticeable change in the compression process. Ordinarily, it would be expected that when water is introduced to a heated charge, the effect would be to lower the pressure and the temperature, and a thermometer placed on the intake manifold between the injection nozzle and the inlet valve showed such a decrease in the temperature of the charge. However, in the case of extreme water rates, there is actually enough heat transferred from the cylinder walls to increase the cylinder pressure.

Effect on Spark Advance

It is to be expected that with constant piston speed and constant inlet conditions, the flame speed will decrease

of the other hand, the water must be allowed to run
 off from the surface of the cylinder, and it must be
 kept at a temperature of about 100 degrees Fahrenheit
 by means of a steam jacket, or other suitable
 arrangement, so that the water may be kept at
 a constant temperature of about 100 degrees Fahrenheit.

Effect of Temperature

The effect of temperature on the rate of reaction
 is very important, and it is found that the rate
 of reaction increases with increasing temperature.
 This is due to the fact that the molecules of the
 reacting substances have more energy at a higher
 temperature, and therefore a greater number of
 them are able to overcome the energy barrier of the
 reaction. It is found that the rate of reaction
 increases about twice for every 10 degrees
 increase in temperature. This is due to the fact
 that the number of molecules which have sufficient
 energy to overcome the energy barrier of the
 reaction increases with increasing temperature.
 It is found that the rate of reaction increases
 with increasing temperature, and this is due to
 the fact that the molecules of the reacting
 substances have more energy at a higher
 temperature, and therefore a greater number of
 them are able to overcome the energy barrier of
 the reaction.

Effect of Surface Area

It is found that the rate of reaction increases
 with increasing surface area, and this is due to
 the fact that a greater number of molecules are
 able to come into contact with the other
 reacting substance when the surface area is
 increased.

with an inert diluent in the charge. The results show that the rate of pressure rise (Fig. 23) is nearly linear with water/fuel ratio. Also, the spark advance must be increased as the flame speed decreases to keep the time losses at a minimum. The results show that the spark advance (Fig. 22) required for best power is also a linear function of the water/fuel ratio.

Experimental Error

In this work it was found that the greatest source of error was in the transfer of the $dp/d\theta$ diagram to the pressure-volume diagram. The utmost care in the operation of the MIT transfer machine is required.

After the data for this investigation had been obtained, test runs were made under the same conditions as previous runs and the computations from these runs produced results within one and one-half percent of the original runs.

The first object of the survey was to determine the extent of the disease in the various districts. It was found that the disease was most prevalent in the districts of the north and south of the island. The results of the survey are given in the following table.

Table showing the results of the survey

The following table shows the results of the survey. It is divided into three columns: District, Number of cases, and Remarks. The first column lists the districts of the island. The second column gives the number of cases in each district. The third column contains remarks on the prevalence of the disease in each district. The results show that the disease is most prevalent in the districts of the north and south of the island.

CONCLUSIONS

As a result of this investigation of the effects of manifold water injection on the engine indicator card, the following conclusions may be drawn:

1. The indicated efficiency remains substantially constant within the range of water/fuel ratios needed to quell detonation when the spark is set for best power with no injection. However, adjusting the spark for best power at each water rate causes the efficiency to increase within the same range.
2. As the water/fuel ratio is increased, the volumetric efficiency decreases linearly. This decrease is the same for engine operation under constant best power spark advance set for no water rate and for best power spark advance set for each water rate, since the inlet conditions do not change.
3. The indicated mean effective pressure decreases with an increase in water/fuel ratio, the decrease being less when best power spark is set for each water rate than when constant spark advance is used.
4. The maximum pressures of the cycle decrease with water/fuel ratio increase, the decrease being greater in the case of constant spark advance set for best power with no water. The pressure peaks also occur further after top center with water rate increase except for best power spark advance, where they all peak at approximately the same distance after top center.

CONCLUSIONS

The results of the investigation of the effects of
various factors on the rate of reaction are
summarized in the following table:

1. The rate of reaction is directly proportional to the
concentration of the reactants.
2. The rate of reaction is inversely proportional to the
square of the concentration of the reactants.
3. The rate of reaction is directly proportional to the
square of the concentration of the reactants.

4. The rate of reaction is directly proportional to the
square of the concentration of the reactants.
5. The rate of reaction is directly proportional to the
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square of the concentration of the reactants.
11. The rate of reaction is directly proportional to the
square of the concentration of the reactants.

5. The time losses increase with water rate, but the expansion line becomes higher, partially compensating for the time loss.
6. The best power spark advance varies linearly with water/fuel ratio, increasing with an increase in the water rate.
7. The amount of water that can be injected into the manifold of an engine before it commences to miss is a function of the inlet pressure. An engine with higher inlet pressure is able to absorb a greater amount of water before missing.

1. The first feature is the presence of a...

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4. The fourth feature is the presence of a...

5. The fifth feature is the presence of a...

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11. GILBERT, R. A. THE NEW PARADIGM, PART X. THE NEW PARADIGM.

APPENDIX I

Symbols Used in Sample Calculations

- A - Area of indicator card in square inches.
- e - Volumetric efficiency.
- E_c - Heating value of fuel (19000 Btu per lb).
- E_{comb} - Energy due to the change in base of the fuel-air mixture.
- E_s - Sensible energy of the mixture.
- f - Ratio of residual gas to gas in total charge.
- F/A - Fuel-Air Ratio.
- h - Inches of water pressure difference across the orifice.
- h_s - Sensible enthalpy of the mixture.
- IHP - Indicated horse power.
- IMEP - Indicated mean effective pressure.
- K - Spring constant of indicator lbs/in.
- L - Length of indicator card (5 inches).
- M_a - Lbs of air/sec. supplied.
- M_f - Lbs of fuel/sec. supplied.
- n - Number of suction strokes/sec.
- N - RPM = 1200.
- η_i - Indicated thermal efficiency
- P - Pressure before orifice in inches of Hg.
- P_1 - Inlet pressure in lbs/in² measured in the mixing tank.
- ρ_i - Density at inlet lbs/ft³.
- R - 53.3 ft lbs/lb °R.

Appendix 2

Physical Test in Heavy Construction

1	-	Test of endurance with in heavy work.
2	-	Endurance test.
3	-	Endurance test at 1500 ft (see test 1).
4	-	Endurance test in heavy work.
5	-	Endurance test at 1500 ft (see test 1).
6	-	Endurance test at 1500 ft (see test 1).
7	-	Endurance test at 1500 ft (see test 1).
8	-	Endurance test at 1500 ft (see test 1).
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10	-	Endurance test at 1500 ft (see test 1).
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13	-	Endurance test at 1500 ft (see test 1).
14	-	Endurance test at 1500 ft (see test 1).
15	-	Endurance test at 1500 ft (see test 1).
16	-	Endurance test at 1500 ft (see test 1).
17	-	Endurance test at 1500 ft (see test 1).
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23	-	Endurance test at 1500 ft (see test 1).
24	-	Endurance test at 1500 ft (see test 1).
25	-	Endurance test at 1500 ft (see test 1).
26	-	Endurance test at 1500 ft (see test 1).
27	-	Endurance test at 1500 ft (see test 1).
28	-	Endurance test at 1500 ft (see test 1).
29	-	Endurance test at 1500 ft (see test 1).
30	-	Endurance test at 1500 ft (see test 1).

- T - Temperature at orifice °R.
- T₁ - Inlet temperature of air.
- 2545 - Conversion factor (Btu/IMU-hr).
- .01825 - Conversion factor and orifice coefficient for .515 inch diameter orifice.

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SAMPLE CALCULATIONS

For run with 20" of mercury inlet pressure:

$$M_a = .01825 \sqrt{\frac{P}{T} h} = .01825 \sqrt{\frac{29.74 \times 2.75}{538}} = .00712 \text{ lbs. air/sec.}$$

$$F/A = \frac{M_f}{M_a}$$

$$M_f = F/A \times M_a = .0782 \times .00712 = .000556 \text{ lbs. fuel/sec.}$$

$$IHP = \frac{IMEP \times V_d \times N}{2 \times 12 \times 33000}$$

$$IMEP = \frac{A \times K}{L} = \frac{3.542 \times 100}{5}$$

$$IHP = \frac{70.85 \times 37.33 \times 1200}{2 \times 12 \times 33000} = 4.0 \text{ H.P.}$$

$$\eta_i = \frac{IHP \times 2545}{M_f \times E_c \times 3600} = \frac{IHP \times .0000372}{M_f} = \frac{4.0 \times .0000372}{.000556} = .278$$

$$e = \frac{M_a}{\rho_i n V_d}$$

$$\rho_i = \frac{P_i}{R T_i} \quad 20'' \text{ Hg.} = 9.82 \text{ lbs/in.}$$

$$\rho_i = \frac{9.82 \times 144}{53.345 \times 620} = .0428 \text{ lbs/cubic foot.}$$

$$e = \frac{.00712 \times 1728}{.0428 \times 37.33 \times 10} = .77$$

PROBABILITY

For the first two of the following problems:

$$P(A \cap B) = \frac{P(A) \cdot P(B)}{P(A \cup B)}$$

$$P(A) = \frac{1}{2}$$

$$P(B) = \frac{1}{3}$$

$$P(A \cup B) = \frac{1}{2} + \frac{1}{3} - \frac{1}{6} = \frac{2}{3}$$

$$P(A \cap B) = \frac{1}{2} \cdot \frac{1}{3} = \frac{1}{6}$$

$$P(A \cup B) = \frac{1}{2} + \frac{1}{3} - \frac{1}{6} = \frac{2}{3}$$

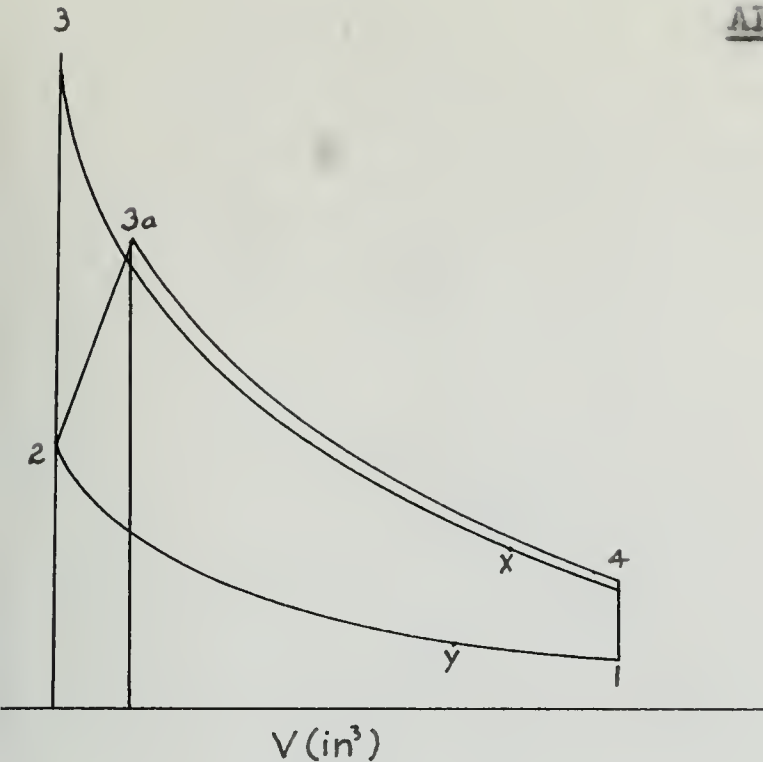
$$P(A \cap B) = \frac{P(A) \cdot P(B)}{P(A \cup B)} = \frac{\frac{1}{2} \cdot \frac{1}{3}}{\frac{2}{3}} = \frac{1}{4}$$

$$P(A) = \frac{1}{2}$$

$$P(B) = \frac{1}{3}$$

$$P(A \cup B) = \frac{1}{2} + \frac{1}{3} - \frac{1}{6} = \frac{2}{3}$$

$$P(A \cap B) = \frac{1}{2} \cdot \frac{1}{3} = \frac{1}{6}$$

APPENDIX IIData from P.-V. diagram

$$V_D = 37.33 \text{ cu. in.}$$

$$V_{CL} = 6.628 \text{ cu. in.}$$

$$P_x = 71.2 \text{ lbs/in.}^2$$

$$V_x = 36.88 \text{ cu. in.}$$

$$P_y = 22.2 \text{ lbs/in.}^2$$

$$V_y = 32.93 \text{ cu. in.}$$

Construct the equivalent cycle for 31" Hg.

$$B = \text{Mass air/cycle} = .00118 \text{ lbs. air/cycle}$$

$$v_{\text{chart } x} = v_{\text{cyl}} \times \frac{1-f}{B}$$

$$f = \frac{V_2}{V_1}$$

By trial and error find $f = .052$

Using this f find:

$$v_{\text{chart } x} = 17.15 \text{ cu. ft.}$$

$$v_{\text{chart } 2} = 3.08 \text{ " "}$$

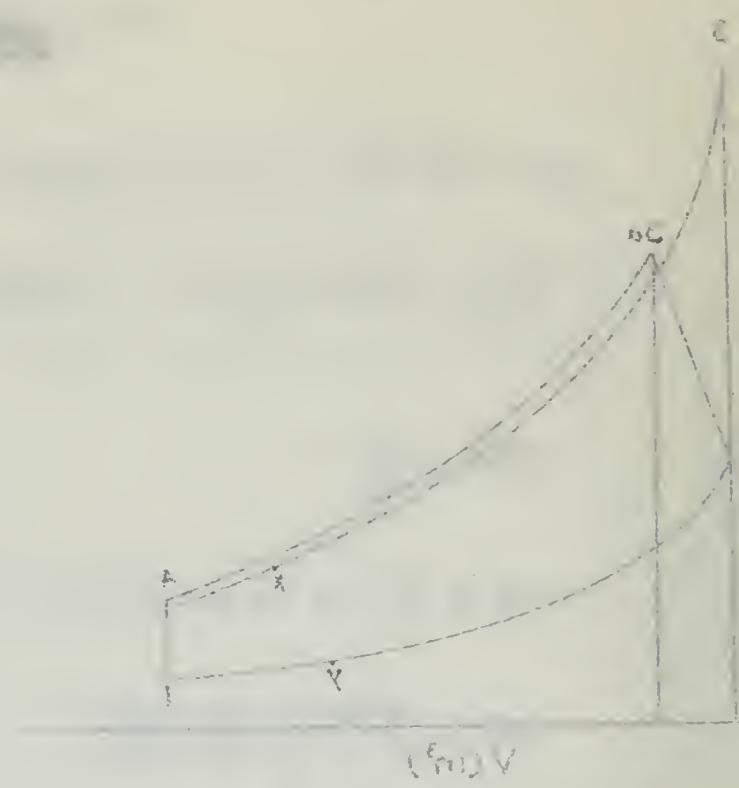
$$v_{\text{chart } y} = 15.33 \text{ " "}$$

$$v_{\text{chart } 1} = 20.45 \text{ " "}$$

Q. 10

Example 10.1

- 1. $\frac{1}{2} \times 10 \times 10 = 50$
- 2. $\frac{1}{2} \times 10 \times 10 = 50$
- 3. $\frac{1}{2} \times 10 \times 10 = 50$
- 4. $\frac{1}{2} \times 10 \times 10 = 50$
- 5. $\frac{1}{2} \times 10 \times 10 = 50$
- 6. $\frac{1}{2} \times 10 \times 10 = 50$



Consider the following data for the flow of water through a pipe of diameter 100 mm. The velocity profile is shown in the figure below.

$$V_{max} = 10 \text{ m/s}$$

$$\frac{V}{V_{max}} = \frac{r}{R}$$

Find the discharge through the pipe.

Solution:

- 1. $V_{max} = 10 \text{ m/s}$
- 2. $V_{avg} = 5 \text{ m/s}$
- 3. $V_{avg} = 5 \text{ m/s}$
- 4. $V_{avg} = 5 \text{ m/s}$

At state 1:

$$T = 800 \quad E_s = 57 \quad H_s = 114 \quad p = 150 \quad v = 20.45$$

Compress isentropically to $v = 3.08$ (state 2)

At state 2:

$$T = 1370 \quad E_s = 193 \quad H_s = 290 \quad p = 164 \quad v = 3.08$$

Burn at constant volume:

$$E_{\text{comb.}} = 1507(1-f) + 300f = 1443$$

At state 3:

$$T = 5100 \quad E = 1636 \quad p = 705 \quad v = 3.08$$

Expand isentropically to $v = 20.45$ cu. in.

At state 4:

$$P_4 = 68 \text{ lbs/in}^2 \quad v = 20.45 \quad E = 1025$$

From this data compute engine performance.

$$\text{First Law of Thermodynamics} \quad E_4 - E_1 = Q - W$$

$$W = E_1 - E_4 = 475 \text{ Btu/lb.}$$

$$\text{IMEP} = \text{work/cycle} = 148 \text{ lb/in.}^2$$

$$\eta_i = \text{IMEP}/(1-f) \cdot E_c = 33.7\%$$

Now assume that the charge burns at varying volume.

Find from actual engine data the volume at which peak pressure occurs is 8.86 cu. in. This gives a $v_{\text{chart}} = 4.13$ cu. ft.

By trial and error find end pressure at this volume = 520 lbs./sq. in., and work done in this process = 64 Btu.

Expanding from this point isentropically, find that

$$p_4 = 70 \text{ lbs./in.}^2, E_4 = 1065$$

$$E_1 - E_4 = 1500 - 1065 = 435$$

$$= 30.85$$

If we assume cylinder pressure ended on original expansion line, and subtract the work lost, the efficiency = 30.2%.

Exhibit 100 Case Files (approximately 1700)

$$P = 70 \text{ (or } \sqrt{49} \text{), } P = 100$$

$$P - P = 100 - 100 = 0$$

$$P = 0$$

If we assume that the above is a normal distribution

then the standard deviation is 100, the mean is

$$= 100$$

[The following text is extremely faint and illegible, appearing to be a series of paragraphs or a list of items.]

TABLE I

Fuel Rotometer Calibration

3/13/47

 $T_{\text{fuel}} = 78^{\circ}\text{F}$

<u>Roto-</u> <u>meter</u> <u>Readings</u>	<u>Time</u> <u>Secs.</u>	<u>Wt.</u> <u>gms.</u>	<u>lbs/sec</u>
5.4	133.3	10	.000165
7.0	53.6	10	.000411
7.75	44.3	10	.00498
8.625	71.6	20	.000615
8.92	65.6	20	.000671
9.65	58.2	20	.000758
10.3	51.8	20	.00085
11.05	45.44	20	.00097
11.95	61.00	30	.001085
12.35	57.50	30	.00115
13.6	49.7	30	.001328
14.9	43.1	30	.001535
11.6	43.45	20	.001015
13.02	36.15	20	.00122
15.8	40.2	30	.001645
15.81	52.0	40	.001692
16.88	47.9	40	.001840

Fuel Rotometer Calibration

2/11/47

 $T_{\text{fuel}} = 68^{\circ}\text{F}$

<u>Roto-</u> <u>meter</u> <u>Readings</u>	<u>Time</u> <u>Secs.</u>	<u>Wt.</u> <u>gms.</u>	<u>lbs/sec</u>
5.20	82.7	5	.0001333
6.37	85.45	10	.000256
7.8	91.9	20	.000481
8.7	73.9	20	.0005975
9.6	61.45	20	.000718
10.2	27.1	10	.000813
10.9	48.6	20	.000906
11.55	44.4	20	.000994
12.20	82.24	40	.001072
12.60	77.4	40	.00114
13.22	71.1	40	.00124
14.05	64.4	40	.001371
14.88	59.8	40	.001475
15.71	54.37	40	.001625
16.72	49.36	40	.001791
17.80	44.95	40	.001967
18.40	43.00	40	.002050
18.2	44.4	40	.001988
18.75	41.88	40	.00210
18.60	42.4	40	.002085
19.66	38.1	40	.002315
20.75	34.54	40	.002555
17.4	45.7	40	.001927
17.1	47.8	40	.001845
14.83	59.85	40	.001475

Table

Left Subgroup Definition				Right Subgroup Definition			
Time = 1974		Time = 1975		Time = 1974		Time = 1975	
Year	Age	Rate	Rate	Year	Age	Rate	Rate
1974	15	7.86	81.6	1974	15	8.82	8.6
1974	16	8.20	82.2	1974	16	8.52	8.7
1974	17	8.19	81.7	1974	17	8.31	87.7
1974	18	8.27	81.2	1974	18	8.17	88.2
1974	19	8.28	81.1	1974	19	8.20	88.8
1974	20	7.72	80.8	1974	20	8.12	89.3
1974	21	8.21	80.8	1974	21	8.12	89.8
1974	22	8.22	80.8	1974	22	8.12	90.1
1974	23	8.22	80.8	1974	23	8.12	90.1
1974	24	8.22	80.8	1974	24	8.12	90.1
1974	25	8.22	80.8	1974	25	8.12	90.1
1974	26	8.22	80.8	1974	26	8.12	90.1
1974	27	8.22	80.8	1974	27	8.12	90.1
1974	28	8.22	80.8	1974	28	8.12	90.1
1974	29	8.22	80.8	1974	29	8.12	90.1
1974	30	8.22	80.8	1974	30	8.12	90.1
1974	31	8.22	80.8	1974	31	8.12	90.1
1974	32	8.22	80.8	1974	32	8.12	90.1
1974	33	8.22	80.8	1974	33	8.12	90.1
1974	34	8.22	80.8	1974	34	8.12	90.1
1974	35	8.22	80.8	1974	35	8.12	90.1
1974	36	8.22	80.8	1974	36	8.12	90.1
1974	37	8.22	80.8	1974	37	8.12	90.1
1974	38	8.22	80.8	1974	38	8.12	90.1
1974	39	8.22	80.8	1974	39	8.12	90.1
1974	40	8.22	80.8	1974	40	8.12	90.1
1974	41	8.22	80.8	1974	41	8.12	90.1
1974	42	8.22	80.8	1974	42	8.12	90.1
1974	43	8.22	80.8	1974	43	8.12	90.1
1974	44	8.22	80.8	1974	44	8.12	90.1
1974	45	8.22	80.8	1974	45	8.12	90.1
1974	46	8.22	80.8	1974	46	8.12	90.1
1974	47	8.22	80.8	1974	47	8.12	90.1
1974	48	8.22	80.8	1974	48	8.12	90.1
1974	49	8.22	80.8	1974	49	8.12	90.1
1974	50	8.22	80.8	1974	50	8.12	90.1
1974	51	8.22	80.8	1974	51	8.12	90.1
1974	52	8.22	80.8	1974	52	8.12	90.1
1974	53	8.22	80.8	1974	53	8.12	90.1
1974	54	8.22	80.8	1974	54	8.12	90.1
1974	55	8.22	80.8	1974	55	8.12	90.1
1974	56	8.22	80.8	1974	56	8.12	90.1
1974	57	8.22	80.8	1974	57	8.12	90.1
1974	58	8.22	80.8	1974	58	8.12	90.1
1974	59	8.22	80.8	1974	59	8.12	90.1
1974	60	8.22	80.8	1974	60	8.12	90.1
1974	61	8.22	80.8	1974	61	8.12	90.1
1974	62	8.22	80.8	1974	62	8.12	90.1
1974	63	8.22	80.8	1974	63	8.12	90.1
1974	64	8.22	80.8	1974	64	8.12	90.1
1974	65	8.22	80.8	1974	65	8.12	90.1
1974	66	8.22	80.8	1974	66	8.12	90.1
1974	67	8.22	80.8	1974	67	8.12	90.1
1974	68	8.22	80.8	1974	68	8.12	90.1
1974	69	8.22	80.8	1974	69	8.12	90.1
1974	70	8.22	80.8	1974	70	8.12	90.1
1974	71	8.22	80.8	1974	71	8.12	90.1
1974	72	8.22	80.8	1974	72	8.12	90.1
1974	73	8.22	80.8	1974	73	8.12	90.1
1974	74	8.22	80.8	1974	74	8.12	90.1
1974	75	8.22	80.8	1974	75	8.12	90.1
1974	76	8.22	80.8	1974	76	8.12	90.1
1974	77	8.22	80.8	1974	77	8.12	90.1
1974	78	8.22	80.8	1974	78	8.12	90.1
1974	79	8.22	80.8	1974	79	8.12	90.1
1974	80	8.22	80.8	1974	80	8.12	90.1
1974	81	8.22	80.8	1974	81	8.12	90.1
1974	82	8.22	80.8	1974	82	8.12	90.1
1974	83	8.22	80.8	1974	83	8.12	90.1
1974	84	8.22	80.8	1974	84	8.12	90.1
1974	85	8.22	80.8	1974	85	8.12	90.1
1974	86	8.22	80.8	1974	86	8.12	90.1
1974	87	8.22	80.8	1974	87	8.12	90.1
1974	88	8.22	80.8	1974	88	8.12	90.1
1974	89	8.22	80.8	1974	89	8.12	90.1
1974	90	8.22	80.8	1974	90	8.12	90.1
1974	91	8.22	80.8	1974	91	8.12	90.1
1974	92	8.22	80.8	1974	92	8.12	90.1
1974	93	8.22	80.8	1974	93	8.12	90.1
1974	94	8.22	80.8	1974	94	8.12	90.1
1974	95	8.22	80.8	1974	95	8.12	90.1
1974	96	8.22	80.8	1974	96	8.12	90.1
1974	97	8.22	80.8	1974	97	8.12	90.1
1974	98	8.22	80.8	1974	98	8.12	90.1
1974	99	8.22	80.8	1974	99	8.12	90.1
1974	100	8.22	80.8	1974	100	8.12	90.1

TABLE II

Water Rotometer Calibration

4/17/47

 $T_{\text{water}} = 80^{\circ}\text{F}$

(Engine Running at operating temperatures)

<u>Rotometer Reading</u>	<u>Time Secs.</u>	<u>Wt. gms.</u>	<u>lbs/sec</u>
11	628.0	20	.0000701
23	308.3	20	.0001428
35	154.7	20	.000285
15.5	535.7	20	.0000823
31	198.8	20	.000221
41	118.0	20	.000373
50	113.25	30	.000583
58	102.2	40	.000862
63.80	105.2	50	.00134
60.5	113.1	50	.000973
72.0	111.3	70	.001385
77.7	97.95	70	.001575
83.0	84.57	70	.00182
88.0	75.9	70	.00203
99.7	69.7	80	.00253
65.5	99.8	50	.001104
53.2	126.88	40	.000695
48.1	134.82	30	.000491
16.5	568.0	20	.0000775
20	348.4	20	.00001265

TABLE

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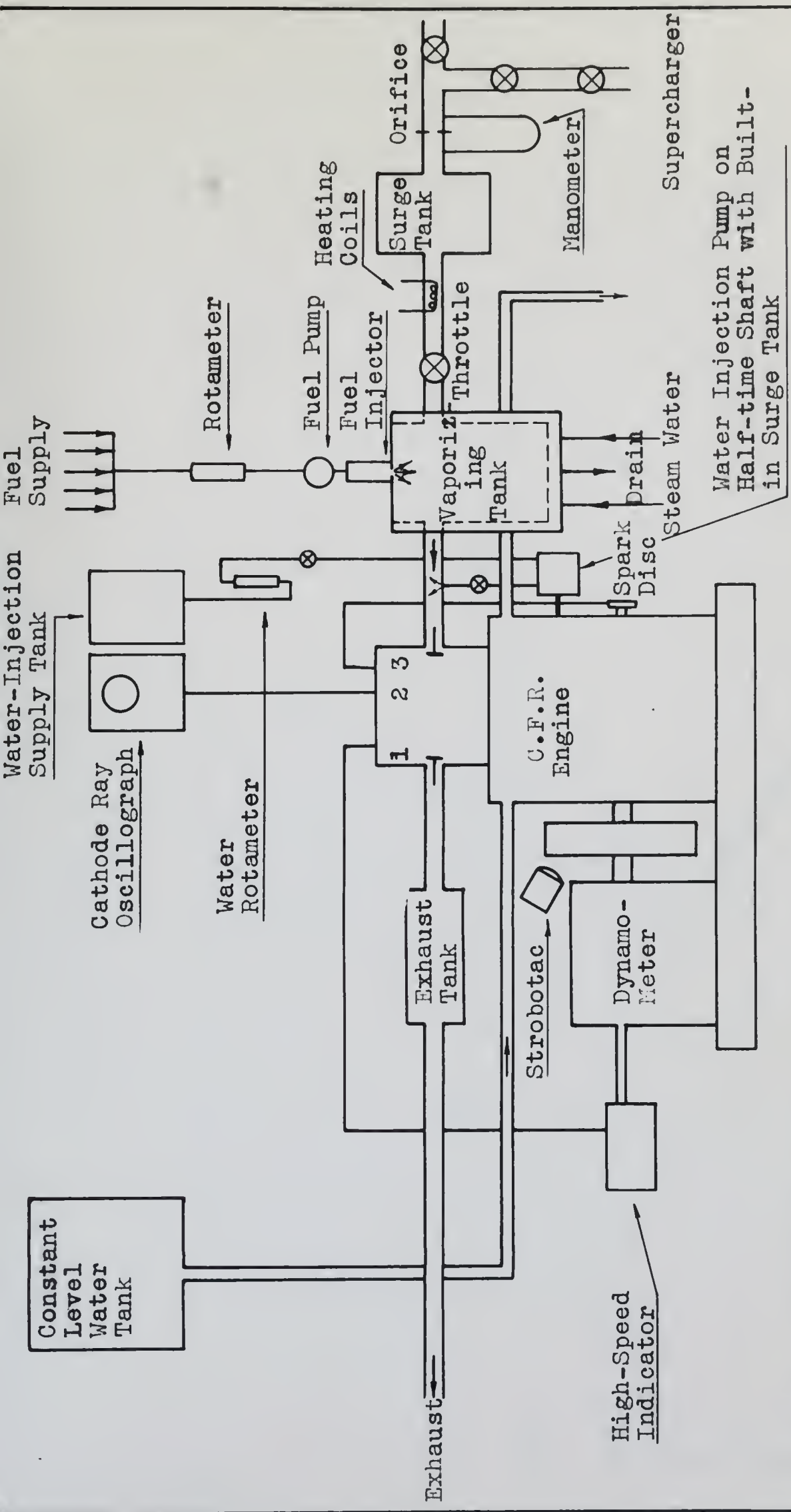
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19. Author's Awards	1	1	1
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96. Author's Clubs	1	1	1
97. Author's Groups	1	1	1
98. Author's Organizations	1	1	1
99. Author's Societies	1	1	1
100. Author's Associations	1	1	1

M.I.T. AERO ENGINE LABORATORY

ENGINE CFR BORE 3.25" STROKE 4.5" COMPRESSION RATIO 6.63

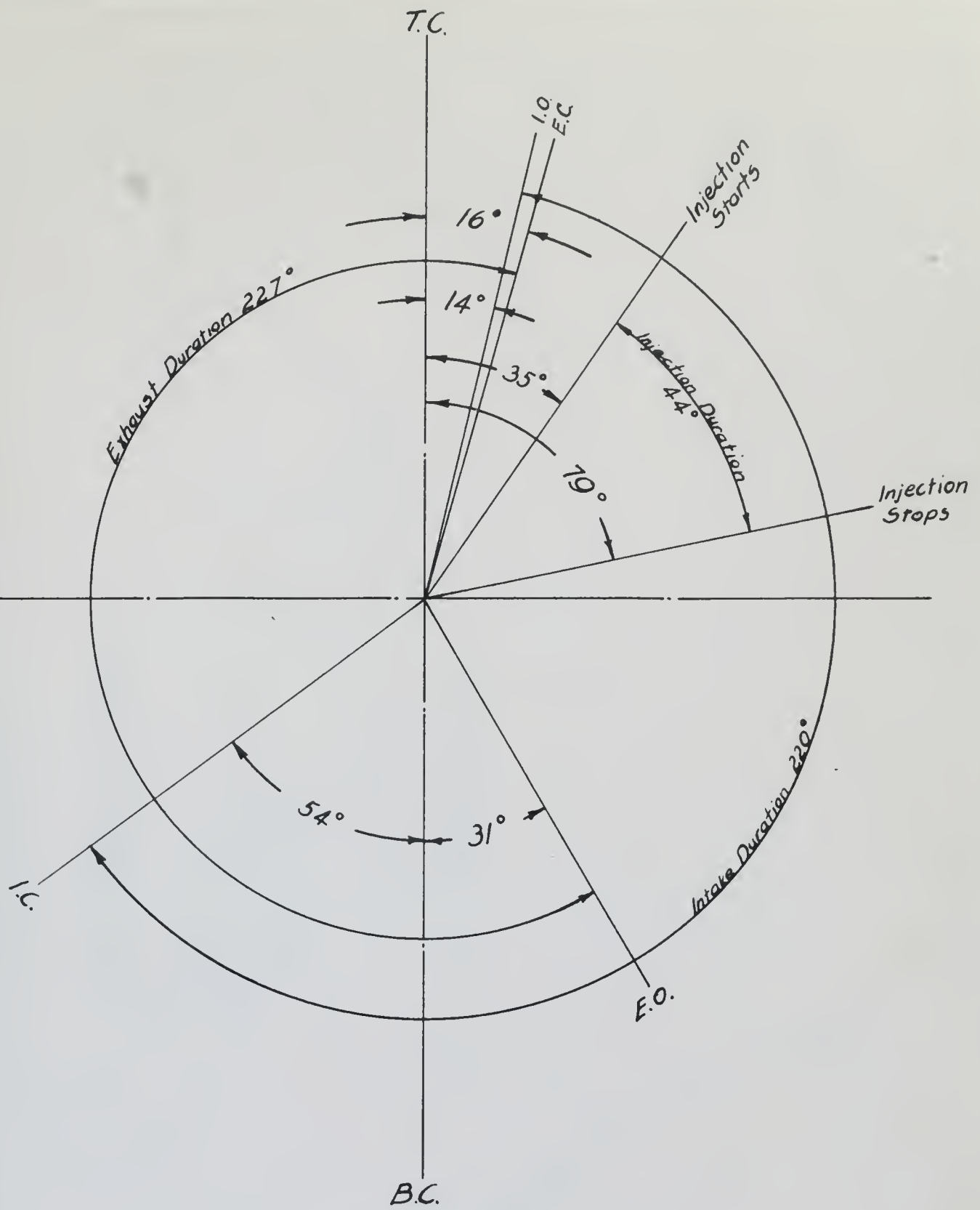
REMARKS	DATE	TIME	RPM	BAL	OIL TEMP	JAC TEMP	OIL PRESS	BAR. PRESS	P _i	P _c	T _i	AIR CONS.	FUEL CONS.	F/A	S.A.	ΔP _e	ΔP _i	T _{ORIF.}	ΔP _{ORIF.}	ΔP _{ABS. PRESS.}	FUEL PRESS	T _{i2}	T _{FUEL}	T _{WATER}	FUEL ROTO	WATER ROTO
							"Hg	"Hg	"Hg	"Hg	°F	LB/SEC	LB/SEC		"Hg	"Hg	°F	"H ₂ O	"Hg	"Hg	°F	°F	°F			
	1/12/47	1130	1	22.1	150	210	44	2995	31	32	160	.01180	.000373	.0182	19	2.05	1.05	77	6.8	3.1	20	170	80	80	10.74	0
	"	1210	2	22.0	"	"	"	"	"	"	"	.01170	.000394	"	"	"	"	79	6.7	3.05	19	132	81	80	10.70	28
	"	1231	3	21.8	"	209	43	"	"	"	"	.01160	.000307	"	"	"	"	80	6.6	3.30	"	124	81	81	10.6	51
	"	1256	4	21.2	"	"	"	"	"	"	"	.01142	.000394	"	"	"	"	81	6.4	3.1	"	116	83	81	10.54	67
ENGINE MISSING →	"	1317	5	19.2	"	"	41	"	"	"	"	.01131	.000385	"	"	"	"	81	6.25	3.3	"	111	83	81	10.37	79
DETONATING. →	1/15/47	1100	1	17.5	150	211	40	30.00	45	32	160	.01177	.001385	.0182	17	2.0	1.50	79.5	10.7	17.5	2.0	170	82	79	13.85	0
INCIPIENT DETONATION →	"	1125	2	17.5	"	210	"	"	"	"	"	.0116	.001375	"	"	"	"	80	10.55	17.6	"	146	85	79	13.75	23
	"	1150	3	17.5	"	"	"	"	"	"	"	.0116	.001315	"	"	"	"	80	10.55	17.6	"	134	85	79	13.70	36
	"	1230	4	15.7	"	"	33	"	"	"	"	.0112	.001345	"	"	"	"	81	10.1	17.65	"	119	85	80	13.50	96
	"	1315	5	17.0	"	"	33	"	"	"	"	.01145	.001365	"	"	"	"	81	10.35	17.85	"	122	86	80	13.6	66
	"	1515	6	16.9	"	"	39	"	"	"	"	.01133	.001251	"	"	"	"	80	10.15	18.0	19	116	86	80	13.5	79
	1/11/47	1030	1	11.3	150	209	46	29.74	20	32	160	.00127	.000564	.0182	21	2.26	9.74	76	7.85	0	2.0	173	80	78	8.15	0
	"	1110	2	11.1	"	"	"	"	"	"	"	.00112	.000556	"	"	"	"	78	7.76	0	"	122	81	78	8.02	26
	"	1140	3	10.7	"	"	"	"	"	"	"	.00105	.000551	"	"	"	"	79	7.70	0	"	116	81	78	8.0	40
	"	1200	4	"	"	"	"	"	"	"	"	.00092	.000544	"	"	"	"	78	7.6	0	"	110	80	78	7.9	49
	"	1225	5	10.2	"	"	"	"	"	"	"	.00097	.000533	"	"	"	"	80	7.72	0	"	117	81	78	8.0	35
	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"	"
	1/29/47	1027	1	22.7	150	211	42	30.20	31	32	160	.01175	.000372	.0182	19	1.80	0.80	76	5.82	8.02	2.0	172	80	80	10.72	0
PEAK TOO FAR RIGHT	"	1052	2	22.3	"	210	"	"	"	"	"	.01168	.000371	"	20.3	"	"	76	5.72	8.18	"	129	80	80	10.68	29
PEAK O.K.	"	1100	3	21.7	"	"	"	"	"	"	"	.01147	.000356	"	22.2	"	"	"	5.50	8.22	"	117	80	80	10.52	53.5
PEAK TOO FAR LEFT	"	1125	3	21.7	"	"	"	"	"	"	"	.01141	.000394	"	25.0	"	"	"	5.80	8.22	"	116	80	80	10.52	54.5
PEAK O.K.	"	1200	4	21.1	"	"	"	"	"	"	"	.01132	.000387	"	30.0	"	"	77	5.38	8.15	"	108	80	80	10.48	68.5
MILKING 5 TIMES PER MINUTE	"	1207	4	21.3	"	"	"	"	"	"	"	.01132	.000387	"	28.5	"	"	"	5.38	8.15	"	111	81	80	10.48	69.0
CHECK POINTS	"	1235	5	21.2	"	"	"	"	"	"	"	.01120	.000374	"	30.0	"	"	"	5.28	8.15	"	106	81	80	10.38	74.0
REPRODUCIBILITY	"	1315	6	22.0	"	"	"	"	"	"	"	.01153	.000372	"	19	"	"	"	5.61	8.05	"	114	81	80	10.57	54.0



- 1. Indicator Pickup
- 2. Rate of Pressure Pickup
- 3. Spark Plug

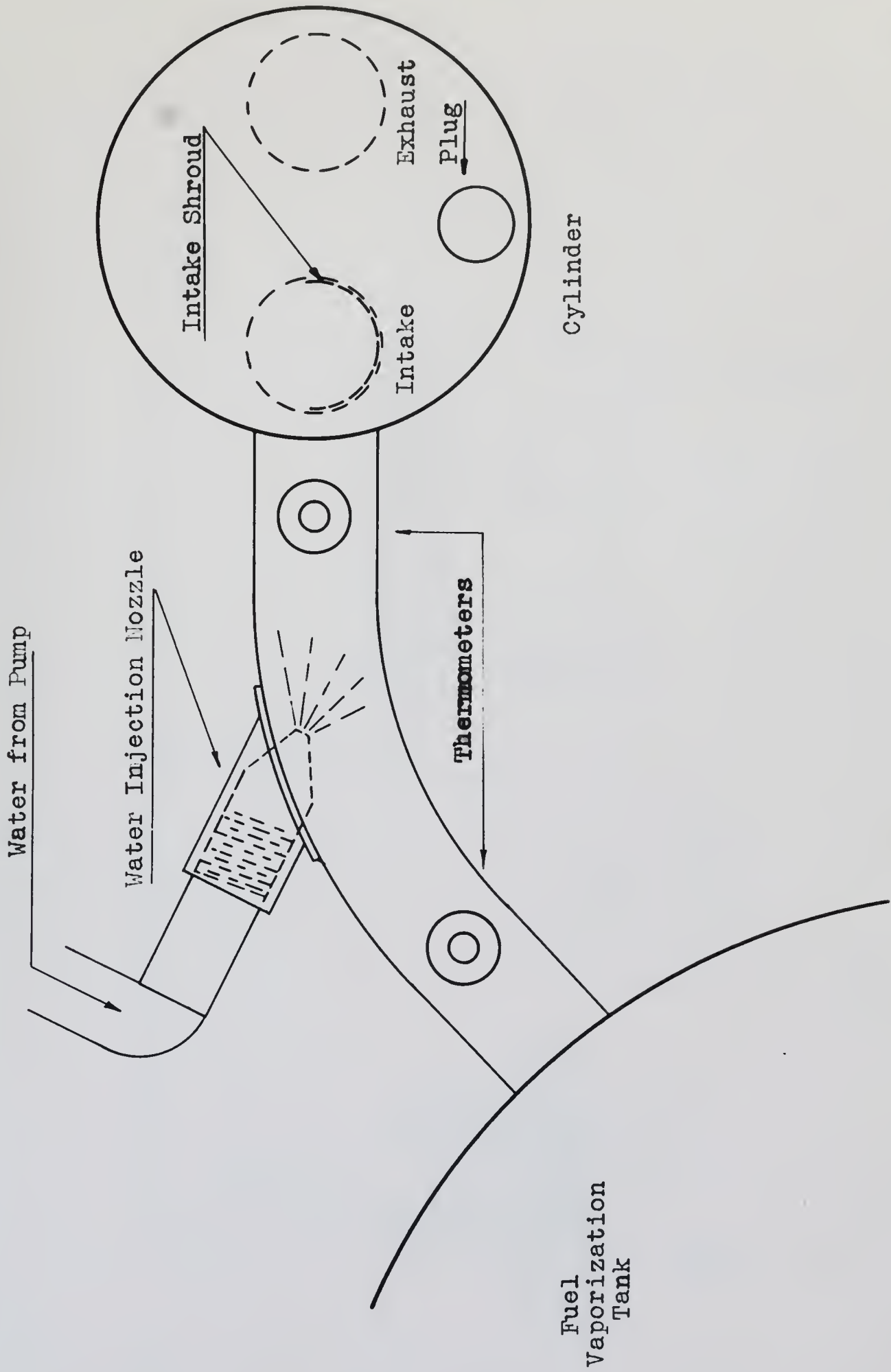
SLOAN LABORATORY
EXPERIMENTAL C.F.R. ENGINE SETUP

Fig. 1



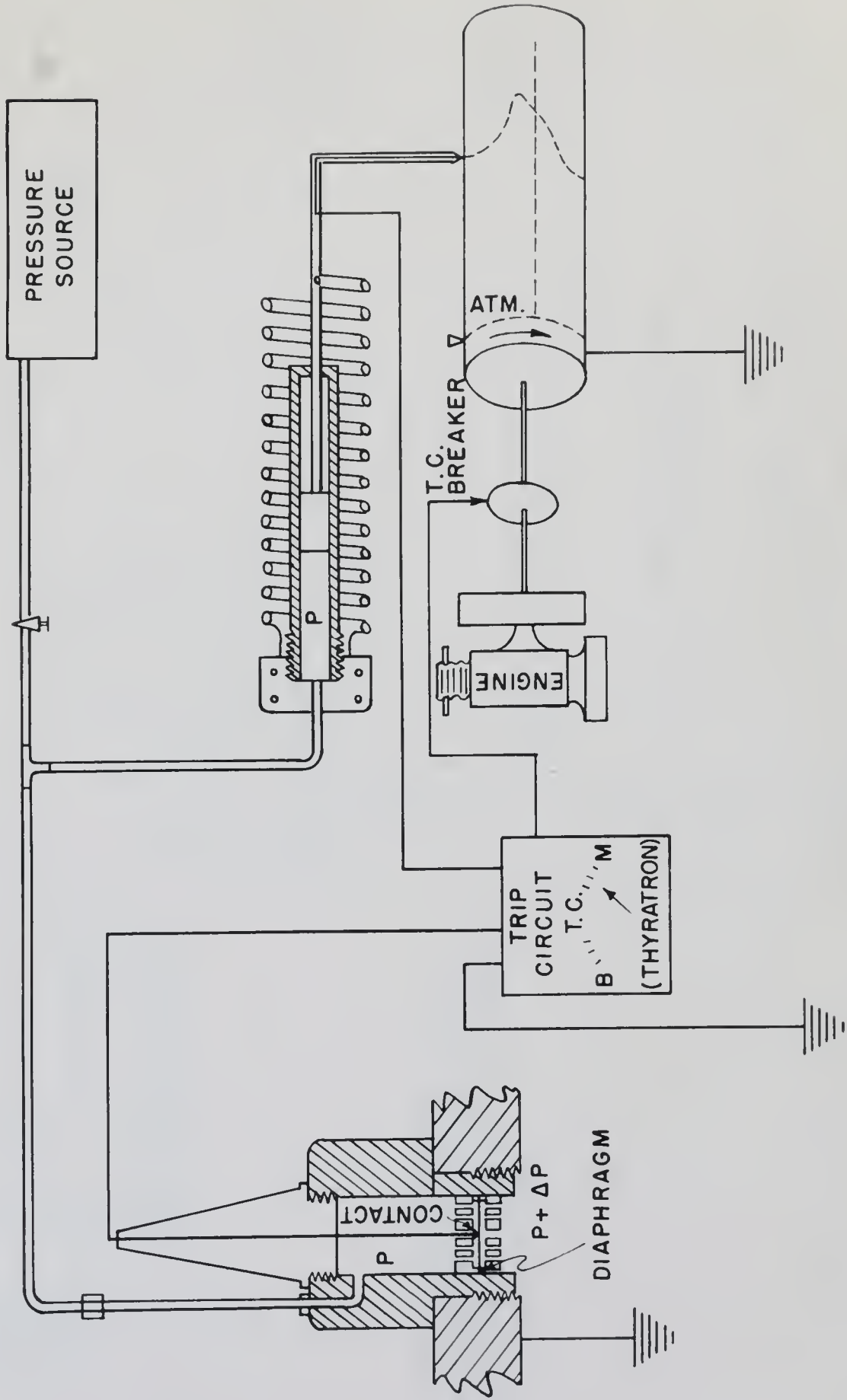
Timing Diagram

Fig.2



DIAGRAMATIC DRAWING OF SYSTEM USED
TO INJECT WATER INTO MANIFOLD

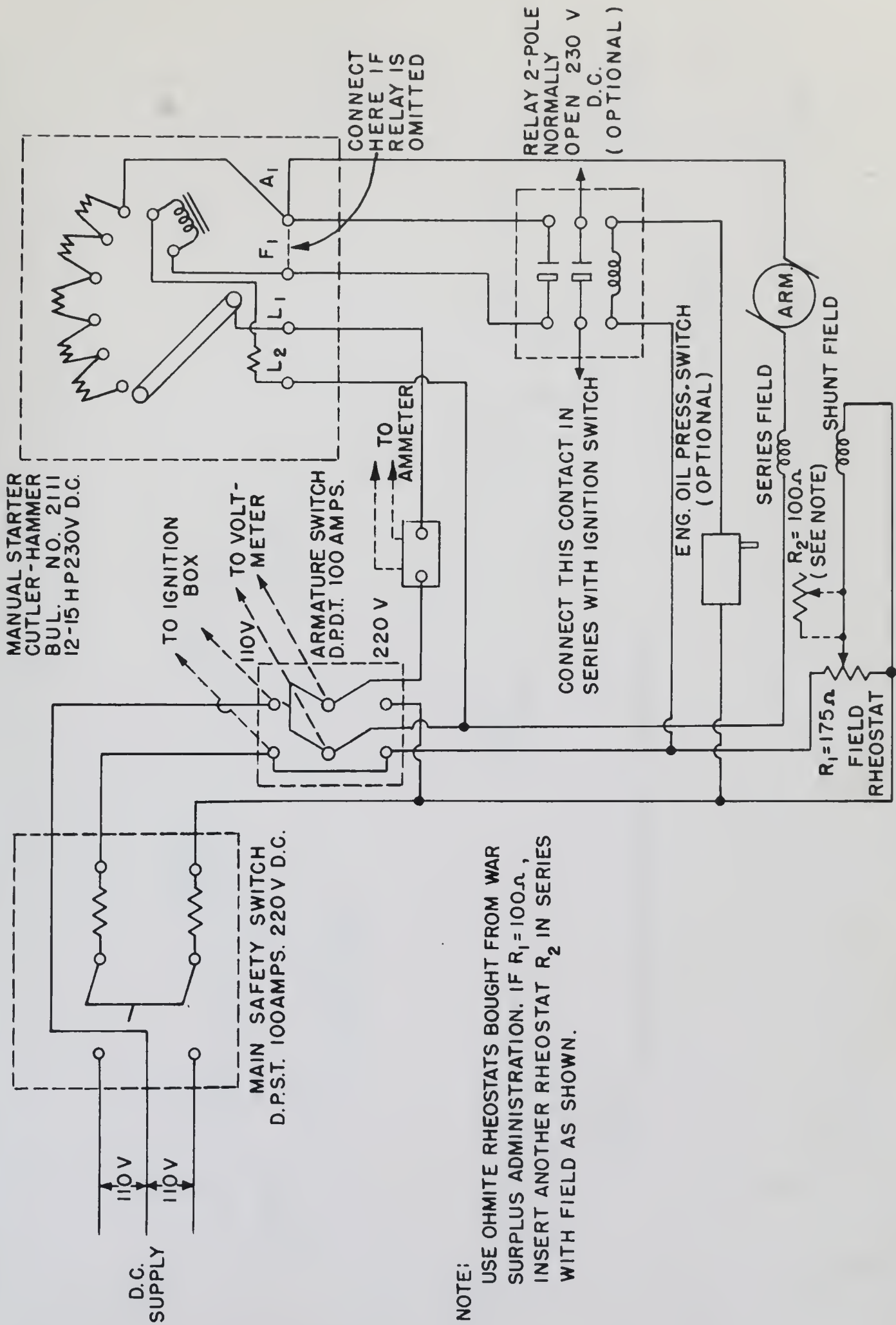
Fig.3



HIGH SPEED INDICATOR

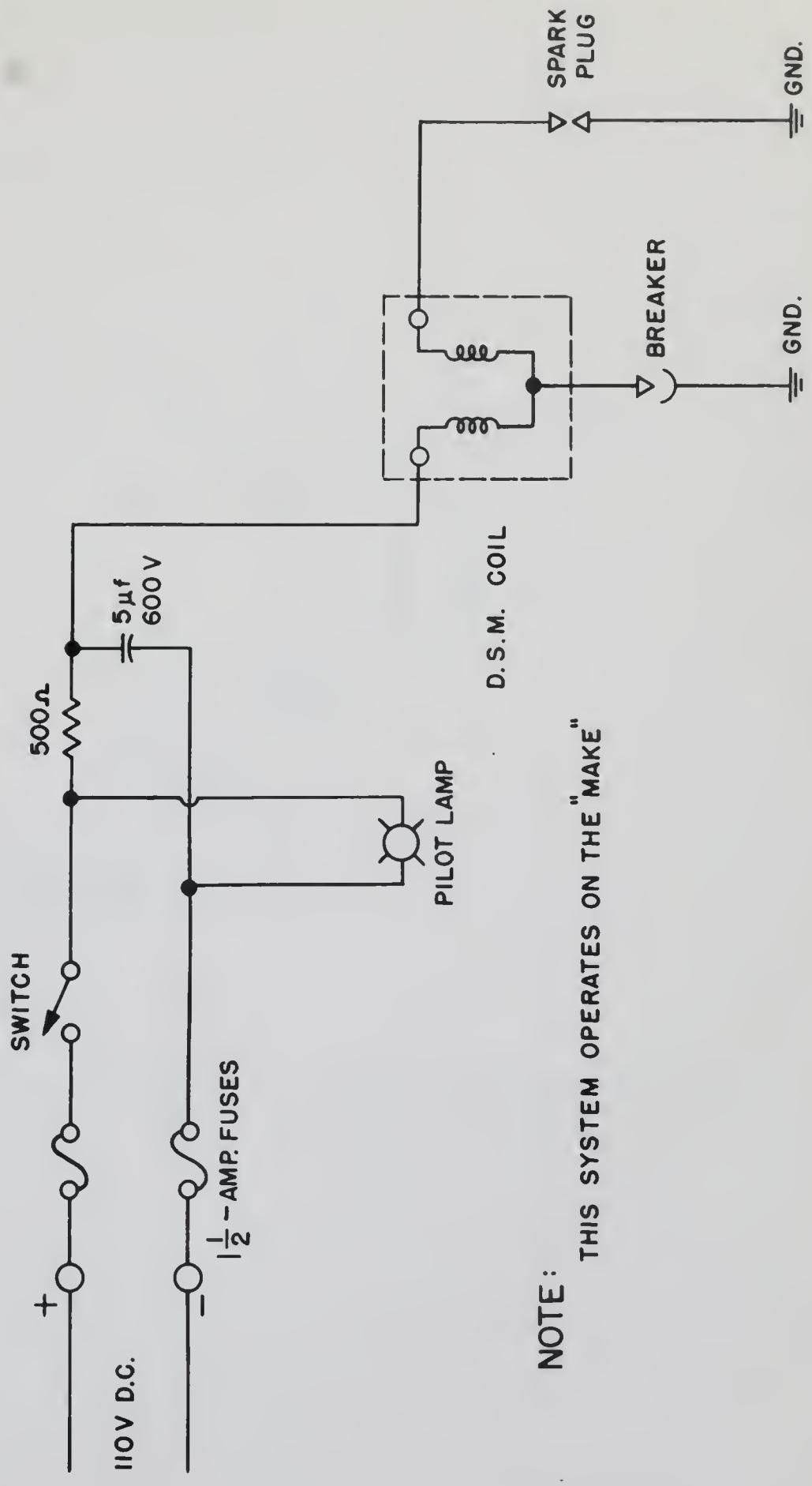
M. I. T.

FIG. 4



WIRING DIAGRAM OF STAR DYNAMOMETER - CFR ENGINE SETUP

FIG. 5

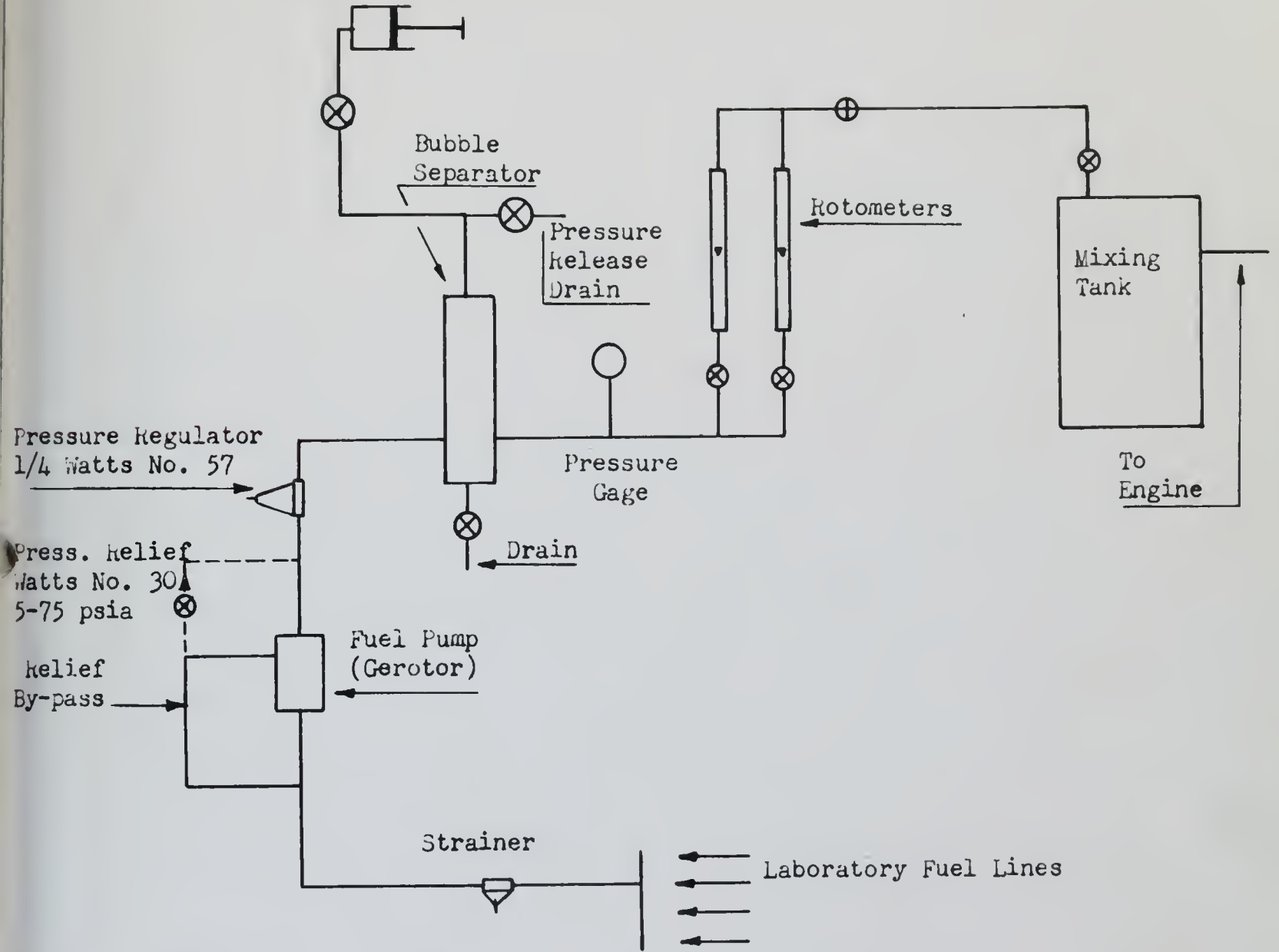


NOTE: THIS SYSTEM OPERATES ON THE "MAKE"

WIRING DIAGRAM OF IGNITION SYSTEM

FIG. 6

Hand Pump for Maintaining Pressure in Bubble Tank



SCHEMATIC DIAGRAM OF FUEL SYSTEM

Fig.7

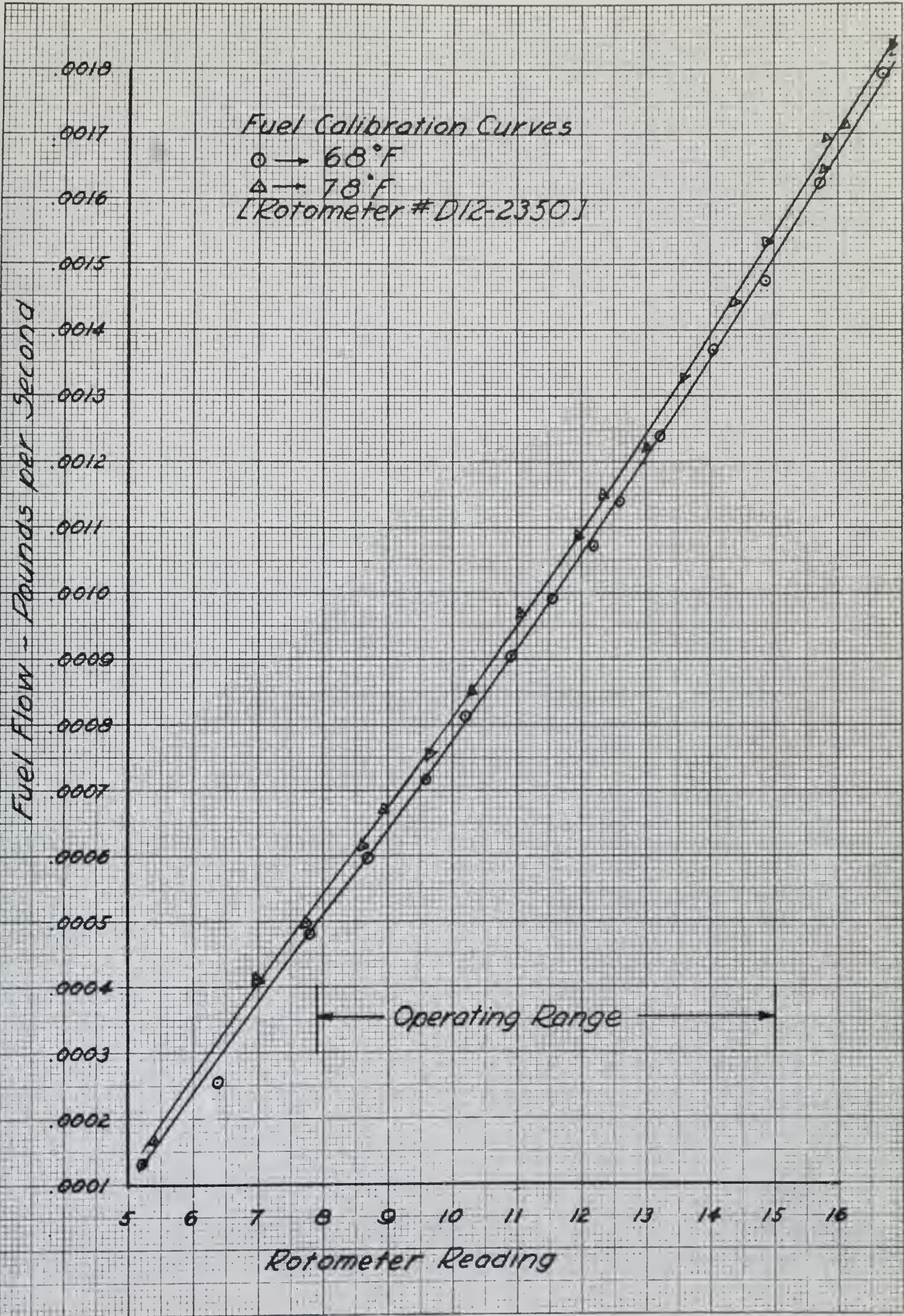


Fig. 8

Water Calibration Curve
Temperature - 80°F
[Rotometer # 398034]

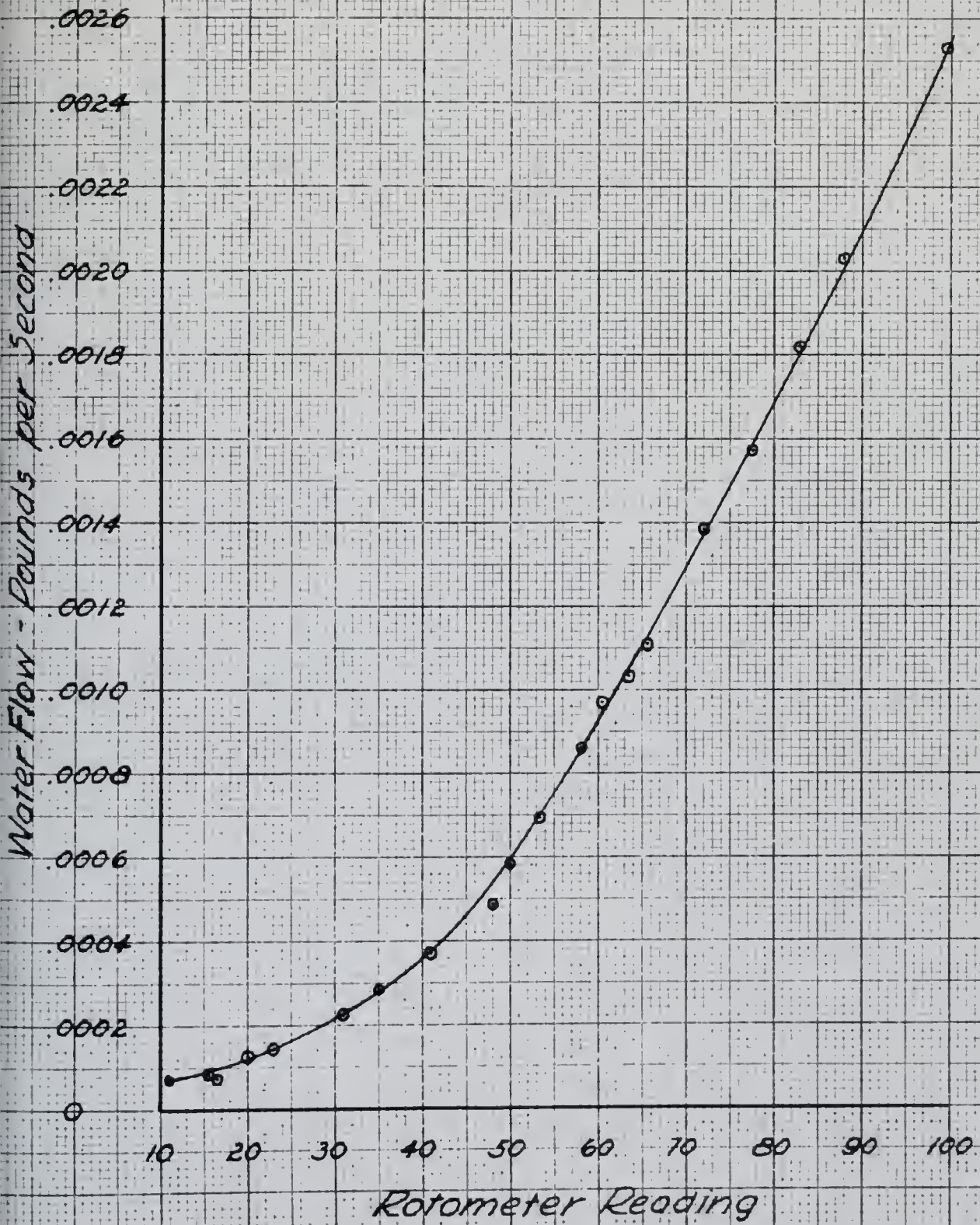
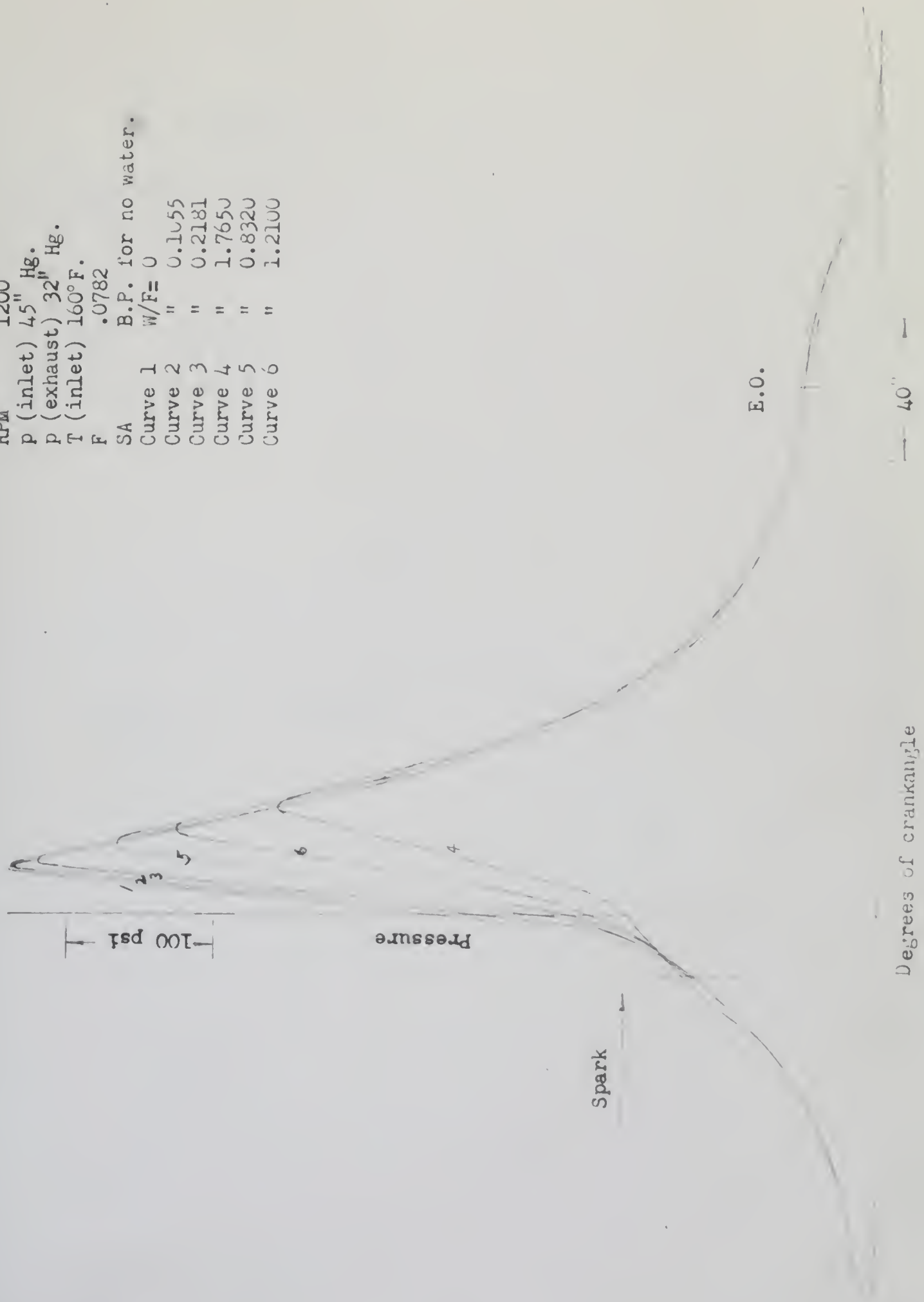


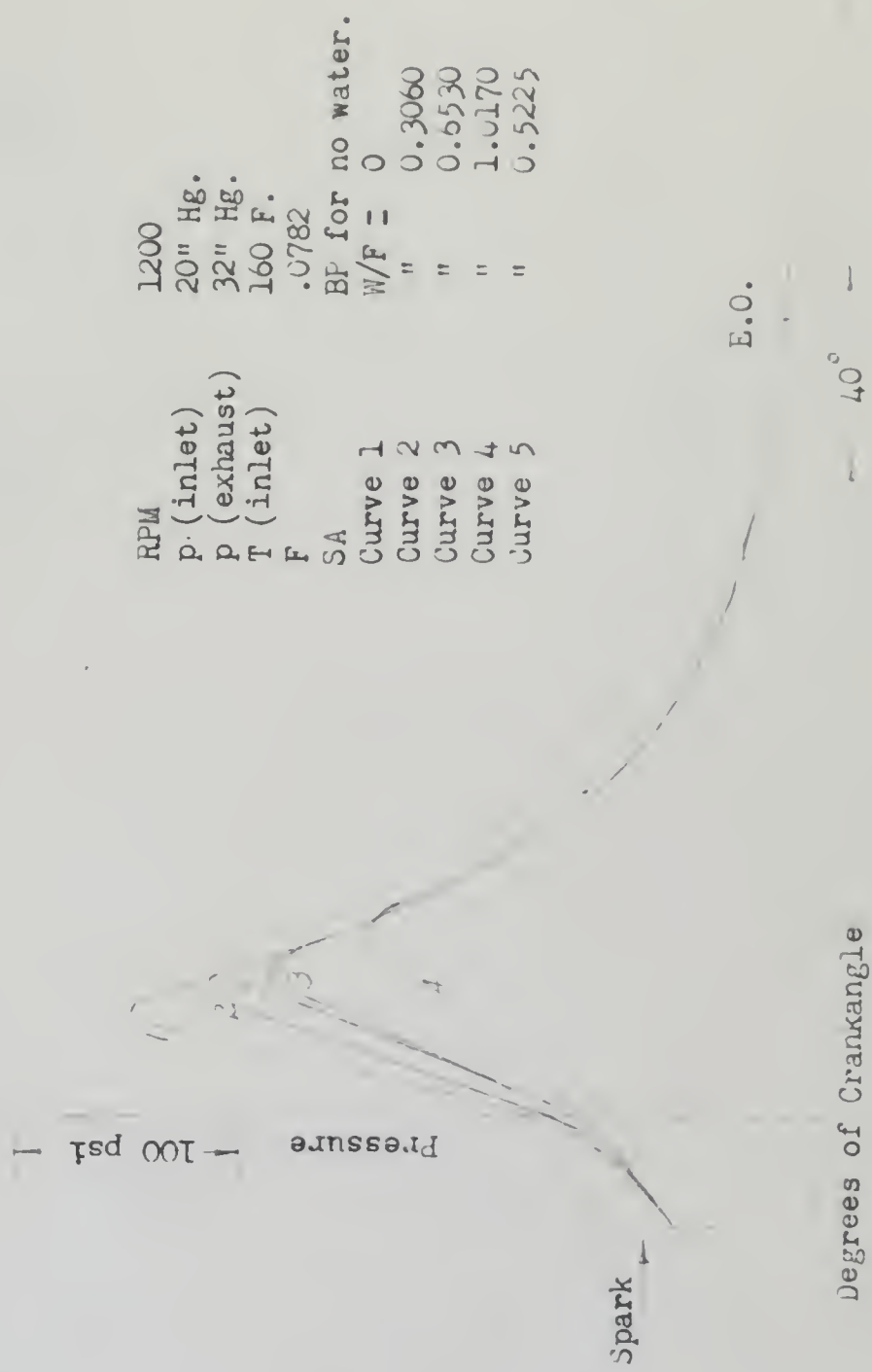
Fig. 9

RPM 1200
 p (inlet) 45" Hg.
 p (exhaust) 32" Hg.
 T (inlet) 160°F.
 F .0782
 SA B.P. for no water.
 W/F= 0
 Curve 1 0.1055
 Curve 2 0.2181
 Curve 3 1.7650
 Curve 4 0.8320
 Curve 5 1.2100
 Curve 6



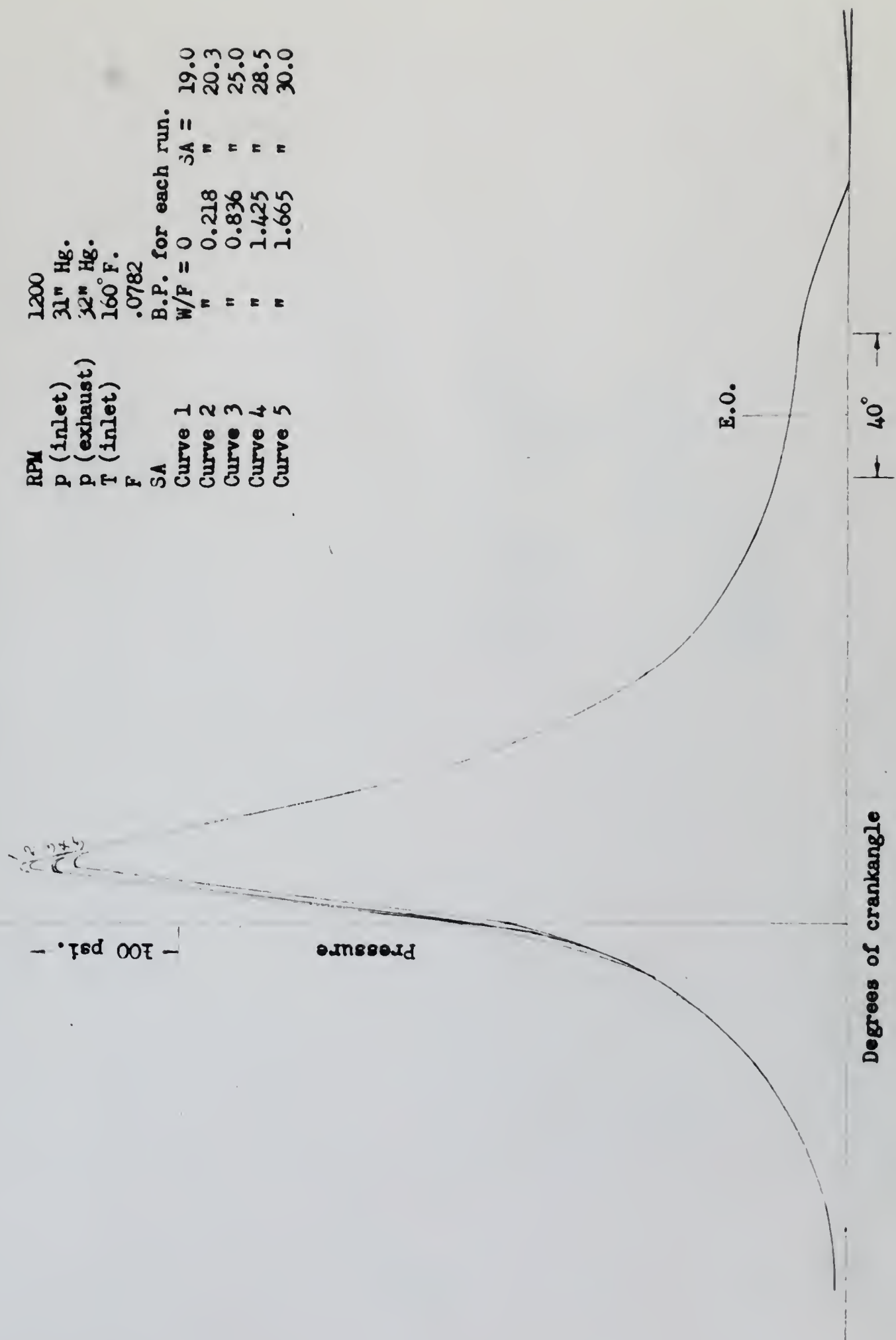
Degrees of crankangle

Fig. 10



RPM	1200
p. (inlet)	20" Hg.
p (exhaust)	32" Hg.
T (inlet)	160 F.
F	.0782
SA	BP for no water.
Curve 1	W/F = 0
Curve 2	" 0.3060
Curve 3	" 0.6530
Curve 4	" 1.0170
Curve 5	" 0.5225

Fig. 12



RPM	1200
p (inlet)	31" Hg.
p (exhaust)	32" Hg.
T (inlet)	160° F.
F	.0782
SA	B.P. for each run.
Curve 1	W/F = 0 SA = 19.0
Curve 2	" 0.218 " 20.3
Curve 3	" 0.836 " 25.0
Curve 4	" 1.425 " 28.5
Curve 5	" 1.665 " 30.0

Fig. 13

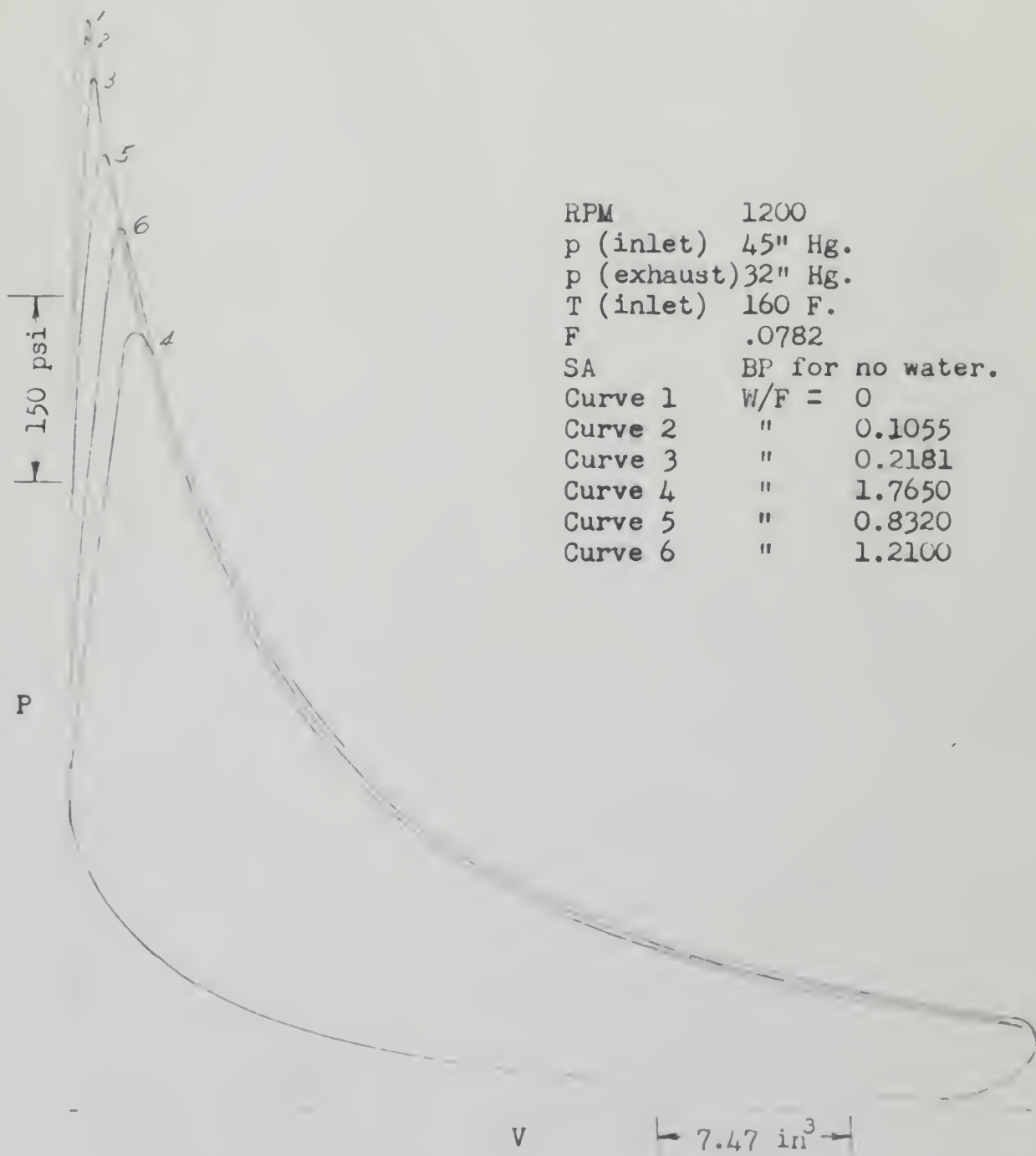
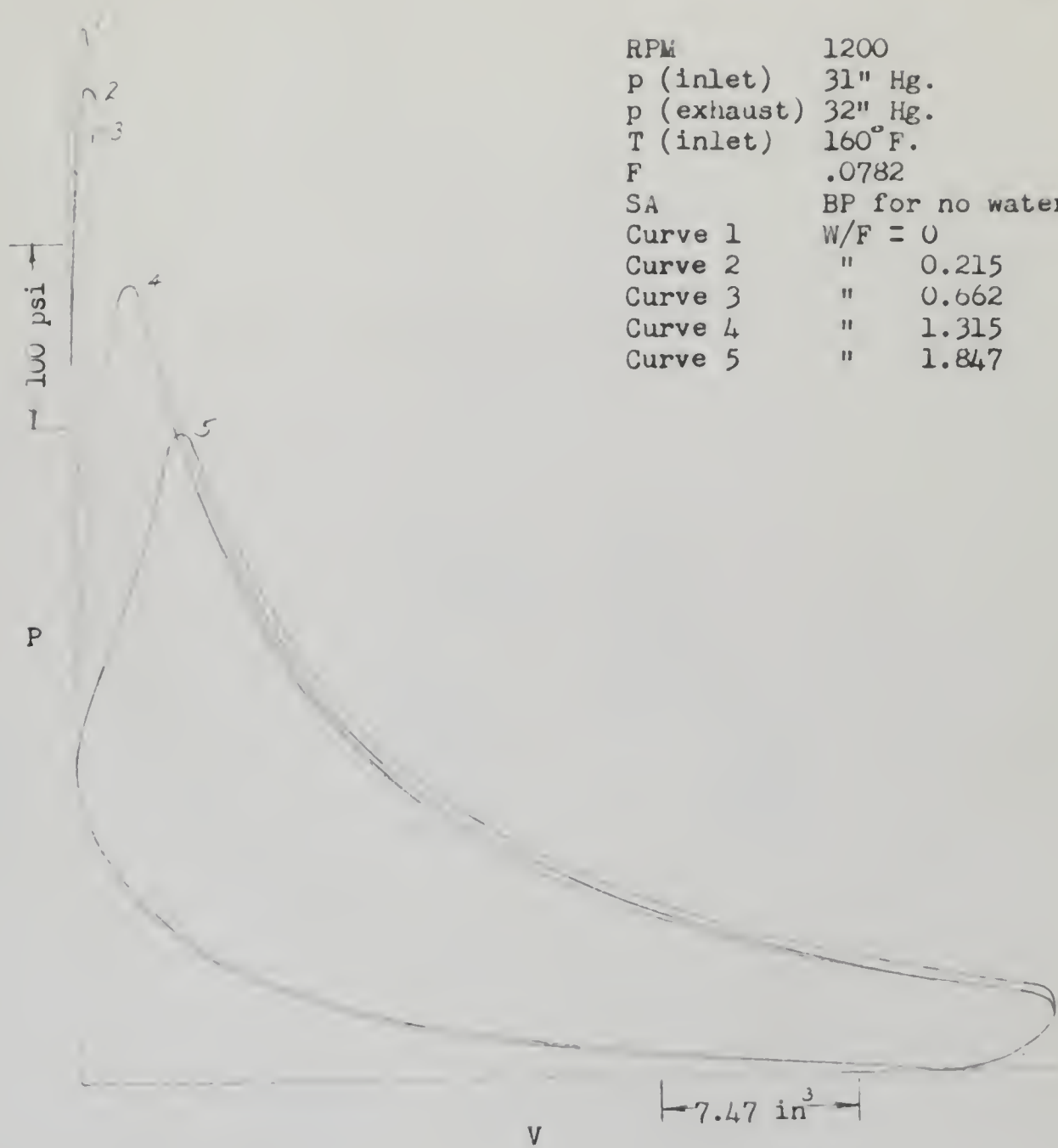


Fig. 14



RPM	1200
p (inlet)	31" Hg.
p (exhaust)	32" Hg.
T (inlet)	160°F.
F	.0782
SA	BP for no water.
Curve 1	W/F = 0
Curve 2	" 0.215
Curve 3	" 0.662
Curve 4	" 1.315
Curve 5	" 1.847

Fig. 15

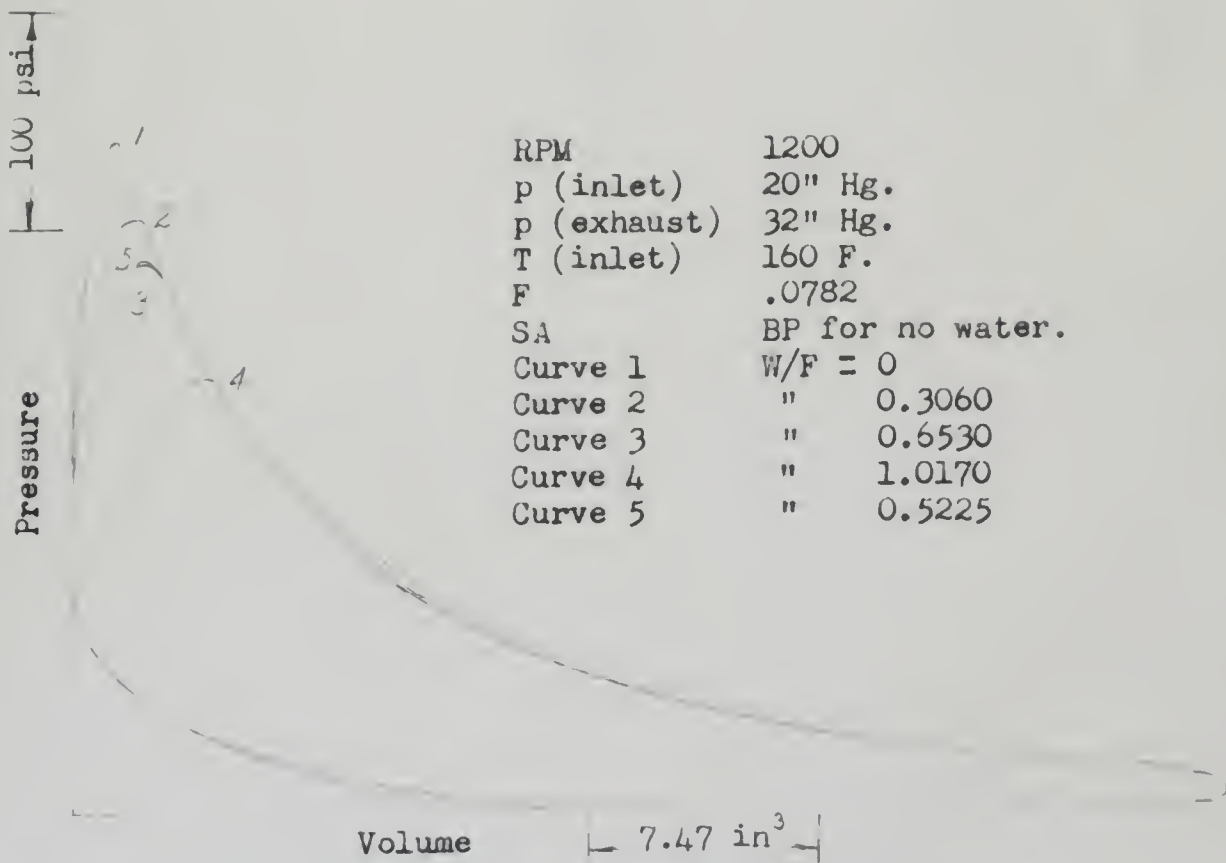
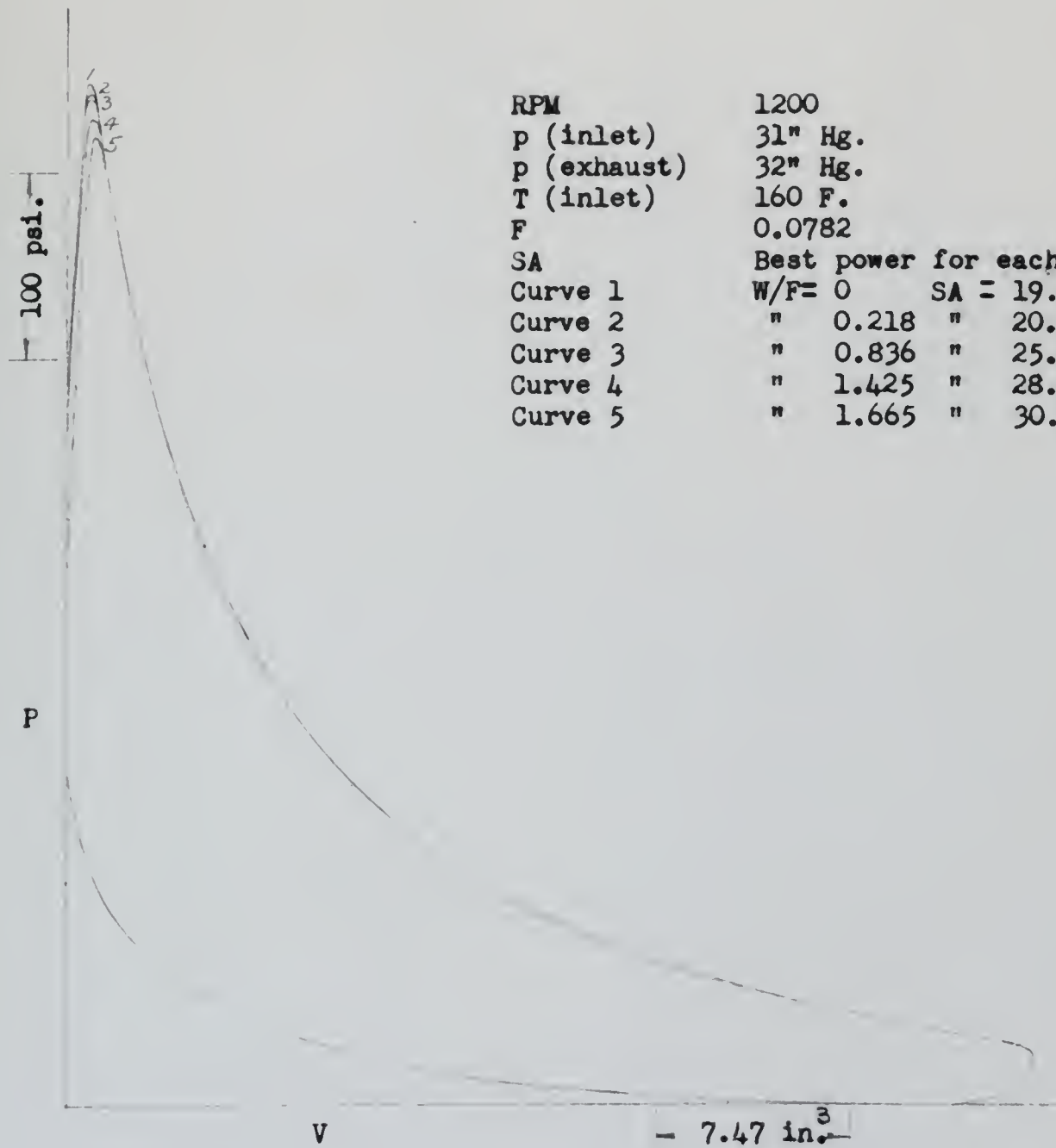


Fig. 16



RPM	1200
p (inlet)	31" Hg.
p (exhaust)	32" Hg.
T (inlet)	160 F.
F	0.0782
SA	Best power for each run.
Curve 1	W/F= 0 SA = 19.0
Curve 2	" 0.218 " 20.3
Curve 3	" 0.836 " 25.0
Curve 4	" 1.425 " 28.5
Curve 5	" 1.665 " 30.0

Fig. 17

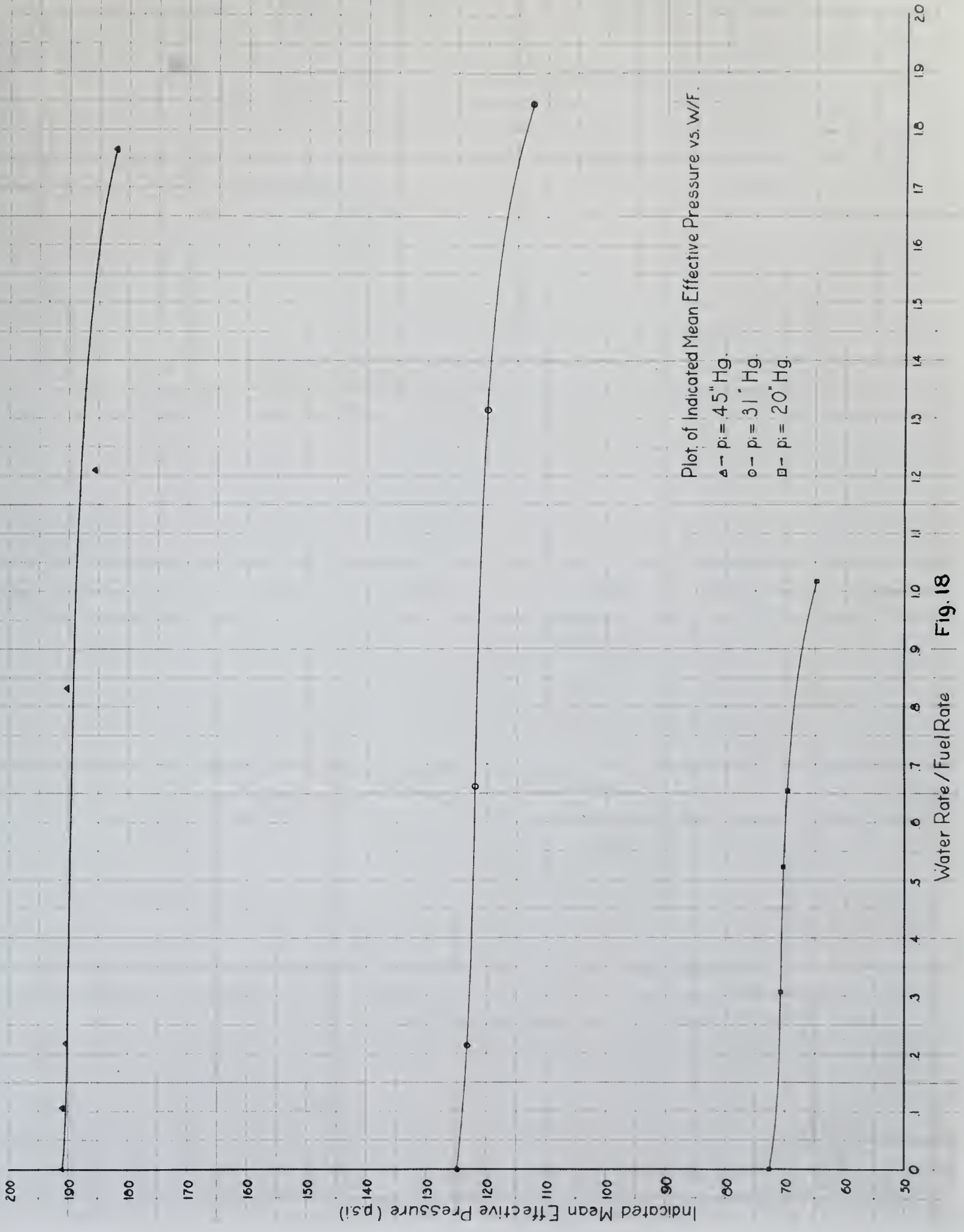


Fig. 18

Plot of Efficiency vs. W/F.

- Δ - $p_i = 45$ " Hg.
- \circ - $p_i = 31$ " Hg.
- \square - $p_i = 20$ " Hg.

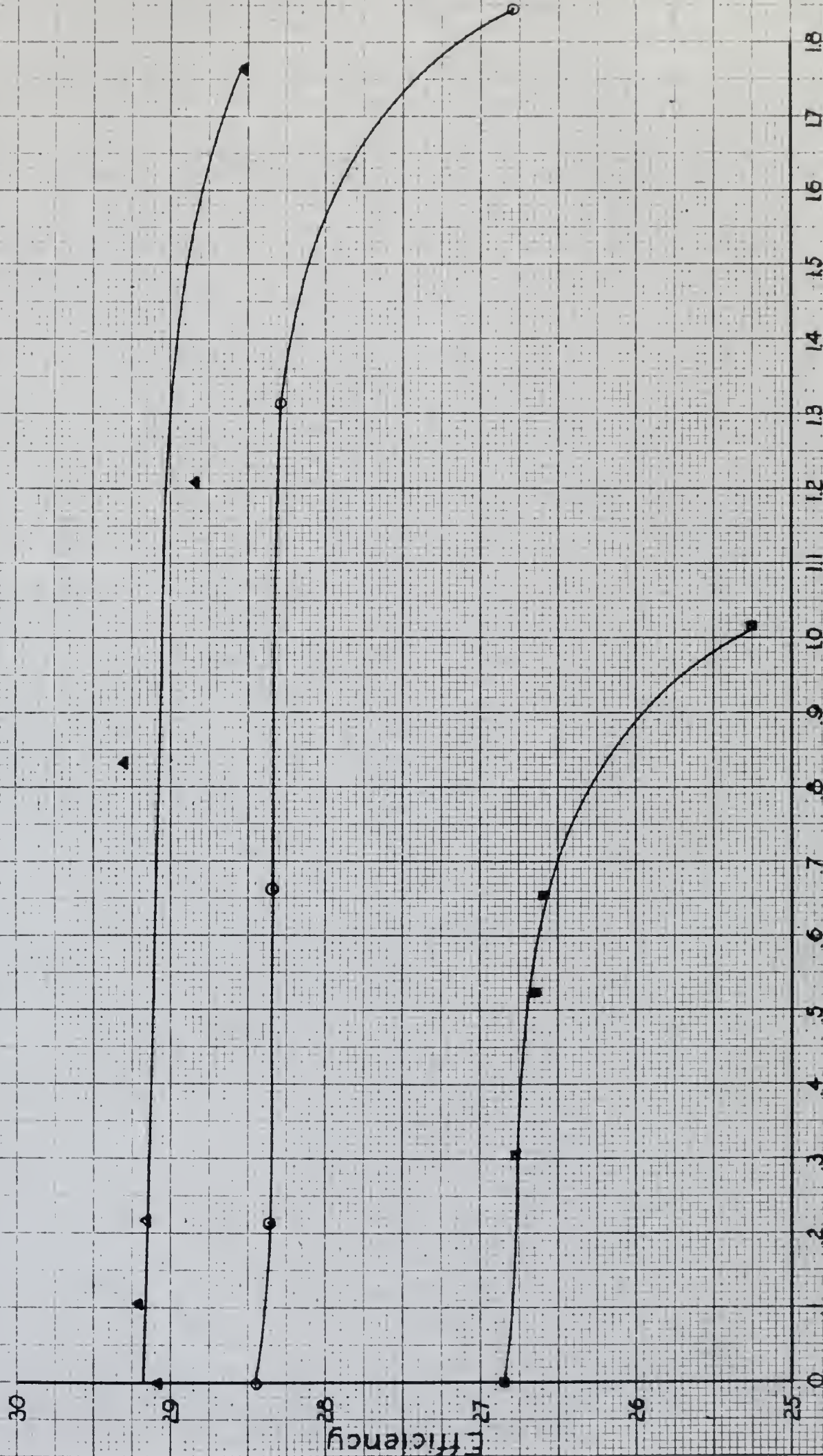
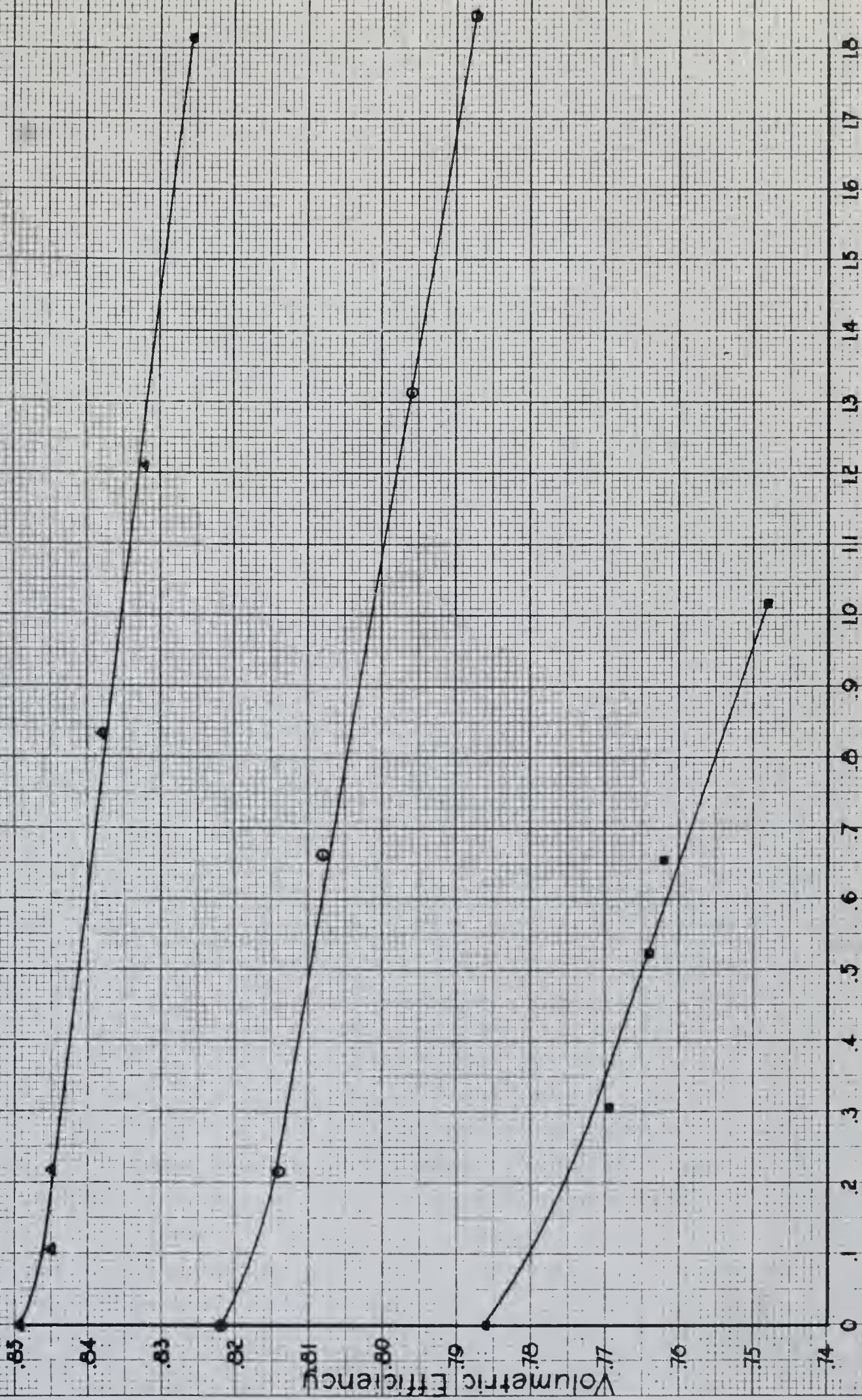


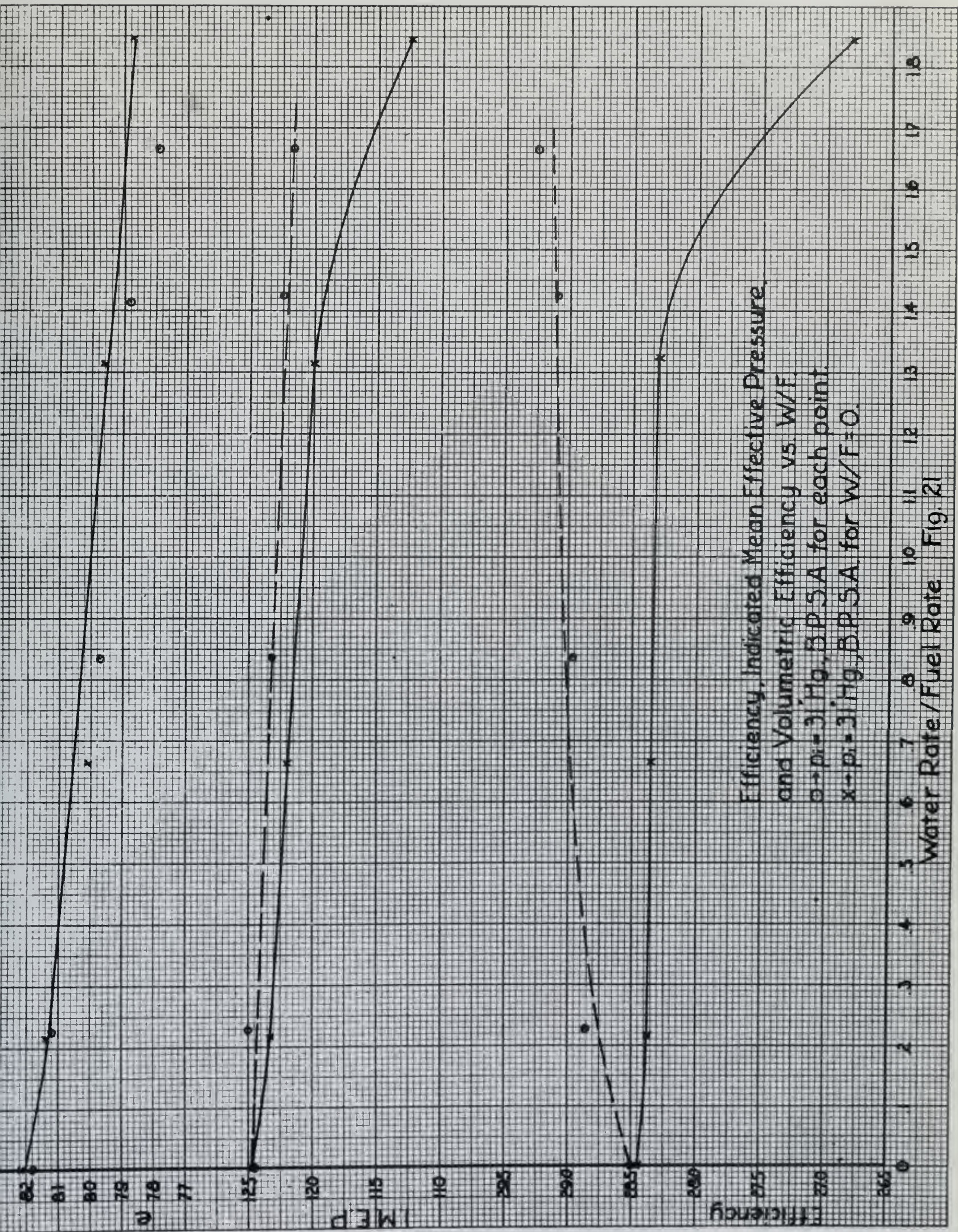
Fig. 19

Plot of Volumetric Efficiency vs. W/F

- $\Delta \rightarrow p_i = 45'' \text{ Hg}$
- $\circ \rightarrow p_i = 31'' \text{ Hg}$
- $\square \rightarrow p_i = 20'' \text{ Hg}$

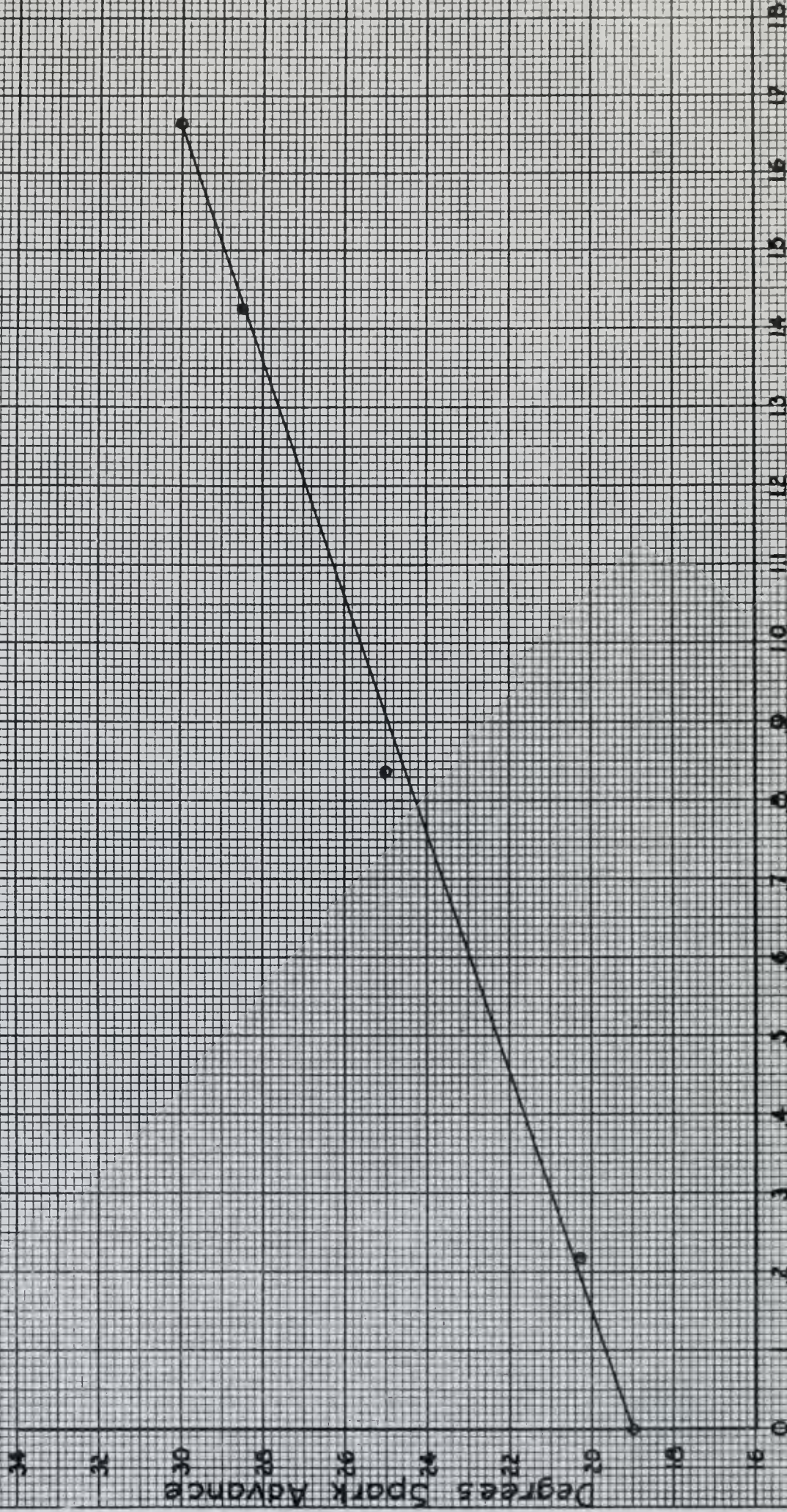


Water Rate/Fuel Rate Fig. 20



Efficiency, Indicated Mean Effective Pressure, and Volumetric Efficiency vs. W/F.
 o \rightarrow $\pi = 31$ Hg, BPSA for each point.
 x \rightarrow $\pi = 31$ Hg, BPSA for W/F = 0.

Plot of Spark Advance vs. W/F
(B.P.S.A. for all points)



Plot of Pressure Rise vs. W/F

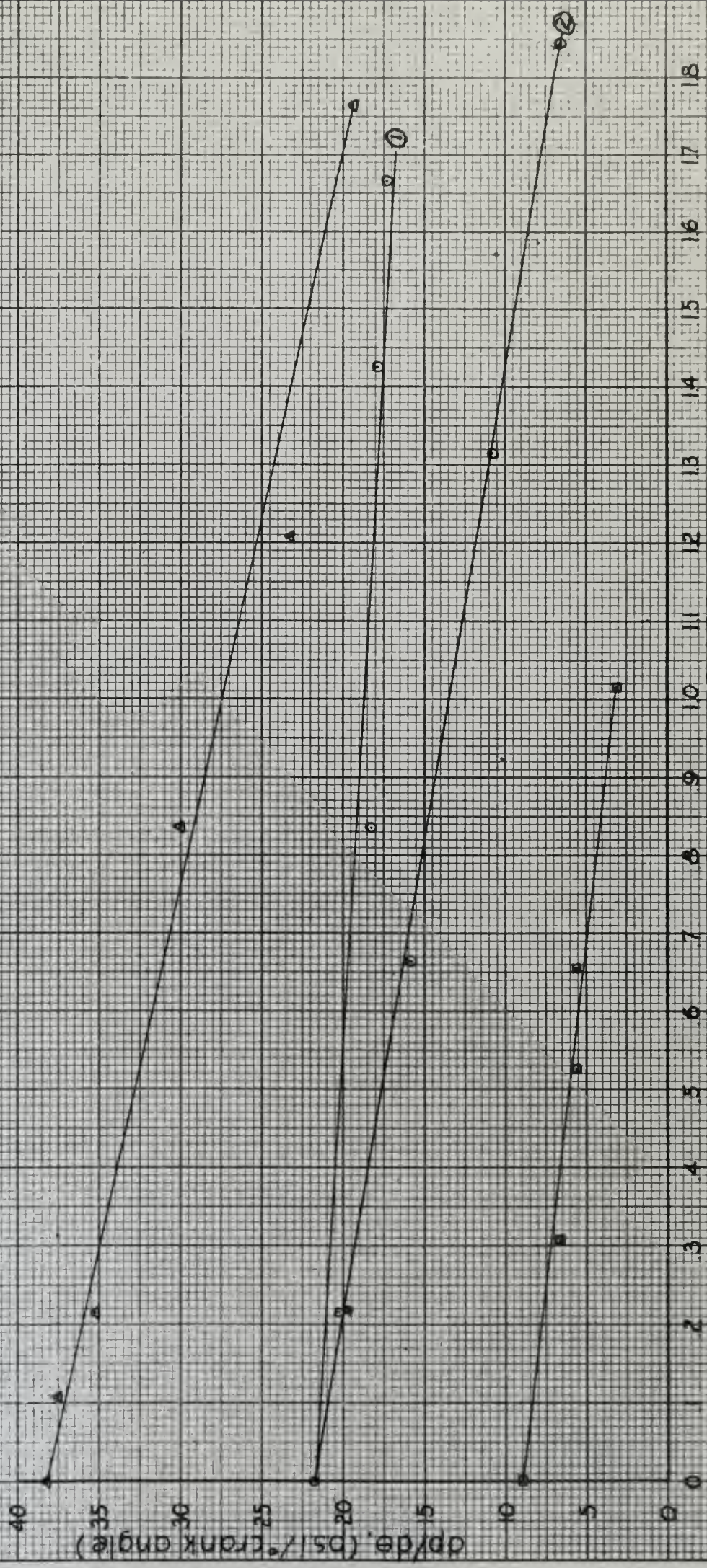
△ - $p_i = 4.5$ Hg.

○ - $p_i = 31$ Hg.

□ - $p_i = 20$ Hg.

Curve 1 - Variable SA (BP for all points)

Curve 2 - Constant SA (BP for $W/F = 0$)



Water Rate/Fuel Rate Fig. 23

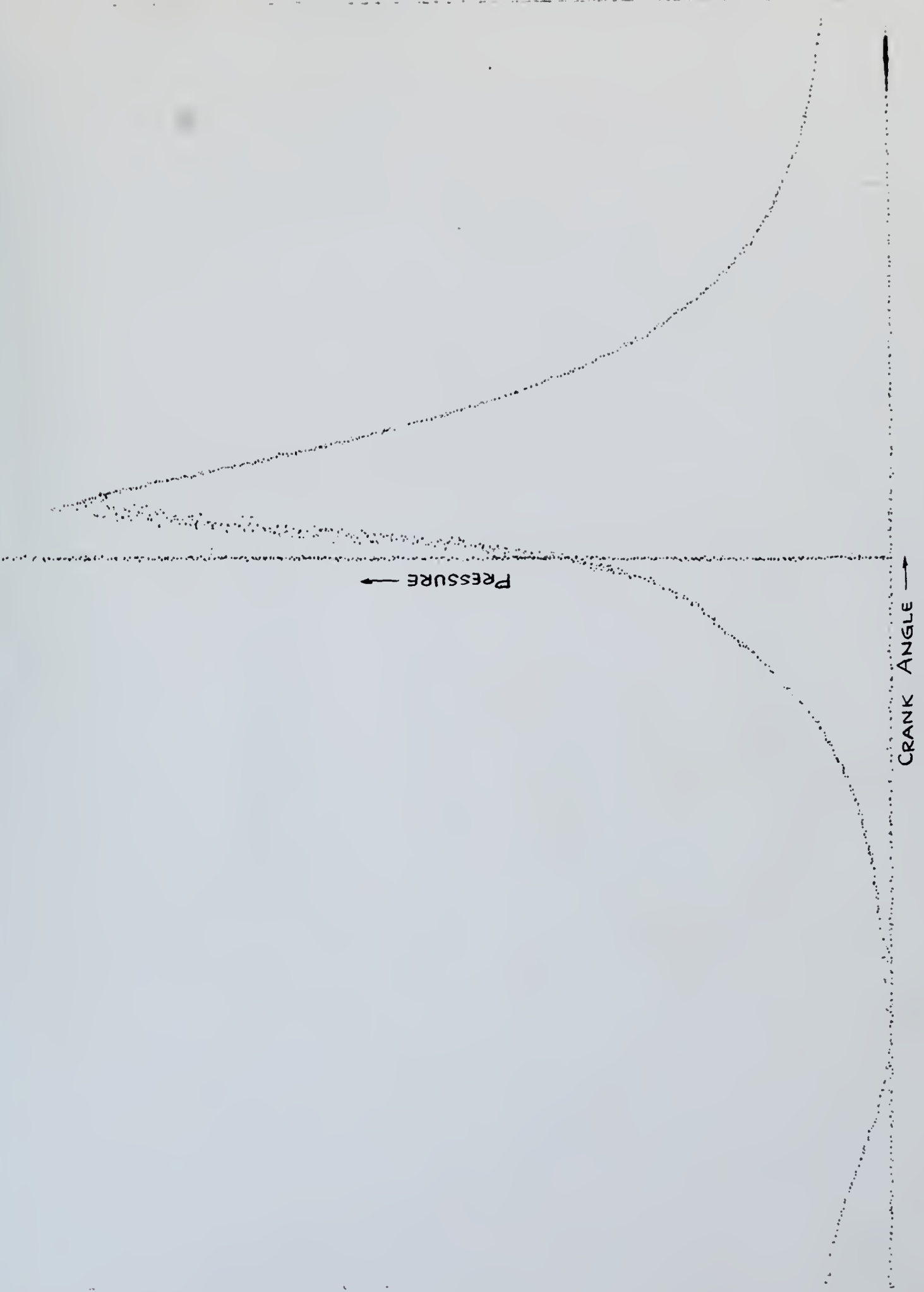
T.D.C.

← PRESSURE

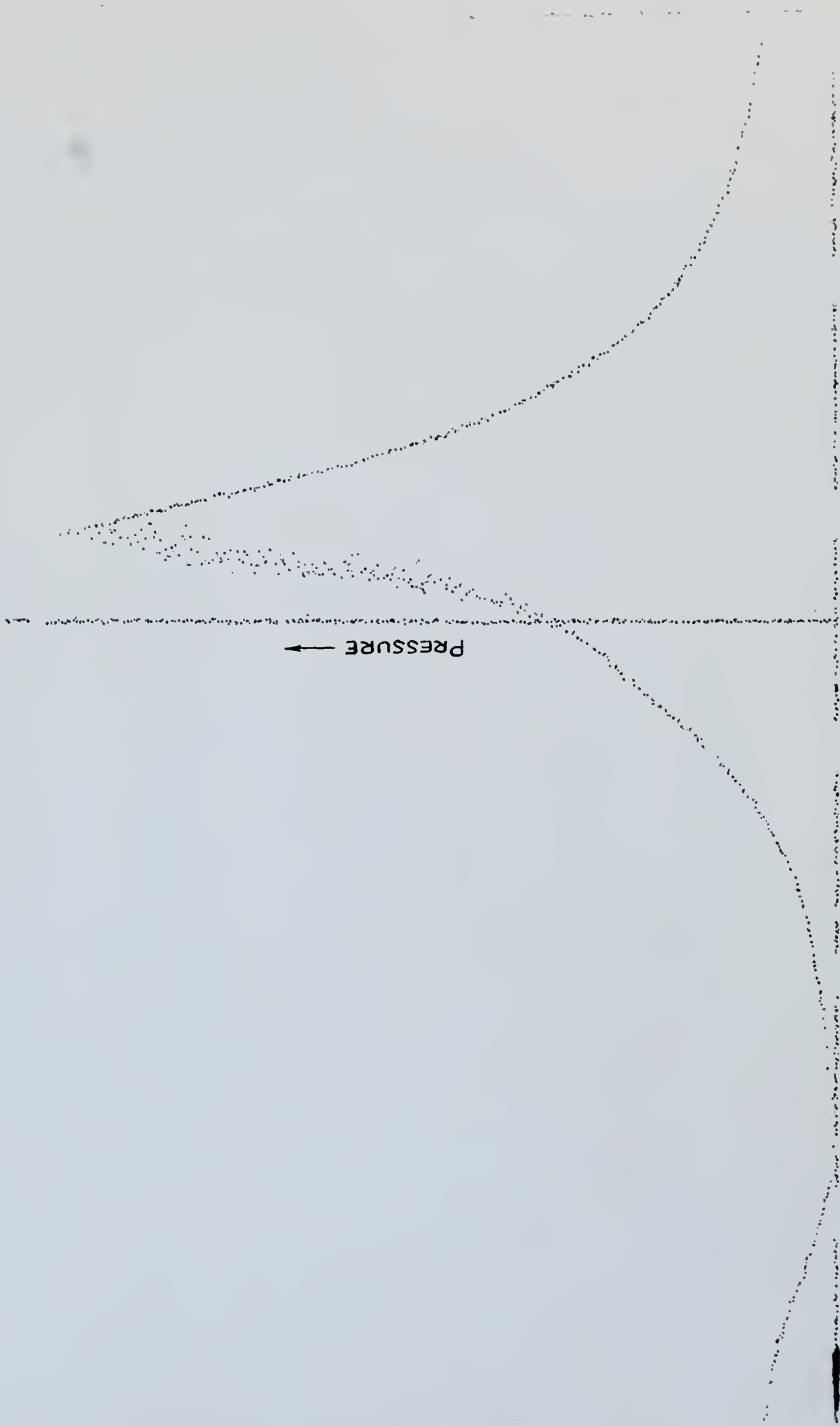
→ CRANK ANGLE

SAMPLE INDICATOR CARD (NO WATER INJECTED)

FIG. 24



T.D.G.

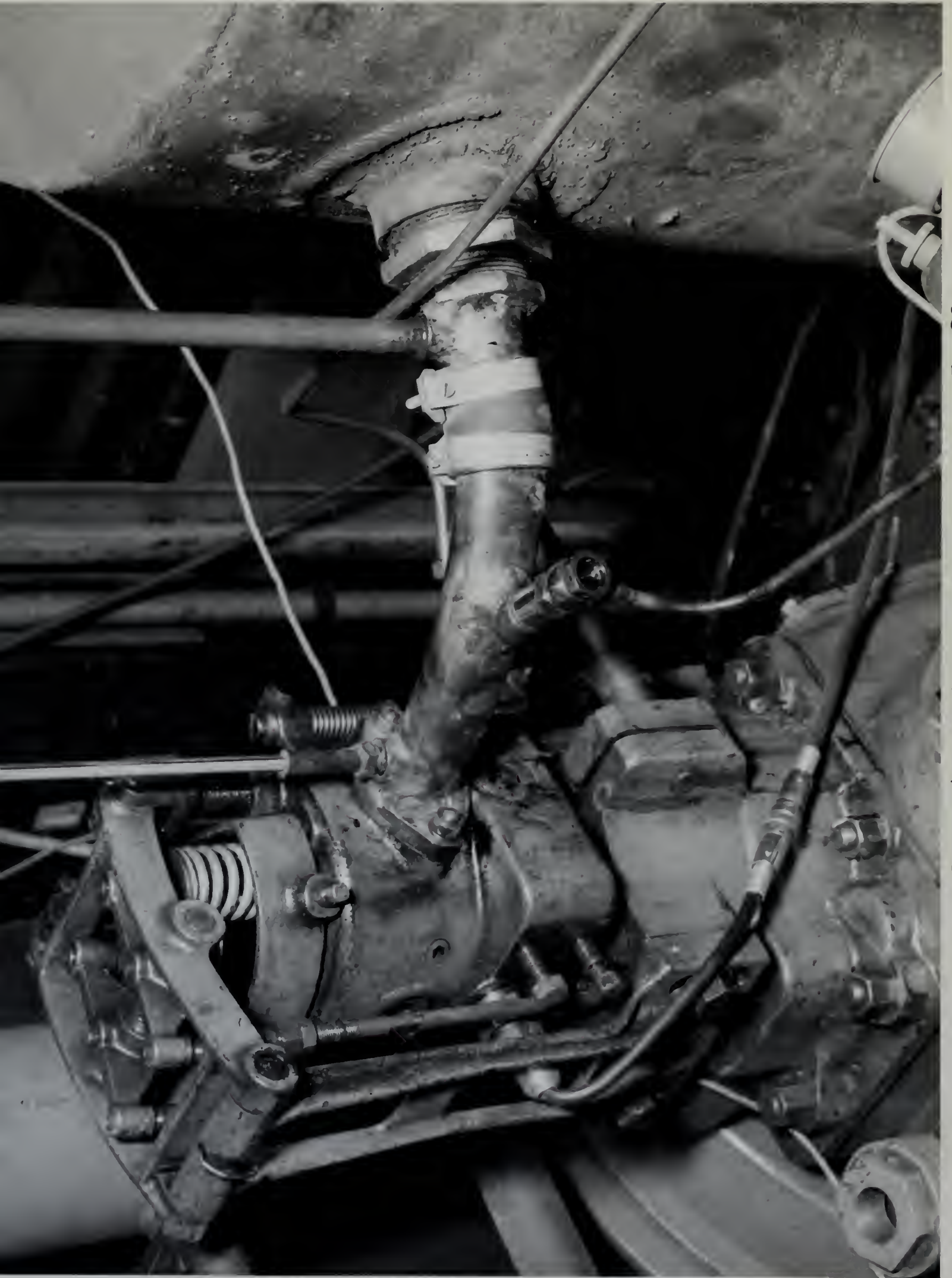


PRESSURE ↑

CRANK ANGLE →

SAMPLE INDICATOR CARD (WITH WATER)

FIG. 25



DETAIL- INLET MANIFOLD AND CYLINDER FIG. 26

8092

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W2 The effect of water injection on the indicator card.

8092

Thesis

Wadsworth

W2

The effect of water injection on the indicator card.

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