THE POSSIBILITY OF INCREASING COMPRESSION RATIOS BY USING WATER AS AN ANTI-DETONANT

By

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A thesis submitted to the Graduate Committe in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.

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INTRODUCTION

In discussing the problem of increasing compression ratios, this investigation will consider its application to the automotive and aviation industries only, since these two fields obviously embrace an overwhelming majority of the internal combustion engines now in use.

During the past eight or ten years engineering enterprises and genius have created from a piece of mechinery, capable of delievering a small amount of power, the present powerful and complex and compact internal combustion engine. What then is to limit its future development? It has formerly been generally conceded that the best method of getting more power from an engine was to increase either the number of cylinders or the size of the cylinders. At present both of these methods seem to be quite definitely checked.

In the automotive field one of the chief requirements of a car is rapid acceleration. Practically every car on the road to-day has more power than it actually needs. If, however, a car were put on the market to-morrow which had acceleration qualities 20% in advance of any model now in use the obsolescence of those cars on the road to-day would be practically instantaneous. The exhilarating joy, performance and ease of driving such a vehicle would give it a near monopoly on the automotive market.

What then prevents a manufacturer from putting a car on the market with power necessary for this increased acceleration?

Consider the two methods of increasing the power previously described. To increase the number of cylinders means to increase the length and weight of the motor. Increasing the length of the motor requires a longer wheel base and a corresponding increase in the weight of structural members. The acceleration qualities of a car are proportional to its power and inversely proportional to its mass. An increase in the power and mass in the same ratio then would gain nothing so far as acceleration is concerned. On the other hand increasing the size of the cylinders entails physical difficulties. Large clearances required for large bore pistons increase oil consumption and carbon formations. Large pistons form a very difficult cooling problem and in many cases the reduction in mean effective pressure incurred by increasing the piston diameters prevents any increase and in some cases causes a decrease in power output. It seems then that sooner or later both of these methods must be discarded due to the inherent difficulties involved.

The methods then remaining are:

(1) To increase the speed of the engine

(2) To supercharge the engine

(3) To increase the compression ratio.

Consider these methods in the order named. Increasing the speed of the engine entails lubrication as well as mechanical difficulties. Inertia forces in an engine increase rapidly as the speed of revolution is increased and present a serious problem. There seems to be little room left for exploitation in this field unless new and extremely light metals or alloys are developed.

Supercharging also presents serious mechanical difficulties and requires expensive equipment. Exhaust temperatures in a super charged engine run very high and comprise a difficult cooling problem.

Consider then the problem of increasing the compression ratio. There seems to be only one major problem to be confronted and that is detonation. Many of the other supposed difficulties when studied and analyzed more closely are found to be actual assets. For example, it is commonly considered that a high compression pressure will tend to pound out the bearings. Actual tests of the bearing pressures in an engine prove that this is not true except for engines operating at low speeds. Earl Bartholemew of the engineering laboratory of the Ethyl Gasoline Corporation says "To the uninitiated it might appear that an increase in compression ratio causes an increase in bearing loads. Actually however, the average bearing load can ordinarily be materially diminished by an increase in compression ratio. This seeming paradox is due to the fact that the inertia forces of an engine are almost invariably larger than those due to gas pressure". Figures 1B, 2B, and table 1B, in Appendix B show the results of a test on bearing pressures in both airplane and automobile engines. Heat balances in a high compression engine show that more of the heat is given up to power and that less is left to be dissipated through the exhaust and cooling water than in a low compression engine. This fact is of importance in the field of aviation because it means that radiators may be made smaller thus reducing the frontal area and wind resistance.

There seems then to be only one deterrent factor which prevents our taking advantage of the possibilities concurrent with increasing the compression ratios and that factor is detonation.

Engineering experiment and research have shown that detonation may be decreased by the addition of certain anti-detonating fluids to the fuel charge. We have literally dozens of chemical compounds and some elements which will limit detonation when added to the fuel mixture, however, expense and destructive properties of these compounds limit their use. To date the most commercially successful anti-detonant has been tetraethyl lead. However tetraethyl lead is expensive and does not adequately provide for an extreme increase in compression ratios. It also produces a deadly vapor on combustion which makes its use in large quantities outlawed.

We have on hand an extremely cheap and plentiful compound which is at the same time an anti-detonant, that compound is water. Water, in spite of its abundance and cheapness, provides a very difficult problem if we attempt to use it as an anti-detonant. It will not mix with gasoline and we cannot introduce it into the engine in that manner. Due to its relatively high surface tension water is difficult to carburate. However, if a means were found for controlled injection of water into an engine, what compression ratio would it enable us to use in the average internal combustion engine? It is to that problem that this investigation will be confined.

REVIEW OF LITERATURE

J. A. Moyer and J. P. Calderwood in their bulletin on The Prevention of Pounding in Kerosene Engines, (Bulletin Number 10, Pennsylvania State College Annual Report 1913-14) determine that running the engine with the spark advance at dead center gives a minimum of pounding.

G. W. Hobbs and M. L. Surl in their bulletin The Effect of Varying Compression Ratio and Inlet Temperatures on Engine Performance, (Pennsylvania State College 1933) state: "As the spark setting is advanced the power increases up to the point of detonation for any given compression ratio. Spark setting is dependent on compression ratio for a given fuel. The rate of decrease of power after detonation sets in is dependent upon compression ratio and is uniform in rate. The same power may be obtained from an engine by using a small spark advance and high compression ratio or a greater spark advance and lower compression ratio.

Carl A. Norman in The Economical Utilization of Liquid Fuel, (Ohio State University, 1921) says, "Water acts as a knock suppressor simply by absorbing in its evaporation some of the heat of combustion. "The reputed efficiency of water in small quantities as a carbon remover has been rendered highly questionable by recent tests of the Bureau of Standards".

Altho a good deal of literature is available concerning various phases of the detonation problem, the author found no record of an attempt to raise compression ratios to an extreme by using large quantities of water as a knock-suppressor.

Records were found of attempts to gain high compression ratios by using ethyl fluid as an anti-detonant. The highest compression ratio used to the authors knowledge was 8.61 to 1.

OBJECT OF INVESTIGATION

It will be the object of this experiment to determine to what compression ratio a single cylinder gasoline engine may be raised by injecting water with the air-fuel mixture to control detonation.

In the course of the tests run, this investigation will attempt to check the work done by Mr. G. B. Lea in the mechanical laboratory of the Virginia Polytechnic Institute. This work was done in 1935 and published under the title, An Investigation of the Effect of Water-Gasoline Mixture on the Performance of an Internal Combustion Engine.

If, in the investigation, it is found feasible to raise the compression ratio to any extent above that for which the engine used has been designed, an attempt will be made to study the effect of water injection on the lubrication of the engine and on the carbon deposits in the combustion chamber.

PLAN OF PROCEDURE

A small internal combustion engine operating on the Otto cycle was selected for the investigation.

By careful calculation the volumetric compression ratio of the engine was determined. This compression ratio was found to be approximately 6.0 to 1. Since the engine had been designed to operate at this compression ratio it was not deemed necessary to run tests to determine whether it would operate satisfactorily or not. The cylinder block was then planed down a carefully predetermined amount to raise the compression ratio to 6.5 to 1. At this ratio an exhaustive set of tests was run to determine the power output, specific fuel consumption and general running characteristics of the engine. The cylinder block was then planed down to increase the compression ratio to 7.0 to 1. Similar tests were again run to determine the operating characteristics of the engine. The same procedure was followed for each successive compression ratio.

METHOD OF PROCEDURE

An attempt was made to run the tests at each successive compression ratio as nearly as possible in accordance with the A.S.T.M. standards. The A.S.T.M. standards as published in the, A.S.T.M. Standards on Petroleum Products and Lubricants, prepared by committee D-2 and published in September 1935, specify a C.F.R. engine. Such an engine was not available so strict accordance was not feasable for this investigation.

With the engine at a compression ratio of 6.5 to 1 the first set of tests was run. The engine was started and allowed to thoroughly warm up so that the jacket water temperature maintained a constant value. After the warming up period the throttle opening was set to about 90% of wide open, which gives maximum volumetric efficiency according to the A.S.T.M. The carburetor needle was then set to give maximum power output. The water needle was set to 25 graduations and the engine speed controlled to 900 R.P.M. by advancing or retarding the spark advance.

Fifty cubic centimeters of gasoline were allowed to run through the measuring burrette and the time for consumption carefully noted and recorded. The water consumption during this time was determined by recording the difference in the level of the water flowing through the water measuring burrette. The power output was observed and recorded as were the readings of the knockmeter and jacket water temperature. The water carburetor needle was then reduced to 20 graduations and the same procedure repeated. Similar runs were made for each variation of the water needle in steps of five graduations from 25 to 0.

When this set of runs had been completed an identical set was made with the exception that the water needle settings were varied in the reverse order, that is, from 0 to 25.

In this manner four complete sets of runs were made in order that any possible discrepancies during any one of the runs might be noted.

When the four sets of runs had been completed, the engine was dismantled and the cylinder block turned down a carefully determined amount to raise the compression ratio to 7.0 to 1. With the engine at a compression ratio of 7.0 to 1 four similar sets of runs were made, the engine was then again dismantled and the cylinder block turned down to raise the compression ratio to 7.5 to 1. The same procedure was followed for each successive increase in compression ratio.

While operating the engine at a compression ratio of 6.5 to 1, eight complete sets of runs were made in order to aquaint the author with the operating characteristics of the engine and the carburetion device designed and employed by Mr. G. B. Lea. From these tests it was determined that the two carburetors when connected in parallel did not provide adequate control of the air-fuel ratio. The data to support this has been inserted in the appendix, under the headings Runs 1-8 inclusive, Appendix A.

A modification in the carburetion arrangement was then made which provided a sensitive and adequate control over the air-fuel ratio. This revised carburetion apparatus was used in all of the runs succeeding those listed 1-8, Appendix A.

APPARATUS

Engine: The engine used for this investigation was developed by the Ethyl Gasoline Corporation for the comparison of the detonation characteristics of gasolines and was designed for use in the Ethyl Gasoline Corporation's laboratories. Several parts of a 1250 watt Delco lighting plant have been incorporated in both the engine and generator. The crankshaft, gears, connecting rod and rocker arms are the same as those used in a Model 850 Delco Lighting Plant. Other parts such as the cylinder, cylinder head, camshaft, valves, valve springs, piston, piston rings etc, are special and may be obtained only from the Ethyl Gasoline Corporation.

Cylinder: The cylinder is made of steel, has a 2½ inch bore and is completely water jacketed. The top of the cylinder is so designed that the cylinder head gasket is completely shielded from the hot combustion gases.

Cylinder Head: The cylinder head is of cast iron and so designed that intake and exhaust ports and spark plug and bouncing pin openings are completely surrounded by cooling water.

Piston: The piston is of an aluminum alloy and specially designed for the rapid dissipation of heat. It has three compression rings and two special oil grooves designed to keep at a minimum the amount of oil which passes from the crankcase to the combustion chamber.

Ignition System: Ignition current for starting is supplied by a 6 volt battery. After starting, current is taken from the generator after having been reduced to 6 volts by a series resistor coupled to the ignition coil. The change in ignition is effected by means of a double-pole, double-throw jacknife switch. The ignition system is of the Bosch, high tension, jump spark type.

Spark Plug: The spark plug used in the investigation is an A.C. No. 575 especially designed for high compression ratios.

Valves: Both intake and exhaust valves are made of special alloy steel. A special camshaft is used which gives the following valve timing:

(1) Intake opens 20 degrees plus or minus 10 degrees after top dead center.

(2) Intake closes 10 degrees plus or minus 10 degrees after bottom dead center.

(3) Exhaust opens 55 degrees plus or minus 10 degrees before bottom dead center.

(4) Exhaust closes 10 degrees plus or minus 10 degrees after top dead center.

Carburetors: Two Schebler DLX-87 carburetors were used in the original set-up as designed by Mr. G. B. Lea. These carburetors were placed one on each side of a bronze chamber which was directly connected to the combustion chamber. To direct the flow of the water and gas mixture into the combustion chamber Mr. Lea used a wooden double entry port located in the bronze chamber.

When, due to the discrepancies in results obtained, it was decided that this set-up was unsatisfactory an attempt was made to remedy the situation by constructing an aluminum double port entry valve to take the place of the wooden one. The aluminum port did not remedy the situation, altho it was constructed to much closer tolerances than was the wood port.

A new system of carburetion was then devised. The two original carburetors were connected in series so that the incoming air charge would pass through the water carburetor before entering the gasoline carburetor, from the gasoline carburetor the water, gas and air mixture passes into the combustion chamber. The choke valve was removed from the gasoline carburetor.

Cooling System: An evaporative system was used to cool the engine for the purpose of maintaining constant temperature. Vapor passing from the system at the top of the head water jacket was condensed in a small water cooled condenser and then returned to the water jacket at the base of the cylinder.

Generator: The generator directly connected to the motor base was specially wired by the Ethyl Gasoline Corporation to permit loading to capacity at speeds as low as 500 R.P.M. The field was connected in series with the armature which was in turn connected in series with the resistance coils fastened to the back of the panel board and used for loading the engine.

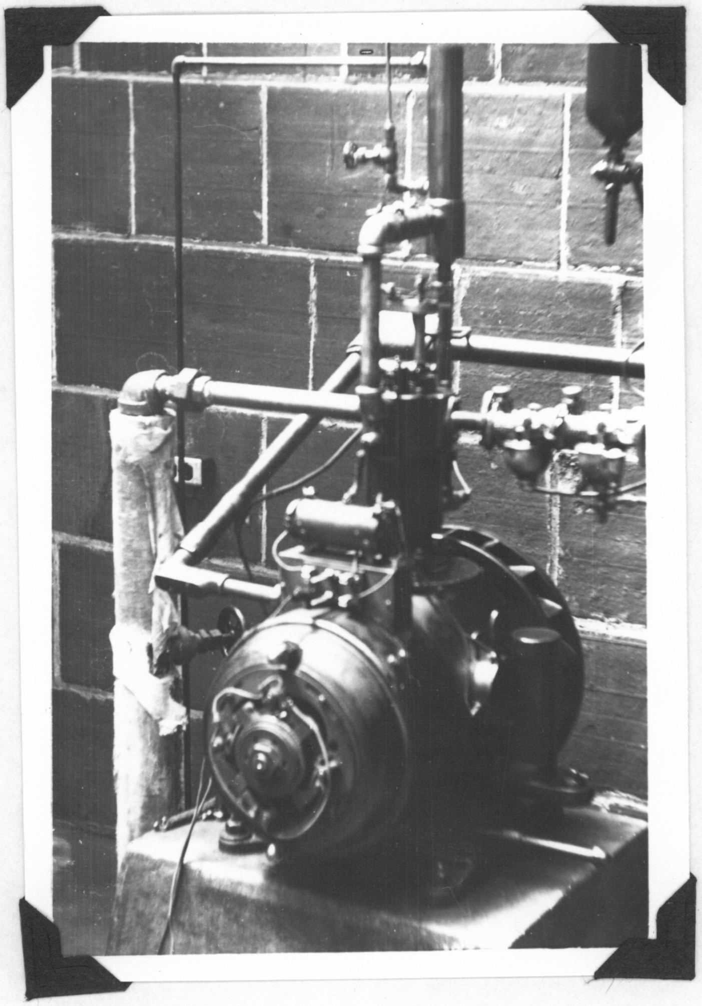
METERING DEVICES

Knockmeter: The knockmeter consists of a Midgely bouncing pin incorporated in series with a heater element in a millivoltmeter and a source of direct current. The intermittent current pulsations through the bouncing pin circuit heat the resistance wire in the millivoltmeter. The conduction to the hot junctions of the thermocouple assembly of the portion of the heat generated in the resistance wire raises the temperature of the hot junctions and generates a current in the thermocouple circuit which is indicated by a millivoltmeter on the panel board. Since the temperature attained by the thermocouple assembly is proportional to the heat generated in the resistance unit and since the heat is proportional to the square of the average current, the induction on the millivoltmeter is proportional to the average current flowing through the system. A potentiometer is used to vary the current through the system and to thus control the scale readings.

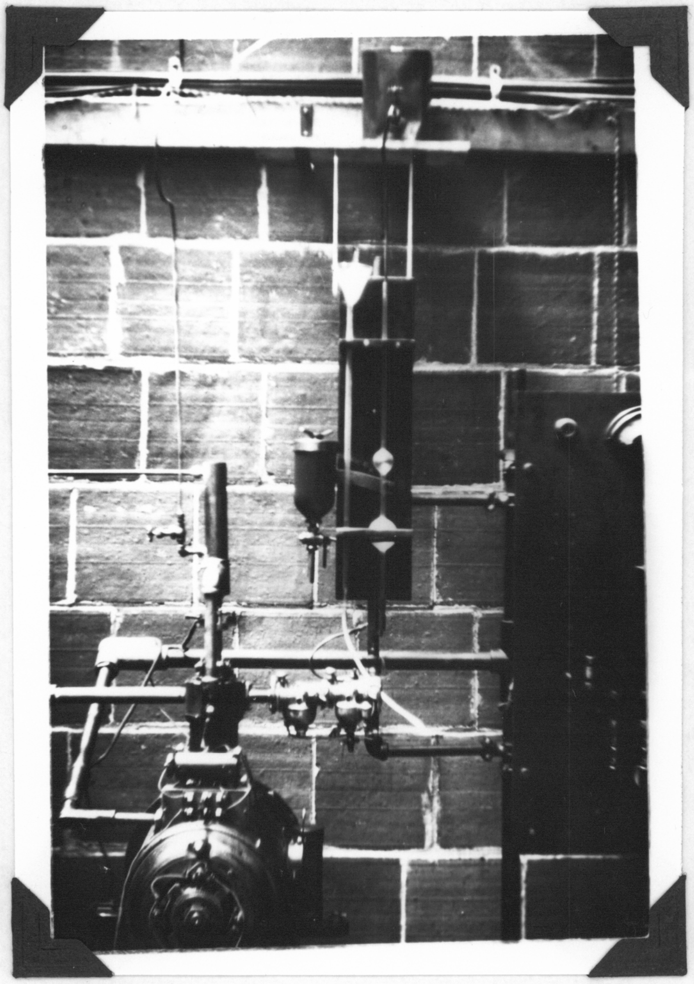
Tachometer: The tachometer is of the electric magneto type. The magneto pulley is connected to the crankshaft of the engine by a belt drive. Current generated in the magneto is used to deflect a needle in a galvonometer set-up. The galvonometer scale is direct reading.

Pyrometer: A thermocouple is used for measuring the temperature of the jacket water. The thermocouple inserted near the base of the cylinder has one iron and one constantan wire which terminate at binding posts on the panel board and are from there connected to a millivoltmeter which is scaled to read directly in degrees.

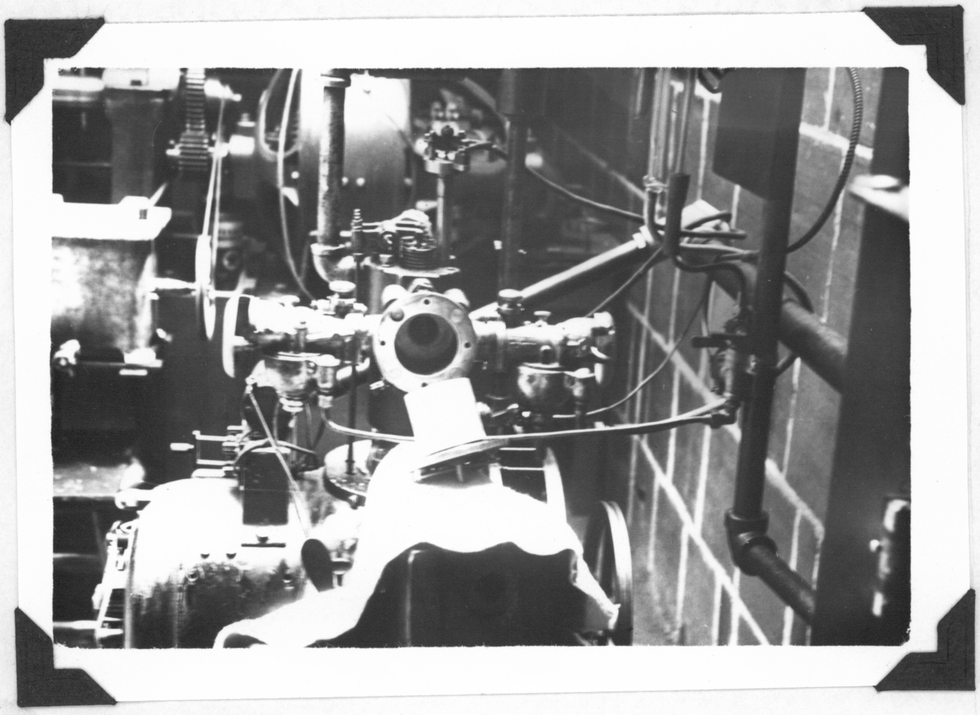
Voltmeter and Ammeter: A standard voltmeter and ammeter are mounted on the panel board. The voltmeter is connected in parallel and the ammeter in series with the load. From the readings of these instruments the power output of the engine is determined.



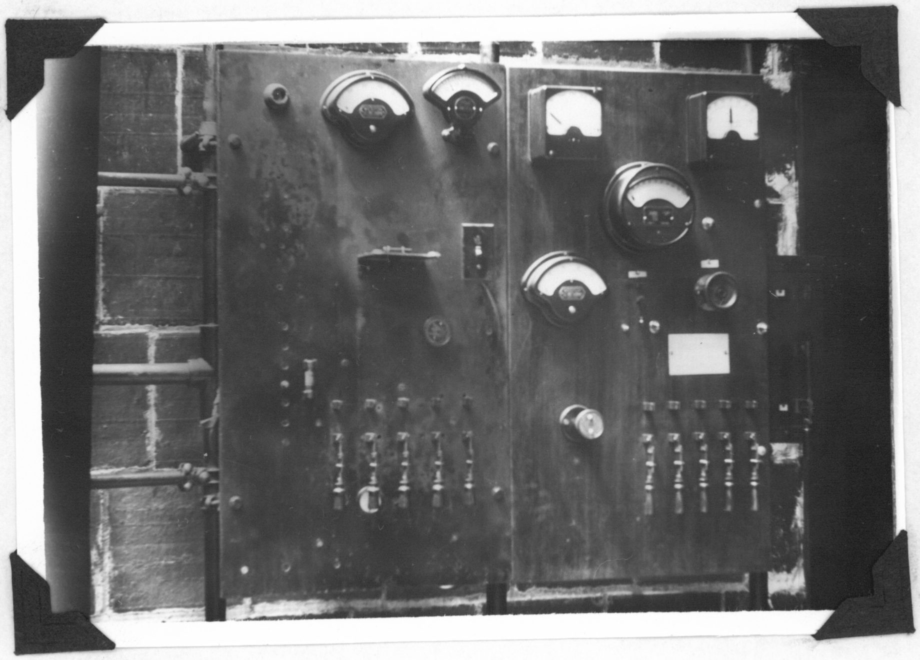
The above photograph of the engine shows the carburetors attached in tandem.



This photograph shows the metering devices attached to the tandem carburetors.



The above photograph shows the carburetors attached in parallel. The aluminum double-entry port is shown alongside.



This picture shows the panel board with the in-
cating instruments attached.

MATERIALS

Gasoline: The gasoline used for these tests was "Essolene" made by the Standard Oil Company of New Jersey. Specific gravity at 60°F. = 0.741.

Water: The water used in this investigation was double distilled water prepared in the Sanitary Engineering Laboratory of the Virginia Polytechnic Institute.

Oil: The oil used for these runs was "Essolube", S.A.E. 30 made by the Standard Oil Company of New Jersey.

RESULTS

Figure 1-D in Appendix D shows graphically the results obtained from the tests run at a compression ratio of 6.5 to 1. It will be noticed that as the water needle setting is increased, the water-fuel ratio is also increased. It was necessary to advance the spark to maintain the desired speed (900 R.P.M.) as more water was admitted. As the water admission to the combustion chamber was increased the fuel consumption was decreased up to a water needle setting of about 10 graduations, after that the fuel consumption remained fairly constant with a slight upward trend as the water approached a maximum. The knock intensity as recorded by the knockmeter showed a decided drop as the water needle setting was increased.

Figure 2-D in Appendix D illustrates the results for the runs at 7.0 to 1. In general the results shown in figure 2-D are very similar to those obtained for a compression ratio of 6.5 to 1, with one noticeable exception. The fuel consumption is greatly decreased through all openings of the water needle from five upward. The knock intensity is decreased and the water-fuel ratio and spark advance are increased as the setting of the water needle is increased.

Figure 3-D shows graphically the results obtained from the run at 7.5 to 1. These results are also similar to those obtained at 6.5 to 1 compression ratio. As the water needle

setting was increased the fuel consumption and knock intensity were decreased while the water fuel ratio and spark advance were increased.

Figure 4-D shows the results obtained from the run at 8.0 to 1 compression ratio. To supply enough water at this compression ratio it was necessary to use a larger jet in the water carburetor. The water fuel ratio was greatly increased at this compression ratio while the fuel consumption and knock intensity do not show as great a decrease as during the previous runs. The rise in spark advance necessitated by increasing the water fuel ratio was steeper than any in the earlier runs.

Figure 5-D represents the results obtained with the compression ratio increased to 8.5 to 1. These curves were very similar to those for the compression ratio of 8.0 to 1. The decrease in knock intensity becomes less evident than in any previous run. The fuel economy was increased as the spark advance and water-fuel-ratio were increased with the water needle setting.

When the compression ratio was increased to 9.0 to 1 the engine knocked violently. It was impossible to introduce enough water to stop the knocking without stalling the engine. The engine could be operated quite smoothly while running with no load but as soon as it was loaded the knock became violent. No attempt was made to obtain a set of data for this compression ratio for fear of damaging the engine.

LUBRICATION AND CARBON DEPOSITS

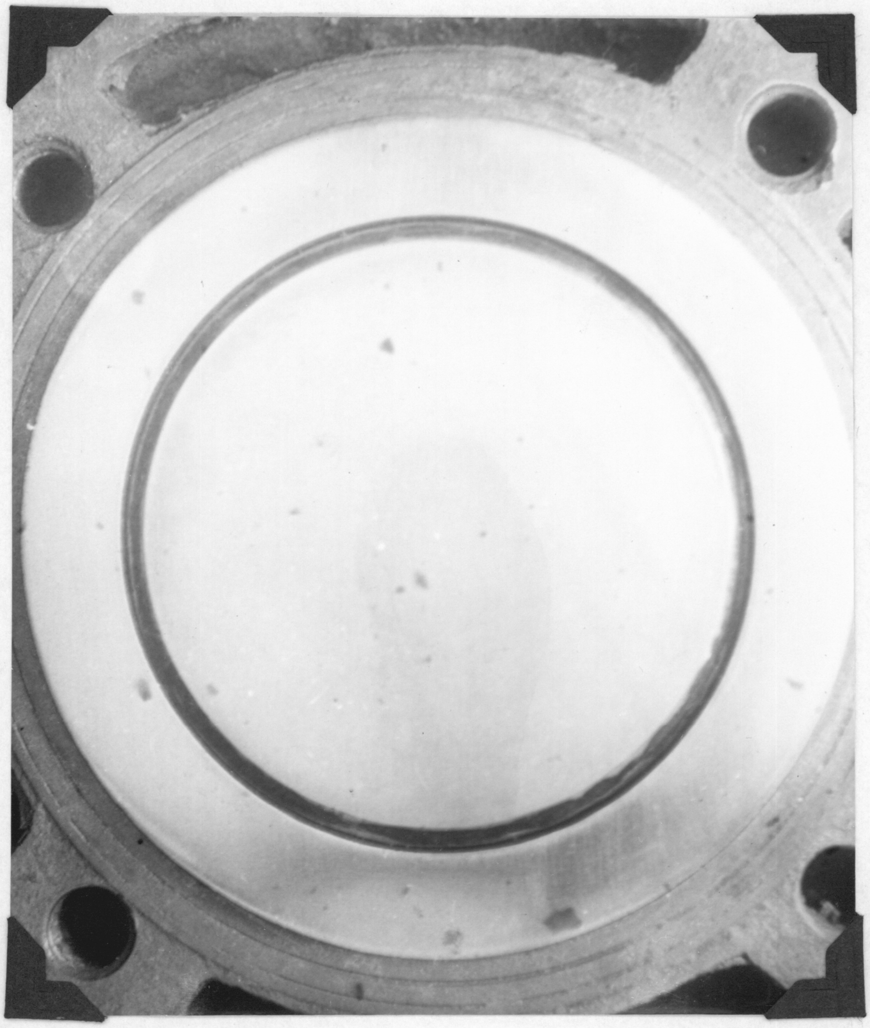
Before the initial runs were made the top of the cylinder boss and piston were polished to a mirror finish using emery papers numbers 1, 1-0, 2-0, 3-0 and 4-0. The surface had previously been covered with small, peen-like indentations characteristic of heavy detonation. The engine was then run intermittently for 15 hours using various percentages of water in the air-fuel charge. After this period of running the engine was torn down and the effects of the water injection on the polished surfaces noted.

Both the piston head and cylinder boss were heavily coated with a soft carbon deposit. That portion of the piston directly below the intake valve was found to be fairly free from carbon deposits.

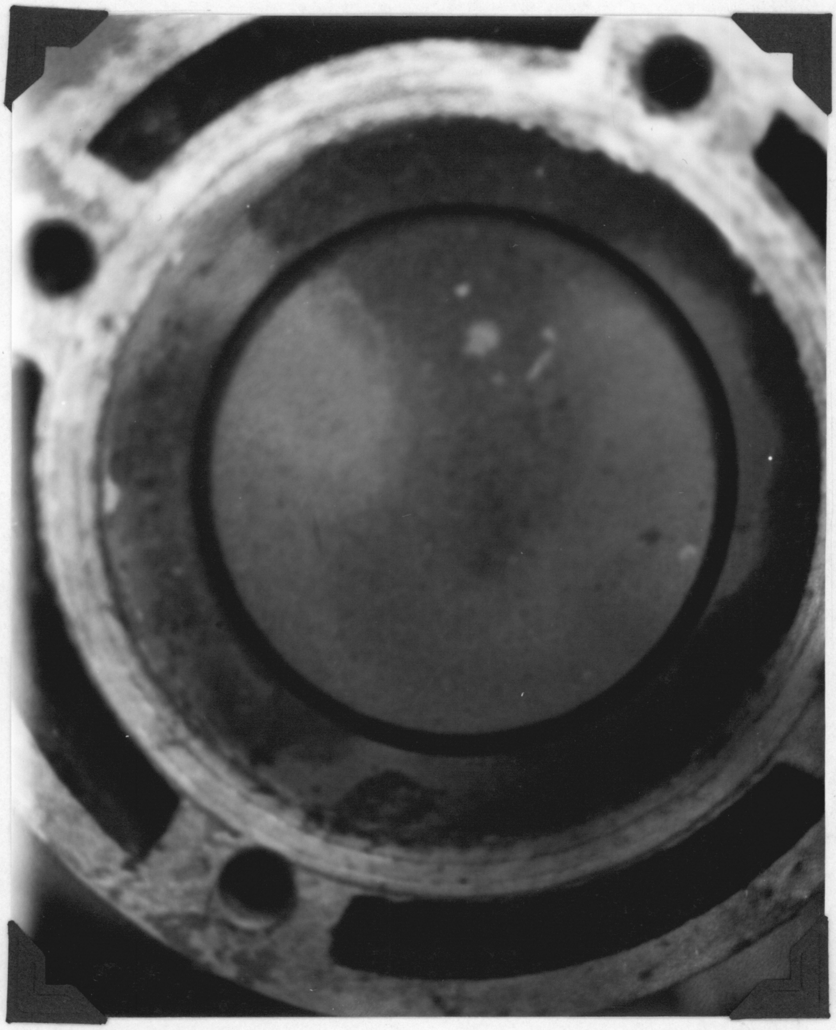
When the carbon deposits were removed by washing with gasoline the piston surface became clear and as bright as before the run. The cylinder boss surface, however, did not attain its original brightness. It was found to be covered with a hard film closely adhering to the surface of the metal and which no amount of washing with gasoline would remove. This film had a glazed appearance and closely resembled a sheet of mica which has been subjected to subsequent heating and cooling such as is often seen in stove fronts.

The cylinder walls were darkened and showed evidence of poor lubrication altho the rings and oil grooves of the piston and the piston skirt itself remained untarnished.

A sample of the crankcase oil was centrifuged for 15 minutes in accordance with the A.S.T.M. Standards on Petroleum Products and Lubricants. No trace of water was found to be present, nor crankcase dilution in any form. About 0.02% sludge was found in the centrifuged sample.



The above photograph shows the cylinder boss and piston head after being polished to a mirror finish and prior to the initial runs.



This photograph shows carbon deposits on the cylinder boss and piston head after 15 hours of intermittent operation. The comparatively clean spot directly beneath the intake valve is quite noticeable.

The above photograph shows the formation of iron oxide on the steel cylinder boss. The carbon deposits have been removed by washing with gasoline. Part of the cylinder boss has been polished to contrast and off-set formations.

DISCUSSION OF RESULTS

While water is an excellent knock suppressor, its use in large enough quantities to permit operation of an engine of the type used in this investigation at extreme compression ratios is quite definitely limited by its choking or flooding out the engine or by its harmful effects upon the engine.

In the tests run the limits of satisfactory operation were taken as the least permissable amount of water and the point where the water choked out the engine or made running so irregular as to be quite unsatisfactory. For the least permissable amount of water the limit was set at that point where pounding became distinctly audible. The higher limit was set at that point where it became impossible to control the engine within plus or minus 20 R.P.M. of the speed desired.

For these conditions it was found possible to raise the compression ratio of the engine used to 8.5 to 1 and still maintain satisfactory operation.

As the compression ratio was increased the spark advance was definitely lowered (this is in accordance with Messers G. W. Hobbs and M. L. Surl's observations as noted in the Review of Literature) but a minimum point is reached. As the amount of water admitted is increased the spark advance must also be increased. These two factors balance to set a minimum point of spark advance. When the water admission outweighs the compression ratio in its effect upon the spark advance, as it did in the runs at 8.0 to 1 and 8.5 to 1, the spark advance required will be increased.

This is more clearly illustrated by the curves shown in Fig. 9-D of Appendix D plotted from the maximum and minimum points of the curves shown in Fig. 6-D, Appendix D.

Since the reading of the knockmeter could not be kept constant over a period of three months, which was the time required for making the runs, except by tedious recallibrations for each run, no attempt was made to get a comparison of knock intensity between the various runs. Only the trend of knock intensity for any one run was recorded. The comparison between runs was noted by ear and an attempt was made to keep all runs within the same range by the amount of water admitted. This range was determined by the lower limit of the run or that point where detonation became distinctly audible.

The author found the carburetion apparatus as designed by Mr. G. B. Lea decidedly unsatisfactory. The device useed by the author worked very well within the limits of this investigation and seems to be a satisfactory method of metering the water to the engine. It leaves much to be hoped for from the viewpoint of safe operation, however. Should a particle of dirt clog the water jet at an extreme compression ratio, the resulting violent pounding of the engine might be serious.

The operating characteristics of the authors metering device are well depicted by the curves in Fig. 7-D, Appendix D. Fig. 10-D, Appendix D, shows curves plotted from the maximum and minimum points of the curves in 7-D. This shows the operating limits of the water-fuel ratio for the various compression ratios.

The addition of water to the combustible charge decreases the fuel consumption for all compression ratios within the scope of this investigation. The decrease in fuel consumption, however, is not so apparent at the higher compression ratios as it is at the lower. Increasing the compression ratio also decreases the fuel consumption, but a minimum point is reached when using water as a knock suppressor. This is graphically illustrated by Fig. 8-D, Appendix D. Fig. 9-D, Appendix D shows curves plotted for the maximum and minimum points in curves 7-D.

? See 1-D

Why the fuel consumption should reach a minimum at 7.5 to 1, and then rise for 8.0 to 1 and 8.5 to 1, is a matter of conjecture. The author offers the following possible explanation: As the compression ratio of the engine is increased it becomes necessary to admit more and more water to control the pounding. In the carburetion device designed by the author, the incoming air charge passes first through the water carburetor. After picking up a large amount of water, as it did at the high compression ratios, this charge must approach a supersaturated state. It is also at a comparatively low temperature due to the vaporization of the water. It becomes increasingly difficult for the air-water charge to properly vaporize the gasoline charge before passing into the combustion chamber. This condition will cause inefficient combustion and could well account for the increase in fuel consumption at the higher compression ratios.

In so far as the author was able to determine the introduction of water into the cylinder did not cut down the carbon deposits, although no standards were available for comparison. Where the water-gas mixture impinged on the combustion chamber there was a noticeably clean spot. The water may have been vaporizing at this point and the boiling or ebullition may have kept carbon from forming. Theoretically this is one of the cooler portions of the combustion chamber and a logical place for carbon to form.

The rather unusual film, previously mentioned, coating the cylinder boss, the author assumed to be deposits of iron oxide which had formed under extreme pressure. The fact that the aluminum piston was not affected in this manner supports this theory.

CONCLUSIONS

(1) Water is a knock suppressor.

(2) Water does not act as an anti-detonant by slowing down the rate of flame propagation, but merely removes a portion of the heat of combustion.

(3) Increasing the compression ratio requires a decrease in spark advance.

(4) When the compression ratio is increased by using water as an anti-detonant the spark advance will reach a minimum and then will increase.

(5) Two carburetors connected in tandem, or series, will meter water and fuel to the combustion chamber, but not at as high an efficiency as either would separately admit its component.

(6) The amount of water required to control pounding is increased with an increase in compression ratio.

(7) For any given compression ratio the fuel consumption is decreased by the admission of water to the air-fuel charge.

(8) The fuel consumption is decreased by increasing the compression ratio, but reaches a minimum point when this type of carburetion apparatus is employed and then increases.

(9) Water admitted to the combustion charge does not cut down carbon formation appreciably except possibly at the first point of impingement in the combustion chamber.

(10) Water when admitted to the combustion chamber in large quantities will wash the lubricating film from the cylinder walls.

(11) Water will rust steel or iron surfaces in the combustion chamber, when admitted to the combustion chamber in large quantities.

(12) Water has little effect on crankcase dilution when admitted to the combustion chamber up to 1.5 water-fuel ratio.

RECOMMENDATIONS

The author offers the following recommendations for future work to be carried on along this line:

(1) To design a water-fuel metering system operating on the injection spray principle, spraying the water and gasoline into the intake manifold.

(2) To attempt to raise compression ratios by rapid cooling of the exhaust valves and stacks.

(3) To attempt to raise compression ratios by using four or five separate ignition systems, each slightly out of phase with the other, to control the rate of flame propagation.

(4) To investigate the possibility of using a hot spot ignition system at a compression ratio of 9.0 to 1 or 9.5 to 1, controlling timing by water injection.

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation for the aid and advice given him by Associate Professor J. B. Jones, without whose help this investigation could not have been made.

To Captain F. F. Groseclose, for his aid in obtaining and designing the apparatus required, he is deeply grateful.

For the help received from Mr. H. B. Groseclose in constructing and setting up apparatus, his sincere appreciation is acknowledged.

APPENDIX A

Tabular Data

Jet Area = .00126 in. Compression Ratio 6.5:1 Run No. 1

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'58''	17	60	50	24.6	0	900	201	63	50	24
4'15''	16	50	50	25.4	0	900	201	58	50	24
4'15''	16	40	50	27.2	0	900	201	57	50	24
4'14''	16	30	50	27.5	0	900	201	53	50	24
4'08''	16	20	50	20.5	0	900	201	51	50	24
4'02''	16	10	50	5:7	0	900	201	55	50	24
				Run No. 2						
3'59''	17	30	50	24.0	0	900	201	59	50	24
3'57''	17	25	50	23.5	0	900	201	57	50	24
3'48''	17	20	50	19.4	0	900	201	58	50	24
3'42''	17	15	50	15.0	0	900	201	55	50	24
4'03''	17	10	50	8.4	0	900	201	52	50	24
4'06''	17	5	50	2.7	0	900	201	52	50	24
4'22''	17	0	50	.6	0	900	201	50	50	24

Jet Area = .00126 Compression Ratio 6.5:1 Run No. 3

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'55''	17	30	50	20.7	0	900	201	59	50	24
3'49''	17	25	50	20.0	0	900	201	61	50	24
3'49''	17	20	50	18.5	0	900	201	62	50	24
3'43''	17	15	50	13.8	0	900	201	50	50	24
4'06''	17	10	50	5.7	0	900	201	50	50	24

Run No. 4

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'43''	17	30	50	23.3	0	900	201	54	50	24
3'51''	17	25	50	23.0	0	900	201	51	50	24
3'59''	17	20	50	22.0	0	900	201	50	50	24
4'00''	17	15	50	15.5	0	900	201	50	50	24
3'59''	17	10	50	6.0	0	900	201	55	50	24
4'13''	17	5	50	2.9	0	900	201	54	50	24
4'21''	17	0	50	.9	0	900	201	53	50	24

Jet Area = .00126 in. Compression Ratio 6.5:1 Run No. 5

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'49''	17	30	50	23.3	0	900	201	59	50	24
3'50''	17	25	50	20.0	0	900	201	64	50	24
3'49''	17	20	50	18.5	0	900	201,	70	50	24
3'44''	17	15	50	14.6	0	900	201	64	50	24
4'13''	17	10	50	4.8	0	900	201	64	50	24
4'26''	17	5	50	2.0	0	900	201	65	50	24
4'10''	17	0	50	.9	0	900	201	73	50	24

Run No. 6

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'58''	17	30	50	22.4	0	900	201	57	50	24
3'58''	17	25	50	22.2	0	900	201	59	50	24
3'57''	17	20	50	19.5	0	900	201	60	50	24
3'56''	17	15	50	13.0	0	900	201	63	50	24
4'15''	17	10	50	3.2	0	900	201	67	50	24
4'11''	17	5	50	.6	0	900	201	68	50	24
4'08''	17	0	50	.5	0	900	201	72	50	24

Jet Area = :00126 in. Compression Ratio 6.5:1 Run No. 7

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
4'05''	16	0	50	.6	0	900	200	75	50	24
4'16''	16	5	50	1.0	0	900	200	75	50	24
4'24''	16	10	50	3.0	0	900	200	72	50	24
4'08''	16	15	50	14.5	0	900	200	70	50	24
4'35''	16	20	50	24.0	0	900	200	68	50	24
4'15''	16	25	50	30.0	0	900	200	70	50	24
4'16''	16	30	50	25.0	0	900	200	73	50	24
Run No. 8										
4'15''	16	30	50	24.0	0	900	200	64	50	24
4'13''	16	25	50	25.1	0	900	200	62	50	24
4'15''	16	20	50	26.0	0	900	200	59	50	24
4'14''	16	15	50	25.4	0	900	200	60	50	24
4'14''	16	10	50	5.7	0	900	200	57	50	24
4'10''	16	5	50	2.3	0	900	200	55	50	24
4'02''	16	0	50	.6	0	900	200	50	50	24

Jet Area = .00126 in.   Compression Ratio 6.5:1   Run No. 1-A

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps
3'26''	15	5	50	1.8	0	900	200	40	50	24
3'29''	15	10	50	2.9	0	900	200	47	50	24
3'31''	15	15	50	10.9	0	900	200	43	50	24
3'39''	15	20	50	17.9	0	900	200	39	50	24
3'40''	15	25	50	20.0	0	900	200	37	50	24
3'41''	15	30	50	20.5	0	900	200	39	50	24

Run No. 2-A

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps
3'18''	15	0	50	.6	0	900	200	57	50	24
3'34''	15	5	50	.9	0	900	200	55	50	24
3'36''	15	10	50	2.2	0	900	200	50	50	24
3'41''	15	15	50	12.2	0	900	200	49	50	24
3'44''	15	20	50	14.4	0	900	200	48	50	24
3'45''	15	25	50	19.6	0	900	200	48	50	24
3'45''	15	30	50	20.5	0	900	200	40	50	24
3'45''	15	35	50	20.6	0	900	200	41	50	24

Jet Area = .00126 in. Compression Ratio 6.5:1 Run No.3-A

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'34''	15	0	50	.1	0	900	200	47	50	24
3'49''	15	5	50	.6	0	900	200	44	50	24
3'51''	15	10	50	3.0	0	900	200	40	50	24
3'51''	15	15	50	12.o	0	900	200	38	50	24
3'52''	15	20	50	14.2	0	900	200	35	50	24
3'50''	15	25	50	20.0	0	900	200	33	50	24

Run No. 4-A

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'49''	14	25	50	19.0	0	900	200	43	50	24
3'43''	14	20	50	17.6	0	900	200	41	50	24
3'36''	14	15	50	12.1	0	900	200	45	50	24
3'48''	14	10	50	3.4	0	900	200	39	50	24
3'52''	14	5	50	.6	0	900	200	39	50	24
3'55''	14	0	50	.0	0	900	200	38	50	24

Jet Area = .00125 in. Compression Ratio 6.5:1 Run No. 1-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'29''	14	0	50	.1	0	900	200	35	50	24
3'31''	14	5	50	.5	0	900	200	35	50	24
3'34''	14	10	50	5.0	0	900	200	34	50	24
3'35''	14	15	50	13.1	0	900	200	33	50	24
3'35''	14	20	50	20.3	0	900	200	31	50	24
Run No. 2-B										
3'39''	14	20,	50	20.3	0	900	200	29	50	24
3'35''	14	15	50	15.0	0	900	200	29	50	24
3'35''	14	10	50	4.8	0	900	200	30	50	24
3'39''	14	5	50	1.0	0	900	200	31	50	24
3'35''	14	0	50	.4	0	900	200	39	50	24

Jet Area = .00126 in. Compression Ratio 6.5:1 Run No. 3-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'35''	14	0	50	.0	0	900	200	50	50	24
3'44''	14	5	50	.7	0	900	200	46	50	24
3'44''	14	10	50	1.4	0	900	200	41	50	24
3'45''	14	15	50	12.8	1	900	200	40	50	24
3'43''	14	20	50	19.9	3	900	200	35	50	24

Run No. 4-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'42''	14	20	50	20.1	3	900	200	36	50	24
3'44''	14	15	50	13.6	1	900	200	40	50	24
3'44''	14	10	50	5.4	0	900	200	41	50	24
3'41''	14	5	50	1.0	0	900	200	41	50	24
3'45''	14	0	50	.4	0	900	200	42	50	24

Jet Area = .00126 in. Compression Ratio 6.5:1 Run Average -B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps	Fuel Econ.	Water-Fuel Ratio
3'33.5''	14	0	50	.22	0	900	201	41.50	50	24	.734	.0044
3'38.8''	14	5	50	.80	0	900	201	38.20	50	24	.715	.016
3'41.8''	14	10	50	3.02	0	900	201	36.50	50	24	.708	.064
3'39.8''	14	15	50	13.62	1	900	201	35.50	50	24	.710	.273
3'39.8''	14	20	50	20.15	3	900	201	32:70	50	24	.710	.402
3'40.0''	14	25	50	20.00	4	900	201	32.50	50	24	.714	.400

Jet Area = .00126 in.　　Compression Ratio 7.0:1　　Run No. 1-A

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'23''	14	25	50	19.8	-3	900	201	56	50	24
3'22''	14	20	50	20.0	-3	900	201	60	50	24
3'21''	14	15	50	15.0	-3	900	201	65	50	24
3'23''	14	10	50	4.1	-2	900	201	66	50	24
3'21''	14	5	50	1.6	-2	900	201	68	50	24
3'16''	14	0	50	.0	1	900	201	69	50	24
				Run No. 2-A						
3'39''	13	5	50	.4	-3	900	201	45	50	24
3'43''	13	10	50	3.7	-3	900	201	40	50	24
4'04''	13	15	50	13.9	-2	900	201	35	50	24
4'13''	13	20	50	17.3	-1	900	201	32	50	24
4'18''	13	25	50	21.6	1	900	201	29	50	24

Jet Area = .00126 in. Compression Ratio 7.0:1 Run No. 1-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'55''	13	25	50	20.8	1	900	203	29	50	24
3'40''	13	20	50	19.3	-1	900	203	30	50	24
3'36''	13	15	50	10.3	-2	900	203	30	50	24
3'33''	13	10	50	5.0	-3	900	203	30	50	24
3'27''	13	5	50	.6	-3	900	203	33	50	24
3'23''	13	0	50	.0	-3	900	203	37	50	24

Run No. 2-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'25''	13	0	50	.0	-3	900	203	30	50	24
3'28''	13	5	50	.3	-3	900	203	29	50	24
3'38''	13	10	50	3.6	-3	900	203	29	50	24
3'48''	13	15	50	12.0	-2	900	203	29	50	24
3'44''	13	20	50	17.1	-1	900	203	28	50	24
4'09''	13	25	50	20.0	1	900	203	25	50	24

Jet Area = .00126 in. Compression Ratio 7.0:1 Run No. 3-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
4'31''	13	25	50	19.7	1	900	203	24	50	24
4'19''	13	20	50	19.0	-1	900	203	26	50	24
4'05''	13	15	50	13.0	-2	900	203	27	50	24
4'06''	13	10	50	3.9	-3	900	203	28	50	24
4'03''	13	5	50	.4	-3	900	203	29	50	24
4'03''	13	0	50	.1	-3	900	203	29	50	24

Run No. 4-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'39''	13	0	50	.0	-3	900	203	28	50	24
3'44''	13	5	50	.2	-3	900	203	27	50	24
3'51''	13	10	50	2.5	-3	900	203	26	50	24
4'03''	13	15	50	12.5	-2	900	203	25	50	24
4'07''	13	20	50	17.0	-1	900	203	24	50	24
4'07''	13	25	50	20.1	1	900	203	23	50	24

Jet Area = .00126 in. Compression Ratio 7.0:1 Run Average -B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.	Fuel Econ.	Water-Fuel Ratio
3'37''	13	0	50	0	-3	900	203	30.5	50	24	.723	.00
3'41''	13	5	50	.4	-3	900	203	28.5	50	24	.719	.008
3'47''	13	10	50	3.75	-3	900	203	27.75	50	24	.690	.075
3'53''	13	15	50	11.95	-2	900	203	27.25	50	24	.674	.293
3'58''	13	20	50	18.10	-1	900	203	27.00	50	24	.660	.361
4'10''	13	25	50	20.10	1	900	203	25.25	50	24	.625	.402

Jet Area = .00126 in.   Compression Ratio 7.5:1   Run No. 1-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
4'36''	12	0	50	.2	-5	900	208	26	50	24
4'32''	12	5	50	1.0	-5	900	208	24	50	24
4'35''	12	10	50	6.1	-5	900	208	24	50	24
4'40''	12	15	50	15.0	-3	900	208	24	50	24
4'41''	12	20	50	22.9	-2	900	208	23	50	24
4'44''	12	25	50	21.0	0	900	208	22	50	24

Run No. 2-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
4'37''	12	25	50	23.5	0	900	208	25	50	24
4'30''	12	20	50	20.0	-2	900	208	27	50	24
4'35''	12	15	50	14.0	-3	900	208	26	50	24
4'30''	12	10	50	6.0	-5	900	208	28	50	24
4'34''	12	5	50	.6	-5	900	208	28	50	24
4'26''	12	0	50	.2	-5	900	208	29	50	24

Jet Area = .00126 in.   Compression Ratio 7.5:1   Run No. 3-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'50''	12	0	50	0	-5	900	202	50	50	24
3'57''	12	5	50	.3	-5	900	202	49	50	24
4'00''	12	10	50	6.0	-5	900	202	45	50	24
4'04''	12	15	50	13.0	-3	900	202	35	50	24
4'11''	12	20	50	20.0	-2	900	202	32	50	24
4'16''	12	25	50	22.0	0	900	202	30	50	24

Run No. 4-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
4'15''	12	25	50	23.6	0	900	202	32	50	24
4'12''	12	20	50	20.6	-2	900	202	34	50	24
4'09''	12	15	50	14.0	-3	900	202	35	50	24
4'10''	12	10	50	5.0	-5	900	202	38	50	24
4'10''	12	5	50	.3	-5	900	202	40	50	24

Jet Area = .00126 in. Compression Ratio 7.5:1 Run Average-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps	Fuel Econ.	Water-Fuel Ratio
4'17''	12	0	50	.1	-5	900	205	35	50	24	.610	.002
4'18''	12	5	50	.6	-5	900	205	35	50	24	.607	.012
4'19''	12	10	50	5.8	-5	900	205	34	50	24	.605	.116
4'22''	12	15	50	14.0	-3	900	205	30	50	24	.596	.280
4'24''	12	20	50	20.9	-2	900	205	29	50	24	.593	.418
4'28''	12	25	50	22.5	0	900	205	27	50	24	.584	.450

Jet Area = .00515 in. Compression Ratio 8.0:1 Run No. 1-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
4'05''	12	30	50	67	3	900	203	30	50	24
4'08''	12	25	50	61	1	900	203	31	50	24
4'02''	12	20	50	45	0	900	203	30	50	24
4'00''	12	15	50	32	-1	900	203	33	50	24
					Run No. 2-B					
4'00''	12	30	50	68	3	900	203	27	50	24
3'58''	12	25	50	60	1	900	203	27	50	24
3'58''	12	20	50	46	0	900	203	28	50	24
3'58''	12	15	50	32	-1	900	203	29	50	24

Jet Area = .00515 in.   Compression Ratio 8.0:1   Run No. 3-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'59''	12	30	50	65	3	900	204	26	50	24
3'59''	12	25	50	58	1	900	204	26	50	24
3'59''	12	20	50	45	0	900	204	27	50	24
3'56''	12	15	50	32	-1	900	204	28	50	24

Run No. 4-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'56''	12	30	50	66	3	900	204	23	50	24
3'53''	12	25	50	61	1	900	204	23	50	24
3'53''	12	20	50	44	0	900	204	24	50	24
3'51''	12	15	50	30	-1	900	204	25	50	24

Jet Area =.00515 in. Compression Ratio 8.0:1 Run Average-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.	Fuel Econ.	Water-Fuel Ratio
3'56''	12	15	50	31	-1	900	204	28.75	50	24	.665	.620
3'58''	12	20	50	45	0	900	204	27.25	50	24	.657	.900
3'59''	12	25	50	60	1	900	204	26.75	50	24	.654	1.200
4'00''	12	30	50	67	3	900	204	26.25	50	24	.652	1.340

Jet Area = .00515 in. Compression Ratio 8.5:1 Run No. 1-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'58''	12	35	50	75	5	900	204	17	50	24
3'58''	12	30	50	67	3	900	204	17	50	24
3'55''	12	25	50	57	1	900	204	18	50	24
3'55''	12	20	50	44	0	900	204	18	50	24

Run No. 2-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'53''	12	35	50	78	5	900	204	21	50	24
3'54''	12	30	50	63	3	900	204	20	50	24
3'53''	12	25	50	50	1	900	204	21	50	24
3'53''	12	20	50	40	0	900	204	21	50	24

Jet Area = .00515 in. Compression Ratio 8.5:1 Run No. 3-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.
3'58''	12	35	50	74	5	900	205	20	50	24
3'59''	12	30	50	65	3	900	205	21	50	24
3'56''	12	25	50	50	1	900	205	21	50	24
3'56''	12	20	50	39	0	900	205	21	50	24
				Run No. 4-B						
3'53''	12	35	50	72	5	900	205	18	50	24
3'50''	12	30	50	63	3	900	205	19	50	24
3'51''	12	25	50	51	1	900	205	19	50	24
3'50''	12	20	50	40	0	900	205	19	50	24

Jet Area = .00515 in.   Compression Ratio 8.5:1   Run Average-B

Time	Gas Needle	Water Needle	Gas Volume ml	Water Volume ml	Spark Advance °	R.P.M.	Temp. °F	Knock Meter	Volts	Amps.	Fuel Econ.	Water-Fuel Ratio
3'56''	12	35	50	75	5	900	205	19.00	50	24	.657	1.50
3'55''	12	30	50	65	3	900	205	19.00	50	24	.667	1.30
3'54''	12	25	50	52	1	900	205	19.75	50	24	.670	1.04
3'53''	12	20	50	41	0	900	205	19.75	50	24	.671	.82

APPENDIX B

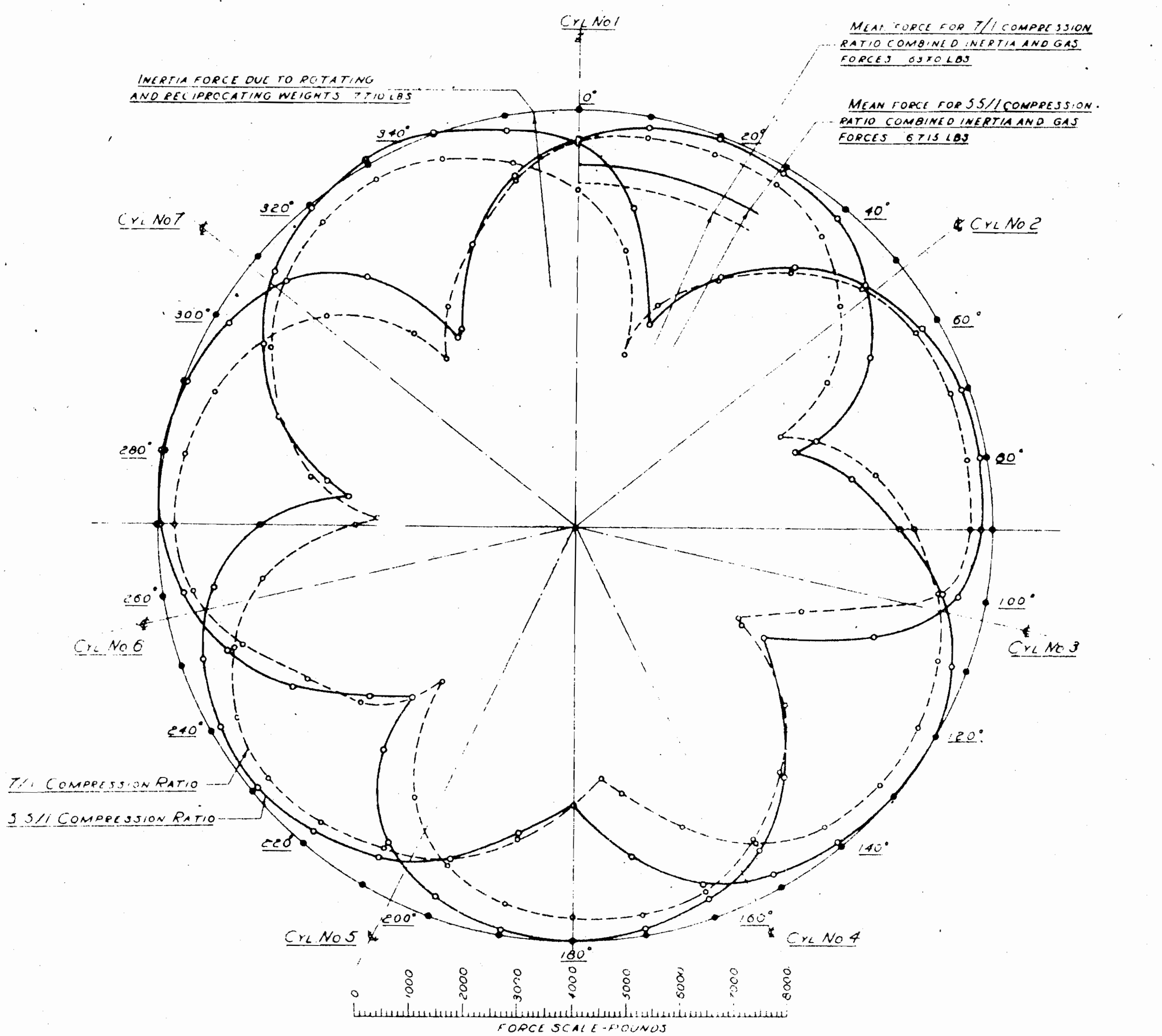
Illustration of Effect of Compression Ratio

on Bearing Pressures

TABLE I

EFFECT OF COMPRESSION RATIO ON MEAN CRANK PIN PRESSURE AT FULL THROTTLE

Engine	Speed	Compression Ratio	Bearing Pressure Full Throttle Lb.	Bearing Pressure Inertia Only Lb.
Wright Cyclone 9	1900	5.5	17,600	20,050
" " 9	1900	7.0	16,300	20,050
Continental A-70	1485	5.5	3,710	3,485
" A-70	1485	7.0	3,765	3,485
" A-70	1800	5.5	4,710	5,160
" A-70	1800	7.0	4,630	5,160
" A-70	2200	5.5	6,715	7,700
" A-70	2200	7.0	6,370	7,700
8-cylinder Automobile				
" "	1000	5.5	532	286
" "	1000	7.0	580	286
" "	2000	5.5	1,208	1,138
" "	2000	7.0	1,222	1,138
" "	3000	5.5	2,492	2,590
" "	3000	7.0	2,480	2,590
" "	4000	5.5	4,460	4,600
" "	4000	7.0	4,300	4,600
" "	5000	5.5	7,081	7,251
" "	5000	7.0	7,027	7,251



POLAR DIAGRAM SHOWING MAGNITUDE OF RESULTANT FORCE ON CRANK PIN AT THE VARIOUS CRANK ANGLE POSITIONS FOR ONE COMPLETE ENGINE CYCLE. CONTINENTAL A-70 ENGINE. WIDE OPEN THROTTLE AT 2200 R.P.M.

ETHYL GASOLINE CORPORATION
ENGINEERING LABORATORY
DETROIT MICHIGAN

Fig. [illegible] - Bearing Pressure on Crank Pin End of Master Rod of a Continental A-70 Engine at Compression Ratios of 5.5 and 7.0, at a speed of 2200 R.P.M.

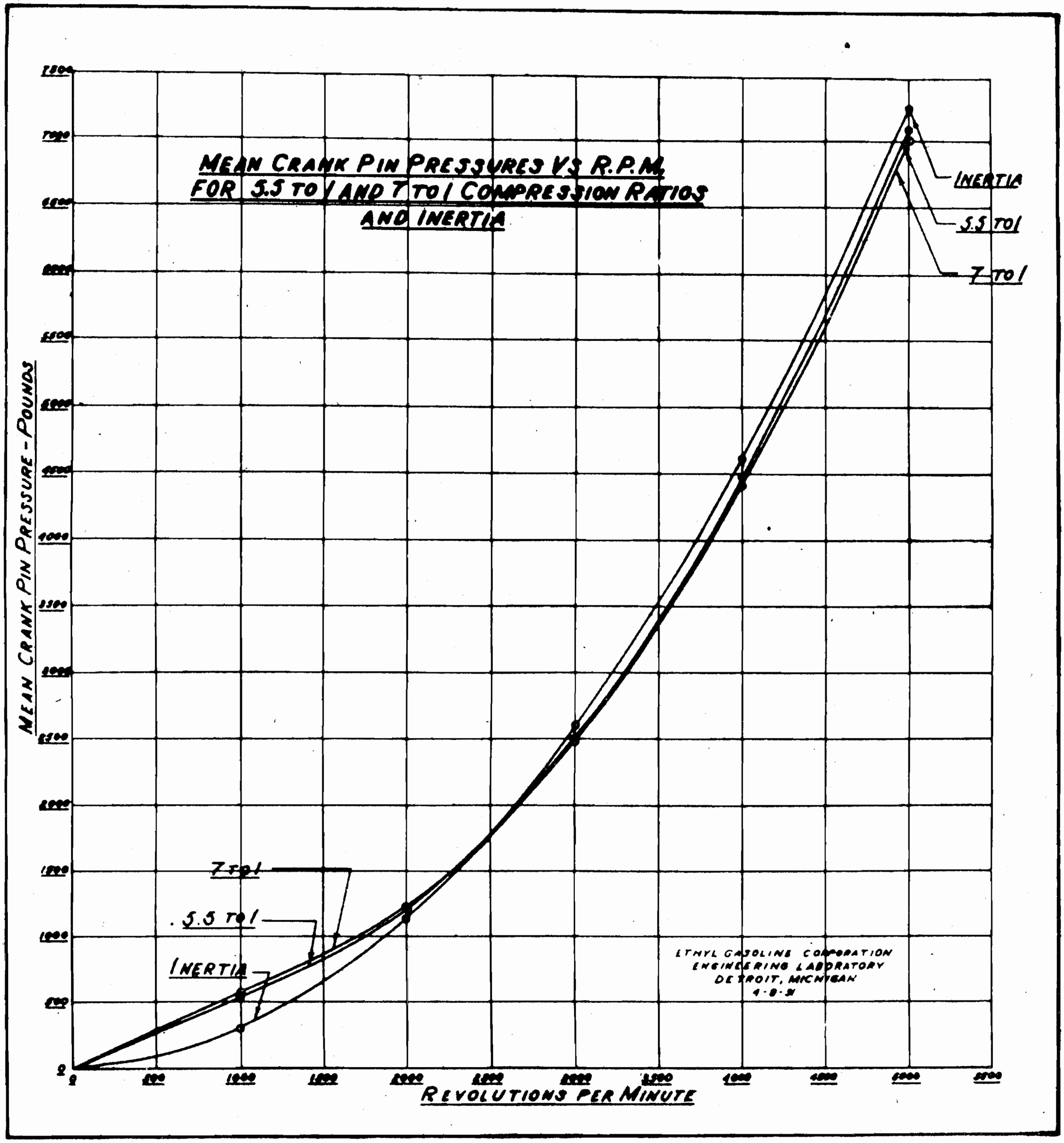
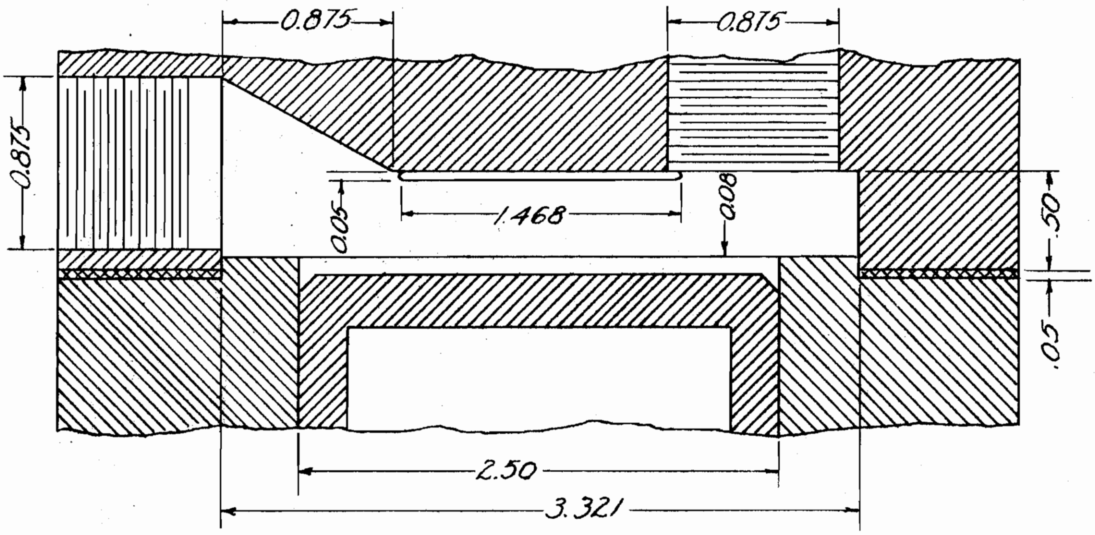


Fig. [illegible] - Mean Crank Pin Pressures Due to Inertia Forces and to Combined Inertia Forces and Gas Pressure for an Eight Cylinder Engine at Compression Ratios of 5.5 and 7.0 to 1.

APPENDIX C

Illustration of Computations for Planing Down Cylinder



Detail of Delco Combustion Chamber Design
Scale: Full Size

Partial Head Volume	3.768 in^3
Spark Plug Breech Volume	.088 in^3
Spark Plug Internal Volume	.244 in^3
Bouncing Pin Inlet Volume	.037 in^3
Valve Head Volume	.169 in^3
Cylinder Overlap Volume	.393 in^3
Piston Bevel Volume	.032 in^3
Piston Sweep Volume	22.709 in^3
Sum of Head Volumes	4.393 in^3
Total Volume	27.102 in^3
Compression Ratio	6.169
Amount to be Planed from Plate to Raise Compression Ratio to 6.5-1	.0538 in.

To Increase Compression Ratio to 11.5-1

$(22.709 + X) \div X = 11.5$, $X = 2.163$ = Head Volume

Head Volume to be Displaced $4.393 - 2.163 = 2.230\ in^3$

$h(\frac{3.321}{2}) \times 3.1416 = 2.230$ $h = .2575$ in.

Total Height (h) to be Removed ———— .2575 in.

Height to be Removed for Each Successive Compression Ratio: (inches)

6.5-1 to 7.0-1	.0702	9.0-1 to 9.5-1	.1987
7.0-1 to 7.5-1	.1039	9.5-1 to 10.0-1	.2159
7.5-1 to 8.0-1	.1327	10.0-1 to 10.5-1	.2312
8.0-1 to 8.5-1	.1578	10.5-1 to 11.0-1	.2450
8.5-1 to 9.0-1	.1794	11.0-1 to 11.5-1	.2575

Fig. 1-C

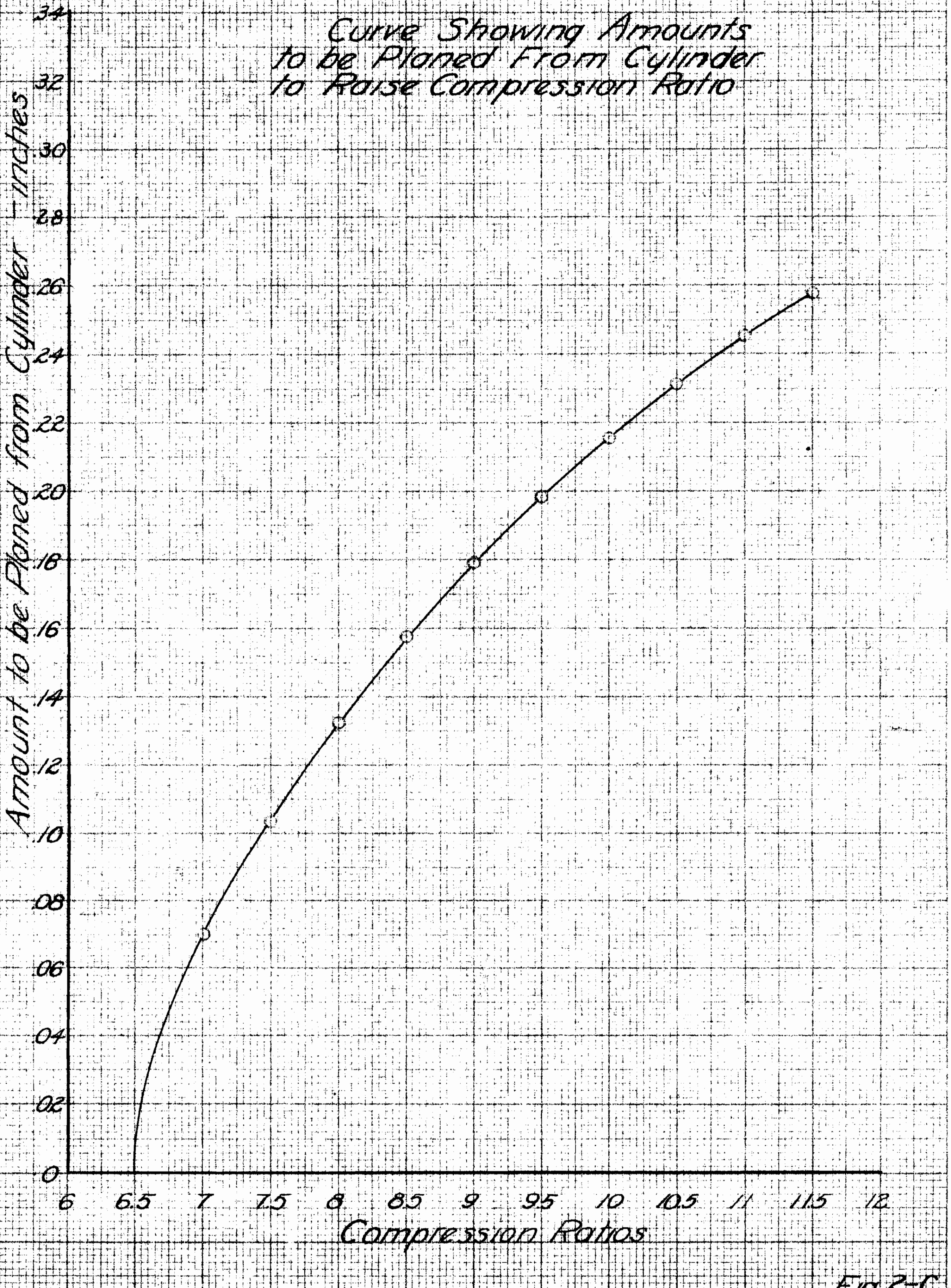

Curve Showing Amounts
to be Planed From Cylinder
to Raise Compression Ratio
Amount to be Planed from Cylinder — inches
.34
.32
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
0
6
6.5
7
7.5
8
8.5
9
9.5
10
10.5
11
11.5
12
Compression Ratios

Fig 2-C

APPENDIX D

Curves Showing Operating Characteristics at

Various Compression Ratios

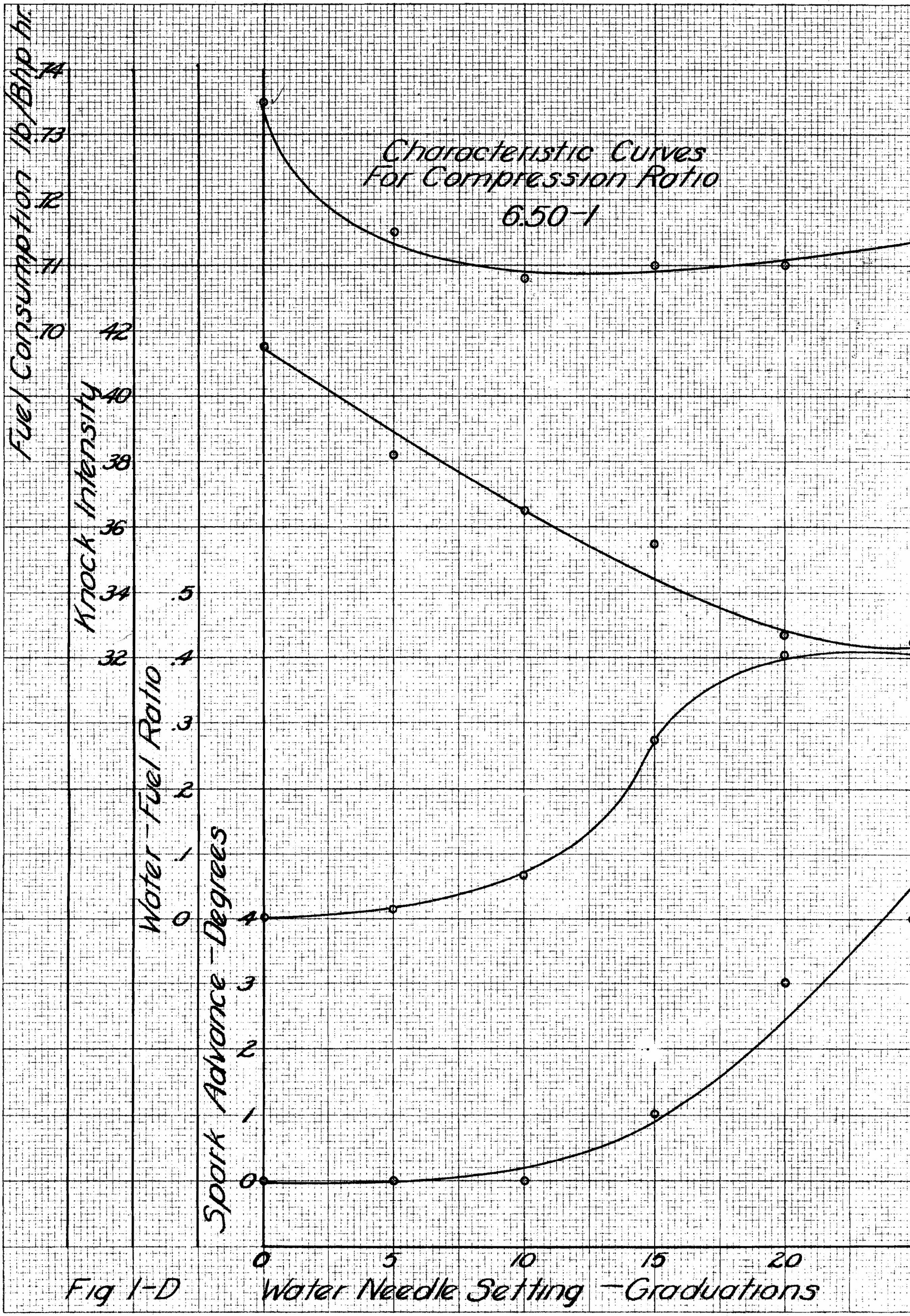


Fig 1-D

PRINTED IN U.S.A.
EUGENE DIETZGEN CO. NO. 350

PRINTED IN U.S.A.

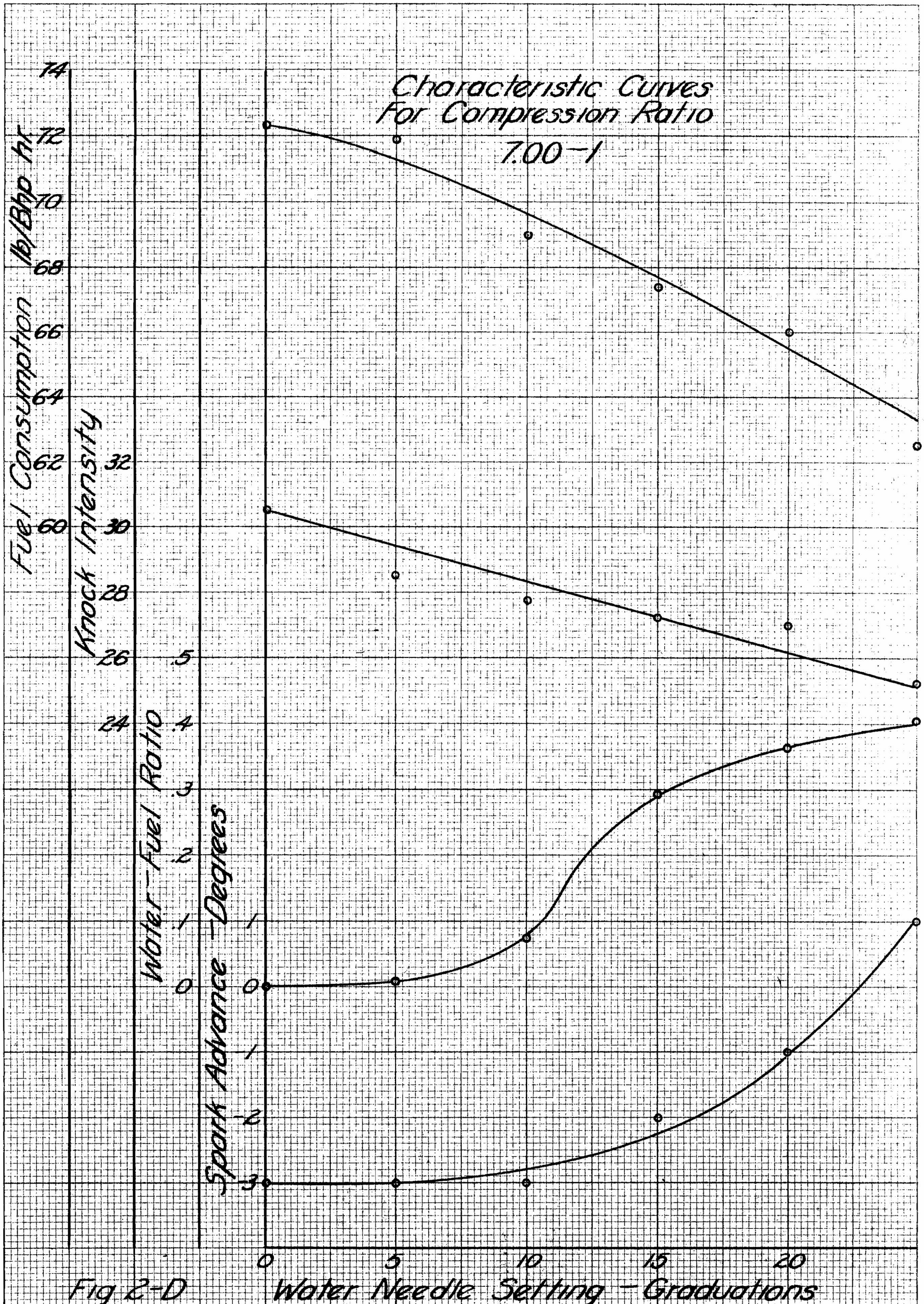


Fig 2-D

EUGENE DIETZGEN CO. NO. 350

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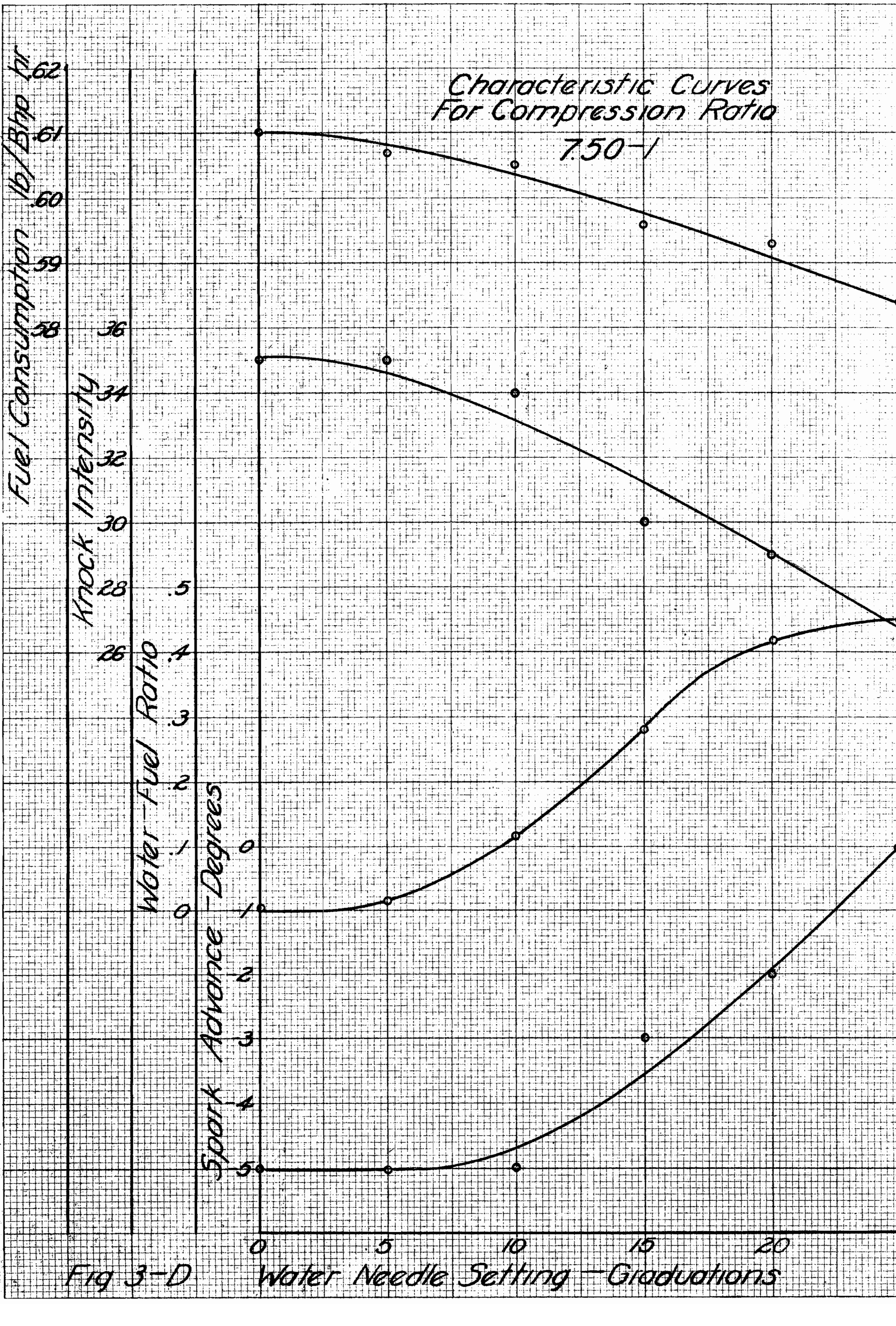

Fig 3-D

EUGENE DIETZGEN CO. NO. 350

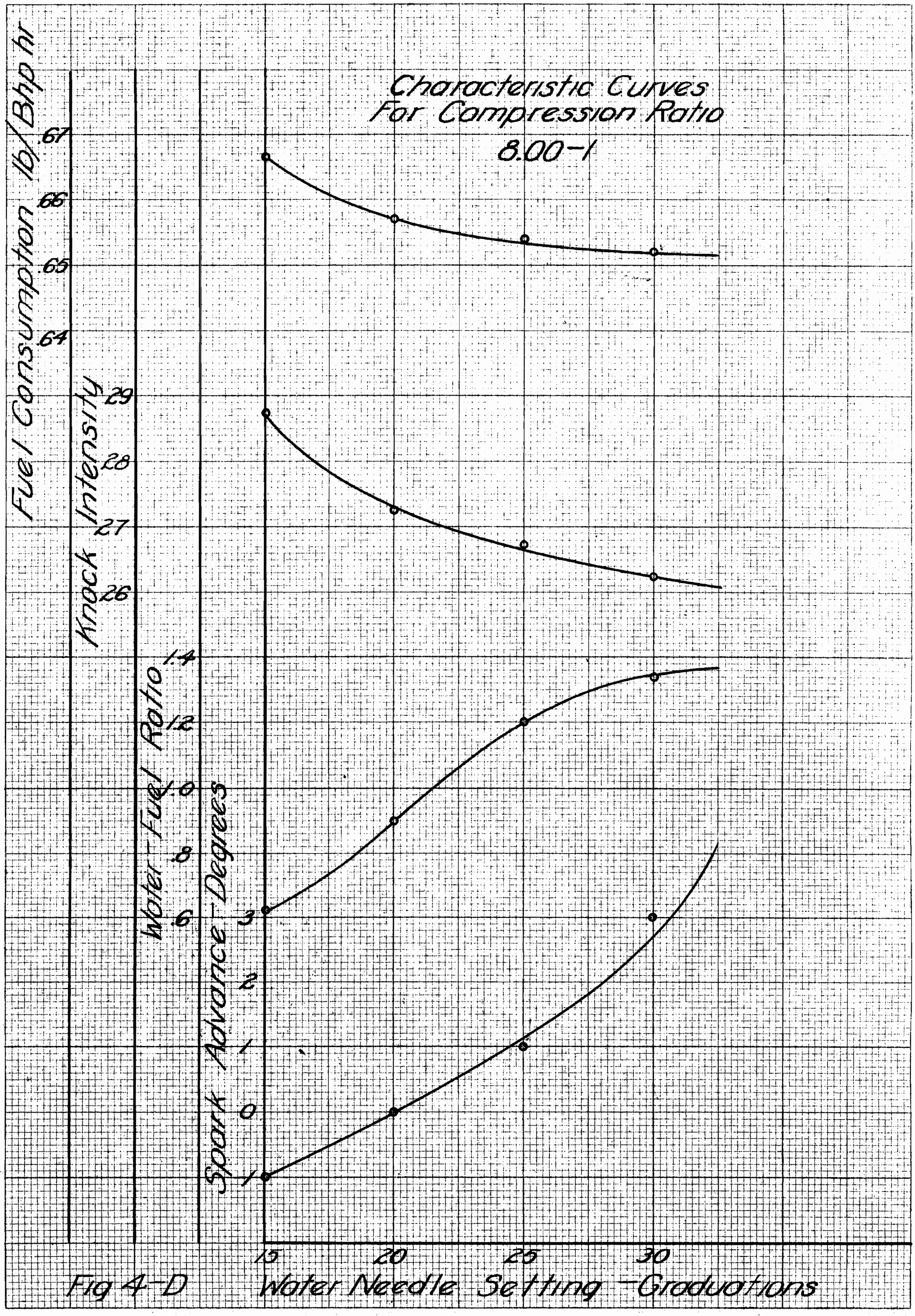

Fig 4-D

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EUGENE DIETZGEN CO. NO. 350

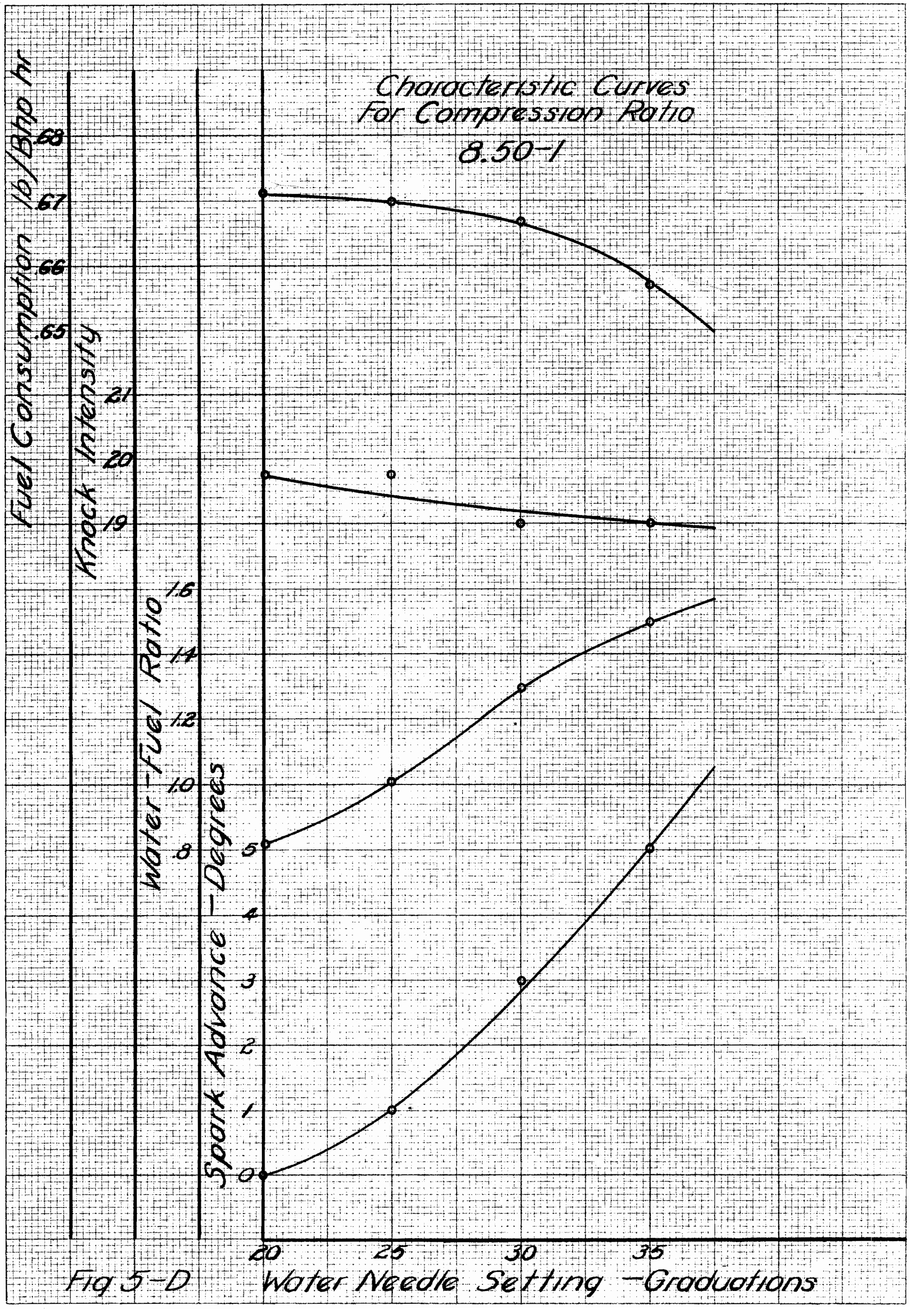

Fig 5-D
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EUGENE DIETZGEN CO. NO. 350

EUGENE DIETZGEN CO. NO. 350
PRINTED IN U.S.A.

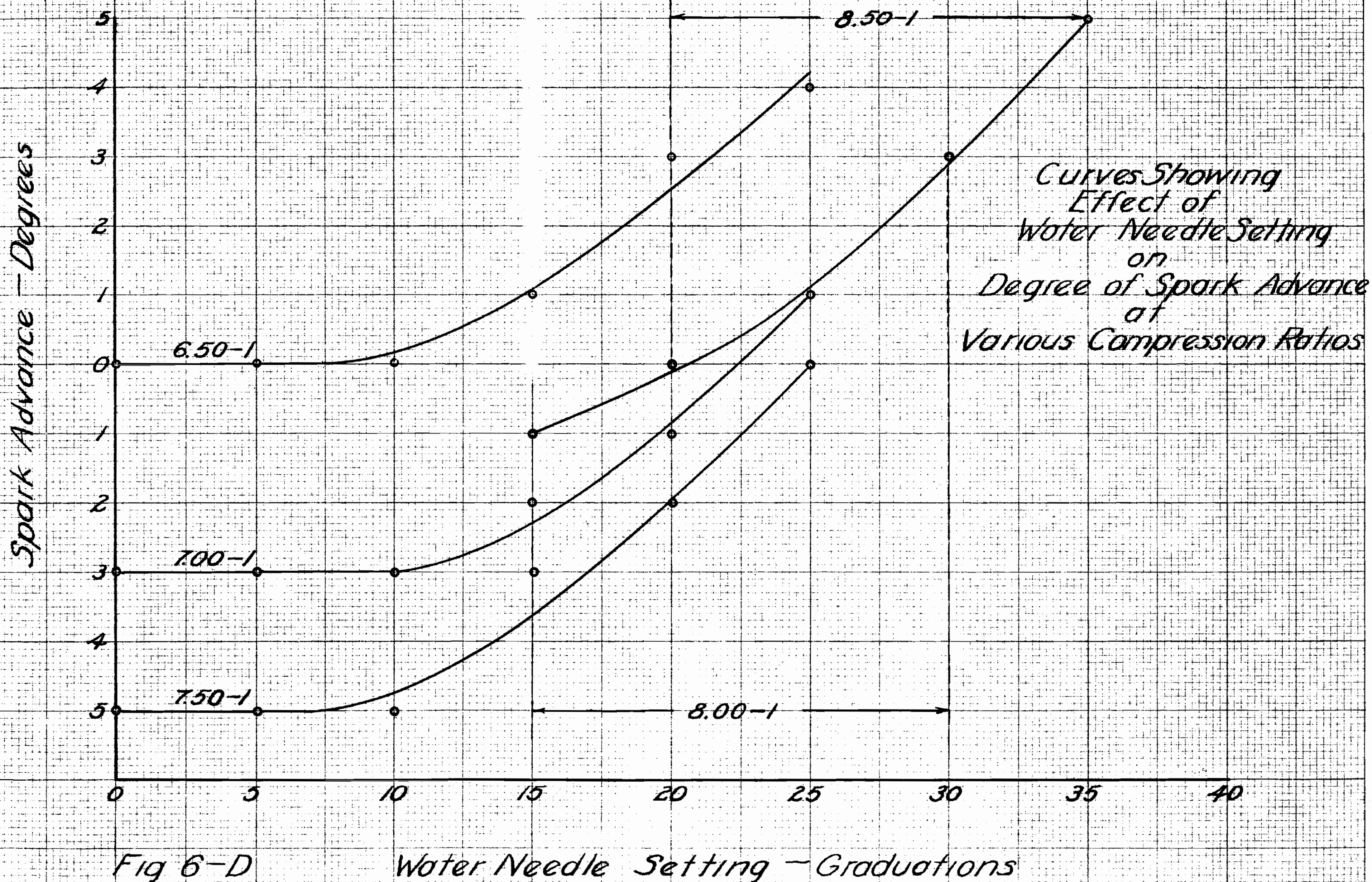

Fig 6–D

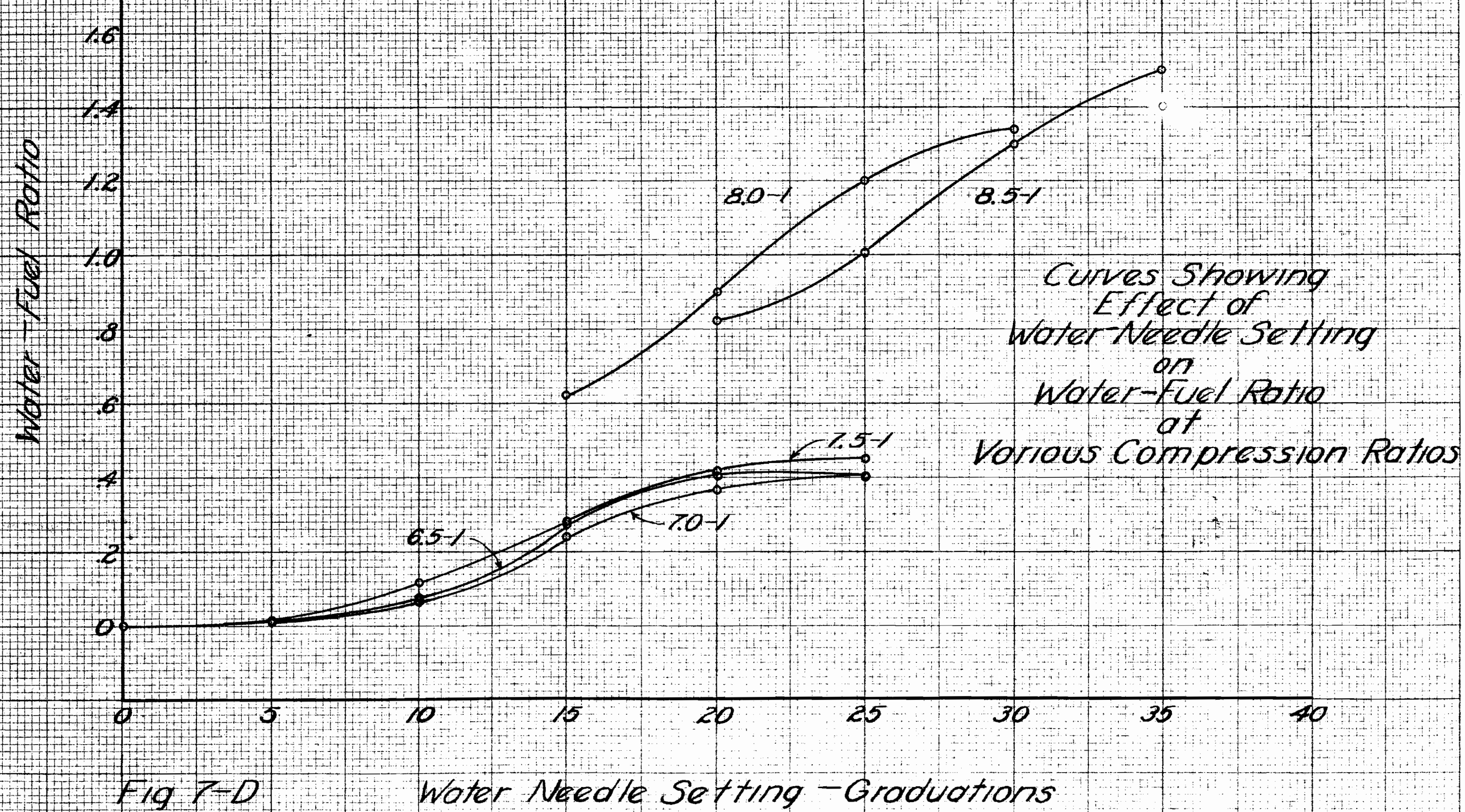

Fig 7-D

EUGENE DIETZGEN CO. NO. 350
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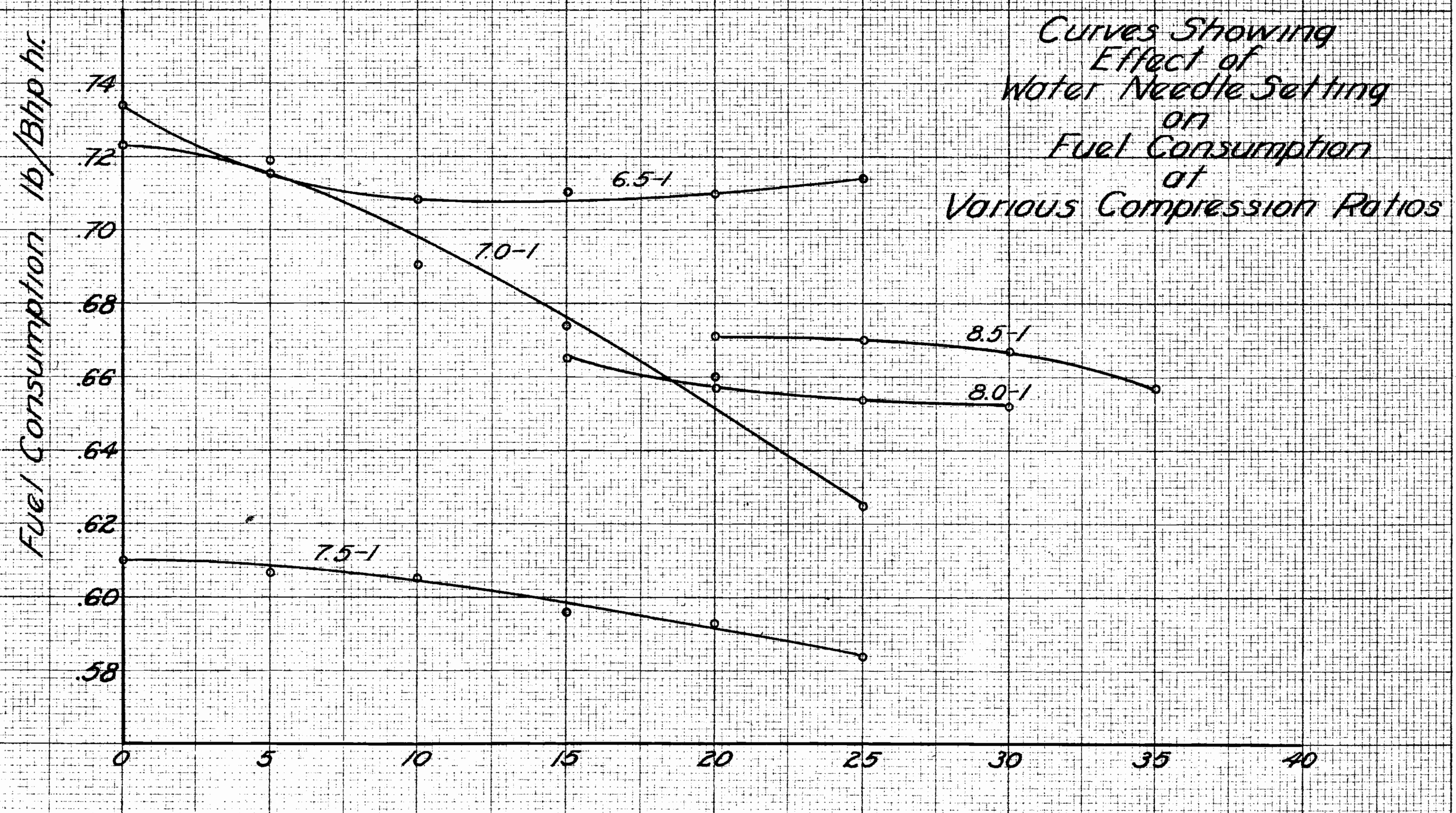

Fig 8-D

EUGENE DIETZGEN CO. NO. 350
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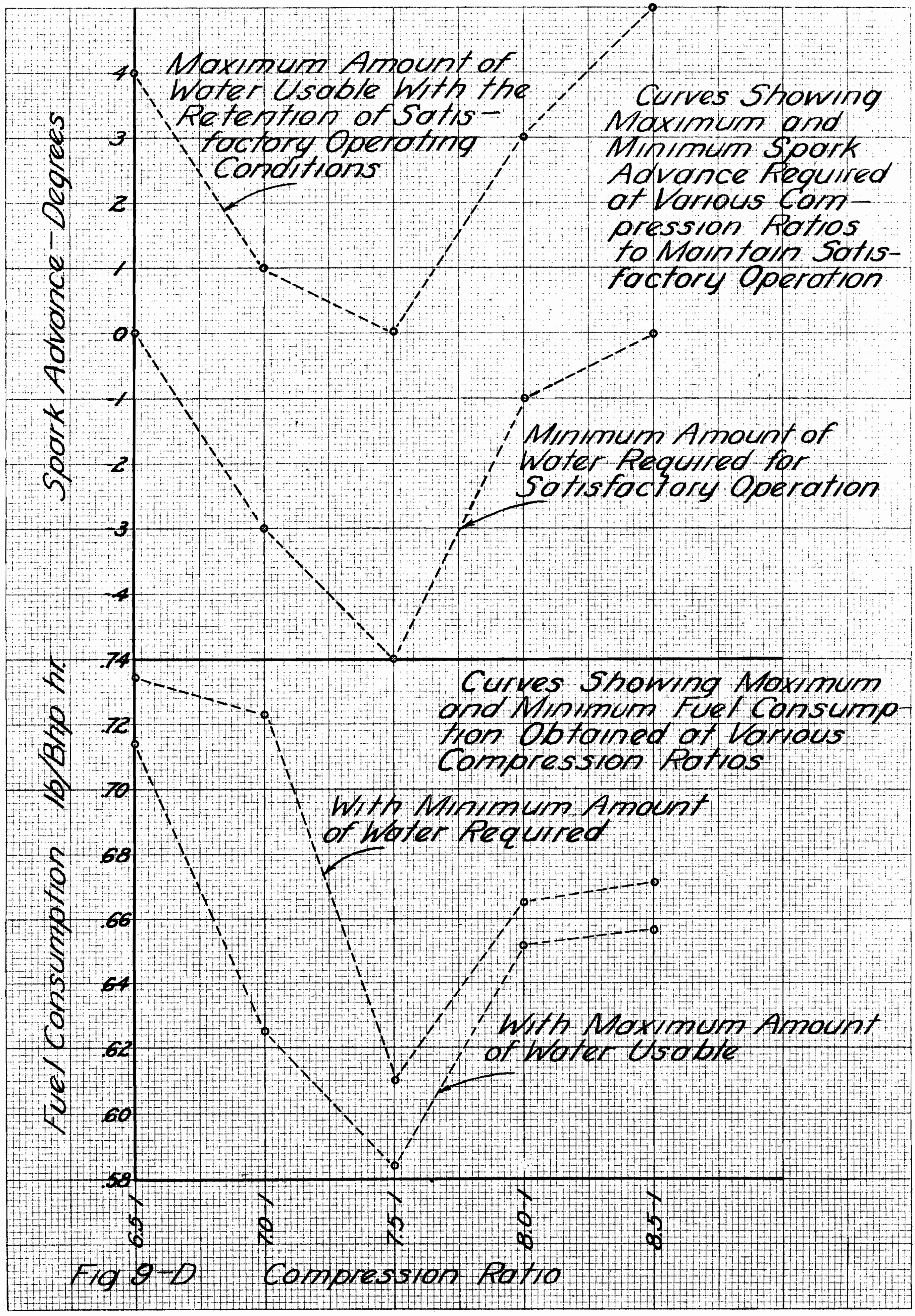

Fig 9-D

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EUGENE DIETZGEN CO. NO. 350

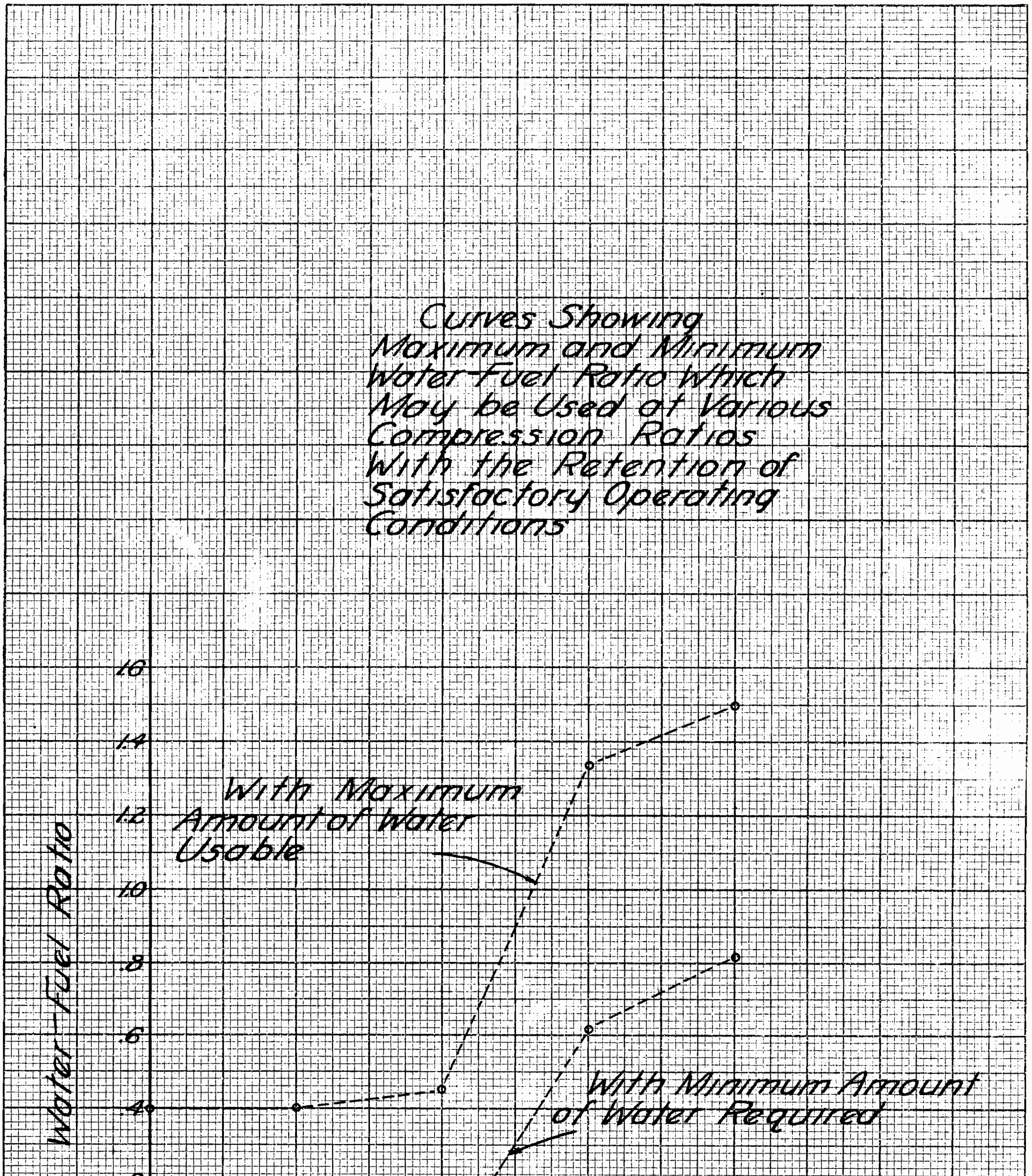
Curves Showing Maximum and Minimum Water-Fuel Ratio Which May be Used at Various Compression Ratios With the Retention of Satisfactory Operating Conditions
Water-Fuel Ratio
1.6
1.4
1.2
1.0
.8
.6
.4
.2
0
With Maximum Amount of Water Usable
With Minimum Amount of Water Required
6.5-1
7.0-1
7.5-1
8.0-1
8.5-1
Compression Ratio

Fig 10-D

APPENDIX E

Curves showing knock intensity, fuel consumption, water-needle setting and spark advance plotted against the water-fuel ratio as abscissae.

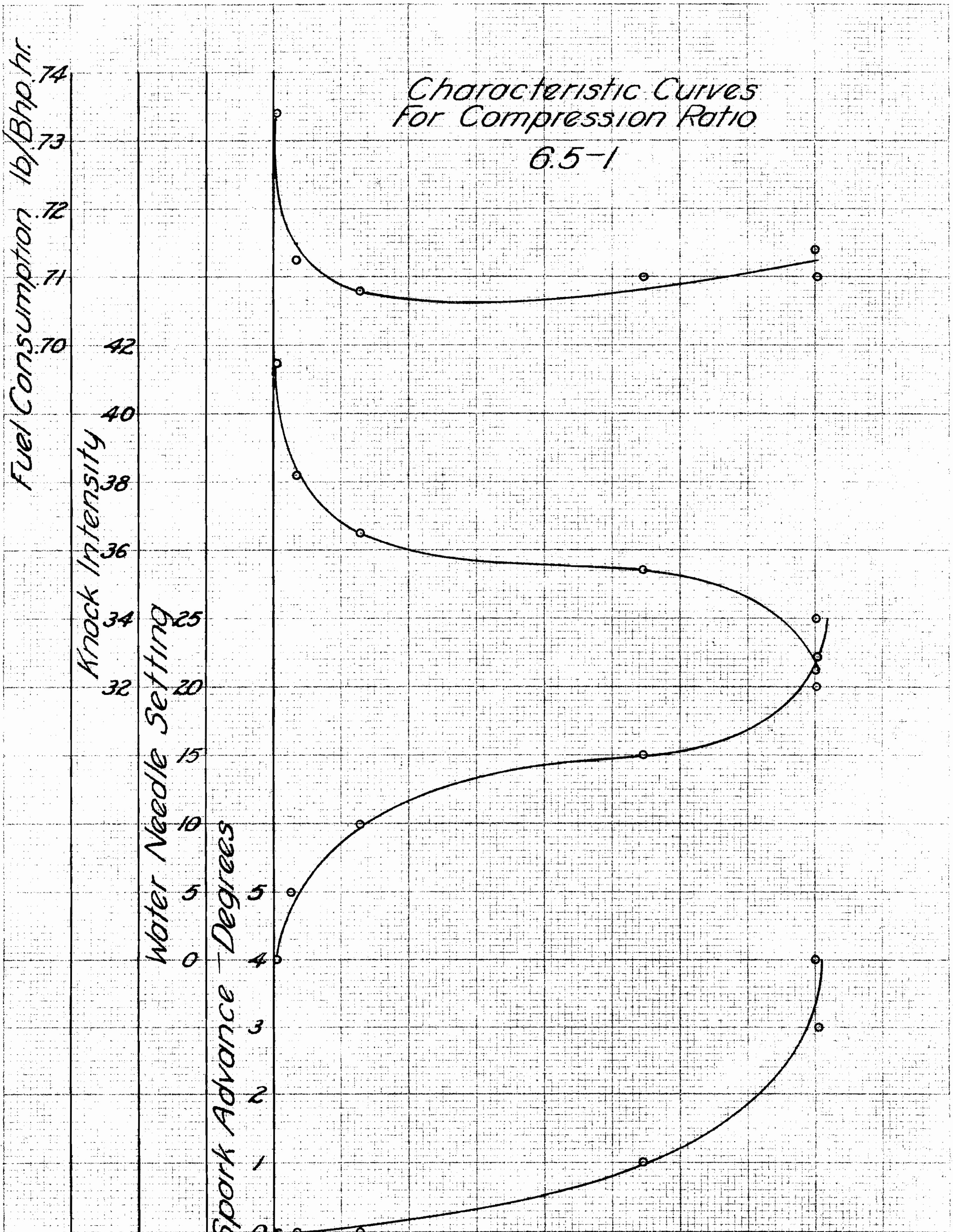
Characteristic Curves
For Compression Ratio
6.5-1
Fuel Consumption lb/Bhp.hr.
.74
.73
.72
.71
.70
Knock Intensity
42
40
38
36
34
32
Water Needle Setting
25
20
15
10
5
0
Spark Advance - Degrees
4
3
2
1
0
0
.1
.2
.3
.4
Water-Fuel Ratio

Fig 1-E

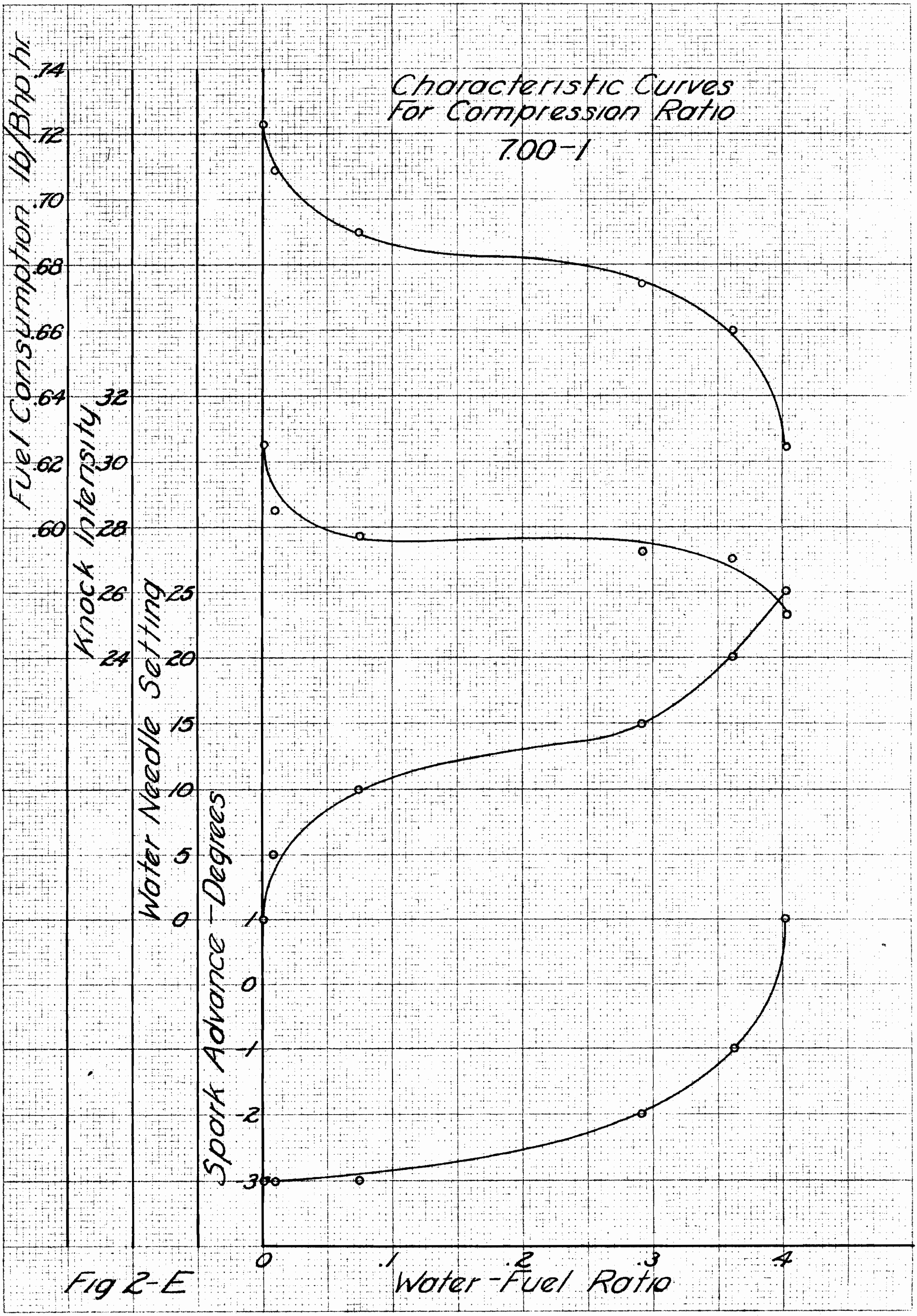

Fig 2-E

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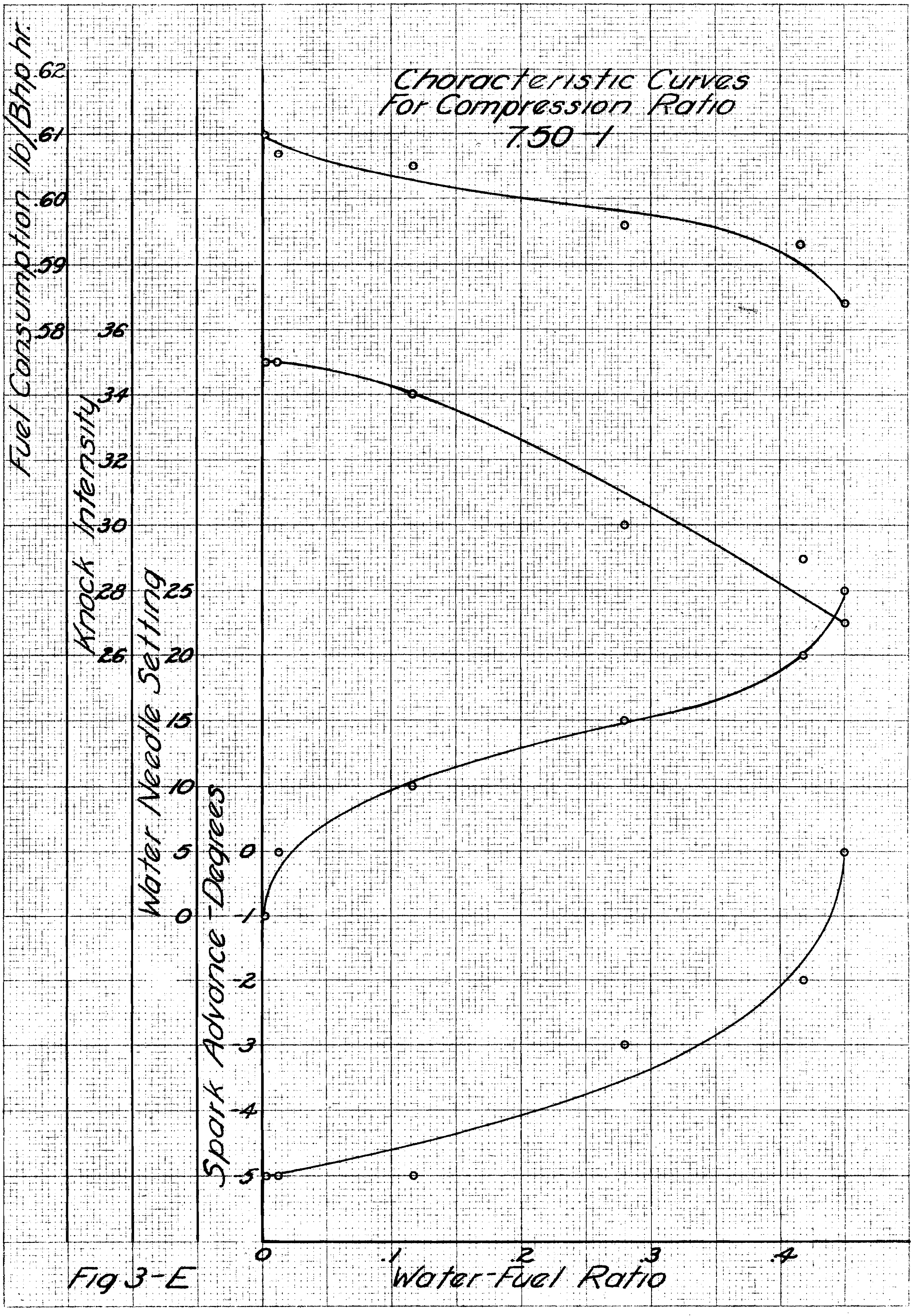

Fig 3-E

EUGENE DIETZGEN CO. NO. 350

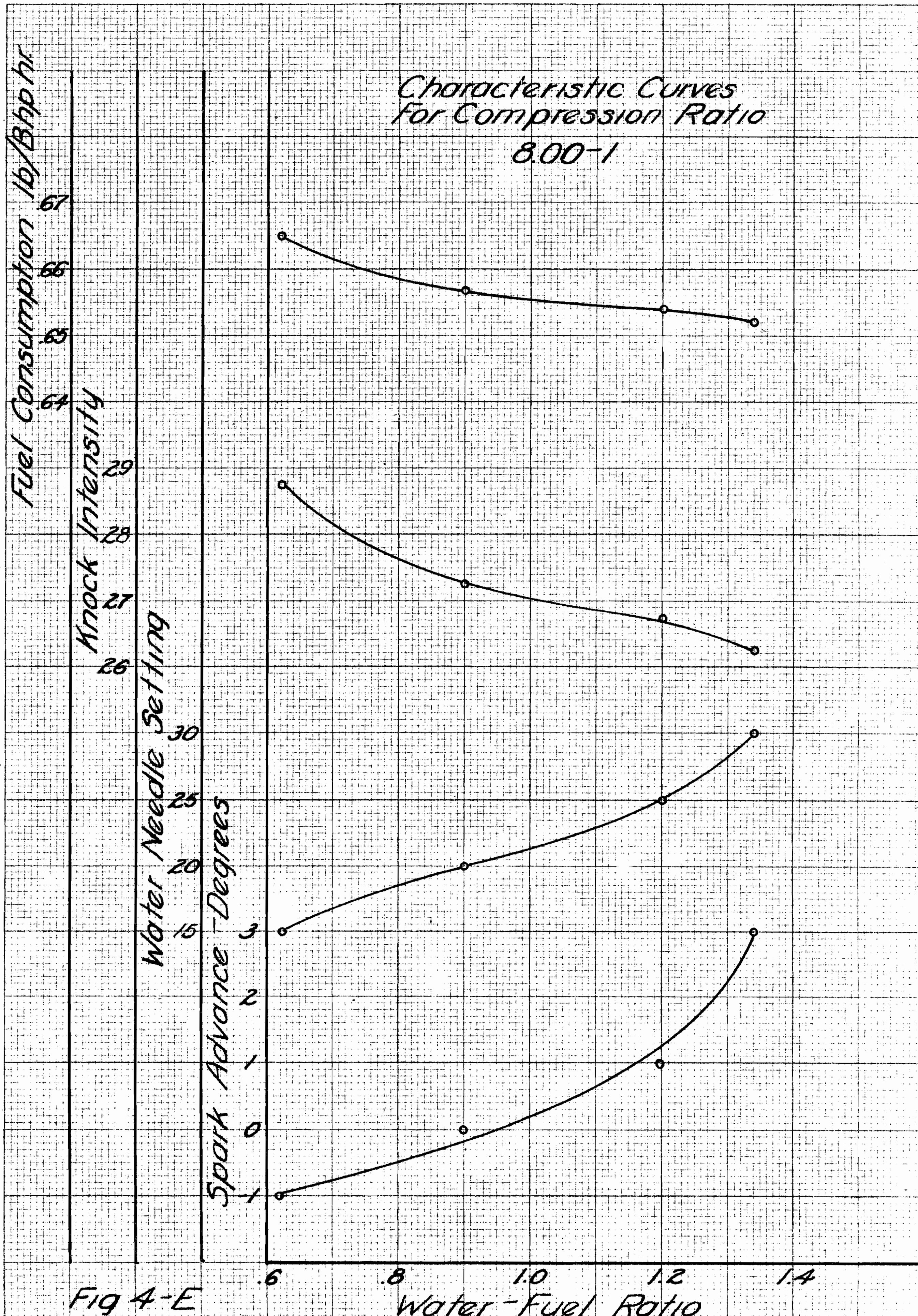

Fig 4-E

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EUGENE DIETZGEN CO. NO. 350

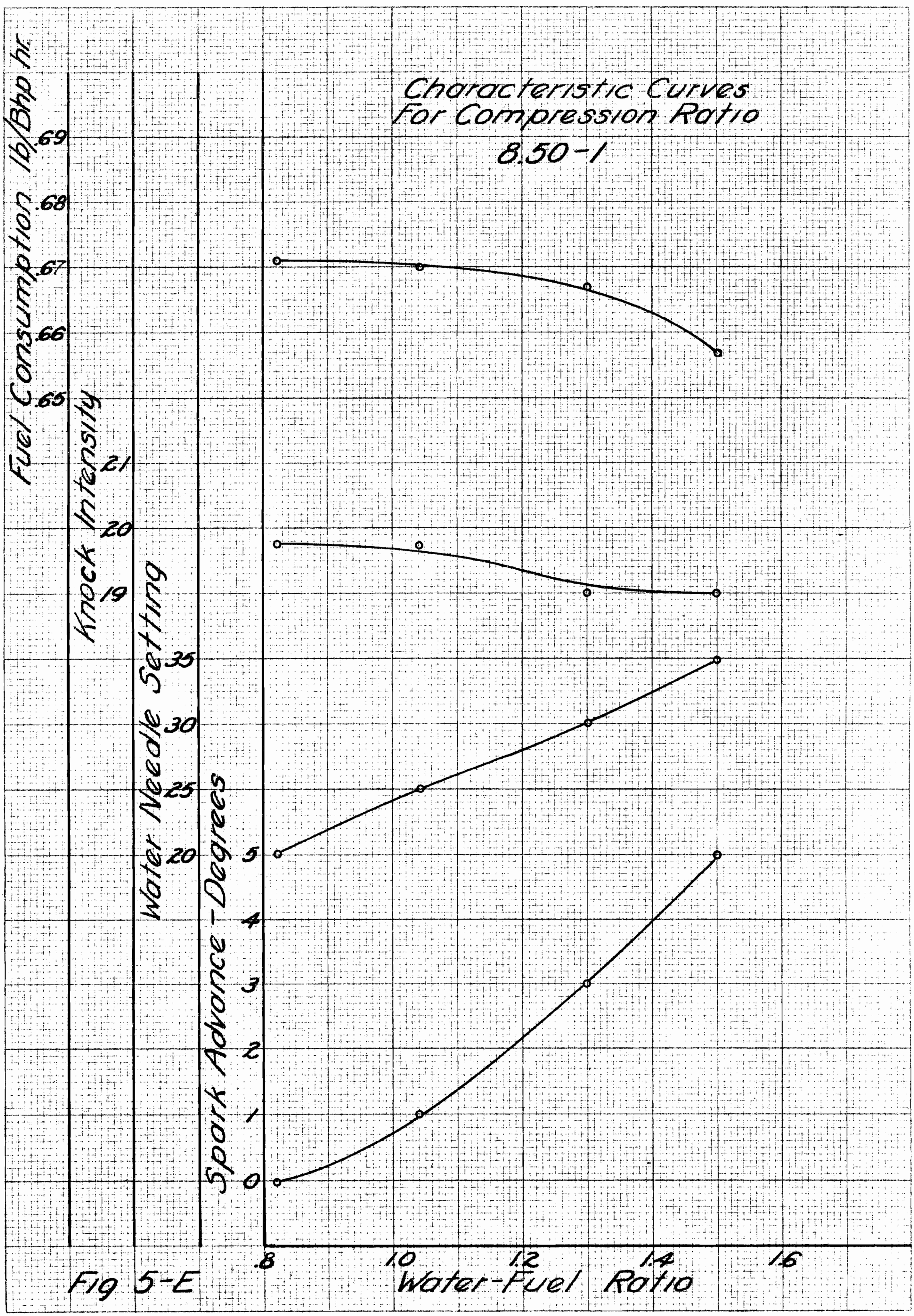

Fig 5-E

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EUGENE DIETZGEN CO. NO. 350

APPENDIX F

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