1953

Effect of viscosity on the cetane number of a diesel fuel

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EFFECT OF VISCOSITY ON THE CETANE NUMBER OF A DIESEL FUEL

BY

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A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE IN MECHANICAL ENGINEERING

Rolla, Missouri

1953

Approved by Aaron J. Miles
Professor of Mechanical Engineering

ACKNOWLEDGEMENTS

The author wishes to express his indebtedness to Dr. Aaron J. Miles, for his guidance and timely suggestions during the course of this investigation.

Gratefulness is acknowledged to Dr. Walter T. Schrenk, Chemical Engineering Department Chairman, for making his department's oil laboratory available; to Professor I. H. Lovett, Electrical Engineering Department Chairman, for kindly lending equipment from his department laboratories; and mostly to Associate Professor Reagan H. Young, for his sincere cooperation and help, guidance and suggestions, in the mechanical engineering laboratory.

I also would like to, herewith, state my sincerest and special thanks to Assistant Professor Leonard C. Nelson, for the initial and most important assistance he rendered me in getting the engine running and his most valuable help in the selection and layout of the problem.

Thanks are also due to all my friends who were kind enough to get interested in the problem and extended their indirect support throughout the preparation of this thesis.

CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

LIST OF PLATES

PART 1

INTRODUCTION

The object of this paper is to determine or rather experimentally establish the effect of a change in viscosity of a given diesel oil in regard to the ignition quality (cetane rating) of the oil.

The author did not attempt to prove why or find out how much the cetane number was affected. But, merely, tried to experimentally verify the fact that the cetane number of the fuel used underwent a change when its viscosity was decreased by preheating it.

Since his professional interests lie in the field of automotive engineering, several thesis problems were suggested to him by Dr. A. J. Miles, Chairman of the Mechanical Engineering Department, all to be investigated on the C.F.R. gasoline and diesel test engines. Originally "sensitivity" (see p. 6) was taken as a thesis problem, for it was a fairly new subject not explored intensively. But later the facilities in the laboratory and the fact that diesel research is still a wide open field led the author to carry his experiments on the C.F.R. diesel testing engine. The author's original idea was to investigate a diesel fuel in regard to a simulation of "sensitivity" as established for the octane numbers of gasolines. He chose, as a first step in doing so, to investigate the relation the fuel viscosity would have on the cetane rating.

Up to 1930 not much research work had been carried out on diesel engines and especially on diesel fuel oils. The following decade, since the tendency toward increasing the speeds of diesel engines had caused them to become more sensitive to fuels and research on the latter had brought out the importance of ignition quality, research work was carried out to standardize a method of test by which diesel fuels could be rated. The importance of ignition quality and viscosity was first recognized by Mr. H. R. Ricardo and attempt in research in this respect was stressed by him.

The following statements, excerpted from various articles written by authorities on diesel engineering and diesel research fields, and studied by the author, were found to be useful for quotation hereinafter.

"Appreciable divergencies were sometimes noted with fuels of high viscosities.

"A study of the viscosities and initial boiling points of the cetane blends as well as those of the test fuels may be of interest."(1)

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(1) Schweitzer, P. H., discussion on paper by MacGregor, J. R., Diesel fuels - significance of ignition characteristics. SAE Transactions, Vol. 38., No. 5., May, 1936. p. 223.

"Surely diesel fuel is just as much a part of the engine as the piston or crankshaft, and the lack of proper quality will result in inefficient operation and high maintenance costs just as readily as the use of inferior castings, poor design, or improper machining.

"It is possible entirely too much emphasis has been placed on cetane number and not enough on the relationship between cetane number, volatility characteristics, and chemical impurities.

"The question of cetane in diesel fuels has been, and is, a much discussed requirement."(2)

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(2) Kelly, W. W., Diesel fuel in railroad operation. Forum on diesel fuel oils. Technical publication No. 71, Pa., American Society for Testing Materials, March, 1947. p. 9.

"The automotive high-speed diesel engine is highly sensitive to the quality of the fuel."(3)

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(3) Morse, R. H. Jr., Increasing diesel horsepower vs. diesel fuel supply. p. 21, Ibid.

"Of the various properties to be considered in selecting a diesel fuel, the most important are ignition quality, viscosity, boiling range, and cleanliness."(4)

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(4) Adams, O., Elements of diesel engineering. N.Y., Henley, 1938. p. 160.

"The viscosity and surface tension of the liquid injected through the nozzle have an important effect on the size of the droplets formed.

"The spray characteristics of one nozzle may be more sensitive to fuel viscosity, air density, etc., than those of another. These effects are very complex and interrelated."[5]

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(5) Fraas, A. P., Combustion engines. 1st ed. N.Y., McGraw-Hill, 1948. p. 180 and 185.

"The viscosity of the fuel exerts a strong influence on the shape of the fuel spray: high viscosities, for example, cause low atomization (large-sized droplets) and high penetration of the spray jet. In small combustion chambers, the effect of viscosity may be critical, hence maximum and also minimum values may be specified.

"The SU viscosity required for most high-speed engines ranges between 35 and 70 sec. (100 F.). Heavy distillates, when used in low-speed engines are usually preheated to reduce the viscosity to a desirable value."[6]

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(6) Obert, E. F., Internal combustion engines analysis and practice. 2nd ed. Pa., International, November, 1950. p. 254.

As can plainly be seen, all the above statements bring forth the fact that no actual research was undertaken in that respect. They also give an idea on the history of the subject and converge on the importance of same for the author's justification in selecting the particular problem.

The parts that follow will give the reader first the definitions of most of the terms used and then the test equipment, procedures followed, results obtained, and discussions on the curves plotted.

PART 2

DEFINITIONS AND ABBREVIATIONS

(in order of appearance in the text)

IGNITION QUALITY: The ease of igniting the fuel oil in the engine by autoignition is called the ignition quality of the fuel. Ignition quality is approximately, but not exactly, quite indicative of combustion knock.

CETANE RATING: is the usual index of ignition quality.

CETANE NUMBER: of diesel fuels is analogous to the octane number of gasolines. The American Society for Testing Materials has selected the cetane number for measuring ignition quality and as the standard method for reporting results. The cetane number is defined as the percentage by volume of normal cetane in a mixture of normal cetane and alpha - methylnaphthalene and is a term usually used for fuel ignitability.

CETANE: known also as normal hexadecane ($C_{16}H_{34}$) is the alpha isomer of cetene ($C_{16}H_{32}$) and a straight chain hydrocarbon of the normal paraffin series, without the double bond of cetene which is an unsaturated hydrocarbon of the ethylene series. Cetane is a pure compound inherently stable and with an ignition quality somewhat higher than cetene.

ALPHA - METHYLNAPHTHALENE: ($C_{11}H_{10}$), is a pure aromatic hydrocarbon of very low ignitability.

SENSITIVITY OF FUELS: A sensitive fuel is one that will exhibit decreasing knock-resisting ability as engine conditions increase in severity. The response of a motor fuel to the change in engine severity between the operating conditions of the research and motor methods is commonly referred to as its sensitivity. Sensitivity is evaluated as the difference in octane ratings when the fuel is rated by both the motor and research methods. Thus, sensitivity equals the research rating minus the motor rating, in octane numbers.

C.F.R. - Coordinating Fuel Research.

SU viscosity - Saybolt Universal Viscosity, unit of viscosity in seconds at 100 F. indicating that 60 ml. of oil at 100 F. will take so many seconds to flow from a tube and orifice made to the Saybolt specifications.

F. or deg. F. - unit of temperature in degrees Fahrenheit.

"Cetane Method" - method of test for ignition quality of diesel fuels, ASTM Designation: D 613 - 47T.

ASTM - American Society for Testing Materials

atdc - after top dead center.

abdc - after bottom dead center.

bbdc - before bottom dead center.

btdc - before top dead center.

"Motor Method" - standard method of test for knock characteristics of motor fuels by the motor method, ASTM Designation: D 357 - 47.

"Research Method" - method of test for knock characteristics of motor fuels by the research method, ASTM Designation: D 908 - 47T.

PART 3

TEST EQUIPMENT

A fairly detailed description, if not complete, of the test equipment has been reproduced for a better conception of, and familiarization with, the engine used for the experiments. Since the scope of this paper is not concerned with the investigation of the "Cetane Method" itself, the author deemed it wise not to include the various instruments, attachments, and accessories of the engine pictorially to the body of the paper. But references are made as much as possible to the picture views illustrated in the actual ASTM Manual for further and more extensive study. In the following page, a photograph of the engine and all its accessories shows the complete unit used as a whole.

The tests were run on a single cylinder diesel engine, with a serial number of 807903 and date of 8 - 50 on the name plate, of continuously-variable-compression ratio with suitable loading and accessory equipment and instruments, mounted on a stationary base of concrete, 15 inches in height above the floor level, in the North West section of the Mechanical Engineering Laboratory. The complete unit is known as the "ASTM-CFR Engine" or the CFR Diesel Fuel Testing Unit (referred to, hereafter, as the cetane engine) and is marked by the emblem of the American Society for Testing Materials and the Coordinating Fuel Research Committee. Up to the present, the Waukesha Motor Company, Wauke-

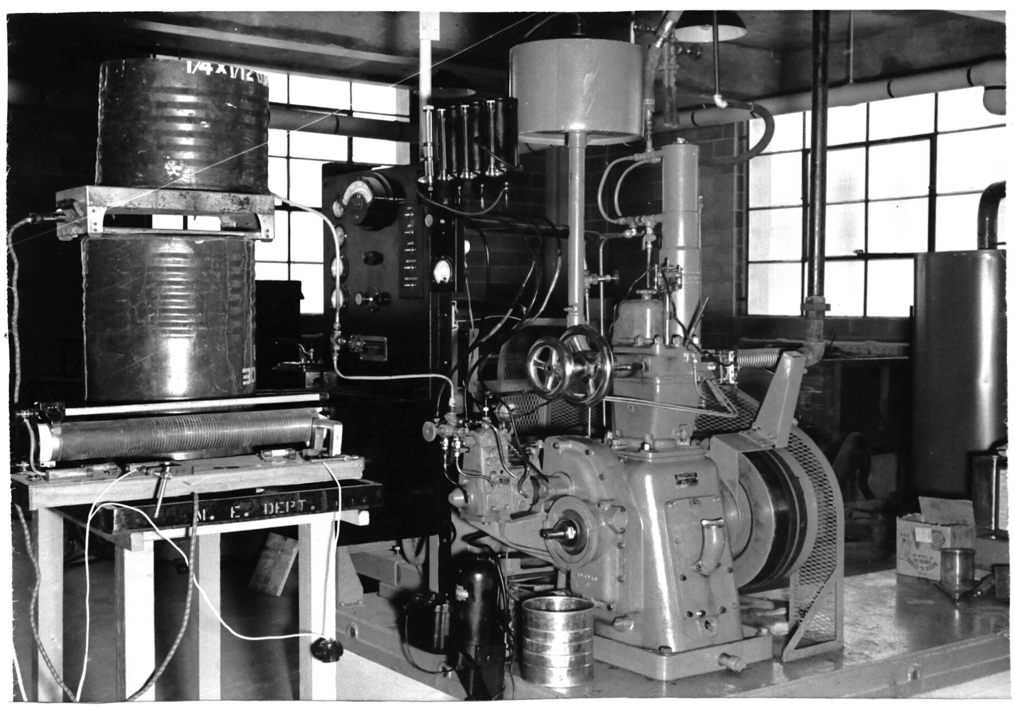

Fig. 1. Photograph of Test Equipment

sha, Wisconsin, has been the sole manufacturer of the ASTM-CFR engine. All necessary instruments and accessories are furnished by the same manufacturer.[7] [8]

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(7) ASTM Manual of Engine Test Methods for Rating Fuels. Pa., American Society for Testing Materials, March, 1948. p. 65.

(8) CRC Handbook, Coordinating Research Council, Inc. 1946 ed. N.Y., Little & Ives, January, 1946. pp. 320 and 325.

ENGINE (and Cylinder Assembly and Power Section): The dimensional specifications are as follows (see ASTM Manual, p. 67, and CRC Handbook, p. 321.),

Bore, in.	3.25
Stroke, in.	4.50
Displacement, cu. in.	37.33
Turbulence combustion-chamber,	
bore, in.	1.625
length, in., adjustable	0.375 to 2.750
Valve-port diameter, in.	1.187
Connecting-rod bearing,	
diameter, in.	2.50
length, in.	1.625
Front main bearing,	
diameter, in.	2.50
length, in.	2.25

ear main bearing,

diameter, in.	2.50
length, in.	4.906
Piston-pin, floating, diameter, in.	1.250
Connecting-rod, length, center-to-center, in.	10.00
Timing-gear face, in.	1.00
Piston rings, number	5
Exhaust pipe, minimum diameter, in.	1.25
Weight of engine, lbs. (approximate)	650
Weight of complete unit, lbs. (approximate)	1550

The cylinder, with a detachable head, is made of a cast iron alloy, bored and honed, and has a Brinell hardness of 220±20. The cylinder head is of variable compression, high turbulence type. A handwheel micrometer is used to measure the length of the combustion chamber. The cast iron piston has four plain compression rings and one ventilated oil-control ring. The piston pin is of the full floating hollow type and is held in position by circlips. The valves are plain and without shrouds. They are made of silcrome or equivalent. Both valve-seat inserts are made of solid stellite. The valve guides are cast iron. The valve springs are cadmium plated and the pressure with the valve open is 104±6 lbs., and with the valve closed 83±6 lbs. The intake valve opens 10 deg. bbdc and closes 15 de atdc. This constitutes the valve timing. The valve clea ance is 0.010 in. on both valves for checking the valve lift and valve timing. Both the intake and exhaust valves must be adjusted to 0.008 in. for hot and running clearances with the engine running under standard operating conditions on a reference fuel of 50 cetane number. The push rods are of the mushroom type with lock-nut adjustment.

The power section, composed of the crankcase, main bearings, crankshaft, connecting rod, and camshaft, is as specified, and its mandatory characteristics as shown, in p. 80 of the ASTM Manual and p. 321 of the CRC Handbook.

FUEL SUPPLY SYSTEM: The injection system includes the following,

a. Injector Pump: Bosch specification PE1B50A302.

b. Injector: Bosch specification DN-30S3.

c. Fuel line: Tank to pump 3/8 in. copper tubing with bottom of 3 fuel tanks 25 ± 1 in. above pump inlet.

d. Injection line: 1/4 in. outside and 1/16 in. inside diameter and 27 in. in length.

e. Riser: Vertical open riser with a measuring buret located on pump sump outlet.

INTAKE AIR SYSTEM: An electric heater equipped surge tank is connected to the intake port of the engine. This heater maintains the intake air temperature within specified limits. A thermometer, having a range of 0 to 220 deg. F., graduated in 2-deg. divisions, and inserted just above the elbow in the base of the intake air tube, records the intake air temperature. The thermometer is horizontal and located so that the center of the bulb is on the center line of the intake tube. The surge tank is part of the humidity control apparatus used in the Motor and Research Methods. The humidity control apparatus is necessary when air in the room where the engine is located contains less than 25 or more than 50 grains of water vapor per pound of dry air. Humidity is controlled by the ice tower (see fig. 15, p. 73, ASTM Manual) which consists of an insulated cylindrical tank arranged to pass the intake air through an ice bed, thus chilling it and delivering saturated air at approximately 32 deg. F. with a moisture content of 26 to 28 grains per pound of dry air. The ice tower is arranged to receive air at the top with a down flow through the ice pack. The center tube, 2-5/8 in. minimum inside diameter, provides a chilled outlet passage, thus preventing evaporation of any entrained moisture. This permits the addition of ice without interrupting the operation of the engine. The tank is made of galvanized sheet metal insulated around the sides and bottom with 2½ in. of rock wool. The ice is supported on a ½-in. mesh wire screen held 4 in. above the bottom of the tank to form a surge chamber. The outlet pipe connects through a bend and flexible rubber hose connections to the pipe leading to the combination surge tank and air heater located on the intake air pipe. The tower is supported on an iron stand to allow convenient drainage through a trap at the bottom. A removable wood cover on the top of the tank permits convenient access for filling. The opening in the cover for intake air is 3 in. in diameter and is closed by a slide cover to save ice when the engine is shut down.

The ice tower was used unsuccessfully, when the intake air temperature was varied, to obtain air temperatures less than 80 deg. F.

The tests were run during the months of June and July and the room temperature around the running engine never dropped below 80 deg. F. Although the air passing through the ice tower was cooled considerably, it was warmed up again to 70-80 deg. F. by the time it reached the intake air thermometer because it passed through four feet of tubing before ever reaching the surge tank and then it passed through the surge tank and two additional feet of intake air tube which were heated by conduction and radiation of the running engine. Thus, the author was not able to get air less than 80 deg. F. in temperature to reach the combustion chamber when he varied the intake air temperature during the test.

EXHAUST SYSTEM: Since the Tentative Method of Test for Ignition Quality of Diesel Fuels by the Cetane Method or ASTM Designation: D 613 - 47T cites that it is permissible to use the apparatus for the Motor or Research Methods, the latter was used. The exhaust system for this Method consists of the following parts (see figs. 96, 97, and 98, pp. 312 and 313, ASTM Manual),

1. Flexible exhaust pipe: of $1\frac{1}{4}$ in. in internal diameter and 30 in. long connects the engine exhaust port and the surge tank.
2. Spacer: The flexible pipe is connected to the surge tank by a special flange and spacer.
3. The surge tank: has a minimum inside diameter of 10 in. with a minimum outside diameter of 10-3/4 in. and a minimum volume of 1 cu. ft. It is mounted horizontally and it is rigidly supported.
4. Exhaust back pressure: The maximum permissible back pressure at the surge tank is 10 in . of water.
5. The discharge pipe: has a minimum inside diameter of 2 in. and is connected to the main discharge pipe of the laboratory.

COOLING AND VENTILATION: An evaporative cooling system equipped with a flexible coolant return pipe and a water cooled condenser coil above the coolant level is used with distilled water to maintain the coolant temperature (see Fig. 90, p. 300, ASTM Manual). An electric heater in the cooling-water line between the outlet of the condenser and the inlet to the cylinder jacket is used to bring water to the operating temperature quickly. A thermometer inserted between the condenser and the heater indicates the temperature.

Crankcase ventilation is furnished by a breather valve located on the rear crankcase door. In the top of the assembly is a cap enclosing a diaphragm or flutter valve which has a clearance of 0.010 in. The outlet, which is not connected to the engine exhaust, is tapped for a 3/4-in. pipe to conduct the crankcase vapors out of the laboratory (see Fig. 18 "A", p. 79, ASTM Manual).

LUBRICATION SYSTEM: Pressure feed is used to lubricate the main bearings, connecting-rod bearings, idler gear stud, and gears. For schematic lubrication diagrams refer to the ASTM Manual, Figs. 17, 94, pp. 78, 308, and for oiling system connections to Figs. 18, 95, pp. 79, 309. An electric heater is mounted on the base of the crankcase to provide rapid warm up. A temperature gage on the instrument panel and of the thermocouple type, having a range of 100 to 200 deg. F., is used to indicate the temperature of the crankcase oil - SAE 30, having a Saybolt Universal viscosity of 185 to 255 sec. at 130 deg. F. determined by ASTM Method D 88. An oil pressure gage also on the instrument panel and having a range of 0 to 70 psi is used to indicate the oil pressure. A safety feature embodied in the design of the engine stops it in case of oil pressure failure. The whole lubrication unit is composed of an oil pump, an oil cooler of the coil type, an oil filter, and the tubing.

INSTRUMENTS (Coincident Flash Indicators): The ignition quality of a diesel fuel is measured by the coincident-flash fixed-delay method, using neon lights which are located on the periphery of the flywheel and are operated by contact points on the combustion and injection indicators. The necessary instruments are as follows,

a. The combustion indicator which is screwed into a tapped hole, 7/8 in. by 18 threads per inch, in the combustion chamber is equipped with a spring-steel indicator diaphragm 0.543±0.003 in. in diameter and 0.015±0.005 in. in thickness. Graduated spring tension adjusting screws are provided. In addition, a graduated gap adjusting screw is provided with a spring cushion plunger to protect the contact points against overloading as the result of combustion pressures (see Fig. 64, p. 316, CRC Handbook).

b. The injection indicator, which utilizes contact-point assembly parts similar to the combustion indicator, with brackets for attachment to the injector to permit operation of the contact points by the movement of the injector pin (see Fig. 11, p. 58, ASTM Manual).

c. The neon-light mount, which carries two 0.250-watt, 110-volt, neon bulbs, located behind an aperture plate with 13-deg. spacing between openings.

d. The sight tube and the reference mark with brackets.

e. Flywheel slip rings and brush holders with necessary brackets and wiring for the neon light support.

f. A 110-volt d.c. generator to supply current for the injection and combustion indicators. This generator is belt-driven from the power-absorbing unit. The voltage is controlled to 115±5 volts by means of a field rheostat located on the instrument panel.

For better view of wiring diagram of the coincident flash unit see Fig. 88, p. 297, ASTM Manual. For better comprehension and visualization of the instrument or control panel see same Fig. 88 and Fig. 1, p. 8, ASTM Manual.

ELECTRICAL SYSTEM (Wiring Diagrams): The wiring diagram is the same as for the Motor or Research Methods (see Fig. 87, p. 296, ASTM Manual), except that the knockmeter and bouncing pin circuits are not used. The injection and combustion indicators are connected to separate 110-volt d.c. supply (see Fig. 88, p. 297, ASTM Manual).

POWER-ABSORBING UNIT: The engine is connected by V-type belts to an electric generator which preferably should be an induction motor with synchronous characteristics, but may be any electric generator capable of starting the engine, absorbing the power developed by it, and maintaining proper operating conditions and specially the speed specified in the method as 900±9 rpm. The electric generator was actually a multispeed continuous induction motor.

PART 4

GENERAL OUTLINE OF PROCEDURE

This part consists of the experiments performed and procedures followed in investigating the influence of the fuel viscosity on its ignition quality. It also includes the data and curves resulting from the tests run, followed by a discussion of their behavior. There were four different tests.

The first one was performed with the purpose of determining the cetane number of the diesel fuel available in the laboratory (referred to, hereafter, as the commercial fuel). The procedure followed was the Tentative Method of Test for Ignition Quality of Diesel Fuels by the Cetane Method, A.S.T.M. Designation: D 613 - 47T (referred to, hereafter, as the cetane method).

The second one was introduced to find and show a direct relation between the viscosity of the fuel and its temperature. This was attempted because of the easiness and practicality of varying temperatures along with their use in plotting the curves instead of viscosity. Since there is a direct relation between the cetane number and compression ratio (see p. 49), the cetane engine, therefore, makes it possible to obtain data in compression ratios rather than the cetane number. Consequently, compression ratios versus temperatures curves give a better conception of the influence of viscosity on the cetane number.

With the purpose of decreasing its viscosity, the fuel temperature is varied by preheating it on the third experiment and its effect on the ignition quality, namely, its cetane rating, is studied and discussed. Here, the temperature is used as a direct function of the viscosity as well as the compression ratio as a direct function of the cetane number. Hence, the experiment is run as fuel temperature versus compression ratio.

The fourth one, where, this time, the intake air temperature is varied and the fuel kept at constant room temperature, is performed for the purpose of studying and comparing its relation as to the cetane rating.

1. DETERMINATION OF THE CETANE NUMBER

Throughout the experiments two fuels of same cetane number were used. The first one was the commercial fuel used in the Power Plant. The second one was ordered from Shell Oil Co., Inc., Wood River, Illinois, and is a blend made of secondary reference fuels, T-12 and U-5.

The method for determining the cetane number of fuel oils is based on comparing a fuel in the ASTM engine under standard test conditions with reference fuels of known ratings. Therefore, the cetane scale is based on two hydrocarbons, one of high and the other of low ignition quality. The hydrocarbon of high ignition quality is normal cetane. This fuel in its pure state has by definition a cetane number of 100. The fuel of low ignition quality is alpha-methylnaphthalene. This fuel in its pure state has by definition a cetane number of 0. The cetane number of a mixture of those two pure hydrocarbons is equal to the percentage by volume of cetane in the blend of the two. The ASTM Cetane Reference Fuels are n - cetane and alpha - methylnaphthalene. Certified Secondary Reference Fuels are normally used in actual testing by the cetane method. Batches of secondary reference fuels as T and U are calibrated as required against n - cetane and alpha - methylnaphthalene by the Division on Combustion Characteristics.[9]

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(9) ASTM Manual, op. cit., p. 89.

The determination of the cetane number of the commercial fuel was made by the cetane method and the use of blends of T-12 and U-5. Once the cetane number of the commercial fuel thus determined, a blend by volume of T-12 and U-5 was obtained to match the determined cetane number.

The cetane method is the standard one of ASTM designation D 613 - 47T. The outline of the method is as follows: The cetane number of a diesel fuel is determined by comparing its ignition quality with those for blends of the reference fuels of known cetane numbers at 900 RPM under standard conditions. This is done by varying the compression ratio for the sample (commercial fuel) and each reference fuel to obtain a fixed "delay period," that is the time interval between injection and ignition. When the compression ratio is bracketed between those for the two reference fuel blends differing by not more than five cetane numbers, the rating of the sample is calculated by interpolation.

The operating conditions, mandatory by the cetane method were kept throughout the tests as follows:

Engine Speed, 900±9 RPM

Injection Advance, 13.0 deg. btdc.

Injection Opening Pressure, 1500±50 psi.

Injection Quantity, 13.0±0.2 ml. per min., that is, 13.0 ml. in 60±1 sec. (this adjustment was made for each sample and run)

Injector Water Jacket Temperature, 100±5 F.

Oil Pressure, 25 to 30 psi.(10)

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(10) The oil pressure could not be maintained within this range throughout all the test runs. It always remained above 30 psi and around 44 to 46 psi.

Oil Temperature, 135±15 F.

Coolant Temperature, 212±3 F., constant within 1 F.

Intake Air Temperature, 150±1 F.

After all the adjustments were made as required and shown in the cetane method, the engine was motored and the compression ratio was increased until the engine fired. Throughout the tests, the author noticed that the compression ratio reached just before the engine fired was around 19 to 1 most of the time. After the engine fired properly, it was kept running to warm up for about an hour before all the temperatures reached their operating conditions. The oil temperature and specially the pressure were the two factors that gave the most trouble. Most of the time it was practically impossible to obtain an oil pressure between 25 to 30 psi. The engine was warmed up using the commercial fuel all the time.

The "lingering flash" procedure (see pp. 59-62, ASTM Manual) was used to obtain the 13-deg. ignition delay. Neon bulbs on the flywheel produced two flashes. One for the injection actually occurring 13 deg. btdc but with the neon bulb so set that it would flash at tdc and the second when combustion took place. By varying the compression ratio, the combustion flash could be made to coincide with the injection flash at the reference mark. This would give the necessary 13-deg. ignition delay (see following page).

Actually a handwheel micrometer is read for the compression ratio. The handwheel micrometer is calibrated with the clearance volume. It has a scale with a range of .6 to 2.9 in. graduated to 0.001 of an inch. The compression ratio depends upon the position of the expansion plug in the cylinder head. The compression ratio is the ratio of the volume of the combustion chamber when the piston is at bdc to the volume when the piston is at tdc. The piston has a stroke of 4.50 inches and a displacement of 37.33 cu. in. This volume is equivalent to a theoretical 18.00-in. segment of the cylinder in which the expansion plug moves, if the cylinder were 18 inches long. When the piston is at tdc with the expansion plug set for a micrometer reading (handwheel setting) of 2.00 in., the volume of the combustion space is 4.15 cu. in. This volume is the same as that of a 2.00-in. segment of the cylinder in which the expansion plug moves. With the clearance volume and micrometer scale accurately set, the compression ratio of the cetane engine for any position of the expansion plug may therefore be calculated from the equation:

$$C.R. = \frac{18 + \text{handwheel setting}}{\text{handwheel setting}} \quad . \; . \; . \; (1)$$

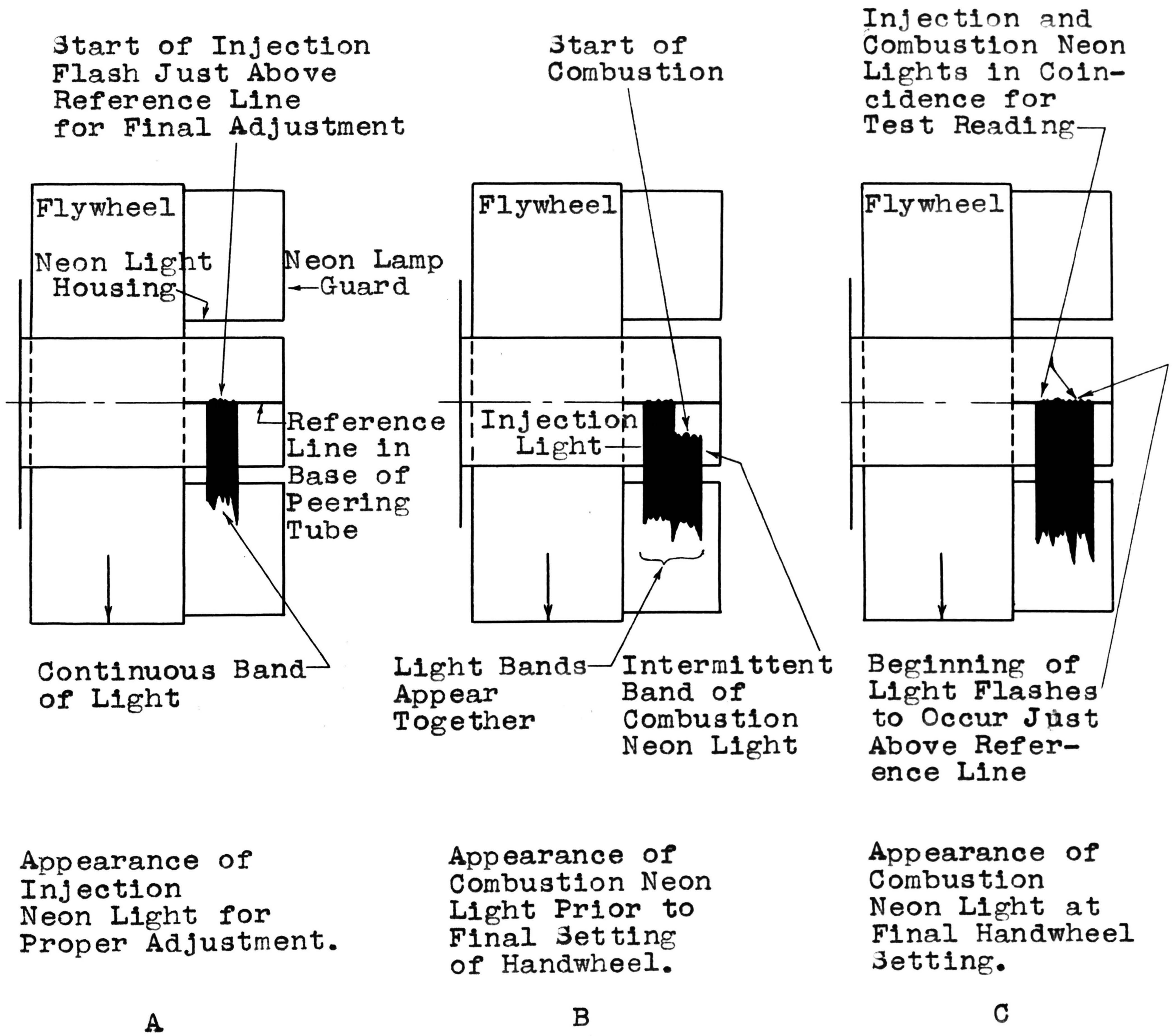

Fig. 2. Injection and Combustion Neon-Flash Patterns.

For convenience and making use of this equation, a table (Table 1, p. 27) has been prepared for the conversion of handwheel reading to compression ratio for the cetane engine.(11)

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(11) ASTM Manual, op. cit., Table XX, p. 184.

Since compression ratios cannot be determined directly, it is common practice to use handwheel readings and accordingly compression ratios throughout the tests are stated in terms of handwheel readings. Obviously, handwheel readings of themselves are meaningless unless accurately related to compression ratios, as described above.

After several breaking in and warming up runs and final adjustments of flashes, it was observed that the 13-deg. ignition delay for the commercial fuel would be obtained at a handwheel reading between approximately 1.120 and 1.320 which is equivalent to a compression ratio range of 17.07/1 to 14.64/1 (See Table 1, p. 27).

Using this observation as a starting point, a handwheel reading of 1.255 was taken and using the Guide Curve (see Plate 1, p. 28) as a guide, the cetane number of the commercial fuel was estimated to be 33.(12)

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(12) ASTM Manual, op. cit., fig. 47, p. 187.

Since the two blends of reference fuels should differ by not more than five cetane numbers and for convenience's

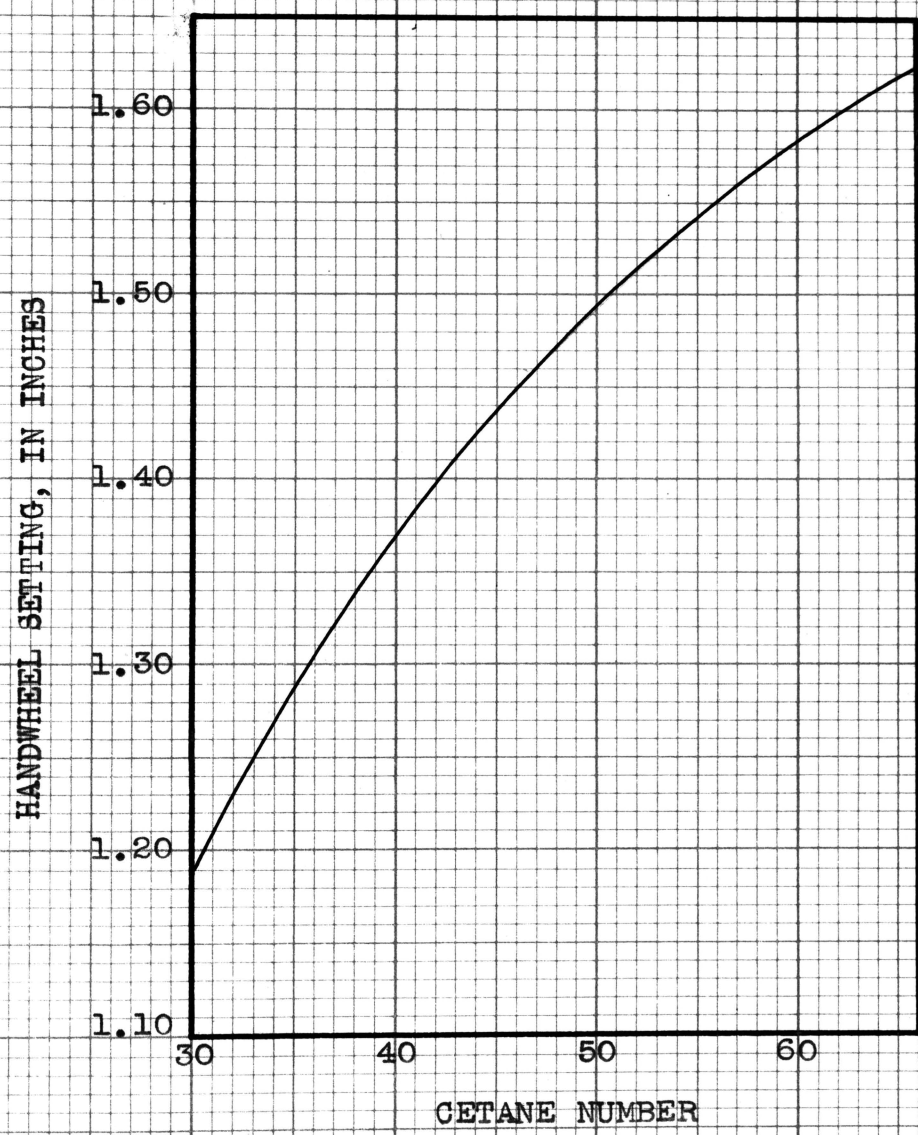
TABLE 1

CONVERSION OF HANDWHEEL READING TO COMPRESSION RATIO FOR CETANE ENGINE

H. R.	0.00	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09
	Compression Ratio									
0.8	23.50	23.22	22.95	22.69	22.43	22.18	21.93	21.69	21.45	21.22
0.9	21.00	20.78	20.57	20.35	20.15	19.95	19.75	19.56	19.37	19.18
1.0	19.00	18.82	18.65	18.48	18.31	18.14	17.98	17.82	17.67	17.51
1.1	17.36	17.22	17.07	16.93	16.79	16.65	16.52	16.38	16.25	16.13
1.2	16.00	15.88	15.75	15.63	15.52	15.40	15.28	15.17	15.06	14.95
1.3	14.85	14.74	14.64	14.53	14.43	14.33	14.24	14.14	14.04	13.95
1.4	13.80	13.77	13.68	13.59	13.50	13.41	13.33	13.24	13.16	13.08
1.5	13.00	12.92	12.84	12.76	12.69	12.61	12.54	12.46	12.39	12.32
1.6	12.25	12.18	12.11	12.04	11.98	11.91	11.84	11.78	11.71	11.65
1.7	11.59	11.53	11.47	11.40	11.34	11.29	11.23	11.17	11.11	11.05
1.8	11.00	10.94	10.89	10.84	10.78	10.73	10.68	10.62	10.57	10.52
1.9	10.47	10.42	10.38	10.33	10.28	10.23	10.18	10.14	10.09	10.05
2.0	10.00	9.96	9.91	9.87	9.82	9.78	9.74	9.69	9.65	9.61
2.1	9.57	9.53	9.49	9.45	9.41	9.37	9.33	9.29	9.26	9.22
2.2	9.18	9.14	9.11	9.07	9.04	9.00	8.96	8.93	8.89	8.86
2.3	8.83	8.79	8.76	8.73	8.69	8.66	8.63	8.59	8.56	8.53
2.4	8.50	8.47	8.44	8.41	8.38	8.35	8.32	8.29	8.26	8.23
2.5	8.20	8.17	8.14	8.11	8.09	8.06	8.03	8.00	7.98	7.95

PLATE 1

GUIDE CURVE FOR CETANE METHOD



sake, 32.8 was taken as the low cetane number blend and 37.2 as the high cetane number blend. The two secondary reference fuel blends of 32.8 and 37.2 cetane number were obtained by referring to the calibration table for Blends of Diesel Secondary Reference Fuels T-12 and U-5 (see Table 2, p. 30) which required a 21% of T-12 in U-5 by volume for a cetane number of 32.8 and a 30% of T-12 in U-5 by volume for a cetane number of 37.2

Thus, the first test to determine the cetane number of the commercial fuel was begun by using the low cetane number (32.8) blend in the fuel bowl No. 1, the commercial fuel with an estimated cetane number of 33 in the fuel bowl No. 2, and the high cetane number (37.2) blend in fuel bowl No. 3.

First the engine was let run with the commercial fuel and using the lingering-flash method to fix the 13-deg. ignition delay a handwheel reading of 1.327 was taken when the two flashes coincided. Then, the fuel blend in bowl No. 1 was used to feed the engine and the engine was allowed to run for some time for the whole fuel injection system to be flushed by it. When the flashes coincided for this fuel blend the handwheel reading was taken down as 1.125. The same thing done for the fuel blend in bowl No. 3 gave a handwheel reading of 1.304. Since the handwheel reading of 1.327 for the commercial fuel was not in between the range of 1.125 and 1.327 for the reference fuel blends, the first estimation of 33 as the cetane number for the commercial fuel was wrong.

TABLE 2

CALIBRATION TABLE FOR BLENDS OF DIESEL SECONDARY REFERENCE FUELS T-12 AND U-5

% T-12 in U-5	Cetane No.	% T-12 in U-5	Cetane No.	% T-12 in U-5	Cetane No.
0	22.5	35	39.6	70	56.8
1	23.0	36	40.1	71	57.3
2	23.5	37	40.6	72	57.8
3	24.0	38	41.1	73	58.3
4	24.5	39	41.6	74	58.8
5	25.0	40	42.1	75	59.2
6	25.4	41	42.6	76	59.7
7	25.9	42	43.1	77	60.2
8	26.4	43	43.6	78	60.7
9	26.9	44	44.1	79	61.2
10	27.4	45	44.6	80	61.7
11	27.9	46	45.0	81	62.2
12	28.4	47	45.5	82	62.7
13	28.9	48	46.0	83	63.2
14	29.4	49	46.5	84	63.7
15	29.8	50	47.0	85	64.2
16	30.3	51	47.5	86	64.6
17	30.8	52	48.0	87	65.1
18	31.3	53	48.5	88	65.6
19	31.8	54	49.0	89	66.1
20	32.3	55	49.4	90	66.6
21	32.8	56	49.9	91	67.1
22	33.3	57	50.4	92	67.6
23	33.8	58	50.9	93	68.1
24	34.3	59	51.4	94	68.6
25	34.8	60	51.9	95	69.0
26	35.2	61	52.4	96	69.5
27	35.7	62	52.9	97	70.0
28	36.2	63	53.4	98	70.5
29	36.7	64	53.9	99	71.0
30	37.2	65	54.4	100	71.5
31	37.7	66	54.8		
32	38.2	67	55.3		
33	38.7	68	55.8		
34	39.2	69	56.3		
35	39.6	70	56.8		

Therefore, this time, an assumption of 38 was made for the cetane number of the commercial fuel. The low and high reference blends differing by not more than five cetane numbers were taken as 34.8 and 39.6. When a test run was made for a second time with these new blends, the handwheel readings were recorded as,

1.160 for the 34.8 cetane number blend

1.347 for the 38.0 cetane number commercial fuel

1.255 for the 39.6 cetane number blend

These results revealed that the second assumption was wrong too. So a third assumption was made as 42 for the cetane number of the commercial fuel. Going through the same procedure the handwheel readings were recorded as,

1.200 for the 39.6 cetane number blend

1.343 and

1.360 for the 42.0 cetane number commercial fuel

1.375 and

1.356 for the 44.6 cetane number blend

The unstability of the coincidence of the two flashes forced the recording of two handwheel readings for the commercial fuel and the high cetane blend. Since 1.360 fell out of the range of 1.200 to 1.356, the third assumption of 42 as the cetane number for the commercial fuel was accepted to be wrong and a fourth assumption of 45 was attempted. Following the same procedure, the handwheel setting was noticed to stay within the range of the handwheel readings for the low and high cetane number reference blends of 42.1 and 47.0. Several test runs were made with these last blends and several handwheel readings were obtained. The results lead to the conclusion that a 45 cetane number for the commercial fuel was the best assumption so far and the handwheel readings obtained could be bracketed with the ones of the reference fuel blends.

Therefore, a final and complete test to determine the cetane number was made using 40% of T-12 in U-5 by volume for a cetane number of 42.1 for the low cetane number reference blend and 50% of T-12 in U-5 by volume for a cetane number of 47.0 for the high cetane number reference blend. Thus, eleven runs were made beginning with the sample, meaning the commercial fuel, followed by the low reference blend, followed by the sample, and then followed by the high reference blend, this procedure repeated once more. The results obtained are shown in the following table.

TABLE 3

DATA OF CETANE NUMBER DETERMINATION[13]

Run	Low cet. num. Ref. blend (42.1)	Sample (Comm. Fuel) (45.0)	High cet. num. Ref. Blend (47.0)
1		1.267	
2	1.230		
3		1.271	
4			1.3175
5		1.285	
6	1.257		
7		1.304	
8			1.312 1.318
9		1.304	
10	1.269		
11			1.313
Average	1.252	1.286	1.314 1.316

(13) In handwheel readings in inches.

To determine the cetane number of the sample the averages of the handwheel readings are taken and the cetane number is found by interpolation from the averages so obtained.

Thus,

47.0 minus 42.1 gives a 4.9 difference of cetane number

1.316 minus 1.252 gives a 0.064 difference in handwheel readings corresponding to a 4.9 difference in cetane number.

1.316 - 1.286 = 0.030 and

1.286 - 1.252 = 0.034

(4.9 x 0.030) ÷ 0.064 = 2.296 to be deducted from 47.0

and (4.9 x 0.034) ÷ 0.064 = 2.603 to be added to 42.1

giving, 42.1 + 2.603 = 44.703

and 47.0 - 2.296 = 44.704

Using 1.314 as the average for the high cetane number reference blend we get,

1.314 - 1.252 = 0.062 handwheel difference corresponding to a difference of 4.9 in cetane number

1.314 - 1.286 = 0.028 and

1.286 - 1.252 = 0.034

(4.9 x 0.028) ÷ 0.062 = 2.212

(4.9 x 0.034) ÷ 0.062 = 2.686

giving, 42.1 + 2.686 = 44.786

and 47.0 - 2.212 = 44.788 which can be taken as 44.8

The cetane method suggests to report the cetane number to the nearest integer. Therefore, the cetane number of the commercial fuel was determined to be 45.

With the cetane number of the commercial fuel thus determined as 45, it is easy to obtain a blend of secondary reference fuels of the same cetane number by taking 46% of T-12 in U-5 by volume.

Thus, two fuels of same and known cetane number which is 45 are at hand for the following tests for the purpose of comparison and relation in behavior.

2. RELATION BETWEEN FUEL TEMPERATURE AND VISCOSITY

Viscosity, a property of a fluid which can be discerned only when motion takes place between the different parts of the fluid body, has a definite variation with temperature. For a given pressure, the viscosity of liquids decreases with an increase in temperature. The decrease per degree is much greater at low than high temperatures. Since no general law has been found by which the viscosity can be expressed in terms of temperature, the variation can be represented with a fair degree of accuracy by empirical formulas and consequently by graphs.

To investigate the effect on the cetane rating of the fuel that a change in its viscosity would bring about, the temperature of the fuel was varied with the assumption that the temperature change would directly influence and bring about a change in its viscosity.

The relation between the fuel temperature and its viscosity was obtained by a test made with a technical type instrument in the Oil Laboratory of the Chemical Engineering Department. The instrument used was the standard Saybolt Universal Viscosimeter (see Fig. 3, p. 37).

The principle of this viscosimeter is based on the time of efflux at a given temperature of an oil to be tested. It is developed mainly for the measurement of the viscosity of oils and consists of the oil tube, bath, receiver, thermo-

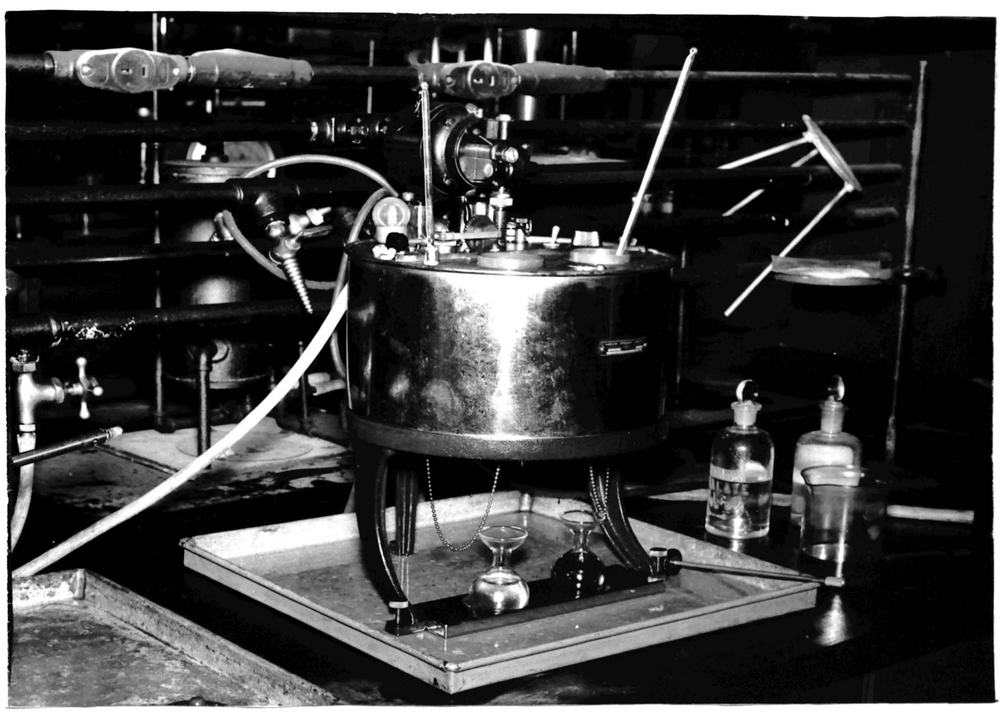


Fig. 3. Photograph of Saybolt Universal Viscosimeter.

meters, timer, and withdrawal tube. Its essential element is the oil tube, made entirely of a corrosion resistant metal. The inside diameter of the outlet tube (the orifice) is 0.1765±0.0015 cm. and the length of the tube is 1.225±0.010 cm. Surrounding the oil tube is the bath which offers support for the oil tube and serves as a container for the bath liquid. It contains a stirring device hooked up to a small electric motor for obtaining uniform temperatures and an electric heating device to provide for a means of heating or cooling. The receiving flask has a capacity of 60 ml. The time for obtaining this discharge is taken by means of a stop-watch.

The viscosity was tested for the same temperature range the fuels were heated to in the experiments, namely, 80 F. to 180 F.

The data obtained for the commercial fuel and a blend of secondary reference fuel of same cetane number of 45 is tabulated in the next page.

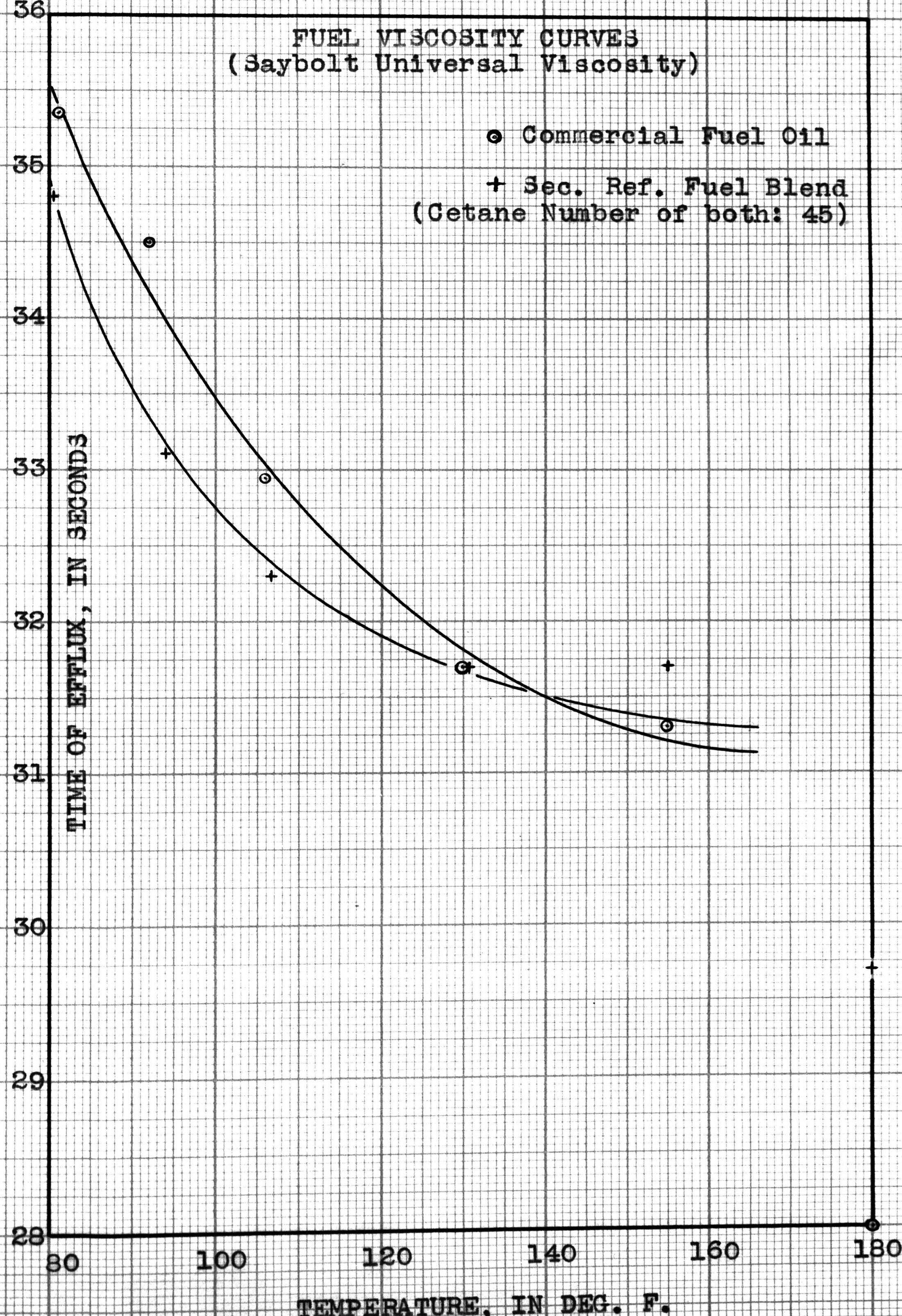
TABLE 4

DATA OF FUEL TEMPERATURE - VISCOSITY RELATION RUN

Run	Commercial Fuel		Reference Fuel Blend	
	Temperature in deg. F.	Time of Efflux in sec.	Temperature in deg. F.	Time of Efflux in sec.
1	81	35.35	80.5	34.8
2	92	34.5	94	33.1
3	106	32.95	106.6	32.3
4	130	31.7	130.5	31.7
5	155	31.3	155	31.7
6(14)	180	28	180	29.7

(14) This last reading is obsolete since the Saybolt Universal Viscosimeter can only be used if the time of efflux is 32 seconds or more.

PLATE 2


FUEL VISCOSITY CURVES
(Saybolt Universal Viscosity)
Commercial Fuel Oil
Sec. Ref. Fuel Blend
(Cetane Number of both: 45)
TIME OF EFFLUX, IN SECONDS
36
35
34
33
32
31
30
29
28
80
100
120
140
160
180
TEMPERATURE, IN DEG. F.

Plotting the fuel temperatures in degrees F. as abscissas against the time of efflux in seconds as ordinates, curves denoting the viscosity are obtained for both fuels as in the previous page.

The curves are decreasing with an increase in fuel temperature. This aspect of the curves parallel the common behavior of viscosity when plotted against temperatures. For low temperatures, that is around 80 deg. F., the curve having a steep slope confirms with the idea that there is a greater decrease in viscosity per degree of temperature around that range. When higher temperatures are reached the slope tends to get smoother and changes gradually meaning that there is not a great change in the viscosity over 180 deg. F.

3. FUEL TEMPERATURE VERSUS COMPRESSION RATIO

This is the actual test for the purpose of investigating the effect of a change in viscosity of the commercial fuel and its equivalent in cetane number - the secondary reference fuel blend, in regard to the ignition quality, namely, the cetane rating.

For this purpose and having once established the fact that the viscosity undergoes a change with a change of the temperature of the fuel, the ASTM Cetane Engine and the Cetane Method was used. All the operating conditions of the cetane method were kept the same and the same procedure was followed as for determining the cetane number. The only exception made was to vary the fuel temperature which for the cetane method was at standard room temperature all the time.

To be able to do so, a small size fuel tank was built and used. This fuel tank was heated by means of an electric hot plate heater and a 30-ohm 6.5-ampere slide-wire rheostat was used to regulate the current supplied to the heater for the purpose of maintaining the fuel temperature fairly steady. The fuel tank was connected directly to the fuel selector valve on the fuel injection pump of the cetane engine in the shortest possible way with a tubing about two feet long to prevent heat losses as much as possible.

The fuel temperature was varied over a range of 100 degrees F. and in approximately 10-degree intervals at a time. The room temperature at the time the experiment was performed, was 80 F. Colder temperatures than the room temperature were attempted to be reached. The attempt proved to be unsuccessful as described in the intake air system (see p. 14). Thus 80 F. was established as the fuel temperature to start the tests with.

Temperatures over 180 F. were not reached for several reasons. First of all, it took a long time for the fuel in the heated tank to reach temperatures above 120 F., even longer after 150 F. Since the temperatures reached never stayed steady for over ten to fifteen minutes and since it required more than ten to fifteen minutes to adjust the neon flashes once the warmed up engine was shut off, the engine was kept running for all the time needed to heat the fuel. During the long time it required to reach temperatures above 150 F. the engine would heat up excessively and compel the author to shut it off and allow it to cool for a while. These factors made it, if not impossible, impractical to reach temperatures above 180 F. Another reason was that although the final boiling point of the fuel would be actually much higher, the author had no guaranty as to the resulting boiling point of a 46% mixture by volume of T-12 in U-5 would not make it fall into the bracket of a hydrocarbon boiling below 350 degrees F. Besides the fuel fumed considerably at 180 F. Therefore, the author decided to drop the idea of reaching temperatures up to 250 F. for safety's sake. A third reason can be attributed to the unorthodox behavior of the compression ratios obtained when the fuel temperatures reached 150 F. and above. The compression ratios recorded from 80 F. to 130 F. behaved to give a smooth curve. Over temperatures of 150 F. the compression ratios seemed to stay steady. This can naturally be expected since at higher temperatures the rate of change in viscosity would be much slower than at low temperatures.

The data and curves obtained for both fuels follow on the next pages, respectively.

TABLE 5

DATA FOR COMMERCIAL FUEL RUN

Run	Temperature deg. F.	Handwheel Reading in inches	Compression Ratio
1	80	1.267	15.20
2	94.5	1.295	14.90
3	104	1.305	14.80
4	115	1.313	14.71
5	126	1.315	14.69
6	133.5	1.311	14.73
7	144	1.301	14.84
8	152	1.314	14.70
9	161	1.314	14.70
10	166.5	1.314	14.70

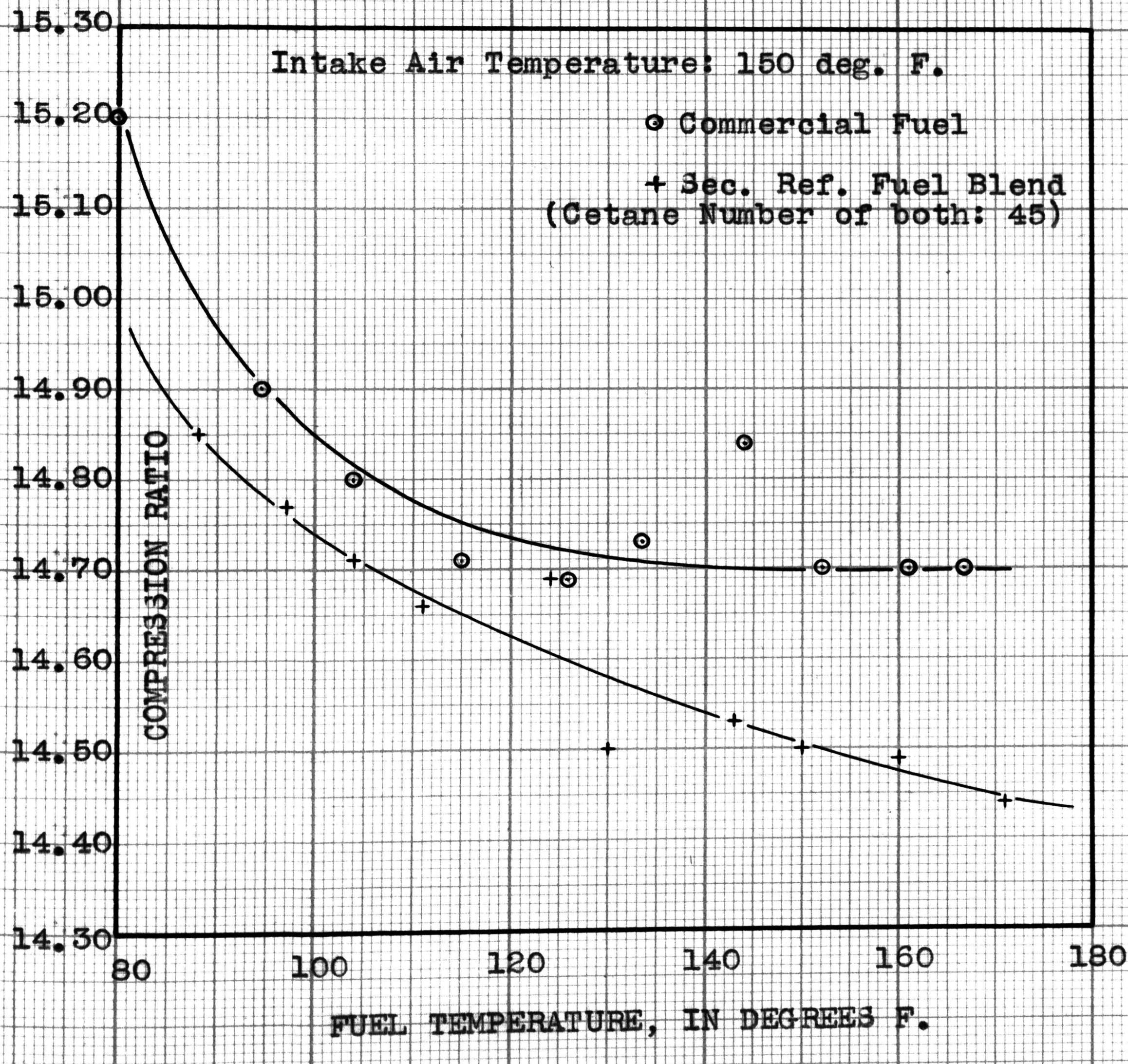
TABLE 6

DATA FOR REFERENCE FUEL BLEND RUN

Run	Temperature deg. F.	Handwheel Reading in inches	Compression Ratio
1	88	1.300	14.85
2	97	1.307	14.77
3	104	1.313	14.71
4	111	1.318	14.66
5	124	1.315	14.69
6	130	1.333	14.50
7	143	1.330	14.53
8	150	1.333	14.50
9	160	1.334	14.49
10	171	1.339	14.44

PLATE 3

COMPRESSION RATIO - FUEL TEMPERATURE CURVES



If a variation in the temperature of the fuel had no effect whatsoever on the cetane number of the fuel under the same operating conditions and procedure, no matter what the fuel temperature, the handwheel reading recorded when the two flashes coincided should have been the same for every run. In other words, under the same operating conditions, reaching the 13-deg. fixed delay period should have occurred at the same compression ratio for all the runs if the cetane number of the fuel was not affected in the least by its viscosity. In that case, a curve obtained by plotting the fuel temperature as abscissas against the compression ratio as ordinates should have yielded a horizontal straight line.

A study of the graph in the previous page reveals a decreasing curve with increasing temperatures which contradicts the deduction in the above paragraph. Therefore, it can definitely be stated that the cetane number is affected by a change in its temperature and consequently by a change in its viscosity.

At temperatures between 80 and 120 F., the compression ratio decreases on a smooth portion of the curve. After 110 F. the compression ratios fall out of the curve appreciably and the slope of the curve for that portion is not very accurate. At 150 F. the compression ratio tends to level off and the curve becomes almost a straight line. For temperatures over 180 F. the curve tends to stay on that straight line. This means that for higher temperatures than this one the compression ratio will not decrease any more and will not be effected by higher temperatures where the change in viscosity per degree is not bery great. For temperatures below 80 F., the curves tend to have a steep slope for increasing compression ratios. For really low temperatures, the compression ratio gets to be really high. It seems that at a certain lower temperature, no matter how high the compression ratio, combustion will not occur properly, if not at all.

"The Cetane Method requires adjustment of the compression ratio to attain a specific condition of engine operation for each sample tested. In the Cetane Method, the compression ratio must be adjusted so that the fuel ignites at tdc on the compression stroke, that is, 13 degrees after fuel injection begins. Low cetane fuels have more inherent ignition lag and therefore require higher compression ratios to ignite them at tdc than high cetane fuels. Thus there is a direct relation between cetane number and compression ratio."(15)

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(15) ASTM Manual, op. cit., P. 346 (a), p. 183.

Since the compression ratio decreases with increasing temperatures, the fuel tends to act as a fuel of high cetane as pointed out in the above paragraph. That is, the fuel which had a cetane number of 45 at a surrounding temperature of 80 F. behaves as if it had a higher cetane number than 45 as its temperature increases or, in other words, as its viscosity decreases.

4. INTAKE AIR TEMPERATURE VERSUS COMPRESSION RATIO

The cetane method requires the intake air temperature to be maintained constant at 150 degrees F. In the tests made so far, the intake air temperature was kept constant at that temperature and only the influence of the viscosity on the cetane number was investigated. The experiments done varying the intake air temperature showed that an increase in the temperature has similar influences as an increase in viscosity and hence the cetane number of the fuel. Therefore, any variation in the intake air temperature may lead to tempting values for the cetane number or by increasing the intake air temperature, a fuel of low cetane number can be substituted for one of a higher cetane.

With both fuels at room temperature and same operating conditions and procedure of the cetane method, tests were run varying the intake air temperature from a room temperature of 80 F. to 200 F.

The data and curves obtained for both fuels follow on the next pages, respectively.

TABLE 7

DATA FOR COMMERCIAL FUEL RUN

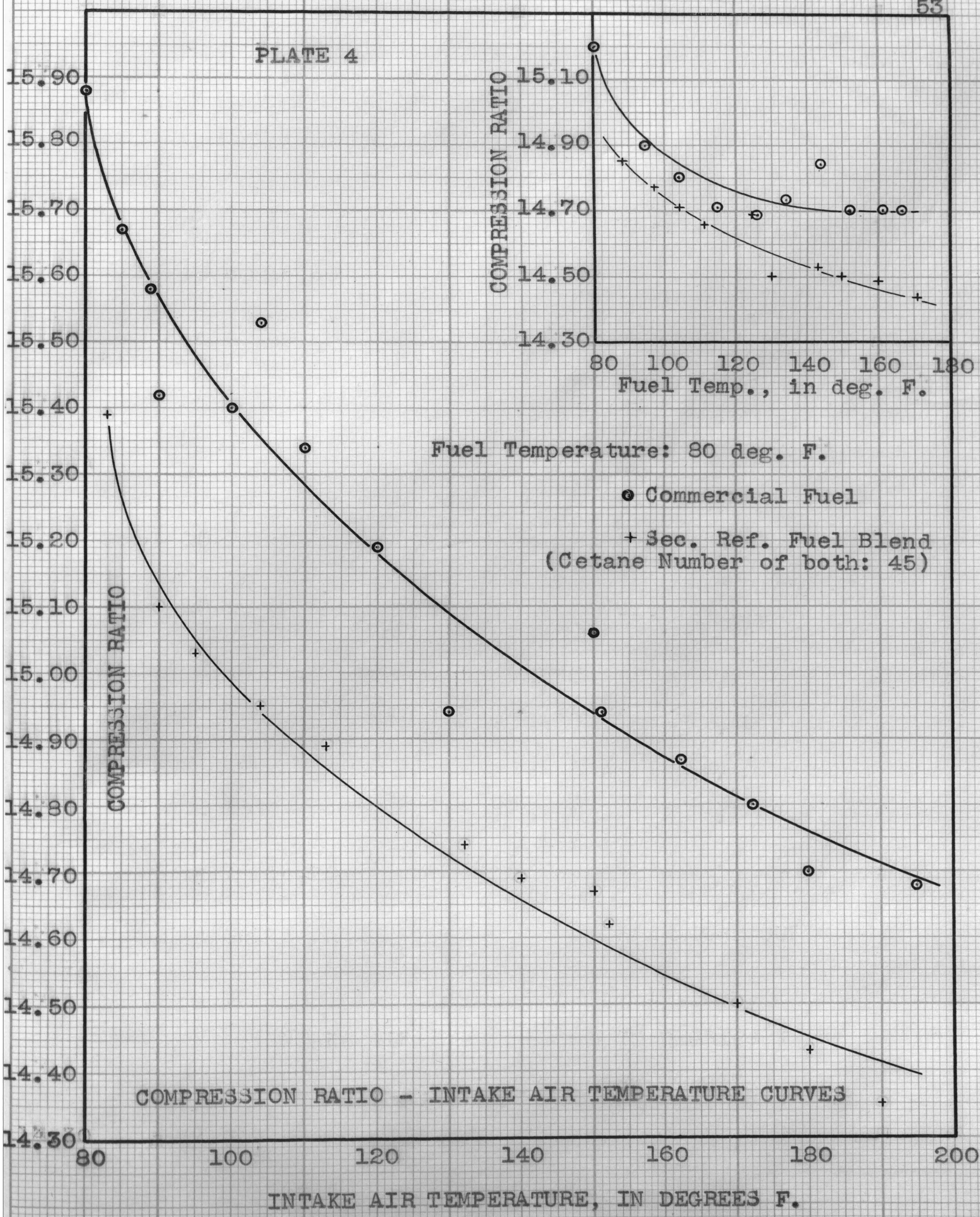
Run	Temperature deg. F.	Handwheel Reading in inches	Compression Ratio
1	80	1.210	15.88
2	85	1.227	15.67
3	89	1.235	15.58
4	90	1.248	15.42
5	100	1.250	15.40
6	104	1.239	15.53
7	110	1.255	15.34
8	120	1.268	15.19
9	130	1.291	14.94
10	150	1.280	15.06
11	151	1.291	14.94
12	162	1.298	14.87
13	172	1.305	14.80
14	180	1.314	14.70
15	195	1.316	14.68

TABLE 8

DATA FOR REFERENCE FUEL BLEND RUN

Run	Temperature deg. F.	Handwheel Reading in inches	Compression Ratio
1	83	1.251	15.39
2	90	1.276	15.10
3	95	1.283	15.03
4	104	1.290	14.95
5	113	1.296	14.89
6	132	1.310	14.74
7	140	1.315	14.69
8	150	1.317	14.67
9	152	1.322	14.62
10	170	1.333	14.50
11	180	1.340	14.43
12	190	1.345	14.35

PLATE 4



COMPRESSION RATIO - INTAKE AIR TEMPERATURE CURVES

When the intake air temperatures are plotted as abscissas against the compression ratios as ordinates, the graphs obtained reveal decreasing smooth curves with increasing temperatures.

If the curves are compared with the fuel temperature-versus-compression ratios curves redrawn to a smaller scale on the upper right-hand corner, a similarity in their nature can easily be detected. The compression ratios are more consistent and of slightly higher values for intake air temperatures than for fuel temperatures. For temperatures below room temperature, both sets of curves have steep slopes for increasing compression ratios, in common. In the case of the intake air temperature, the curves do not tend to level off for temperatures over 160 F. as they do for fuel temperatures. Likewise, the compression ratios seem to keep on decreasing when higher temperatures are reached and continue to do so beyond 200 F.

The similarity in the behavior of the curves suggests that the cetane number is affected too by a variation in the intake air temperature. For higher intake air temperatures, the fuels with cetane numbers of 45 behave as fuels having higher cetane numbers since the compression ratios decrease appreciably.

PART 5

CONCLUSIONS AND RECOMMENDATIONS

The results of the second test run indicate clearly that, when the viscosity of the fuel oil is decreased by preheating it, it does affect the cetane number of the fuel in such a way as to have it react as a fuel of higher cetane number and hence better ignitability.

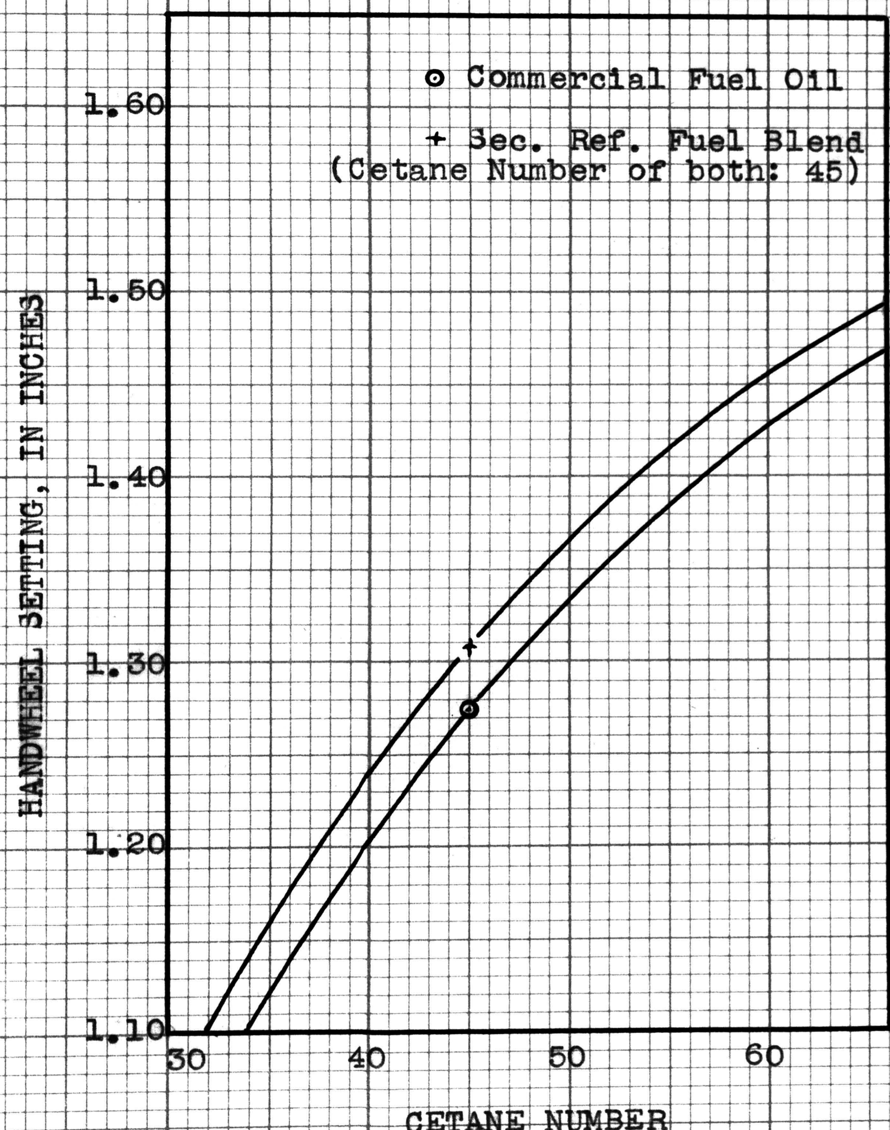
The author confidently comes to the conclusion that, within the scope of this thesis, it is apparent a decrease in viscosity of the fuel oil affects its ignition quality (cetane rating) for the better.

It can also be concluded that, under these circumstances, diesel fuels do not refrain from showing signs of "sensitivity" as defined on page 6. But since sensitivity is more dependent on the severity of engine conditions, it cannot definitely be commented upon unless a second method of test, analogous to the motor and research methods for motor fuels, is introduced for the ignition quality of diesel fuel oils.

Before going into his recommendations the author would like to introduce, herewith, the following curves originated by him and to be used as a basis for further developments in investigating the same subject more thoroughly.

PLATE 5

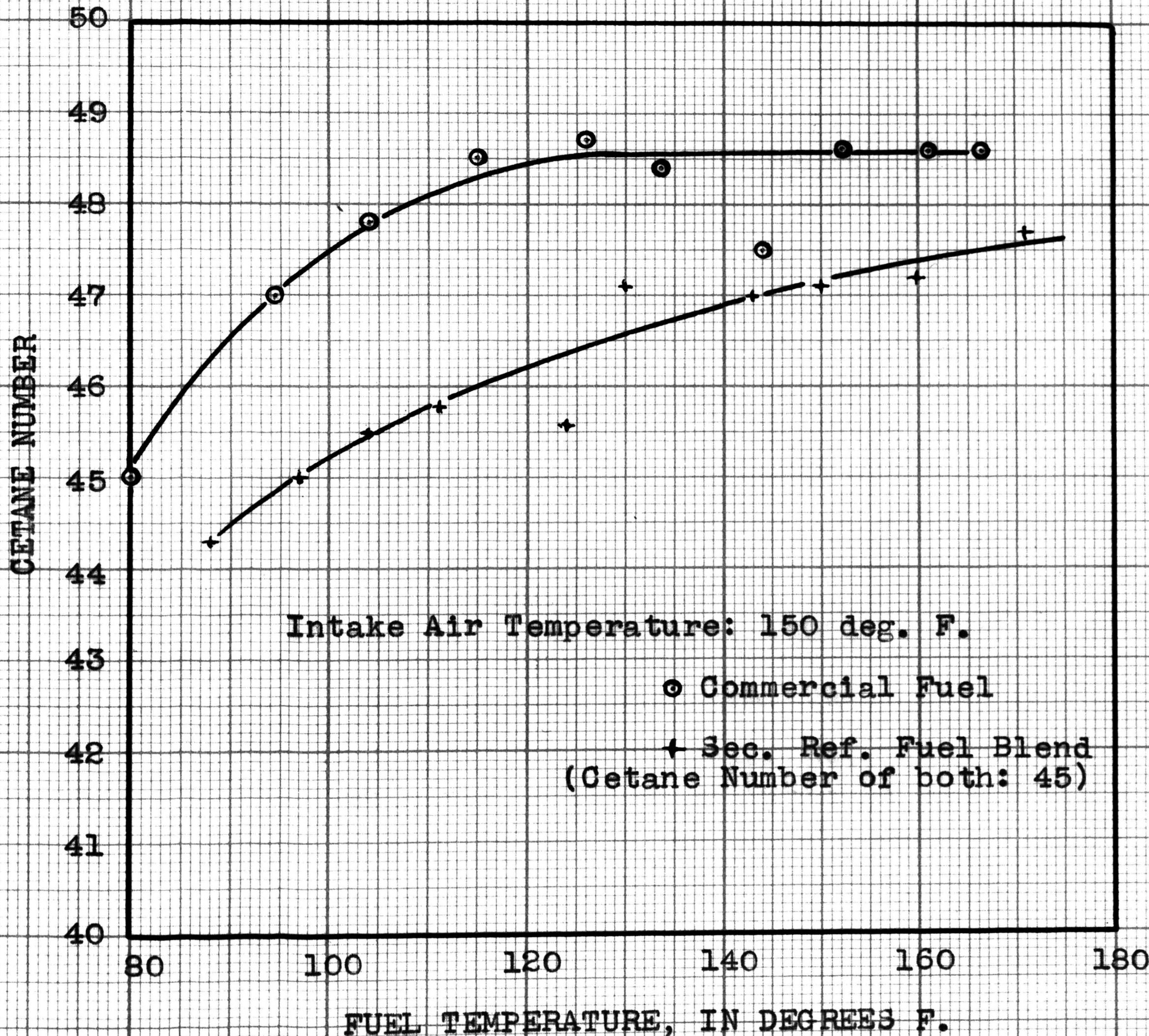
GUIDE CURVES(16)



(16) reproduced from Plate 1 for the possible behavior of the fuels of 45 cetane number.

PLATE 6

CETANE NUMBER - FUEL TEMPERATURE CURVES



The guide curves on page 56 were constructed in the following manner.

The two varied standard conditions, where the cetane number of both fuels is 45, are an intake air temperature of 150 deg. F. and the fuel at a room temperature of 80 deg. F. A consultation of Tables 5, 7, and 6, 8, yields only handwheel readings of 1.267 and 1.280 for the commercial fuel and 1.300 and 1.317 for the reference fuel blend respectively, for these conditions. The averages of these readings were taken to plot the curves. Since these are only one single point to plot the curves with, the author took the liberty here to assume that the guide curves to be constructed would have the same slope as the one in page 28. Therefore, he drew two curves parallel to the guide curve of Plate 1, but passing through the cetane number of 45 and handwheel readings of 1.273 for the commercial fuel and 1.308 for the reference fuel blend. These guide curves, which are not necessarily consistent within any degree of accuracy, were used as a basis to plot the curves on Plate 6, page 57.

This last set of curves as introduced hereinbefore for the sole purpose of showing the behavior of the fuel ignition quality when its viscosity was decreased, to facilitate its better visualization. The cetane numbers were read directly from the guide curves on Plate 5 for every handwheel reading corresponding to their fuel temperatures recorded on Tables 5 and 6. A conclusion on the last set of curves is obsolete to be drawn since they can really be called fictitious curves and hence to discuss them will not be attempted. But, it can distinctly be observed that, the fuels show signs of best improved ignitability between the fuel temperature range of 90 to 130 deg. F. In other words, it seems that decreasing the viscosity of the fuels beyond a certain point will not help improve its ignitability any further.

If and when the subject of this thesis attracts further study, the author strongly recommends:

a. The use of several commercial fuels having different and a wide range of cetane numbers. Or, the use of several blends of reference fuels having a wide range of cetane numbers, which will enable the plotting of a consistent guide curve,

b. The change of the temperature range from 80 - 180 to 40 - 220 deg. F.,

c. The decrease of the temperature interval from 10-deg. F. to 5-deg. F., which with (b) above will provide more points and thus enable the plotting of better and more consistent curves,

d. The closer study of the behaviors of the curves beyond fuel temperatures of 120 deg. F. for the purpose of verifying the author's statement that the ignition quality is no longer affected to an appreciable degree by slowing decreases in the viscosity beyond that fuel temperature,

e. The location of the particular fuel temperature, if any, where the effect is no longer distinguishable, by running several tests,

f. The determination of the particular fuel temperature, if any, where the maximum cetane number is attained in the improvement in ignition quality caused by the decrease of viscosity at that fuel temperature,

g. Further study of "sensitivity" in connection with the cetane numbers of diesel fuels by better or new methods,

h. The investigation of the lag existing between the reference fuel blend and commercial fuel of same cetane number in the curves plotted in this thesis.

Where better ignition qualities are required and where the fuels available are of poorer cetane ratings, it can very well be resorted to the use of preheating the available fuels for the purpose of decreasing their viscosities which in turn will improve their ignitability.

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