BURNER TESTING OF FUEL OILS

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Prepared for presentation at
Combustion Conference
University of Michigan
Ann Arbor, Michigan
March 21-22, 1951

Gulf Research and Development Company
Pittsburgh, Pennsylvania

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It seems to be agreed by manufacturers of diesel engines, fuel-oil burners, the oil industry, and various national security agencies that a concerted effort should be made by all parties to achieve the most efficient possible use of fuel oil and fuel-oil equipment. The oil industry has constantly strived to produce better, more efficient fuels for the modern power plants. One of the results of such efforts has been the development of the catalytic cracking process, which has been instrumental in producing a greater yield of high-octane gasoline as well as catalytic cracked fuel oil.

The first step in the refining of crude petroleum is separating the crude into its various fractions. Average crudes yield about 15 to 35 per cent gasoline, about 6 per cent kerosene, about 20 to 30 per cent middle distillate, and about 30 to 50 per cent residual oil. Lubricating-oil stocks are obtained from selected crudes. The straight-run fuel-oil distillates which comprise the home heating oils are obtained from the middle distillate. They are composed of paraffinic, naphthenic, olefinic and aromatic type hydrocarbons of which the first two are in the majority and are the most desirable from a burning standpoint. In order to make more gasoline, the heavier oils are reprocessed at high temperature by either of two generally used methods. By these methods the relatively large hydrocarbon molecules are decomposed or "cracked" into smaller ones by means of heat. In the ordinary thermal cracking process heavy distillates and residual oils are charged to the cracking still, where they are simply heated to the order of 1000°F, usually under high pressure. The products are cracked gasoline and fuel oil, gas, tar, and coke. In the catalytic cracking process the oil is heated in the presence of certain natural or synthetic clays. These clays may be either in the form of granules, pellets, beads, or powder. This process yields cracked gasoline, fuel oil, gas, and tar, with no net coke resulting.

Whereas straight thermal cracking makes products containing a relatively large portion of unsaturated olefinic hydrocarbons which are unstable or gum-forming, the catalytic process makes fewer olefins and more aromatics. The significance of this to the fuel-oil industry is that the cracked distillates produced by the catalytic process are more stable to oxidation in the storage tank and therefore can be used as domestic heating fuel without any expensive re-treating. A discussion of the numerous factors involved in catalytic cracking, such as regeneration, recycling, fixed-bed vs. moving-bed catalyst, boiling range of the charge stock, etc., is beyond the scope of this discussion. Suffice it to say that the advantages of the process make it indispensable for the production of essential war materials as well as peace-time products of superior quality. The valuable characteristic of catalytic cracking is that the gasoline produced has high antiknock value in the high-boiling portion, which is not true of straight-run or thermally cracked gasoline. As a result, with the removal of the gasoline fraction from the catalytic cracked distillate, no No. 1 grade fuel remains, and the part which is used for No. 2 grade fuel is likely to have an A.S.T.M. 10 per cent point around 480°F instead of below 440°F as is desirable. Therefore, at present, the practice of the oil industry is to supply domestic fuel oil composed of a blend of catalytic cracked and virgin distillates, which complies with the specifications for No. 2 grade fuel.

While catalytic fuels may at the present time offer some disadvantage when compared with straight-run oil, they contain more Btu per gallon and are more stable than the intermediate thermal cracked fuels. Anticipating the ultimate need for a comprehensive study of catalytically cracked fuel oil, the Gulf Oil Company initiated a program of fuel-oil tests in 1944. From a modest beginning of two domestic fuel oil burners installed in temporary quarters, the fuel oil program has expanded until today the Gulf Fuel Oil Laboratory is a relatively large permanent structure (Fig. 1), in which are installed more than a dozen different types of fuel-oil furnaces for the study of fuel oil and burner problems.

The tests conducted in these burners are not necessarily set up to simulate the household conditions under which the burner would ordinarily operate but have been devised to provide, in a much shorter time, results equivalent to those that would be obtained in the household during a heating season. The test procedures are also devised to permit burner rating of various fuel oils.

Two basic tests are used, one a smoke and CO_2 test of about one day's duration and the other a deposits test of about ten days' duration. In the first test the burner is operated on a 10-min.-off — 20-min.-on cycle, and the air supply is changed in increments during each "off" period to permit readings of CO_2 over a range of air-inlet openings. At each CO_2 value tested, the smoke density is taken, and the character of fuel ignition at the start of each "on" period is observed. During the test, the draft and fuel flow rate are constant. From the data obtained on this test, curves of smoke density vs. CO_2 are plotted for any given fuel in any given burner. Such a curve can then be used as an indicator of the relative quality of various fuel oils as well as to determine the sensitivity of a burner to fuel type.

Fig. 2 shows the performance of a rotary wall-flame burner on 100 per cent straight-run and 100 per cent catalytically cracked fuel. It may be noted that smoke density decreases with increase of CO_2 for both fuels and that this particular burner is sensitive to change in fuel-oil type. Fig. 3 shows the performance of two typical conventional high-pressure gun-type burners (curves A and B) and a gun burner equipped with a combustion head (curves C and D). It may be seen that with these burners smoke density increases with increase of CO_2 and that the conventional burners are insensitive to fuel type, i.e., the curves practially coincide, whereas the third burner is appreciably affected by fuel type.

The deposits test is also conducted on a 10-min.-off — 20-min.-on cycle, but is run with a constant air gate setting. Flow rate and draft are maintained constant throughout the test. This test is conducted seven hours per day for ten days. With this procedure ten cold starts are involved so that an opportunity is afforded for observing ignition and flame stability. At the conclusion of the seventy hours of operation the accumulated soot is carefully removed from the furnace heating surfaces and the amount determined both by volume and weight. Such a test provides a reliable indication of the deposits characteristics of the fuel and the corresponding change in furnace efficiency.

Using the data of both the smoke test and the deposits test, a given oil is rated by means of a rating method which was derived from the results of a number of smoke and deposits tests. In this rating method, three factors of smoke density, soot thickness and stack rise are given individual ratings which are then combined into an over-all burner rating for the fuel. This procedure provides a good tool or index by which fuel quality may be determined.

In order to determine the value for maximum permissible smoke density, a full-term burner test is run. This test provides an indication of how high the smoke density can go before a boiler will fail in a year's operation from deposits accumulation, either by throwing the burner off CO_2 setting or by raising the draft resistance sufficiently to produce pressure in the combustion chamber. It has been found that equilibrium conditions with respect to stack temperature rise and soot accumulation are reached in from sixty to one hundred days. In this test the burner is run for two and one-half months on an 18-min.-on — 42 min.-off cycle representing fall operation, three months with a 37-min.-on — 23 min.-off cycle representing winter, and two months with the former cycle representing spring.

It has been determined that in order to establish the same combustion performance with catalytic fuel as obtained with straight-run fuel, it is necessary that more air be provided by increasing the air-inlet opening. The readings of smoke density taken on tests conducted on straight-run and catalytic fuels in the conventional high-pressure gun-type burner, referred to on curves B of Fig. 3, are plotted against area of air-inlet opening on Fig. 4. It may be seen from this curve that for a given value of smoke, the area of the air-inlet opening must be increased approximately 15 per cent for catalytic fuel over that used for straight-run fuel, the fuel-flow rate in gph remaining unchanged. A similar condition was found to exist in the case of the high-pressure gun-type burner covered by curves A of Fig. 3. On a third gun-type burner, curves C and D, it was found that the air-inlet opening had to be increased approximately 200 per cent for catalytic fuel to obtain the same value of smoke as existed with straight-run fuel.

The amount of increase in area depends on the characteristic performance curve of the blower for the restriction imposed. In Fig. 5 are plotted the fan delivery vs. air-inlet area curves for the three burners mentioned above. It may be noted that for the conventional burner "B" a steep characteristic fan curve is obtained because of a low resistance to air flow. The fan delivery is therefore sensitive to changes of inlet opening, and only a 20 per cent increase in area of opening is required for comparable combustion performance between the two fuels. A similar condition exists for the other conventional burner "A." The flat characteristic fan curve results for the burner equipped with the combustion head because of the high resistance which it offers to air flow. In order to obtain equivalent operating conditions with catalytically cracked fuel with this burner, a very large increase in inlet area is required to obtain the increased volume of air needed.

A thorough knowledge of the characteristic performance curve of the blower is essential as indicated from the above discussion. With a flat characteristic curve, it is possible that sufficient air cannot be obtained even if the air inlet is opened fully because of a high fuel flow rate. Uniform smoke and CO_2 can be obtained by other means, however, such as reducing the fuel-flow rate in the case of the catalytic cracked fuel. If the flow is reduced to the point of producing the same Btu input, little or no increase in air volume is required to obtain the same combustion conditions.

If measurements of smoke density and CO_2 indicate that a burner is operating on a border-line between a passable and unpassable condition, various mechanical items concerning the burner can be investigated. It has been said (Mr. E. G. Bailey of Babcock and Wilcox and the Bailey Meter Company) that combustion depends upon the factors of time, turbulence, and temperature, and the following examples verify this statement.

It was found that better combustion resulted when the desired flow rate was obtained in a high-pressure gun burner through the use of a large orifice nozzle operated at low pressure (100 psi) than when a small orifice nozzle was operated at high pressure (150 psi), the spray angle of the nozzle being the same in both cases (Fig. 6). The interpretation of this is that the mixing of air and oil is improved with the large nozzle operated at low pressure, because the velocity of the oil particles is lower relative to air velocity and more time is allowed for the mixing to take place in the mixing zone.

With reference to the second factor, i.e., turbulence, Fig. 7 shows the performance of several types of turbulators purchased for use with a high-pressure gun-type burner. Curve A shows the burner performance with a straight air-blast tube, without use of turbulator. The turbulator whose performance is shown by curve B consisted of two parts, one an eight-bladed cone and the other a four-bladed stabilizer. The cone is mounted at the end of the air-blast tube, and the stabilizer is placed four inches to the rear of the cone. These two items were opposed in pitch so as to reverse the motion of the air through the blast tube. Curve C covers another turbulator made in two parts. A cone having a restricted outlet with no blades is mounted at the end of the blast tube, and an eight-bladed swirler is installed inside this cone. Curve D shows the performance with a four-bladed turbulator having the blades at such an angle as to impart a counter-clockwise motion to the air.

It may be noted from the curve that best performance was secured with the simple-four-bladed cast-iron turbulator installed in the end of the blast tube; it is apparent, however, that all three turbulators show definite improvement over the plain blast tube. Analysis of these curves indicates excessive restriction to the flow of air in the case of turbulator C and insufficient mixing action in the case of turbulator B.

The real problem involving the function of turbulence in oil burners would seem to be the maintenance of a flow of fresh air over each particle of oil so as to wash off the envelope of burned gases as fast as they form and provide a fresh supply of oxygen to continue the combustion until the droplet is entirely consumed. Different sizes of turbulators and different designs of oil nozzles are, generally speaking, intended to produce this effect, but so far many of these turbulators merely produce additional resistance to flow of air through the blast tube. It may be concluded that a turbulator, if it is to be successful, should provide a turbulent mixture of the air and oil without imposing excessive restriction to air flow.

Tests conducted in a rotary wall-flame burner indicate that the fan diameter should be increased in order to obtain better mixing of the air and oil. In this connection, it has been found that optimum performance is obtained with a ratio of flame-rim diameter to fan diameter of about 2.6 to 1. for fans rotating at 1600 rpm. This corresponds to a peripheral velocity of 3.0 fps per inch of flame-rim diameter. Radial air velocity leaving the fan, relative to flame-rim diameter, is the underlying basic factor.

Fig. 8 shows the smoke density obtained for various ratios of flame-rim to fan diameter for a constant CO_2 value of 12 per cent. It is not suggested that larger ratios be used because difficulty is likely to be experienced with ignition.

It is suggested that attention should be directed to the design of nozzles used in high-pressure gun burners with a view to improving atomization and providing a form of spray which will facilitate mixing the air and oil. Tests have been conducted on an experimental target-type nozzle in which the stream from the nozzle orifice impinges against a conical target positioned in line with the orifice by means of a supporting bridge fastened to the body of the nozzle. The top of the target was provided with a small flat surface so that two separate sprays were created, one being almost perpendicular to the nozzle axis and of minor intensity, the other being the main conical spray. Under this condition, the air stream from the air-blast tube was preheated by the small circular flame before coming in contact with the main conical flame, and operation at higher CO_2 values was possible without excess smoke.

It is not necessarily recommended that a target-type nozzle be adopted because of the interference in the spray cone due to the target support, but this information is given to show what might be accomplished by the use of a nozzle designed to provide two or more separate and distinct sprays. In these tests with the experimental nozzle, the flame, instead of being orange with smoky tips, was shorter and of a blue base with clean orange tips.

In this connection several makes of burner nozzles have been calibrated, and it has been found that quite a few of these nozzles have a rather wide variation, both in capacity and spray angle, from that stamped on the nozzle. Calibration of three makes of 80-degree, 1.75 gph nozzles at 100 psi pressure on 37 S.U.V. oil showed a variation from 1.5 to 1.72 gph, a maximum variation of 15 per cent. The spray angles of these nozzles varied between 70 degrees and 95 degrees, a total variation of 35 per cent. Two 45-degree nozzles of the same make were checked; one was found to measure 60 degrees and the other 80 degrees, a maximum variation of 78 per cent. A check of the orifice diameters of these two nozzles on a comparator showed values of 0.012 in. and 0.016 in., respectively. "Fuel Oil and Oil Heat" for January, 1947, reports a case where a 3.5 gph nozzle, when measured at 100 psi pressure actually delivered 5.0 gph, an excess of 43 per cent.

Flow tests conducted on several nozzles over a range of oil viscosity showed that the flow rate of the nozzle increased with increase of viscosity. The explanation is given that the nozzle incorporates a number of slots which impart a rapid swirl to the oil before it is discharged from the final orifice. This oil swirl increases when the oil viscosity decreases. It is nearly at right angle to the direction of nozzle discharge and is obtained at the expense of part of the pump pressure, i.e., pressure head converted to velocity head. Less pressure head is then available for discharging the oil from the main orifice. Performance curves of nozzle capacity vs. oil viscosity are given in A.S.M.E. Transactions 1939, Vol. 61, pp. 373-381. It is suggested that, if possible, nozzles giving 100 per cent turbulent flow should be developed because with such a nozzle, viscosity will have no effect upon its capacity at any given pressure. This is an important item in connection with the nozzle in a high-pressure gun-type burner. For example, if a high-pressure gun-type burner were adjusted when it was operating on a long-"on" — short-"off" cycle at a value of CO_2 of let us say 11 per cent, with a passable amount of smoke, a reduction of oil temperature at the nozzle which would occur when the "on" time of the burner had decreased, could cause a 5 per cent increase in the flow rate due to the increase of oil viscosity. The air inlet not having been changed, the value of CO_2 would be higher, so that operation of the burner would then be occurring at a higher point on the smoke-performance curve. This increase in smoke might then be sufficient to be objectionable. While the change of flow rate with change of oil viscosity in a nozzle may be considered of little consequence, it can be seen that it is of real importance when the nozzle is used in a burner having a characteristic which can cause a very pronounced change in smoke density due to a small change in CO_2.

In view of the fact that proper matching of the flame and combustion changer is an essential factor in satisfactory burner performance, the selection of a correct spray angle and capacity nozzle is important. Tests were conducted on three different spray-angle nozzles of the same make and capacity in a rectangular combustion chamber, and it was found that a 60-degree angle nozzle gave considerably improved performance over either a 45-degree or an 80-degree nozzle. In the case of the 80-degree nozzle, there was considerable flame impingement on the side walls of the combustion changer, resulting in a smoky flame at the areas of impingement. In the case of the 45-degree nozzle the flame did not touch the side walls but impinged over a small area at the far end of the chamber, thereby causing a smoky condition. These tests confirm the importance of matching the flame with the shape of the combustion chamber.

Tests conducted on a high-pressure gun-type burner equipped with a special combustion head indicate considerable improvement in combustion of 100 per cent straight-run fuel over that obtained with the two conventional high-pressure gun-type burners shown on Fig. 3. However, when this combustion head was tested on 100 per cent catalytic fuel, using the same settings used with the straight-run fuel, unsatisfactory performance was obtained; CO_2 was increased but excess smoke resulted. The performance of this combustion head with straight-run fuel is indicated by curve C, and that obtained on 100 per cent catalytic fuel with the same settings is represented by curve D of Fig. 3.

It is also concluded from experiments with gun-type burners that, for best performance with respect to smoke and ignition, the nozzle must be properly centered in the air-blast tube and axially located correctly with respect to the end of the air-blast tube or turbulator.

Fig. 9 shows the performance characteristics of a typical vaporizing pot burner when operated on kerosene, No. 2 grade straight-run and catalytic fuels. It may be seen that this burner is sensitive to change in fuel-oil type. In this case, the various values of CO_2 are obtained by change in fuel-flow rate.

Indications are that with some experimentation on the part of pot-type manufacturers, they may be able to modify the equipment to handle catalytic fuels successfully. In this case, as with other burners, the degree of mixing air and oil vapors is important, and increased turbulence should help in this matter.

Fig. 10 shows the properties of the two fuels shown on the performance curves. As previously stated, the present practice of the oil industry is to supply domestic fuel oils containing some catalytic cracked distillate. The performance of these fuels is likely to be better than that shown on the curves for the 100 per cent catalytic cracked fuel.

ROTARY WALL FLAME BURNER PERFORMANCE

SMOKE DENSITY – DISC NUMBER VS. PERCENT CO_2

FLAME RIM TO FAN DIAMETER RATIO – 2.6 : 1

(BASED ON 1600 R.P.M.)

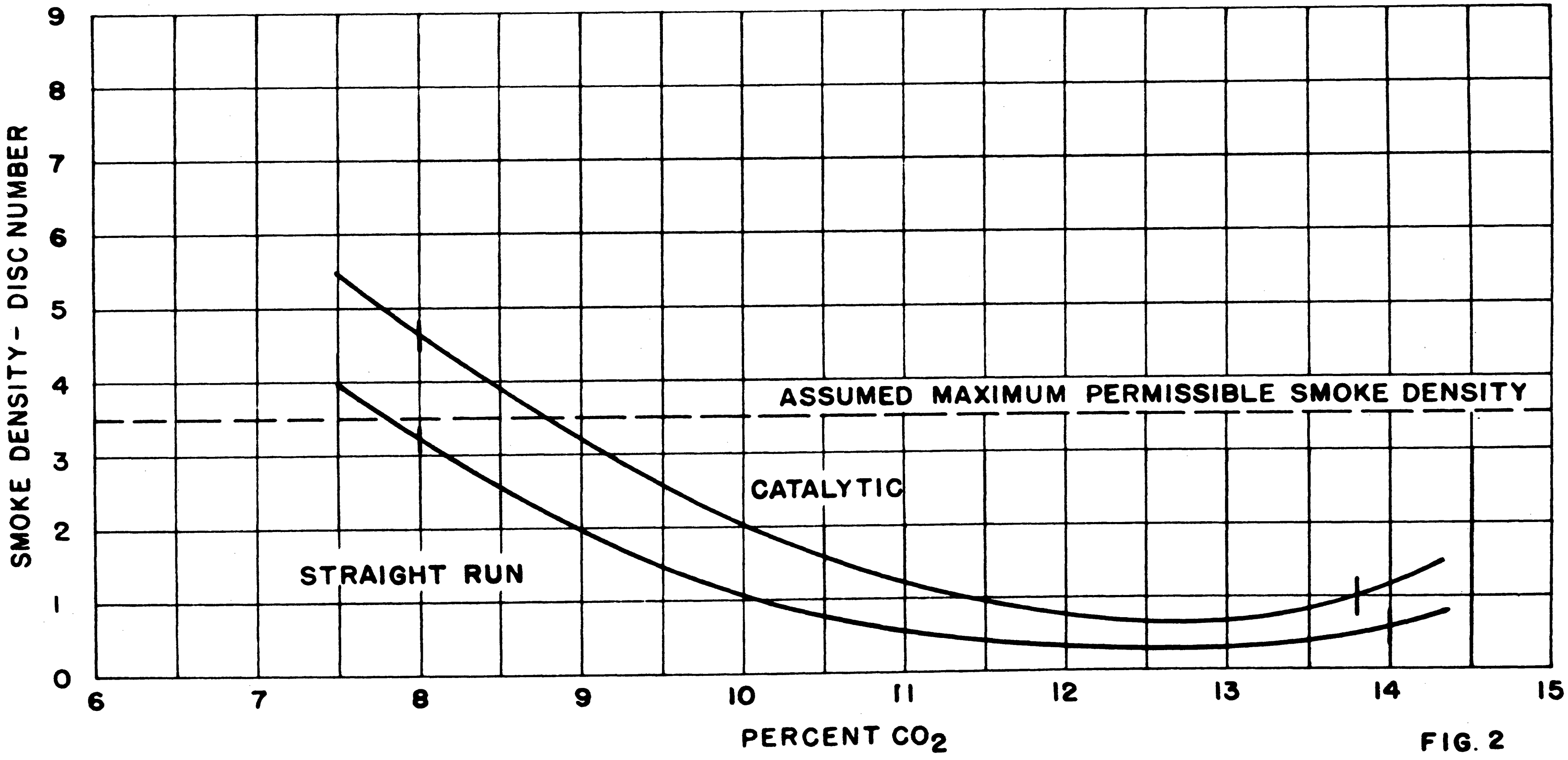

FIG. 2

HIGH PRESSURE GUN TYPE BURNER
SMOKE DENSITY - DISC NUMBER VS. PERCENT CO_2

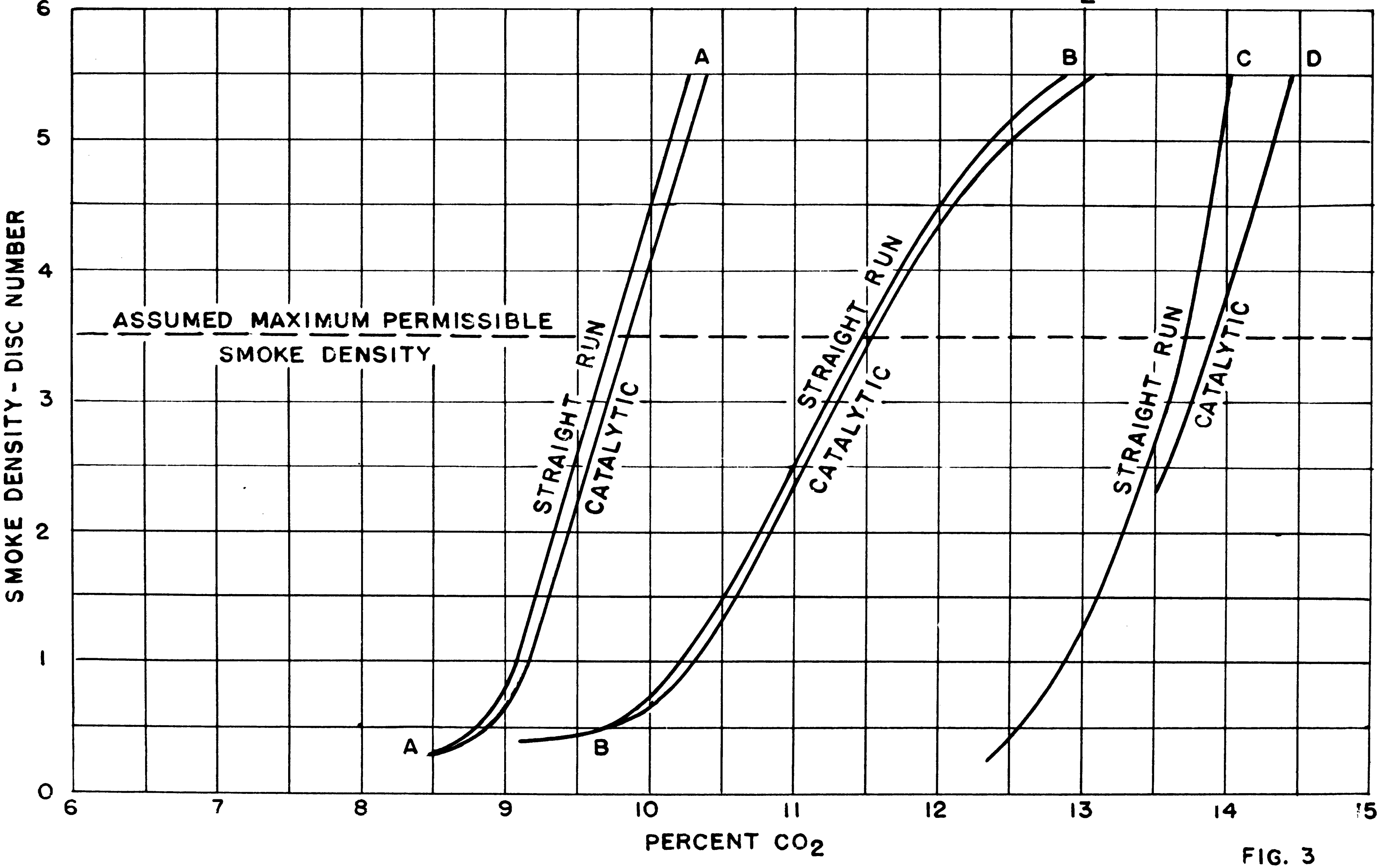

FIG. 3

HIGH PRESSURE GUN TYPE BURNER
SMOKE DENSITY - DISC NUMBER VS AIR INLET OPENING - SQ.IN.

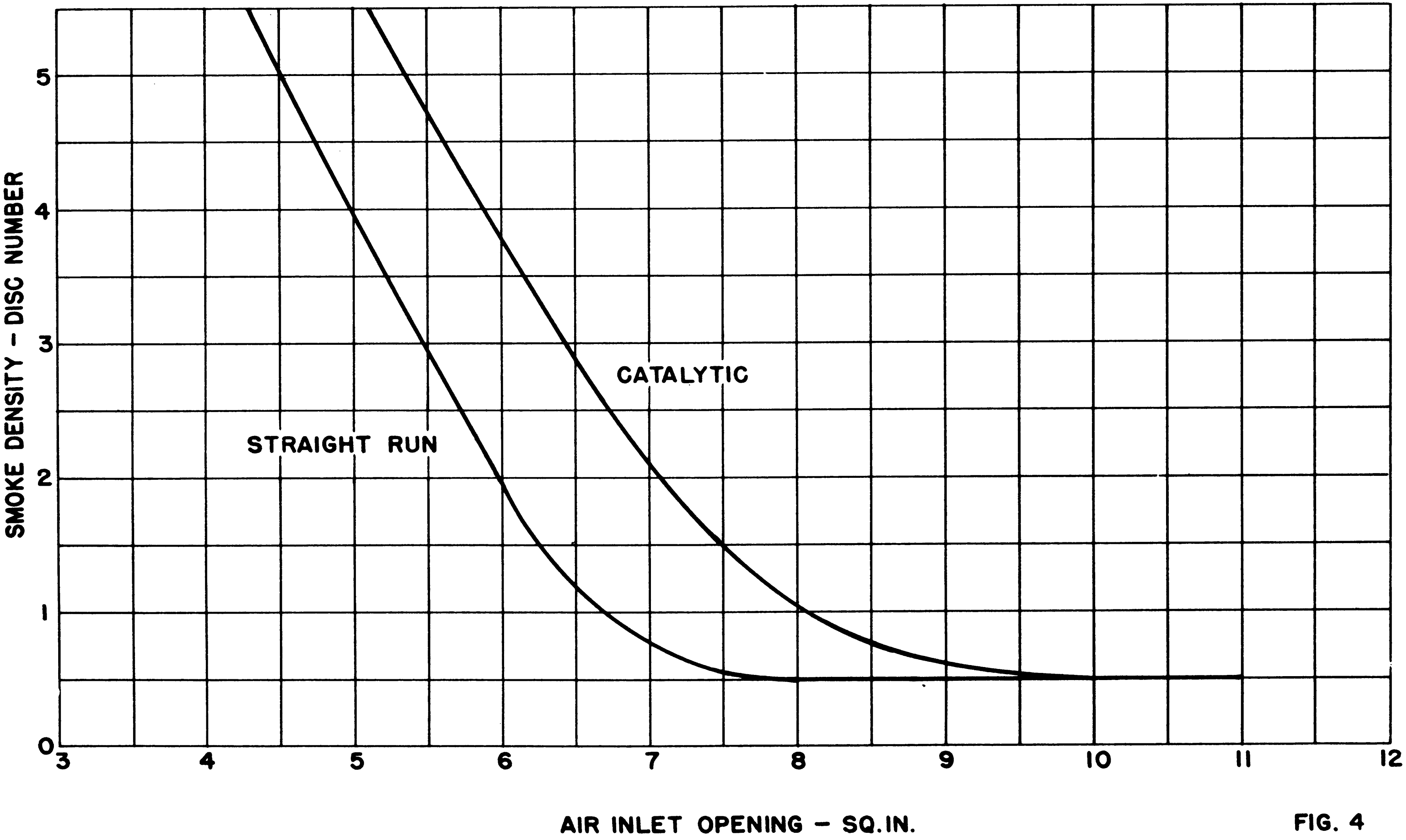

FIG. 4

HIGH PRESSURE GUN TYPE BURNER
FAN DELIVERY
AIR FLOW VS. AIR INLET AREA

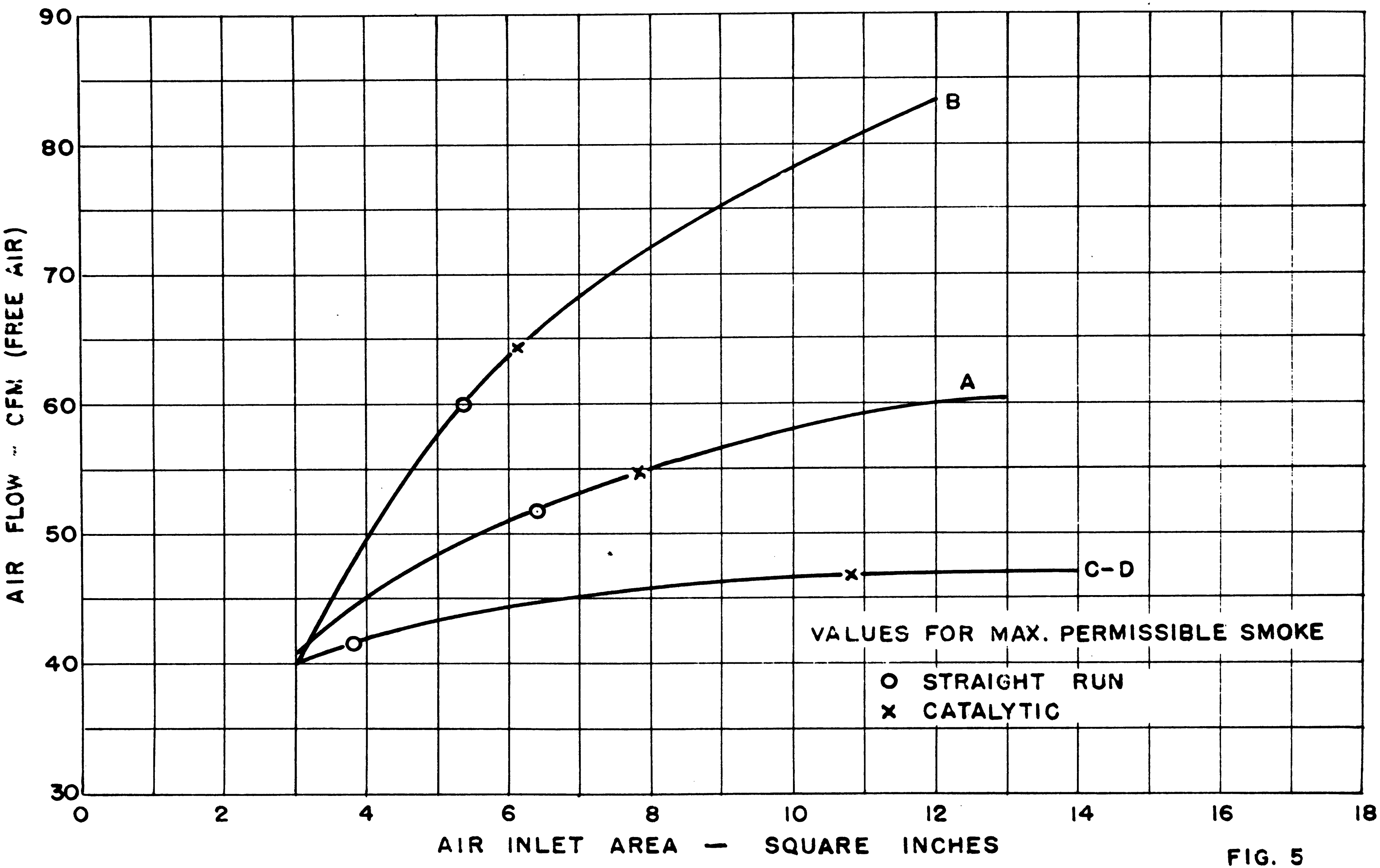

FIG. 5

HIGH PRESSURE GUN TYPE BURNER – NOZZLE PRESSURE PERFORMANCE
SMOKE DENSITY – DISC NUMBER VS PERCENT CO_2
STRAIGHT RUN FUEL
80° SPRAY ANGLE

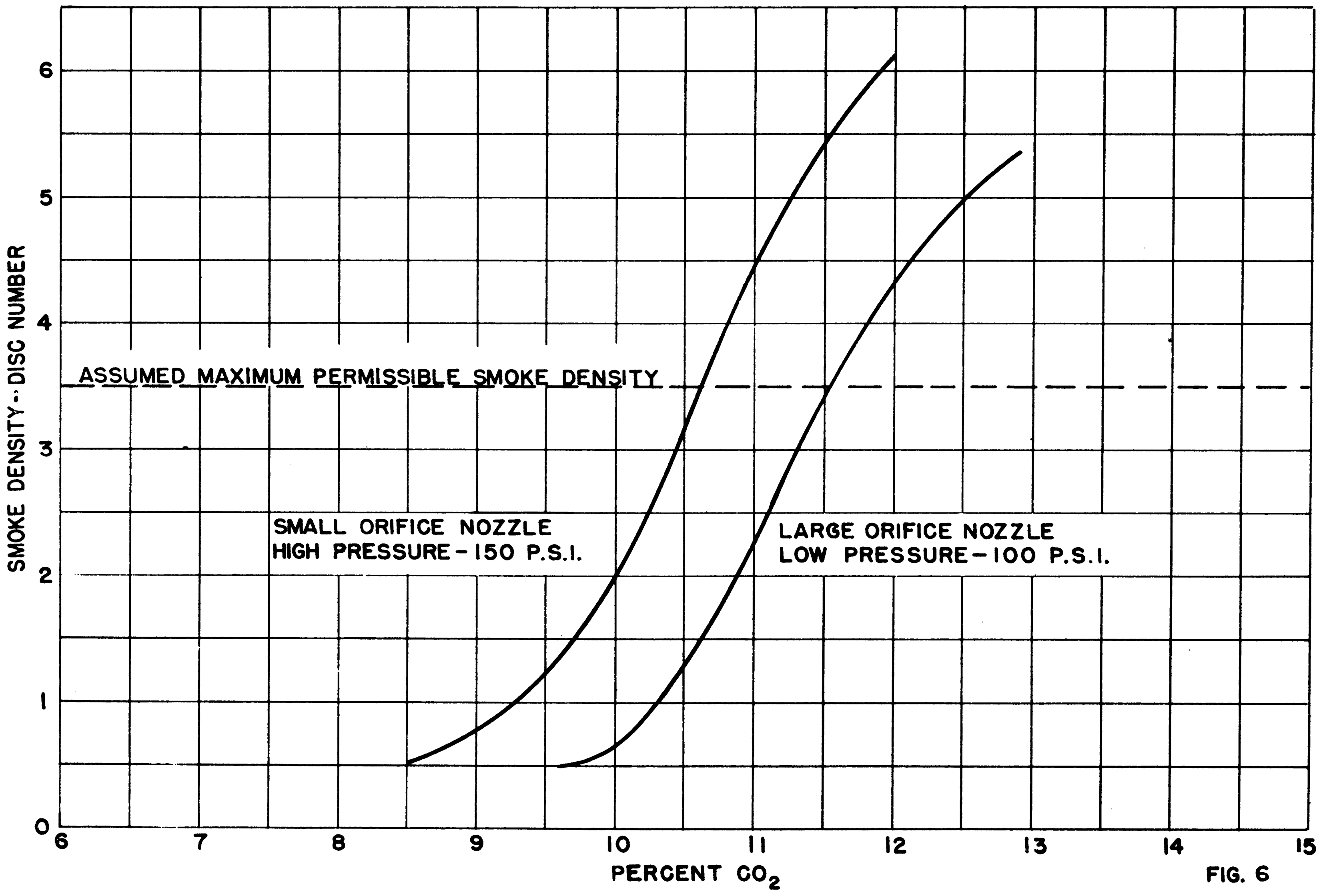

FIG. 6

HIGH PRESSURE GUN TYPE BURNER - TURBULATOR PERFORMANCE
SMOKE DENSITY - DISC NUMBER VS PERCENT CO_2

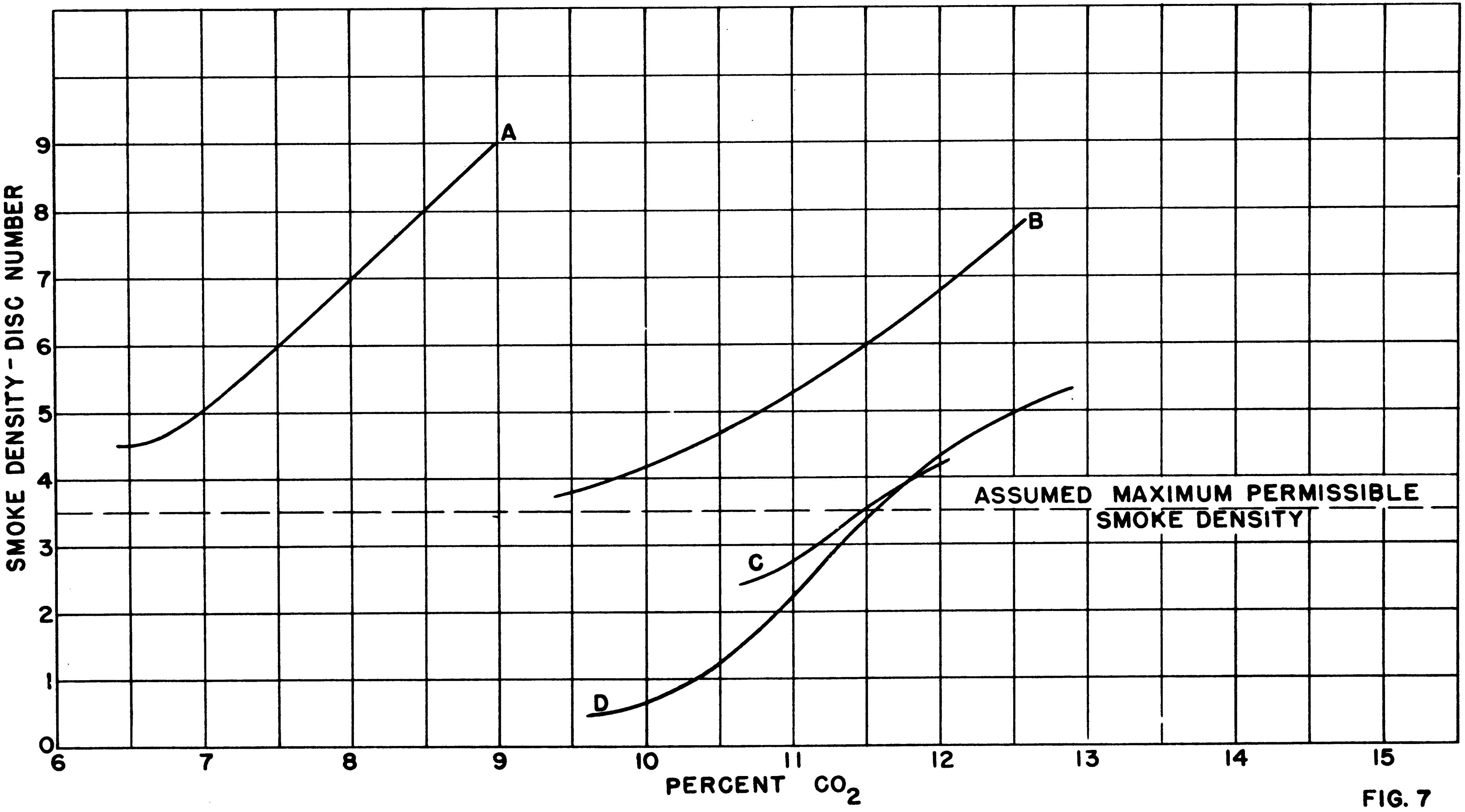

FIG. 7

ROTARY WALL FLAME BURNER - FAN PERFORMANCE

SMOKE DENSITY - DISC NUMBER VS. FLAME RIM TO FAN DIAMETER RATIO

1600 R.P.M. MOTOR

CATALYTIC FUEL 12 % CO_2

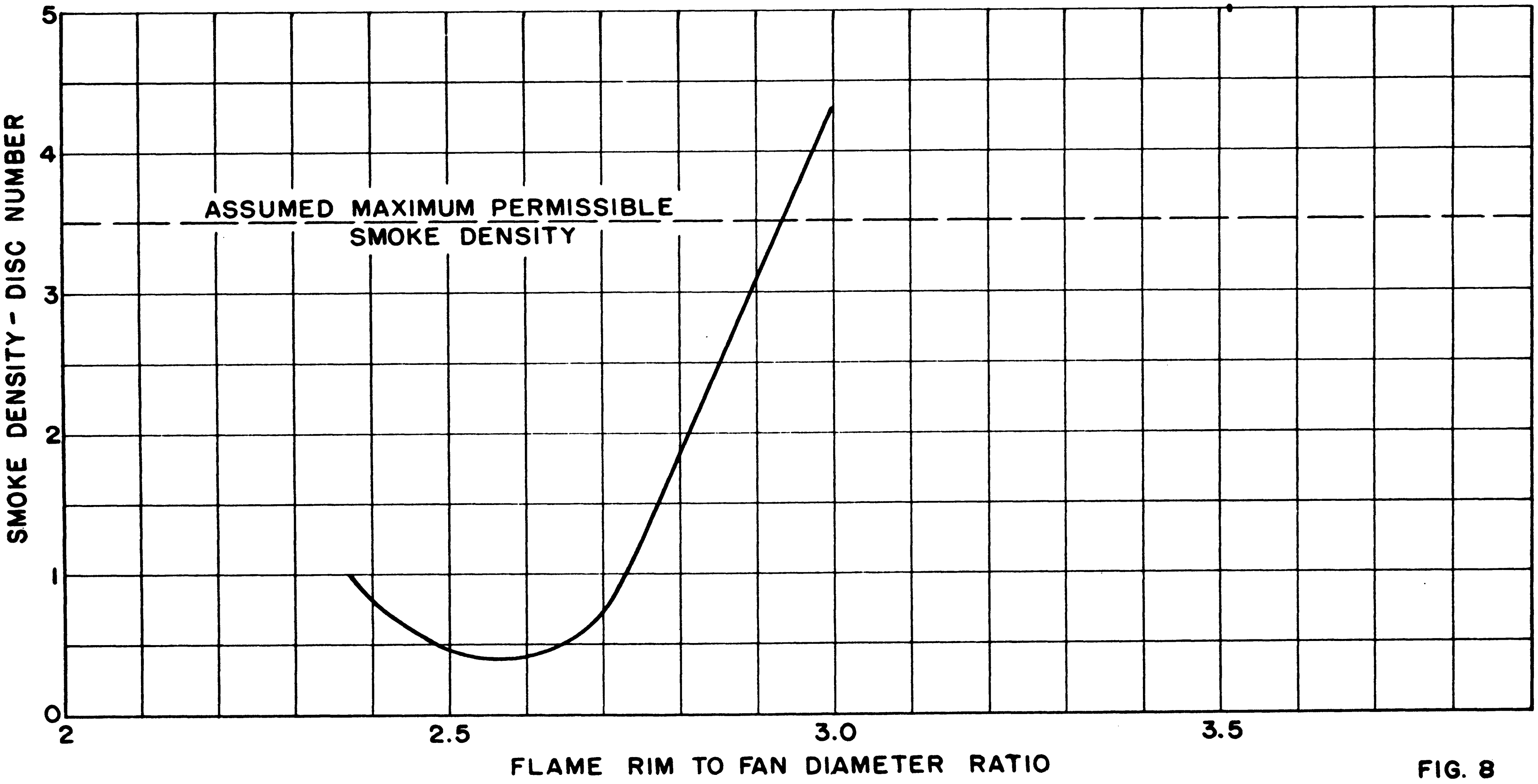

FIG. 8

SPACE TYPE HEATER PERFORMANCE
SMOKE DENSITY-DISC NUMBER VS. PERCENT CO_2

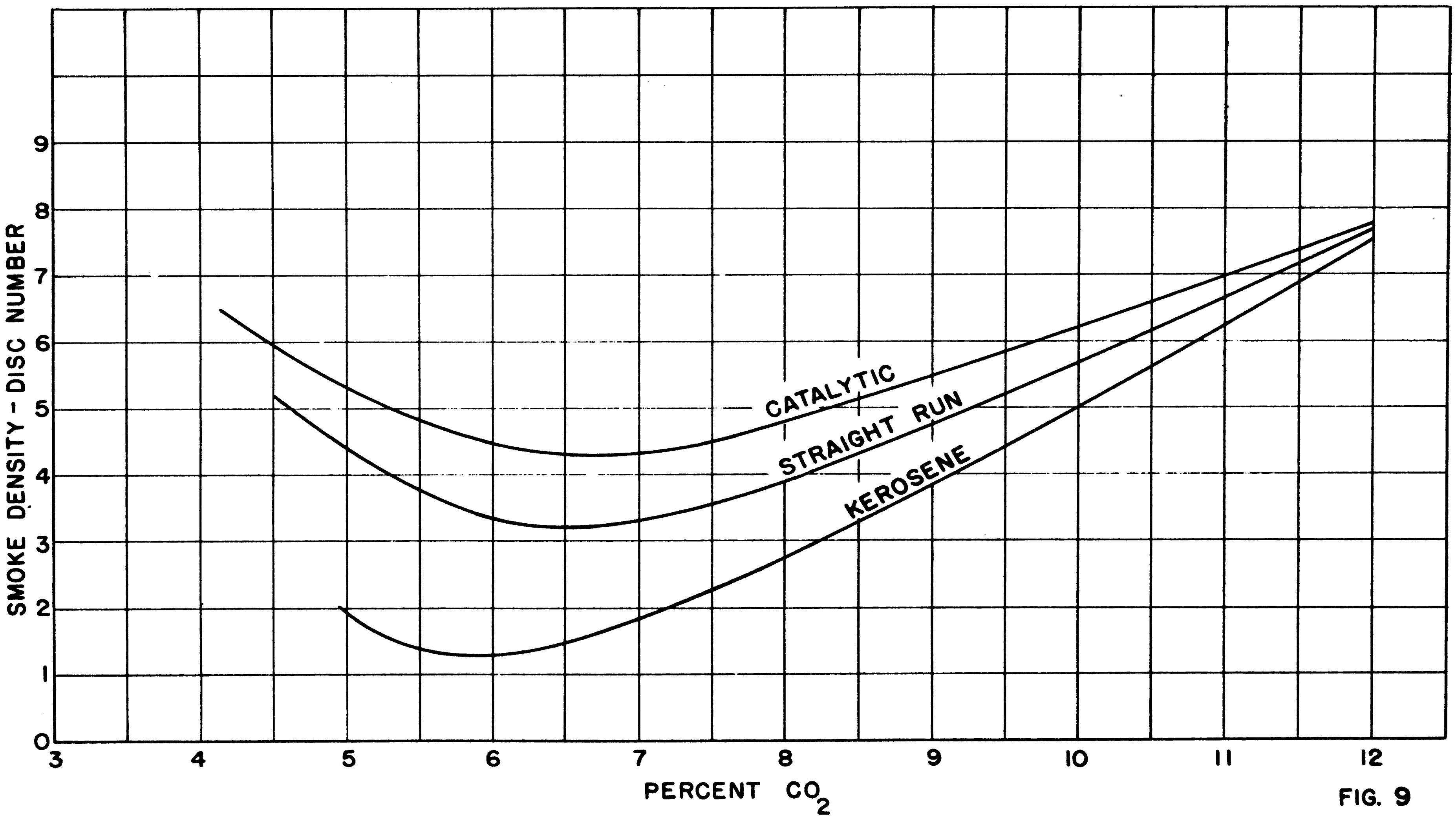

FIG. 9

PROPERTIES OF FUELS TESTED

	STRAIGHT RUN	CATALYTIC CRACKED
GRAVITY-A.P.I.	36.6	26.0
SPECIFIC GRAVITY	0.8418	0.8984
LB. PER. GAL. AT 60 F	7.009	7.481
B.T.U. PER GAL.	137,840	144,300
VISCOSITY: S.U.V. AT 100 F	34.3	36.0
FLASH: PM -°F	152	195
DISTILLATION, A.S.T.M. D-158-°F.		
OVERPOINT	360	440
10%	413	482
50%	489	526
90%	587	592
ENDPOINT	638	630
SULFUR %	0.31	0.60
C:H RATIO	6.56	7.87
ANILINE POINT- °F	146.6	94.3
DIESEL INDEX	54	25

FIG. 10