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COMPARATIVE STUDY OF METHANOL, ETHANOL, ISOPROPANOL, AND BUTANOL AS MOTOR FUELS, EITHER PURE OR BLENDED WITH GASOLINE

by

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COMPARATIVE STUDY OF METHANOL, ETHANOL,
ISOPROPANOL, AND BUTANOL AS MOTOR FUELS,
EITHER PURE OR BLENDED WITH GASOLINE

This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable as meeting the thesis requirements for this degree, but without implying that the conclusions reached by the candidate are necessarily the conclusions of the major department.

Thesis Advisor Date

Head, Mechanical Engineering Department Date

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COMPARATIVE STUDY OF METHANOL, ETHANOL, ISOPROPANOL, AND BUTANOL AS MOTOR FUELS, EITHER PURE OR BLENDED WITH GASOLINE

Abstract

Ajit Kelkar

A primary area of recent experimental research efforts in the use of fuel alcohol is to investigate the performance of spark-ignition engines, originally designed for gasoline, when burning alcohol/gasoline blends or pure alcohol. In the work reported here, a number of performance tests using gasoline, alcohol/gasoline mixtures, and alcohol alone were conducted on a spark-ignition engine. Methanol, ethanol, isopropanol, and butanol, either pure or blended with gasoline, were used.

An International Harvester, Silver Diamond, six-cylinder engine with a compression ratio of 6.77 was used for the experiment. It was equipped with an adjustable load needle, rather than fixed jets, and a distributor having centrifugal spark advance only. The engine was mounted on a test stand and attached to an electrical generator which dissipated its output in resistor banks.

Fuels chosen were gasoline only, alcohol/gasoline mixtures with volumetric ratios of 10-90, 50-50, and alcohol only. These three alternate fuel combinations were chosen for comparative purposes and easy interpretation. The tests were run with a wide-open throttle, and the load was varied so the engine speed ranged from 1000 to 3000 rpm. The speed of the engine was measured by using a stroboscope, and exhaust gas analysis was carried out using an Orsat apparatus. The test series

was repeated with an increased compression ratio of 7.76 to study the effect of a change in compression ratio on the performance of the engine.

The principle results show:

*For the compression ratios studied, and optimum engine adjustments, the thermal efficiencies of gasoline, alcohol, and alcohol/gasoline blends are substantially similar.

*The power output of all such fuels is essentially proportional to the energy content of the fuel conveyed to the cylinder.

*The energy content of alcohol and alcohol/gasoline fuels is lower than that of gasoline; therefore, the specific fuel consumption was nearly always greater for alcohol and alcohol/gasoline blends than for pure gasoline.

*It was observed that engine performance was better for the higher compression ratio of 7.76 than for 6.77. Increase in power output, lower fuel consumption, and higher thermal efficiency were observed with the higher compression ratio.

Symbols and Abbreviations

B	butanol
bhp	brake horse power
bsfc	brake specific fuel consumption
C_v	combustion-chamber volume
C_2	combustion-chamber volume (cylinder head)
C_1	combustion-chamber volume (cylinder block)
CO	carbon monoxide
CO_2	carbon dioxide
CR	compression ratio
d	diameter
D_v	displacement volume
E	ethanol
f	coupling force
G	gasoline
h	stroke
I	isopropanol
IH	International Harvester Corp.
J	joule
k	C_p/C_v
lb	pound mass
m	mass
M	methanol
N	revolutions per unit of time
O_2	oxygen
P	load in lbs.

Q	heat of combustion
r	radius
R	dynamometer constant
SI	spark ignition
t	time
T	torque
η_t	thermal efficiency
ξ_v	compression ratio

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CHAPTER I

INTRODUCTION

At the beginning of this century, gasoline was nothing more than a by-product of the production of kerosene for lamps. The kerosene market was destroyed by Edison's invention of the electric light bulb. The oil industry, seeking new markets, began refining vast quantities of petroleum into gasoline for use in internal-combustion vehicles. This gasoline was so plentiful and cheap that it became the standard motor fuel.

From that time, internal-combustion engines were optimized for petroleum-based liquid fuels, and the early primitive forms of gasoline have been considerably improved through refined formulation. Due to the abundance of fossil resources little or no consideration was given to liquid and gaseous fuels derived from biomass until the late 1960s.

During the past decade, man has become increasingly aware of the limitations of energy supplies. With the 1970s came a drastic change in the world petroleum market. First came the 1973 embargo with its dramatic rise in the price of oil imposed by the Organization of Petroleum Exporting Countries (OPEC). Then came further price increases and, in 1979 and 1980, the specters of revolution and war in the oil-rich Middle East.

With the expected future rates of energy consumption, we are faced with the question of how long there will be sufficient reservoirs of conventional fuels for our industrialized societies. The increasing scarcity of fossil fuels, and the attendant increase in the cost of petroleum products, make it imperative to find alternate energy sources in the next decade, especially those derived from renewable resources.

Recently, considerable attention has been given to alcohol fuel production from biomass. Today's petroleum shortages have created renewed interest in alcohol fuels. This has stimulated new research in applications and bio-conversion techniques, as well as reassessments of the environmental advantages and disadvantages of using alcohol fuels.

The United States uses more petroleum than any other nation on Earth. In 1980, America consumed an average of 16.5 million barrels of petroleum per day. Gasoline and diesel fuel for engines of automobiles, trucks, buses, and trains accounted for 53 percent of all petroleum products supplied in 1980, 80 percent of which was consumed by passenger cars.

Gasoline consumption showed a decline of six percent in 1980 as compared to 1979. Even with slightly reduced consumption, the internal combustion engines will undoubtedly remain the largest users of petroleum products in the 1980s. Thus, the development of alcohol as a motor fuel that helps to offset the use of petroleum in transportation, and other sectors, is critically important.

Alcohol fuels are liquids and can be readily used, without further refining, in internal-combustion engines. Further, the technology to produce alcohol fuels is well known. Therefore, alcohol production can begin on a large scale more quickly than can production of other synthetic fuels. Also, the resources for producing alcohol fuels are renewable, including sugar crops, livestock feed grains and cellulose materials.

Alcohol fuels will become precursors of several energyoriented economic, political, and sociological changes in the world. Gasohol, alcohol, and biomass fuels are the ABCs of an energy system of major proportions that is about to dawn. It will contribute significantly to lifting the yoke of dependence on foreign oil and the reduction of the rate of consumption of the world and national oil reserves.

Current favorite alcohols are ethyl alcohol and methyl alcohol. The technology to produce both of them from bio-mass is already well developed. There are good chances that in the near future other alcohols like isopropanol and butanol may be produced from bio-mass, so isopropanol and butanol are also being studied as alternate fuels.

CHAPTER II

HISTORY OF ALCOHOL FUELS

The use of alcohol-based fuels is not a new concept. In fact, alcohols have been utilized extensively throughout the world as petroleum substitutes during periods of shortage.

Alcohol fuels have been used often in both wartime and peacetime. Henry Ford designed the Model T so that it could run on alcohol, gasoline, or any mixture in between. Alexander Graham Bell in 1922 called alcohol a beautifully clean and efficient fuel which can be produced from vegetable matter...waste products of our farms and even the garbage of our cities. [2]

The first modern internal-combustion engine, the Otto Cycle (1876) ran on alcohol as well as gasoline. During WW II, the U.S. operated an ethanol plant in Omaha to produce motor fuel for the army, and gas stations in Kansas, Nebraska, and Illinois sold an alcohol/gasoline blend, "agrol". In 1934, Hiram Walker marketed an alcohol/gasoline mixture called "alcoline".

Nevertheless, until recently the relatively inexpensive price of gasoline has made alcohol fuel uneconomical to produce on a large scale. Now, however, with increased crude oil and gasoline prices, substantial public and private activity has centered on alcohol fuels, particularly "gasohol". "Gasohol" is fast becoming a generic term for alcohol/gasoline blends (usually 90% regular unleaded gasoline and 10% ethanol, anhydrous).

Recently, considerable attention is being given to gasohol and pure alcohol fuels. California began a 10-year Experimental Methanol

Fuel program in January 1980. In 1979 the Bank of America, with headquarters in San Francisco, began to convert its 1800-vehicle fleet to methanol use.

The California State Energy Commission is planning a three-year, $2-million, fleet-vehicle program to test both ethanol and methanol fuels in approximately 60 vehicles. Under this program, a company called Alcohol Energy Systems is providing eight modified Ford Pintos for testing both ethanol and methanol. Volkswagen of American will provide a production-line fleet of 25 alcohol VW Rabbits for similar tests. [1]

Elsewhere, the North Carolina Department of Transportation, under a grant from the North Carolina Energy Institute, will convert 15 state vehicles to methanol operation. The New York City Police Department is also testing a converted pure-methanol vehicle. In mid-1981, the U. S. Postal Service will start a modified fleet of 42 Pintos on delivery routes, half using pure ethanol and the other half pure methanol. [1]

Foreign Experience with Alcohol Fuels

Although many nations are interested in alcohol fuels, Brazil has the most practical experience with pure-alcohol fuels and vehicles.

Brazil

An aggressive program to introduce pure-alcohol vehicles into market, PROALCOOL, sets both alcohol fuel and vehicle rate targets for 1985: 2.8 billion gallons of ethanol and 350,000 alcohol vehicles to be produced annually. Another 470,000 older vehicles will be converted annually to operate on pure ethanol.

The major companies that will help Brazil to meet its targets are Brazilian subsidiaries of Volkswagen, Ford, General Motors, and Fiat. Their government has instituted a number of incentives to promote the program. PROALCOOL was initiated in 1975 in response to the massive oil price increases that began in 1973. Currently there are about 1500 ethanol pumps, and the number is rapidly growing.

Because some 5.3 billion gallons of diesel fuel are consumed annually in Brazil, compared with about 3.9 billion gallons of gasoline, considerable research is also underway to reduce diesel fuel consumption through the development of methods to use alcohol in diesel engines.

CHAPTER III

FUEL ALCOHOL RESEARCH AT SOUTH DAKOTA STATE UNIVERSITY

The Agricultural Engineering, Mechanical Engineering, Dairy Science, Economics, and Microbiology departments at South Dakota State University are conducting extensive research on alcohol fuels. The research is sponsored by the U. S. Department of Agriculture. The overall objective is to make a multidisciplinary study of the operational farm-scale fuel-alcohol plant at South Dakota State University to determine the energy balance, the cost of producing one gallon of alcohol fuel, and to evaluate the performance of spark ignition engines using various gasoline/alcohol mixtures. This evaluation was for the utilization of these mixtures with minimal modifications of the engine. Other objectives were to determine phase separation of alcohol-non-leaded-gasoline fuel mixtures and relate the results to engine efficency, to prepare an economic analysis, to evaluate the animal feed characteristics of the stillage feed products, to prepare engineering estimates of cost of construction, etc.

As there are more than 100 million engines in the United States designed to use gasoline, this study was made to find out if those engines may be inexpensively modified to use alcohol/gasoline blends or pure alcohol.

CHAPTER IV

ROLE OF MECHANICAL ENGINEERING DEPARTMENT IN THE FUEL-ALCOHOL RESEARCH PROGRAM

OBJECTIVES:

In view of the overall SDSU program, the specific objectives of the experiment reported here were:

1. To study the feasibility of methanol, ethanol, isopropanol, and butanol, either pure or blended with gasoline, as alternative fuels.

2. To compare the performance of the engine with methanol, ethanol, isopropanol, and butanol, either pure or blended, with gasoline. Simple engine modifications, such as timing changes, carburetor modifications, etc. were made to optimize performance with each fuel tested. Modifications were limited to those which could be easily made, and reversed, on passenger cars.

3. To study the effect of an increase in compression ratio on the performance of the engine using each of the fuels above.

4. To compare the performance of the engine using pure methanol and methanol/gasoline blends by performing two different tests, vis:

   a. Using an existing gasoline engine suitably modified (engine timing and carburetor adjustment) to optimize the performance, for each of the fuels, either pure methanol or methanol/gasoline blends.

   b. Using an existing gasoline engine with the same setting as in the case of gasoline, and without any modifications, for each of the fuels, either pure methanol or methanol/gasoline blends.

EQUIPMENT

1. Engine: See Figure 1 for a photograph of the engine.

Make: International Harvester

Model: Silver Diamond

Type: Reciprocating, spark-ignition engine.

Number of Cylinders: Six

Cylinder arrangement: In-line, vertical

Bore x stroke: 3 9/16" X 4"

Displacement: 240.00 cubic inches

Compression ratio: 1. Original head: 6.77:1
2. Modified head: 7.76:1

Type of cooling: Water cooled

The cooling arrangement of the engine was modified by removing the radiator and water pump; cooling water was supplied from city water modulated through a temperature sensor.

The carburetor on this engine was fitted with a load needle rather than a fixed jet. To ensure enough supply of alcohol to the engine, the orifice for the load screw was rebored and the main jet tube was redrilled to give a 35% increase in area. Also, to avoid vapor-lock problems arising from radiation of the exhaust manifold, the fuel line was changed to a neoprene hose of a larger diameter and a radiation shield was improvised to stop undesired fuel boiling since the boiling point of alcohol is lower than that of gasoline.

2. Dynamometer:

Determining engine torque requires the measurement of a force acting through a distance. Any apparatus that permits such a measurement

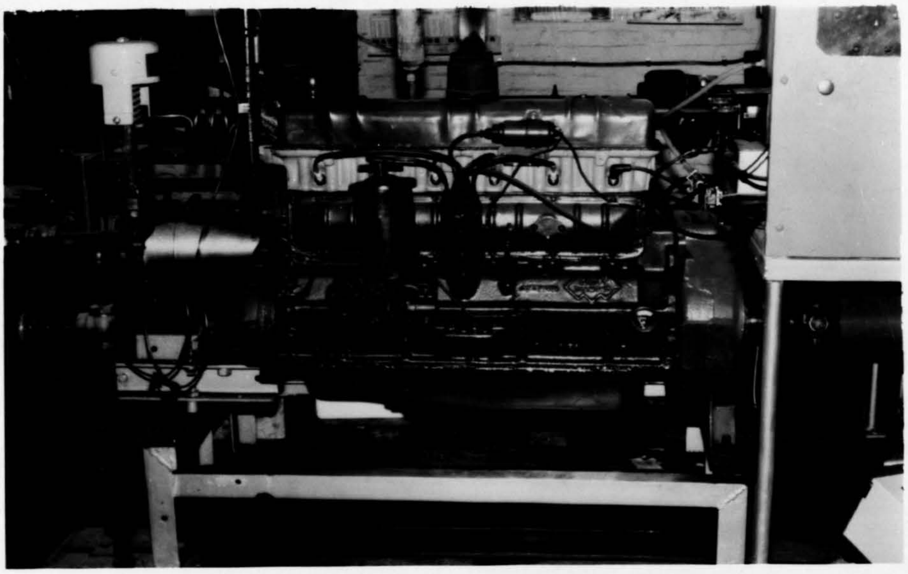

Figure 1: The Engine

is called a dynamometer.

Principle of the dynamometer: See Figure 2.

The rotor a, driven by the engine to be tested, is coupled to the stator b. In one revolution of the shaft, the periphery of the rotor of radius r moves through a distance $2\pi r$ against the coupling force f. Thus the work per revolution is

$$\text{Work} = 2\pi rf$$

The external moment, with the product of the reading P of the scale and the arm of length R, balance the turning moment. Hence for N revolutions, Work = $2\pi PRN$. Since horsepower is a power unit defined as 33,000 ft-lb per minute, the horsepower of the dynamometer becomes

$$\text{hp} = \frac{2\pi PRN}{33{,}000}$$

An electric generator was used for loading the engine. The generator output was dissipated in resistor banks. The electric generator (dynamometer) having a dynamometer constant (R) of 1.33 and provision for measuring the direct load (P) in lbs was used.

3. An Orsat apparatus; See Figure 3 of the photograph of the Orsat apparatus.

The Orsat apparatus measures concentrations of carbon dioxide, carbon monoxide, and oxygen in exhaust gas. The Orsat consists of a measuring burette and three absorption pipettes. The pipettes are provided with solutions of potassium hydroxide, pyrogallic acid, and cuprous chloride. Potassium hydroxide absorbs carbon dioxide, pyrogallic acid absorbs oxygen, and cuprous chloride absorbs carbon monoxide from an exhaust-gas sample.

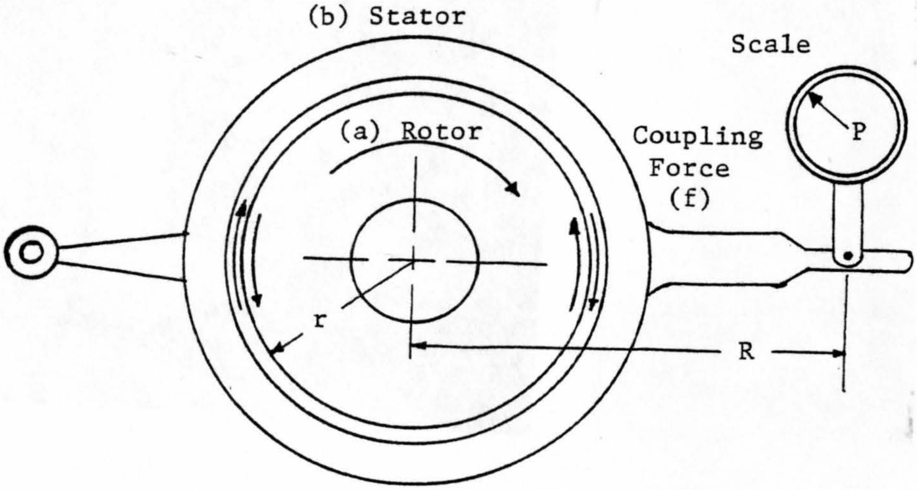

Figure 2: The dynamometer principle

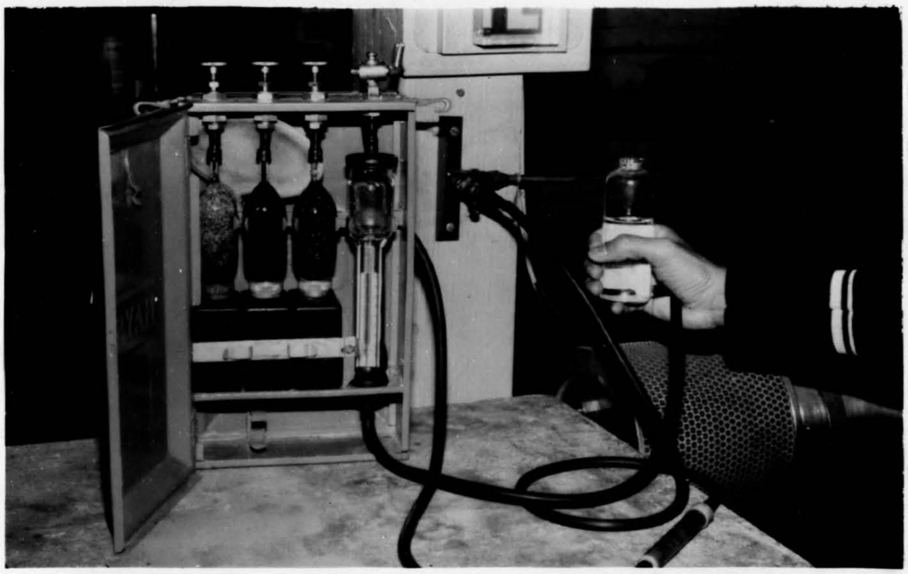

Figure 3: The Orsat apparatus

In the Orsat apparatus, the analysis of the exhaust gases is determined volumetrically.

4. Fuel weighing scales:

To measure the amount of fuel fed to the engine, the fuel weighing scales are used as shown in Figure 4. The balance is adjusted until the fuel container is slightly heavier than the balancing weights. As the fuel is consumed by the engine, the scale will gradually approach the balance point. At the instant of perfect balance, the stopwatch is started. The beam weights are then recorded. The balance is readjusted by removing known weights and when perfect-balance is again reached after the consumption of more fuel, the watch is stopped. The difference between the two weights at balance is the amount of fuel consumed in the time indicated by the stopwatch. This procedure gives the average fuel consumption during the time of the test.

The fuel-weighing-scale method was chosen over other methods such as volumetric-determination of fuel consumption or flowmeters because a variety of fuels having different specific gravities were to be used.

5. Stroboscope:

A stroboscope is a measuring device for determining the speed of rotation or frequency of vibration in machine parts. The stroboscope consists of a timed, flashing light which gives an periodic view of a moving object.

The flywheel of the engine is marked with a piece of chalk. When the flywheel is rotating at a certain speed, the stroboscope is used directly as an instantaneous speed indicator by adjusting the

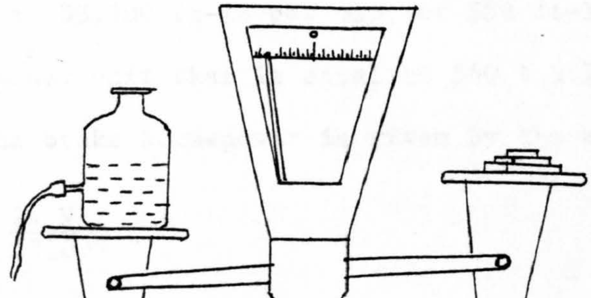

Figure 4: Fuel weighing scales

flash frequency until a rotating part appears to stand still.

Other equipment such as thermometers, timing light, pressure gauges etc. were used to record the other engine parameters.

Performance Factors:

a. Power: The power obtained from the engine is most frequently called brake horsepower (bhp) and sometimes shaft horsepower. Power is defined as the time rate of doing work, and horsepower is a power unit defined as 33,000 ft-lb per min, or 550 ft-lb per sec. The kilowatt is a power unit that is equal to 550 ÷ 0.746 or 738 ft-lb per sec. The engine brake horsepower is given by the equation

$$\text{bhp} = \frac{2\pi\ N\ T}{33,000} \qquad 4.1$$

where N is speed of the engine in RPM and T is engine torque in ft-lb.

b. Torque: Torque is the twisting or turning moment, visualized as the work per unit of rotation (radians). Refer to the dynamometer mechanism illustrated in Figure 2. The external moment, which is the product of the reading P of the scale and the arm R is called torque

$$T = PR \qquad 4.2$$

Torque is a measure of the ability of an engine to do work, or torque determines whether an engine can drive a vehicle through sand or other obstacles.

c. Brake Specific Fuel Consumption:

If an engine consumes m mass of fuel in t sec, then

$$\text{Fuel flow per hr} = \frac{3600m}{t} \qquad 4.3$$

$$\text{Fuel flow per bhp-hr} = (\text{bsfc}) = \frac{3600m}{\text{bhp}(t)} \qquad 4.4$$

and bsfc has units of either pound, gram, or kilogram (mass) per bhp-hr. The brake specific fuel consumption is a comparative parameter that shows how efficiently an engine is converting fuel into work.

d. Thermal Efficiency:

i) The thermal efficiency is defined for a cycle to show the efficiency of conversion of heat into work:

$$\eta_t = \text{thermal efficiency} = [\frac{\text{work}}{\text{heat supplied}}]$$

If this equation is applied to the engine process, it is necessary to determine the heat of combustion of the fuel. The value of the heat of combustion (Q) depends upon the fuel used. The calculation of Q values for different alcohols and alcohol/gasoline blends is shown in the Appendix A, and the Q values are tabulated in Appendix A under Table A-2. Since there are by definition

1 hp-hr = 1,980,000 ft-lbf

1 ft-lbf = 1,355,818J

1 hp-hr = 2,684,519J and

1 Btu = 1055.056J.

Thus 1 hp-hr = 2544.433 Btu

= 2545 Btu

and the energy conversion becomes

$$\text{bsfc}\ (\frac{\text{lb}}{\text{bhp-hr}})\ Q\ (\frac{\text{Btu}}{\text{lb}}) = (\text{bsfc})\ Q\ \frac{\text{Btu}}{\text{hp-hr}}$$

Then the equation for thermal efficiency may be written as

$$\eta_t = \frac{2545}{\text{bsfc x Q}} \qquad 4.5$$

and the percentage thermal efficiency $= \frac{2545}{\text{bsfc x Q}} \times 100$ 4.6

ii. Theoretical Thermal Efficiency: Theoretically, the thermal efficiency for the Otto engine, operating in an air-standard Otto cycle, is given by

$$\eta_t = 1 - \frac{1}{(\xi_v)^{k-1}} \qquad 4.7$$

in which k is the ratio of the specific heats of an ideal gas. Here ξ_v is the expansion ratio of the cycle. But this is also the compression ratio since the piston will retrace its steps in completing the cycle. [In a true thermodynamic cycle, the terms expansion ratio and compression ratio are synonymous. However, in the real engine, these two ratios need not be equal because of the valve timing.]

e. Compression ratio of the engine: If the displacement (D_v) is the volume swept by the piston in one stroke, The clearance volume (C_v) is the volume of the compressed gases; which is also volume of the combustion chamber; the compression or expansion ratio (CR and ξ_v) equals

$$\xi_v = \frac{C_v + D_v}{C_v} = \text{CR} \qquad 4.8$$

See Appendix A for the calculations of the compression ratios.

Using the above equations and the test data, the performance factors were calculated as shown in Appendix A. The results are tabulated in Appendix B.

Also the computer programs given in Appendix C were used to compare the results graphically. These graphical comparisons of various engine parameters using different alchols and alcohol/gasoline blends are shown in Appendix D.

PROCEDURE

The engine was mounted on the test stand and was attached to an electric generator. The engine was run with the throttle partly opened, and the engine was loaded until the lowest desired speed was attained. The engine was run for a period of time until the water and lubricating oil reached definite operating temperatures.

When the engine was operating in approximate temperature equilibrium, the test was started. The throttle was fully opened, and the engine was loaded until the engine speed of 2700 rpm was reached. At this time, the carburetor was adjusted by turning out the load needle. See Figure 5 for a photograph of the load needle. The load needle was adjusted in such a manner that the fuel supplied to the engine was optimum. This was done by first supplying a rich mixture to the engine and then further reducing the fuel supply to the engine until the maximum speed of the engine was achieved. This was checked by a stroboscope. The engine was further loaded to compensate for this gain in rpm, and it was set back to 2700 rpm.

Once the engine carburetor was adjusted, the adjustment of the engine timing was done by rotating the distributor manually (see Figure 6 for a photograph of the distributor) with the aid of a stroboscope. The distributor position was fixed when the engine reached maximum rpm. Once again the engine was loaded to compensate for the further gain in rpm above 2700 rpm. At this time, with the help of a timing light, the engine timing angle was recorded.

The engine speed of 2700 rpm was chosen mainly because it was

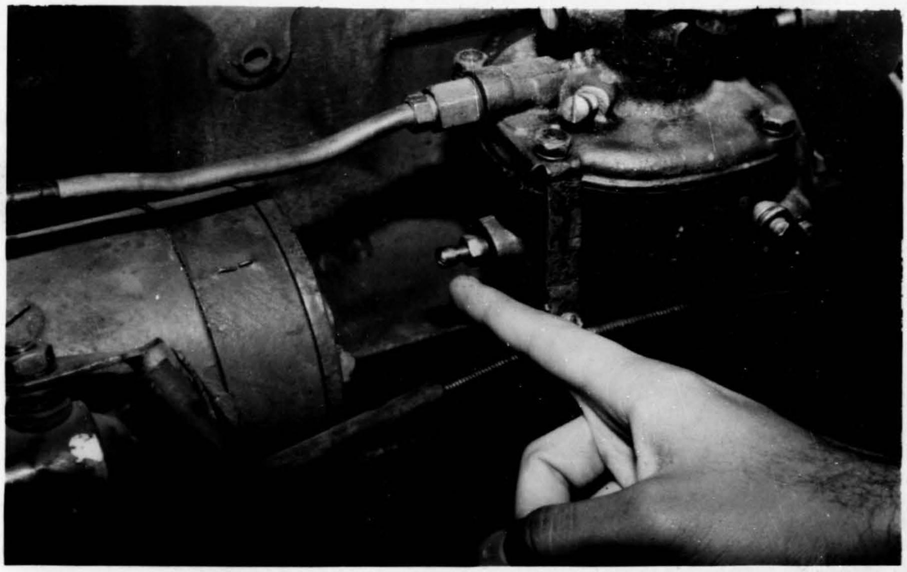

Figure 5: Carburetor load needle adjustment

Figure 6: Distributor adjustment

observed that the horsepower developed by the engine is maximum at this speed, and the main objective was to achieve maximum horsepower at lowest possible fuel consumption.

The load on the engine was then reduced to obtain a speed of 3000 rpm. With the engine operating at a speed of 3000 rpm, corresponding readings such as fuel consumption in lbs, time in seconds required to consume the specific amount of fuel, engine speed in rpm, load in ft-lbs on the engine, air flow in inches of water, etc. were recorded. After that, the engine load was varied in such a manner that engine speed was decreased from 3000 rpm to 1000 rpm in intervals of 200 rpm. Corresponding readings similar to those at 3000 rpm were recorded.

By using the Orsat apparatus, an exhaust gas analysis was carried out with a sample of the exhaust gas taken at 2700 rpm.

Similar tests were carried out using gasoline, and methanol, ethanol, isopropanol, and butanol, either pure or blended with gasoline. The test data are shown in Appendix B. (Table 1 to Table 14).

Also, three tests using blends of methanol and gasoline with volumetric proportions of 10:90, 20:80 and 50:50 respectively were carried out without any adjustment of carburetor or engine timing in the existing gasoline engine, having a compression ratio of 6.77. Test data are shown in Appendix B (Table No. 28 to Table No. 30).

Modification of the engine was made by increasing the compression ratio of the engine to 7.76. (See Appendix A). Tests identical to those discussed above were carried out using methanol, ethanol, isopropanol, and butanol, either pure or blended with gasoline, and gasoline alone. Test data are shown in the Appendix B (Table No. 15 to Table No. 27).

CHAPTER V

DISCUSSION AND RESULTS

In the beginning of the experiment, the engine was run with 10-90 and 50-50 mixtures of alcohol and gasoline. No problems were encountered with 10-90 mixture. Smooth operation was experienced, and satisfactory results were obtained. However the 50-50 mixture caused a problem. No appreciable loading could be applied without stalling the engine. This problem was investigated, and it was observed that due to lower energy content in the alcohol as compared to gasoline, the air/fuel ratio required for alcohol was different from that for gasoline. Also, the alcohol contains oxygen while gasoline does not, and thus the alcohol requires less air to ignite. To solve this problem, it was decided to adjust the carburetor on the engine.

The carburetor on this engine is fitted with a load needle. The load needle is a tapered shaft inserted into the main jet by means of a screw thread adjustment. The screw thread arrangement allows the tapered shaft to be moved in and out of the hole in the jet. When the shaft is inserted into the hole, the fuel supply to the engine is reduced, and when shaft is unscrewed or withdrawn the hole opening becomes larger and more fuel is supplied to the engine.

Using the load needle, an attempt was made to supply more 50-50 fuel mixture to the engine, to ensure satisfactory operation. However, turning out the load needle did not seem to alleviate the problem. Even three full turns were insufficient. The orifice for the load screw was therefore rebored, and the main jet tube redrilled for a 35% increase in area. After this modification, satisfactory operation was experienced, for both the 50-50 mixture of the alcohol and gasoline, and the pure alcohol.

It is very important to select the proper drill for boring the jets. If jets are drilled too large or too small, a number of undesirable consequences occur. If the drill is too large, the resulting hole causes enormous fuel consumption. Alcohol will keep burning in an engine long after the same volume of gasoline would have simply flooded and stalled the engine. If the jet size is too small, the valves might burn. An engine designed for gasoline will sputter and misfire if the jets are too small when it is running on alcohol.

A second important factor is ignition timing. Alcohol is a cooler and slower burning fuel than gasoline. The slower burning requires an advance in ignition timing. That is, the spark plug must fire at a point, or time, before that required for gasoline. During the experiment, it was observed that timing adjustments do help to give better fuel economy and power. During each test on the engine with various alcohols and alcohol/gasoline mixtures, the engine timing was advanced as described earlier to ensure the optimum engine performance with the individual fuel being tested.

A third important factor is compression. How much the piston compresses the fuel air mixture in the combustion chamber determines, to a large extent how much energy is extracted. To extract maximum power and economy from alcohol, the compression ratio was raised to 7.76 from 6.77. It was not possible to raise the compression ratio above 7.76. As high-compression-ratio pistons for the particular engine model were not available, and due to the expensive, complicated, and timeconsuming process of decking the block, the only way to increase the compression ratio was milling the cylinder head. However after 100/1000 of an inch was removed, it was observed that it was not practical to remove more material because it would have resulted in weak cylinder-head sections. So, the maximum compression ratio of 7.76 was used for comparative purposes, although a higher compression ratio than 7.76 would have given better results.

The experimental results indicate that the power output of alcohol and alcohol/gasoline blends is essentially proportional to the energy content of the fuel conveyed to the cylinder. Referring to the Figure D-1, butanol produced maximum horsepower among the alcohols whereas methanol produced minimum horsepower at most engine rpm values. Note that the energy content of butanol is highest of the alcohols tested and the energy content of methanol is lowest (Table A-1). The same results are also observed for the higher compression ratio of 7.76, see Figure D-2.

Also it is observed that brake specific fuel consumption is always greater for alcohol and alcohol/gasoline blends than for gasoline, and it depends upon the energy content of the mixture. Figure D-3 indicates that the engine burning methanol consumes maximum fuel, followed by ethanol, isopropanol, and butanol. These consumption rates vary inversely with the heating values of the alcohols. Also it is observed that for any particular alcohol, the 10-90 mixture produces maximum horsepower and minimum brake specific fuel consumption as compared to 50-50 mixture, and pure alcohol. (See Figures D-5 to D-8).

For the given compression ratios and optimum engine adjustments, the thermal efficiencies of gasoline, alcohol, and alcohol/gasoline blends are found to be substantially similar. See Tables 1-14 for the compression ratio of 6.77, and Table 15-27 for the compression ratio of 7.76.

The increase in power output, better fuel consumption, and higher thermal efficiency are observed for both alcohol and alcohol/gasoline blends for the compression ratio of 7.76 compared to that of 6.77 (See Figures D-9 to D-14).

Referring to the Table No. 1 at 1600 rpm brake horsepower developed by the engine was 47.85 and brake specific fuel consumption was found as 0.4906 LBS/BHP-HR. That means in one hour the engine would have consumed 23.47 lbs of gasoline. In the similar manner referring to Table No. 2 the engine would have consumed 24.54 lbs of 10:90 mixture of methyl alcohol and gasoline and 24.50 lbs. of 10:90 mixture of ethyl alochol and gasoline at 1600 rpm, (Table No. 3). Also in the cases of 50:50 mixtures the fuel consumption figures at 1600 rpm were 28.42 lbs and 29.99 lbs respectively (see Table No. 7 and 8).

Taking into consideration the specific gravities of different alcohols as per Table A-1, the amount of gasoline consumed in 10:90 mixture of methyl alcohol and gasoline was 21.78 lbs and in the 10:90 mixture of ethyl alcohol and gasoline was 21.76 lbs. Also in the cases of 50:50 mixtures the same figures were 14.03 lbs and 13.22 lbs of gasoline for methyl and ethyl alcohol respectively. This clearly shows that when alcohol gasoline blends are used there is substantial saving in the gasoline consumption and this saving is more when percentage of alcohol in the alcohol gasoline blend is more.

Lastly, it is observed that when various blends of methanol/gasoline are used in the engine having optimal setting for 100 percent gasoline, the power output of the engine is found to be reduced as compared to the power output with the same methanol/gasoline blend with the engine setting changed for optimal performance for that particular methanol/gasoline blend. Although the difference in the power output for 10-90 mixture is not much (see Figure D-18), the power output difference for the 50-50 mixture, is significant (see Figure D-20). Also it is observed that the engine failed to run on 100% alcohol without making any changes in the carburetor and engine timing which were set for operation with 100-percent gasoline.

CHAPTER VI

CONCLUSIONS

The spark ignition gasoline fueled, internal combustion engine dominates the motor vehicle market, and is anticipated to do so through the remainder of this century. It is used in almost every type of vehicle from motorcycles and automobiles to light- and medium-duty trucks and buses, as well as non-highway applications including chain saws, garden equipment, fork-lift trucks, and stationary power generators.

Today with the growing scarcity of petroleum and the search for an independent energy base for transportation, alcohols are being proposed as fuels to supplement domestic oil and natural gas supplies.

The experimental results show that 10% alcohol/90% gasoline may be used in engines designed for gasoline without modifications, and this pertains to methanol, ethanol, isopropanol, and butanol.

Gasoline blends up to 50/50 with any of these alcohols may be used if easy modifications like carburetor adjustment and ignition timing are made to the IC engines designed for pure gasoline; however, a spark-ignition engine designed to use gasoline must be modified to use pure alcohol. Changes required for methanol, ethanol, isopropanol, and butanol use are technically similar, but the fuels cannot be used interchangeably without carburetor adjustment. The basic engine changes include increasing the compression ratio, enlarging the carburetor jets, and adjusting the ignition timing.

Since the experiment was performed on a stationary engine and under laboratory conditions, further research in the area of coldweather starting and operation is recommended. Also, instead of a stationary engine, an automobile should be used for the experiment. Different operating conditions such as testing an automobile with various throttle positions, higher compression ratios etc. should be investigated.

Lastly, the duration of the engine test with each type of alcohol was only for a few hours and it is not possible from these tests to predict the long-term ability of the engine materials to withstand the corrosive characteristics of alcohols for longer periods. Further study is recommended in this area also.

A nationwide program of alcohol-fuel production could have favorable direct and indirect consequences for the country. Some of the expected benefits that would result from a large-scale alcohol fuel program include an improvement in trade deficit, and decrease in foreign oil dependence, and a reduction in the rate of consumption of the world and national oil reserves.

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APPENDIX A

Calculations for determining heating values of gasoline and alcohol/gasoline blends:

a) Gasoline - 88 octane

A reference scale to measure SI knock has been established by arbitrarily selecting two primary reference fuels. Isooctane has been assigned an "octane rating" of 100 while heptane, has been assigned an "octane rating" of 0. The "octane rating" of any fuel is found by comparing its knock intensity with various mixtures of heptane and isooctane. For example, an octane rating of 88 assigned to gasoline means that the knock intensity in a standard engine and at standard conditions is equivalent to that of a mixture of 88 parts isooctane and 12 parts of heptane by volume. By using Table A-1 we can write for the heating value of 88 octane gasoline:

$$= \frac{(0.88 \text{ x sp. gr. of isooctane x higher heating value of isooctane, Btu/lb}) + (0.12 \text{ x sp. gr. of heptane x higher heating value of heptane Btu/lb})}{(0.88 \text{ x sp. gr. of isooctane}) + (0.12 \text{ x sp. gr. of heptane})}$$

$$= \frac{(0.88 \text{ x } 0.692 \text{ x } 20556 + (0.12 \text{ x } 0.684 \text{ x } 20668)}{(0.88 \text{ x } 0.692) + (0.12 \text{ x } 0.684)}$$

$$= \frac{118623.28}{5.767}$$

$$= 20569.3 \text{ Btu/lb}$$

This higher heating value of 88 octane gasoline is used to calculate other heating values of the different gasoline/alcohol blends.

b) Sample calculations for determining higher heating value of methanol and 88 octane gasoline blend.

Referring to Table A-1 we have a higher heating value of methanol as 9770 Btu/lb and specific gravity of 0.792. Therefore we

Table A-1

FORMULA	NAME	MOLE WEIGHT M	SPECIFIC GRAVITY	FREEZING TEMPERATURE, °F AT 1 ATM	BOILING TEMPERATURE °F AT 1 ATM	VAPOR PRESSURE PSIA AT 100°F	CONSTANT PRESSURE HIGHER HEATING VALUE AT 77°F BTU/LB
C_7H_{16}	Heptane	100.20	0.684	-131	209	1.62	20,668
C_8H_{18}	Isooctane	114.22	0.692	-161	211	1.72	20,556
CH_4O	Methanol	32.04	0.792	-144	149	4.55	9,770
C_2H_6O	Ethanol	46.06	0.785	-170	172	2.25	12,780
C_3H_8O	Isopropanol	60.08	0.749	-193	208	0.89	14,500
$C_4H_{10}O$	Butanol	74.10	0.805	-112	244	0.33	15,500

Properties of the paraffin and alcohol family members:

Source: Internal Combustion Engines by E. F. Obert (1968) can write higher heating value of 10:90 methanol-gasoline blend (volume basis)

$$= \frac{\text{(0.1 x sp. gr. methanol x higher heating value of) + methanol in Btu/ lb} \quad \text{+(0.9 x sp. gr. of 88 octane gasoline x higher heating value of gasoline Btu/lb)}}{\text{(0.1 x sp. gr. of methanol + 0.9 x sp. gr. of gasoline)}}$$

$$= \frac{(0.1 \times 0.792 \times 9{,}770 + (0.9 \times 0.691 \times 20569)}{(0.1 \times 0.792) + (0.9 \times 0.691)}$$

$$= \frac{13565.64}{0.7011} = 19349 \text{ Btu/lb.}$$

In the similar manner higher heating values of other alcohol/ gasoline blends were determined. These values are tabulated in Table A-2.

Table A-2

Higher heating values for gasoline, pure alcohol and alcohol/gasoline blends.

Name of the fuel	Percentage Alcohol	Percentage Gasoline	Higher heating value Btu/lb
Gasoline	0	100	20,569
Methanol	100	0	9,770
Methanol	50	50	14,801
Methanol	20	80	18,163
Methanol	10	90	19,349
Ethanol	100	0	12,780
Ethanol	50	50	16,426
Ethanol	10	90	19,696
Isopropanol	100	0	14,500
Isopropanol	50	50	17,314
Isopropanol	10	90	19,878
Butanol	100	0	15,500
Butanol	50	50	17,841
Butanol	10	90	19,988

Calculations for determining the compression ratio of the engine

a) Compression ratio of the engine with an original head.

Compression ratio as per equation 4.2 is equal to

$$CR = \frac{C_v + D_v}{C_v}$$

where D_v = the volume swept by the piston in one stroke and

C_v = the clearance volume and is the volume of the combustion chamber.

Since diameter (d) of the piston is $3\frac{9}{16}$ inches and stroke (h) is 4 inches the volume swept by the piston in one stroke will be

$$D_v = \pi d^2 h/4$$

$$= \frac{\pi \times (3\frac{9}{16})^2 \times 4}{4}$$

$$= 39.87 \text{ cubic inches.}$$

i) The clearance volume is comprised of two volumes, i) volume (C_1) in the cylinder block (volume between the surface of the piston when piston is in top dead center position and the top surface of the cylinder block).

ii) Volume (C_2) in the cylinder head where exhaust and intake valves are located.

Due to the unsymmetric design of the cylinder head and cylinder block combustion chambers, it was not possible to determine the total combustion chamber volume by measuring physical dimensions of the chamber. The chamber volume was therefore measured by filling with water through a flat glass plate. (See Figure 7 of the photograph of the plate, used to measure the volume of the combustion chamber).

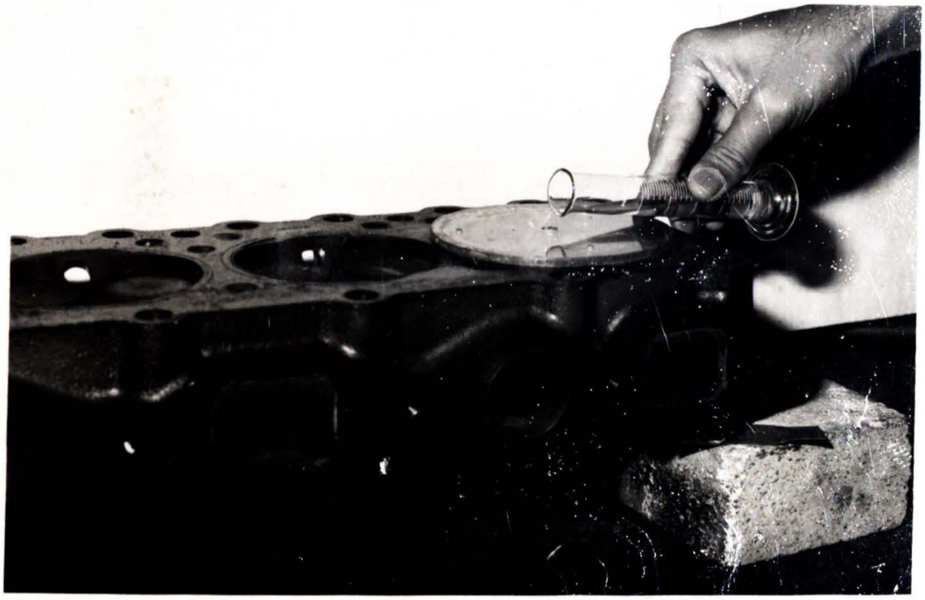


Figure 7: Measurement of combustion chamber volume of the cylinder head.

By using the plate as mentioned above, the surface between plate and cylinder head was sealed by means of grease. Then liquid was slowly poured in the chamber through the hole in the plate, until the combustion chamber in the cylinder head was completely filled. The total volume of the liquid required to fill the combustion chamber is equal to the volume of the combustion chamber C_2, in the cylinder head. The same procedure was repeated to determine the combustion chamber volume C_1, in the cylinder block.

The actual results showed that

$$C_1 = 50 \text{ ml}$$

$$C_2 = 63 \text{ ml}$$

Thus the total combustion chamber volume

$$C_v = C_1 + C_2 = 50 + 63 \text{ ml} = 113 \text{ ml}$$

Further by converting 113 ml to cubic inches we get

$$C_v = 6.90 \text{ cubic inches}$$

Thus the compression ratio of the engine with the original head equals:

$$CR = \frac{C_v + D_v}{C_v} = \frac{6.90 + 39.87}{6.90}$$

$$CR = 6.77$$

b) Compression ratio of the engine with the modified head:

Since the objective of the experiment was to increase the compression ratio of the engine and then to study the performance of the engine using pure alcohol and alcohol/gasoline blends, it was decided to increase the compression ratio of the engine by modifying the existing cylinder head. Although there are number of ways by which the compression ratio of the engine can be increased, the simplest and most economical way is to modify the cylinder head or in other words to reduce the volume of the combustion chamber in the cylinder head. This modification was achieved by removing 100/1000 of an inch of material by surface milling of the cylinder head. (See Figure 8 of the photograph of the cylinder head plane milling operation). The 100/1000 of a inch was the maximum possible amount which could be taken off from the cylinder head without weakening the cylinder head. (Although more material removal would have resulted in higher compression ratio, at the same time it would have resulted in very weak cylinder head sections).

After the cylinder head was modifed the volume of the combustion chamber in the cylinder head was measured and was found 46.5 ml. Thus there was a reduction of 16.5 ml volume in the combustion chamber of the cylinder head and the new total combustion chamber volume of the engine with the modified cylinder head was equal to

$$\begin{aligned} C_v \text{ (new)} &= C_1 + C_2 \text{ (new)} \\ &= 50 + 46.5 \text{ ml} \\ &= 96.5 \text{ ml.} \end{aligned}$$

Converting 96.5 ml to cubic inches we get

$$C_v \text{ (new)} = 5.89 \text{ cubic inches.}$$

The compression ratio of the engine with the modified head equals to:

$$CR = \frac{C_v \text{ (new)} + D_v}{C_v \text{ (new)}} = \frac{5.89 + 39.87}{5.89} \text{ cubic inches}$$

$$CR \text{ (new)} = 7.76$$

Thus the compression ratio of the engine was increased by an approximate value of unity by modifying the existing cylinder head.

Sample calculations for determining the performance factors of the engine:

For the sample calculations, data obtained using 10:90 mixture of methanol/gasoline and the compression ratio of 6.77 was used. Referring to Table No. 16 from Appendix B, a test shows that when engine speed (N) was 1793 rpm, the dynamometer recorded a load (P) of 109.1 lbs. and 0.5 lbs of fuel was consumed in 66 seconds. By using the equation 4.2 as discussed in Chapter IV we can write

1) Torque = P x R

where P = dynamometer or scale reading lbs.

R = dynamometer constant = 1.33

Substituting values of P and R we get

$$\text{Torque} = T = PR$$

$$= 109.1 \times 1.33$$

$$= 145.10 \text{ ft-lbs.}$$

2) Brake Horse Power: (bhp)

By using equation 4.1 we can write

$$\text{bhp} = \frac{2\pi \times 1793 \times 145.10}{33000} = 49.53$$

3) Brake specific fuel consumption (bsfc) by using equation 4.4 we can write

$$\text{bsfc} = \frac{3600 \times m}{t \times \text{bhp}}$$

where m = mass of fuel in lbs consumed in t seconds.

Substituting the values of m, t and bhp we get,

$$\text{bsfc} = \frac{3600 \times 0.5}{66 \times 49.53} = 0.5506 \text{ lbs/bhp-hr}$$

4) Thermal efficiency:

Using equation 4.6 we can write

$$\text{Thermal efficiency} = \frac{2545}{\text{bsfc x Q}} \text{ x } 100$$

where Q = Higher heating value of the fuel in Btu/lb

bsfc = Brake specific fuel consumption in lbs/bhp-hr.

Substituting the value of bsfc and the Q value of the 10:90 mixture of methanol/gasoline, from Table A-2 we get

Q = 19,349 Btu/lb.

$$\text{Thermal efficiency} = \frac{2545}{0.5506 \text{ x } 19,349} \text{ x } 100 = 23.88\%$$

b) Theoretical thermal efficiency:

Using equation 4.7 we can write theoretical thermal efficiency

$$\eta_t = 1 - \frac{1}{\xi_v^{\,k-1}}$$

where ξ_v is the expansion ratio which is also the compression ratio (CR) and k is the ratio of specific heats of the ideal gas. In this experiment since the ideal gas is air, value of k becomes 1.4. Substituting the values of k and CR we get theoretical thermal efficiency

$$= 1 - \frac{1}{\xi_v^{\,k-1}}$$

$$= 1 - \frac{1}{6.77^{1.4-1}}$$

$$= 1 - \frac{1}{2.1489}$$

$$= 1 - 0.4653 = 0.5346 \text{ or}$$

$$= 53.46\%$$

In a similar manner, theoretical thermal efficiency of the engine with the modified cylinder head and compression ratio of 7.76 would be 55.93%.

By using the equations as discussed in Chapter IV and the sample calculations as discussed above, the test data for various pure alcohols and alcohol/gasoline blends were analyzed and results are tabulated in the Appendix B.

APPENDIX B

TABLE NO. 1
TEST DATA

DATE: Feb. 21, 1981
TYPE OF ALCOHOL: None
COMPRESSION RATIO: 6.77
GASOLINE PERCENTAGE: 100
ALCOHOL PERCENTAGE: 0

ORSAT ANALYSIS AT 2700 RPM
CO_2 % 13.4
CO % 0.4
O_2 % 0
ENGINE TIMING: 42°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3000	74.5	0.5	52	99.08	56.59	0.6116	20.23	2.50
2798	82.0	0.5	54	109.06	58.10	0.5737	21.56	2.50
2598	92.6	0.3	32	123.15	60.92	0.5540	22.33	2.45
2400	99.6	0.3	33	132.46	60.53	0.5406	22.88	2.30
2200	107.2	0.3	35	142.57	59.72	0.5166	23.95	2.20
2001	112.0	0.3	38	148.96	56.75	0.5008	24.70	2.10
1800	116.1	0.3	41	154.41	52.92	0.4977	24.85	2.00
1600	118.1	0.3	46	157.07	47.85	0.4906	25.21	1.80
1401	121.2	0.3	50	161.19	42.99	0.5024	24.62	1.60
1192	120.8	0.3	56	160.66	36.46	0.5289	23.39	1.40
1002	119.6	0.3	65	159.06	30.34	0.5476	22.59	1.20

TABLE NO. 2
TEST DATA

DATE : March 13, 1981

TYPE OF ALCOHOL :Methyl

COMPRESSION RATIO : 6.77

GASOLINE PERCENTAGE : 90

ALCOHOL PERCENTAGE : 10

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 12.4

CO % 0.2

O_2 % 1.8

ENGINE TIMING: 44°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3011	72	0.3	29	95.76	54.89	0.6784	19.38	2.5
2803	84	0.3	28	111.72	59.62	0.6469	20.33	2.5
2598	90.20	0.3	29	119.96	59.34	0.6275	20.96	2.45
2400	95.40	0.3	32	126.88	57.97	0.5997	21.93	2.40
2201	99.70	0.3	33	132.60	55.56	0.5889	22.33	2.30
2000	103.80	0.3	36	138.05	52.57	0.5706	23.05	2.10
1800	108.20	0.3	39	143.90	49.31	0.5615	23.42	1.92
1607	108.60	0.3	44	144.43	44.19	0.5554	23.68	1.80
1401	111.20	0.3	48	147.89	39.45	0.5703	23.06	1.6
1205	113.40	0.2	35	150.82	34.60	0.5945	22.12	1.4
1009	114.70	0.2	39	152.55	29.30	0.6298	20.88	1.2

TABLE NO. 3
TEST DATA

DATE: March 14, 1981

TYPE OF ALCOHOL: Ethyl

COMPRESSION RATIO: 6.77

GASOLINE PERCENTAGE: 90

ALCOHOL PERCENTAGE: 10

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 14.4

CO % 0.2

O_2 % 0.2

ENGINE TIMING: 42°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2996	74.3	0.5	51	98.81	56.37	0.6260	20.64	2.50
2803	84.3	0.5	50	112.11	59.83	0.6016	21.47	2.50
2602	91.6	0.3	30	121.82	60.35	0.5964	21.66	2.45
2402	96.3	0.3	32	128.07	58.57	0.5761	22.43	2.40
2176	100.2	0.3	35	133.26	55.20	0.5589	23.11	2.30
2002	104.6	0.3	37	139.11	53.02	0.5504	23.47	2.20
1800	109.3	0.3	41	145.36	49.81	0.5287	24.43	2.00
1602	111.6	0.3	44	148.42	45.26	0.5423	23.82	1.80
1403	113.6	0.3	47	151.08	40.35	0.5694	22.69	1.60
1200	114.8	0.3	54	152.68	34.88	0.5733	22.53	1.40
1007	115.6	0.3	63	153.74	29.47	0.5816	22.21	1.20

TABLE NO. 4
TEST DATA

DATE; March 14, 1981

TYPE OF ALCOHOL: Isopropyl

COMPRESSION RATIO; 6.77

GASOLINE PERCENTAGE : 90

ALCOHOL PERCENTAGE : 10

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13.5

CO % 0.3

O_2 % 0.0

ENGINE TIMING: 46°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3006	74.8	0.5	53	99.48	56.93	0.5965	21.46	2.6
2825	84.3	0.5	52	112.11	60.30	0.5739	22.30	2.5
2606	92.1	0.3	32	122.49	60.77	0.5553	23.05	2.5
2406	96.2	0.3	35	127.94	58.61	0.5414	23.64	2.4
2192	103.0	0.3	35	136.99	57.17	0.5397	23.72	2.4
2005	106.3	0.3	38	141.37	53.97	0.5265	24.31	2.2
1800	112.8	0.3	41	150.02	51.41	0.5123	24.99	2.0
1617	113.8	0.3	46	151.34	46.59	0.5039	25.40	1.8
1392	115.0	0.3	52	152.95	40.53	0.5123	24.99	1.6
1181	117.2	0.3	57	155.87	35.10	0.5397	23.72	1.4
1000	119.2	0.3	65	158.53	30.18	0.5505	23.25	1.2

TABLE NO. 5
TEST DATA

DATE: March 18, 1981

TYPE OF ALCOHOL: Butyl

COMPRESSION RATIO: 6.77

GASOLINE PERCENTAGE 90

ALCOHOL PERCENTAGE 10

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 14.2

CO % 0.4

O_2 % 0

ENGINE TIMING: 45°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2988	77.2	0.5	51	102.67	58.41	0.6042	21.07	2.40
2814	85.4	0.5	52	113.58	60.85	0.5688	22.38	2.40
2599	94.10	0.5	53	125.15	61.93	0.5483	23.22	2.35
2366	97.3	0.5	58	129.40	58.29	0.5324	23.91	2.30
2193	104.0	0.5	60	138.32	57.75	0.5194	24.51	2.20
1972	107.90	0.5	62	143.50	53.88	0.5388	23.63	2.00
1800	113.10	0.5	68	150.42	51.55	0.5134	24.80	1.80
1575	114.8	0.3	45	152.68	45.78	0.5242	24.28	1.70
1403	115.6	0.3	49	153.74	41.07	0.5366	23.72	1.50
1194	117.6	0.3	56	156.40	35.55	0.5424	23.47	1.30
984	118.7	0.3	66	157.87	29.57	0.5533	23.01	1.20

TABLE NO. 6
TEST DATA

DATE: March 10, 1981	ORSAT ANALYSIS AT 2700 RPM
TYPE OF ALCOHOL: Methyl	CO_2 % 12.00
COMPRESSION RATIO: 6.77	CO % 0.10
GASOLINE PERCENTAGE: 80	O_2 % 0.60
ALCOHOL PERCENTAGE: 20	ENGINE TIMING: 44°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3021	73.3	0.5	45	97.48	56.07	0.7133	19.64	2.50
2802	83.7	0.5	46	111.32	59.38	0.6589	21.26	2.50
2589	89.9	0.3	28	119.56	58.93	0.6545	21.40	2.45
2400	94.6	0.3	30	125.81	57.49	0.6261	22.37	2.40
2204	98.2	0.3	31	130.60	54.80	0.6357	22.04	2.30
2000	101.6	0.3	34	135.12	51.45	0.6173	22.69	2.20
1806	106.7	0.3	37	141.91	48.79	0.5982	23.42	2.05
1670	108.8	0.3	40	144.70	46.01	0.5868	23.87	1.90
1406	113.3	0.2	30	150.68	40.33	0.5950	23.54	1.65
1199	112.6	0.2	33	149.75	34.18	0.6383	21.95	1.40
1007	111.3	0.2	38	148.02	28.38	0.6676	20.98	1.20

TABLE NO. 7
TEST DATA

DATE: Feb. 12, 1981

TYPE OF ALCOHOL: Methyl

COMPRESSION RATIO: 6.77

GASOLINE PERCENTAGE: 50

ALCOHOL PERCENTAGE: 50

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 11.8

CO % 0.1

O_2 % 0.3

ENGINE TIMING: 46°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2995	74.4	0.5	38	98.95	56.42	0.8395	20.48	2.40
2801	83.0	0.5	39	110.39	58.72	0.7859	21.87	2.40
2599	89.4	0.4	32	118.90	58.83	0.7649	22.47	2.35
2402	93.8	0.3	26	124.75	57.04	0.7282	23.61	2.30
2204	96.7	0.3	28	128.61	53.96	0.7148	24.05	2.20
2001	100.6	0.3	30	133.79	50.96	0.7064	24.34	2.05
1800	105.6	0.3	33	140.44	48.12	0.6801	25.28	1.90
1607	109.3	0.3	36	145.36	44.47	0.6746	25.48	1.65
1402	115.3	0.3	39	153.34	40.92	0.6767	25.40	1.50
1202	114.8	0.2	29	152.68	34.93	0.7107	24.19	1.30
1003	110.0	0.2	35	146.30	27.93	0.7365	23.34	1.10

TABLE NO. 8
TEST DATA

DATE : Feb. 10, 1981

TYPE OF ALCOHOL: Ethyl

COMPRESSION RATIO: 6.77

GASOLINE PERCENTAGE: 50

ALCOHOL PERCENTAGE: 50

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13.1

CO % 0.2

O_2 % 0.4

ENGINE TIMING: 44°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3004	74.4	0.5	40	98.95	56.58	0.7953	19.48	2.45
2799	83.3	0.5	41	110.78	59.03	0.7437	20.83	2.40
2602	90.1	0.5	42	119.83	59.36	0.7219	21.46	2.40
2401	94.8	0.3	27	126.08	57.63	0.6940	22.32	2.35
2204	98.5	0.3	29	131.00	54.96	0.6776	22.86	2.30
2002	102.5	0.3	31	136.32	51.95	0.6706	23.10	2.10
1801	106.1	0.3	34	141.11	48.38	0.6565	23.59	2.00
1602	109.2	0.3	38	145.23	44.29	0.6417	24.14	1.80
1399	111.6	0.3	41	148.42	39.53	0.6663	23.25	1.60
1201	110.2	0.2	31	146.56	33.51	0.6931	22.35	1.40
1006	108.3	0.2	37	144.03	27.58	0.7055	21.96	1.20

TABLE NO. 9
TEST DATA

DATE : Feb. 14, 1981

TYPE OF ALCOHOL : Isopropyl

COMPRESSION RATIO : 6.77

GASOLINE PERCENTAGE: 50

ALCOHOL PERCENTAGE: 50

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13.6

CO % 0.3

O_2 % 0.0

ENGINE TIMING: 44°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3002	71.2	0.5	44	94.69	54.12	0.7558	19.44	2.45
2801	81.6	0.5	44	108.52	57.87	0.7069	20.79	2.40
2599	91.1	0.5	45	121.16	59.94	0.6673	22.02	2.40
2406	95.3	0.5	47	126.74	58.05	0.6597	22.28	2.30
2197	102.1	0.5	49	135.79	56.79	0.6468	22.72	2.25
2000	104.8	0.5	52	139.38	53.07	0.6522	22.53	2.10
1803	111.3	0.5	56	148.02	50.81	0.6326	23.23	1.90
1600	112.6	0.5	64	149.75	45.61	0.6166	23.83	1.70
1406	116.1	0.5	69	154.67	41.40	0.6301	23.32	1.50
1200	118.1	0.5	75	157.07	35.88	0.6688	21.97	1.30
998	117.1	0.5	88	155.74	29.59	0.6912	21.26	1.15

TABLE NO. 10
TEST DATA

DATE: Feb. 14, 1981

TYPE OF ALCOHOL: Butyl

COMPRESSION RATIO: 6.77

GASOLINE PERCENTAGE: 50

ALCOHOL PERCENTAGE: 50

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13.8

CO % 0.2

O_2 % 0.1

ENGINE TIMING: 45°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3003	76.4	0.5	43	101.61	58.09	0.7206	19.79	2.40
2796	83.8	0.5	44	111.45	59.32	0.6896	20.68	2.40
2598	92.3	0.3	27	122.75	60.71	0.6588	21.65	2.35
2391	98.1	0.3	30	130.47	59.38	0.6062	23.53	2.35
2201	104.3	0.3	30	138.71	58.12	0.6194	23.02	2.20
2004	111.6	0.3	34	148.42	53.00	0.5993	23.80	2.10
1803	114.6	0.3	35	152.41	52.31	0.5898	24.18	1.90
1581	117.3	0.3	38	156.00	46.95	0.6053	23.56	1.70
1413	118.1	0.3	42	157.07	42.25	0.6086	23.43	1.50
1203	122.2	0.3	46	162.39	37.22	0.6307	22.61	1.30
985	117.3	0.3	56	156.00	29.25	0.6593	21.63	1.10

TABLE NO. 11
TEST DATA

DATE : Feb. 3, 1981
TYPE OF ALCOHOL : Methyl
COMPRESSION RATIO: 6.77
GASOLINE PERCENTAGE: 0
ALCOHOL PERCENTAGE 100

ORSAT ANALYSIS AT 2700 RPM
CO_2 % 9.8
CO % 0.1
O_2 % 1.3
ENGINE TIMING:

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3001	75.3	0.5	26	100.149	57.22	1.209	21.546	2.50
2801	82.1	0.5	27	109.193	58.23	1.144	22.770	2.45
2599	88.0	0.5	28	117.04	57.91	1.110	23.467	2.40
2410	92.3	0.5	30	122.75	56.32	1.065	24.459	2.32
2198	95.7	0.5	33	127.28	53.26	1.024	25.438	2.25
2000	99.3	0.5	36	132.06	50.29	0.994	26.206	2.10
1800	101.9	0.3	24	135.83	46.44	0.9689	26.885	1.95
1601	106.7	0.3	26	141.91	43.25	0.9604	27.123	1.60
1400	103.7	0.3	28	137.92	36.76	1.049	24.832	1.50
1203	101.2	0.2	22	134.50	30.82	1.061	24.551	1.15
1008	100.4	0.2	24	133.53	25.62	1.17	22.2642	1.00

TABLE NO. 12
TEST DATA

DATE: Feb. 3, 1981

TYPE OF ALCOHOL: Ethyl

COMPRESSION RATIO: 6.77

GASOLINE PERCENTAGE: 0

ALCOHOL PERCENTAGE: 100

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 12

CO % NIL

O_2 % 1.9

ENGINE TIMING: 46°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3002	75.6	0.5	27	100.54	57.46	1.160	17.167	2.60
2806	83.1	0.5	29	110.52	59.04	1.05	18.965	2.50
2594	88.7	0.5	31	117.97	58.25	0.9968	19.97	2.49
2410	94.2	0.5	32	125.28	57.48	0.9786	20.24	2.40
2207	97.3	0.5	35	129.40	54.37	0.9458	21.05	2.30
2000	101.0	0.3	24	134.33	51.14	0.8799	22.63	2.20
1802	103.6	0.3	26	137.78	47.26	0.8789	22.65	2.00
1600	107.9	0.3	29	143.50	43.71	0.8520	23.37	1.80
1400	104.4	0.3	33	138.85	37.00	0.8845	22.51	1.70
1203	103.2	0.2	25	137.25	31.43	0.9163	21.73	1.40
1002	102.6	0.2	30	136.45	26.03	0.9219	21.60	1.20

TABLE NO. 13
TEST DATA

DATE: Feb. 5, 1981

TYPE OF ALCOHOL: Isopropyl

COMPRESSION RATIO: 6.77

GASOLINE PERCENTAGE: 0

ALCOHOL PERCENTAGE 100

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 11.8

CO % 0.2

O_2 % 0.2

ENGINE TIMING: 43°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3055	67.6	0.5	34	89.90	52.29	1.01	17.377	2.60
2798	79.9	0.5	33	106.26	56.61	0.9264	18.946	2.60
2600	90.4	0.5	33	120.23	59.52	0.9159	19.163	2.50
2400	95.0	0.5	35	126.35	57.73	0.8900	19.721	2.48
2198	99.9	0.5	38	132.86	55.60	0.8516	20.610	2.40
2000	104.4	0.3	24	138.85	52.87	0.8169	21.485	2.20
1800	108.2	0.3	28	143.90	49.31	0.7818	22.450	2.00
1600	109.3	0.3	33	145.36	44.28	0.7390	23.750	1.80
1401	107.8	0.2	26	143.37	38.24	0.7837	22.395	1.60
1200	111.9	0.2	26	148.82	34.00	0.814	21.562	1.40
1000	116.6	0.2	29	155.07	29.52	0.8410	20.870	1.25

TABLE NO. 14
TEST DATA

DATE; Feb. 7, 1981

TYPE OF ALCOHOL; Butyl

COMPRESSION RATIO; 6.77

GASOLINE PERCENTAGE; 0

ALCOHOL PERCENTAGE; 100

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 14.2

CO % 0.2

O_2 % 0.0

ENGINE TIMING: 42°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2998	73.6	0.5	35	97.88	55.87	0.9205	17.837	2.50
2807	83.5	0.5	35	111.05	59.35	0.866	18.959	2.40
2602	91.7	0.5	35	121.96	60.42	0.8511	19.291	2.40
2402	99.7	0.5	36	132.60	60.64	0.824	19.926	2.32
2203	106.9	0.5	38	142.17	59.63	0.7938	20.684	2.22
1999	110.9	0.3	24	147.49	56.13	0.802	20.473	2.05
1796	115.8	0.3	27	154.01	52.66	0.7588	21.638	1.90
1605	118.7	0.3	30	157.87	48.24	0.699	23.489	1.70
1400	119.4	0.2	23	158.80	42.33	0.7393	22.209	1.50
1197	121.2	0.2	26	161.55	36.73	0.7532	21.799	1.30
997	122.1	0.2	30	162.39	30.82	0.7784	21.093	1.20

TABLE NO. 15
TEST DATA

DATE: Oct. 15, 1980
TYPE OF ALCOHOL:
COMPRESSION RATIO: 7.76
GASOLINE PERCENTAGE: 100
ALCOHOL PERCENTAGE: 0

ORSAT ANALYSIS AT 2700 RPM
CO_2 % 13.2
CO % 0.3
O_2 % 0.1
ENGINE TIMING: 35°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3000	78.2	0.5	50	104.00	59.40	0.6060	20.41	2.50
2801	87	0.5	52	115.71	61.70	0.5610	22.05	2.50
2592	94.5	0.5	53	125.68	62.02	0.5476	22.59	2.45
2401	100.2	0.5	55	133.26	60.92	0.5372	23.03	2.40
2206	108.5	0.5	57	144.30	60.60	0.5211	23.74	2.30
1990	114.8	0.5	60	152.68	57.85	0.5185	23.86	2.15
1800	120.0	0.5	66	159.60	54.69	0.4986	24.81	1.95
1578	122.6	0.5	76	163.05	48.99	0.4834	25.59	1.90
1402	125.10	0.5	82	166.38	44.41	0.4942	25.03	1.60
1200	123.00	0.3	56	163.59	37.37	0.5160	23.97	1.40
1000	122.20	0.2	44	162.52	30.94	0.5288	23.39	1.20

TABLE NO. 16
TEST DATA

DATE: Oct. 17, 1980

TYPE OF ALCOHOL: Methyl

COMPRESSION RATIO: 7.76

GASOLINE PERCENTAGE: 90

ALCOHOL PERCENTAGE: 10

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 14.75

CO % 0.3

O_2 % 0.0

ENGINE TIMING: 40°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3035	72.6	0.3	29	95.83	55.79	0.6675	19.70	2.60
2793	85.5	0.5	48	113.71	60.47	0.6201	21.21	2.55
2554	92.5	0.5	49	123.02	59.82	0.6140	21.42	2.40
2360	96.1	0.5	53	127.81	57.43	0.5913	22.24	2.30
2202	101.2	0.5	56	134.59	56.43	0.5696	23.09	2.20
2010	104.2	0.5	60	138.58	53.03	0.5657	23.25	2.00
1793	109.1	0.5	66	145.10	49.53	0.5506	23.88	1.80
1559	111.6	0.5	72	148.42	44.05	0.5675	23.17	1.60
1453	111.8	0.5	78	148.69	41.13	0.5610	23.44	1.50
1161	114.0	0.5	92	151.62	33.51	0.5838	22.53	1.30
1008	112.60	0.5	102	149.75	28.74	0.6140	21.42	1.10

TABLE NO. 17
TEST DATA

DATE: Oct. 10, 1980

TYPE OF ALCOHOL: Ethyl

COMPRESSION RATIO: 7.76

GASOLINE PERCENTAGE: 90

ALCOHOL PERCENTAGE 10

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 12.35

CO % 0.3

O_2 % 0.6

ENGINE TIMING: 38.5°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2986	74.9	0.3	31	99.61	56.63	0.6151	21.00	2.73
2781	86.1	0.3	30	114.51	60.63	0.5937	21.76	2.70
2627	91.9	0.3	29	122.22	61.13	0.5711	22.62	2.60
2439	96.5	0.2	21	128.34	59.60	0.5752	22.46	2.45
2221	100.1	0.3	35	133.13	56.29	0.5481	23.57	2.35
1955	106.1	0.3	39	141.11	52.53	0.5271	24.51	2.10
1790	110.6	0.3	42	147.09	50.13	0.5129	25.19	1.90
1554	114.2	0.2	30	151.88	44.94	0.5340	24.19	1.70
1406	115.3	0.2	31	153.33	41.05	0.5657	22.84	1.60
1219	114.9	0.2	36	152.81	35.46	0.5640	22.91	1.40
1031	113.6	0.2	42	151.08	29.65	0.5781	22.35	1.20

TABLE NO. 18
TEST DATA

DATE: Oct. 20, 1980

TYPE OF ALCOHOL: Isopropyl

COMPRESSION RATIO: 7.76

GASOLINE PERCENTAGE: 90

ALCOHOL PERCENTAGE: 10

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13.60

CO % 0.40

O_2 % 1.20

ENGINE TIMING: 36°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3065	74.5	0.5	52	99.08	57.82	0.5986	21.38	2.65
2825	84.5	0.5	50	112.38	60.44	0.5970	21.44	2.60
2615	93.0	0.5	53	123.69	61.58	0.5515	23.21	2.55
2429	96.5	0.3	34	128.34	59.35	0.5352	23.92	2.45
2147	103.9	0.3	37	138.18	56.48	0.5168	24.77	2.25
2014	107.2	0.2	26	142.57	54.67	0.5065	25.27	2.10
1855	113.1	0.3	41	150.42	53.12	0.4958	25.82	2.00
1663	114.2	0.3	44	151.88	48.09	0.5104	25.08	1.85
1380	115.6	0.3	53	153.74	40.39	0.5045	25.37	1.50
1217	114.8	0.3	58	152.68	35.37	0.5264	24.32	1.40
985	113.8	0.3	67	151.35	28.38	0.5679	22.54	1.15

TABLE NO. 19
TEST DATA

DATE: Oct. 22, 1980

TYPE OF ALCOHOL: Butyl

COMPRESSION RATIO: 7.76

GASOLINE PERCENTAGE: 90

ALCOHOL PERCENTAGE: 10

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13.4

CO % 0

O_2 % 0.7

ENGINE TIMING: 35°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2974	78.7	0.5	52	104.67	59.50	0,5817	21.88	2.50
2809	85.4	0.3	32	113.58	60.63	0.5565	22.87	2.50
2581	94.8	0.3	32	126.08	62.56	0.5394	23.60	2.49
2401	102.8	0.3	34	136.72	62.60	0.5073	25.09	2.40
2198	106.6	0.3	35	141.77	59.49	0.5185	24.55	2.30
2002	109.9	0.3	38	146.16	55.46	0.5123	24.85	2.10
1800	114.0	0.3	42	151.62	51.99	0.5065	25.13	1.90
1603	116.2	0,2	33	154.54	47.16	0.4914	25.91	1.80
1406	118.4	0.2	34	157.47	42.27	0.5008	25.42	1.60
1208	121.6	0.2	37	161.72	37.13	0.5233	24.33	1.40
1000	123.4	0.2	42	164.12	31.24	0.5486	23.20	1.20

TABLE NO. 20
TEST DATA

DATE: Nov. 3, 1980

TYPE OF ALCOHOL: Methyl

COMPRESSION RATIO: 7.76

GASOLINE PERCENTAGE: 50

ALCOHOL PERCENTAGE: 50

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13

CO % 0

O_2 % 2.8

ENGINE TIMING: 42°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2955	76.2	0.5	40	101.34	57.01	0.7893	21.78	2.68
2771	84.0	0.5	41	111.72	58.93	0.7449	23.08	2.60
2600	91.5	0.5	42	121.69	60.23	0.7114	24.16	2.60
2349	96.3	0.5	45	128.07	57.27	0.6984	24.61	2.45
2229	100.7	0.5	47	133.93	56.83	0.6739	25.51	2.35
2076	102.2	0.5	49	135.92	53.72	0.6838	25.14	2.25
1807	106.6	0.5	55	141.77	48.77	0.6710	25.62	2.00
1698	107.2	0.3	36	142.57	46.06	0.6513	26.39	1.90
1469	113.6	0.3	39	151.08	42.25	0.6554	26.23	1.65
1194	111.8	0.3	48	148.69	33.79	0.6658	25.82	1.40
978	110.6	0.3	58	147.10	27.38	0.6800	25.28	1.15

TABLE NO. 21
TEST DATA

DATE: Oct. 3, 1980

TYPE OF ALCOHOL: Ethyl

COMPRESSION RATIO: 7.76

GASOLINE PERCENTAGE: 50

ALCOHOL PERCENTAGE: 50

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13.6

CO % 0.1

O_2 % 1.3

ENGINE TIMING: 39°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3045	74.1	0.5	41	98.55	57.13	0.7684	20.16	2.60
2814	85.8	0.5	41	114.11	61.21	0.7172	21.60	2.58
2640	91.2	0.3	26	121.29	60.96	0.6814	22.73	2.55
2400	96.2	0.3	28	127.94	58.45	0.6599	23.47	2.45
2220	99.1	0.3	30	131.80	55.70	0.6463	23.97	2.30
2009	103.2	0.3	33	137.25	52.49	0.6234	24.85	2.15
1810	106.8	0.3	36	142.04	48.94	0.6129	25.27	2.00
1564	111.2	0.3	39	147.89	44.03	0.6289	24.63	1.70
1413	114.8	0.3	41	152.68	41.07	0.6413	24.15	1.55
1199	112.9	0.3	46	150.15	34.27	0.6850	22.61	1.35
1000	110.6	0.3	56	147.09	28.00	0.6887	22.49	1.10

TABLE NO. 22
TEST DATA

DATE: Oct. 31, 1980
TYPE OF ALCOHOL: Isopropyl
COMPRESSION RATIO: 7.76
GASOLINE PERCENTAGE: 50
ALCOHOL PERCENTAGE: 50

ORSAT ANALYSIS AT 2700 RPM
CO_2 % 13.4
CO % 0
O_2 % 0.7
ENGINE TIMING: 39°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2945	76.3	0.5	44	101.47	56.90	0.7189	20.44	2.60
2793	82.3	0.5	45	109.45	58.20	0.6872	21.38	2.55
2604	91.8	0.3	27	122.09	60.52	0.6609	22.24	2.50
2333	98.1	0.3	29	130.47	57.94	0.6427	22.87	2.40
2189	102.9	0.3	31	136.85	57.03	0.6108	24.06	2.25
1999	107.0	0.3	33	142.31	54.15	0.6043	24.32	2.15
1791	112.8	0.3	36	150.02	51.15	0.5865	25.06	2.00
1545	114.1	0.3	41	151.75	44.63	0.5902	24.90	1.85
1400	118.0	0.2	28	156.94	41.82	0.6148	23.90	1.60
1230	118.3	0.2	31	157.34	36.84	0.6304	23.31	1.35
1027	116.9	0.2	36	155.47	30.39	0.6581	22.33	1.20

TABLE NO. 23
TEST DATA

DATE: Nov. 11, 1980

TYPE OF ALCOHOL: Butyl

COMPRESSION RATIO: 7.76

GASOLINE PERCENTAGE: 50

ALCOHOL PERCENTAGE: 50

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13.8

CO % 0.2

O_2 % 0

ENGINE TIMING: 38°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2989	76.5	0.3	26	101.74	57.85	0.7180	19.86	2.65
2747	87.5	0.3	26	116.37	60.81	0.6830	20.88	2.61
2589	92.7	0.3	27	123.29	60.72	0.6352	22.45	2.55
2383	99.2	0.3	29	131.93	59.80	0.6227	22.90	2.45
2208	104.6	0.3	31	139.11	58.47	0.5958	23.94	2.35
1974	112.2	0.3	33	149.22	56.07	0.5836	24.44	2.15
1809	115.1	0.3	36	153.08	52.72	0.5690	25.06	2.00
1638	118.0	0.3	40	156.94	48.93	0.5518	25.85	1.85
1385	119.2	0.2	30	158.53	41.80	0.5741	24.84	1.55
1211	117.8	0.2	33	156.67	36.12	0.6040	23.61	1.40
1003	116.8	0.2	38	155.34	29.66	0.6388	22.33	1.15

TABLE NO. 24
TEST DATA

DATE: Nov. 12, 1980
TYPE OF ALCOHOL: Methyl
COMPRESSION RATIO: 7.76
GASOLINE PERCENTAGE: 0
ALCOHOL PERCENTAGE: 100

ORSAT ANALYSIS AT 2700 RPM
CO_2 % 13.8
CO % 0
O_2 % 1.2
ENGINE TIMING: 44°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3047	73.80	0.5	27	98.15	56.94	1.1708	22.26	2.55
2808	83.40	0.5	28	110.92	59.30	1.084	24.03	2.50
2627	88.10	0.5	29	117.17	58.60	1.059	24.59	2.45
2395	94.80	0.5	31	126.08	57.49	1.00	26.04	2.30
2209	98.5	0.5	33	131.00	55.04	0.9910	26.28	2.20
2001	101.5	0.5	36	134.99	51.43	0.9721	26.79	2.00
1829	103.5	0.4	32	137.65	47.89	0.9396	27.72	1.90
1605	109.1	0.4	36	145.10	44.34	0.9021	28.87	1.75
1403	105.0	0.3	33	139.65	37.27	0.9347	27.86	1.50
1208	102.5	0.3	35	136.32	31.35	0.9842	26.46	1.30
1020	101.2	0.3	40	134.59	26.13	1.033	25.21	1.10

TABLE NO. 25
TEST DATA

DATE: Oct. 6, 1980
TYPE OF ALCOHOL: Ethyl
COMPRESSION RATIO: 7.76
GASOLINE PERCENTAGE: 0
ALCOHOL PERCENTAGE: 100

ORSAT ANALYSIS AT 2700 RPM
CO_2 % 12.1
CO % 0
O_2 % 2.2
ENGINE TIMING: 42°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3034	76.5	0.5	28	101.74	58.72	1.094	18.20	2.65
2818	85.5	0.5	30	113.71	60.95	0.9844	20.22	2.60
2590	91.3	0.5	32	121.42	59.82	0.9403	21.17	2.45
2385	95.8	0.5	34	127.41	57.85	0.9151	21.76	2.35
2222	97.9	0.5	36	130.20	55.07	0.9079	21.93	2.20
2061	99.3	0.5	40	132.06	51.81	0.8685	22.92	2.10
1807	105.1	0.5	45	139.78	48.08	0.8319	23.93	1.90
1603	109.1	0.5	48	145.10	44.28	0.8468	23.51	1.65
1412	106.6	0.3	32	141.77	38.10	0.8858	22.48	1.55
1199	103.2	0.3	38	137.25	31.33	0.9071	21.95	1.40
1012	102.9	0.3	44	136.85	26.36	0.9311	21.38	1.30

TABLE NO. 26
TEST DATA

DATE: Nov. 14, 1980

TYPE OF ALCOHOL: Isopropyl

COMPRESSION RATIO: 7.76

GASOLINE PERCENTAGE: 0

ALCOHOL PERCENTAGE: 100

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 13.6

CO % 0.2

O_2 % 0.4

ENGINE TIMING: 39.5°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3042	71.1	0.5	33	94.56	54.77	0.9959	17.62	2.60
2813	80.0	0.5	34	106.40	59.93	0.8833	19.87	2.55
2608	92.5	0.5	33	123.02	61.03	0.8937	19.63	2.50
2414	97.6	0.5	35	129.80	59.65	0.8621	20.35	2.40
2189	104.2	0.5	38	138.58	57.76	0.8200	21.40	2.25
2034	107.1	0.5	42	142.44	55.15	0.7771	22.58	2.10
1785	112.2	0.5	50	149.22	50.67	0.7400	23.71	1.90
1579	112.7	0.5	56	149.89	45.02	0.7139	24.58	1.75
1410	113.6	0.3	36	151.08	40.52	0.7403	23.70	1.55
1210	115.2	0.3	39	153.21	35.29	0.7847	22.36	1.35
1016	117.0	0.3	44	155.61	30.09	0.8157	21.53	1.15

TABLE NO. 27
TEST DATA

DATE: Nov. 19, 1980
TYPE OF ALCOHOL; Butyl
COMPRESSION RATIO; 7.76
GASOLINE PERCENTAGE; 0
ALCOHOL PERCENTAGE 100

ORSAT ANALYSIS AT 2700 RPM
CO_2 % 13.8
CO % 0.2
O_2 % 0
ENGINE TIMING: 39°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3031	73.5	0.5	36	97.75	56.36	0.8871	18.50	2.60
2807	87.5	0.5	37	116.37	62.13	0.8271	19.85	2.60
2590	96.0	0.5	36	127.68	62.90	0.794	20.67	2.50
2416	99.3	0.5	38	132.06	60.69	0.780	21.05	2.40
2215	103.8	0.5	41	138.05	58.16	0.754	21.77	2.30
2020	111.1	0.5	44	147.76	56.82	0.7198	22.81	2.10
1811	115.9	0.5	48	154.14	53.14	0.7056	23.27	1.90
1589	116.3	0.3	34	154.67	46.79	0.6788	24.18	1.70
1407	114.0	0.3	36	151.62	40.61	0.7116	23.07	1.55
1174	118.2	0.3	40	157.20	35.13	0.7685	21.36	1.30
997	119.3	0.3	44	158.66	30.11	0.8151	20.14	1.15

TABLE NO. 28
TEST DATA *

DATE : March 12, 1981
TYPE OF ALCOHOL: Methyl
COMPRESSION RATIO: 6.77
GASOLINE PERCENTAGE: 90
ALCOHOL PERCENTAGE: 10

ORSAT ANALYSIS AT 2700 RPM
CO_2 % 12.8
CO % 0
O_2 % 0.6
ENGINE TIMING: 42°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
3010	70.9	0.3	29	94.29	54.04	0.6891	19.08	2.60
2851	79.2	0.3	29	105.33	57.17	0.6514	20.19	2.60
2583	86.9	0.3	30	115.57	56.84	0.6333	20.76	2.55
2403	91.1	0.3	32	121.16	55.43	0.6088	21.60	2.50
2225	94.3	0.3	34	125.41	53.13	0.5978	22.00	2.30
2003	100.0	0.3	36	133.00	50.72	0.5914	22.23	2.20
1807	103.1	0.3	40	137.12	47.17	0.5723	22.97	2.00
1626	104.9	0.3	45	139.51	43.19	0.5556	23.67	1.90
1405	106.2	0.3	48	141.24	37.78	0.5955	22.08	1.65
1214	106.0	0.3	53	140.98	32.58	0.6254	21.02	1.45
1007	105.4	0.3	60	140.18	26.87	0.6698	19.63	1.25

* Results with carburetion and timing unchanged from test using 100 percent gasoline.

TABLE NO. 29
TEST DATA *

DATE: March 12, 1981

TYPE OF ALCOHOL: Methyl

COMPRESSION RATIO: 6.77

GASOLINE PERCENTAGE: 80

ALCOHOL PERCENTAGE: 20

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 12.6

CO % 0.1

O_2 % 0.8

ENGINE TIMING: 42°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2987	68.8	0.5	46	91.50	52.04	0.7519	18.63	2.50
2806	77.5	0.5	46	103.07	55.06	0.7106	19.71	2.45
2593	83.6	0.3	29	111.18	54.89	0.6784	20.65	2.45
2402	87.3	0.3	31	116.10	53.10	0.6560	21.35	2.40
2200	91.0	0.3	33	121.03	50.69	0.6456	21.70	2.30
2002	94.1	0.3	36	125.15	47.70	0.6289	22.27	2.10
1807	99.3	0.3	39	132.06	45.43	0.6095	22.98	1.90
1593	104.4	0.3	43	138.85	42.11	0.5964	23.49	1.75
1398	106.1	0.3	46	141.11	37.56	0.6250	22.41	1.55
1205	104.3	0.2	35	138.71	31.82	0.6464	21.67	1.30
997	103.0	0.2	42	136.99	26.00	0.6593	21.25	1.15

* Results with carburetion and timing unchanged from test using 100 percent gasoline.

TABLE NO. 30
TEST DATA *

DATE: March 12, 1981

TYPE OF ALCOHOL: Methyl

COMPRESSION RATIO: 6.77

GASOLINE PERCENTAGE: 50

ALCOHOL PERCENTAGE: 50

ORSAT ANALYSIS AT 2700 RPM

CO_2 % 12.6

CO % 0

O_2 % 1.1

ENGINE TIMING: 42°

SPEED RPM	LOAD LBS.	FUEL CONSUMED LBS.	TIME SECS.	TORQUE FT-LBS.	B.H.P.	BSFC LBS/BHP-HR	THERMAL EFFICIENCY PERCENT	AIR FLOW METER INCHES OF WATER
2964	58.8	0.5	45	78.20	44.13	0.9064	18.96	2.50
2805	65.8	0.3	27	87.51	46.73	0.8559	20.08	2.50
2601	72.20	0.3	27	96.02	47.55	0.8412	20.43	2.50
2385	74.00	0.3	29	98.42	44.69	0.8333	20.63	2.45
2204	74.50	0.3	32	99.08	41.58	0.8116	21.18	2.40
2004	76.20	0.3	35	101.34	38.66	0.7981	21.54	2.25
1801	76.50	0.3	40	101.74	34.88	0.7740	22.21	1.95
1605	76.80	0.3	45	102.14	31.21	0.7689	22.36	1.85
1403	78.20	0.3	52	104.00	27.78	0.7476	22.99	1.70
1204	80.30	0.3	58	106.79	24.48	0.7606	22.60	1.50
1004	86.80	0.3	61	115.44	22.06	0.8025	21.42	1.20

* Results with carburetion and timing unchanged from test using 100 percent gasoline.

APPENDIX C

COMPUTER PROGRAM NO.1

PLOTS POWER OUTPUT OF METHANOL, ETHANOL, ISOPROPANOL, AND BUTANOL VS ENGINE SPEED. COMPRESSION RATIO OF THE ENGINE IS 6.77. SEE FIGURE D-1.

```
//      EXEC  FORTGCLG,OUT=0
//FORT.SYSIN DD *
       DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428),
      1DATAX3(11),DATAY3(11),DATAX4(11),DATAY4(11)
       READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
      1(DATAX2(J),DATAY2(J),J=1,11),(DATAX3(J),DATAY3(J),J=1,11),
      1(DATAX4(J),DATAY4(J),J=1,11)
4      FORMAT(F16.1,F16.2)
       CALL PLOTA(I,900.,3100.,0.,70.,1)
       CALL PLOTB(DATAX1,DATAY1,'M',11)
       CALL PLOTB(DATAX2,DATAY2,'E',11)
       CALL PLOTB(DATAX3,DATAY3,'I',11)
       CALL PLOTB(DATAX4,DATAY4,'B',11)
       CALL PLOTC('ENGINE SPEED VS BRAKEHORSEPOWER',32,
      1'BHP',3,'RPM',3)
       STOP
       END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.2

PLOTS POWER OUTPUT OF METHANOL, ETHANOL, ISOPROPANOL, AND BUTANOL VS ENGINE SPEED. COMPRESSION RATIO OF THE ENGINE IS 7.76. SEE FIGURE D-2.

```
//      EXEC  FORTGCLG,OUT=0
//FORT.SYSIN DD *
       DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428),
      1DATAX3(11),DATAY3(11),DATAX4(11),DATAY4(11)
       READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
      1(DATAX2(J),DATAY2(J),J=1,11),(DATAX3(J),DATAY3(J),J=1,11),
      1(DATAX4(J),DATAY4(J),J=1,11)
4      FORMAT(F16.1,F16.2)
       CALL PLOTA(I,900.,3100.,0.,70.,1)
       CALL PLOTB(DATAX1,DATAY1,'M',11)
       CALL PLOTB(DATAX2,DATAY2,'E',11)
       CALL PLOTB(DATAX3,DATAY3,'I',11)
       CALL PLOTB(DATAX4,DATAY4,'B',11)
       CALL PLOTC('ENGINE SPEED VS BRAKE HORSEPOWER',32,'BHP',3,'RPM',3)
       STOP
       END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

CCMPLTER PRCGRAM NC.3

PLOTS BSFC OF METHANCL, ETHANCL, ISCPRCPANCL, ANC BUTANOL VS ENGINE SPEED. CCMPRESSICN RATIC OF THE ENGINE IS 6.77. SEE FIGURE C-3.

```
//     EXEC   FCRTGCLG,CLT=0
//FORT.SYSIN CD *
       DIMENSION CATAX1(11),CATAY1(11),DATAX2(11),DATAY2(11),I(1428),
      1DATAX3(11),CATAY3(11),CATAX4(11),CATAY4(11)
       READ(5,4)(CATAX1(J),DATA Y1(J),J=1,11),
      1(DATAX2(J),CATAY2(J),J=1,11),(CATAX3(J),CATAY3(J),J=1,11),
      1(DATAX4(J),CATAY4(J),J=1,11)
4      FCRMAT(F16.1,F16.4)
       CALL PLCTA(I,900.,3100.,C.,2.,1)
       CALL PLCTB(CATAX1,CATAY1,'M',11)
       CALL PLCTB(CATAX2,CATAY2,'E',11)
       CALL PLCTB(CATAX3,CATAY3,'I',11)
       CALL PLCTB(DATAX4,CATAY4,'B',11)
       CALL PLCTC('ENGINE SPEEC VS BRAKE SPECIFIC FUEL CCNSLMPTION',48,
      1'BSFC LBS/BHP-HR',16,'RPM',3)
       STCP
       END
//GO.FT06F001 DC SYSCLT=(E,,NLIN)
//GO.SYSIN DC *
/*
```

CCMPUTER PRCGRAM NC.4

PLOTS BSFC CF METHANCL, ETHANCL, ISCPRCPANCL, ANC BUTANCL VS ENGINE SPEED. CCMPRESSICN RATIC OF THE ENGINE IS 7.76. SEE FIGURE C-4.

```
//     EXEC   FCRTGCLG,CLT=0
//FORT.SYSIN CC *
       DIMENSICN CATAX1(11),CATAY1(11),CATAX2(11),DATAY2(11),I(1423),
      1CATAX3(11),CATAY3(11),CATAX4(11),CATAY4(11)
       READ(5,4)(CATAX1(J),CATA Y1(J),J=1,11),
      1(DATAX2(J),CATAY2(J),J=1,11),(CATAX3(J),CATAY3(J),J=1,11),
      1(CATAX4(J),DATAY4(J),J=1,11)
4      FCRMAT(F16.1,F16.4)
       CALL PLCTA(I,900.,3100.,C.,2.,1)
       CALL PLCTB(CATAX1,CATAY1,'M',11)
       CALL PLCTB(CATAX2,CATAY2,'E'.11)
       CALL PLCTB(CATAX3,CATAY3,'I',11)
       CALL PLCTB(CATAX4,CATAY4,'B',11)
       CALL PLCTC('ENGINE SPEEC VS BRAKE SPECIFIC FUEL CCNSLMPTICN',48,
      1'BSFC LBS/BHP-HR',16,'RPM',3)
       STCP
       END
//GO.FT06F001 CC SYSCLT=(E,,NLIN)
//GO.SYSIN CC *
/*
```

COMPUTER PROGRAM NO.5

PLOTS BSFC OF 100 PERCENT METHANOL, AND METHANOL GASOLINE BLENDS OF 10-90 AND 50-50, VS ENGINE SPEED. COMPRESSION RATIO OF THE ENGINE IS 6.77. SEE FIGURE D-5.

```
//      EXEC FORTCLG,CUT=C
//FORT.SYSIN DD *
       DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428),
      1DATAX3(11),DATAY3(11)
       READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
      1(DATAX2(J),DATAY2(J),J=1,11),(DATAX3(J),DATAY3(J),J=1,11)
4      FORMAT(F16.1,F16.4)
       CALL PLOTA(I,900.,3100.,0.,2.,1)
       CALL PLOTB(DATAX1,DATAY1,'A',11)
       CALL PLOTB(DATAX2,DATAY2,'B',11)
       CALL PLOTB(DATAX3,DATAY3,'C',11)
       CALL PLOTC('ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION',48,
      1'BSFC LBS/BHP-HR',16,'RPM',3)
       STOP
       END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.6

PLOTS BSFC OF 100 PERCENT METHANOL, AND METHANOL GASOLINE BLENDS OF 10-90 AND 50-50, VS ENGINE SPEED. COMPRESSION RATIO OF THE ENGINE IS 7.76. SEE FIGURE D-6.

```
//      EXEC  FORTGCLG,CUT=0
//FORT.SYSIN DD *
       DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428),
      1DATAX3(11),DATAY3(11)
       READ(5,4)(DATAX1(J),DATA Y1(J),J=1.11),
      1(DATAX2(J),DATAY2(J),J=1.11),(DATAX3(J),DATAY3(J),J=1,11)
4      FORMAT(F16.1,F16.4)
       CALL PLOTA(I,900.,3100.,0.,2.,1)
       CALL PLOTB(DATAX1,DATAY1,'A',11)
       CALL PLOTB(DATAX2,DATAY2,'B',11)
       CALL PLOTB(DATAX3,DATAY3,'C',11)
       CALL PLOTC('ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION',48,
      1'BSFC LBS/BHP-HR',16,'RPM',3)
       STOP
       END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD*
/*
```

COMPUTER PROGRAM NO.7

PLOTS BSFC OF 100 PERCENT ETHANOL, AND ETHANOL GASOLINE BLENDS OF 10-90 AND 50-50, VS ENGINE SPEED. COMPRESSION RATIO OF THE ENGINE IS 6.77. SEE FIGURE C-7.

```
//     EXEC   FORTGCLG,OUT=D
//FORT.SYSIN DD *
       DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428),
      1DATAX3(11),DATAY3(11)
       READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
      1(DATAX2(J),DATAY2(J),J=1,11),(DATAX3(J),DATAY3(J),J=1,11)
4      FORMAT(F16.1,F16.4)
       CALL PLOTA(I,900.,3100.,0.,2.,1)
       CALL PLOTB(DATAX1,DATAY1,'A',11)
       CALL PLOTB(DATAX2,DATAY2,'B',11)
       CALL PLOTB(DATAX3,DATAY3,'C',11)
       CALL PLOTC('ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION',43,
      1'BSFC LBS/BHP-HR',16,'RPM',3)
       STOP
       END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.8

PLOTS BSFC OF 100 PERCENT ETHANOL, AND ETHANOL GASOLINE BLENDS OF 10-90 AND 50-50, VS ENGINE SPEED. COMPRESSION RATIO OF THE ENGINE IS 7.76. SEE FIGURE C-8.

```
//     EXEC   FORTGCLG,OUT=D
//FORT.SYSIN DD *
       DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428),
      1DATAX3(11),DATAY3(11)
       READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
      1(DATAX2(J),DATAY2(J),J=1,11),(DATAX3(J),DATAY3(J),J=1,11)
4      FORMAT(F16.1,F16.4)
       CALL PLOTA(I,900.,3100.,0.,2.,1)
       CALL PLOTB(DATAX1,DATAY1,'A',11)
       CALL PLOTB(DATAX2,DATAY2,'B',11)
       CALL PLOTB(DATAX3,DATAY3,'C',11)
       CALL PLOTC('ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION',48,
      1'BSFC LBS/BHP-HR',16,'RPM',3)
       STOP
       END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.9

PLOTS POWER OUTPUT OF 10-90 ETHANOL AND GASOLINE BLEND FOR THE COMPRESSION RATIOS OF 6.77 AND 7.76, VS ENGINE SPEED. SEE FIGURE D-9.

```
//      EXEC   FORTGCLG,CLT=D
//FORT.SYSIN DD *
        DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
        READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
       1(DATAX2(J),DATAY2(J),J=1,11)
 4      FORMAT(F16.1,F16.2)
        CALL PLOTA(I,900.,3100.,25.,70.,1)
        CALL PLOTB(DATAX1,DATAY1,'A',11)
        CALL PLOTB(DATAX2,DATAY2,'B',11)
        CALL PLOTC('ENGINE SPEED VS BRAKE HORSEPOWER',32,
       1'BHP',3,'RPM',3)
        STOP
        END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.10

PLOTS POWER OUTPUT OF 50-50 ETHANOL AND GASOLINE BLEND FOR THE COMPRESSION RATIOS OF 6.77 AND 7.76, VS ENGINE SPEED. SEE FIGURE D-10.

```
//      EXEC   FORTGCLG,CLT=D
//FORT.SYSIN DD *
        DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
        READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
       1(DATAX2(J),DATAY2(J),J=1,11)
 4      FORMAT(F16.1,F16.2)
        CALL PLOTA(I,900.,3100.,25.,70.,1)
        CALL PLOTB(DATAX1,DATAY1,'A',11)
        CALL PLOTB(DATAX2,DATAY2,'B',11)
        CALL PLOTC('ENGINE SPEED VS BRAKE HORSEPOWER',32,
       1'BHP',3,'RPM',3)
        STOP
        END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.11

PLOTS POWER OUTPUT OF 100 PERCENT ETHNOL AND 0 PERCENT GASOLINE, FOR THE COMPRESSION RATIOS OF 6.77 AND 7.76, VS ENGINE SPEED. SEE FIGURE C-11.

```
//      EXEC   FORTGCLG,OUT=D
//FORT.SYSIN DD *
        DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
        READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
       1(DATAX2(J),DATAY2(J),J=1,11)
 4      FORMAT(F16.1,F16.2)
        CALL PLOTA(I,900.,3100.,25.,70.,1)
        CALL PLOTB(DATAX1,DATAY1,'A',11)
        CALL PLOTB(DATAX2,DATAY2,'B',11)
        CALL PLOTC('ENGINE SPEED VS BRAKE HORSEPOWER',32,
       1'BHP',3,'RPM',3)
        STOP
        END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.12

PLOTS BSFC OF 10-90 ETHANOL GASOLINE BLEND, FOR THE COMPRESSION RATIOS OF 6.77 AND 7.76, VS ENGINE SPEED. SEE FIGURE C-12.

```
//      EXEC   FORTGCLG,OUT=D
//FORT.SYSIN DD *
        DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
        READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
       1(DATAX2(J),DATAY2(J),J=1,11)
 4      FORMAT(F15.1,F16.4)
        CALL PLOTA(I,900.,3100.,0.3,0.8,1)
        CALL PLOTB(DATAX1,DATAY1,'A',11)
        CALL PLOTB(DATAX2,DATAY2,'B',11)
        CALL PLOTC('ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION',48,
       1'BSFC LBS/BHP-HR',16,'RPM',3)
        STOP
        END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.13

PLOTS BSFC OF 50-50 ETHANOL GASOLINE BLEND, FOR THE COMPRESSION RATIOS OF 6.77 AND 7.76, VS ENGINE SPEED. SEE FIGURE D-13.

```
//      EXEC    FORTGCLG,OUT=0
//FORT.SYSIN DD *
        DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
        READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
       1(DATAX2(J),DATAY2(J),J=1,11)
4       FORMAT(F16.1,F16.4)
        CALL PLOTA(I,900.,3100.,0.4,0.9,1)
        CALL PLOTB(DATAX1,DATAY1,'A',11)
        CALL PLOTB(DATAX2,DATAY2,'B',11)
        CALL PLOTC('ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION',48,
       1'BSFC LBS/BHP-HR',16,'RPM',3)
        STOP
        END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.14

PLOTS BSFC OF 100-0 ETHANOL GASOLINE BLEND, FOR THE COMPRESSION RATIOS OF 6.77 AND 7.76, VS ENGINE SPEED. SEE FIGURE D-14.

```
//      EXEC    FORTGCLG,OUT=0
//FORT.SYSIN DD *
        DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
        READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
       1(DATAX2(J),DATAY2(J),J=1,11)
4       FORMAT(F16.1,F16.4)
        CALL PLOTA(I,900.,3100.,0.8,1.3,1)
        CALL PLOTB(DATAX1,DATAY1,'A',11)
        CALL PLOTB(DATAX2,DATAY2,'B',11)
        CALL PLOTC('ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION',48,
       1'BSFC LBS/BHP-HR',16,'RPM',3)
        STOP
        END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.15

PLOTS PERCENTAGE THERMAL EFFICIENCY OF METHANOL, ETHANOL, ISOPROPANOL, BUTANOL, AND GASOLINE, VS ENGINE SPEED. COMPRESSION RATIO=6.77. SEE FIGURE D-15.

```
//      EXEC    FORTGCLG,OUT=0
```

```
//FORT.SYSIN DD *
      DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428),
     1DATAX3(11),DATAY3(11),DATAX4(11),DATAY4(11),DATAX5(11),DATAY5(11)
      READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
     1(DATAX2(J),DATAY2(J),J=1,11),(DATAX3(J),DATAY3(J),J=1,11),
     1(DATAX4(J),DATAY4(J),J=1,11),(DATAX5(J),DATAY5(J),J=1,11)
4     FORMAT(F16.1,F16.2)
      CALL PLOTA(I,900.,3100.,10.,35.,1)
      CALL PLOTB(DATAX1,DATAY1,'M',11)
      CALL PLOTB(DATAX2,DATAY2,'E',11)
      CALL PLOTB(DATAX3,DATAY3,'I',11)
      CALL PLOTB(DATAX4,DATAY4,'B',11)
      CALL PLOTB(DATAX5,DATAY5,'G',11)
      CALL PLOTC('ENGINE SPEED VS THERMAL EFFICIENCY',36,
     1'THERMAL EFFICIENCY PERCENT',25,'RPM',3)
      STOP
      END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.16

PLOTS PERCENTAGE THERMAL EFFICIENCY OF 100 PERCENT METHANOL, FOR THE COMPRESSION RATIOS OF 6.77 AND 7.76, VS ENGINE SPEED. SEE FIGURE D-16.

```
//     EXEC   FORTGCLG,OUT=D
//FORT.SYSIN DD *
      DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
      READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
     1(DATAX2(J),DATAY2(J),J=1,11)
4     FORMAT(F16.1,F15.2)
      CALL PLOTA(I,900.,3100.,15.,30.,1)
      CALL PLOTB(DATAX1,DATAY1,'A',11)
      CALL PLOTB(DATAX2,DATAY2,'B',11)
      CALL PLOTC('ENGINE SPEED VS THERMAL EFFICIENCY',36,
     1'THERMAL EFFICIENCY PERCENT',26,'RPM',3)
      STOP
      END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.17

PLOTS PERCENTAGE THERMAL EFFICIENCY OF 100 PERCENT ETHANOL, FOR THE COMPRESSION RATIOS OF 6.77 AND 7.76, VS ENGINE SPEED. SEE FIGURE D-17.

```
//     EXEC   FORTGCLG,OUT=D
//FORT.SYSIN DD *
```

```
      DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
      READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
     1(DATAX2(J),DATAY2(J),J=1,11)
4     FORMAT(F16.1,F16.2)
      CALL PLOTA(I,900.,3100.,15.,30.,1)
      CALL PLOTB(DATAX1,DATAY1,'A',11)
      CALL PLOTB(DATAX2,DATAY2,'B',11)
      CALL PLOTC('ENGINE SPEED VS THERMAL EFFICIENCY',36,
     1'THERMAL EFFICIENCY PERCENT',26,'RPM',3)
      STOP
      END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.18

PLOTS POWER OUTPUT OF 10-90 METHANOL GASOLINE BLEND, FOR THE COMPRESSIO
RATIO OF 6.77, VS ENGINE SPEED, USING CHANGED AND UNCHANGED SETTING OF
THE ENGINE. SEE FIGURE D-18.

```
//      EXEC   FORTGCLG,OUT=D
//FORT.SYSIN DD *
      DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
      READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
     1(DATAX2(J),DATAY2(J),J=1,11)
4     FORMAT(F16.1,F16.2)
      CALL PLOTA(I,900.,3100.,25.,70.,1)
      CALL PLOTB(DATAX1,DATAY1,'A',11)
      CALL PLOTB(DATAX2,DATAY2,'B',11)
      CALL PLOTC('ENGINE SPEED VS BRAKE HORSEPOWER',32,
     1'BHP',3,'RPM',3)
      STOP
      END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.19

PLOTS POWER OUTPUT OF 20-80 METHANOL GASOLINE BLEND, FOR THE COMPRESSION
RATIO OF 6.77, VS ENGINE SPEED, USING CHANGED AND UNCHANGED SETTING OF
THE ENGINE. SEE FIGURE D-19.

```
//      EXEC   FORTGCLG,OUT=D
//FORT.SYSIN DD *
      DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
      READ(5,4)(DATAX1(J),DATA Y1(J).J=1,11),
     1(DATAX2(J),DATAY2(J),J=1,11)
```

```
4       FORMAT(F16.1,F16.2)
        CALL PLOTA(I,900.,3100.,25.,70.,1)
        CALL PLOTB(DATAX1,DATAY1,'A',11)
        CALL PLOTB(DATAX2,DATAY2,'B',11)
        CALL PLOTC('ENGINE SPEED VS BRAKE HORSEPOWER',32,
       1'BHP',3,'RPM',3)
        STOP
        END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

COMPUTER PROGRAM NO.20

PLOTS POWER OUTPUT OF 50-50 METHANOL GASOLINE BLEND, FOR THE COMPRESSION RATIO OF 6.77, VS ENGINE SPEED, USING CHANGED AND UNCHANGED SETTING OF THE ENGINE. SEE FIGURE C-20.

```
//      EXEC  FORTGCLG,OUT=D
//FORT.SYSIN DD *
        DIMENSION DATAX1(11),DATAY1(11),DATAX2(11),DATAY2(11),I(1428)
        READ(5,4)(DATAX1(J),DATA Y1(J),J=1,11),
       1(DATAX2(J),DATAY2(J),J=1,11)
4       FORMAT(F16.1,F16.2)
        CALL PLOTA(I,900.,3100.,20.,70.,1)
        CALL PLOTB(DATAX1,DATAY1,'A',11)
        CALL PLOTB(DATAX2,DATAY2,'B',11)
        CALL PLOTC('ENGINE SPEED VS BRAKE HORSEPOWER',32,
       1'BHP',3,'RPM',3)
        STOP
        END
//GO.FT06F001 DD SYSOUT=(E,,NLIN)
//GO.SYSIN DD *
/*
```

APPENDIX D

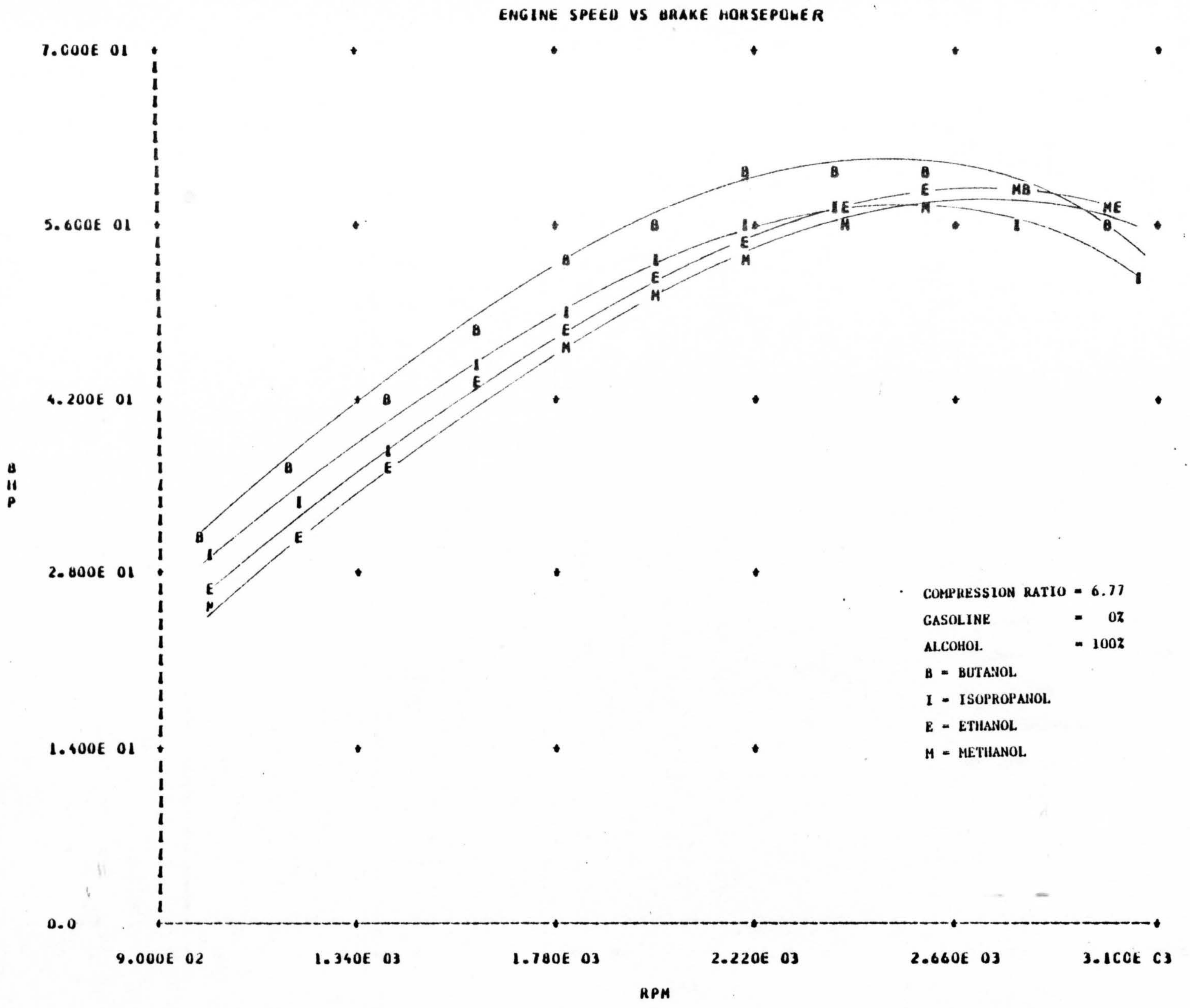

ENGINE SPEED VS BRAKE HORSEPOWER
7.000E 01
5.600E 01
4.200E 01
2.800E 01
1.400E 01
0.0
B
H
P
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
COMPRESSION RATIO = 6.77
GASOLINE = 0%
ALCOHOL = 100%
B = BUTANOL
I = ISOPROPANOL
E = ETHANOL
M = METHANOL

Figure D-1

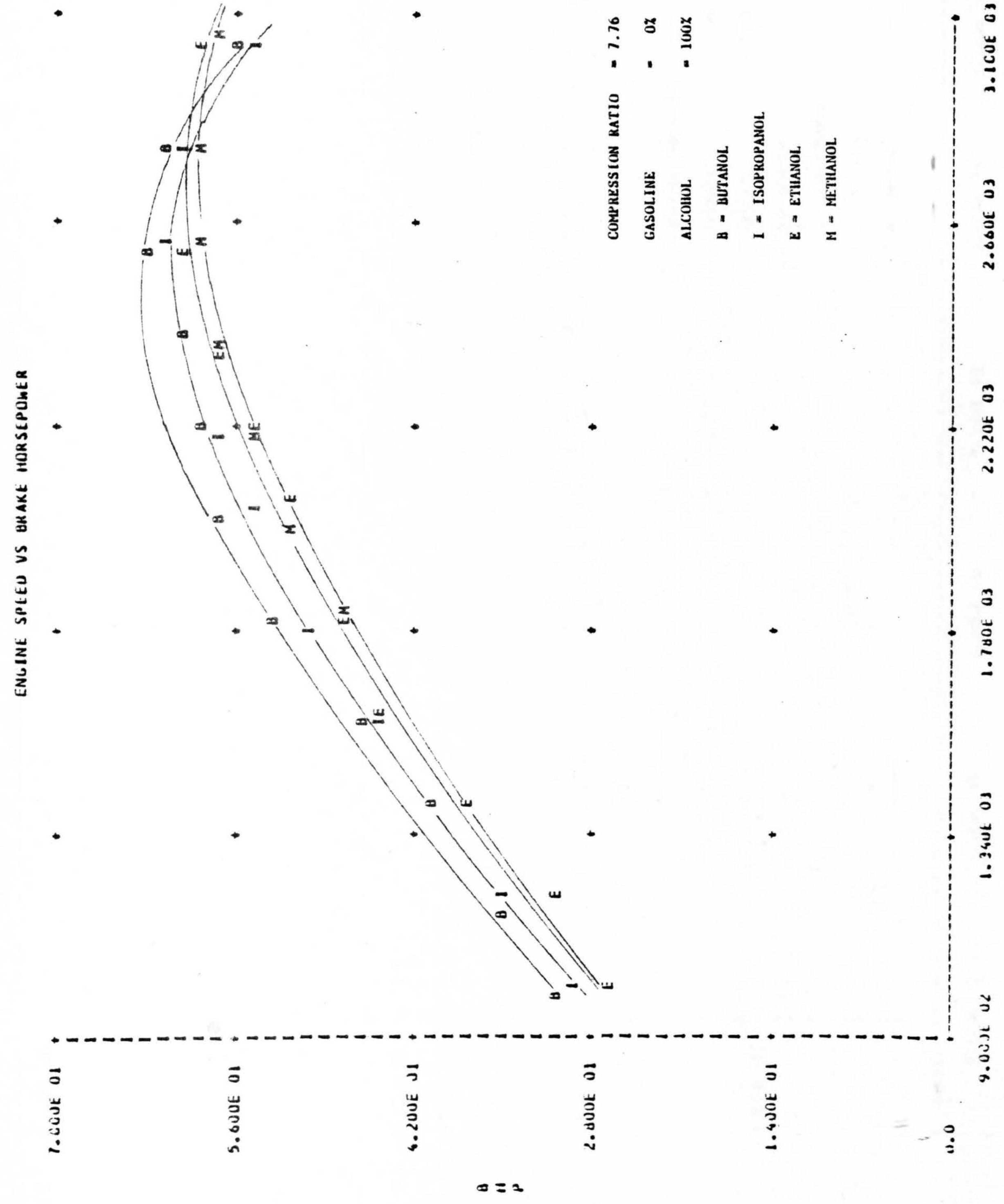

ENGINE SPEED VS BRAKE HORSEPOWER
BHP
7.000E 01
5.600E 01
4.200E 01
2.800E 01
1.400E 01
0.0
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
COMPRESSION RATIO = 7.76
GASOLINE = 0%
ALCOHOL = 100%
B = BUTANOL
I = ISOPROPANOL
E = ETHANOL
M = METHANOL

Figure D-2

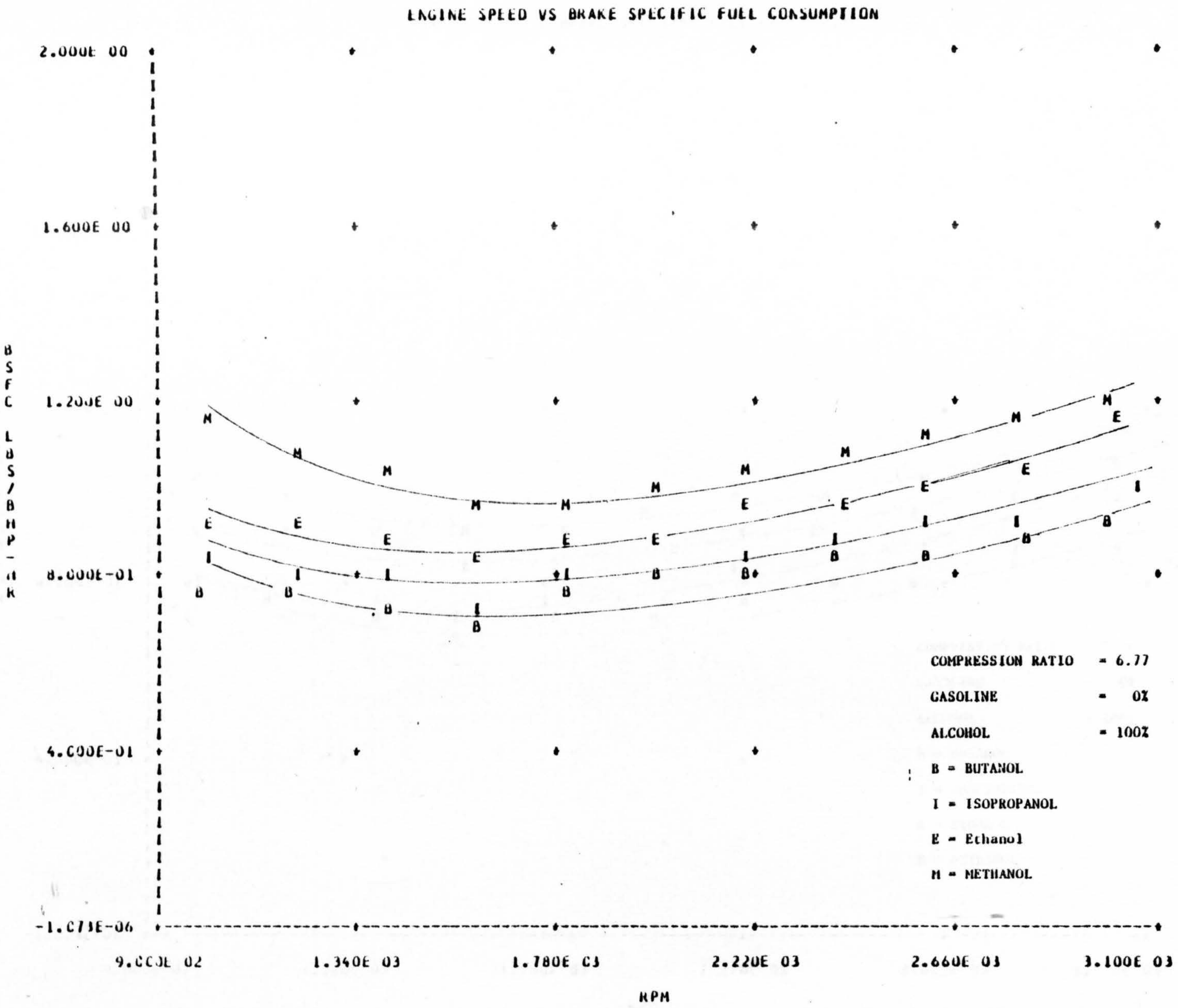

ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION
BSFC LBS/BHP-HR
2.000E 00
1.600E 00
1.200E 00
8.000E-01
4.000E-01
-1.073E-06
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
COMPRESSION RATIO = 6.77
GASOLINE = 0%
ALCOHOL = 100%
B = BUTANOL
I = ISOPROPANOL
E = Ethanol
M = METHANOL

Figure D-3

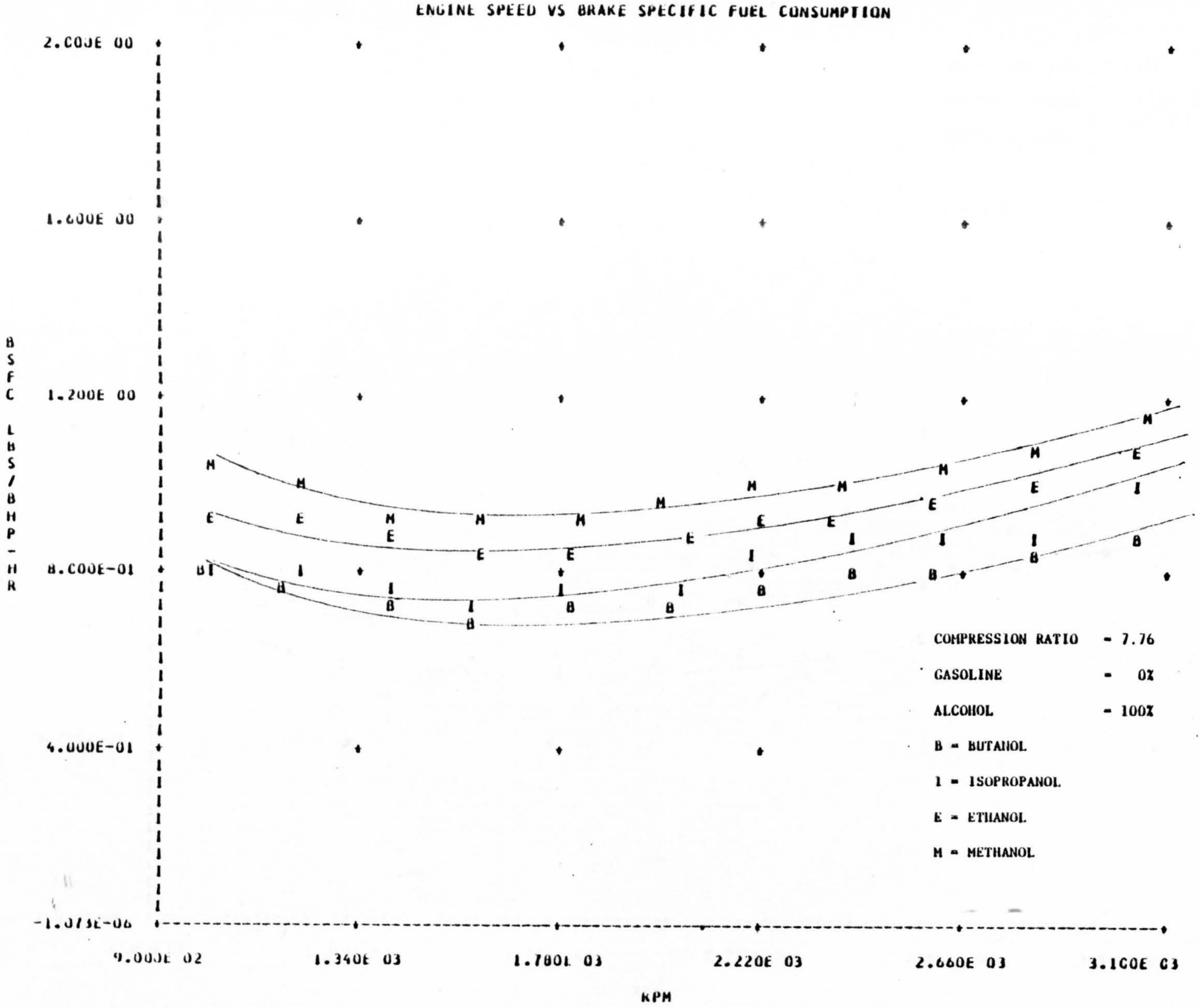

ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION
BSFC LBS/BHP-HR
2.000E 00
1.600E 00
1.200E 00
8.000E-01
4.000E-01
-1.073E-06
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
COMPRESSION RATIO - 7.76
GASOLINE - 0%
ALCOHOL - 100%
B = BUTANOL
I = ISOPROPANOL
E = ETHANOL
M = METHANOL

Figure D-4

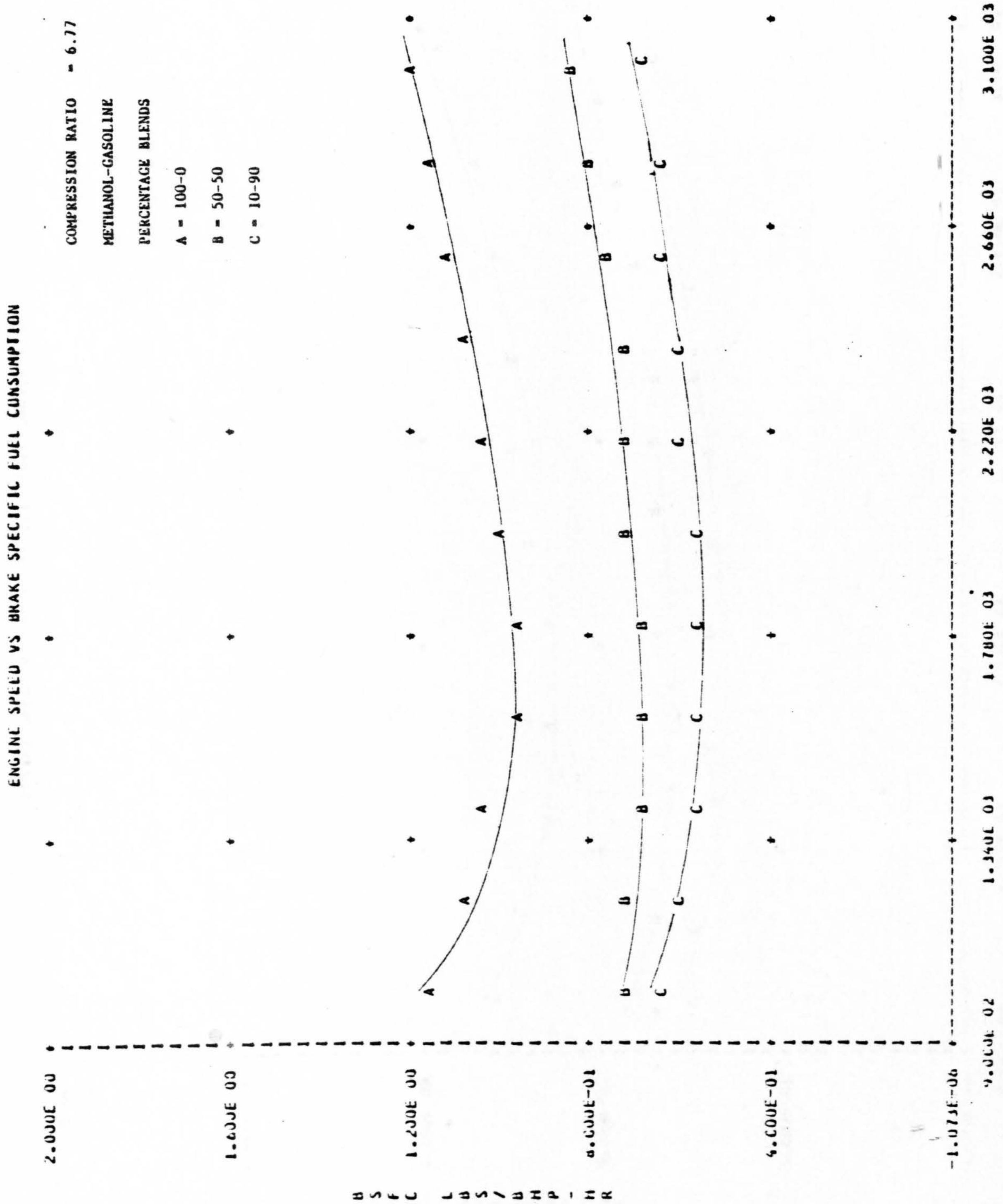

ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION
COMPRESSION RATIO = 6.77
METHANOL-GASOLINE
PERCENTAGE BLENDS
A = 100-0
B = 50-50
C = 10-90
2.000E 00
1.600E 00
1.200E 00
8.000E-01
4.000E-01
-1.073E-06
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
BSFC LBS/BHP-HR

Figure D-5

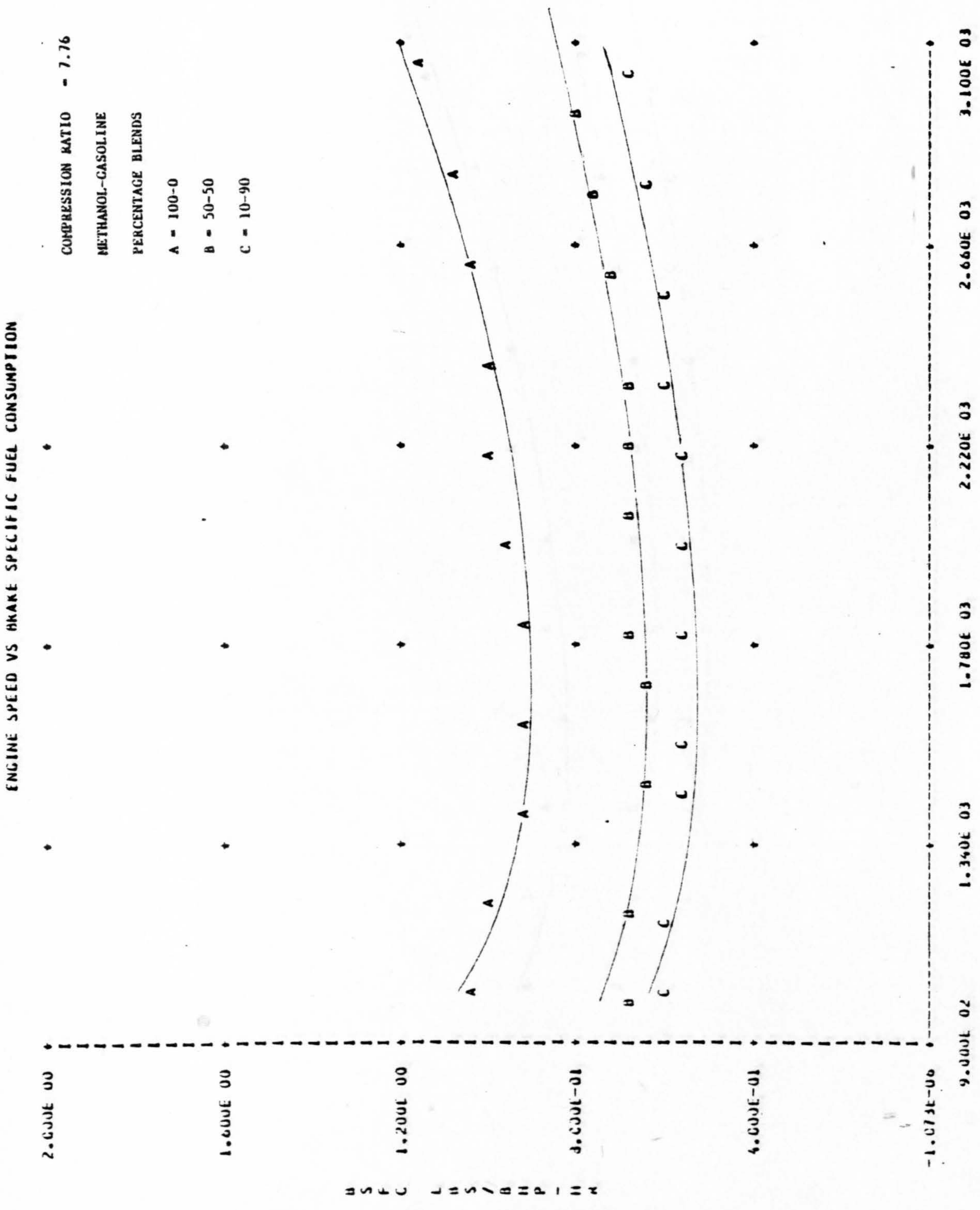

ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION
COMPRESSION RATIO - 7.76
METHANOL-GASOLINE
PERCENTAGE BLENDS
A = 100-0
B = 50-50
C = 10-90
2.000E 00
1.600E 00
1.200E 00
8.000E-01
4.000E-01
-1.073E-06
BSFC LBS/BHP-HR
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
A
B
C

Figure D-6

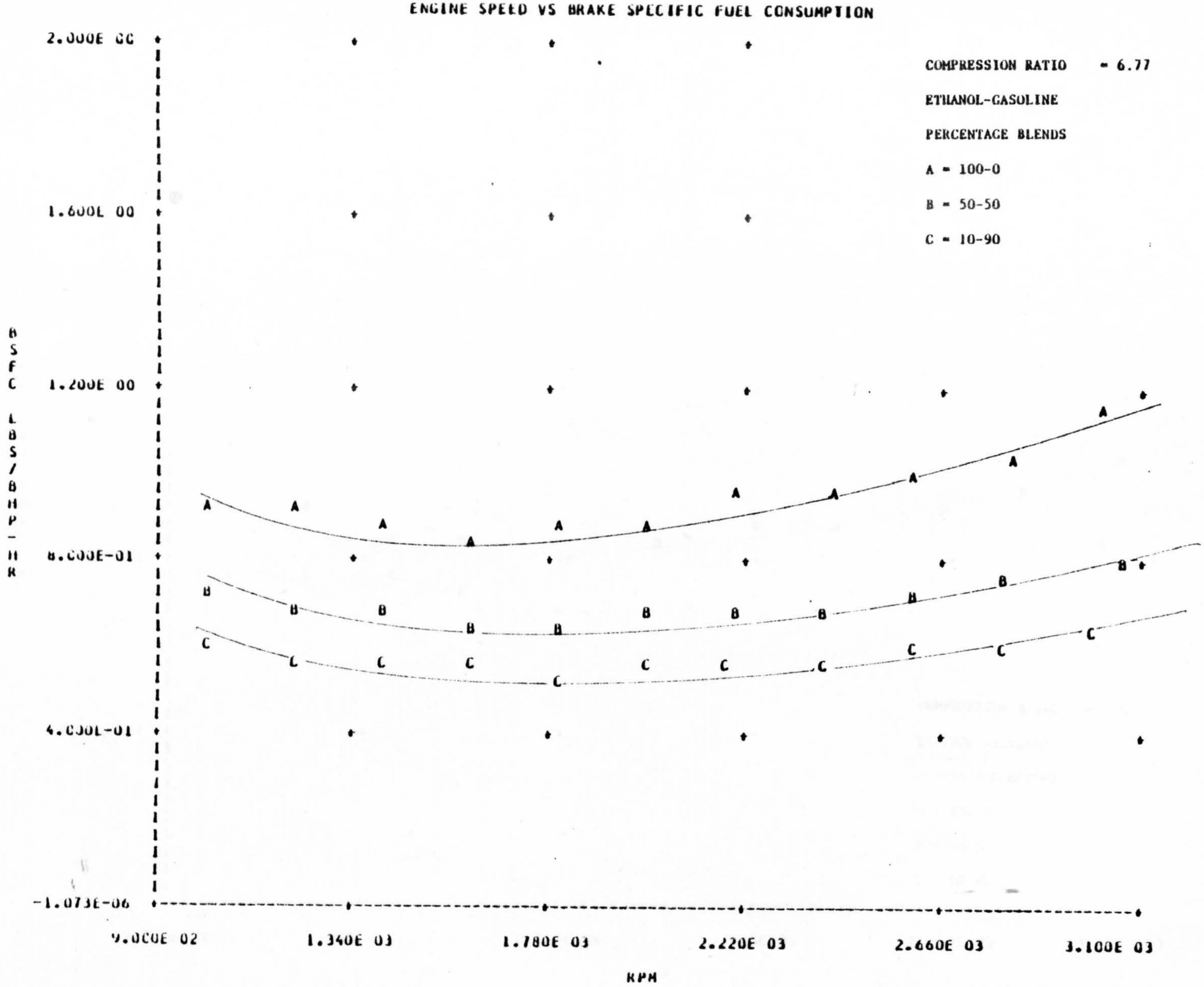

ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION
COMPRESSION RATIO = 6.77
ETHANOL-GASOLINE
PERCENTAGE BLENDS
A = 100-0
B = 50-50
C = 10-90
BSFC LBS/BHP-HR
2.000E 00
1.600E 00
1.200E 00
8.000E-01
4.000E-01
-1.073E-06
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM

Figure D-7

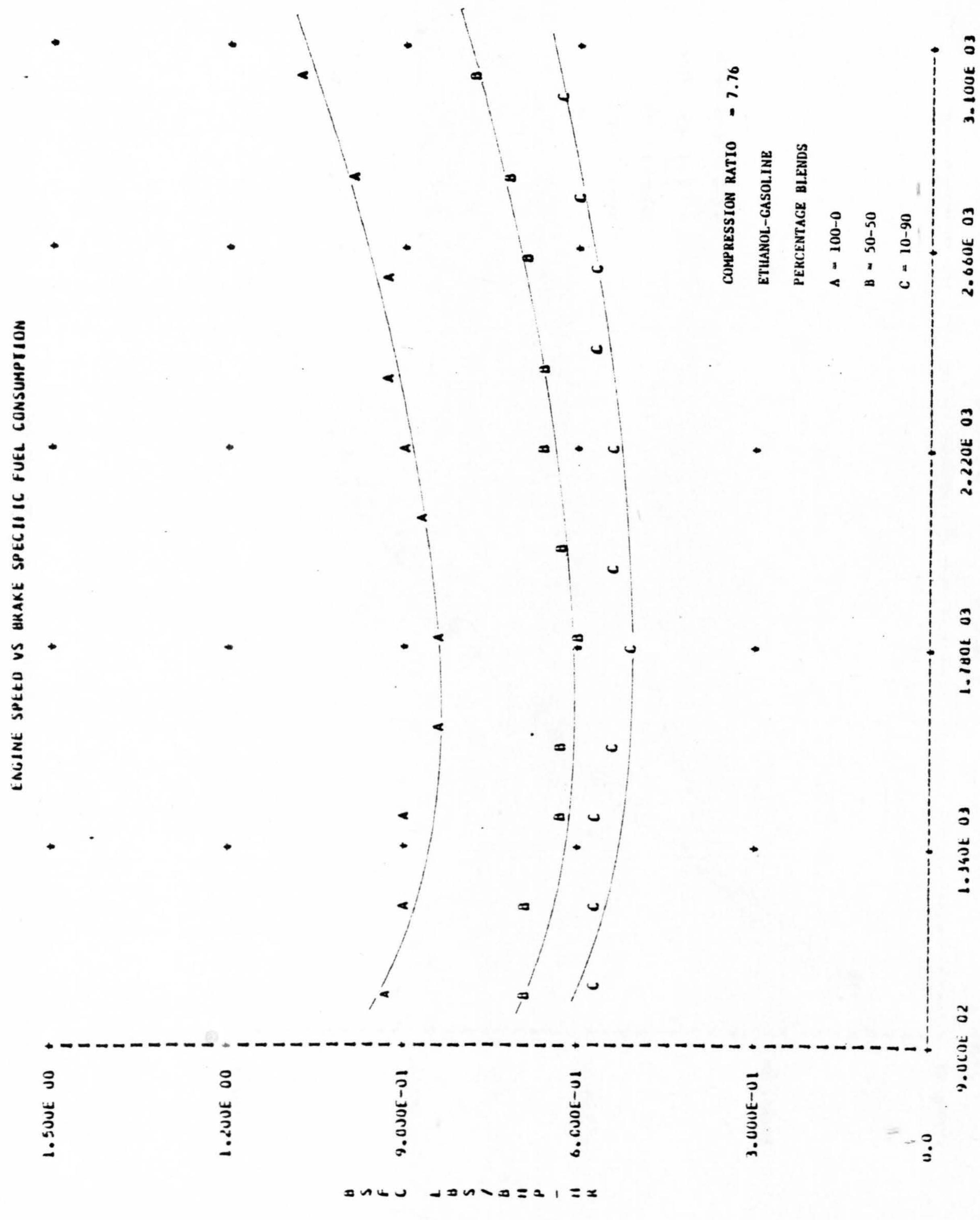

ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION
1.500E 00
1.200E 00
9.000E-01
6.000E-01
3.000E-01
0.0
BSFC LBS/BHP-HR
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
COMPRESSION RATIO = 7.76
ETHANOL-GASOLINE
PERCENTACE BLENDS
A = 100-0
B = 50-50
C = 10-90

Figure D-8

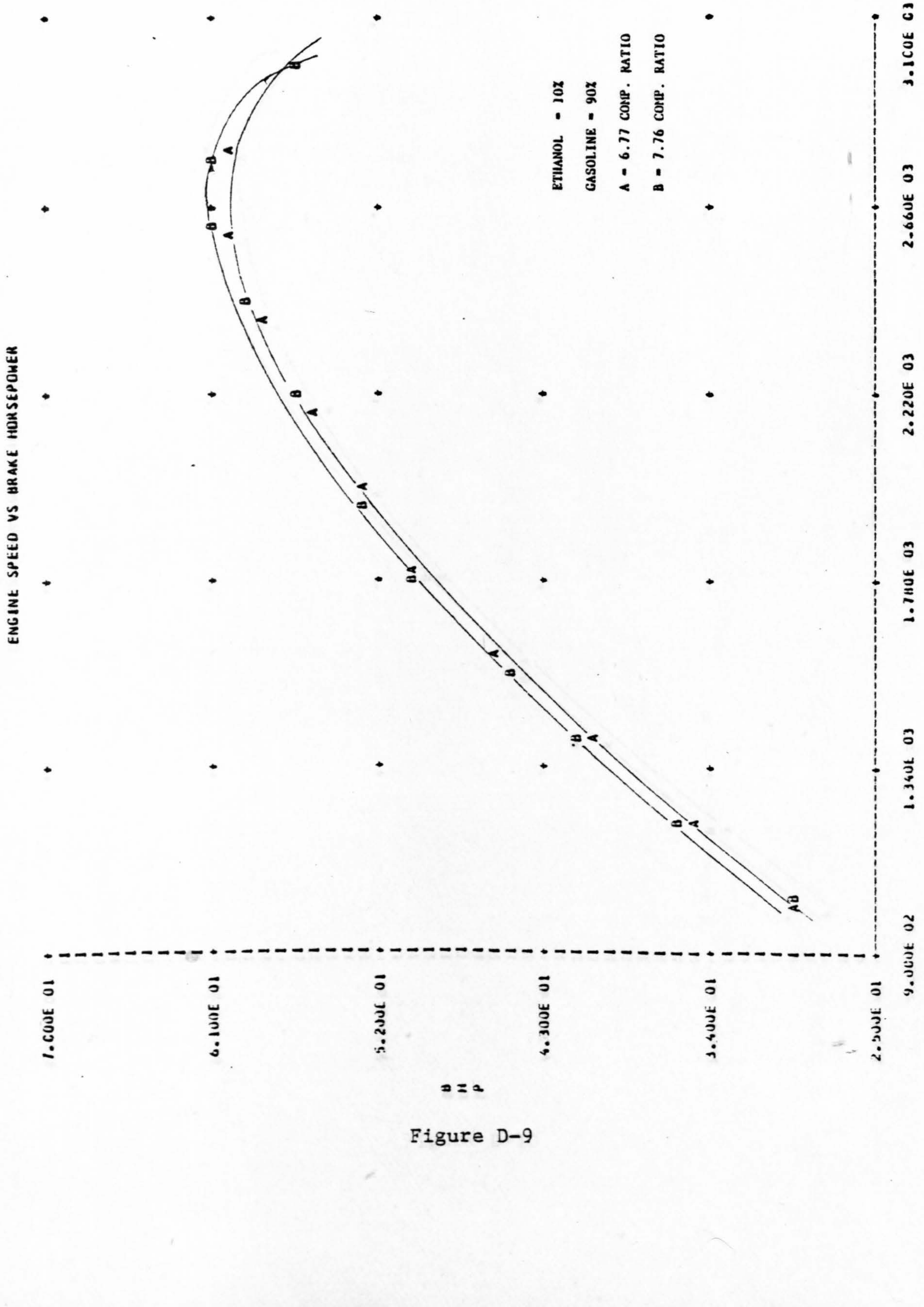

ENGINE SPEED VS BRAKE HORSEPOWER
BHP
7.000E 01
6.100E 01
5.200E 01
4.300E 01
3.400E 01
2.500E 01
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
ETHANOL - 10%
GASOLINE - 90%
A - 6.77 COMP. RATIO
B - 7.76 COMP. RATIO

Figure D-9

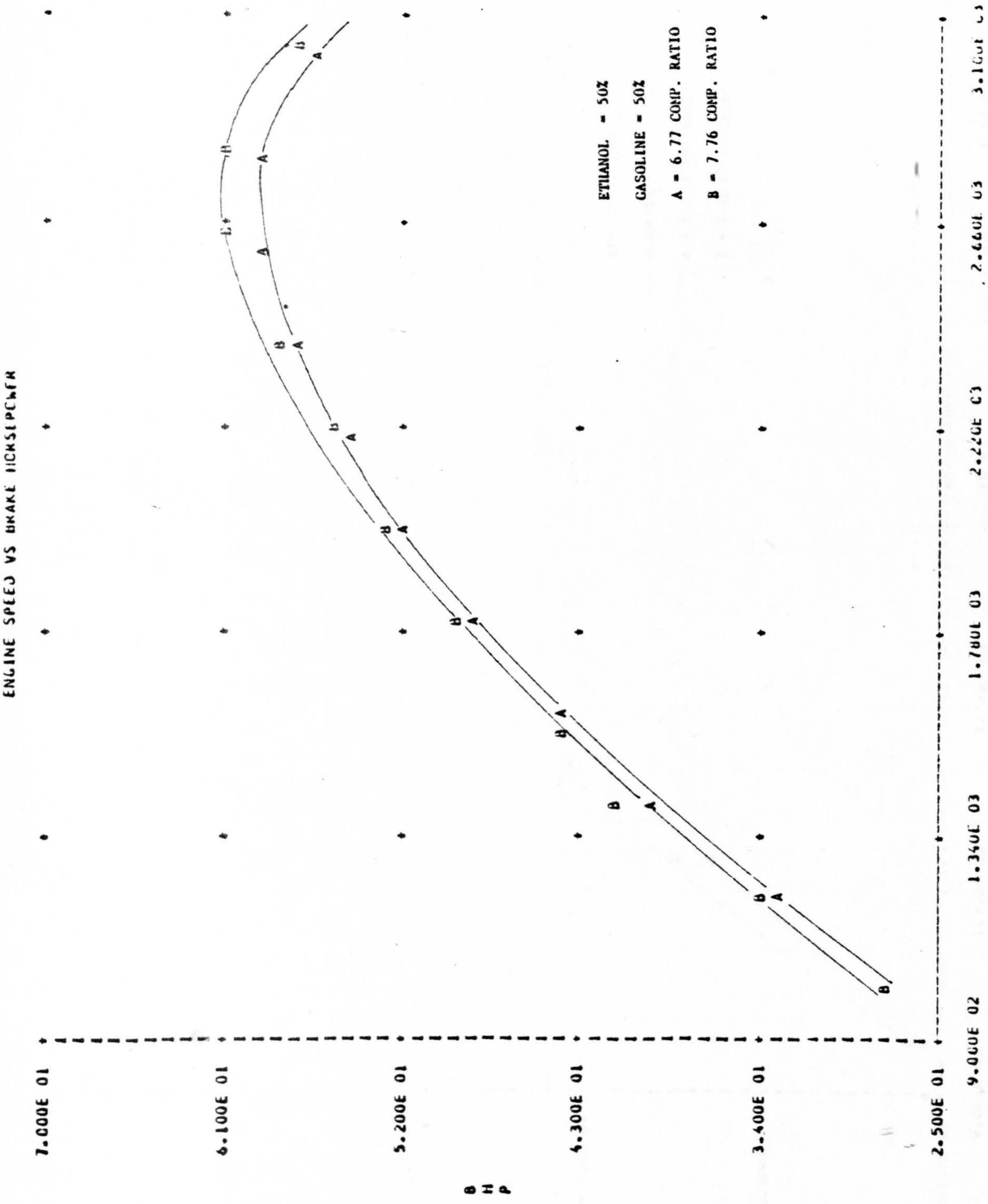

ENGINE SPEED VS BRAKE HORSEPOWER
B H P
7.000E 01
6.100E 01
5.200E 01
4.300E 01
3.400E 01
2.500E 01
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
ETHANOL = 50%
GASOLINE = 50%
A = 6.77 COMP. RATIO
B = 7.76 COMP. RATIO

Figure D-10

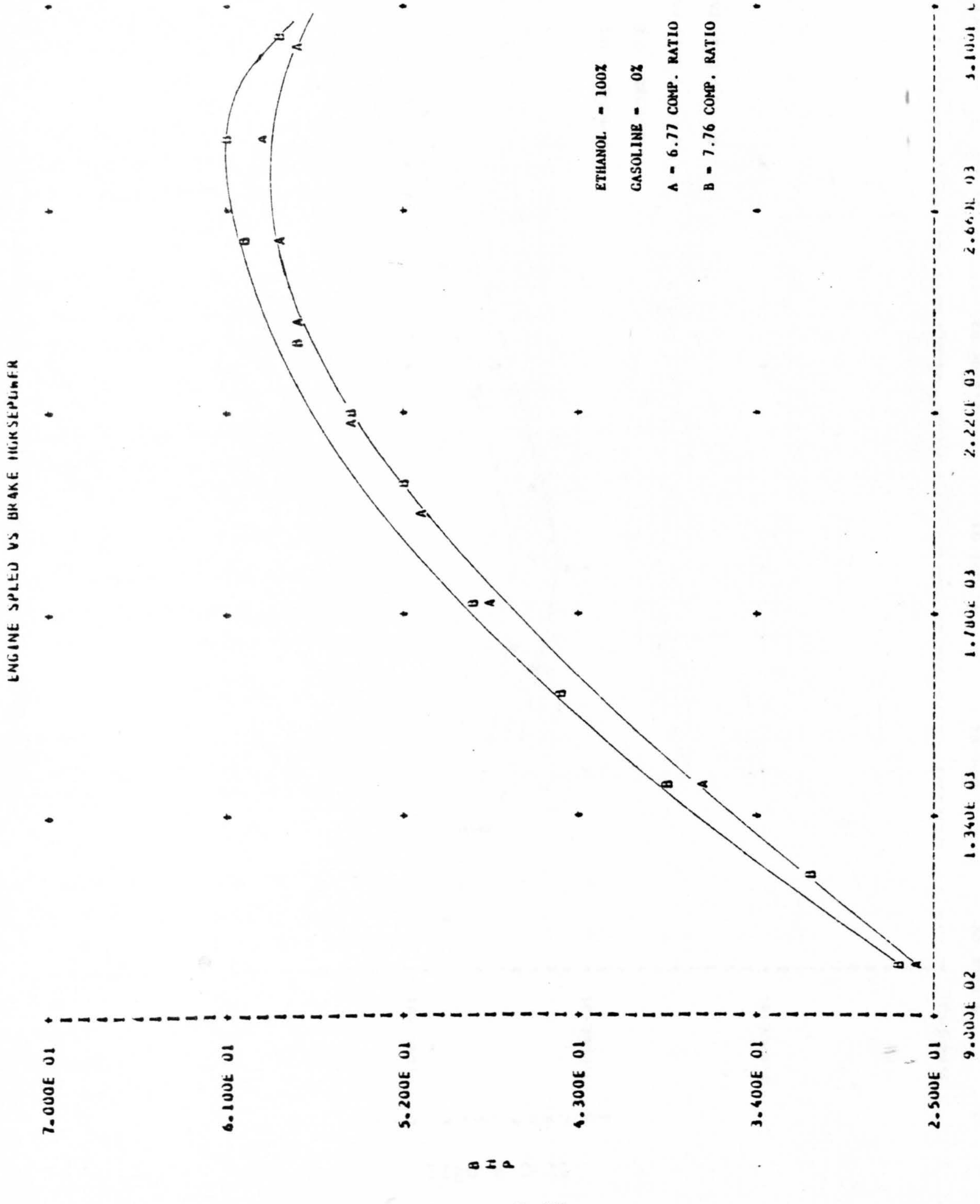

ENGINE SPEED VS BRAKE HORSEPOWER
7.000E 01
6.100E 01
5.200E 01
4.300E 01
3.400E 01
2.500E 01
BHP
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
ETHANOL = 100%
GASOLINE = 0%
A = 6.77 COMP. RATIO
B = 7.76 COMP. RATIO

Figure D-11

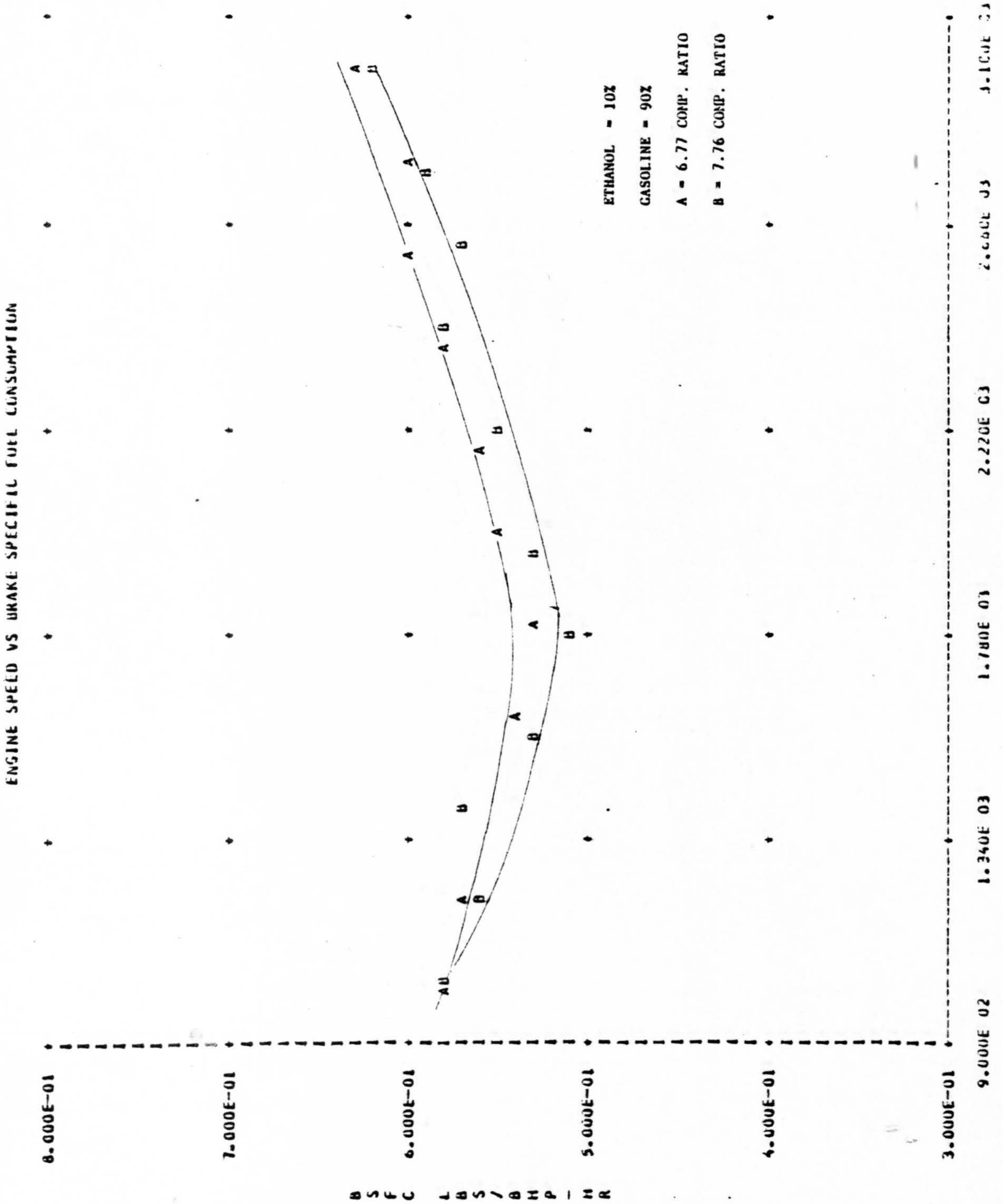

ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION
BSFC LBS/BHP-HR
8.000E-01
7.000E-01
6.000E-01
5.000E-01
4.000E-01
3.000E-01
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
ETHANOL = 10%
GASOLINE = 90%
A = 6.77 COMP. RATIO
B = 7.76 COMP. RATIO

Figure D-12

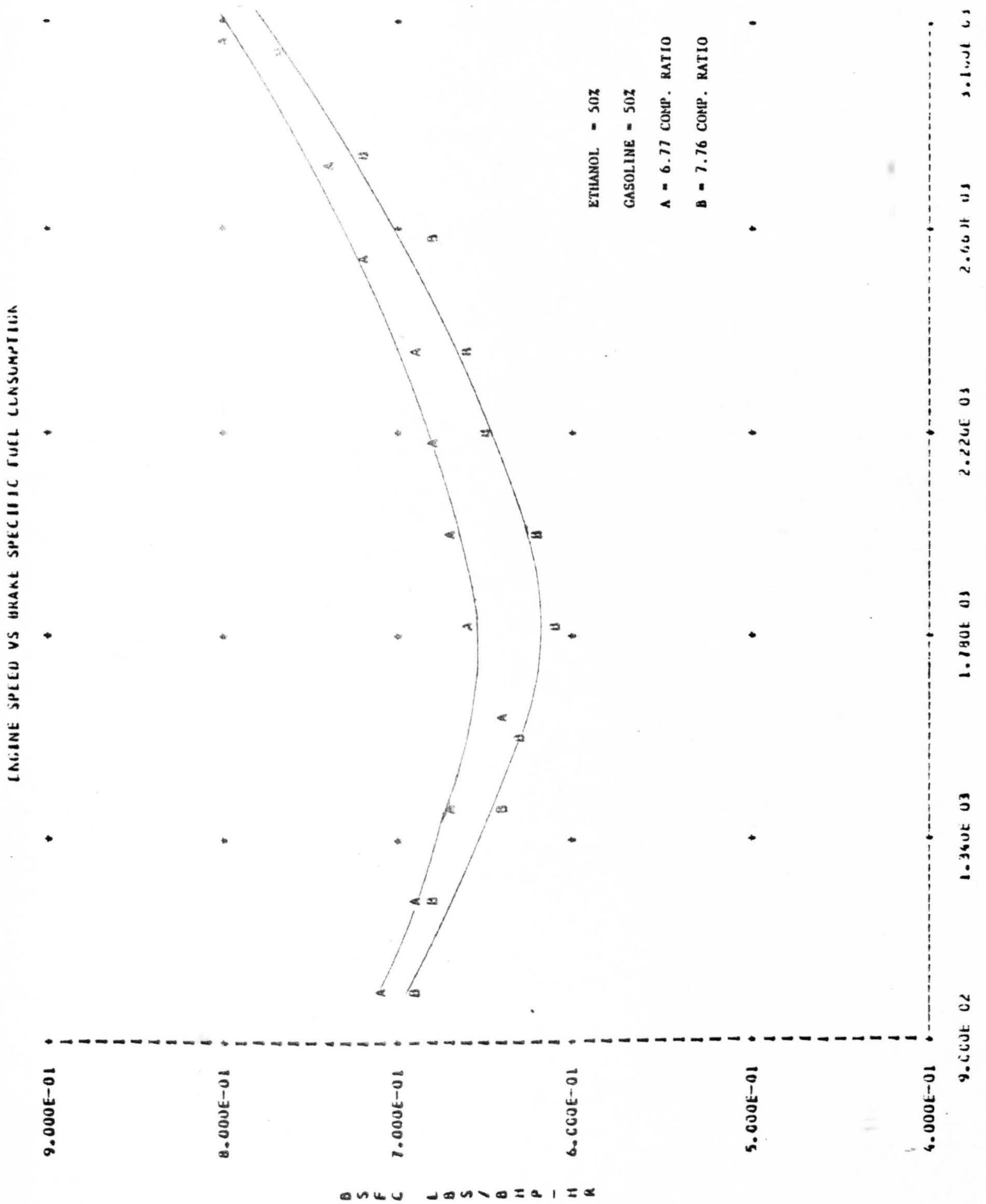

ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION
9.000E-01
8.000E-01
7.000E-01
6.000E-01
5.000E-01
4.000E-01
BSFC LBS/BHP-HR
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
ETHANOL = 50%
GASOLINE = 50%
A = 6.77 COMP. RATIO
B = 7.76 COMP. RATIO
A
B

Figure D-13

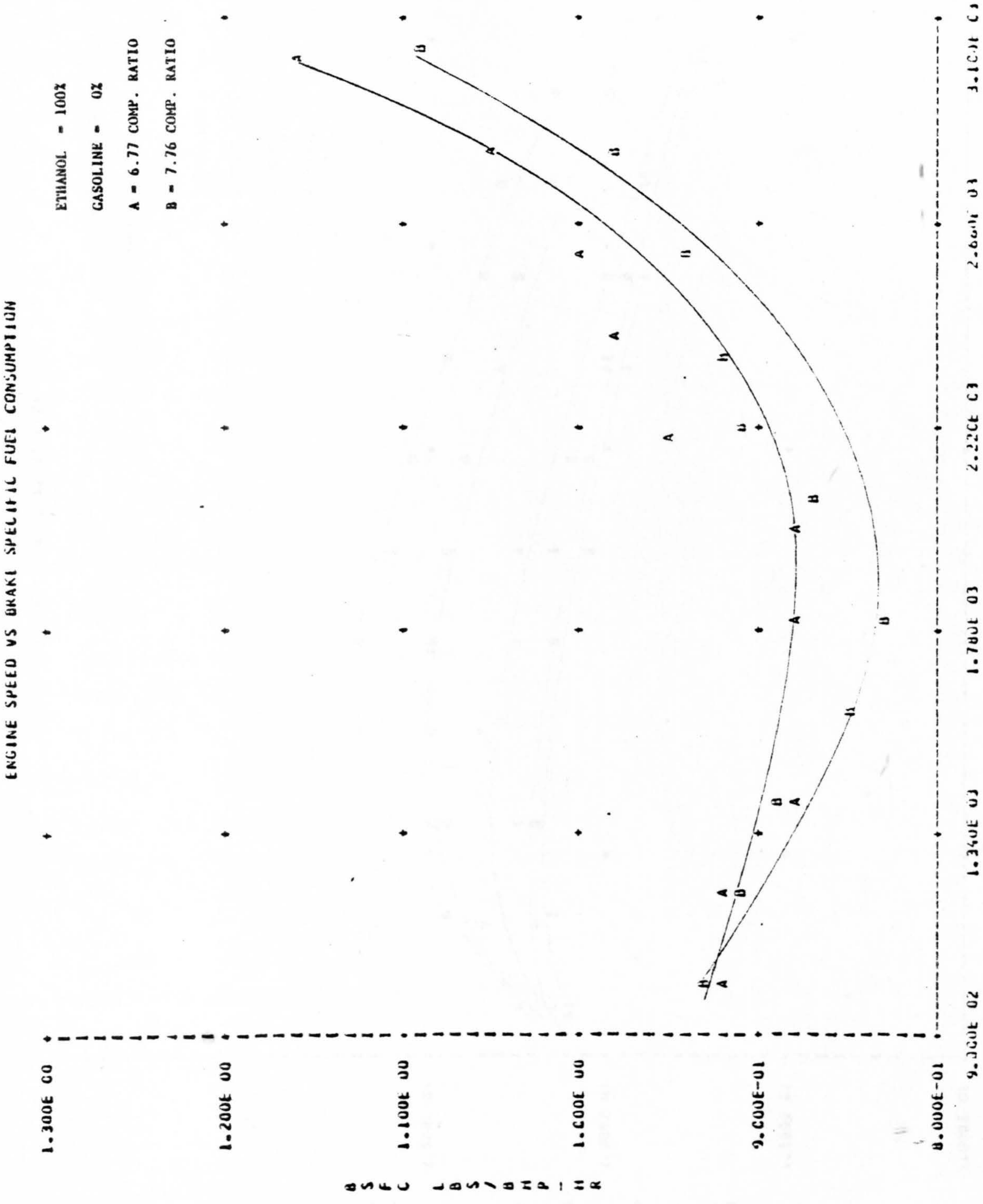

ENGINE SPEED VS BRAKE SPECIFIC FUEL CONSUMPTION
ETHANOL = 100%
GASOLINE = 0%
A = 6.77 COMP. RATIO
B = 7.76 COMP. RATIO
1.300E 00
1.200E 00
1.100E 00
1.000E 00
9.000E-01
8.000E-01
BSFC LBS/BHP-HR
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM

Figure D-14

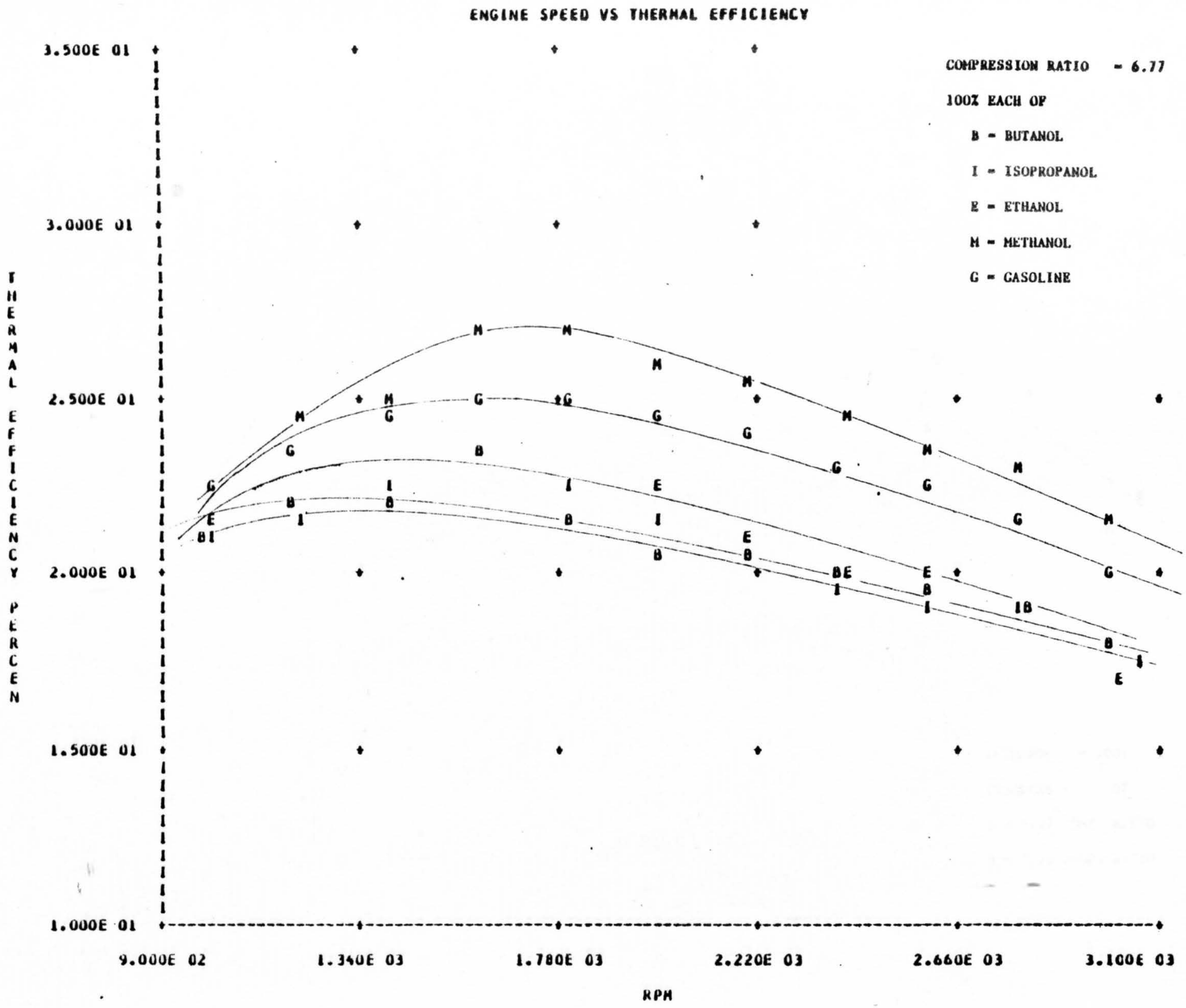

ENGINE SPEED VS THERMAL EFFICIENCY
COMPRESSION RATIO = 6.77
100% EACH OF
B = BUTANOL
I = ISOPROPANOL
E = ETHANOL
M = METHANOL
G = GASOLINE
THERMAL EFFICIENCY PERCEN
3.500E 01
3.000E 01
2.500E 01
2.000E 01
1.500E 01
1.000E 01
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM

Figure D-15

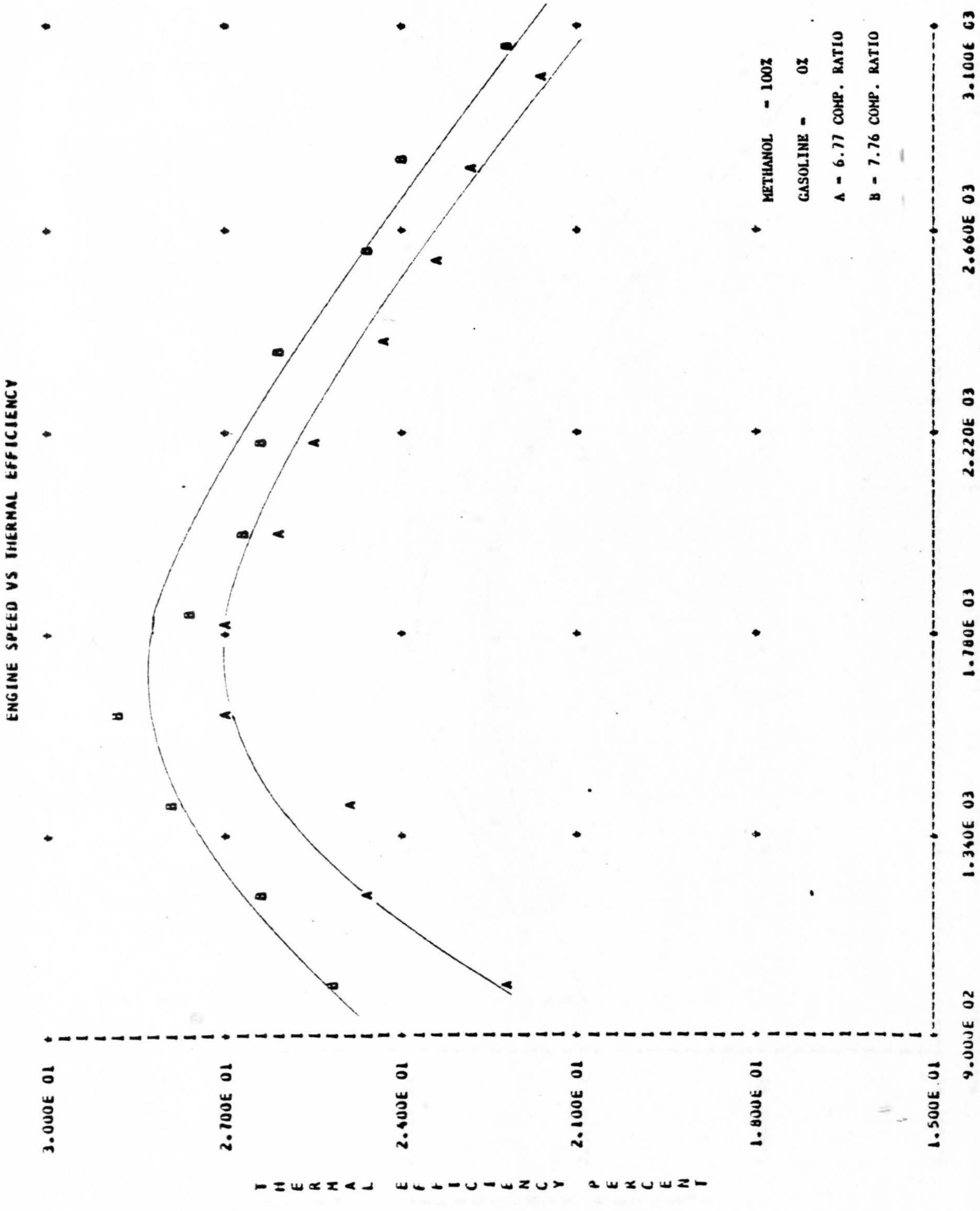

ENGINE SPEED VS THERMAL EFFICIENCY
THERMAL EFFICIENCY PERCENT
3.000E 01
2.700E 01
2.400E 01
2.100E 01
1.800E 01
1.500E 01
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
METHANOL - 100%
GASOLINE - 0%
A - 6.77 COMP. RATIO
B - 7.76 COMP. RATIO

Figure D-16

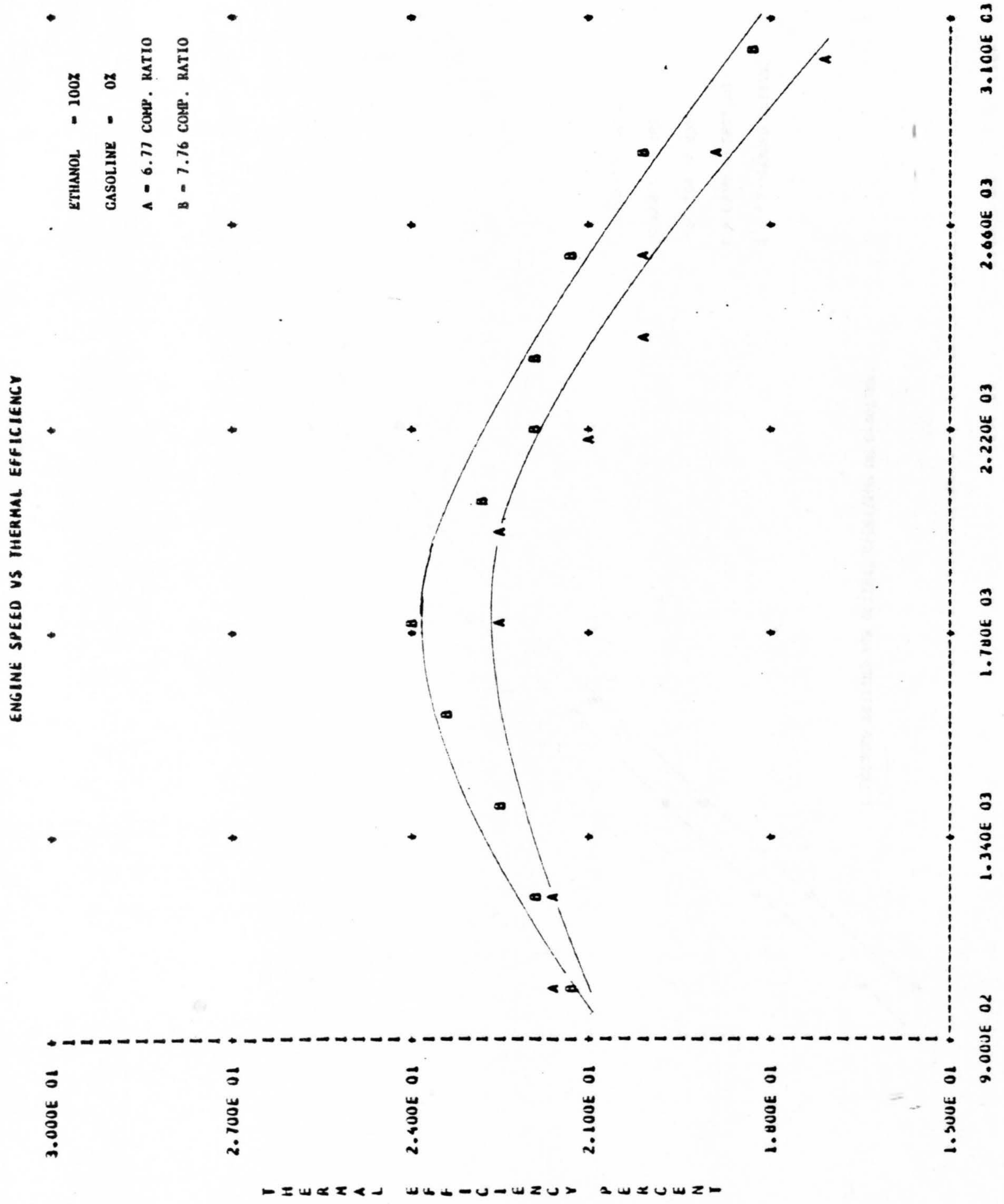

ENGINE SPEED VS THERMAL EFFICIENCY
ETHANOL = 100%
GASOLINE = 0%
A = 6.77 COMP. RATIO
B = 7.76 COMP. RATIO
3.000E 01
2.700E 01
2.400E 01
2.100E 01
1.800E 01
1.500E 01
THERMAL EFFICIENCY PERCENT
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM

Figure D-17

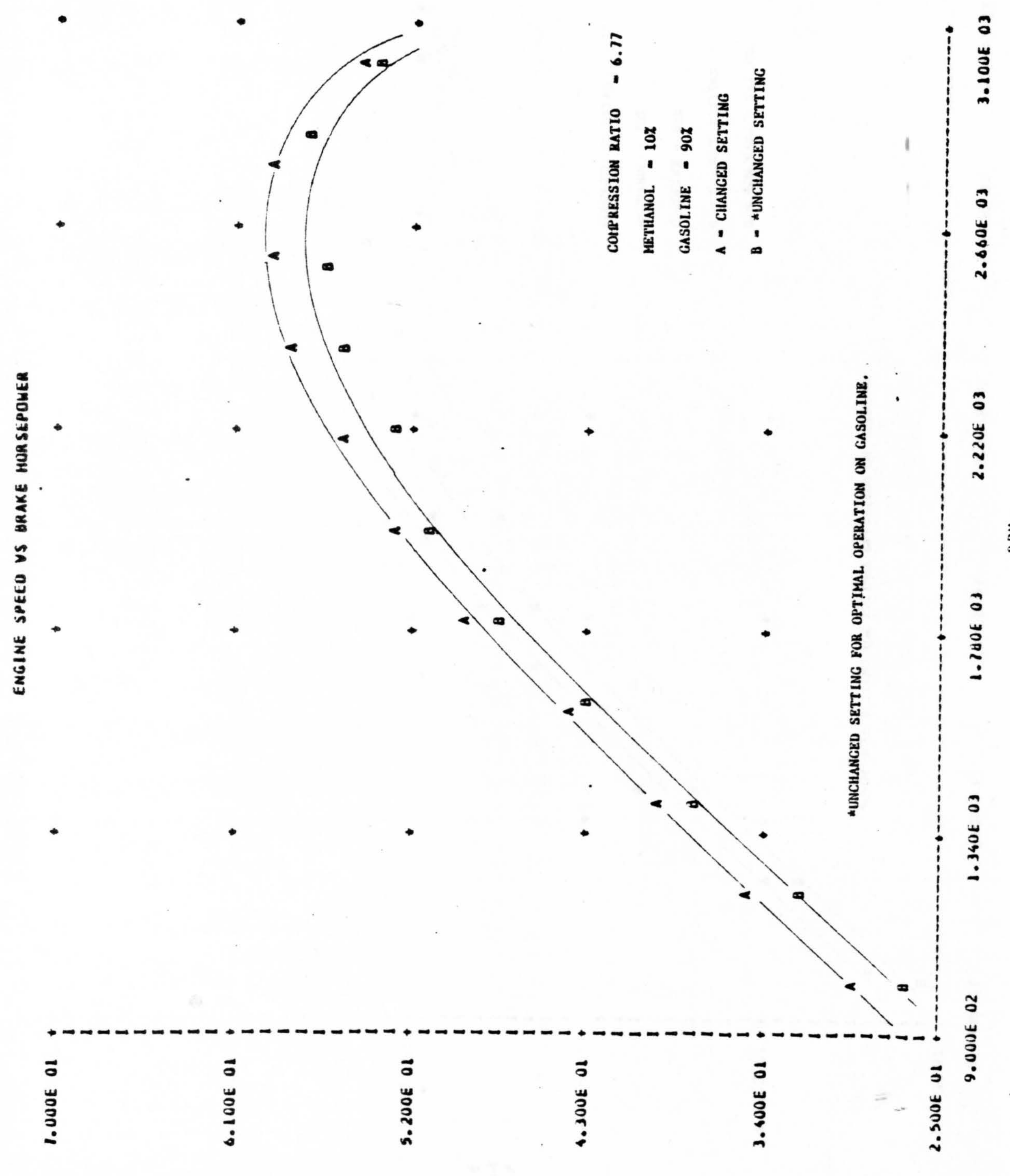
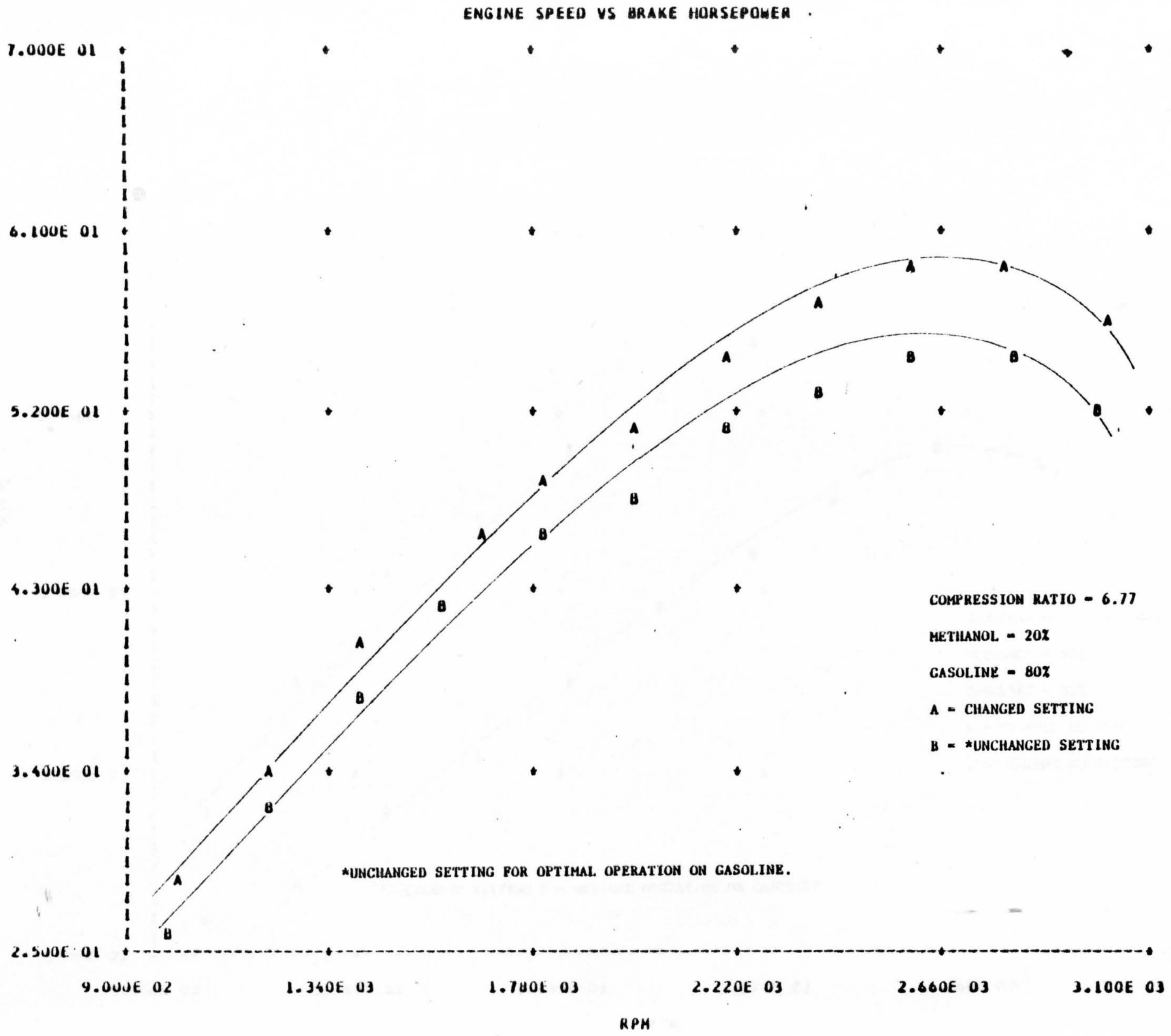

ENGINE SPEED VS BRAKE HORSEPOWER
BHP
7.000E 01
6.100E 01
5.200E 01
4.300E 01
3.400E 01
2.500E 01
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
COMPRESSION RATIO = 6.77
METHANOL = 10%
GASOLINE = 90%
A - CHANGED SETTING
B - *UNCHANGED SETTING
*UNCHANGED SETTING FOR OPTIMAL OPERATION ON GASOLINE.
A
B

Figure D-18



*UNCHANGED SETTING FOR OPTIMAL OPERATION ON GASOLINE.

Figure D-19

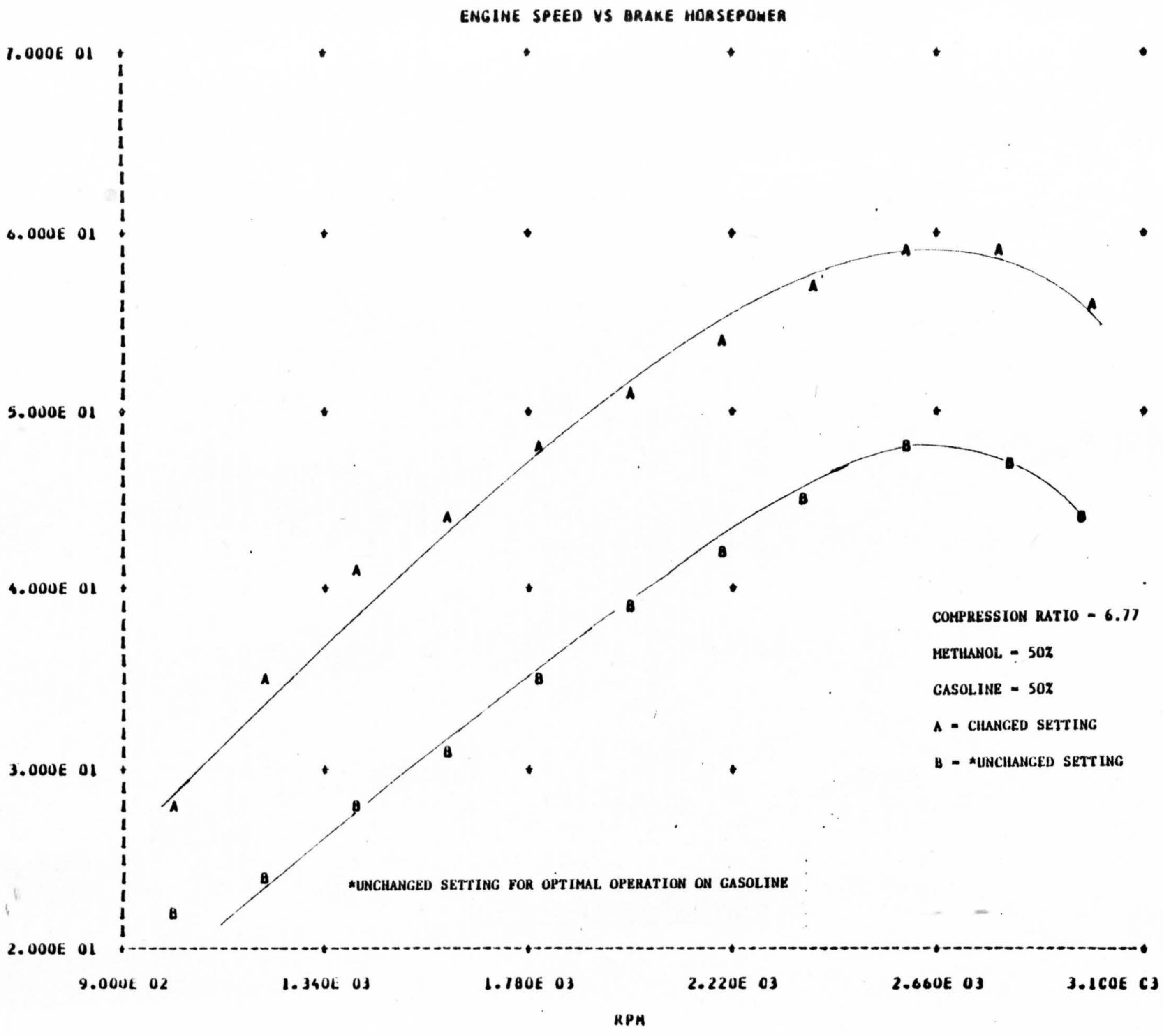

ENGINE SPEED VS BRAKE HORSEPOWER
7.000E 01
6.000E 01
5.000E 01
4.000E 01
3.000E 01
2.000E 01
BHP
9.000E 02
1.340E 03
1.780E 03
2.220E 03
2.660E 03
3.100E 03
RPM
COMPRESSION RATIO - 6.77
METHANOL - 50%
GASOLINE - 50%
A - CHANGED SETTING
B - *UNCHANGED SETTING
*UNCHANGED SETTING FOR OPTIMAL OPERATION ON GASOLINE

Figure D-20