

SOYA OIL AS ALTERNATIVE FUEL FOR DIESEL ENGINE

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ABSTRACT

The increasing concern on energy resources and the environment leads to a detailed analysis on the performance, emission and economy of compression ignition engine using alternative fuels. The objective of this paper is to present and compare the performance and emission characteristics of diesel oil and soya oil as an alternative fuel over a range of compression ratio at constant speed and injection rate and at the experimented optimum injection advance for maximum power in a compression ignition engine.

Results of the fuel property measurements indicate that the empirical chemical symbol of soya oil is $C_{13}H_{22.6}O_{1.2}$ while diesel oil is $C_{14.4}H_{26.1}$. Soya oil can release 87% of the energy released by diesel oil. Soya oil has higher optimum injection advance for each compression ratio. Operating at optimum injection advance for maximum power and at higher compression ratios ($r = 19:1, 20:1$), the brake mean effective pressure of soya oil is 95% of the brake mean effective pressure produced by diesel oil, and soya oil is 10% less thermally efficient than diesel oil.

I. Introduction

Energy resources are unevenly distributed and similarly, energy consumption is unequally divided among nations. World economy is expected to grow at an annual average of 2.7 to 3.7% from 1996 to 2010 [7] and may further increase due to expected improvement in economic activities, population growth, increasing income levels and urbanization, which require more energy. In the Philippines, for the expected annual growth rate of the gross domestic product at 5.4% from 1998 to 2004 and 7% from 2004 to 2008, the total energy requirement is projected to grow at an average annual rate of 6% where new and renewable energy will account for 22% of the total requirement of 416.5 million barrels of fuel oil equivalent by 2008 [8]. A review of recent energy consumption patterns, oil prices, foreign monetary exchanges and political situation, leads to the conclusion that many governments will be forced to turn to alternative energy sources for economic and geopolitical reasons. It is therefore momentous to find an alternative fuel that will substitute or extend the lifetime of petroleum products. Alternative fuels will have to meet the demand for energy as petroleum production inevitably levels off and then falls. By ensuring competitive prices and readily available supplies for various alternative fuels, the impact of prices and availability of petroleum products is lessen until an acceptable and appropriate substitute is technologically, economically, environmentally and sociologically feasible.

A promising alternative fuels are plant oils, particularly vegetable oil. Vegetable oil has the property of being renewable, can be widely propagated and easily extracted from an impressive range of plants, which include among others sunflower, palm, soya bean, olive, jojoba, copaita, and coconut. Soya oil was used in the experiment. However, soya oil must satisfy some requirements to be competitive as fuel such as storing over a long period of time without deteriorating; storing, transporting and distributing economically; handling safely without imposing additional hazards (i.e., explosion, fire, etc.) and without requiring major engineering changes to processes and/or systems using them [3].

This paper aims to present and compare the performance and exhaust emission characteristics of diesel and soya oils at experimented optimum injection advance for maximum power over a range of compression ratios without any engine modification. A variable compression engine was used as a compression ignition engine at a constant speed and injection rate setting. The engine was run at straight diesel oil and straight soya oil at various injection advance settings and compression ratios. The optimum conditions for maximum power were computed for each compression ratio (r) and then the engine was operated at these optimum conditions. Subsequently, the properties of the fuels such as chemical component, calorific value and density were determined.

The National Institute of Technology in Brazil completed a series of tests in running local buses on diesel oil and vegetable oil mixture. In one trial, the fuel was a mixture of 80% diesel and 20% peanut oil and the other trial used 73% diesel, 20% palm oil and 7% ethanol without any readjustments. The trial showed that the fuel consumption was 3.4% less than with diesel oil alone [14].

Coconut oil was tested in a diesel engine in the Philippines [5] and resulted in a performance nearly as well and sometimes better than when the engine used diesel oil. In another project [6], a test on a 25 kVA Ford diesel engine generator set using diesel and coconut oils resulted a comparable efficiency (24%) at normal load on the generator.

The principle of the compression ignition engine (Diesel cycle) [2] is that air alone is drawn into the cylinder and compressed by the upstroke of the piston. The fuel is atomized into the charge of heated air and the high temperature achieved by the initial compression is sufficient to cause spontaneous ignition. The rate of pressure rise in the cylinder is therefore controlled to a great extent by the rate and period of fuel injection. The speed of the engine and the general level of cylinder temperature set a time limitation on the amount of fuel that can be injected and burned efficiently. Fuel properties control performance such as storage, pumping, handling and filtering. The processes wherein the fuel goes through are atomization and mixing with air, combustion, power extraction, heat exchange and exhaust.

The basic requirements of the combustion process are formation of a mixture of fuel and air, ignition of the mixture and completion of combustion. The final air compression pressure and temperature vary with compression ratio, speed and engine design. Fuel is injected before top dead center, which is controlled by the fuel injection timing system. The length of the delay period (beginning of injection to ignition) is controlled by engine design, fuel and air inlet temperatures, degree of atomization of the fuel and fuel composition. Self-ignition occurs and the flame spread progressively as fuel is still injected. Completion of burning is the final part of combustion after the fuel injection has ceased. The relevant fuel parameters on combustion applications are discussed by Goodger (1980) [13].

II. Methodology

A Ricardo E6/T variable compression ignition engine was used to determine the performance characteristics of diesel and soya oils. The engine was warmed up and allowed to attain steady state condition before the beginning of each experimental run. It was run at a constant speed of 2,000 revolutions per minute (rpm) and at a constant injection rate setting of 5. The injection advance (α) was varied from 20 to 45 degrees for each compression ratio. The fuel consumption was set at 50 cm³ per experimental run. At steady state condition, the data collected at the beginning and end of each run were: compression ratio, injection advance (degree), engine speed (rpm), dynamometer load (pound force), time to consume for a 50 cm³ of fuel (second), line voltage (Volt) and current (Ampere), air flow rate (manometer scale reading), cooling water flow rate (inches mercury), cooling water inlet and outlet temperatures (°C), oil pressure (pound per square inch) and temperature (°C), and ambient temperature (°C) and barometric pressure (inches mercury). The compression ratio was then varied from 14:1 to 20:1. From the above runs, the optimum injection advance for maximum power was calculated by a least squares polynomial approximation for every compression ratio on each fuel. The experiment was repeated using the optimum injection advance for each compression ratio on each fuel. The experimental flowchart is shown in Figure 1.

The engine [9] is a single cylinder, poppet valve, single acting, vertical, and reciprocating engine working on a four-stroke cycle. Ricardo & Co. Engineers Ltd. made the engine. The engine has the following specifications: bore of 76.2 mm, stroke of 111.1 mm, swept volume of 507 cm³ and speed from 1,000 to 3,000 rpm. It can attain a maximum output of 6.71 kW at 3,000 rpm when used as a compression ignition engine. The compression ratio can be varied while the engine is running by moving the complete cylinder head unit up or down relative to the crankshaft and hence varying the clearance volume. A micrometer measures the cylinder position and the compression ratio is obtained from a calibration curve. The two poppet valves, one inlet and one exhaust, are operated via rocker arms from an overhead camshaft. The camshaft drive is transmitted through two pairs of bevel gears and a vertical shaft from the crankshaft. The vertical shaft consists of two concentric tubes keyed together to allow for the vertical movement of the cylinder head unit.

The head is a Comet Mk. V compression swirl combustion chamber. Air is forced into the chamber and is given a rotating motion by the shape of the chamber and by the position of the communicating passage on the compression stroke. The fuel is injected into the chamber via a pintle-type nozzle and the organized swirl of the air in the chamber ensures that there is maximum contact between the fuel particles and the air. The fuel pump is a CAV BPEIB type with a 6-mm diameter plunger. A CAV type BK80624 injector body is used with a BDNOSD21 nozzle and an injection valve loaded with a 4-mm spring. The hand control provides a range of timing up to 45 degrees in advance.

The lubricating oil system is of the wet sump type. An electrical oil heater of 0.5 kW rating is provided in the crankcase to reduce the warming up period. The engine is cooled by water, which is circulated by convection. The cooling water flow rate is measured by an orifice-type flow meter.

Aside from measuring instruments inherent in the engine such as oil pressure gauge and thermometer, the other important test equipment are air meter, fuel meter, dynamometer, tachometer and gas analyzer. An Alcock viscous flow air meter measures the volumetric airflow rate using a low slope inclined manometer. Fuel rate was measured by recording the time to

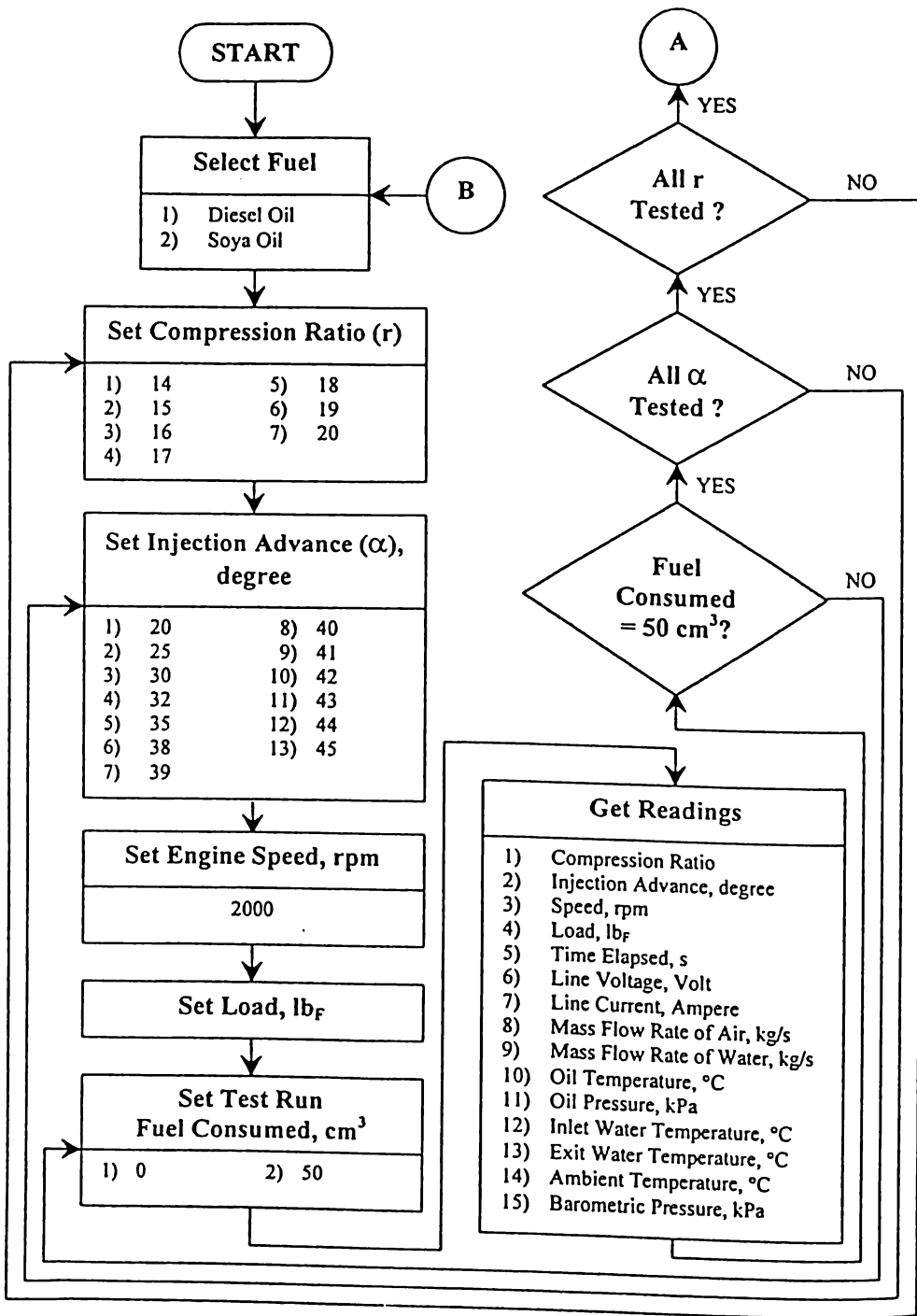


Figure 1a. Experimental flow chart

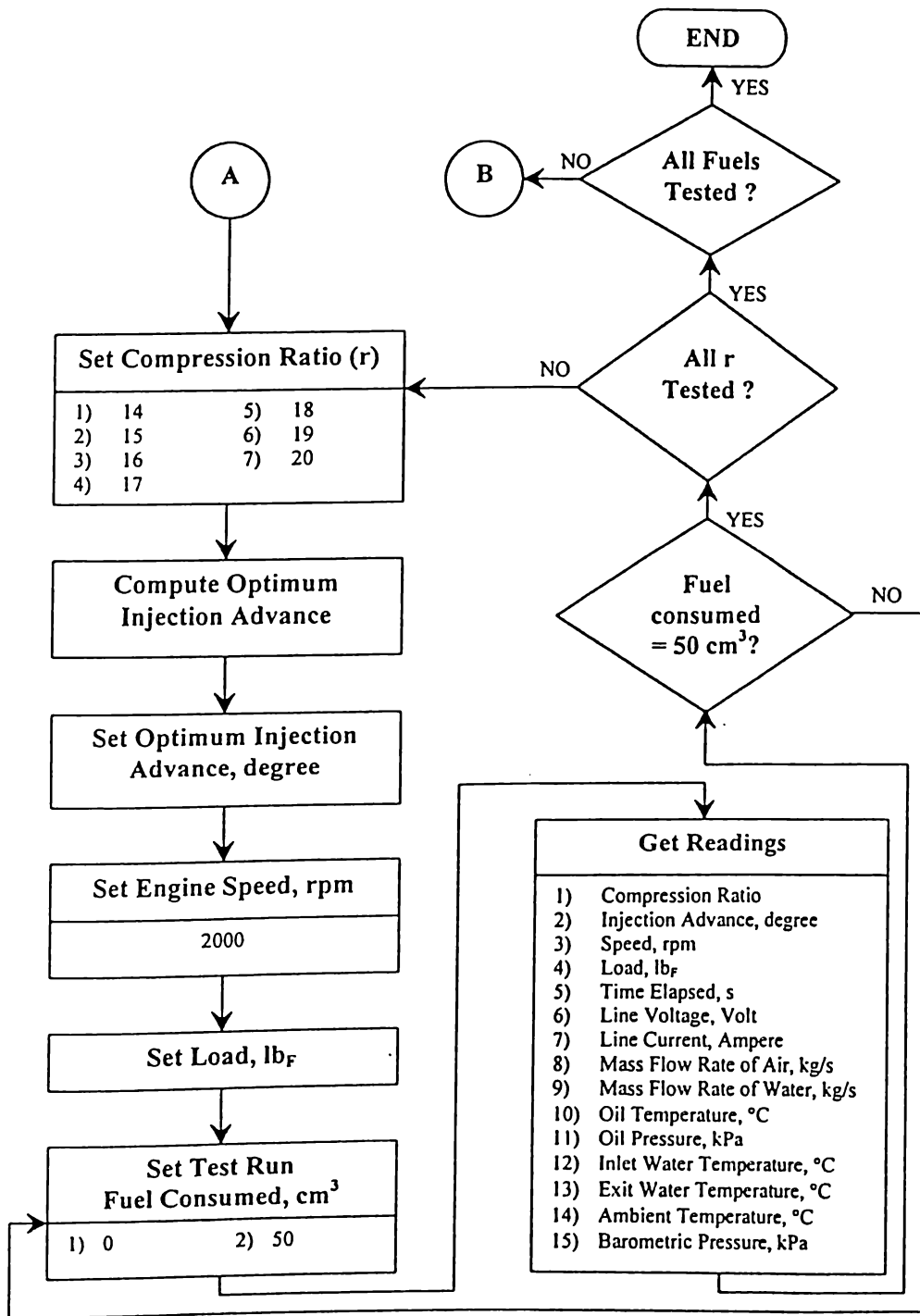


Figure 1b. Continuation of experimental flow chart

consume a 50 cm³ of fuel drawn from a pipette, which is incorporated in the fuel tank. A Casio LCD stopwatch with an accuracy of up to one-hundredth of a second was used for timing.

The engine is connected to a swinging field electric DC dynamometer, which absorbs and measures the power developed. It can also be operated as a motor to start the engine or for the determination of friction and pumping losses. A bank of resistance grids having a negligible temperature coefficient of resistance absorbs the energy developed by the dynamometer. Course and fine field regulators were used to control the load and speed. The Crompton Parkinson electric tachometer is driven by a generator coupled to the end of the dynamometer shaft to measure rotational engine speed in rpm.

The exhaust gas products pass directly from the cylinder through a flexible piping to an exhaust box where they are sucked by the central exhaust fan and expelled to the atmosphere. A sampling tap at the pipe bend is provided for taking exhaust gas samples for analysis. The gas sampling line is made up of a water trap and dust filter, a heated line with a thermostat technical heater and a three-way heated box. The temperatures were monitored by three battery-operated Comark platinum thermocouples. The first line was connected to the Flame Ionization Detector (FID) Hydrocarbon Analyzer Series 520, which was made by Analysis Automation Ltd. The unburned hydrocarbon as propane equivalent was measured as "wet" concentration by the analyzer. The ranges can be varied from 0 to 100,000 parts per million (ppm). The fuel used by the FID was 40% H₂ in helium. The second line was connected to a water trap and drying tube filled with silica gel crystals to measure "dry" concentrations. The carbon dioxide and carbon monoxide were measured by Grubb Parsons Infrared Gas Analyzer model 20 NDLR with ranges of 0-0.1% to 0-15%. A Beckman Model 715 Process Oxygen Monitor with ranges of 0.5% and 0-25% gave the oxygen in "dry" concentration polarographically. The last line was connected to a similar water trap and drying tube to give a "dry" concentration. A Model 10A self-contained Chemiluminescent NO-NO_x Gas Analyzer made by Thermo Electro Corporation measured NO and NO_x. The ranges can be varied from 0 to 10,000 ppm.

The gas analyzers were warmed up for about one (1) hour. To avoid contamination from exhaust gases leaking into the test area, the FID, CO₂ and CO analyzers were zeroed using the NO/N₂ gas while the NO/NO_x analyzer was zeroed with C₃H₈/CO₂/N₂ gas. The FID, CO₂ and CO analyzers were calibrated by calibration gases containing 7527 ppm propane (C₃H₈), 9.87% CO₂, and 0.47% (for high range) and 9.96% (for low range) CO in N₂ respectively. The O₂ analyzer was calibrated with dry air assumed to contain 21% O₂ while the NO-NO_x analyzer was calibrated using calibration gas containing 48 ppm NO in N₂. The wet concentration of C₃H₈ and the dry concentrations of CO₂, CO, O₂ and NO were taken for each compression ratio at optimum injection advance. The ranges of the analyzers were constantly adjusted to give a better reading before converting them to percentages.

The equipment used to test the fuels were oxygen bomb calorimeter to calculate the calorific value, hydrometer to determine the relative density, and elemental analyzer to identify the elemental components. There were three (3) samples tested and the averages of the results were considered. Baird and Tatlock (London) Ltd. made the oxygen bomb calorimeter 2302. The apparatus conformed to the British Standards (BS) 1506. The calorific value determination was carried out at constant volume. The relative densities were measured by using a hydrometer STS50 that conforms to BS 718. The densities of the fuels were expressed relative to water. The method was based on

the buoyancy of a hydrometer floating in the sample at equilibrium temperature. The barometric pressure and temperature were also recorded.

The elements contained in the fuel were detected and measured by Perkin-Elmer Model 240 Elemental Analyzer. A pure oxygen was used for sample combustion while helium was used to carry the combustion products from the combustion train, through the analytical system and finally to the atmosphere. Combustion occurred under static conditions in excess amount of oxygen at about 950°C. A reduction furnace at 700°C reduced to nitrogen any oxides of nitrogen and removed any residual oxygen. Carbon, hydrogen and nitrogen of the fuels were determined by detecting and measuring their combustion products (CO₂, H₂O and N₂). The combustion products were analyzed automatically in a self-integrating, steady state thermal conductivity analyzer and the results were recorded in bar graph form on a 0.1 mV recorder and converted to percentages. The detector outputs were calibrated using a known standard to obtain the sensitivity factors for use in relating the recorder deflection in microvolt to microgram of nitrogen, carbon and hydrogen in the fuel. A blank run in which the analyzer was run in a program cycle without a sample in the combustion chamber was conducted to set the reference reading.

III. Results and Discussion

3.1 Fuel Properties

The results of the fuel elemental analyses are shown in Table 1. Dividing the elements by their respective molecular weight and neglecting the small contributions of nitrogen and sulfur give the empirical chemical symbol of diesel oil and soya oil to be C_{14.4}H_{26.1} and C₁₃H_{22.6}O_{1.2} respectively. The chemical symbol of soya oil suggests that the presence of oxygen complicate its chemical configurations. Basing from these empirical chemical symbols, the stoichiometric reaction of each fuel can be formulated as follows:

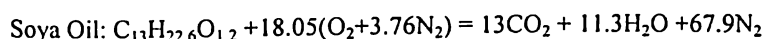
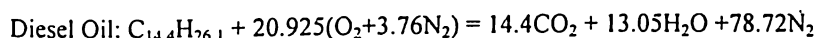


Table 1
Fuel Components

Element	Diesel Oil	Soya Oil
C, %	86.5	78.35
H, %	13.05	11.3
O, %	-	9.7
N, %	0.2	0.35
S, %	0.25	0.3

The stoichiometric air fuel ratios of diesel oil and soya oil on a mass basis were calculated to be 14.51 and 12.59 respectively. The air fuel ratios on a mole basis and other fuel properties are entered in Table 2.

The oxygen bomb calorimeter gives the calorific value at constant volume for diesel oil to be 45,620 kJ/kg at 17.4°C and 29.46 in Hg while for the soya oil is 39,775 kJ/kg at 20.4°C and 29.71 in Hg. The data was subjected to thermometer correction, Regnault-Pfaunder cooling correction, heat gain correction from cotton and firing wire and sulfuric acid and nitric acid corrections. From the calorific values, it follows that soya oil releases 87% of the energy released by diesel oil.

The density taken from the hydrometer at 19°C and 29.42 in Hg of diesel oil is 842 kg/m³ while for soya oil is 921 kg/m³. The density shows that it increases with a decrease in calorific value.

Table 2
Fuel Properties

Property	Diesel Oil	Soya Oil
Symbol	C _{14.4} H _{26.1}	C ₁₃ H _{22.6} O _{1.2}
Molecular Weight	198.9	197.8
Air/Fuel Mass Ratio	14.51	12.59
Air/Fuel Mole Ratio	99.64	85.95
Density, kg/m ³ (19°C & 29.42 in Hg)	892	921
Calorific Value, kJ/kg (17.4°C & 29.46 in Hg) (20.4 °C & 29.71 in Hg)	45620	39775

3.2 Equivalence Ratio

The equivalence ratio (ϕ_D for diesel oil, ϕ_S for soya oil) is the ratio of the fuel consumed to the equivalent amount of fuel required for the stoichiometric quantity of oxidant. Two methods were used in measuring the equivalence ratio: using the mass flow rates of the fuel and air and using the exhaust gas analysis. Using the mass flow rate was considered since it was more reliable because of lesser measurements required and greater accuracy. The average equivalence ratios were 0.757 for diesel oil and 0.775 for soya oil. The variation of the equivalence ratios obviously causes a slight difference in power outputs.

3.3 Brake Power and Break Mean Effective Pressure

The torque or turning moment in Nm is a measure of the capability of the engine in exerting effort and it is the product of the brake load and brake arm length. The engine is coupled to a dynamometer to measure this effect. The brake power in kW is the rate of doing work. It is the product of the torque and the rate of angular rotation. Figure 2 shows the brake power as a function of injection advance at a compression ratio of 20:1 for both fuels. The curves are typical for the various compression ratios for both fuels.

A more appropriate performance characteristic is the brake mean effective pressure (BMEP) in kPa. BMEP is the pressure, which if acting throughout the power stroke would produce the calculated power of that stroke (i.e., power output per unit volume renewal rate). The brake mean effective pressures as a function of injection advance for various compression ratios are shown in Figure 3 for diesel oil and Figure 4 for soya oil. Both the BMEP of the fuels increase with

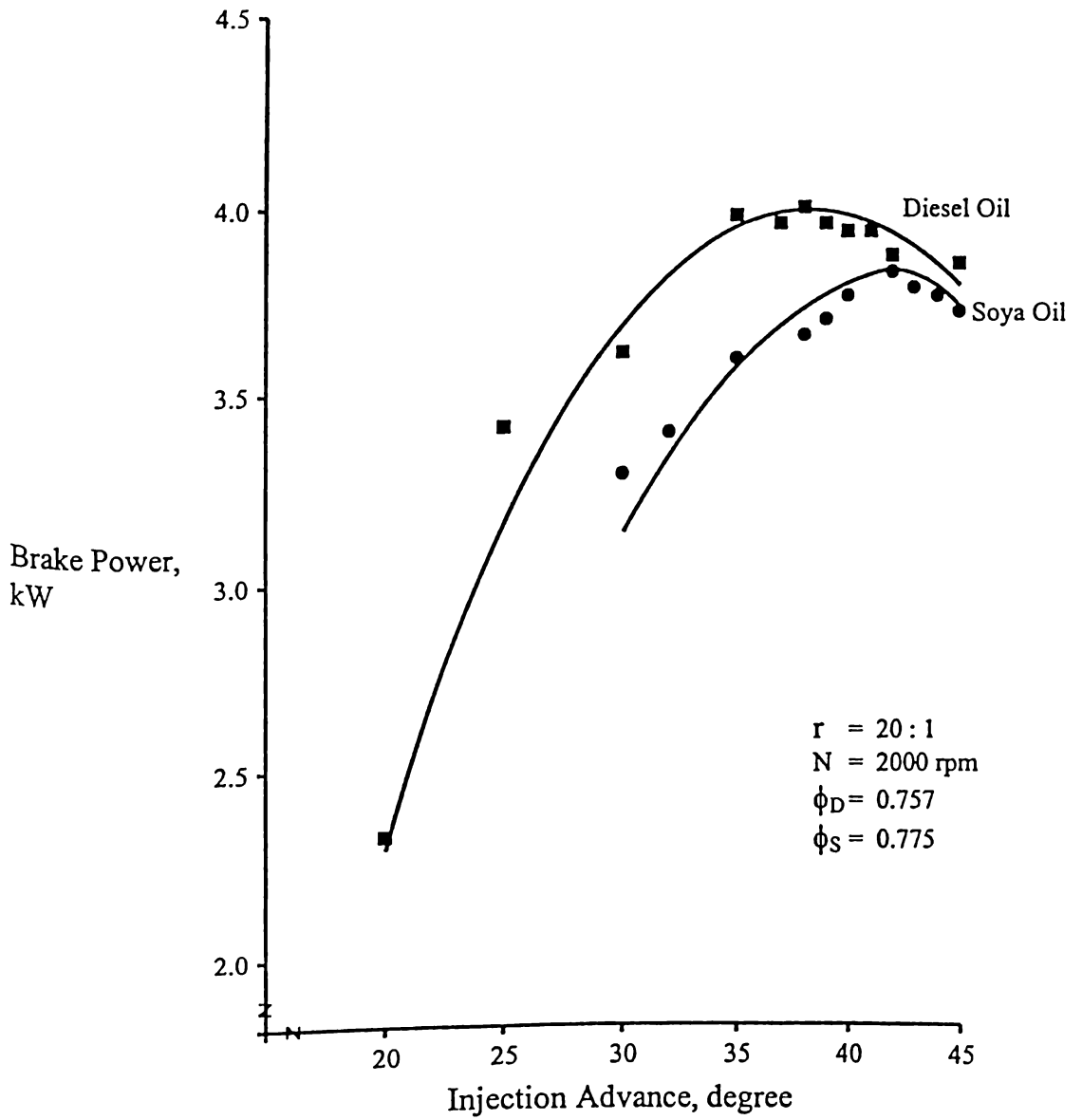


Figure 2. Brake power variation with injection advance.

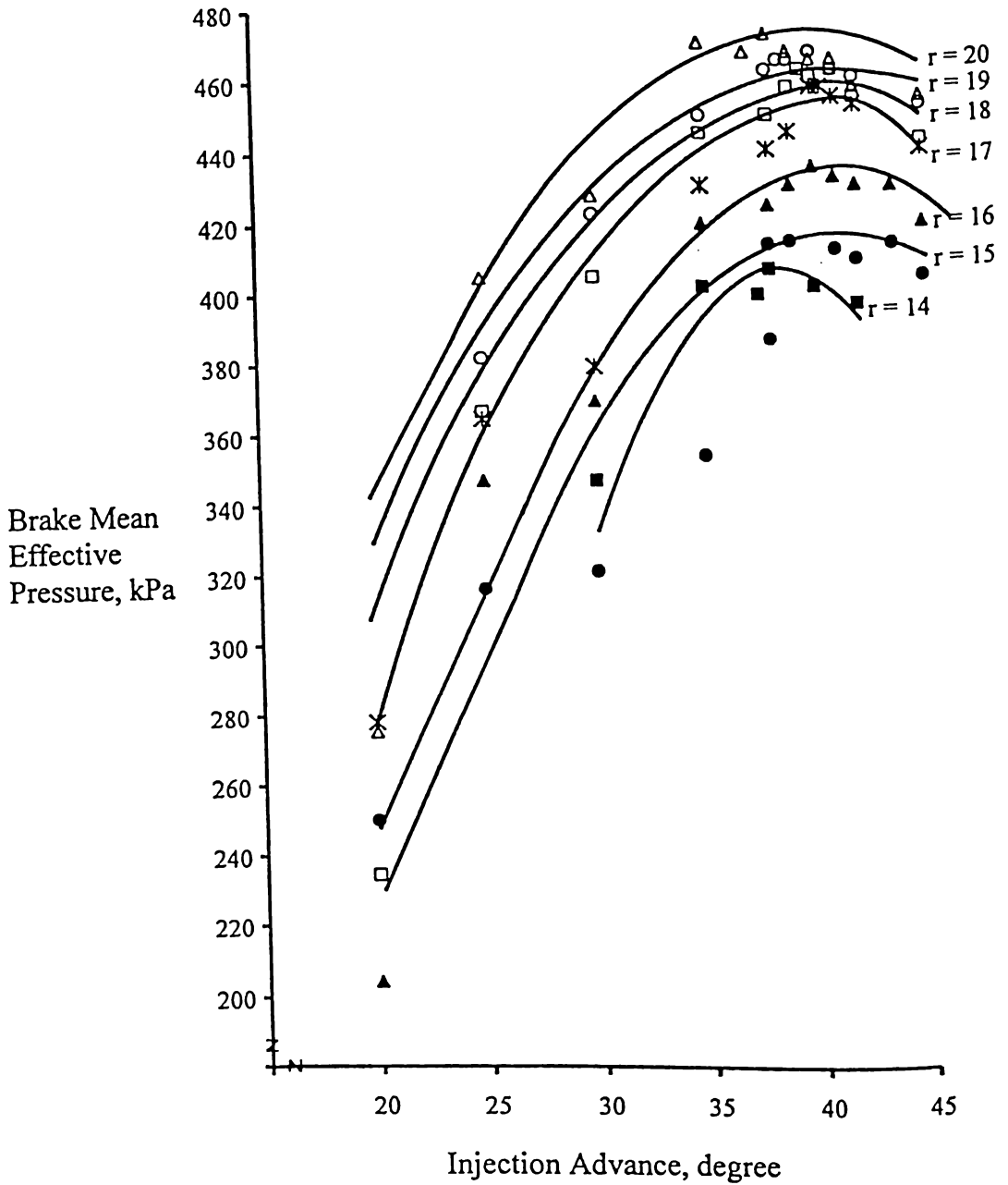


Figure 3. Brake mean effective pressure variation with injection advance using diesel oil at constant engine speed of 2,000 rpm.

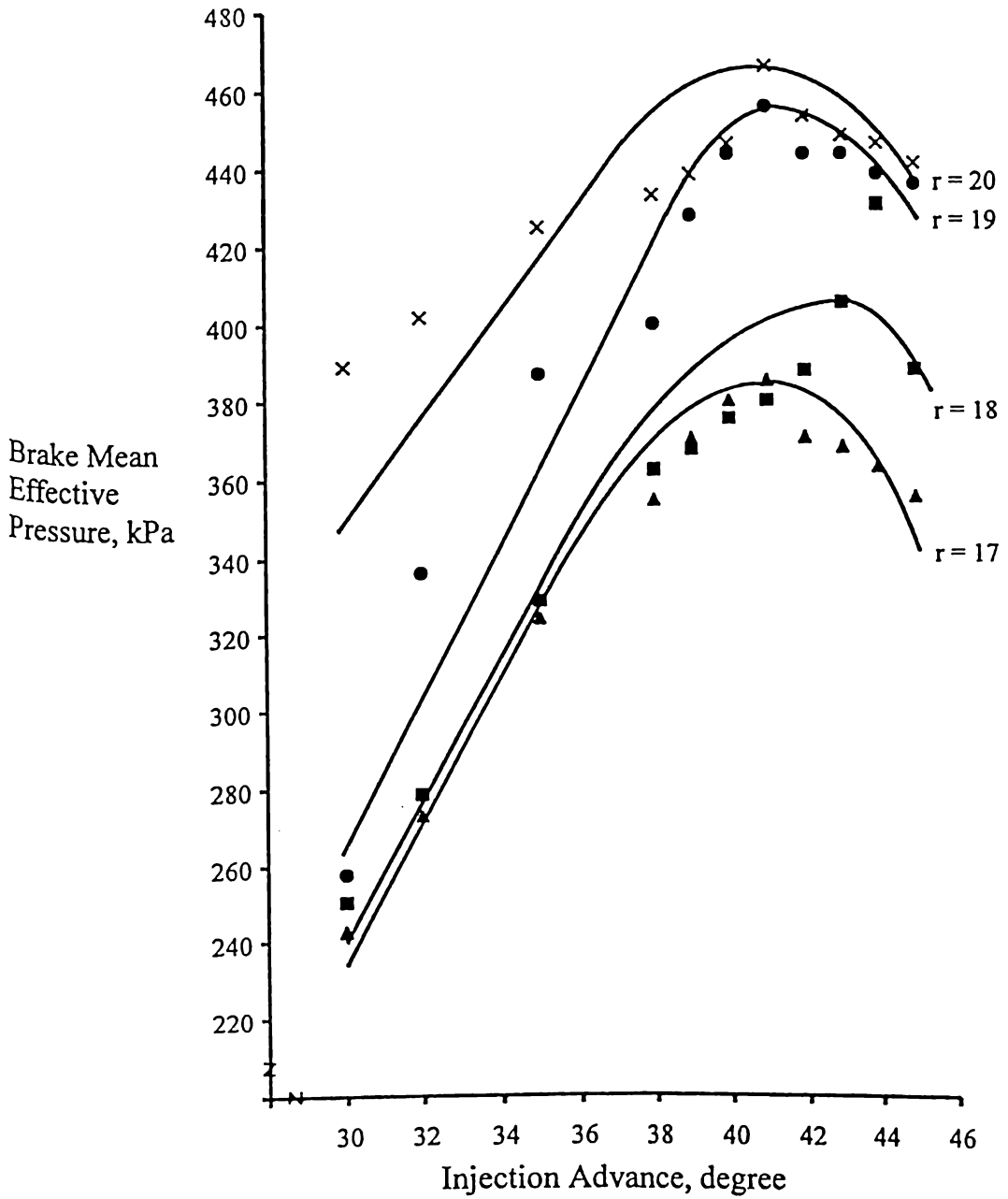


Figure 4. Brake mean effective pressure variation with injection advance using soya oil at constant speed of 2,000 rpm.

compression ratio. As the compression ratio increases, the compression temperature and pressure increase thus, producing wider work area, which resulted in higher BMEP. It is amazing to note that at higher compression ratios ($r = 19:1$; $20:1$), soya oil resulted in 95% of the BMEP output of diesel oil. It is possible that for the diesel oil, the engine may be operating at the limit of maximum burning rate. If the maximum burning rate is reached, the balance of the combustion process will not maintain a constant pressure but rather pressure will fall off and with it a decrease in work output. This is also dependent on the chemical compositions and calorific values of the fuels and their equivalence ratios.

3.4 Misfire Limits and Optimum Injection Advance

It was observed that the engine could not maintain a steady state condition of 2,000 rpm at a compression ratio below 14:1 for diesel oil and 17:1 for soya oil. These misfire limits were detected audibly, by an increase in misfire frequency; sudden decrease in power output; and swift increase in unburned hydrocarbon as the mixture failed to ignite oftenly.

The misfire limits on compression ratio is basically the low pressure and temperature on which the fuel is injected, thereby failing to self-ignite more frequently. The difference in the misfire limits on compression ratio of the two fuels is mainly due to their components. Spontaneous-ignition results from the disruption of a few of the more energetic molecules within the mixture, exposing free bonds available for joining with oxygen. Although the molecular weights are comparable, soya oil is more complex as shown from the empirical chemical symbol (Table 2).

For each compression ratio, the optimum injection advance for maximum power was calculated by fitting the experimental data to a least squares polynomial approximation. An optimum injection advance for maximum power occurs since it is associated with the delay period. The shortest delay occurs when the delay period includes top dead center. Early or late ignition results in longer delays. The longest delay is with the latest injection advance where average pressure and temperature is lowest [16]. Rates of pressure rise are affected by delay angle and piston motion. Early or late injection gives a high rate owing to long delay together with inward or descend of the piston during the rapid combustion. Therefore, a short delay coupled with rapid combustion near the top dead center gives the optimum power.

Combustion for maximum power is a complex function of engine design, fuel properties, atomization and others. The injection advance for maximum power varies with the different combinations of the above parameters. Figure 5 shows the optimum injection advance of both fuels as a function of compression ratio. The optimum injection advance increases abruptly then decreases as the compression ratio increases. As the compression ratio increases, the optimum injection advance also increases which is probably due to a better spray penetration and atomization. Then for high compression ratio, the optimum injection advance decreases because of high temperature and pressure thereby needing shorter delay and thus, lowers optimum injection advance. From Figure 5, soya oil resulted to a high optimum injection advance, which suggests that soya oil have a longer delay period.

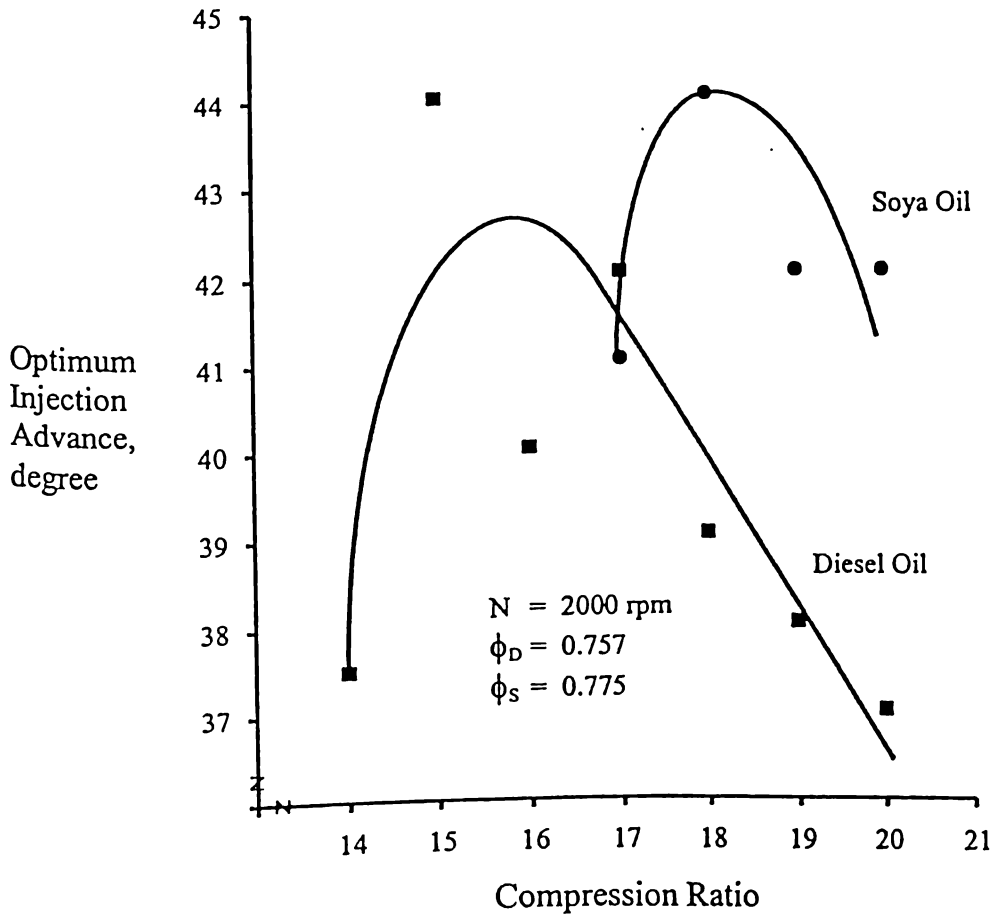


Figure 5. Optimum injection advance for maximum power.

3.5 Fuel Consumption and Efficiencies

The specific fuel consumption in g/kJ is the fuel flow rate necessary to produce a unit power. Figure 6 shows the specific fuel consumption as a function of injection advance. These are typical performance up to the maximum compression ratio (20:1) that the engine can be operated. The specific fuel consumption is inversely proportional to the BMEP for each fuel. Since the BMEP increases with compression ratio, the specific fuel consumption therefore decreases with compression ratio. The specific fuel consumption when either using diesel oil or soya oil is dropping significantly. The higher density and probably higher viscosity and lower volatility of soya oil, which resulted to poorer atomization, cause the variations of the two fuels.

The thermal efficiency is the ratio of the brake power (power output) to the fuel power (chemical energy input). The graphs of the thermal efficiencies against compression ratio at optimum injection advance are shown in Figure 7. As expected, the thermal efficiency increases with compression ratio since it is inversely proportional to the specific fuel consumption. It is encouraging to note that the soya oil attained 90% of the efficiency of diesel oil at a compression ratio of 20:1. This is caused primarily by the differences in calorific values and chemical properties.

The volumetric efficiency is the ratio of the actual air mass flow rate to the ideal mass flow rate. The average volumetric efficiencies are 0.738 for diesel oil and 0.723 for soya oil. The variation is caused by the difference in the equivalence ratios.

The combustion efficiency is a measure of the degree of the conversion of the original fuel to carbon dioxide but does not take into account any hydrogen not fully oxidized to water. The combustion efficiency of diesel oil increases with compression ratio because higher compression ratio produces higher compression pressure and temperature, which favor complete combustion. However, the results of the soya oil are quite doubtful because it was found out and proven later than the CO analyzer was faulty.

3.6 Emissions

The pollutant species are carbon monoxide, nitric oxide and unburned hydrocarbon. There are two ways of expressing the pollutant emitted: emission index or pollutant emission. The emission index of pollutant specie is expressed in grams of pollutant specie per kilogram of fuel while the pollutant emission of pollutant specie is the mass of pollutant specie per power output in kg/kWh. Carbon dioxide and oxygen are plotted against compression ratio as shown in Figure 8. The pollutant emissions and emission indices against compression ratio at optimum injection advance are tabulated in Table 3. Using soya oil gives a lower emitted pollutant as compared to using diesel oil, which is due to their differences in chemical structures and fuel properties.

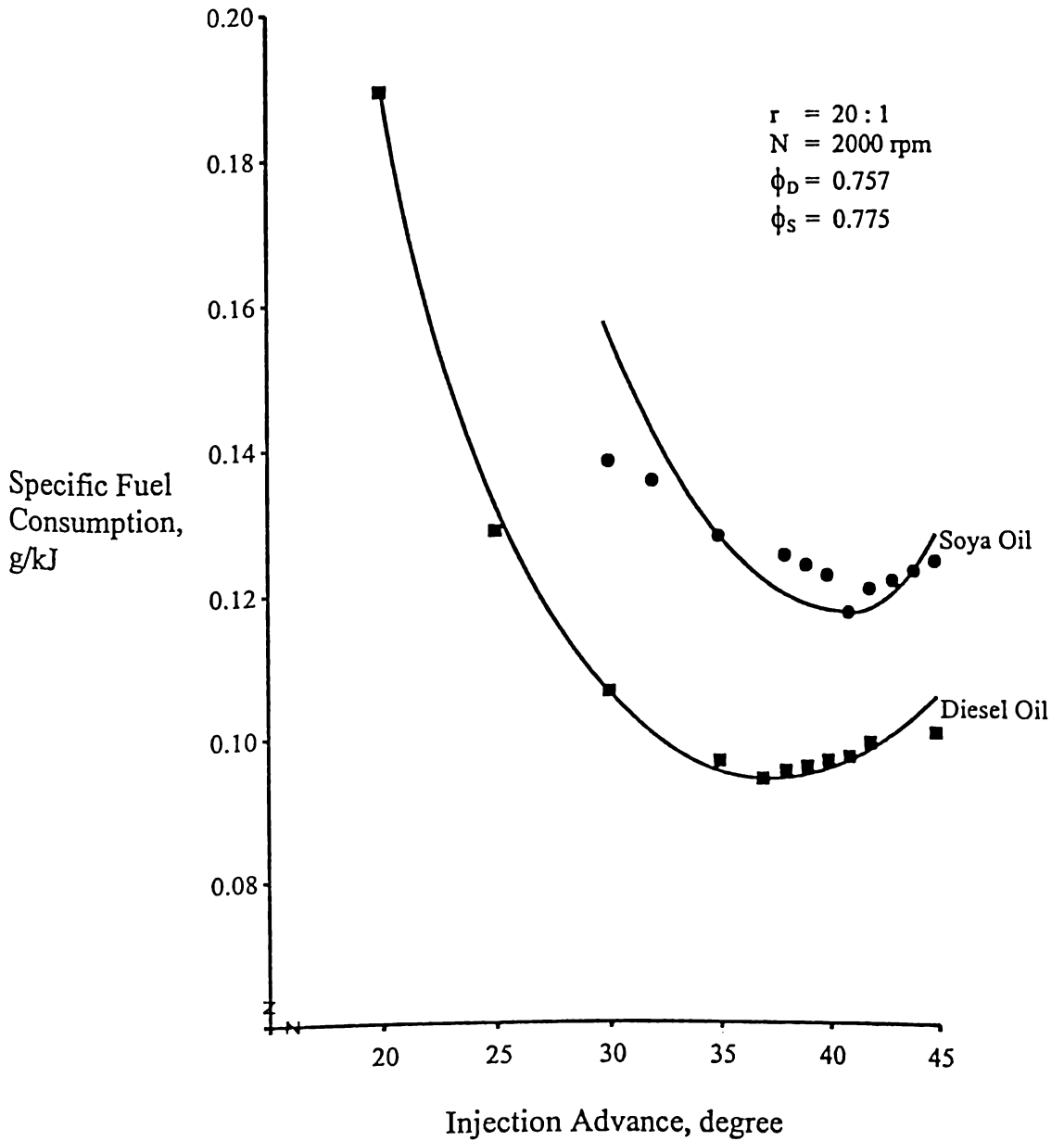


Figure 6. Specific fuel consumption variation with injection advance.

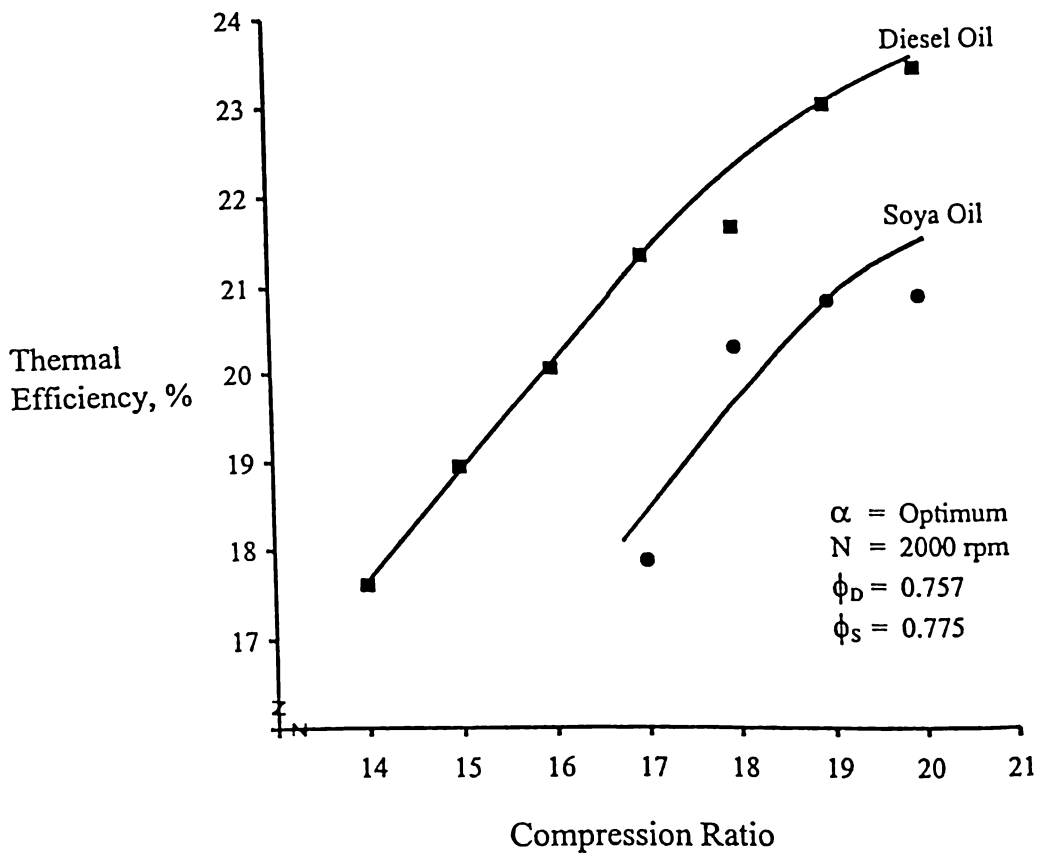


Figure 7. Thermal efficiency variation with compression ratio at optimum injection advance.

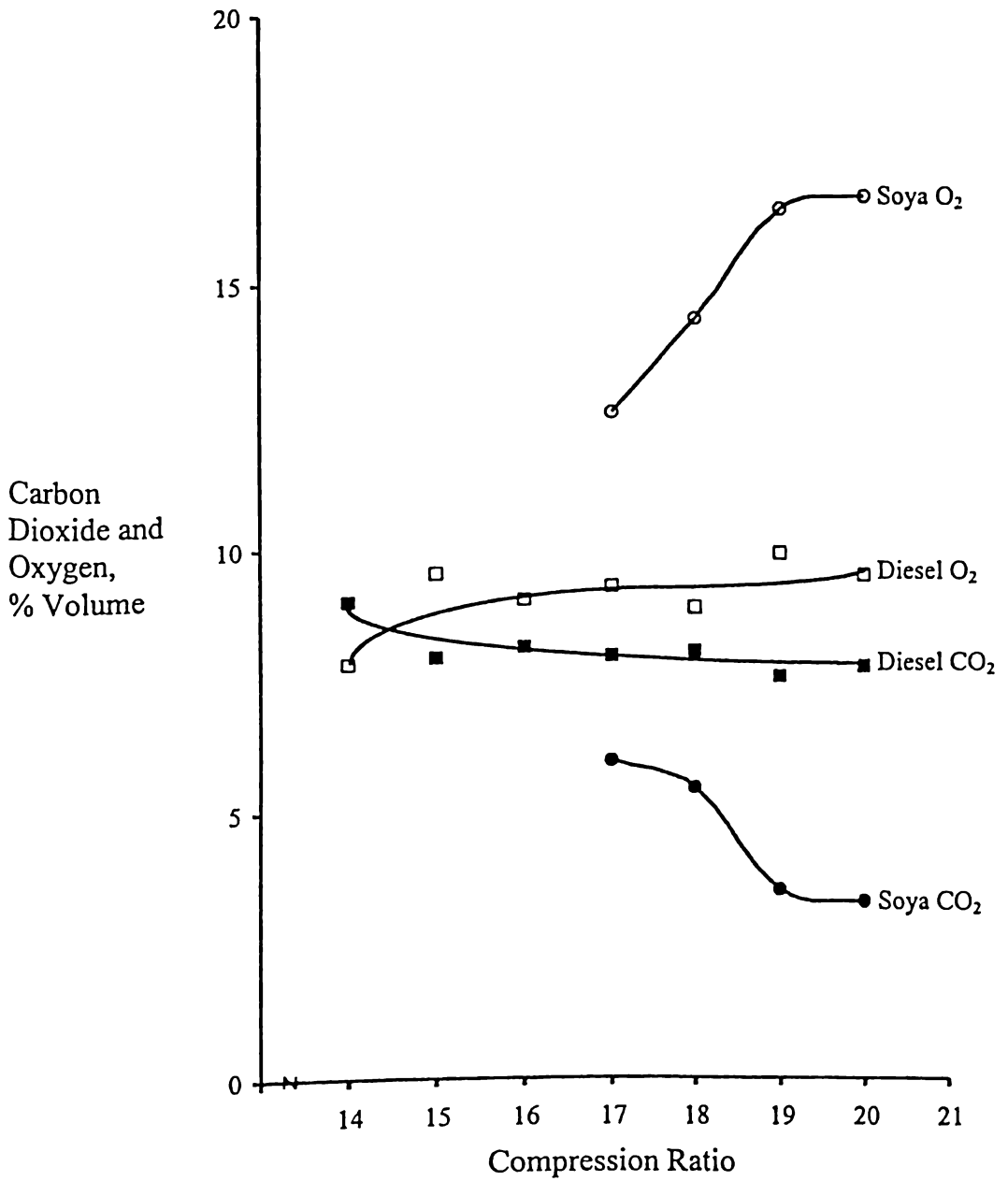
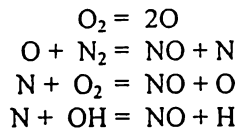


Figure 8. Carbon dioxide and oxygen wet analysis.

Table 3
Emissions

Diesel Oil							
<i>r</i>	α	Pollutant Emission, kg/kWh			Emission Index, g/kg fuel		
		CO	C ₃ H ₈	NO	CO	C ₃ H ₈	NO
14	37.5	0.04443	0.01082	0.00190	99.28	24.19	4.25
15	44.0	0.02637	0.00867	0.00311	62.87	20.68	7.40
16	40.0	0.01817	0.00620	0.00262	45.24	15.43	6.53
17	42.0	0.01856	0.00555	0.00289	48.94	14.63	7.63
18	39.5	0.01277	0.00338	0.00250	33.57	8.88	6.58
19	38.5	0.00714	0.00228	0.00237	20.18	6.45	6.69
20	37.0	0.00483	0.00165	0.00228	13.76	4.72	6.50
Soya Oil							
<i>r</i>	α	Pollutant Emission, kg/kWh			Emission Index, g/kg fuel		
		CO	C ₃ H ₈	NO	CO	C ₃ H ₈	NO
17	41.0	0.01287	0.01488	0.00215	24.81	28.69	4.14
18	44.0	0.00943	0.00672	0.00302	21.65	15.42	6.92
19	42.5	0.01047	0.00795	0.00297	24.15	18.36	6.87
20	42.0	0.01248	0.00697	0.00365	18.79	16.08	8.41

Nitric oxide is formed during the combustion process at various concentrations in all the spray regions. The widely accepted mechanism is that of Zeldovich [4] given below:



The chain reactions are initiated by the atomic oxygen, which is formed from the dissociation of oxygen molecules at high temperature reached in the combustion process. The NO formation is related to the oxygen atom concentration, which is a function of the concentration of the oxygen molecules and temperature. The optimum conditions for NO production are those of high local temperature, pressure, and oxygen availability and residence time. Mild NO is found in the turbulent diffusion-droplet burning region as oxygen entrainment occurs, then falls towards the tail of injection as the residence time and oxygen availability reduce. The lower NO emission of soya oil suggested that it had a lower flame temperature and possibly lower burning rate.

Carbon monoxide and propane concentrations are decreasing while oxygen concentration is increasing with increasing compression ratio. These are due to a better combustion (towards completion) at higher pressure and temperature. Carbon monoxide is one of the compounds formed during the intermediate combustion stages of hydrocarbon fuels [11]. As combustion proceeds to completion, oxidation of CO to CO₂ occurs through recombination reactions between CO and the

different oxidant. Carbon monoxide is maintained when recombination reactions are incomplete due to lack of oxidants or to low temperature. As mentioned earlier, the CO analyzer was faulty hence, the CO results are uncertain.

Unburned hydrocarbon (UHC) consist of either original or decomposed fuel molecules or recombined intermediate compounds with a small portion originally from the lubricating oil. Large droplets associated with injection pressure likely increases fuel impingement, thus, producing more UHC. It is also formed from fuel retained in the sac of the fuel injector, which escapes at a later stage of expansion process. Hydrocarbon oxidation is accelerated by high pressure and temperature and oxygen availability. It is worthy to note that with soya oil, the FID analyzer may not be measuring the actual concentration of UHC since soya oil contains oxygen and it is possible that other reactions are also taking place.

Previous experimental results showed that higher cetane number fuels have a tendency to produce more smoke [12, 15, 17]. This is attributed to the lower stability of these fuels that resulted in higher rates of carbon formation during the combustion process since more fuel is injected after the end of injection delay. Soya oil is possibly of lower cetane number than diesel oil as suggested by the chemical symbol. It was collaborated however, by a lesser smoke when using soya oil during the experiments. In general, the profiles of soot and carbon monoxide are similar [10]. Other reasons, which led to a higher emitted pollutant concentrations on diesel oil could be attributed by operating at the limit of maximum burning rate or at the limit of available oxygen or both [1]. Soya oil may have lower combustion temperature and due to its oxygen content may have introduced some chemical reactions.

IV. Conclusions and Recommendations

Soya oil as a substitute for diesel oil in compression ignition engine is technically feasible. The engine runs using soya oil with no modification at varying compression ratios and injection advances. Soya oil can be represented by an empirical chemical symbol as $C_{13}H_{22.6}O_{1.2}$ while diesel oil as $C_{14.4}H_{26.1}$. Soya oil releases 87% of the energy released by diesel oil. Consequently, soya oil is denser than diesel oil.

The misfire limits of the engine are compression ratios below 14:1 for diesel oil and 17:1 for soya oil at a constant speed of 2,000 rpm and injection rate setting of 5. The difference is due to the more complex molecular structure of soya oil. The optimum injection advance of soya oil is higher than diesel oil in the tested range of compression ratios. This indicates that soya oil has a longer delay period.

Soya oil can produce 95% of the BMEP produce by diesel oil, and soya oil is 10% less thermally efficient than diesel oil at higher compression ratios ($r = 19:1, 20:1$). The deviation can be attributed to their differences in calorific values, chemical compositions and fuel properties.

The CO analyzer was found out to be defective and therefore, the CO result is doubtful. The FID analyzer is also questionable since soya oil contains oxygen and may affect the determination of unburned hydrocarbon. Nitric oxide increases with compression ratio. Diesel oil has a higher nitric oxide emission and implies that it has a higher flame temperature and higher burning rate than soya oil.

It is highly recommended that further research and investigation be conducted for compression ignition engine using alternative fuels such as vegetable oil. The areas for further study should include modeling of the diesel engine using state of the art instrumentation; designing a high compression ratio engine to maximize the use of fuels with lower calorific value and ignitability; and endurance testing. Equally, an intensive research on the implications of alternative fuels on the economy and on the production of vegetable oil for fuel should be undertaken.

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