AN EXPERIMENTAL INVESTIGATION INTO THE USE OF LOCALLY AVAILABLE VEGETABLE OIL AS AN ALTERNATIVE TO DIESEL FUEL IN BANGLADESH

By

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The thesis titled "**AN EXPERIMENTAL INVESTIGATION INTO THE USE OF LOCALLY AVAILABLE VEGETABLE OIL AS AN ALTERNATIVE TO DIESEL FUEL IN BANGLADESH**" submitted by **Shaikh Md. Abdul Latif**, Roll No. 911419P, Session 1989-90 has been accepted as satisfactory in partial fulfillment of the requirement for the degree of Master of Science in Mechanical Engineering on November 9, 1995.

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ABSTRACT

An investigation has been carried out to identify the most promising alternative to diesel fuel from among the locally produced vegetable oils. In this pursuit informations have been collected for a number of locally produced vegetable oils regarding their current use, production potentiality and processing technology. Relevant fuel properties of four pure vegetable oils (Mustard, Groundnut, Linseed and Sunflower) have been measured. High viscosity was identified as one of the main constraints of using the considered vegetable oils in diesel engines directly at the normal temperature. Hence, kerosine was blended with the considered vegetable oils to reduce their viscosity and match their combustion characteristics with that of diesel. Fuel properties of the blended fuels were also determined and the implications of the observations have been analyzed. Test results show that the fuel properties of blends of kerosine with 40%-50% of linseed oil by volume are comparable to that of diesel fuel.

However, the engine performances were studied operating it with four different blends of linseed oil with kerosine (30%, 40%, 50% and 60% linseed oil with 70%, 60%, 50% and 40% kerosine respectively by volume). Test results show that rated power and brake thermal efficiency decrease, and bsfc increases when compared to diesel fuel operation.

From overall assessment of the pure vegetable oils considered and their various blends it is concluded that based on the current use, suitable physical and combustion behavior; linseed oil blended with kerosine may be considered as a suitable alternative fuel and can be used successfully in a diesel engine.

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ABBREVIATIONS

ASTM	American Society for Testing and Materials
A/F Ratio	Air Fuel ratio
Bsfc	Brake specific fuel consumption
BARC	Bangladesh Agriculture Research Council
BARI	Bangladesh Agriculture Research Institute
CI engine	Compression Ignition engines
CDSO	Crude De-gummed Soybean oil
CDP	Crop Diversification Program
Dbt	Dry bulb temperature
Gnt	Groundnut oil
HYV	High Yielding Variety
IC engine	Internal Combustion engine
Ker	Kerosine
Lin	Linseed oil
Mus	Mustard oil
MT	Metric Ton
POD	Palm Oil Diesel
rpm	revolutions per minute
RBO	Rice Bran Oil
SUS	Saybolt Universal Second
SI engine	Spark Ignition engine
SIT	Self Ignition Temperature
SBP	Short Boiling Point
SMT	Shale Mineral Turpentine
Sun	Sunflower oil
Ses	Sesame
Soy	Soybean

CHAPTER - 1
INTRODUCTION

1.1 Introduction

It is said that energy consumption pattern is an indicator of the socio-economic development of a country. It is also a measure of the quality of life. Energy consumption is growing day by day along with technological development. Although the industrialized and developed world consumes most of the energy resources, the demand of energy in the developing world has also increased in recent decades due to their economic take off and sustainability. Internal Combustion (IC) engines are widely employed in many development activities using a greater portion of world's energy resources. From the very beginning, the IC engines are being fuelled mostly by petroleum products like petrol and diesel. IC engines use only a small fraction of distillation products of crude oils. These crude oils have limited reserves. Any shortfall of petroleum fuels in the world market will, therefore, have a great impact on the economy of non-oil third world countries. So, the need for an abundant energy source for IC engine application has raised great concern. Among the various alternatives considered so far, vegetable oils have been identified as potential source in many countries. In view of the growing energy demand of our country it is thus reasonable to examine the use of locally produced vegetable oils of Bangladesh as a substitute fuel for IC engine.

1.2 Conventional Fuels and Their Prospects

Conventional fuels of IC engines are mostly petroleum products. These are produced by fractional distillation of crude oils.

Crude petroleum is generally found as underground deposits in porous rocks or sands or limestones derived from plants and trees buried thousands of years back. Southern Russia, the United States and the Arabian countries have the major reserves of this petroleum. Petroleum products consist of various hydrocarbons like paraffins (C_nH_{2n+2}), napthenes (C_nH_{2n}), aromatics (C_nH_{2n-6}) and olefins (C_nH_{2n}) having different molecular structures. Fractional distillation enables thermal separation of crude oils into a range of products - gasoline, kerosine, gas oil, and the various grades of residual fuel oils. Diesel engines consume diesel as its fuel which is a darkish brown liquid blended from kerosine and gas oil. Diesel engines are widely used in transport vehicles, in irrigation and water pumping in rural areas, in power generating plants and in various industries. This energy source is non renewable in nature and has limited reserve and it will be exhausted in near future if the consumption pattern continues at the present rate. As a result the whole world will have to face a tremendous oil crisis due to the availability constraint. Again, due to burning of theses oils, CO_2 content of the atmosphere rises as an absolute deposit thereby polluting the environment.

1.3 Awareness About The Environment

"Environmental Pollution" is a much talked issue which has drawn alarming concern worldwide. IC engines release Co_2 which is the main contributor to greenhouse effect that leads to global warming, climate change and many other adverse effects. The matter of environment protection strategies has been taken up in many national and international forums over the years. To day around 80% of the carbon emissions to the atmosphere is due solely to fossil fuel burning and it has got about 0.5% annual growth rate (15). Future atmospheric concentration of CO_2 will depend on fuel mix and energy demands as they affect fossil fuel consumption. So, strong emphasis on the use of non-fossil fuel alternative energy sources is necessary. Vegetable oils may be considered as suitable alternative in this regard.

1.4 Search For Alternative Fuels

Search for alternative fuels particularly for IC engine applications have received considerable importance in recent years. Several alternatives have been tried as substitutes to diesel engine fuels. Natural gas, biogas, alcohols, vegetable oils are some examples of such alternatives. Studies on the use of natural gas, biogas, and hydrogen fuels in diesel engines show that they have the relative advantages of availability in different regions. However, none of these fuels have yet proved itself a commercial success, although the practice of partial substitution has been introduced in many countries.

In Bangladesh, all petroleum products needed for IC engines are imported from abroad in exchange of hard earned foreign currency. Its reserve of natural gas is also very limited. This gas is being consumed both in domestic sector and in industrial sector. Even at the current rate of consumption the gas will not be available for a long time. On the other hand Bangladesh being a tropical country has a wide scope of producing a number of vegetable oils which are presently consumed both for edible and non-edible purposes. The overall production of some of these oils are however extremely small at present because of their limited use. It, therefore, seems logical to carryout indepth research on them to establish their true potential for using them widely in place of petroleum fuels for IC engines.

1.5 Suitability of Vegetable Oils as Fuel

Unlike petroleum based fuels, vegetable oils are geographically widely produced from a variety of products. Since, these oils are of plant origin, a large quantity of CO_2 derived from the burning of these oils are consumed by the plants themselves. Therefore, these oils do not contribute to the absolute deposit of CO_2. They are renewable in nature and environmentally sound due to minimum net effect on the pollution.

Vegetable oils are usually composed of about 95% triglycerides and 5% non-triglycerides. Triglycerides are basically esters of one molecule of glycerol and three molecule of fatty acids. Fatty acids are composed of a carboxyl group and a hydrocarbon chain having the chemical formula:

$CH_3-(CH_2)n$ - COOH

Hydrocarbon Chain   Carboxyl group

Fatty acids may be saturated or unsaturated. Vegetable oils are composed of a number of fatty acids depending on the value of 'n' and the degree of unsaturation along the hydrocarbon chain. Due to unsaturation, liquidity of oils at low temperatures are maintained but oxidation results from chemical attack by atmospheric oxygen. Oxidation increases the viscosity and in the long run creates storage problem resulting in heavy gum and wax deposits on metal components and fuel tanks.

Following the fuel properties it is observed that vegetable oils have almost the same heating value as that of conventional diesel fuel. Specific gravities do not differ much and are only 7-9 percent heavier than diesel fuel. High viscosity (about 12 to 17 times higher than that of diesel), long ignition delays, are usually observed. High viscosity affects the spray characteristics which leads to poor atomization, late burning and ultimately incomplete combustion. It also imposes operating difficulties of fuel pumps and injectors but it offers better lubrication performance.

Low cetane numbers of vegetable oils (34 to 40 compared with the range of 45-55 for diesel fuel) deteriorate self-ignition quality thereby creating problems in engine starting and smooth running. The remarkable variation of cetane number of diesel and vegetable oil may be due to the different chemical composition and the degree of unsaturation of vegetable oils. However, research continues to overcome the limitations imposed by vegetable oils to achieve better engine performance.

1.6 Substitution Techniques

Vegetable oils can be introduced in diesel engine by both the direct or indirect injection system. In direct injection system the oil is introduced into the combustion chamber directly by injector as the diesel fuel is injected in a CI engine. Direct injection system requires better atomization. So, pure vegetable oils are not suitable for direct injection at the normal temperature because of their high viscosity. Indirect system is therefore suitable for vegetable oils because the fuel here gets some preparatory time before ignition in the pre-combustion chamber.

High viscosity of vegetable oils can be reduced to a manageable limit by modifying the oils in three ways- either by preheating the oils to a required temperature or by blending it with a less viscous oil or by making vegetable oil ester with alcohol.

Preheating is required to such a temperature to attain the viscosity comparable to diesel fuel and then the oil can be introduced into the engine following direct or indirect injection system.

It has been experienced that vegetable oil has the advantage of miscibility with diesel or kerosine, and the blended fuels do not change the quality of solution for a long time at any mixed ratio. Thus a solution can be prepared by blending vegetable oils with either diesel or kerosine to reduce the viscosity thereby making the oils suitable for engine operation. This blend can be introduced into the engine where a partial substitution is possible.

Vegetable oil when mixed with methanol or ethanol in presence of a catalyst (usually sodium or potassium hydroxide) at about 50 °C, glycerol is replaced and an ester is formed - where fatty acids do not create problems in respect of unsaturation. This method of fuel modification improves fuel properties to meet the requirement of diesel engine, especially the low viscosity and high cetane number requirements.

Another method of using a single vegetable oil is to make emulsion with a certain percentage of water immediately before injection but this technique requires some engine modifications for making emulsion. Using a single vegetable oil in diesel engine a long ignition delay is experienced having its high Self Ignition Temperature (SIT). Addition of an ignition enhancher with the oil before introducing into engine reduces the ignition delay and gives better engine performance.

1.7 Objectives of the Present Research

This research involves investigations regarding the use of locally available vegetable oils in a direct injection, 4- stroke, water cooled, 2- cylinder diesel engine. The specific objectives of the present work may be identified as:

(1) To determine the present status and potentials of locally available vegetable oils in Bangladesh regarding their use in diesel engines.

(2) To determine physical and thermal properties of available vegetable oils relevant from the viewpoint of their use in engines (i.e density, viscosity, volatility, carbon residue, ash content, heating value, flash point etc.) and to compare their properties with those of diesel.

(3) To select suitable vegetable oils for engine performance study based on availability, current use and closeness of properties to diesel.

(4) To study the performance of the engine running it with the suitable vegetable oils following favorable substitution techniques and to compare the performance parameters with diesel fuel.

CHAPTER - 2

LITERATURE REVIEW

The concept of using vegetable oils as a substitute of diesel fuel is an old one which dates back around 70 years (26). Since then very little has been done regarding its vast use as diesel engine fuel primarily due to abundant availability of diesel. Moreover, there was no serious complaint against the use of diesel because its adverse effects on environment were not apparent at that time. In recent years, vegetable oils have received considerable importance to be used in diesel engines, because of its environmental friendliness and renewable nature. As a result, the international interest in the use of vegetable oils as diesel fuel has been once again renewed.

Apart from technical aspects, the study of P D Dunn, and Wasan Jompakdee (17) gives a statistical information regarding vegetable oil production, its demand and relative cost analysis in Northern Thailand. They also compared the data obtained with diesel demand and cost. Several vegetable oils - groundnut oil, black soap, soybean and castor oil were studied. It was established in the investigation that vegetable oils could meet the entire diesel demand in the agricultural sector in Northern Region of Thailand if 10% of cultivable land goes into vegetable oil crop production. Thus the country could even be self-sufficient in fuel. Among the oils studied, Ground nut oil proved to be the most prospective for its highest energy yield and favorable economic suitability and short growth period. Soybean was also established as engine fuel because of its general availability and high economic suitability. In comparison with current available diesel cost, vegetable oil was not found economic as fuel but it was expected that the situation might change in future from the viewpoint of replacing energy sources by renewable vegetable oils and a possible rise in diesel costs at a rate higher than general inflation. Apart from the use of vegetable oil as fuel, its use as a lubricant is another prospective area.

The study of Yaginuma et al (39) reflects the Japanese experience using different vegetable oil blends with kerosine to improve the performance of a small type high speed diesel engine under high load condition. They worked with a single cylinder, direct injection, 4-stroke, air cooled, diesel engine applying four blends (20%, 40%, 60% & 80% by volume) of soybean oil with kerosine as well as rapeseed oil with kerosine and compared the results with that of pure diesel fuel. They also studied the spray distribution of each blend in atmosphere using 4 hole nozzle injector. The result shows that a blend of 20% vegetable oil with 80% kerosine by volume fairly improves the thermal efficiency of the test engine under high load. Therefore, it was recommended to use 20% to 40% vegetable oil blends as a successful alternative. Spray characteristics was studied both under high and low pressure injection in atmosphere where the low pressure injection showed better performance.

Investigation of A. Permsuwan et al (35) was directed towards the suitability of vegetable oils as lubricant considering physical properties of both mineral and vegetable based lubricants. They found vegetable oils more suitable as lubricant than as fuel when compared to conventional mineral oil based lubricants. Sunflower, Olive, Rapeseed and Castor oils were applied to a single cylinder SI engine in place of conventional lubricants. Comparing the physical properties (viscosity index extreme pressure resistance and volatility) of the oils and their performance during the test castor oil proved to be the most promising. They noted that since the vegetable oils have higher viscosity they would result in greater value addition if used as lubricants rather than as fuel. Again vegetable oils are easily biodegraded than mineral oils, so it reduces pollution effect on environment. Following the investigation report vegetable oils are better recommended to be used as alternative lubricant than as alternative fuel.

Masjuki H. H., and Sapuan M. S. (27) investigated the performance characteristics of diesel engine running with Palm Oil Diesel (POD) and its blends with conventional diesel as well as their effects on wear characteristics. Palm Oil Diesel is methyl ester of crude palm oil developed by Palm Oil Research Institute of Malaysia. The research carried out on a 7 hp, 4-stroke, single cylinder, condenser cooled diesel engine - fuelled by POD, conventional diesel as well as their blends of 25%, 50% and 75% by volume. Engine performance and wear characteristics of piston ring, cylinder liner and other rubbing components have been studied for each of the alternative fuel and its blends. The results showed that maximum power was developed at 1950 rpm for 50% POD blend with diesel by volume compared with other blends. They also noted that diesel produced the lowest power at the same speed. So, the use of POD or its blends with diesel improved bhp at the same speed. This was because of the higher specific gravity and viscosity of POD and its blends with diesel resulted in more fuel injection into the engine. Although the test engine required almost the same bsfc at the lower speed up to 2000 rpm, POD fuelling required lower bsfc at the higher speeds. This might happen because POD acted as fuel as well as lubricant resulting in less heat losses. It was concluded that POD and diesel blend of 50% by volume showed the best outcome for bhp and bsfc parameters. The study of wear characteristics showed that POD and its all blends with diesel increased anti-wear characteristics compared to using either pure POD or diesel as fuel.

Bari and Roy (14) examined the suitability and prospects of locally available Rice Bran Oil (RBO) as diesel engine fuel in

Bangladesh. Physical and thermal properties were measured and its higher viscosity was reported as a main problem of using it directly into the diesel engine at normal conditions as an alternative to diesel fuel. They carried out the experiment using kerosine blends with 50% RBO by volume running a 2-cylinder, 4-stroke, direct injection, diesel engine at variable load conditions but at constant speed of 1500 rpm. Performance test results showed a slight decrease of rated power of the engine but an increase in thermal efficiency and bsfc. Bsfc increased because of high fuel consumption to produce the same power. Chemical composition of RBO was analyzed and it was reported that RBO has got 12% oxygen in it. This oxygen might take part in the combustion process thereby supplying excess oxygen to the blended fuel to produce the same power as diesel resulting in higher efficiency. Because of its low cost of production and the present limited utility, RBO was recommended as a potential substitute for diesel fuel for self-reliance of the country and saving foreign currency.

Kotsiopoulos and Yfants (26) tried to use waste olive oil as an alternative to diesel fuel in a 4-stroke, direct injection, diesel engine. Engine performance was observed applying olive oil and kerosine blends of 0/100, 25/75, and 50/50 percent by volume. Running the engine at variable loads showed that as olive oil percentage was increased in the blends, bsfc increased but the maximum pressure decreased. Exhaust emissions from running the engine with each blend were analyzed and the results showed that smoke content of exhaust increased as the load on the engine increased. It was finally concluded that the olive oil and kerosine blend of 50/50 percent by volume proved to be the most promising when compared to other blends.

In U.K, Nwafor and Rice (31) investigated the performance of an air cooled, unmodified diesel engine running with neat rapeseed oil. The results obtained were compared with the performance obtained using only diesel in the same engine. They noted the viscosity of rapeseed oil as a main problem of using it directly into the engine. The overall performance was such that the maximum power output was reduced, brake thermal efficiency was increased due to decrease in friction power having the higher viscosity of rapeseed oil, mechanical efficiency was increased and HC emissions were lower but bsfc at 3000 rpm were similar when compared with the baseline data using only diesel in the engine.

In Nihon University, Japan, Fukuo Yaginuma et al (40) tested a single cylinder, water cooled diesel engine running with blends of a heavy fuel and low grade oil kerosine for comparison of performance to diesel. The results showed that a mixture of 60% fuel oil and 40% kerosine (by volume) improved thermal efficiency fairly in case of heavy loading for high pressure injection. The experiment was carried out at several injection pressure using three types of injection hole diameter in order to observe the spray distribution and penetration effect in the atmosphere. Small size injector hole diameter of 0.3m at high pressure injection developed a tip velocity of 120 m/s in the atmosphere. High tip velocity is very important for improvement of fuel atomization. Also this blended fuel was cost effective than the mere diesel, in Japan.

Apart from vegetable oils use of alcohol fuels as diesel alternative has been studied widely in many countries. In Japan, S. Moriya et al (28) studied the exhaust emission quality and engine performance using various blends of ethanol and diesel, adding kerosine as strong solving agent. Ignition temperature for each blend was measured independently and effect of the blends on engine performance was noted. Ignition temperature of ethanol was the highest whilst ignition temperature of diesel and kerosine were about the same at low level temperature and, therefore, ignition temperature of blend increased as the ethanol percentage in the blend was increased. The result of the experiment showed that although bsfc increased, the thermal efficiency, NO_x and smoke were decreased when ethanol ratio was increased in the blend.

Although further research is required for successfully employing vegetable oils in diesel engine as alternative fuels it has been observed in many cases that the power and efficiency of diesel engine operating with vegetable oil is not significantly different from the performance of the engine when used with diesel fuel alone. Two major problems of using vegetable oils as alternative to diesel fuel are viscosity and the carbon build-up in the cylinder and around the injector. This carbon arises from the formation of gums due to thermal decomposition of the fuels having their unsaturated chemical bonds. Therefore, before selecting a vegetable oil its particular characteristics of carbon formation must be known in order to run the engine safely. P.D. Dunn and W. Jampakdee (18) developed an experimental set-up of measuring the rate of carbon build-up by using a transducer. Due to change in resistance of the carbon film, the transducer's sensor gives a voltage reading which increases with increase in the thickness of carbon film. The authors carried out the experiment running the engine at 1500 rpm applying 40% load. Further tests were recommended at other speeds and load settings and they suggested that the tests can be applied for other fuels.

Highly viscous crude vegetable oil has a tendency to polymerize (40) into three dimensional structure during storage and combustion. When this oil is converted to its esters, its thermal stability is improved as experimentally found by F.N. Ani et al (11) in U.K. They worked with palm oil and its esters and combustion characteristics were also studied using suspended single droplet combustion in a constant temperature furnace. The ignition delay of palm oil methyl ester was observed to be longer than that of diesel fuel. In order to study the combustion behavior, its droplet sizes in the spray was also observed and it was found that viscosity has a significant effect on droplet size distribution.

Higher viscosity caused poor atomization and slow rate of burning of bigger droplets and consequently longer ignition delay. To improve the atomization preheating of crude oil and to improve the ignition quality addition of an ignition enhancer was suggested. Alternatively, increase of injection pressure with some modification of nozzle hole was also suggested to improve the ignition property. Increase in injection pressure increases the engine speed which, in turn, changes the temperature/time and the pressure/time relationships and, therefore, decreases ignition delay.

To overcome the problem of ignition delay and also to improve the engine performance operating with vegetable oils, Bhasker, T et al (30) in India, conducted an experiment with Low Heat Rejection (LHR) engine. The test engine was modified using a ceramic coated cylinder head and air gap cylinder liner to maintain the low heat rejection from the engine. The high incylinder temperature thus, reduced the ignition delay and made the combustion faster for vegetable oil fuel injected into the combustion chamber and therefore, thermal efficiency of the engine was improved significantly due to better vaporization of fuel. Alternatively, they used two ignition improving additives namely Short Boiling Point (SBP) oil and equal quantities of SBP+Shale Mineral Turpentine (SMT) but worked with unmodified engine. The result showed a better engine performance and reduction in smoke emissions thereby reducing ignition delay due to the additive used.

As already mentioned earlier, use of vegetable oils in diesel engine creates a problem of fouling of the injector i.e spray formation is effected and deposits subsequently dislodge and enter the combustion chamber. Another problem is the emission of visible smoke comprising of carbon and heavy hydrocarbons in the exhaust gases. In order to overcome these problem and to reduce the oxides of nitrogen emissions, F. Kiannejad et al (25) suggested to emulsify the fuel with water leading to improved atomization. They studied the engine performance at two operating speeds of 1500 and 750 rpm at variable loads. Dry vegetable oil based fuel and emulsion of this with 5, 10, and 15% by volume of water were tested. The emulsion were prepared continuously, immediately prior to injection by means of a high speed rotary mixing device. The result shows that emulsification reduces the oxides of nitrogen emission and smoke. Emulsified fuels exhibited slightly longer delays and lower thermal efficiencies at the same conditions.

Cost and energy evaluation is necessary before considering any vegetable oil as a viable substitute for diesel fuel. Because it is not only the price of vegetable oil compared to commercially available diesel fuel but also a socio-cultural factor for which vegetable oils are not yet established as a viable alternative to diesel fuel. Dunn, P.D. et al (17) analyzed an index known as energy ratio for vegetable oils available in Northern Thailand. Energy inputs and outputs were evaluated for the production of vegetable oil fuels. Inputs mainly considered the cost of oil production i.e, land preparation, planting, irrigation, fertilizer, pest control, harvesting, threshing or stripping, drying, storage, transportation etc and also the cost involved in the maintenance of relevant agricultural machinery, oil recovery from seeds. Output analysis considered the percentage of oil in seeds, energy content and cost of oil. The main advantage of vegetable oil is that some of the inputs are oil based products, for example, oilcake may be used as fertilizer which enables the cultivator not to spend much money for expensive chemical fertilizers. All these factors were considered in input and output analysis. They defined 'Energy Ratio' as:

$$\textit{Energy Ratio} = \frac{\textit{Energy Content of Vegetable Oil}}{\textit{Total Energy Input}}$$

For successful use of vegetable oil energy inputs must be less than the energy content of the oil. Higher the energy ratio better the vegetable oil to be established as fuel.

Nwafor and Rice (32) studied a single cylinder unmodified diesel engine performance operating with rapeseed oil modified in three ways i.e. using rapeseed methyl ester and its blends with diesel fuel, neat rapeseed oil and its blends with diesel, preheated neat rapeseed oil. They made comparison between the fuels operating on the same engine. Engine performance was normal in all the cases. Blends of rapeseed oil and diesel proved improvement in performance at low speeds operations. Fuel heating method proved to be beneficial at low speed and part load operation. It was concluded that under favorable condition the engine performance with vegetable oil fuel could exceed that of diesel fuel operation.

CHAPTER - 3

STATUS OF VEGETABLE OILS IN BANGLADESH

As Bangladesh is an agro-based country and suitably placed on the globe it has technological suitability and potential resources such as suitable soil, water and climate to grow more than one oilseed crops throughout the year (10), and as such a wide variety of vegetable oilseeds are produced each year mainly in the winter season. Common plant origin vegetable oils are mustard, sesame, soybean, sunflower, linseed, groundnut, cottonseed etc. Among the vegetable oilseeds produced, only a few are used for extraction of oils from them for multi-purpose uses. The production of oilseeds in this country seems to suffer from unplanned input and management strategy. The existing policy is not enough to support a large scale production and processing towards attaining self-sufficiency (24,36). Production of some oilseeds can be increased in a planned way if the current extremely limited use of their oils are extended to non-edible purposes as substitute of petroleum products and mineral oils.

In Bangladesh only around 4.3% of the total cultivable land consisting an area of about 1.45 million acres goes into production (23,29) of mustard, sesame, groundnut and sunflower. An additional 1.2 million acres of lands in tea gardens, forest areas and the uncultivable lands in 'haor' and 'char' can be used for production of vegetable oilseeds. The total production can be estimated upto 1.0 to 1.2 million MT of oilseeds against the current production of 0.45 million MT. Detail production features for the last 5 years are shown in Table 3.1.

Vegetable oils are mainly consumed as cooking oil which is estimated to be around 85% of the total available oils in Bangladesh (23). Although several researches have been carried out on edible oilseeds but no consideration has been given to non-edible oils and their production potentialities. Main non-food uses in Bangladesh are in soap industry, surface coating (e.g. paints, varnishes etc.), printing inks, cosmetics and personal care products (especially coconut oil), textile processing, leather processing, shoe polish etc. Obviously the demand is not very high and there is no drive for increasing their production.

Another remarkable advantage of vegetable oils is the facility of utilizing their by-products. Oilseeds and oil processing based by-products are a source of many industrial raw materials. Livestock and Fishery sectors largely depend on oilcake derived after extraction of oil from oilseeds, Oilcake is largely consumed as traditional feed for cattle and as organic natural fertilizer. Successful poultry and fishery sectors in Bangladesh have generated enormous demand for oilcake in recent years. By-products from oil refineries are used in soap industries as raw materials.

Only a comprehensive plan and strategy involving various agencies in production, processing and policy issues with definite objectives and targets can increase production of High Yielding Variety (HYV) of oilseeds and to explore diversified use of these oils can really contribute to the national economy thereby establishing self-reliance in energy supply both for edible and non-edible purposes and save a large amount of hard earned foreign currency. Fortunately Bangladesh government has taken up a program to strengthen research and extension of oilseed crops under Crop Diversification Program (CDP), associated with a number of organizations and research centres for increasing total oilseed production in the country. In addition to edible oilseeds considerable importance has been received to facilitate non-conventional uses of linseed, cottonseed, castor etc.

3.1 Existing Production Strategy and Technology

A survey of the suburban areas of Dhaka city where a wide variety oilseeds are available and a number of oil mills extract huge amount of branded and non-branded vegetable oils, it was learnt that the technology differs significantly for cultivating different oilseed variants. The matter is discussed briefly in the following sections.

3.1.1 Mustard

This is widely produced and available everywhere in Bangladesh as winter season product and its oil is consumed for edible purpose. Mustard seed covers approximately 70% of the total vegetable oils (10) in this country. In addition to traditional local variety there are 10 High Yielding Varieties (HYV) of mustard namely Kalyania, Sonali Sarisha, Sampad, Sambal, Daulat, Dali, Agrane - which give yield of about 2 to 3 times that of traditional one. Eighty percent of the farmers grow mustard without applying any recommended fertilizer, irrigation and other management practices. Only 2-3% of the oilseed area is covered by irrigation (10) but normally no pesticides are applied. It is usually grown as a sole crop. However, in some areas it is also grown as a mixed or an intercrop. The maturity period varies from 70 to 100 day depending on the variety of crops. Mustard oilseed contains 39-46% (36) oil as shown in Table 3.4. An oilmill reports that some 40 kg seed produces 12-13 litre oil and 25-26 kg of oilcake, it means the oil extraction ratio can be estimated as

3:1. In addition to local products, a small quantity of mustard oilseeds are imported from foreign countries like Poland and Canada to meet the current demand of edible oil of the country. The main reason of this is that the huge productive potentiality of this country is yet to be established to make its production compatible with the needs. Besides a large quantity of non-branded mustard oil, a considerable quantity is also available under a number of branded names. These brands are consumed mainly by the urban people. Rose Brand, Shapla Brand etc. are some examples of Brands of mustard oil available in the local markets. Pure mustard oil is rarely available in the country. In most cases sesame and linseed are mixed with mustard seed and crushed for oil. Current average price of this oilseed is Tk. 20-25 per kg and that of the oil is Tk. 60 - 70 per litre. The price remains lower in January - April period i.e. in the season. Oilcake is obtained as solid substances during extraction of oil from its seed and is sold at a retail price of Tk. 3-4 per kg.

3.1.2 Sesame

Based on area and production sesame stands second in rank i.e. next to mustard. Depending on seed category, appearance, and oil extraction quality and quantity, two distinct types of sesame are noticed in Bangladesh - the white seeded and the red seeded. The white seeded variant also locally known as Guzi sesame is short-day form that is grown in winter. The red seeded also locally known as Baishakhi sesame is long-day variant and are grown in the summer season. This type is available at a low price everywhere in Bangladesh. There is another type of sesame that is rarely found and is grown in the rainy season, preferably in highlands.

The above types of sesame are normally grown without taking any special care - irrigation, pesticides etc., so these are commonly sensitive to waterlogging and susceptible to disease. Three additional HYV have recently been identified by Bangladesh Agricultural Research Institute (BARI) with about 50% higher yield potential over the current one (10). Improved management practices like fertilizer use, time of harvest, practice of intercropping should be followed to have the best possible results from these varieties.

Sesame oil is mainly consumed as edible oil in rural areas but the consumption is limited compared to mustard oil and its potentiality for use in any other purpose is not so far reported. Local sesame oil is not seen in the open market under any Brand name. Some varieties of sesame have the main advantage of producing them round the year and therefore, more potential for increased production.

Oilseed of sesame contains 40-44% (36) oil but the extraction ratio is approximately same as that of mustard i.e. 3:1. The current oil price is Tk. 50-53 per kg.

3.1.3 Soybean

As a crop this is still insignificant in Bangladesh. A small quantity of soybean oilseed is locally cultivated. However, the popularity of this oil for edible purposes is increasing day by day. Import records show that about 65% (10,12) of total edible oil import goes to the account of Crude De-gummed Soybean Oil (CDSO), in recent years. Main supplier countries of CDSO are USA, Brazil and Argentina. This trend continues since the crude soybean oils are available in international markets at a price much favourable compared to other locally produced edible oils like mustard oil, sesame oil etc. No use of soybean oil other than that for edible purposes is so far reported in this country. A number of branded soybean oils are available in local urban markets particularly in major cities - Dhaka, Chittagong, Sylhet, Khulna etc. Some examples of available soybean oil brands and the name of their producers are shown below:

Sl.No	**Brand Name**	**Producer's Name**
1.	TRIPTI	Bengal Foods Ltd, Dhaka.
2.	EVERYDAY	Everyday Foods Corporation, Dhaka.
3.	SURMA	Surma Vegetable Oil, Dhaka.
4.	KINGS	Bangladesh Edible Oil Ltd, Dhaka.
5.	RUPCHANDA	Bangla Edible Oil Ltd, Dhaka.
6.	PHOOLKOPY	Chittagong Vegetable Oil Industries Ltd, Chittagong.
7.	MINAR	Habib Vegetable Products Ltd. Noakhali.
8.	POSTMAN	Dhaka Vegetable Oil Industries.
9.	STARSHIP	Abul Khair Vegetable Oil Industries Ltd, Chittagong.
10.	RUPAN	Rupan Oil & Feeds Ltd, Dhaka.

Average cost of these oils is Tk. 50-55 per litre. Basically, producers of these oils acts as trading channels than as producers. They import crude Soybean oils in exchange of foreign currency, refine those in their own premises using refining equipments set-up, pack those oil in various packsizes and then sell in the local open markets. This common scenario has been observed even over the last years when the demands for edible oil increased rapidly.

3.1.4 Sunflower

Sunflower is a relatively new oilseed crop in Bangladesh and only one variety is produced in a limited quantity in Gazipur and Faridpur districts in the winter season. A large scale production is not seen because of common trend of consuming mustard oil or soybean oil, and the lack of sufficient technical inputs to the cultivators in the country. These plants can be cultivated the year round and can be intercropped with soybean, groundnut and pulses. It contains 40-44% of oil in it (Table 3.4). The crop itself is moderately salt and drought tolerant, so there is bright scope of production area expansion in charlands and saline areas of the southern districts. Because of this potential for adaptability to Bangladeshi farming system huge production targets can be set for its other uses also.

Reportedly, farmers of some highlands area in Gazipur produce this crops with greater interest and prefer to consume its oil for edible purposes than other ones. Unlike soybean or mustard oil, sunflower oil is not widely available in the open market under any brand name or otherwise. Therefore, the representative oil price could not be known but seed can be obtained at Tk. 25-30 per kg.

3.1.5 Linseed

Linseed is widely produced almost everywhere in Bangladesh in the winter season only. It has the main advantage over the other vegetable oil seeds of being produced as a side product of wheat. It means, it can be cultivated simultaneously on the wheat field. No special fertilizer or irrigation is required for its cultivation as all the inputs required for wheat cultivation are sufficient. Linseed productivity is the same as those of mustard or sesame and sometimes gives a higher productivity depending on the technology of input and management practices. It is also grown as a single crop. This crop has a moderate maturity period of 100-115 days (36) and the seed contains about 40% oil. Thus linseed oil has an extraction ratio higher than the extraction ratio 3:1 of mustard or other common vegetable oils. In the winter season the seed price remains considerably low and therefore its oil is used as an adulterating additive to the main edible oils to make the edible oil commercially competitive. Linseed oil on its own is unsuitable for cooking, so, its main use lies in the non-edible field. This is basically a drying oil, and as such, normally is used for industrial purposes i.e. in producing paints and colours, in pudding additives used for glass and wood furniture fittings. Reportedly, a small quantity of linseed oil is used in herbal medicines. In the off season a large amount of dry linseed remain unused and consumed as feed for livestock and fisheries. No potential measure have so far been reported to diversify its alternative uses.

3.1.6 Groundnut

Groundnut is mainly produced in Savar, Pabna and in a small quantity in the other parts of the country. At present, four improved varieties are available for cultivation namely Dhaka-1, DM-1, DG-2 and the ACC-12. Dhaka-1 (10) is the traditional variety, DM-1 is very dwarf and short durated and can be intercropped with sugarcane, maize, cotton etc. Most of the farmers grow local varieties of groundnut without the inputs like irrigation and fertilizer. As a result the present yield level is very low whereas the yield level of HYV's of DG-2, DM-1 & ACC-12 with better management practice is three times. There is much scope for area expansion for groundnut cultivation suitably in river side and charland areas.

Groundnut is not widely used as edible oil source rather it is consumed directly as roasted nut/snack. Raw groundnut is available at a local price of Tk. 20-25 per kg but its oil is rarely found in the open markets. The raw seed contain much more oil than any other oilseed. Table 3.4 shows the oil content to be 48-50% and it can be extracted by the same method as other oilseeds. Therefore, groundnut can be a big source of non-conventional oil to be established for alternative uses.

In addition to the oilseeds described above, oil can be extracted from maize, cottonseed, castor but their true potentialities are not determined because of their extremely limited use. Recently maize is marketed as edible oil in this country. Cottonseed oil is exclusively being used for soap making. Use of castor oil is limited to varnishing industries as it is unsuitable for cooking.

3.2 Oil Extraction Methods

Oil mills in Bangladesh generally utilize outdated technology that yields less than maximum output of edible oil in terms of both quantity and quality. Due to this outdated processing equipment, 6% product is lost which accounts for 10,600 MT of oil loss annually (24). Use of new, more efficient extraction techniques provide a major opportunity to achieve the full potential of the processing industry.

Existing Oil extraction facilities in Bangladesh can be better explained in 3 main types-

i. Indigenous ghanis,
ii. Power driven mechanized oilmills,
iii. Solvent extraction plants.

Bullock driven indigenous village ghanis extract a considerable portion of locally produced oilseeds (about 30%) in rural areas. However, the extraction efficiency of the ghanis is very low where about 20% residue oil remain in the cake. This means it can extract only 70% of the oil content of the oilseeds.

In urban or suburban areas electrical power driven mechanical oilmills process about 65% of oilseeds available in Bangladesh. Efficiency of such mechanical ghanis depends on the maintenance of expellers and ghanis, filter etc., where upto 89% of the extractable oil can be extracted (24). The operation of such oil mills can be better explained with a block diagram of Figure 3.1.

A mechanical ghani consists of a mortar and pestle arrangement drive by an electric motor, pulley and belt system. A typical oilmill consists of 4-10 pairs of ghanis, belt driven from a single shaft. Oil is extracted in two or three stages in such an oil mill.

Oilseed is poured in the rotary conical mortars from top where seed is pressed to extract oil. Oil starts to separate from the highly pressed seed and emerges through an aperture at the base of mortar. It is the first stage extraction where the oil is collected into a large drum of crude oil. Oilcake obtained from this 1st stage contains huge amount of oil and subsequently taken into an expeller for further pressing out of oil. Usually the cake obtained from the 2nd stage expeller operation is sold in the market and the oil is taken into the crude oil drum. As a measure of efficiency a typical oil mill subsequently pass this oilcake through further expeller arrangements for pressing out oils. To remove solid substances from the crude oil obtained from both ghanis and expeller operation, the crude oil is then pumped with a reciprocating pump into a filter press where the oil releases solid substances. Refined oil is then collected from the filtering machine into a pure oil drum for packing and marketing.

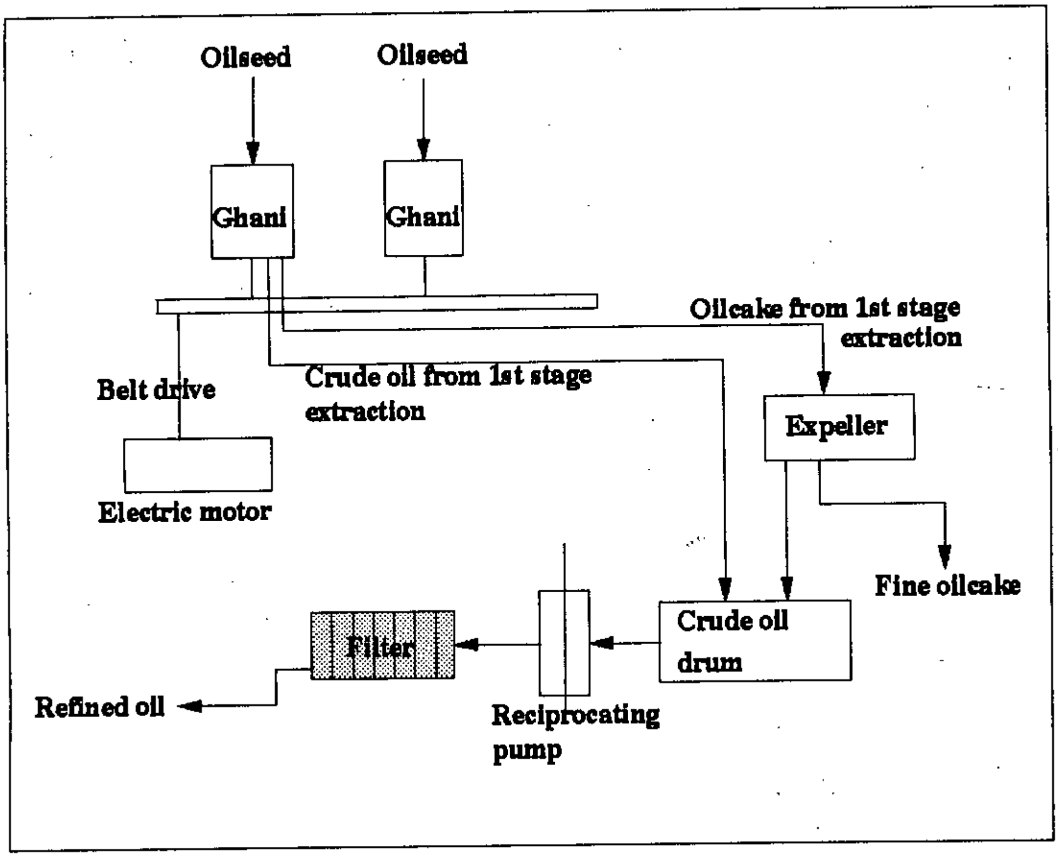

Figure 3.1 : Flow diagram of oil processing in a typical mechanised oil mill.

Solvent extraction is the most modern way of oil extraction where only 1% residue oil remains in oilcake. Presently four solvent extraction plants exist in Bangladesh for extraction of marginal oil remaining with oilcake. However, these mills remain inoperative most of the time for want of vegetable oilseeds. The mills can run only about 5 months in the year which means they have only 42% capacity utilization (24). Therefore, the main constraint lies with production not with the processing industry.

CHAPTER - 4
EXPERIMENTAL SET-UP AND PROCEDURE

This chapter describes the different experimental set-up and procedures both for measuring fuel properties and studying engine performance.

4.1. Determination of Fuel Properties

This section describes experimental set-up and procedures of measuring some relevant fuel properties - density, viscosity, volatility, carbon residue, ash content, heating value and flash point. Individual set-up for each parameter are outlined below:

4.1.1 Density

Density of fuel at different temperatures were measured by a standard 25 ml marked flask. Weight of the fixed volume of fuel (25 ml) was measured at different temperatures by an electronic balance which measures upto 0.0001 gm. The density values are reported in kg/m^3.

4.1.2 Viscosity

Viscosity of fuels were measured as per ASTM standard D88-56 (4) using saybolt viscometer and accessories. Time of falling of 60 ml sample under controlled conditions through a standard oil tube was measured. This time is reported as Saybolt Universal Second (SUS). Corresponding kinematic viscosity was obtained from ASTM standard conversion chart ASTM D2161-79 (3) and the value was checked by computing the same as per empirical formula over a wide range of SUS. Measured values of kinematic viscosities are presented on ASTM standard D341-87 (9) Viscosity- Temperature charts.

4.1.3 Volatility

Volatility characteristics of fuels were determined by distillation as per ASTM standard D86-78 (6). A 100 ml sample was distilled at atmospheric pressure. Temperatures were recorded after every 10 ml of condensate collection, and the results are presented with a Temperature vs. Percentage recovered graph.

4.1.4 Carbon Residue

ASTM standard D189-81 (8) method was followed to determine carbon residue of the test fuels. A weighed quantity of sample was placed in the apparatus subjected to destructive distillation. At the end of specified heating period, the final weight of remaining material in the crucible was taken. The weight of the residue was calculated as the percentage of original sample and the result is reported as Conradson carbon residue.

4.1.5 Ash Content

Ash content of the test fuels were measured by ASTM standard D482-87 (7). Carbonaceous residue obtained after conradson method was subjected to destructive heating in a muffle furnace at 700-800 °C for 10 minutes. Crucible was then cooled and weighed. The residue at this stage was the ash content of the test fuel and it was reported as percentage weight of original sample.

4.1.6 Heating Value

Heating values of fuels used in this research were measured experimentally following ASTM standard D240-87 (1) using an oxygen bomb calorimeter. One gm of previously weighed sample was burnt at constant volume. Heat of combustion was computed from temperature observations using a Beckman thermometer before, during and after combustion with necessary temperature corrections.

4.1.7 Flash Point

Flash point of test fuels were measured as per ASTM standard D93-85 (2) using Pensky-Martens closed tester. The sample taken into the closed-cup tester was heated slowly with continuous stirring. A flame was inserted into the oil cup at every 2°C temperature rise of the oil. Flash point of the fuel was noted as the lowest temperature at which application of the test flame causes the fuel vapor to give flash of fire and then disappear.

4.2 Determination of Engine Performance Parameters

This section describes the experimental set-up for measuring the different engine performance parameters. The engine used in this investigation was a Yanmar model 2TGE, four stroke, two cylinder, water cooled, direct injection diesel engine. The experimental set up in this respect involves the engine and dynamometer assembly, air inlet and exhaust system, cooling water inlet and outlet system fuel inlet system and measuring facility. Figure 4.1 is a schematic diagram while figures 4.2 to 4.5 are the photographs of the engine experimental set-up. The equipments used to measure the different parameters for calculating the engine performance in this test are given below:

4.2.1 Load

A water brake dynamometer model TFJ-250L was used to load the engine. The amount of load in kg applied on engine was measured from the digital display unit connected with an electronic load cell transducer associated with the dynamometer unit.

4.2.2 Speed

The engine speed was measured directly from the same digital indicator unit of the dynamometer, which is a magnetic type tachometer. Although the dynamometer was connected with the engine through a universal joint, power transmission was made by a reduction gear box. Therefore speed obtained on the digital display unit was a reduced fraction of the actual flywheel speed. In calculating brake power, the speed value on the digital unit was used which was incorporated in dynamometer design and its constant.

4.2.3 Temperature

Temperatures at cooling water inlet and outlet, Lub oil cooler outlet, exhaust gas and air inlet, and Lub oil, were measured by chromel - alumel type of thermocouple which were connected to Omega digital thermometers. These thermometers have a measuring range of -50°C to 1200°C with a resolution of 1°C and they require no room temperature correction.

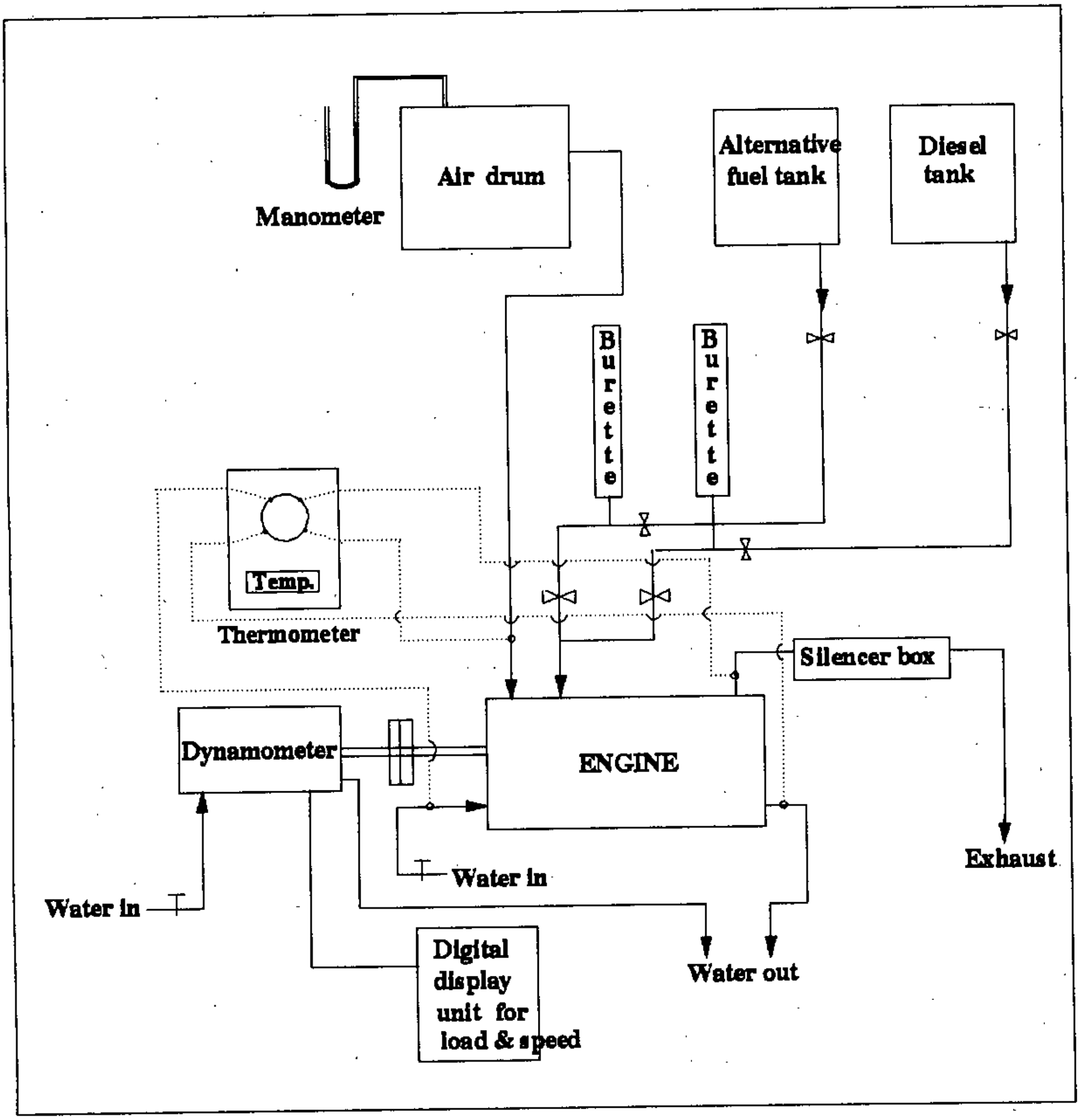

Figure 4. 1 : Schematic diagram of the test engine set-up.

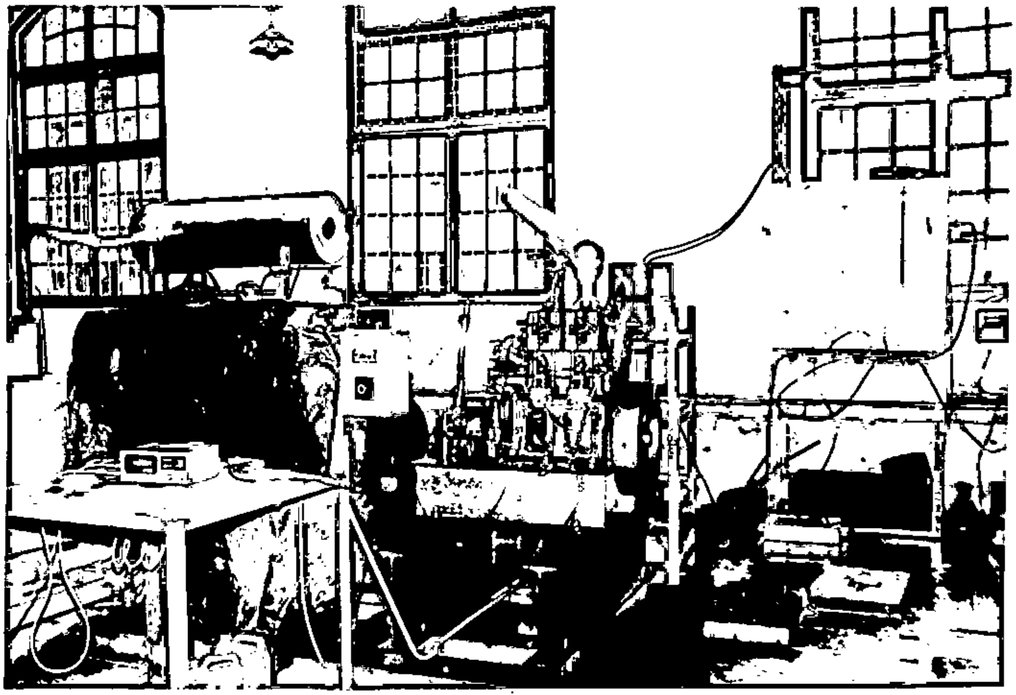

Figure 4.2 : Photograph of the engine and test bed assembly.

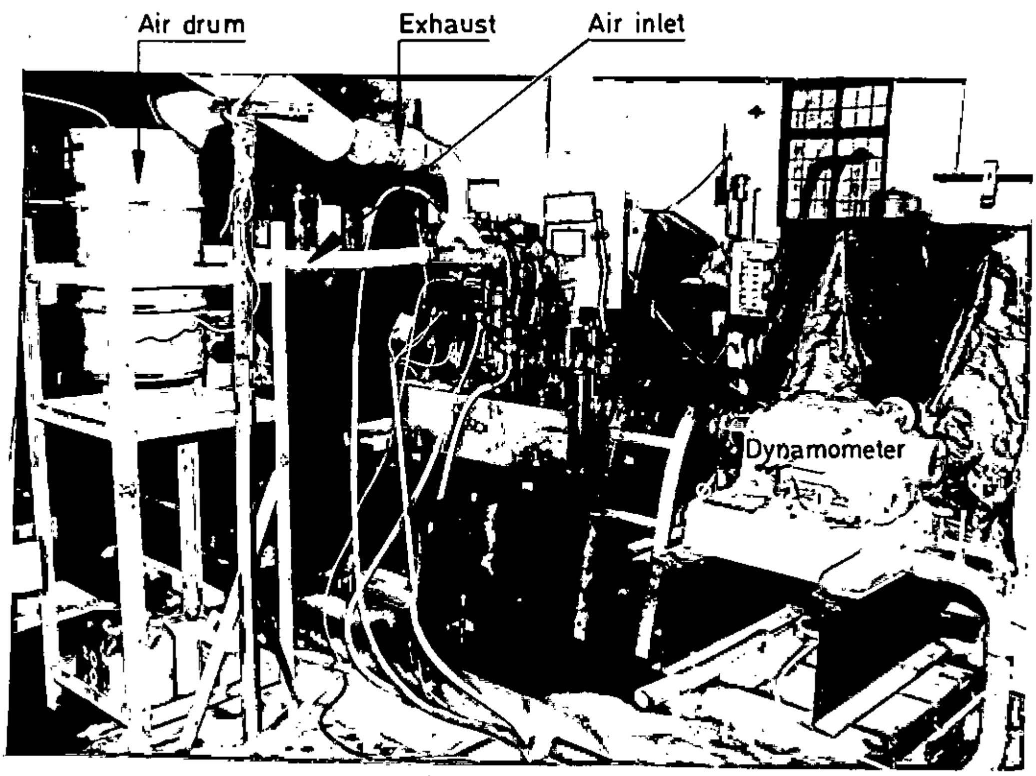

Figure 4.3 : Photograph of the engine, dynamometer, air inlet and exhaust system.

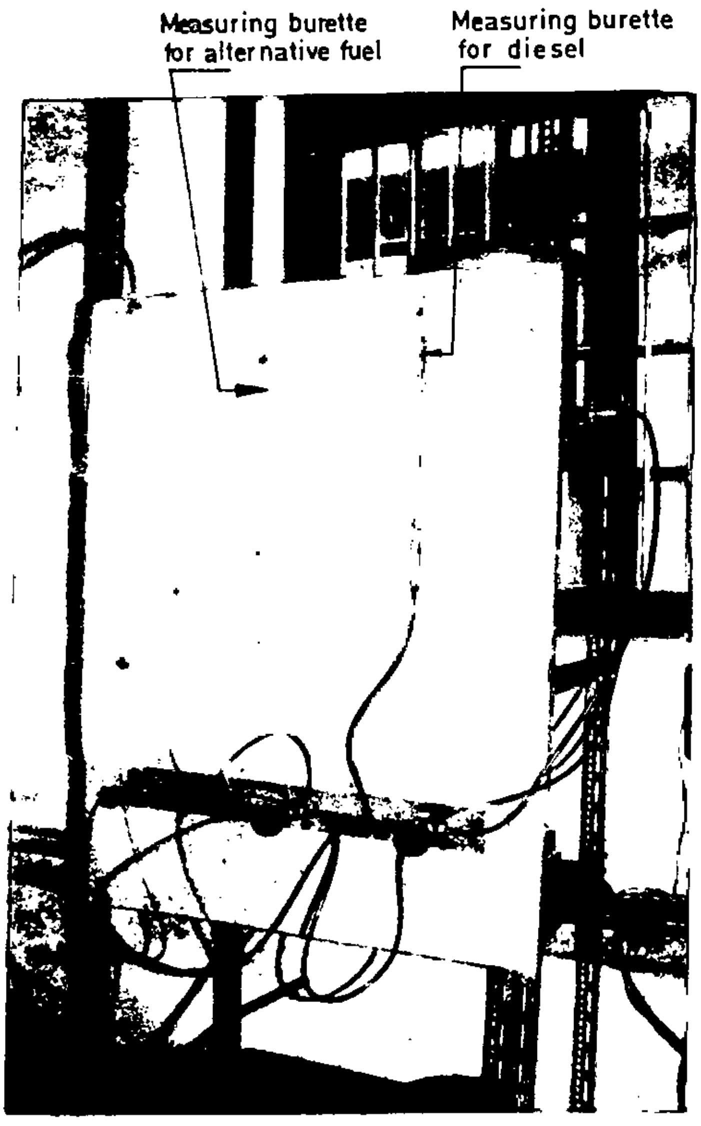

Figure 4.4 : Photograph of fuel measuring system.

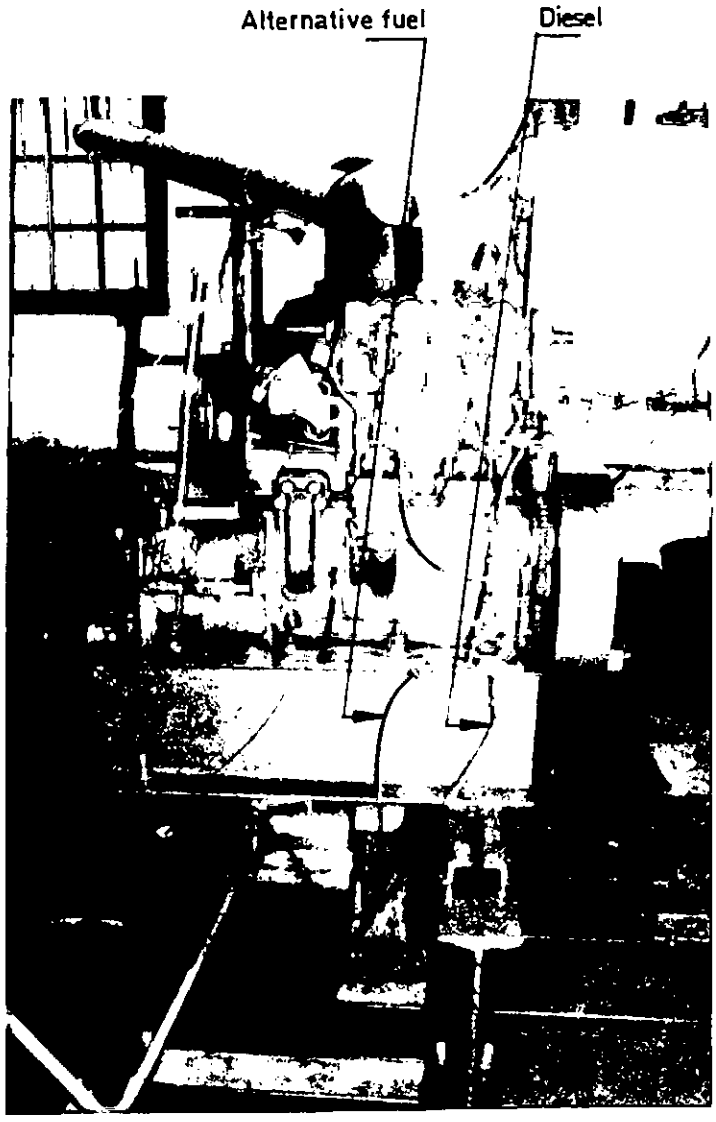

Figure 4.5 : Photograph of fuel inlet system into the engine.

4.2.4 Fuel Flow Rate

The diesel and vegetable oil delivered to the injection pump under gravity were measured volumetrically by a 100 c.c. burette and a stop watch. Figure 4.4 shows a photograph of the fuel measuring system.

4.2.5 Air Flow Rate

The air inlet manifold of the engine was connected to an air drum. A parabolic nozzle with a water manometer connected to the opening of the drum was used to measure the air flow rate. The nozzle diameter was 19 mm and the coefficient of discharge of the nozzle was 0.92.

4.2.6 Cooling Water Flow Rate

Cooling water flow rate was measured by collecting water into a bucket from outlet pipes for a given time measured by a stop watch. By weighing the collected water, flow rate was converted to kg/min.

4.3 Test Procedure

This section deals with the test procedure adopted in running the engine with diesel and vegetable oil fuels.

Before starting the engine, necessary precautions and safety measures such as - checking mechanical joints and connections lubricating oil level, cooling water flow level dynamometer water supply were taken into consideration.

Fuel preparation by mixing the components in desired proportions in the fuel tank was also done prior to starting the engine. Five test runs were conducted - one with pure diesel and four test runs with four blends of linseed oil with kerosine.

Separate fuel blends of 30% Lin + 70% Ker, 40% Lin + 60% Ker, 50% Lin + 50% Ker and 60% Lin + 40% Ker were prepared in separate fuel tanks for test runs. The proportions of linseed oil and kerosine was mixed thoroughly in the fuel tanks before passing the blend into the fuel line.

To establish the baseline for comparison of performance with linseed oil and kerosine fuel blends, the first test run was conducted using diesel fuel only, at various loads and at rated speed of 2000 rpm. This procedure was repeated, keeping the speed constant and running the engine by one of the blends as fuel. To run with blended fuel, the engine was however first started with diesel and the engine was allowed to warm up for 15-20 minutes, before application of any appreciable load. The load was then gradually applied to the engine and correspondingly the governor settings were shifted to maintain the speed constant at 2000 rpm. At about 30% of rated load of the engine, fuelling was switched to the blended fuel and the load was increased slowly. At about 40% of rated load, the engine kept running for a while (approximately 10 minutes) to obtain the steady state condition of the engine at that load and speed operating with blended fuel. From this stage, readings of engine performance parameters were taken. In the same way successive readings were taken at different load settings up to the full load. At each load setting, engine speed was maintained constant by adjusting the governor setting. After completion of taking readings, the engine was kept running for a while with pure diesel to flush off the vegetable oils from the fuel lines, injector pump, fuel filter etc. in order to avoid clogging of fuel line or injector caused by gum formation.

CHAPTER - 5
RESULTS AND DISCUSSION

This chapter deals with analysis of experimental results obtained both in fuel testing and in engine performance study.

5.1 Fuel Testing

In this experimental investigation six different fuels - four pure vegetable oils, diesel and kerosine were tested for their properties related with engine performance. For this purpose, Density, viscosity, volatility, carbon residue, ash content, heating value and flash point were determined for each fuel. In addition to the above single fuels, fuel properties were also determined for seven fuel-blends. Among these, four blends were made from pure linseed oil and kerosine at different proportions by volume (30%, 40%, 50%, and 60% linseed oil with kerosine) and three blends were made from each of 50% mustard, 50% groundnut and 50% sunflower with 50% kerosine. The purpose of blending kerosine with vegetable oils are discussed in the following sections. Diesel properties were measured for comparison with vegetable oils and fuel blends at the same operating conditions.

Fuel testing results are presented in Table 5.1.4 and 5.1.5 and in Figures 5.1.1 to 5.1.9. It may be noted that the three graphs shown in figures 5.1.1 through 5.1.3 depicts the results of viscosity measurement. One graph is for comparison of the viscosities of the six single fuels, one is for comparison of 50-50 of vegetable oil and kerosine with diesel and the other one is for comparison of the four blends of linseed oil and kerosine with diesel which were used in engine performance study.

From Table 5.1.4 it is seen that the variation of heating value among the pure vegetable oils under consideration (mustard, groundnut, linseed and sunflower) are not very significant and they all have heating values less than that of diesel and kerosine. Table 5.1.5 shows that when these vegetable oils are mixed with kerosine, the heating values of the blends are improved in accordance with the amount of kerosine added in the blends. Obviously, this is so because of the higher heating value of kerosine. Heating value of a fuel influences the fuel consumption of the engine, and thereby affects other engine performances. So an engine running with these vegetable oils would require more fuel to compensate their low heating values to produce the same power output when compared to diesel fuel operation. In this respect blends of vegetable oil are expected to give better results than pure vegetable oils.

Figure 5.1.1 compares viscosities of mustard, groundnut, linseed and sunflower oil with that of diesel over a range of temperature. All these vegetable oils have distinguishing viscosity features. At normal atmospheric temperature of about 30-35°C, all these vegetable oils are about ten times viscous than diesel. They are, therefore, unsuitable for use in diesel engines straightway. From the plots of figure 5.1.1 one may note that linseed oil has the lowest viscosity. However although viscosity decreases as the temperature increases none of the pure vegetable oils gives viscosity value comparable to diesel.

Figure 5.1.2 shows the variation of viscosities with temperature for 50%-50% blends of vegetable oils with kerosine, and compares the sample with diesel. It is very clear that these blends have considerably low viscosities compared to the pure vegetable oils. One would also not miss to observe that the viscosity of these 50%-50% blends are still higher than that of diesel at any given temperature. Figures 5.1.2 and 5.1.3 show that the fuel blends follow the same trend in respect of viscosity ranking as pure vegetable oils shown in figure 5.1.1. Among all the blends, the blend of 40% linseed oil and 60% kerosine gives the viscosity variation closest to diesel at the same temperatures, as shown in figure 5.1.3. Therefore, since the property, viscosity is seen to be greatly affected by temperature and the amount of kerosine in the blends and at the same time it has great influence on the engine performance, the blend of 40% linseed & 60% kerosine may be considered most suitable for use in engines from viscosity point of view.

Density of fuel determines the specific gravity which ultimately affects fuel mass flow rate and hence the brake power. So, for fuels having the same heating value and volume flow rate, a low density fuel will give less power output. Figures 5.1.4 through 5.A.6 show the variation of fuel density over a wide range of temperature. Figure 5.1.4 shows that no pure vegetable oil density below 100°C is comparable with that of diesel at 32°C. In figures 5.1.5 and 5.1.6 all the fuel blends show lower density than diesel at any temperature. Therefore, the variation of density over a wide range of temperature will be useful when the heating method of fuel modification is followed to reduce the high viscosity constraint of vegetable oils.

Figure 5.1.7 to 5.1.9 compare the volatility characteristics of single fuels and their blends with kerosine. The plots represent that vegetable oils on their own are less volatile than diesel but when these oils are blended with highly volatile kerosine the blend shows higher volatility upto the point of exhaustion of kerosine in the blend. After the exhaustion of kerosine from the blend, evaporation of pure vegetable oil starts and therefore, follows the pattern as shown in figure 5.1.7. The fuel volatility has the most significant effect on engine starting operation. For easy starting of the engine, fuel must have low boiling temperatures for the initial evaporations. In this experiment fuel recovery was not made over 70% for the pure vegetable oils because after this point, boiling temperatures were observed to drop. In fact, these reduced temperatures are not the true boiling temperatures of that recovery (over 70%). The declining temperatures were observed due to the presence of insufficient fuel vapor at the point of temperature measurement and that the rate of evaporation as per ASTM standard could not be maintained. The 70% oil recovery occurred at some 325-350°C. Above this temperature fatty acid content of vegetable oils start to decompose chemically and form a product having a very high boiling temperature which can not be attained at the normal atmospheric pressure following ASTM distillation procedure (32).

In Table 5.1.4 flash points of the four vegetable oils under consideration, diesel and kerosine are presented. Comparison of these experimental results show that the vegetable oils have very high flash points compared to diesel or kerosine. This parameter is also inter-related with volatility characteristics found in figure 5.1.7. Since the evaporation temperatures of vegetable oils are higher, fuel vapors coming out from these give flash at the corresponding higher temperatures than those for diesel or kerosine. Vegetable oils are composed of longer carbon chains and they have a high degree of unsaturation (3 to 5 double bonds) which explains the higher flash point temperatures. So these oils will have the advantage of having negligible fire hazard in handling and storage operations.

From table 5.1.4 it can also be noted that carbon residue for pure vegetable oils are reasonably low although ash contents are rather high in some cases compared to diesel. Reportedly, when these fuels are used in engine, deposition of carbon in the cylinder and around the injector creates operating problem. This problem probably arises from the gum formation due to thermal decomposition of the vegetable oils at higher temperatures.

From overall assessment of the fuel properties as shown above it appears that blend of linseed oil with kerosine looks considerably promising as a substitute for diesel. Performance studies of the engine was therefore carried out with such blends.

The fuel properties of the considered vegetable oils obtained in the present study are compared with those obtained from the recent work of Zahurul (41) and also with those of Bari (13). This comparison is shown in table 5.1.6. It is found that the fuel properties obtained in this study are comparable to the findings of Zahurul (41) and Bari (13).

5.2 Engine Performance Study

Results obtained from the experimental data running the engine with pure diesel and four blends of linseed oil and kerosine (30% Lin+ 70% Ker, 40% Lin+ 60% Ker, 50% Lin+ 50% Ker and 60% Lin+ 40% Ker) are presented in Tables 5.2.1 through 5.2.5 and in Figures 5.2.1 through 5.2.8. The purpose of running the engine with pure diesel is to establish a baseline result in order to compare the performances of the engine by operating the engine with different fuel blends of linseed oil and kerosine under the same operating conditions. In each test run with fuel blends the engine was first started with diesel and after some time (20-25 minutes) it was switched over to one of the fuel blends. The engine was found to run well with each blend as long as the blend was injected after warm up with pure diesel. No abnormality in respect of sound was observed during operation with any of the fuel blends. In all the test the engine was run at constant speed of 2000 rpm which is the rated speed of the engine, and over a range of loads. For ease of comparison, each of the performance parameters as obtained from all the above test runs with five fuels (diesel and the 4 blends) are displayed on a same graph paper based on derated brake power. Figure 5.2.1 through 5.2.8 show all such plots.

Fuel consumption pattern of an engine has considerable effects on other performance parameters. It is therefore a vital indicator of engine performance. Figure 5.2.4 shows that fuel consumption for all the operations with blended fuels is higher than that for diesel operation at all power outputs. From the fuel properties measurement it was seen that heating value of blended fuels were less than that of diesel and also the heating values decreased as the percentage of linseed oil was increased in the blend. Also density increased with increase in percentage of linseed oil in the blend. Thus the above parameters have significant effect on fuel consumption. As a result, to produce the same power as that of diesel, mass flow rate of the blended fuel increases as shown in figure 5.2.4. This is in line with the findings of Nwafor (32) where higher fuel consumption was observed with neat rapeseed oil operation. Bari and Roy (13) found the same result for RBO operation.

It is also observed from the figure 5.2.4 that at higher loads, fuel consumption with blended fuel increases at a faster rate which is apparent from the increasing gradient of the fuel consumption curves. At higher loads combustion of fuel blend is not completed and thus a portion of blended fuel remains unburnt because of low burning effect of blended fuel. The plots of fuel consumption also indicate that the least fuel consumption occurs with diesel operation and fuel consumption increases as the percentage of linseed oil increases in the blend. Variation of fuel consumption among the blended fuels at light loads are therefore less significant that at high loads.

The plots in Figure 5.2.1 compares brake specific fuel consumption (bsfc) with brake power developed in all the cases of engine operation with different fuels. It is evident from these figures that bsfc for all the blended fuel operations are higher than that for diesel fuel operation and bsfc increases as the percentage of linseed oil increases in the blend. This variation of bsfc is much more significant at higher loads. The plots also show that rated power of the engine with blended fuels is reduced and this reduction increases with increase of linseed oil percentage in the blend. These two observations are also revealed in Figures 5.2.10 and 5.2.11. In quantitative term a decrease of 6.3%, 9.86%, 10.56% and 13.28% of rated power over the diesel operation are observed at 30%, 40%, 50% and 60% of linseed oil respectively in the blend. In respect of bsfc 8.37%, 10.67%, 13% and 16.62% increase over diesel operation are noted corresponding to the rated power output at 30%, 40% 50% and 60% of linseed oil in the fuel blend. Bari and Roy (13) also obtained high bsfc and a 4% reduction of rated power for RBO operation running the same engine. As already noted earlier, for lower heating value of blended fuel its consumption is higher than the corresponding baseline consumption with diesel. Thus to produce the same power, blended fuels result in higher bsfc. To produce the same rated power as diesel, the engine needs relatively more blended fuel which could not be injected by the injector designed for diesel injection. This explains why the rated power of the engine with blended fuel is decreased.

Variation of brake thermal efficiency with brake power produced are shown in Figure 5.2.2. The trend of these plots show lower brake thermal efficiency for blended fuel compared to the baseline result obtained with diesel particularly at high load conditions. At lower loads this variation is insignificant. Moreover it may be noted that the blend with 30% linseed oil shows higher thermal efficiency than that for diesel. Since the engine ran at the same speed, it required less fuel at low loads resulting in complete combustion of the fuel blend which ultimately gives better brake thermal efficiency. With 30% linseed oil in the blend, the 70% portion of kerosine improves combustion rate and therefore a higher brake thermal efficiency than diesel is obtained. For the same reasons, efficiency decreases as the amount of linseed oil added in the blend increases.

Figure 5.2.3 shows the plots of A/F ratios with brake power output. The diesel fuel operation shows improvement over that of the blended fuel operation. At the same power, it is also noted that A/F ratios increases as the amount of linseed oil added in the blend decreases. Since the A/F ratio is defined as the ratio of air flow rate to the fuel flow rate on mass basis, the quality of combustion products depends on this parameter. It was already seen in the bsfc graphs and fuel consumption patterns that for blends of linseed oil, the fuel consumption and hence bsfc was more to produce the same power. At any power the air intake into the engine cylinder per cycle is same for diesel and for all the blended fuel operation. It is thus obvious that A/F ratios for blended fuels are less than that for diesel. Because of higher fuel consumption of the blended fuel containing higher amount of linseed oil, the A/F ratio decreases at the same rate.

Variation of air consumption patterns with brake power output for diesel and blended fuel operations are shown in Figure 5.2.5. Air consumption pattern is basically a measure of breathing ability of the engine. As the graphs show, the air flow rate for all fuel blends are lower than that for diesel and it increases with the increase in the amount of linseed oil in the fuel blend. The decrease of air flow rate is caused by increased inlet air temperature. As the engine runs for a long period and the load increases, the overall temperature of the engine body increases because of higher combustion temperature inside the cylinder. This can be seen from the increasing exhaust temperature as shown in Figure 5.2.6. This graph shows that exhaust temperature increases with decrease in percentage of linseed oil in the blends. It means for any power blended fuel having lower percentage of linseed oil gives higher air inlet temperature. This increase in temperature results in decrease in air density. The mass flow rate of air is thus decreased.

Figure 5.2.6 represents exhaust gas temperature versus brake power output relationships. Exhaust gas temperature is an indication of how much energy is being converted to power inside the cylinder. From this relationship it is observed that exhaust temperatures for all the fuel blend operations are higher than that obtained for diesel fuel operation. This high exhaust temperature may be attributed to slow burning rate because of longer ignition delay. Nwafor (32) also obtained such high temperature operating the engine with neat rapeseed oil. Blended fuels having higher percentage of linseed oil give relatively lower exhaust temperature. As the amount of linseed oil increases in the blends, its viscosity increases and causes self lubrication of the engine cylinder and piston resulting in better heat transfer to the coolant which ultimately leads to lower exhaust temperatures. For better lubrication effect, friction power should be less and the output power should be increased, but it did not happen in this case. A considerable heat is retained with cooling water because of better heat transfer with fuel blend operation having higher percentage of linseed.

Figure 5.2.7 shows the variation of heat energy retained with exhaust gas. The trend of this plots are similar to those for exhaust temperatures. Fuel blend containing lower percentage of linseed gives higher brake power but higher energy is retained with exhaust. This can be explained with the figure 5.2.8 where heat rejection in cooling water is less for fuel blend having lower percentage of linseed oil. Plots of energy in cooling water versus brake power output in figure 5.2.8 shows the similar trend as that for figure 5.2.7 and 5.2.6 for the same reasons.

Figure 5.2.11 shows how rated power and maximum brake thermal efficiency vary with the increase of percentage of linseed oil in the blend and Figure 5.2.10 gives the variation of bsfc at the rated power. It is evident from this two figures that rated power and maximum brake thermal efficiency decrease but bsfc at the rated power increases with the percentage increase of linseed oil in the blend. This is because of the relatively lower heating value of blended fuel having higher percentage of linseed oil. This is explained in figure 5.2.1.

Figure 5.2.9 compares the rated power and the bsfc at the rated power for the blended fuel operations with those for diesel fuel operation. It is observed from this figure that engine gives lower rated power and higher bsfc at the rated power for blended fuel operation compared to diesel fuel operation. A decrease of 6.3%, 9.86%, 10.56%, and 13.28% of rated power and an increase of 8.37%, 10.67%, 13% and 16.62% of bsfc at the rated power over diesel operation are noted corresponding to 30%, 40%, 50% and 60% of linseed oil in the blend.

Bsfc and brake thermal efficiency obtained in the present study in case of a 50%-50% blend of linseed oil with kerosine fuelling are compared in Figures 5.2.12 and 5.2.13 with the results obtained from a recent study of Zahurul (41). In the study of Zahurul (41) 50%-50% blended fuels of sesame and soybean with kerosine were used operating the same engine at the rated speed of 2000 rpm. From Figure 5.2.12 it is clearly observed that the bsfc values are very close to the present study. Figure 5.2.13 shows that 50%-50% blend of sesame with kerosine gives better performance from the brake thermal efficiency point of view.

CHAPTER - 6
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

From this experimental investigation the following conclusions may be drawn:

1. Heating values of the vegetable oils considered do not vary significantly although these are lower than that for diesel. So, vegetable oils when used in a diesel engine will reduce the power output of the engine.

2. High viscosity are identified as a main problem of using the considered vegetable oils directly in diesel engines. However, when these oils are blended with kerosine, their viscosities reduce significantly. A blend of 40% to 50% of linseed oil with kerosine gives viscosity values quite close to that required by the diesel engine. Therefore, 40% to 50% linseed oil can be introduced in diesel with kerosine.

3. Although the boiling temperatures for pure vegetable oils are found to be higher compared to that of diesel, the blended fuels show relatively high volatility characteristics even at the lower temperatures thereby making them suitable for use in diesel engines.

4. Performance test of the engine with blended fuels show that the rated power of the engine is reduced compared to diesel fuel operation. Rated power for 40% and 50% linseed

oil blends with kerosine are very close. Therefore, 50%-50% blend can be successfully used in diesel engine where a considerable fuel substitution is possible.

5. To produce the same power as produced by the diesel fuel, fuel consumption and bsfc are higher in cases of operation with blended fuels.

6. From the overall observations it can be concluded that linseed oil could be a potential substitute for diesel fuel with a little sacrifice of power and efficiency.

7. Since linseed oil has extremely limited use at present, its production for use in diesel engine will not only enable the country to attain self-reliance but also help mitigate the conventional fuel crisis.

6.2 Recommendations

Research on vegetable oils as diesel fuel alternative is an important issue now-a-days not only from the viewpoint of depleting reserve of the fossil fuels but also from the onset of the fossil fuels on the environment. Under the circumstances the future of the IC engines do not look very bright unless reasonably acceptable alternative fuels like vegetable oils are discovered eventually. Alongside sufficient data should be generated to establish the requirement in the modifications of the conventional designs of the engine to make them adaptable to the use of the most suitable vegetable oil. With these expectations the following recommendations are made for future work in this line.

1. Variable speed test may be conducted using the same blends to analyze the effect of linseed oil blends on speeds.

2. Exhaust emissions were not analyzed during this research which can be studied for each fuel blend operation.

3. Linseed oil can be modified by preheating or by making ester with alcohols and the effect of such modifications of the fuel on engine performance can be studied. Researchers in many countries found preheating technique more prospective. Fuel spray characteristics applying preheating technique at different temperatures can be studied in respect of droplet size, cone angle and penetration of the spray.

4. As carbon build-up and gum formation are reported with long term vegetable oil operation, specific study with linseed oil fuelling in this regard may be undertaken.

5. As linseed oil is highly viscous at normal temperatures study of this oil may be conducted using it as alternative lubricant and effect of other performance parameters may be investigated.

6. As high fuel consumption was observed in case of linseed oil and kerosine blend operation using the same injectors as in diesel operation, studies may be undertaken to see the effect of injectors with different nozzle hole diameter on fuel consumption and other performance parameters.

7. All the above studies may be conducted using other available vegetable oils.

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GRAPHICAL PRESENTATION OF RESULTS

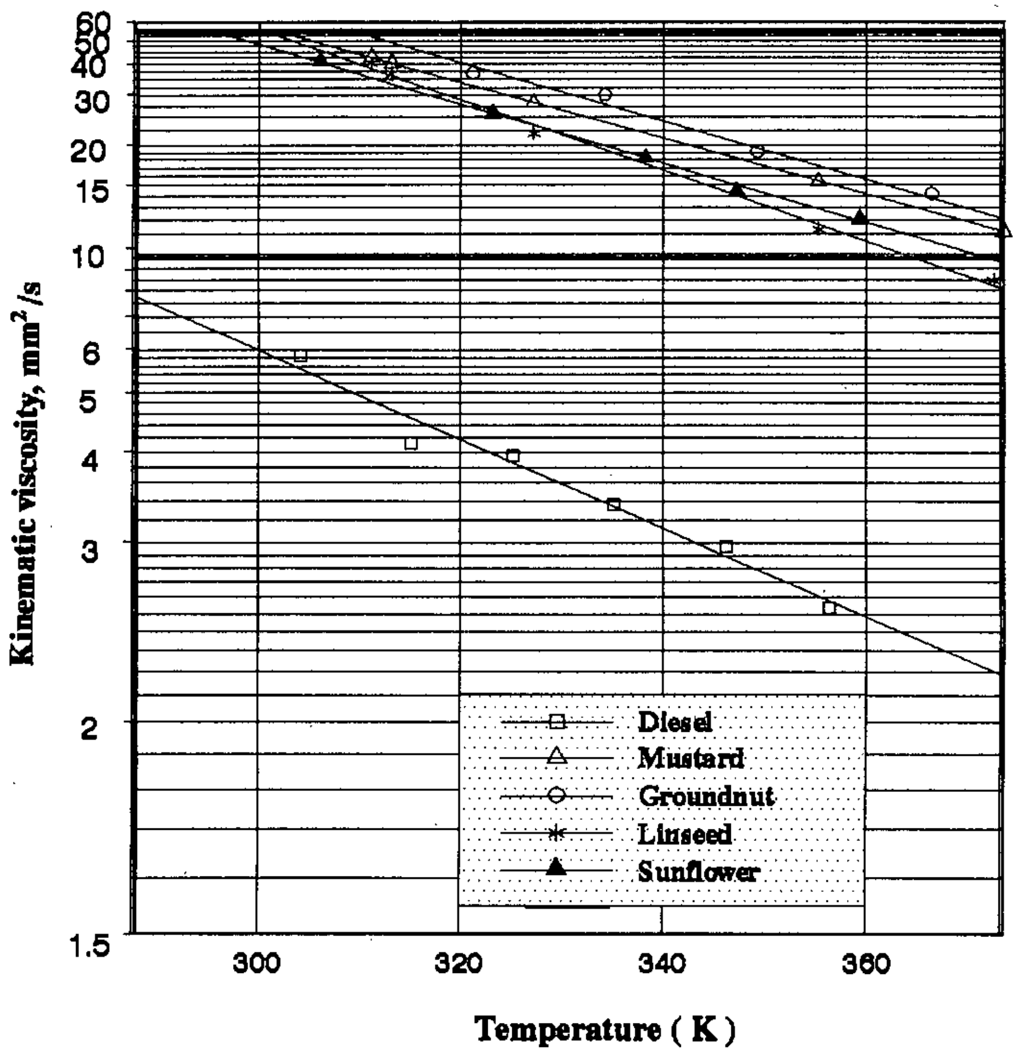


Figure 5.1.1 : Variation of kinematic viscosity with temperature for four single vegetable oils and diesel.

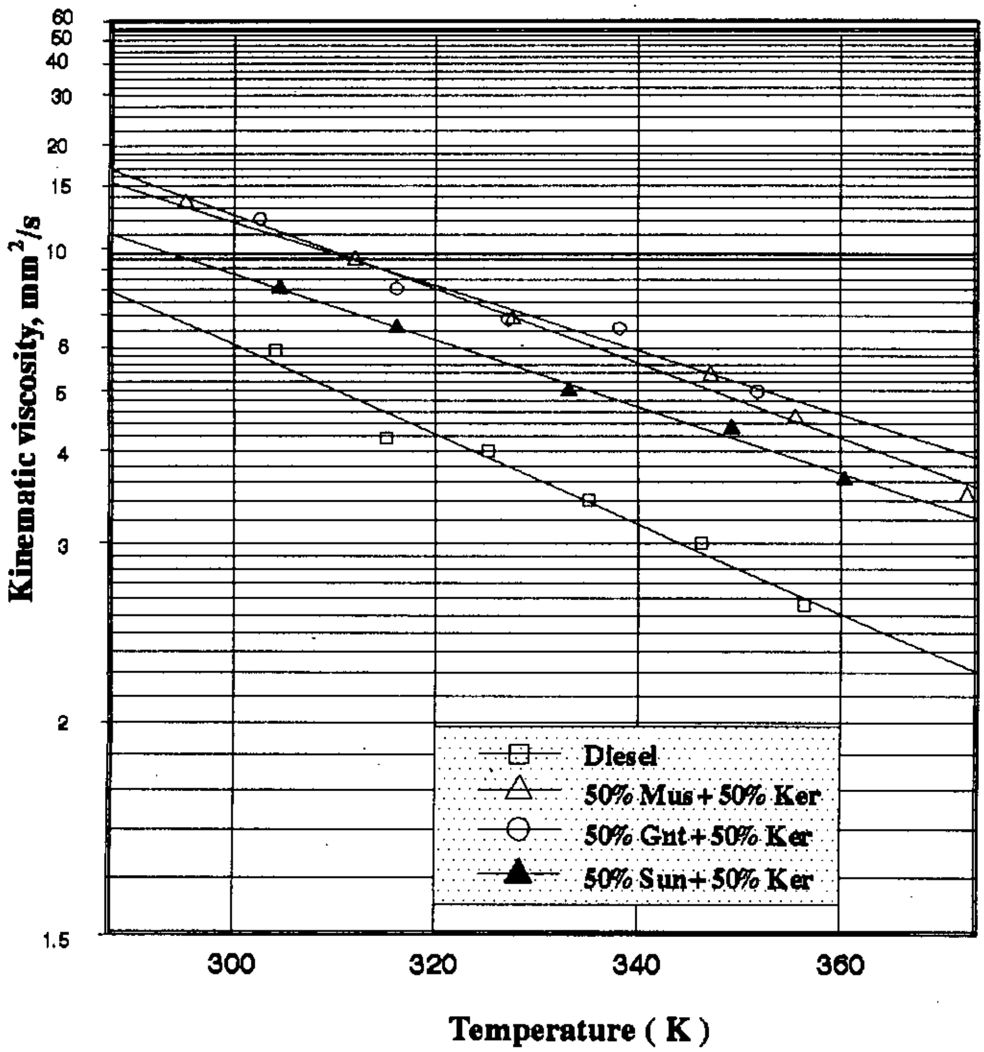


Figure 5.1.2 : Comparison of kinematic viscosity-temperature relationships of three blended fuels of vegetable oil and kerosine with that of diesel.

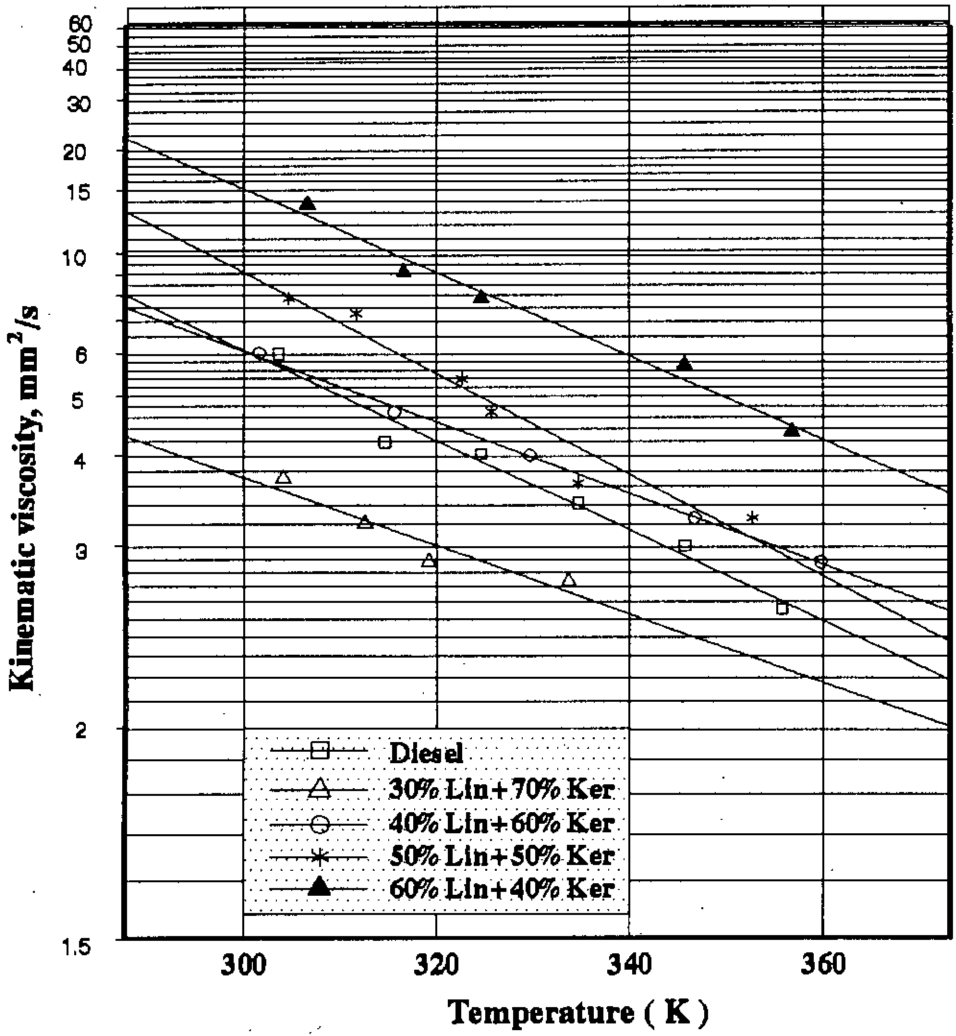


Figure 5.1.3 : Comparison of kinematic viscosity -temperature relationships of four blended fuels of linseed oil and kerosine with that of diesel.

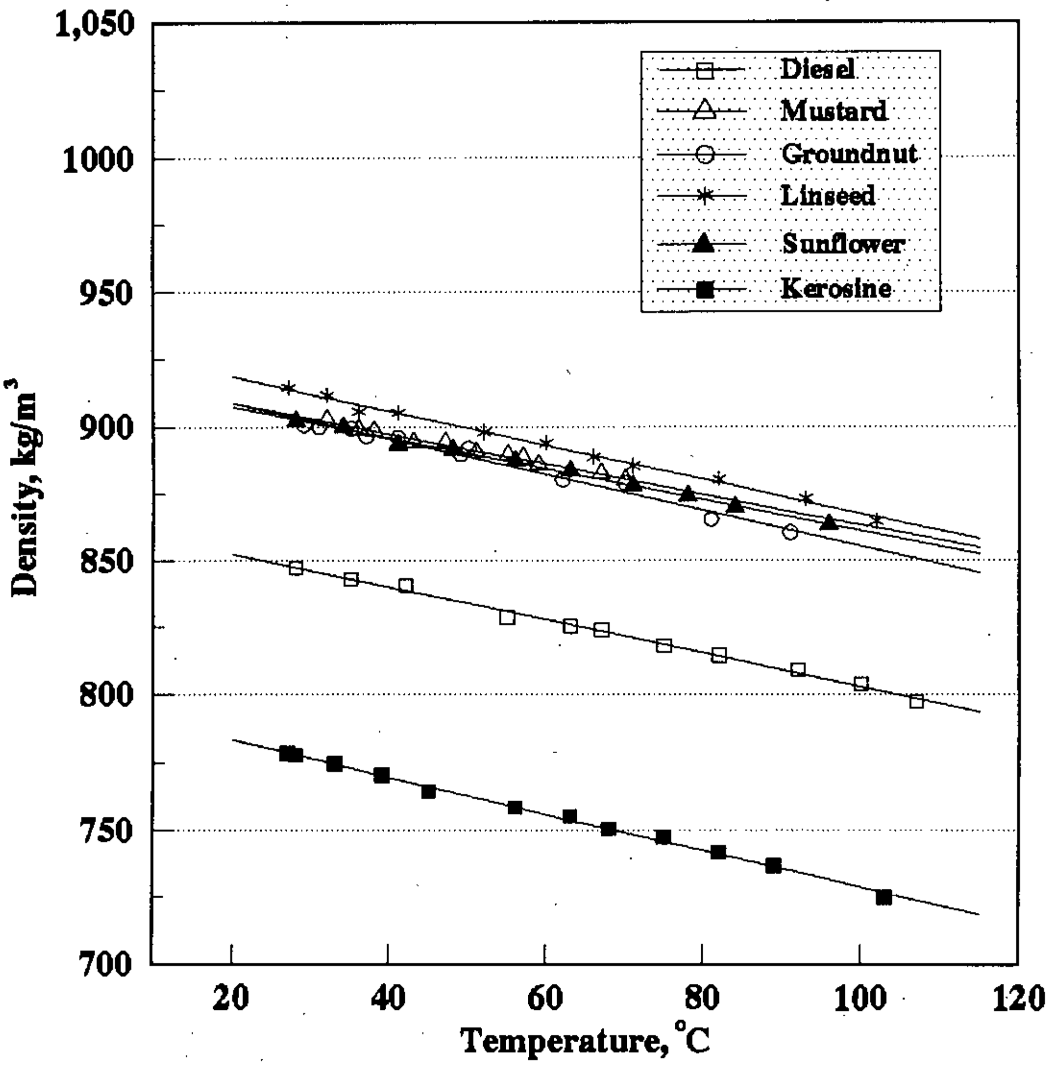


Figure 5.1.4 : Variation of density with temperature for four single vegetable oils, diesel and kerosine.

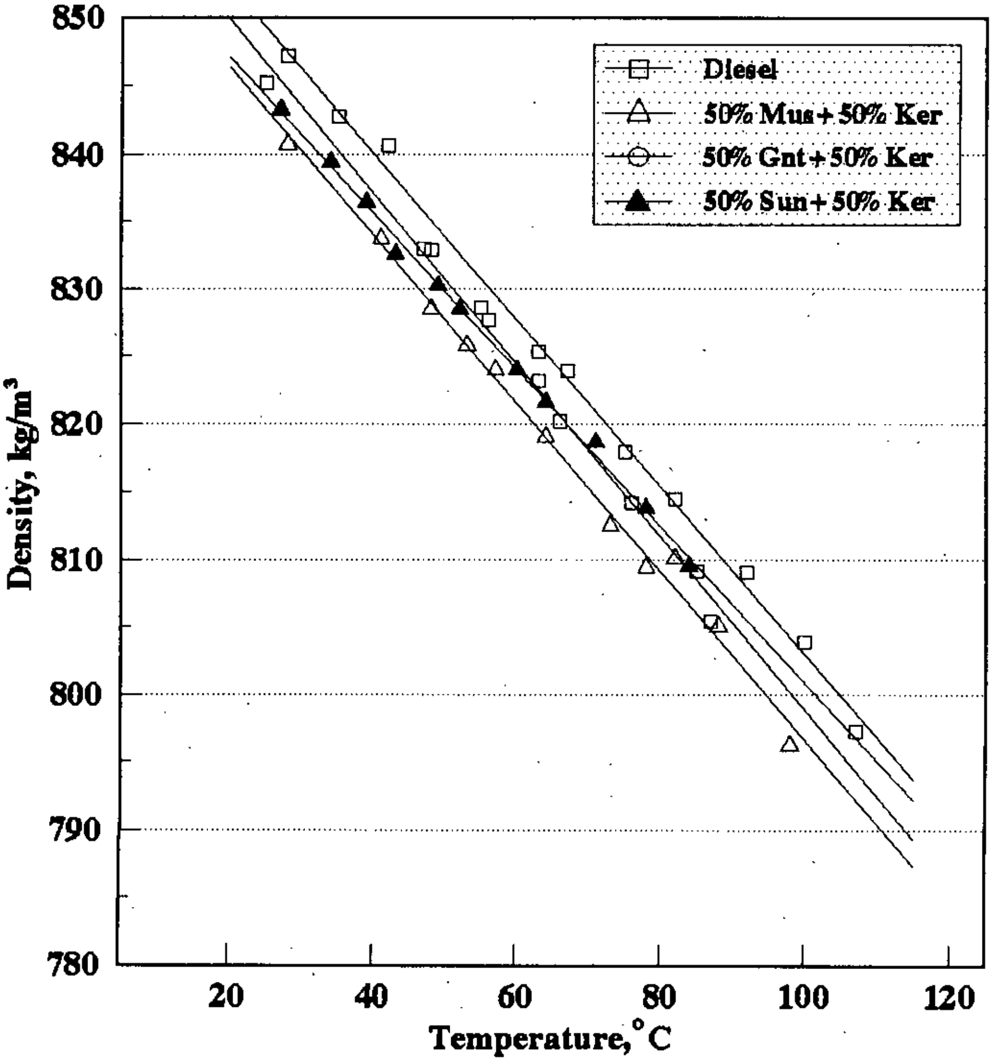


Figure 5.1.5 : Comparison of Density-Temperature relationships of three blended fuels of vegetable oil and kerosine with that of diesel.

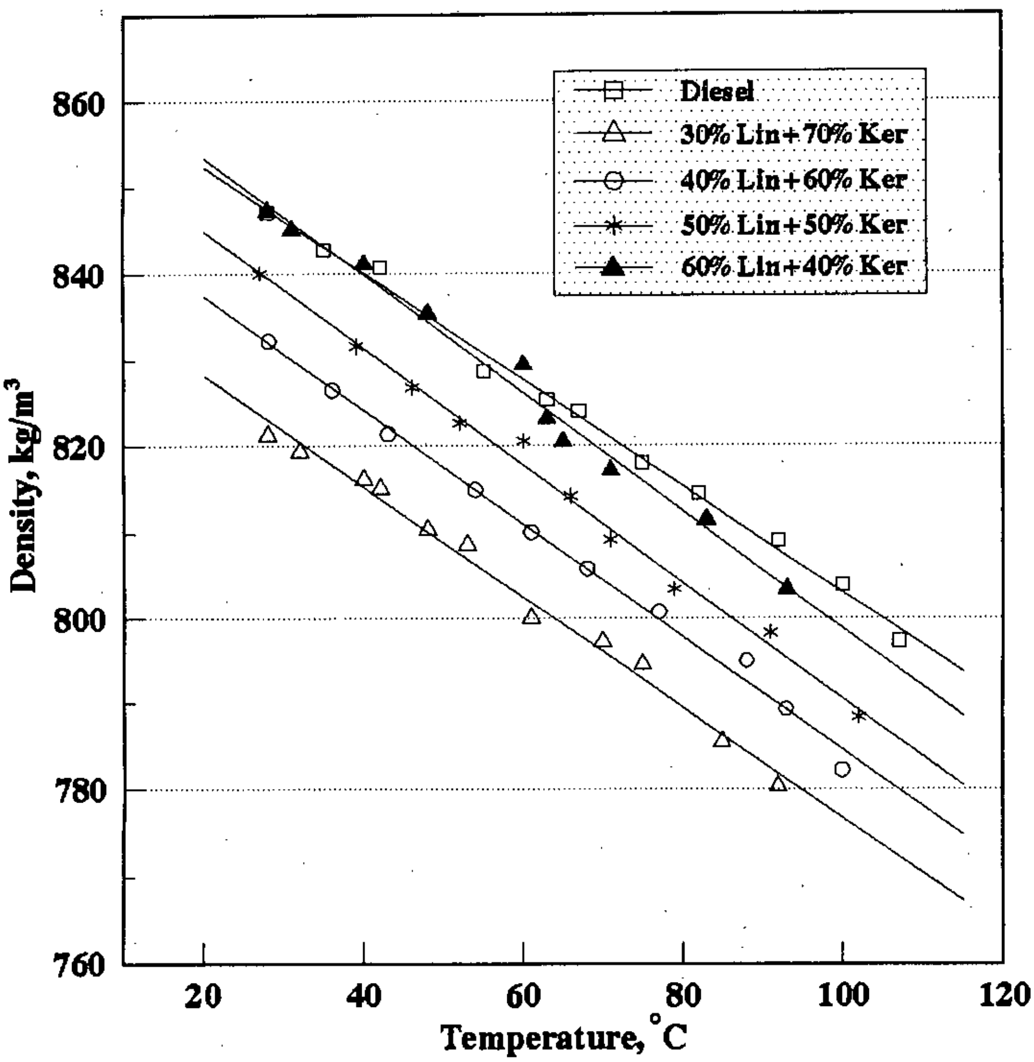


Figure 5. 1. 6 : Comparison of Density-Temperature relationships of four blended fuels of linseed oil and kerosine with that of diesel.

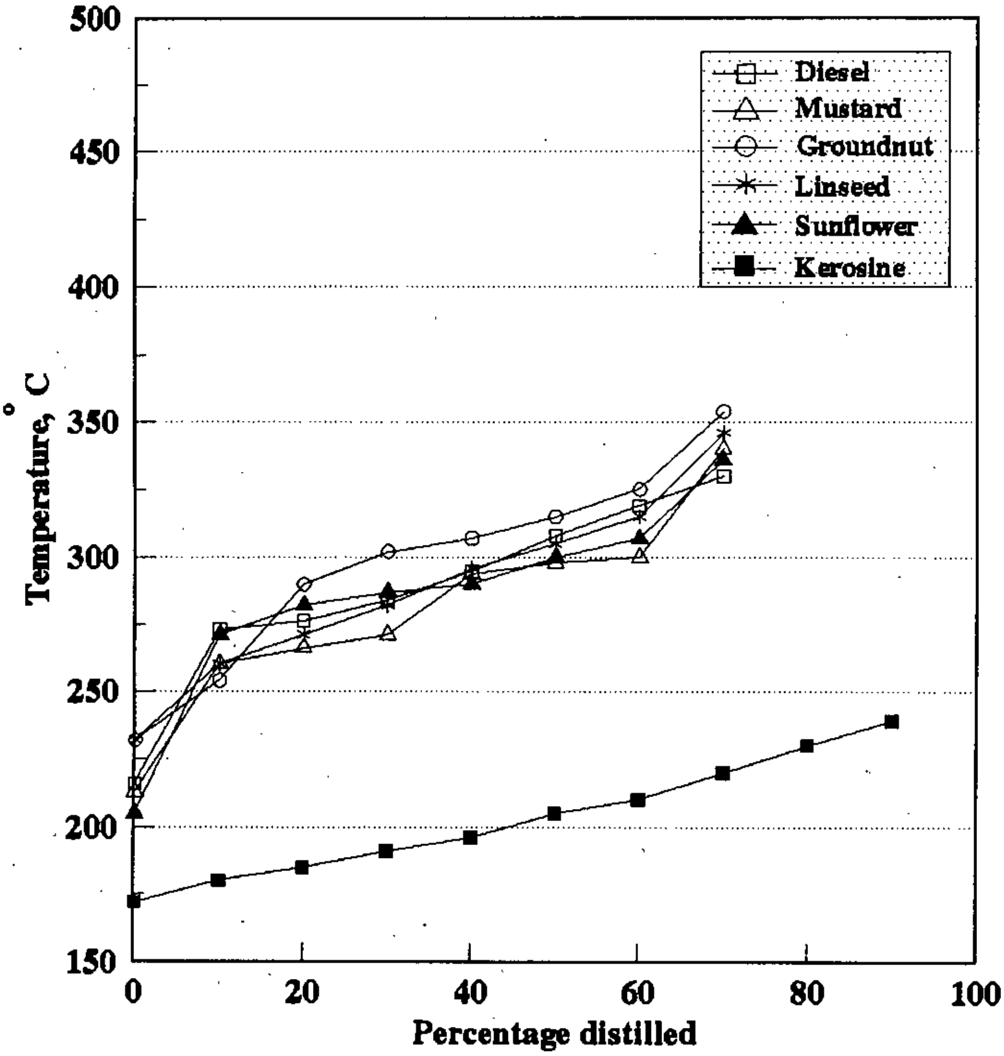


Figure 5.1.7 : Distillation curves of four single vegetable oils, diesel and kerosine.

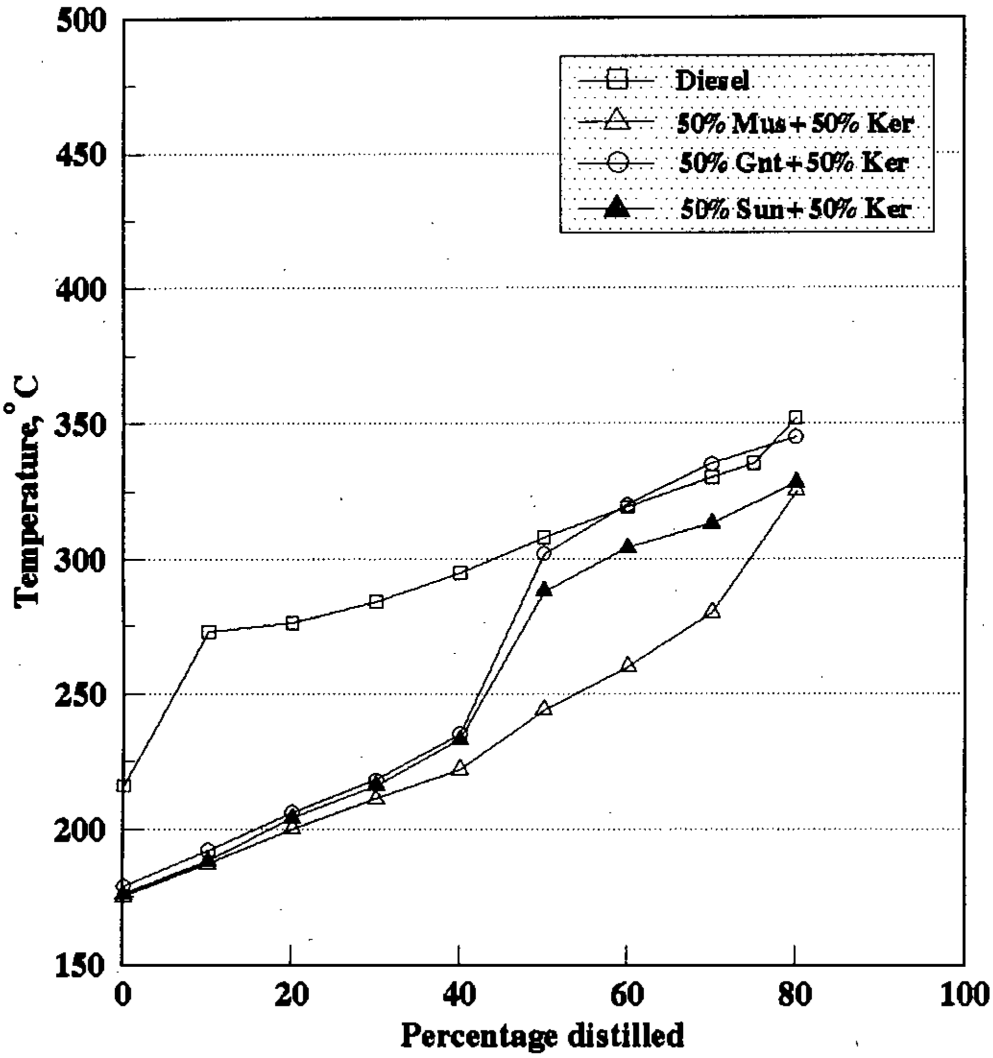


Figure 5.1.8 : Comparison of distillation curves of three blended fuels of vegetable oil and kerosine with that of diesel.

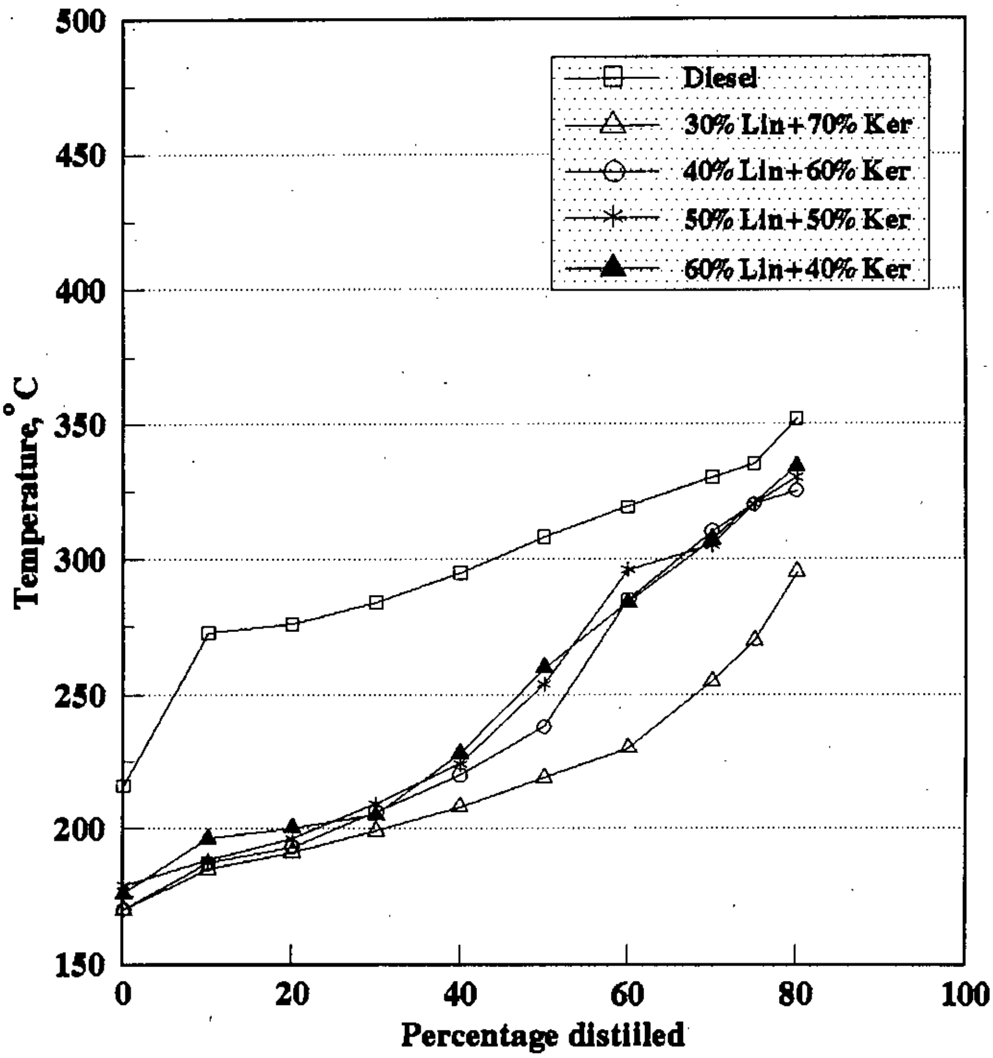


Figure 5.1.9 : Comparison of distillation curves of four blended fuels of linseed oil and kerosine with that of diesel.

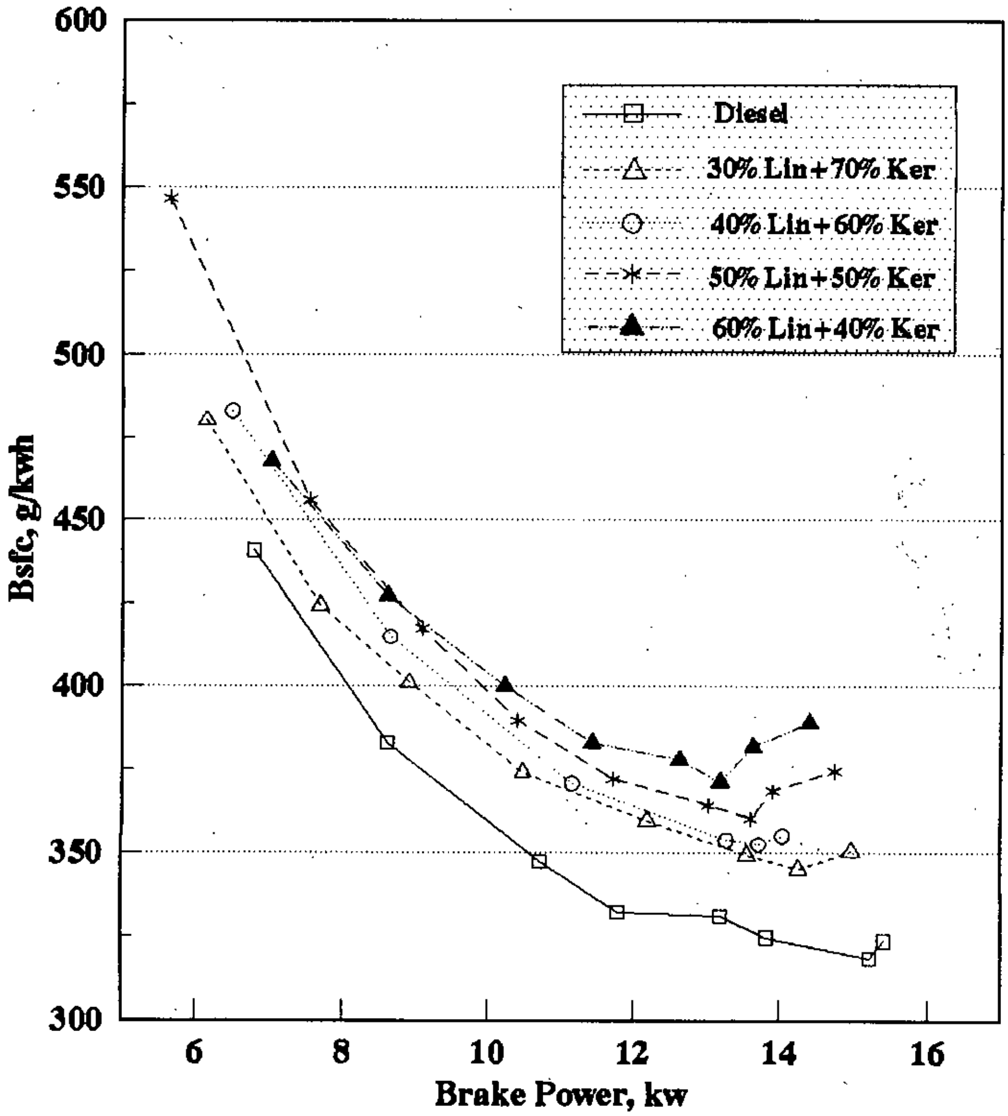


Figure 5.2.1 : Variation of bsfc with brake power.

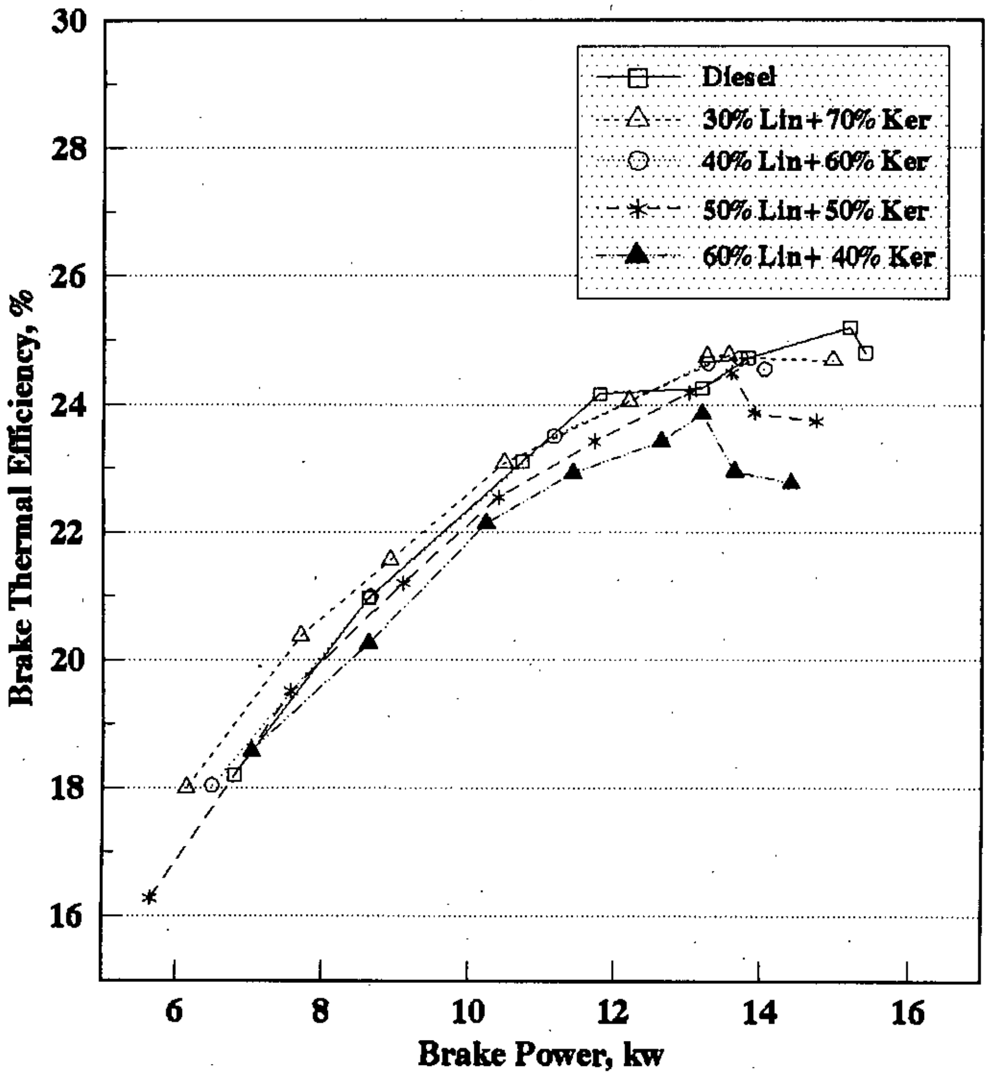


Figure 5.2.2 : Variation of brake thermal efficiency with brake power.

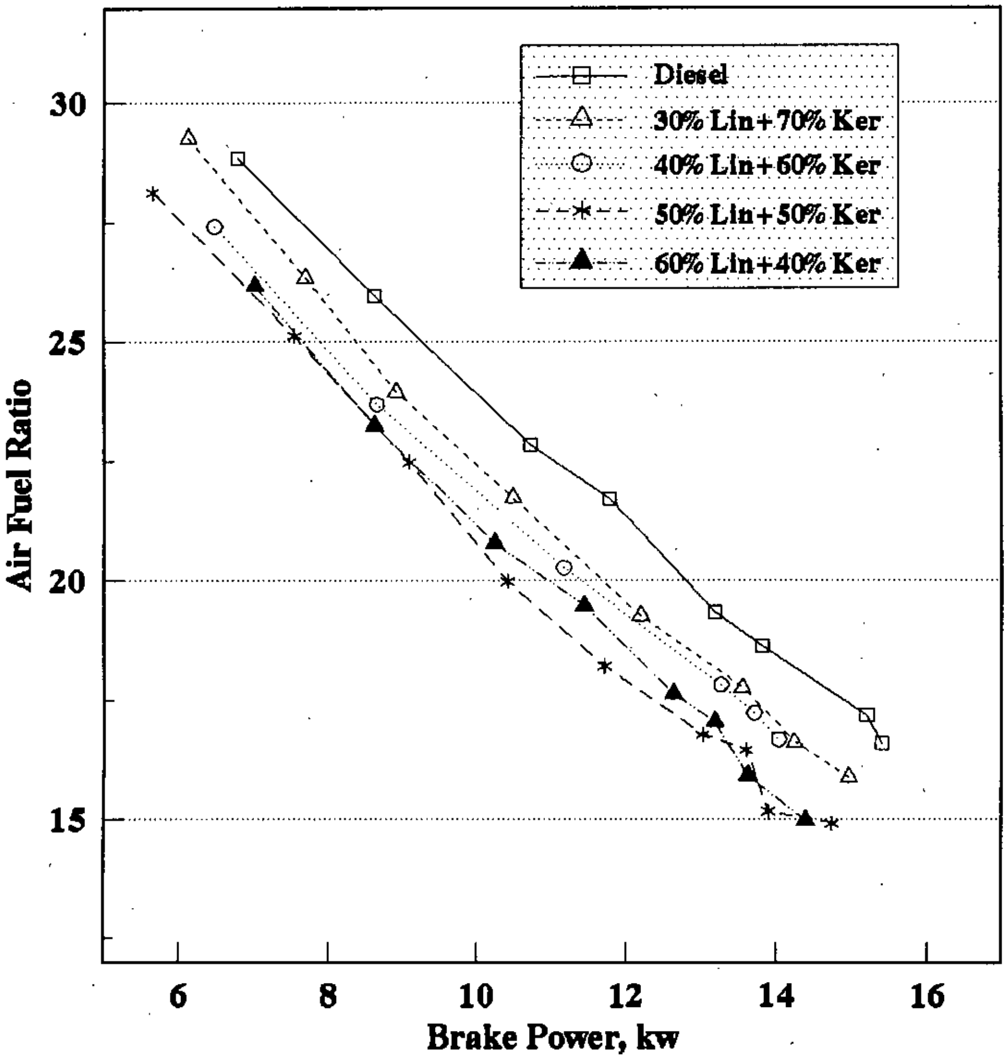


Figure 5.2.3 : Variation of Air Fuel Ratio with brake power.

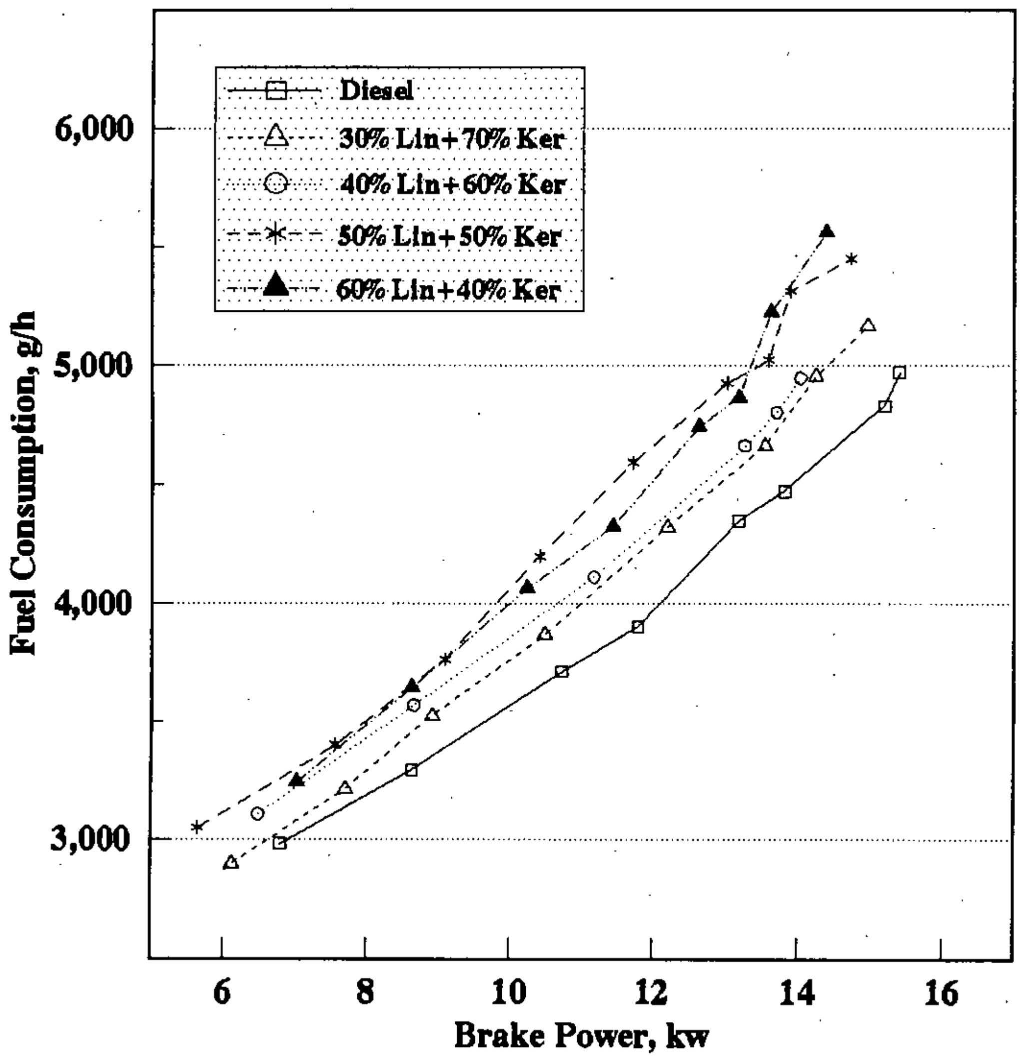


Figure 5.2.4 : Variation of fuel consumption with brake power.

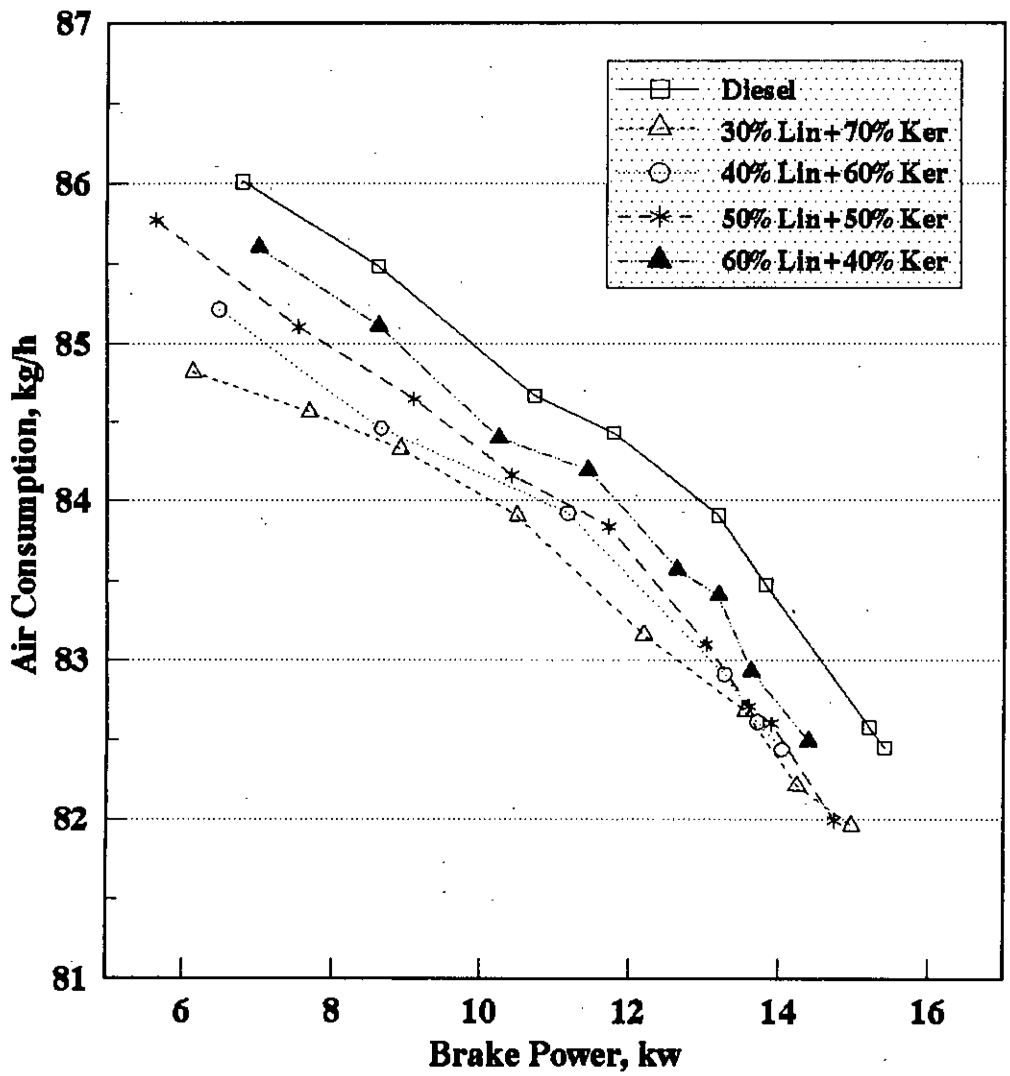


Figure 5. 2. 5 : Variation of air consumption with brake power.

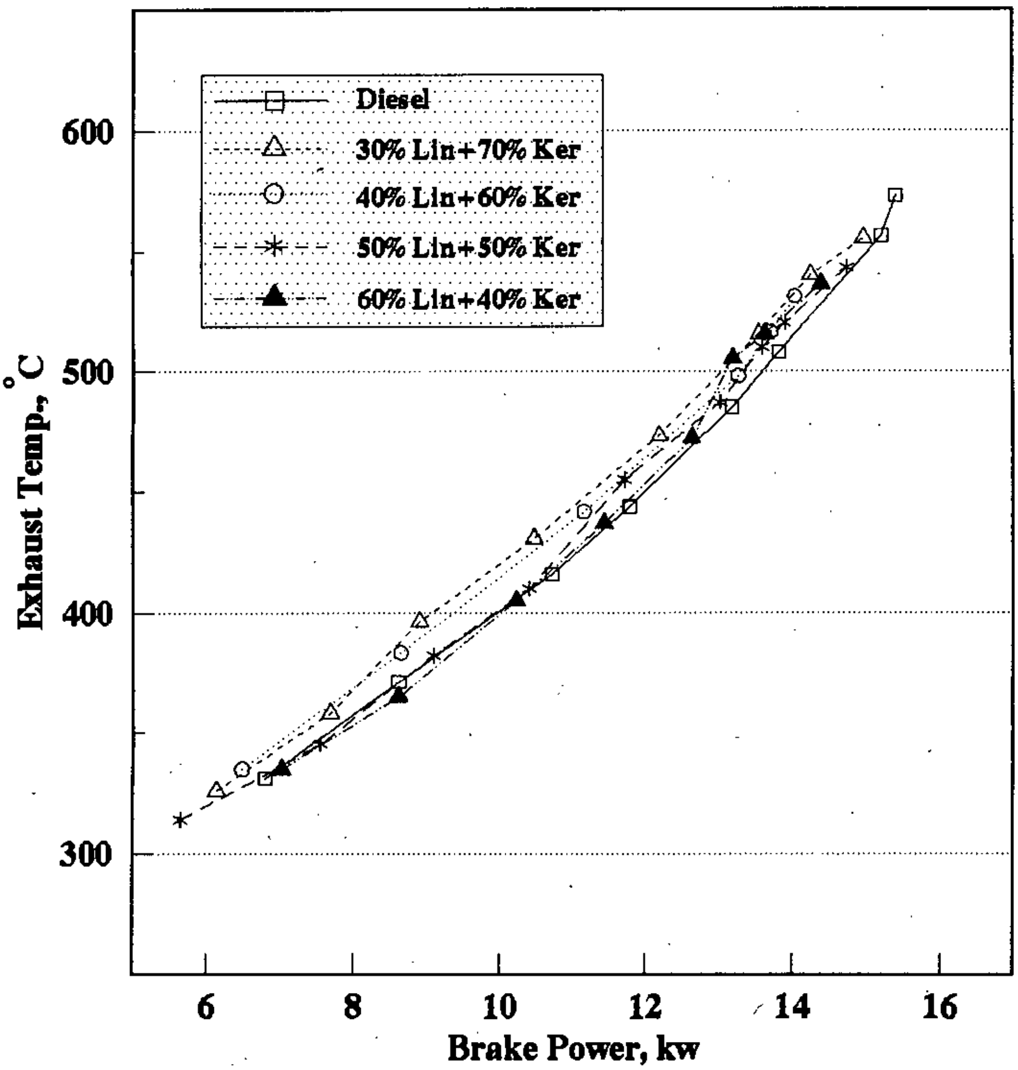


Figure 5.2.6 : Variation of exhaust temperature with brake power.

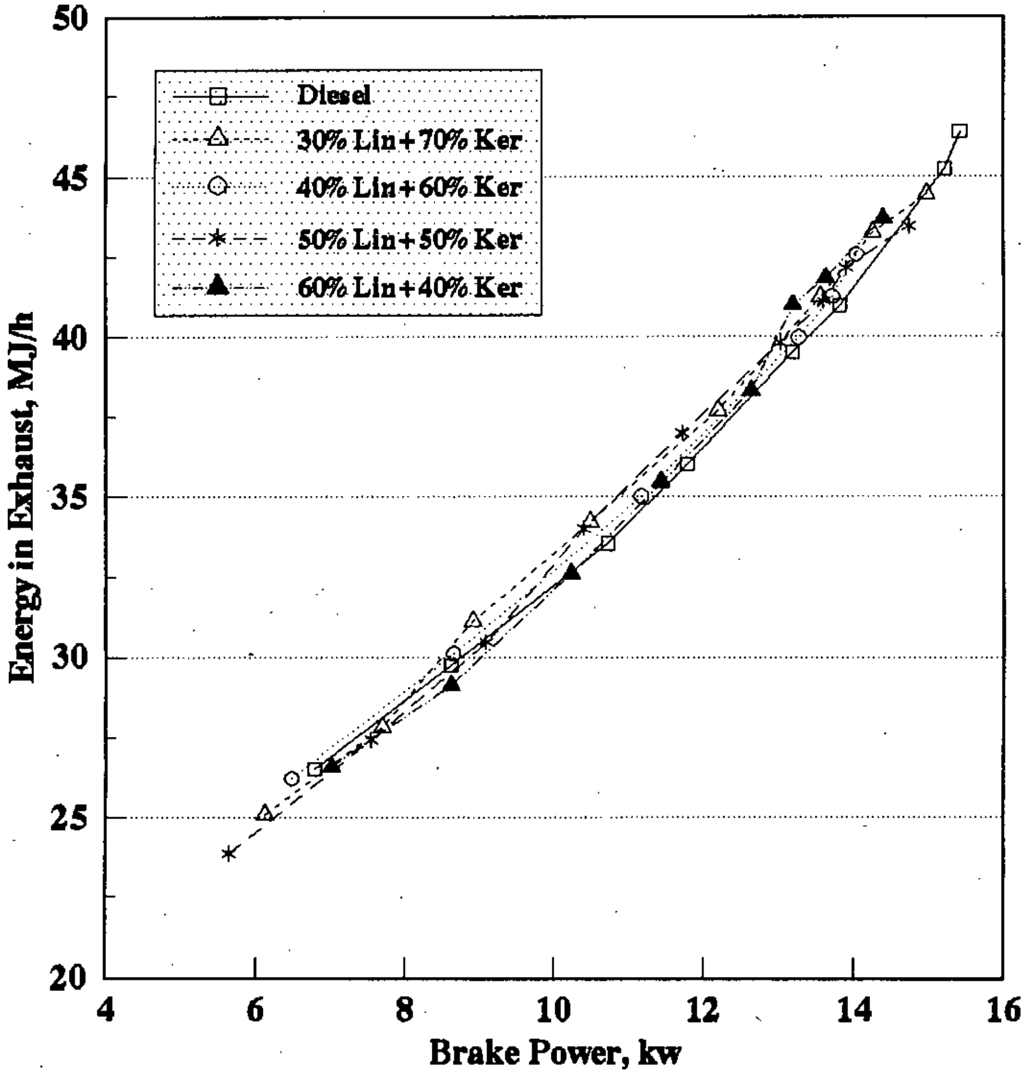


Figure 5.2.7 : Variation of energy in exhaust with brake power.

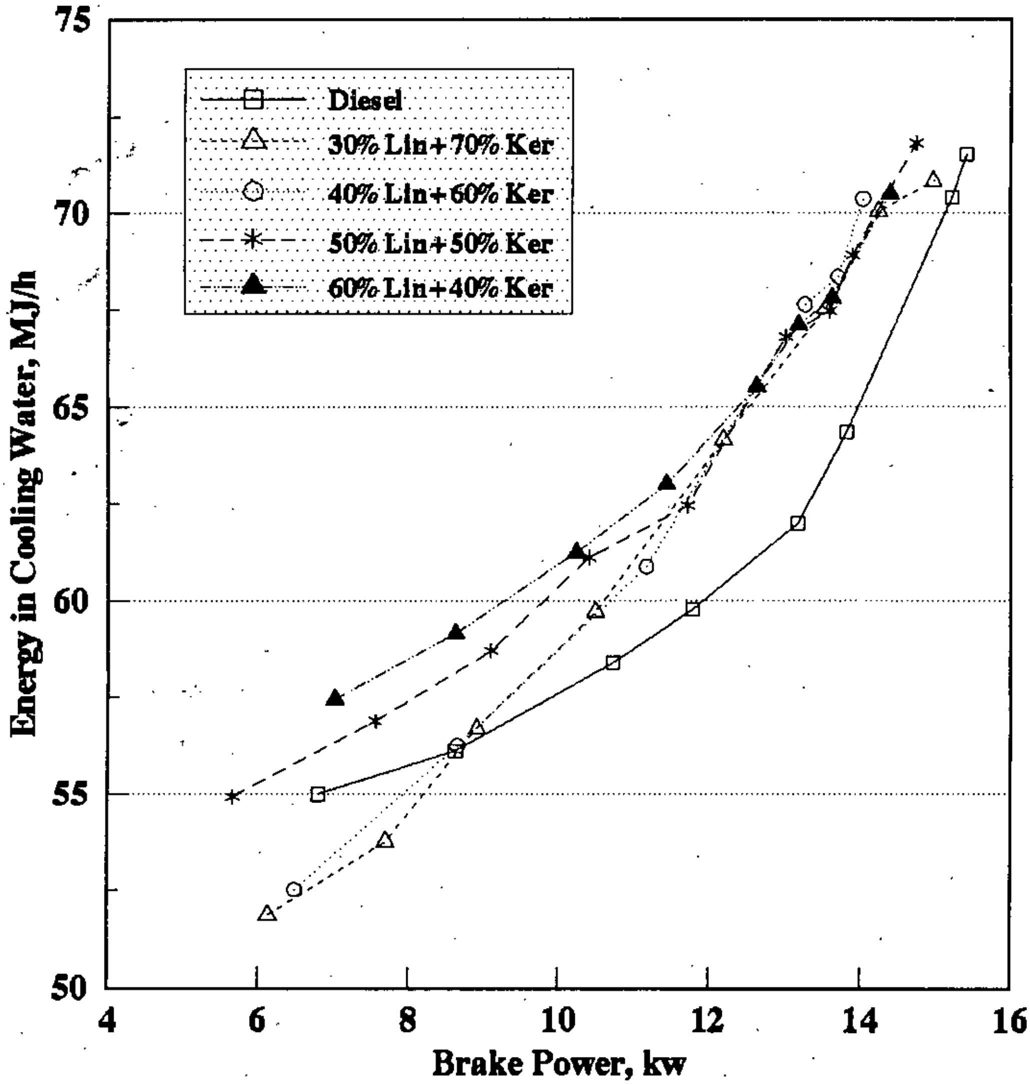


Figure 5.2.8 : Variation of energy in cooling water with brake power.

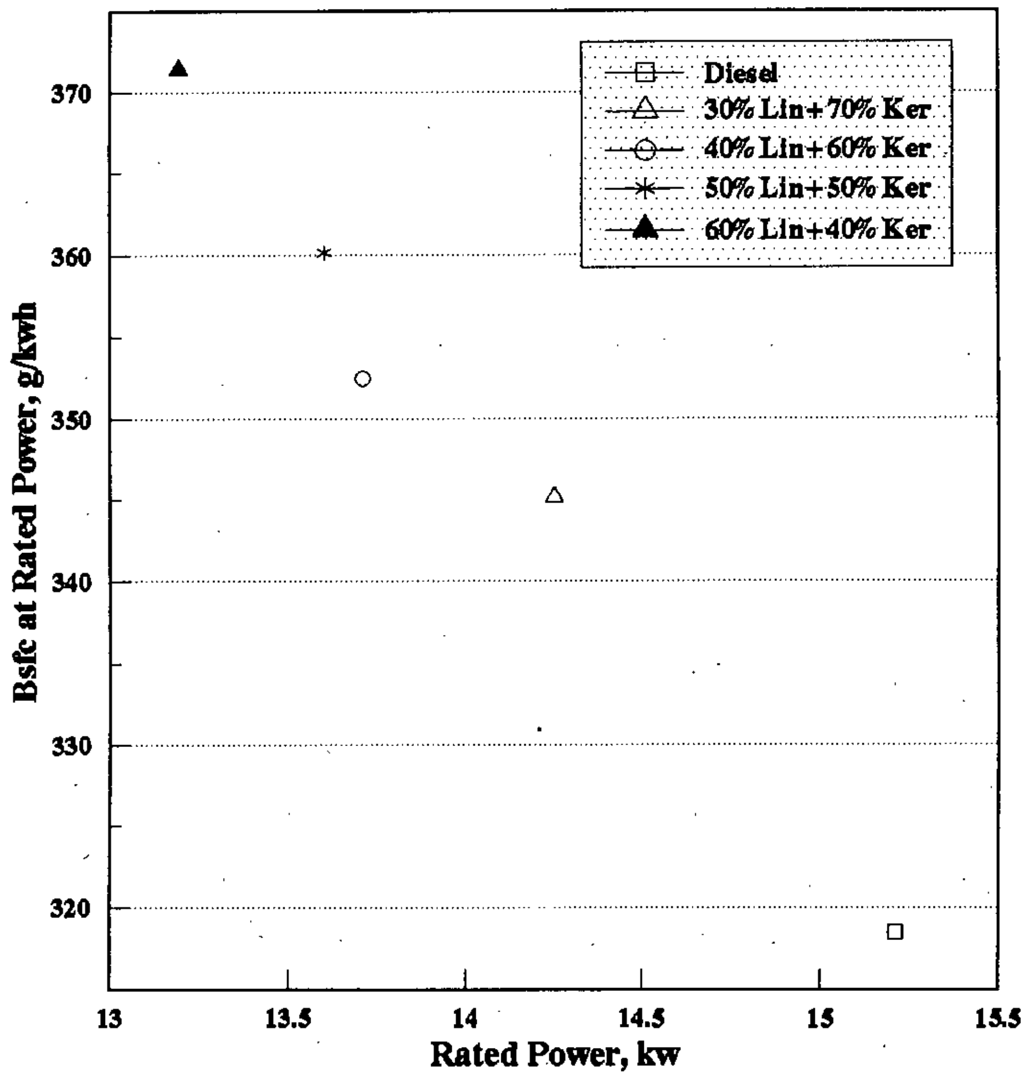


Figure 5.2.9 : Comparison of bsfc at the rated power for the four blended fuels of linseed oil and kerosine with that for diesel (while the engine was running at 2000 rpm).

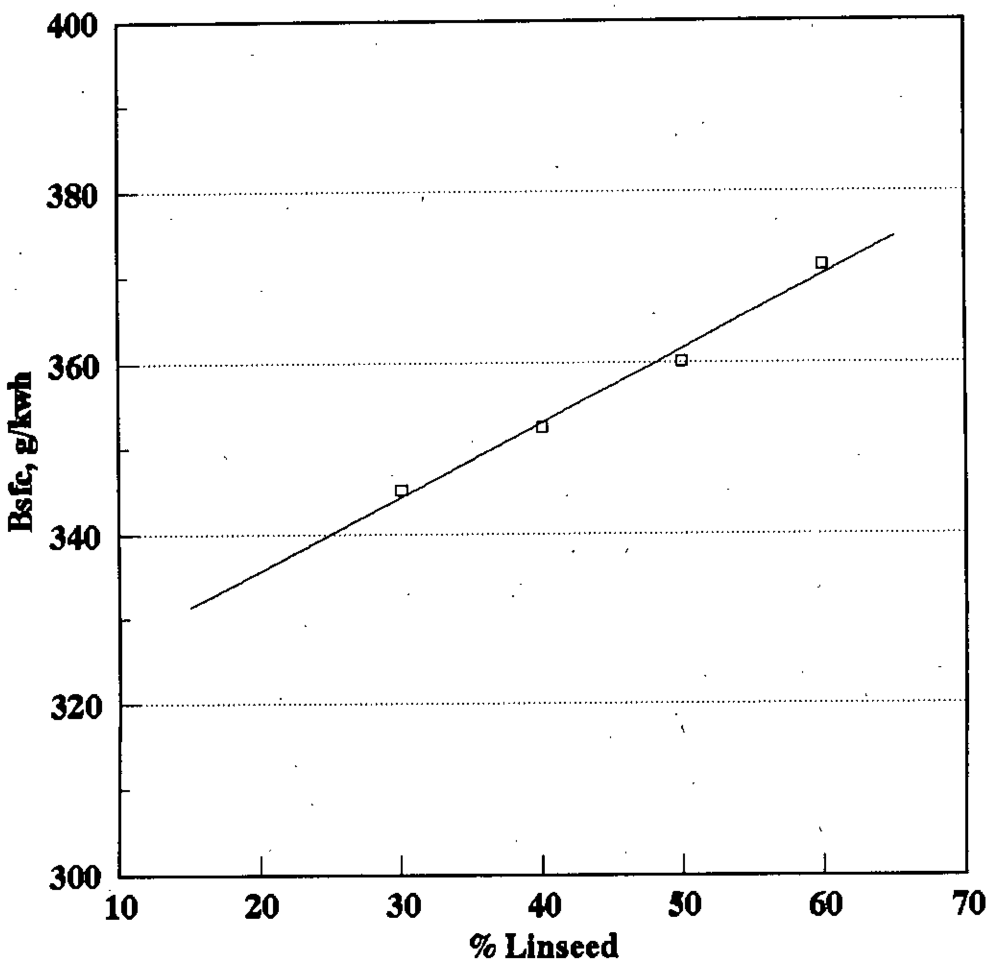


Figure 5.2.10 : Comparison of bsfc at the rated power with the percentage increase of linseed oil in the blended fuel (while the engine was running at 2000 rpm).

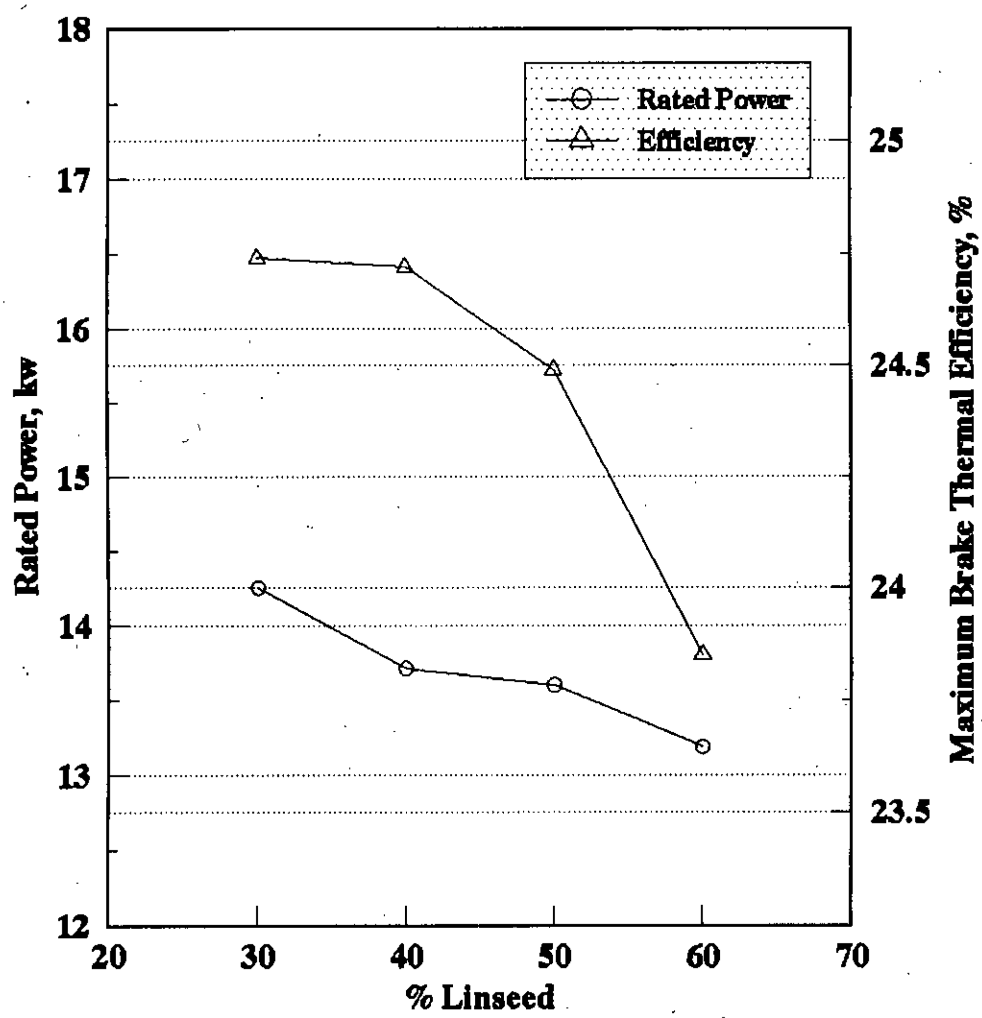


Figure 5.2.11 : Comparison of rated power and maximum brake thermal efficiency attained with the percentage increase of linseed oil in the blended fuel (while the engine was running at 2000 rpm)

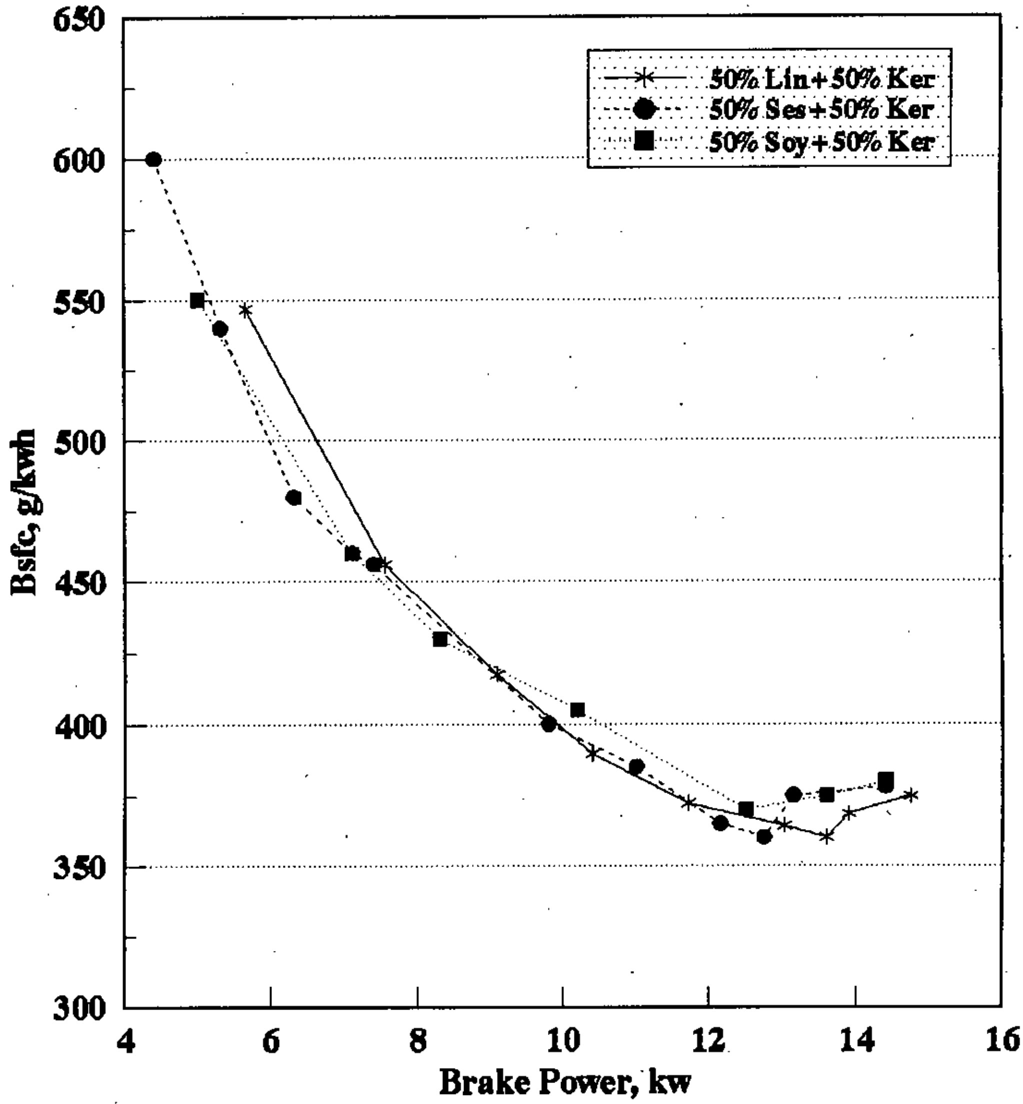


Figure 5. 2. 12: Comparison of bsfc with results obtained from Zahurul (41).

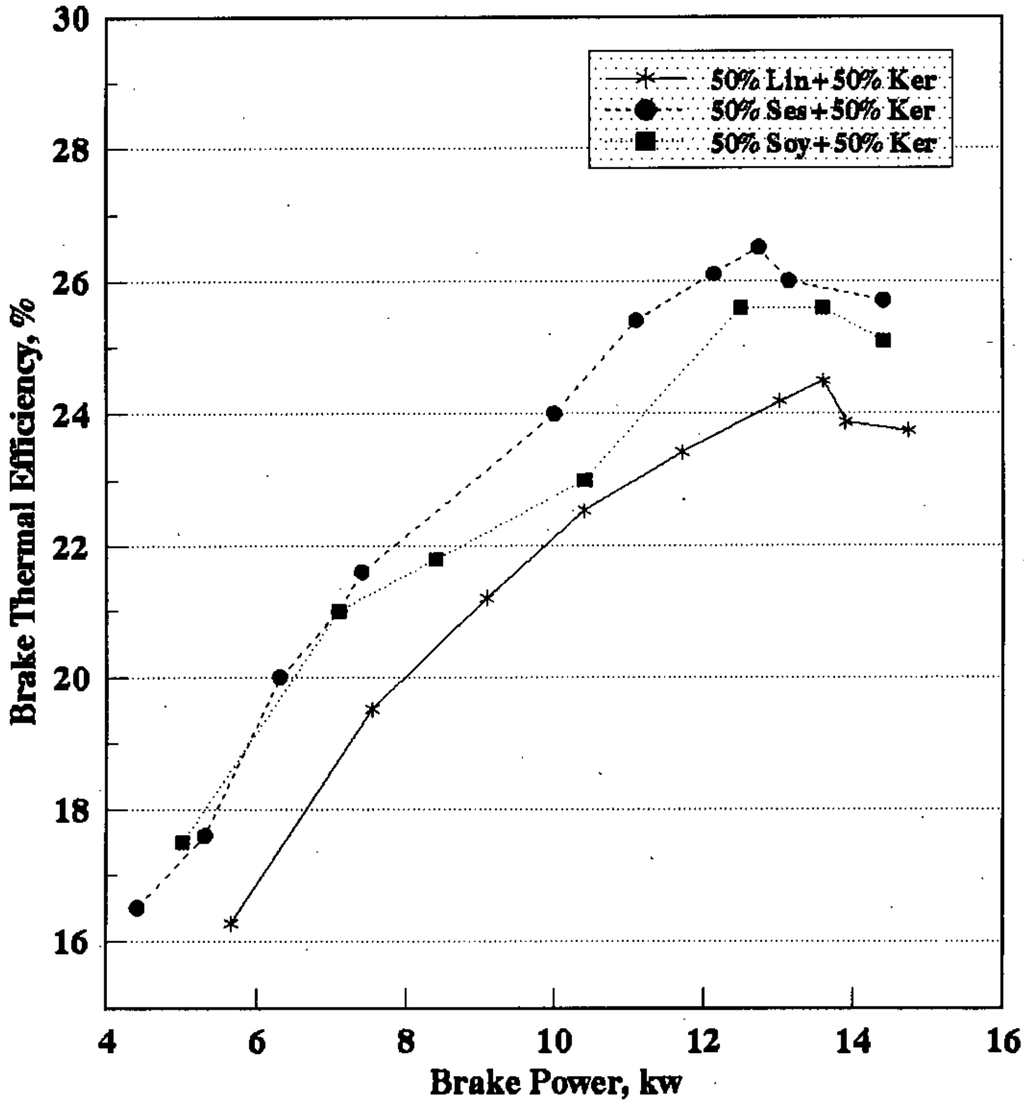


Figure 5.2.13: Comparison of brake thermal efficiency with results obtained from Zahurul (41).

APPENDIX - A

RELEVANT TABLES

Table 3.1: Acreage production of oilseeds, and oil of different variants available in Bangladesh during the last 5 years (29,36).

Area in '000' acres and production in '000' MT

Type		1989-90	1990-91	1991-92	1992-93	1993-94
Mustard	Acreage	836	838	840	836	832
	Seed	217.4	227.5	243	244.3	239.1
	Oil	70.8	74.4	72.9	81.4	79.7
Sesame	Acreage	213	205	199	204	197
	Seed	49.3	48.7	52.8	50.6	53.2
	Oil	16.4	16.2	17.6	16.9	17.2
Linseed	Acreage	190	191	186	185	184
	Seed	48.1	54.5	49.5	49.1	48.3
	Oil	15.6	18.2	16.5	16.4	16.1
Groundnut	Acreage	95	95	96	88	88
	Seed	41.1	41.2	41.9	39.3	41.2
	Oil	-	-	-	-	-
Coconut	Acreage	80	76	76	77	78
	Seed	82	75.9	81.6	92.7	93.8
	Oil	1.4	1.1	1.1	2.2	2.4
Castor	Acreage	1	1	1	1	1
	Seed	0.24	0.26	-	0.16	0.2
	Oil	-	-	-	-	-
Cottonseed	Acreage	-	-	-	-	-
	Seed	10.4	7.6	16.8	18.4	18.9
	Oil	1.5	2.2	2.1	2.2	2.3
Others	Acreage	1	1	1	1	1
	Seed	0.6	0.5	0.5	0.5	0.7
	Oil	0.2	0.1	0.1	0.1	0.2

Table 3.2: Total production projection of oilseeds during Fifth Five Year Plan (36).

Production in '000'MT

Total oilseed production projection	Year						Growth rate
	Base year 1992-93	1995-96	1996-97	1997-98	1998-99	1999-2000	
	474	556	578	619	633	689	5.50%

Table 3.3: National average wholesale price of different oilseeds in Bangladesh (29).

Price in Taka per MT

Year	Mustard	Sesame	Groundnut	Linseed
1984-85	12080	8600	11010	7896
1985-86	11280	8680	12830	8600
1986-87	13370	9377	11010	9564
1987-88	12510	9618	11410	16877
1988-89	13210	11252	13640	12163
1989-90	16020	11761	14580	12752
1990-91	16884	13207	14627	13270
1991-92	15941	14084	18084	13750
1992-93	14892	12730	16396	13250
1993-94	17013	13520	17736	12030
Increase over '84/85 price	41%	57%	61%	52%

Table 3.4: Different oilseed variants of Bangladesh as on March, 1993 (10).

Sl. No.	Crop variant	Maturity period (days)	Oil Content % of weight
1.	Mustard	70-100	39-46
2.	Sesame	85-95	40-44
3.	Linseed	100-115	38-39
4.	Groundnut	105-160	48-50
5.	Sunflower	90-100	40-44
6.	Soybean	100-120	19-20

Table 3.5: Comparison of efficiency and yield of oil from different processing equipments (24).

Description	Bullock driven village ghanis	Powered ghanis & expeller mills	Expeller mills with good repair
Residual oil in oilcake	18%	15%	08%
*Oil production from 1 MT of seed	314 kgs.	339 Kgs.	391 Kgs.
Efficiency of extraction	71%	77%	89%

* Assumption: Seed contains 44% oil, 7% moisture.

APPENDIX - B

TECHNICAL DETAILS OF ENGINE AND DYNAMOMETER

Table B.1: Specifications of the test engine

Manufacturer		Yanmar diesel engine Co. Ltd. Japan	
Type		2 Cylinder Marine Diesel Engine	
Model		2 TGE	
Injection System		Direct Injection	
Rated output hp		Continuous	One hour
		22	25
Rated Speed (rpm)	Crank shaft	2000	2100
	Propeller Shaft	800	840
Method of cooling		Water Cooled	

Table B.2: Specifications of the dynamometer

Manufacturer	Tokyo meter Co. Ltd. Japan
Type of the dynamometer	Water brake dynamometer
Model	TFJ - 250L
Maximum braking horsepower	250
Maximum braking torque (Kg-m)	71.6
Speed at maximum braking horsepower (rpm)	2500 to 5500
Maximum braking water quantity (litre/min)	75
Water temperature (°C)	The temperature of water to be drained out should not exceed 70°C and the difference between water to be supplied in and that to be drained out is 35°C.
Water delivery pressure (Kg/Cm^2)	0.5 to 1.15
Handle revolutions (turns)	22
Weight (Kg)	575
Main bearings	Ball and roller bearings dripfeed lubricated

APPENDIX - C
SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

This chapter shows methods of calculating different parameters from the experimental reading for both fuel properties measurement and engine performance. Some basic data were recorded during experiment which are also important in computational exercise.

Heating Value of Fuel:

The heating value of the fuel was determined experimentally as per ASTM Standard D240-87. In this test procedure, corrected temperature rise Δt, in the isothermal jacket of the bomb calorimeter is expressed as:

$$\Delta t = t_c - t_a - r_1 (b-a) + r_2 (c-b)$$

Where,

- Δt = Corrected temperature rise, °C
- a = Time of ignition, min.
- b = Time when 60% of temperature rise is attained, min.
- c = Time when maximum temperature is attained, min.
- t_a = Temperature at the time of ignition (at a), °C
- t_b = Temperature at time b, °C
- t_c = Maximum temperature attained, °C
- r_1 = Rate of temp. rise during 5 minutes before ignition, °C/min.
- r_2 = Rate of temp. rise during 5 minutes after the maximum temp. attained, °C/min.

Heat energy absorbed by calorimeter water is given by:

$$Q_c = (W_w + 432) x C x \Delta t$$

Where,

Q_c = Heat absorbed by calorimeter, cal
W_w = Weight of calorimeter water, gm.
432 = Water equivalent of calorimeter, gm.
C = Specific heat of water, cal/gm-°C

Heat energy from fuse wire is given by:

$$Q_{fw} = H_w L_B$$

Where,

H_w = Heat of combustion of fuse wire, cal/cm.
L_B = Length of burnt fuse wire, cm.

Heating value of w gm fuel sample can be computed from the equation:

$$H_f = \frac{(Q_c - Q_{fw})}{w} \times \frac{4.187}{1000} \frac{MJ}{kg}.$$

The sample calculation for linseed oil is shown below:

$$\Delta t = 3.8 - 0.006 - (-0.0088)(6.75-5) + 0.018\ (10.33-6.75) = 3.87\ ^{\circ}C$$

a = 5 min.
b = 6.75 min.
c = 10.33 min
t_a = 0.006 ° C
t_c = 3.8 ° C
t_b = 2.2824 ° C

r_1 = - 0.0088 ° C/min.
r_2 = 0.018 ° C/min.

Q_c = (1900+432)x1x3.87
= 9024.84

W_w = 1900 gm.
C = 1 cal/gm- ° C

Q_{fw} = 2.3x5.6
= 12.88 cal

H_w = 2.3 cal/cm.
L_B = 5.6 cm.

∴ For 1.000 gm of sample burnt, heating value

$$H_f = \frac{(9024.84-12.88)}{1.000} \times \frac{4.187}{1000} \frac{MJ}{kg}$$

= 37.76 MJ/kg

Viscosity:

Viscosity was measured as per ASTM Standard D88-56 at wide range of temperatures. For example, at 38°C, Saybolt Universal Second (SUS) was found to be 198.7 see for linseed oil sample. Three governing equations are used in conversion of SUS into Kinematic viscosity in centistoke (mm^2/s).
These are, Kinematic viscosity,

$$\nu = 0.224t - \frac{185}{t}, \; 115 \succ t \succ 34$$

$$\nu = 0.223t - \frac{155}{t}, \; 215 \succ t \succ 115$$

$$\nu = 0.2158t, \; t \succ 215$$

Where t in SUS and ν in centistoke (i.e. mm^2/s)
From the data for example, t = 198.7 sec, second equation is to be used.

$$\nu = 0.223 \times 198.7 - \frac{155}{198.7}$$

$$= 43.53 \ mm^2/s.$$

This value was checked using conversion chart ASTM D2161-79.
From table-1 of D2161-79 at 100 °F and 198.7 SUS, ν = 42.62 mm^2/s
From table-2 of D2161-79, the multiplying factor, A=1.00004
(at 38 °c ie. 100.4 °F)
∴ Kinematic viscosity at 38 °C = 42.62 x 1.00004 = 42.622
where 2% variation was noted.

Density:

Density was measured using ASTM standard graduated flask. For Linseed oil at 32°C, following data were noted. Weight of empty flask, W_f = 13.5684 gm
Volume of oil sample, V_b = 25 ml
∴ Weight of oil + flask, W_t = 36.4309 gm
∴ Weight of oil having 25 ml of volume, $W_l = (W_t - W_f)$ gm
∴ W_l = (36.4309 - 13.5684) = 22.8625 gm.
∴ Density, ρ_l = 22.8625/25 gm/ml

$$= \frac{22.8625}{25} \times 1000 \ \frac{kg}{m3}$$

$$= 911.68 \ kg/m^3.$$

Carbon Residue:

Carbon residue was measured as per ASTM Standard D189-81.
For the linseed oil sample,
(Weight of crucible with glass beads + 10gm oil), W_1 = 31.7132gm
(Weight of crucible with glass beads +carbon residue), W_2=21.7423gm

∴ Loss of oil = (10 gm oil - carbon residue) = $(W_1 - W_2)$ gm

∴ Carbon residue, A = 10 - $(W_1 - W_2)$ = 10 - (31.7132 - 21.7423)
= 0.0291 gm

$$\% \; Carbon\ residue = \left(\frac{10}{A}\right) \times 100$$

= 10 A
= 0.291

Ash Content:

Ash content of the fuel was measured as per ASTM Standard D82-87. Crucible with remaining material from carbon residue determination was subjected to heating upto 750° C.
After heating and cooling the crucible, weight of crucible with glass beads + ash = 21.7407 gm.
∴ Wt of ash content = (21.7423-21.7407) = 0.0016 gm

$$\therefore \text{Percent ash content} = \frac{\text{Wt. of ash}}{\text{Wt. of fuel}} \times 100\%$$

$$= \frac{0.0016}{10.000} \times 100\% = 0.016$$

In calculating engine performance parameters, experimental data of observation no. 5 of 30% Linseed oil and 70% kerosine fuel blend operation (Table 5.2.2) are used for example.

Basic information:

Test Date: 25.8.95

Barometric pressure : 759 m.m. Hg

Relative humidity : 78%

Dry bulb temperature : 31.25°C

Wet bulb temperature : 28°C

Specific gravity of fuel : 0.8255

Heating value : 42.247 MJ/kg

No. of obs	Reading from digital display unit		Fuel		Manometer reading	Air Inlet temp.	Exhaust temp.	Lub oil temp.
	Load (kg)	Speed (rpm)	Volume (c.c.)	Time (min)	h (cm)	tg_1 (°C)	tg_2 (°C)	t_L (°C)
5	60.3	676	80	0.917	36.0	45	473	81

Cooling water						
Temp. °C			Flow rate			
Inlet water t_{w1}	Outlet from cylinder t_{w21}	Outlet from lub oil cooler t_{w22}	Outlet from cylinder W_{w1}, (kg)	Time t_1 (min)	Outlet from lub oil cooler W_{w2}, (kg)	Time t_2 (min)
34	50	41	9.99	0.6725	1.44	0.569

Engine Derating:

Purpose of engine derating is to determine the power adjustment factor α and the fuel consumption adjustment factor β as per BS 5514 standard procedure.

Here,

	Standard Condition	Lab condition
Barometric Pressure	P_r = 100 kpa	P_x = 101.17 kpa
Air Temperature	T_r = 300°K	T_x = 304.25°K
Relative humidity	ϕ_r = 0.6	ϕ_x = 0.78

Following the BS 5514 procedure, the adjustment factors were determined as:

Power adjustment factor, α = 0.98339
Fuel consumption adjustment factor, β = 1.00226

Load and Speed:

Load and speed to calculate brake power of the engine, were measured with an electronic load cell transducer and magnetic pic-up attached with the dynamometer assembly. The system was calibrated with dead weights, prior to experiments.

Engine Brake Power (kw):

Engine brake power was calculated using the relationship:

$$P = \frac{W \times N \times 0.7355}{2500}$$

Where, P = Engine brake power in kw
W = Load on the dynamometer, kg = 51.8 kg,
N = Speed in rpm = 676 (which corresponds to engine flywheel speed of 2000 rpm)

Therefore,

$$P = \frac{60.3 \times 676 \times 0.7355}{2500}$$

$$= 11.99 \text{ kw.}$$

Brake power at standard references condition is given by

$$P_{standard} = \frac{P}{\alpha}$$

Where , α = Power adjustment factor = 0.98339

$\therefore P_{standard}$ = 11.99/0.98339 = 12.19 kw

Fuel Consumption:

Fuel consumption in g/h was calculated using following relation:

$$F = \frac{b\gamma_f}{t} \times 60 \text{ g/h}$$

where, F = Fuel consumption (g/h)

b = Fuel volume measurement (c.c.) = 80 c.c.

t = Time of fuel volume consumption (min) = 0.917 min

γ_f= Specific gravity of fuel = 0.8255

Therefore, F = (80x0.8255x60)/0.917 = 4321.05 g/h

Brake Specific Fuel Consumption:

Bsfc of the engine at the lab condition is given by,

$$Bsfc = \frac{\text{Fuel Consumption}}{\text{Brake Power at Lab condition}}$$

$$= (4321.05/11.99) \text{ g/kwh}$$

$$= 360.39 \text{ g/kwh}$$

Bsfc at the reference standard condition is given by:

$$Bsfc_{standard} = \frac{Bsfc}{\beta}$$

Where, β = Fuel consumption adjustment factor = 1.00226

$$\therefore \; Bsfc_{standard} = (360.39/1.00226) \text{ g/kwh}$$

$$= 359.58 \text{ g/kwh}$$

Brake Thermal Efficiency:

Brake Thermal efficiency of the engine is given by,

$$\eta_t = \frac{\text{Brake Power in kw}}{\text{Kilowatt equivalent of fuel consumed}} \times 100\%$$

Where, η_t = Brake thermal efficiency (%)

For brake power of 11.99 kw, fuel consumption was 4321.05 g/h having the fuel heating value of 42.247 MJ/kg. Kilowatt equivalent of fuel consumed

$$= \frac{H.F.}{3.6 \times 1000}$$

Where, H = Heating value of fuel = 42.247 MJ/kg

F = Fuel consumption = 4321.05 g/h

3.6 = Conversion factor, (1 kw = 3.6 MJ/hr)

∴ Kilowatt equivalent of fuel consumed

= (42.247x4321.05)/3.6x1000 = 50.71 kw

∴ Brake thermal efficiency, η_t = (11.99/50.71) x 100

= 23.64%

Air Consumption:

Air consumption of the engine was measured using a parabolic nozzle and a water manometer connected with air drum.

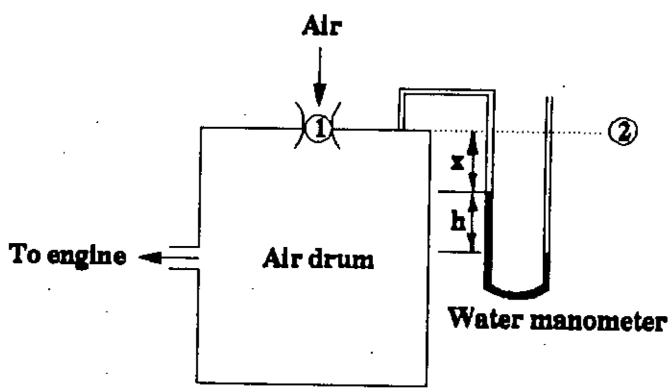
Basic Data:

Nozzle diameter, d = 0.019 m

Co-efficient of discharge of the nozzle , C_d=0.92

Specific weight of water, γ_{water} = 1000 kg/m^3

Acceleration due to gravity, g = 9.81 m/s^2



For manometer,

$$P_1 + x\,\gamma_{air} + h\,\gamma_{water} = P_2 + (x + h)\,\gamma_{air}$$

$$P_2 - P_1 = h\,(\gamma_{water} - \gamma_{air}) \ldots\ldots\ldots\ldots\ldots\ldots (i)$$

Applying Bernoulli's equation at (1) & (2),

$$\frac{P_1}{\gamma_{air}}+\frac{V_1^2}{2g}+Z_1 = \frac{P_2}{\gamma_{air}}+\frac{V_2^2}{2g}+Z_2$$

Here, $Z_1 = Z_2$ and $V_2 = 0$

$$\rightarrow V_1 = \sqrt{\frac{2g(P_2-P_1)}{\gamma_{air}}} \quad \ldots\ldots\ldots\ldots\ldots (ii)$$

From Equation (i) & (ii),

$$V_1 = \sqrt{\frac{2gh(\gamma_{water}-\gamma_{air})}{\gamma_{air}}}$$

Actual flow rate of air,

$$G_a = C_d \ (\pi\frac{d^2}{4})\times V_1\times 3600 \ m^3/h$$

$$= C_d(\frac{\pi d^2}{4}) V_1\times\gamma_{air}\times 3600 \ kg/h$$

$$= C_d(\frac{\pi d^2}{4})\sqrt{\frac{2gh(\gamma_{water}-\gamma_{air})}{100\gamma_{air}}}\times\gamma_{air}\times 3600 \ kg/h$$

Where 'h' is manometric deflection in cm.

Applying the data,

$$G_a = 0.92 \times \left(\frac{\pi \times 0.019^2}{4}\right)\sqrt{\frac{2 \times 9.81 \times 36.0(1000-1.1603)}{100 \times 1.1603}} \times 1.1603 \times 3600$$

= 83.16 kg/h

Air Fuel Ratio:

Air fuel ratio is expressed as:

$$AFR = \frac{\text{Air Consumption, (kg/h)}}{\text{Fuel Consumption, (kg/h)}}$$

= 83.16/(4321.05/1000)

= 19.25

Energy in Exhaust:

Heat energy taken out by the exhaust can be expressed as:

Q_g = $G_g \times C_{pg} \times (t_{g2} - t_{g1})$ MJ/h

Where, Q_g = Energy in exhaust

G_g = Exhaust gas flow rate, kg/h

= Air flow rate + Fuel flow rate

= $(G_a + F/1000)$ kg/h

= (83.16 + 4321.05/1000) kg/h

= 87.48 kg/h

C_{pg} = Specific heat of exhaust at constant pressure which is assumed to be C_p of air (for simplicity)

= 1.0062×10^{-3} MJ/kg-°K.

t_{g1}, t_{g2} = Inlet air and exhaust temperatures respectively

Applying the sample data,

$$Q_g = 87.48 \times 1.0062 \times 10^{-3} \times (473 - 45) \text{ MJ/h}$$
$$= 37.67 \text{ MJ/h}$$

Energy in Cooling Water:

Total heat energy taken out per hour

= (Heat in water for cylinder jacket cooler) + (Heat in Lub oil cooling water)

$$= (60\frac{W_{w1}}{t_1})\, C_{pw}(t_{w21}-t_{w1}) + (60\frac{W_{w2}}{t_2})\, C_{pw}(t_{w22}-t_{w1})$$

Where, W_{w1} and W_{w2} are water collected in kg, t_1, t_2 are time of collection in min.

C_{PW} = Specific heat of water at constant pressure
= 4.187×10^{-3} MJ/kg-°k

tw_1 = Inlet water temperature = 34°C

tw_{21} = Cylinder cooling water outlet temperature = 50 °C

tw_{22} = Lub oil cooling water outlet temperature = 41 °C

∴ Total energy in cooling water

$$= (\frac{60\times9.99}{0.6725})\times4.187\times10^{-3}\times(50-34) + (\frac{60\times1.44}{0.569})\times4.187\times10^{-3}\times(41-34)$$

= 64.16 MJ/h

APPENDIX - D

EXPERIMENTAL DATA AND RESULTS

Table 5.1.1: Viscosity measurement data.

Mustard oil			Groundnut oil		
Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm^2/s)	Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm^2/s)
23	391	84.37	32	290	62.58
38	215	46.40	48	182	39.73
40	200	43.82	61	150	32.42
54	140	30.11	76	97	19.82
82	80	15.61	93	75	14.33
100	62	11.00	102	63	11.17

Table 5.1.1 continued

Linseed oil			Sunflower oil		
Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm^2/s)	Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm^2/s)
23	338	72.89	33	203	44.50
38	199	43.53	50	128	27.33
40	180	39.28	65	93	18.84
54	110	22.96	74	76	14.54
82	63	11.17	86	66	11.98
99	52	8.09	101	55	8.95

Table 5.1.1 continued

Diesel			Kerosine		
Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm^2/s)	Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm^2/s)
31	51	7.80	30	31	0.976
42	45	5.97	32	30	0.553
52	41	4.67	43	30	0.553
62	39	3.99	54	29	0.117
73	37	3.26	76	28	
83	35	2.63			

Table 5.1.1 continued

50% Mus + 50% Ker			50% Gnt + 50% Ker		
Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm^2/s)	Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm^2/s)
22	70.4	13.14	29.5	65	11.71
39	55.0	8.96	43.0	50	7.50
55	46.0	6.28	54.0	46	6.28
74	41.0	4.67	65.0	45	5.97
82	38.5	3.82	78.5	40	4.33
99	35.5	2.74			

Table 5.1.1 continued

30% Lin + 70% Ker			40% Lin + 60% Ker		
Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm²/s)	Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm²/s)
31.5	36	2.93	29	43	5.33
40	35	2.18	43	39	3.99
46.5	34	2.17	57	37	3.29
61.0	33	2.15	74	35	2.55
			87	34	2.17

Table 5.1.1 continued

50% Lin + 50% Ker			60% Lin + 40% Ker		
Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm²/s)	Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic viscosity (mm²/s)
32	49	7.20	34	70	13.04
39	47	6.59	44	53	8.38
50	41	4.67	52	49	7.20
53	39	3.99	73	42	5.00
62	36	2.93	84	38	3.64
80	35	2.55			

Table: 5.1.1 Continued

50% Sun + 50% Ker		
Temp. (°C)	Saybolt Universal Second (SUS)	Kinematic Viscosity (mm²/s)
31.5	50	7.5
43	45	5.97
60	40	4.34
76	38	3.64
87	36	2.92

Table 5.1.2: Density measurement data

No. of obs.	Mustard oil		Groundnut oil		Linseed oil	
	Temp. (°C)	Density Kg/m^3	Temp. (°C)	Density (Kg/m^3)	Temp. (°C)	Density (Kg/m^3)
1.	32	902.55	30	900.00	27	914.5
2.	36	898.84	31	899.95	32	911.67
3.	38	898.21	35	899.01	36	905.07
4.	43	894.04	37	896.00	41	905.07
5.	47	893.89	41	895.60	52	897.77
6.	51	890.54	49	891.60	60	893.75
7.	55	889.38	50	889.95	66	888.47
8.	57	888.24	62	879.87	71	885.19
9.	59	885.80	70	877.01	82	880.11
10.	63	883.30	81	865.24	93	872.86
11.	67	882.24	91	860.25	102	864.45
12.	70	880.05				

Table 5.1.2: continued.

No. of obs.	Mustard oil		Diesel		Kerosine	
	Temp. (°C)	Density Kg/m^3	Temp. (°C)	Density (Kg/m^3)	Temp. (°C)	Density (Kg/m^3)
1.	28	902.27	28	847.17	27	777.84
2.	34	899.96	35	842.78	33	774.53
3.	41	893.33	42	840.68	39	770.23
4.	48	891.14	55	828.61	45	764.44
5.	56	886.82	63	825.34	56	758.18
6.	63	883.50	67	823.93	63	754.93
7.	71	877.60	75	817.93	68	750.34
8.	78	873.73	82	814.49	75	747.31
9.	84	869.49	92	809.08	82	741.28
10.	96	863.14	100	803.86	89	736.57
11.					103	724.75

Table 5.1.2: continued.

No. of obs.	50% Mus+ 50% Ker		50% Gnt+ 50% Ker		30% Lin+ 70% Ker	
	Temp. (°C)	Density Kg/m³	Temp. (°C)	Density (Kg/m³)	Temp. (°C)	Density (Kg/m³)
1.	28	840.72	25	845.21	28	821.21
2.	41	833.76	47	832.96	32	819.32
3.	48	828.51	48	832.92	40	816.11
4.	53	825.81	56	827.68	42	815.03
5.	57	825.03	63	823.14	48	810.31
6.	64	819.04	66	820.15	53	808.61
7.	73	812.49	76	814.16	61	800.01
8.	78	809.41	85	809.17	70	797.13
9.	82	810.07	87	805.37	75	794.54
10.	88	805.04			85	785.43
11.	98	796.24			92	780.39

Table 5.1.2: continued.

No. of obs.	40% Lin+ 60% Ker		50% Gnt+ 50% Ker		60% Lin+ 40% Ker	
	Temp. (°C)	Density Kg/m³	Temp. (°C)	Density (Kg/m³)	Temp. (°C)	Density (Kg/m³)
1.	28	832.23	27	839.97	28	847.21
2.	36	826.48	39	831.60	31	845.11
3.	43	821.37	46	826.77	40	841.05
4.	54	814.89	52	822.61	48	835.31
5.	61	810.02	60	820.53	60	829.34
6.	68	805.78	66	814.16	63	823.03
7.	77	800.69	71	809.20	65	820.39
8.	88	794.94	79	803.39	71	817.12
9.	93	789.34	91	798.23	83	811.44
10.	100	782.22	102	788.43	93	803.38

Table 5.1.2: continued.

No. of obs.	50% Sunflower Oil & 50% Kerosine blend (by volume)	
	Temp. (°C)	Density (Kg/m^3)
1.	27	843.29
2.	34	839.44
3.	39	836.42
4.	43	832.62
5.	49	830.22
6.	52	828.49
7.	60	823.96
8.	64	821.55
29.	71	818.61
10.	78	813.82
11.	84	809.54
12.	96	801.06

Table 5.1.3: Distillation data.

Based on 100 ml of sample.

Percentage of volume recovered	Distillation temperature (°C)					
	Mustard oil	Groundnut oil	Linseed oil	Sunflower oil	Diesel	Kerosine
00	213	232	232	205	216	172
10	260	254	260	271	273	180
20	266	290	271	282	276	185
30	271	302	282	287	284	191
40	294	307	296	290	295	196
50	298	315	305	300	308	205
60	300	325	315	307	319	210
70	340	354	346	336	330	220
80	-	-	-	-	350	230
90	-	-	-	-	-	239

Table 5.1.3: continued.

Percentage of volume recovered	Distillation temperature (° C)		
	50% Mus + 50% Ker	50% Gnt + 50% Ker	30% Lin + 70% Ker
00	175	179	170
10	187	192	185
20	200	206	191
30	211	218	199
40	222	235	208
50	244	302	219
60	260	320	230
70	280	335	255
80	325	345	295

Table 5.1.3: continued.

Percentage of volume recovered	Distillation temperature (°C)			
	40% Lin + 60% Ker	50% Lin+ 50% Ker	60% Lin + 40% Ker	50% Sun + 50% Ker
00	170	179	176	176
10	187	188	196	188
20	193	196	200	204
30	206	209	205	216
40	220	224	228	233
50	238	254	260	288
60	285	296	284	304
70	310	305	307	313
80	325	330	334	328

Table 5.1.4: Fuel properties of various oils used in the study.

Oil variants	Higher heating value (MJ/Kg)	Viscosity* (mm^2/s)	Density* (kg/m^3)	Flash point (°C)	Carbon residue (%)	Ash content (%)
Mustard oil	37.96	61.58	901.00	227	0.321	0.068
Groundnut oil	37.88	62.58	901.00	266	0.244	0.007
Linseed oil	37.76	55.27	910.00	238	0.291	0.016
Sunflower oil	37.71	43.94	901.00	315	0.261	0.008
Diesel	43.93	6.80	847.00	75	0.332	0.009
Kerosine	44.17	1.71	773.00	52	0.319	0.005

Table 5.1.5: Fuel properties of various blended fuels used in the study.

Oil variants	Higher heating value (MJ/Kg)	Viscosity* (mm^2/s)	Density* (kg/m^3)	Carbon residue (%)	Ash content (%)
50% Mus + 50% Ker	41.06	12.40	841.00	0.320	0.036
50% Gnt + 50% Ker	41.02	12.62	845.00	0.281	0.006
30% Lin + 70% Ker	42.25	3.70	821.00	0.310	0.008
40% Lin + 60% Ker	41.61	6.00	830.00	0.308	0.009
50% Lin + 50% Ker	41.00	8.20	837.00	0.305	0.010
60% Lin + 40% Ker	40.32	14.95	847.00	0.302	0.012
50% Sun + 50% Ker	40.94	9.10	842.50	0.290	0.606

* Measured at 32°C.

Table 5.1.6: Comparison of fuel properties of vegetable oils considered in the present study, with those of other research workers.

Oil variants	Higher heating value (MJ/kg)	Viscosity (mm^2/s)	Density (kg/m^3)	Flash point (° C)	Carbon residue (%)	Ash content (%)
Mustard	37.96 (39.709) 38.2*	46.40 (37.0) 45.0*	901.00 (911.5) 905.0*	227 (246)	0.321 (0.30) 0.266*	0.068 (0.054) 0.013*
Groundnut	37.88 (39.782)	54.01 (39.6)	901.00 (902.26)	266 (271)	0.244 (0.24)	0.007 (0.005)
Linseed	37.76 (39.307) 38.7*	43.53 (27.2) 41.0*	910.00 (923.6) 855.0*	238 (241)	0.291 (0.22) 0.329*	0.016 (0.01) 0.011*
Sunflower	37.71 (39.575)	38.95 (33.9)	901.00 (916.1)	315 (274)	0.261 (0.23)	0.008 (0.01)

In this table values within the parenthesis are obtained from Bari (13) and values marked with asterisk are from the recent work of Zahurul (41). Viscosity values of the present study and of Bari (13) are measured at 38° C. Density values of the present study are at 32 °C.

Table 5.2.1: Engine running with pure diesel at variable loads and 2000 rpm

P_{atm} = 759 mm Hg   Dbt = 30 °C ϕ = 80%

α = 0.996189 β = 1.00052

No. of obs	Speed (rpm)	Load (kg)	Power (kw)	Derated power (kw)	Fuel consumption (g/h)	Bsfc (g/kwh)	Derated bsfc (g/kwh)	Brake thermal efficiency (%)
1.	2000	34.0	6.76	6.79	2982.35	441.05	440.82	18.21
2.	2000	43.2	8.59	8.62	3292.21	383.19	382.99	20.96
3.	2000	53.7	10.68	10.72	3711.57	347.53	347.35	23.11
4.	2000	59.0	11.73	11.78	3900.00	332.37	332.20	24.16
5.	2000	66.0	13.13	13.18	4348.20	331.26	331.09	24.24
6.	2000	69.2	13.76	13.82	4470.90	324.86	324.69	24.72
7.	2000	76.2	15.15	15.21	4828.57	318.62	318.46	25.20
8.	2000	77.2	15.35	15.41	4970.59	323.75	323.58	24.81

Table 5.2.1   continued

No. of obs	Air consumption (kg/h)	Air fuel ratio	Cooling water temp. (°C)	Exhaust temp. (°C)	Energy in Exhaust (MJ/h)	Energy in water (MJ/h)
1.	86.01	28.84	43	331	26.51	54.97
2.	85.48	25.96	45	371	29.74	56.11
3.	84.67	22.84	47	416	33.56	58.40
4.	84.43	21.70	49	444	35.99	59.75
5.	83.91	19.33	51	485	39.49	61.98
6.	83.48	18.63	52	508	40.97	64.34
7.	82.58	17.18	53	556	45.22	70.39
8.	82.45	16.59	54	573	46.36	71.50

Table 5.2.2: Engine running with 30% linseed oil and 70% kerosine blend (by volume) at variable loads and 2000 rpm.

P_{atm} = 759 mm Hg   Dbt = 31.25 °C ϕ = 78%

α = 0.98339 β = 1.00226

No. of obs.	Speed (rpm)	Load (kg)	Power (kw)	Derated power (kw)	Fuel consumption (g/h)	Bsfc (g/kwh)	Derated bsfc (g/kwh)	Brake thermal efficiency (%)
1.	2000	30.3	6.03	6.13	2898.61	481.01	479.93	18.01
2.	2000	38.0	7.56	7.69	3213.63	425.23	424.27	20.38
3.	2000	44.0	8.76	8.91	3522.13	401.90	401.00	21.56
4.	2000	51.8	10.30	10.48	3865.76	375.25	374.40	23.09
5.	2000	60.3	11.99	12.19	4321.05	360.31	359.50	24.05
6.	2000	67.0	13.32	13.55	4661.65	349.84	349.06	24.77
7.	2000	72.0	14.32	14.25	4953.00	345.90	345.12	24.74
8.	2000	74.0	14.72	14.97	5166.10	351.03	350.24	24.69

Table 5.2.2: continued.

No. of obs	Air consumption (kg/h)	Air fuel ratio	Cooling water temp. (°C)	Exhaust temp. (°C)	Energy in exhaust (MJ/h)	Energy in water (MJ/h)
1.	84.82	29.26	47	326	25.07	51.84
2.	84.57	26.32	48	358	27.82	53.75
3.	84.33	23.94	48	396	31.11	56.68
4.	83.91	21.72	49	431	34.21	59.70
5.	83.16	19.25	50	473	37.67	64.16
6.	82.68	17.74	51	515	41.22	67.53
7.	82.21	16.60	52	540	43.24	70.03
8.	81.96	15.87	53	555	44.45	70.81

Table 5.2.3: Engine running with 40% linseed oil and 60% kerosine blend (by volume) at variable loads and 2000 rpm.

P_{atm} = 760 mm Hg Dbt = 31 °C ϕ = 79%

α = 0.9919 β = 1.0011

No. of obs.	Speed (rpm)	Load (kg)	Power (kw)	Derated power (kw)	Fuel consumption (g/h)	Bsfc (g/kwh)	Derated bsfc (g/kwh)	Brake thermal efficiency (%)
1.	2000	32.2	6.43	6.48	3108.92	483.33	482.80	18.05
2.	2000	43.1	8.58	8.65	3567.17	415.54	415.09	20.99
3.	2000	55.6	11.07	11.16	4111.50	371.27	370.87	23.50
4.	2000	66.2	13.17	13.27	4661.59	354.07	353.68	24.64
5.	2000	70.0	13.60	13.71	4800.00	352.85	352.46	24.72
6.	2000	68.3	13.92	14.4	4946.88	355.34	354.95	24.55

Table 5.2.3: continued.

No. of obs	Air consumption (kg/h)	Air fuel ratio	Cooling water temp. (°C)	Exhaust temp. (°C)	Energy in exhaust (MJ/h)	Energy in water (MJ/h)
1.	85.21	27.41	47	335	26.21	52.51
2.	84.46	23.68	49	383	30.11	56.24
3.	83.92	20.26	51	442	35.00	60.86
4.	82.91	17.81	53	498	39.98	67.64
5.	82.61	17.21	54	516	41.25	68.36
6.	82.44	16.66	54	531	42.56	70.35

Table 5.2.4: Engine running with 50% linseed oil and 50% kerosine blend (by volume) at variable loads and 2000 rpm.

P_{atm} = 759 mm Hg   Dbt = 31 °C ϕ = 75%

α = 0.98504 β = 1.00204

No. of obs.	Speed (rpm)	Load (kg)	Power (kw)	Derated power (kw)	Fuel consumption (g/h)	Bsfc (g/kwh)	Derated bsfc (g/kwh)	Brake thermal efficiency (%)
1.	2000	28.0	5.57	5.65	3050.00	547.71	546.60	16.27
2.	2000	37.4	7.44	7.55	3387.88	456.82	455.89	19.51
3.	2000	45.0	8.95	9.09	3762.11	420.37	417.51	21.20
4.	2000	53.0	10.54	10.40	4008.00	398.46	389.65	22.54
5.	2000	58.0	11.53	11.71	4391.00	398.04	372.20	23.42
6.	2000	64.5	12.83	13.02	4826.92	384.08	364.20	24.18
7.	2000	70.0	13.92	13.60	5023.53	360.85	360.11	24.49
8.	2000	72.0	14.32	13.90	5314.35	371.20	368.45	23.86
9.	2000	73.0	14.52	14.74	5451.06	375.46	374.70	23.74

Table 5.2.4 continued

No. of obs	Air consumption (kg/h)	Air fuel ratio	Cooling water temp. (°C)	Exhaust temp. (°C)	Energy in exhaust (MJ/h)	Energy in water (MJ/h)
1.	85.77	28.12	45	304	23.86	55.91
2.	85.10	25.12	47	345	27.42	57.5
3.	84.65	22.87	48	382	30.47	58.87
4.	84.16	20.45	51	410	34.01	61.1
5.	83.84	18.98	52	455	36.98	62.45
6.	83.10	17.35	53	487	39.81	66.81
7.	82.71	16.15	55	510	41.10	67.48
8.	82.60	15.72	57	520	42.13	68.91
9.	81.99	14.91	58	543	43.45	71.8

Table 5.2.5: Engine running with 60% linseed oil and 40% kerosine blend (by volume) at variable loads and 2000 rpm.

P_{atm} = 759 mm Hg Dbt = 31 °C ϕ = 79%

α = 0.9919 β = 1.0011

No. of obs	Speed (rpm)	Load (kg)	Power (kw)	Derated power (kw)	Fuel consumption (g/h)	Bsfc (g/kwh)	Derated bsfc (g/kwh)	Brake thermal efficiency (%)
1.	2000	35.0	6.96	7.02	4243.75	468.00	467.49	18.58
2.	2000	43.0	8.55	8.62	3642.11	427.89	427.42	20.26
3.	2000	51.0	10.15	10.23	4082.62	400.54	400.10	22.14
4.	2000	57.0	11.34	11.43	4425.00	389.53	389.10	22.92
5.	2000	63.0	12.53	12.63	4760.73	378.28	377.87	23.42
6.	2000	65.8	13.08	13.19	5000.63	371.81	371.40	23.85
7.	2000	68.0	13.52	13.63	5224.83	382.34	381.92	22.95
8.	2000	71.8	14.28	14.40	5560.71	389.42	388.99	22.77

Table 5.2.5: continued.

No. of obs	Air consumption (kg/h)	Air fuel ratio	Cooling water temp. (°C)	Exhaust temp. (°C)	Energy in exhaust (MJ/h)	Energy in water (MJ/h)
1.	85.6	26.16	46	335	26.59	57.45
2.	85.11	23.22	47	365	29.11	59.14
3.	84.4	20.16	47	405	32.64	61.25
4.	84.19	18.80	48	437	35.45	63.01
5.	83.57	17.53	48	472	38.30	65.51
6.	83.41	16.85	49	505	40.98	67.13
7.	82.93	15.91	50	515	41.81	67.81
8.	82.49	14.98	50	536	43.68	70.50