STUDY OF THE PROPERTIES OF VEGETABLE OIL AS AN ALTERNATIVE TO DIESEL FUEL

by

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Certificate of approval

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To
My parents

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Abstract

In view of the energy crisis and emission problems, alternative fuels are promising substitute to the conventional petroleum fuels. Among them, vegetable oils seem attractive substitute to diesel fuels. They have the advantage of being geographically widely produced, in a variety of products and are renewable in nature and thereby not contributing to the net atmospheric concentrations of the green house gas, CO_2.

However, higher viscosity and lower volatility are identified as the main reasons for the unsuitability of vegetable oils as straight diesel fuel substitute. So, in this study attempts have been made to study the possibility of using vegetable oils as diesel fuel substitute by modifying their properties. Hence, kerosene is blended with 4 different vegetable oils (Rapeseed, Soyabean, Sesame and Linseed) in equal volumes to serve the purpose.

Testing of the properties of the vegatable oils, pure and blended, are then performed. It is found that the desities and viscosities of pure vegetable oils are significantly higher than those of diesel (about 10% higher in case of densities & about 12 times higher in case of viscosities). However, when blended with kerosene, these properties are found reduced to a comparable figure (about 0.50% higher in case of densities & about 2.5 times higher in case of viscosities). It is also found that the energy densities of the blended vegetable oils are very close to that of diesel. Carbon residue of vegetable oils are found lower and the ash percentages are found higher than the diesel values. Volatility curves obtained for the blends also indicate the lower boiling temperatures at the early stage of evporations, while boiling temperatures similar to that of diesel values are observed at the end portions of the distillate.

From these blends, Sesame and Soyabean blends are then tested to study the engine performance. From the experimental results, it is seen that vegetable oil blends result in slightly reduced performance, showing higher bsfc (about 10% higher) and slightly lower brake thermal efficiencies (about 2% lower). It is also found that these two blends result in the performances very close to each other. So, it is concluded that vegetable oils can be substituted for diesel fuel with little sacrifice in power and efficiency. Hence, conclusion is also drawn that with vegetable oil blends, modification in viscosity and volatility would result in comparable performance with diesel fuels.

Contents

List of Figures

List of Tables

Abbreviations

α	power correction factor
β	fuel consumption correction factor
AF	Alternative fuel
ASTM	American Society for Testing and Materials
bdc	Bottom dead Center
bsfc	Brake specific fuel consumption
CI	Compression Ignition engines
CO	Carbon Mono-Oxide
$F_{\mathbf{flow}}$	fuel consumption rate in Kg/hr
$F_{\mathbf{standard}}$	fuel consumption rate after standardization in Kg/hr
HCV	Higher calorific value MJ/Kg
IC	Internal combustion
LCV	Lower calorific value MJ/Kg
NO_x	Oxides of Nitrogen
Lin50K50	Blend of Kerosene and Linseed by 50% by volume
P(hp)	brake power in horse power
P(kW)	brake power in kW
$P_{\mathbf{standard}}$	brake power after standardization
rpm	revolution per Minute
Rap50K50	Blend of Kerosene and Rapeseed by 50% by volume
RON	Research octane number
Ses50K50	Blend of Kerosene and Sesame by 50% by volume
Soy50K50	Blend of Kerosene and Soyabean by 50% by volume
T_{10}	Temperature at which 10% of the fuel is distilled
T_{50}	Temperature at which 50% of the fuel is distilled
T_{90}	Temperature at which 90% of the fuel is distilled

Chapter 1

Compression Ignition Engines

1.1 Introduction

The Compression Ignition engines, also known as Diesel engines, are high performance engines. They are widely used in power generation, in bus and trucks, in marine purposes and also in automobiles. They operate on the constant pressure Diesel cycle or on Dual cycle. They use liquid fuel of low volatility varying from low-grade kerosene and distillates to crude oil. In CI engines no ignition devices are used; load and speed are controlled by varying the fuel quantity injected. They have the advantage of low specific fuel consumption, ability to maintain economy and thermal efficiency at part loads, low fuel cost and practically no CO except near full load or at over load conditions. In the early stages of CI engine, emphasis was given on the economy, productivity and safety. However, the last two decades have witnessed growing concern over the environmental impact and/or exhaustion of conventional fossil fuels. These concerns have highlighted the need for diversification and prompted increased research world wide into potential alternative fuels for CI engines.

1.2 Compression Ignition Engine operation

In CI engines, air alone is compressed and raised to a high temperature on the compression stroke.The compression ratio of CI engines is much higher than typical SI engine values, and is in the range 12 to 24, depending on the type of engine and whether the engine is naturally aspirated or turbocharged. Air at close to atmospheric pressure is induced during the intake stroke and then compressed to a pressure of about 4 to 10 MPa and temperature of about 1000 K during the compression stroke. At about 20° before TDC, fuel injection in the cylinder commences; and a typical injection profile is shown in Fig. 1.1. At full load, the mass of fuel injected is about 5 per cent of the mass of air in the cylinder. The exhaust process is similar to that of the four-stroke SI engine. At the end of exhaust stroke, the cycle starts again.

1.3 Combustion in CI Engines

In CI engines air, diluted by a small fraction of residual gas, is compressed through a volume ratio of from 12 to 24, liquid fuel is sprayed into the cylinder near the top-centre position of the piston. The fuel jet disintegrates into a core of fuel surrounded by a spray envelope of air and fuel particles as shown in fig. 1.2. The later zone is created by the atomization and vaporization of the fuel and the turbulence of the air in the combustion chamber passing across the jet and stripping the fuel particles from the core[2].

In CI engine combustion process is heterogeneous, its spontaneous ignition process is very complex. Though ignition occurs at vapour phase, oxidation reactions can proceed in the liquid phase as well between the fuel molecules and

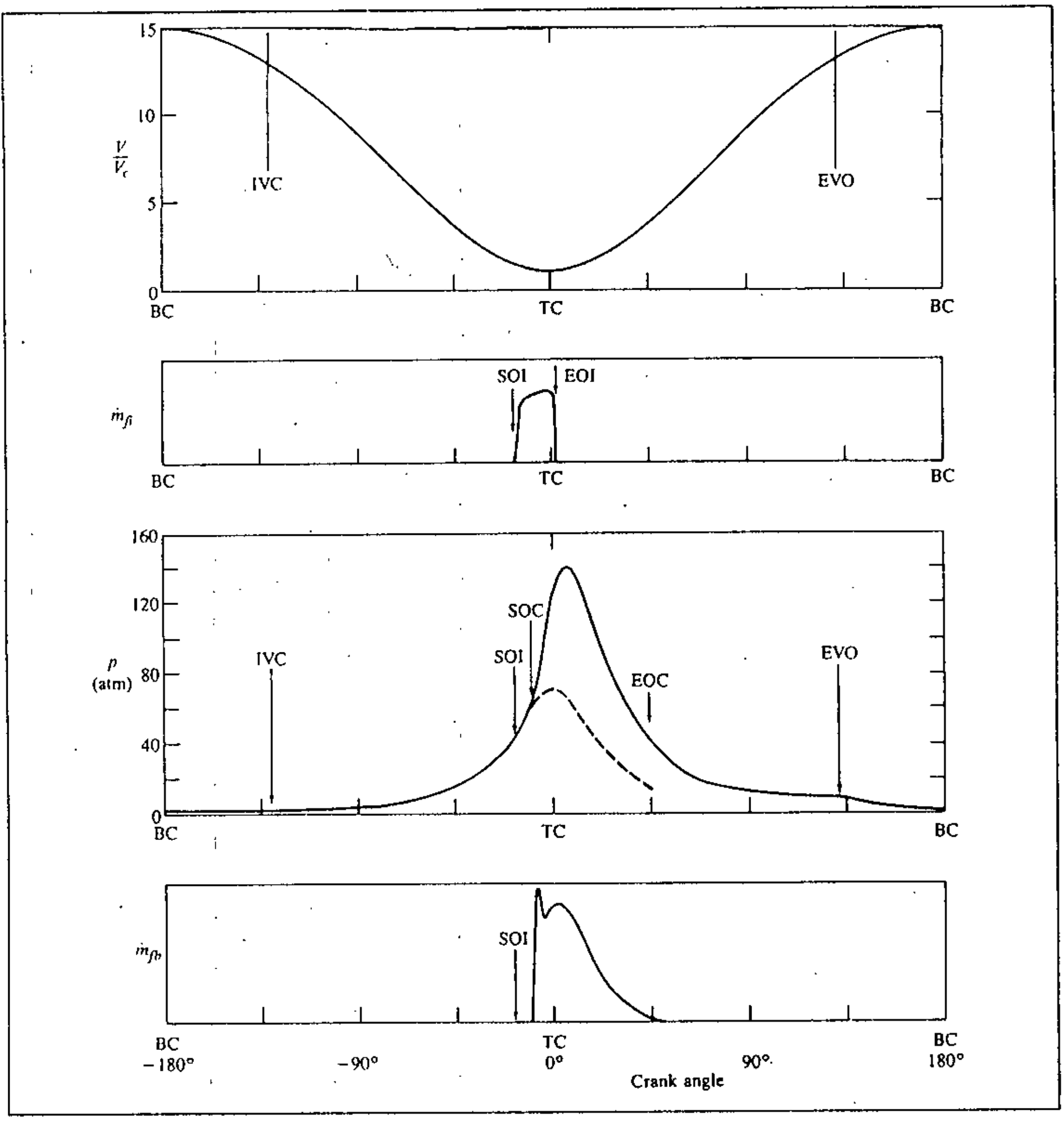

Figure 1.1: Sequence of events during compression, combustion, and expansion processes of a naturally aspirated CI engine operating cycle [1].

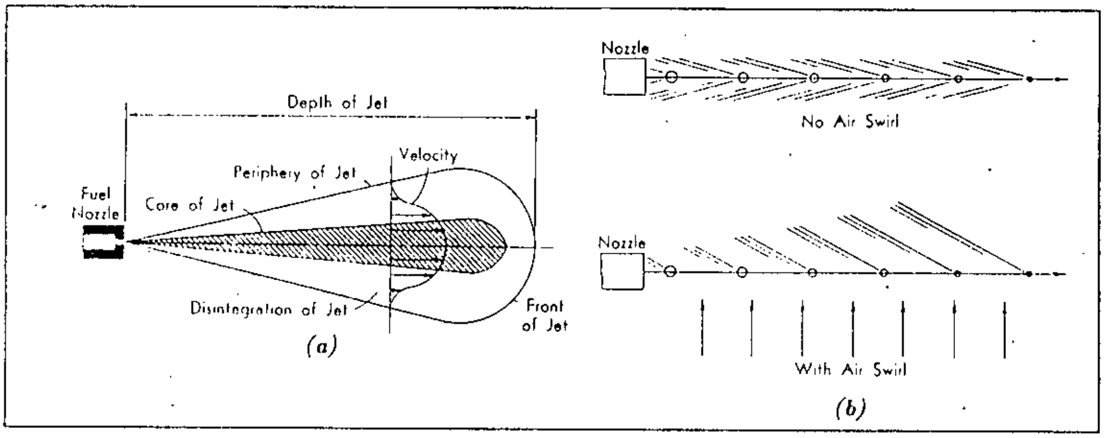

Figure 1.2: Schematic analysis of the disintegration of fuel jet (a) Newman, *SAE Journal*,Nov.1944; (b) Dicksee, *SAE Trans*,Jan,1949.

the oxygen dissolved in the fuel droplets. Also, cranking of large hydrocarbon molecules to smaller molecules are occurring. These chemical processes depend on the composition of the fuel and the cylinder charge temperature and pressure, as well as the physical processes required for the proper distribution of fuel in the chamber.

Because of the high compression ratio, the gases in the cylinder at the time of injection are well above the temperature and pressure required to support the chain reactions in a uniform air fuel mixture. Under these circumstances, the ignition of any element of the charge does not require the transfer of energy from some other portion but will occur when the local circumstances of temperature, pressure, and mixing of fuel and air make combustion of one part of the charge provided they are in a state to support combustion, and combustion of one part may reduce the reaction pressure and temperature. The combustion in the CI engine is an effect of local conditions in each part of the charge and is not dependent on, although it may be assisted by, the spread of flame from one part to another. Thus the combustion rate is affected by the state and distribution of the fuel as well as by the pressure and temperature in the chamber.

The fuel combustion in CI engines have the following stages [2] and they are identified on the typical heat release diagram for a DI engine in fig. 1.3.

1. Ignition delay
2. Rapid pressure rise (probable premixed flame)
3. Mixing controlled combustion phase probable diffusion flame)
4. Late combustion phase.

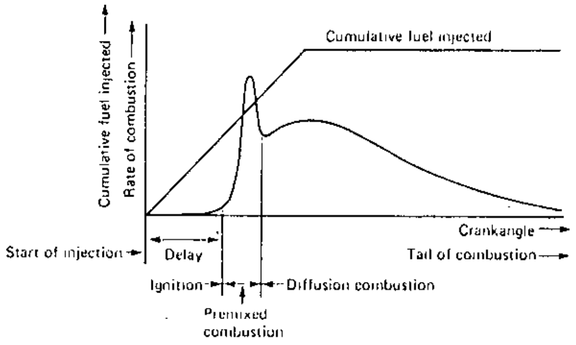

Figure 1.3: Typical DI engine heat release diagram identifying different diesel combustion phases[3].

Hence, the rapid pressure rise occurs because of the myrid ignition points and the accumulation of fuel in the delay period. Following this stage, the final portion of the fuel are injected into flame, and consequently combustion in this portion is somewhat regulated by the injection rate. Since the process is far from being homogeneous, combustion continues when the expansion stroke is well under way. This continued burning can be called the fourth stage of combustion.

1.4 CI Engine Combustion Chamber Design

The shape of the combustion chamber is very important as generated turbulence and swirl of the charge depends on it. Primary swirl and primary turbulence are induced before combustion on the inlet and compression strokes by the flow geometries of the inlet passageways and the chamber(s): secondary turbulence arise from the combustion process and are directed by the flow geometry of the combustion chamber and containing walls. The design of the combustion chamber usually fall on the following broad two category:

1. Direct Injection (DI) Engines
2. Indirect Injection (IDI) Engines
    (a) Precombustion Chamber
    (b) Turbulence Chamber
    (c) Energy cell

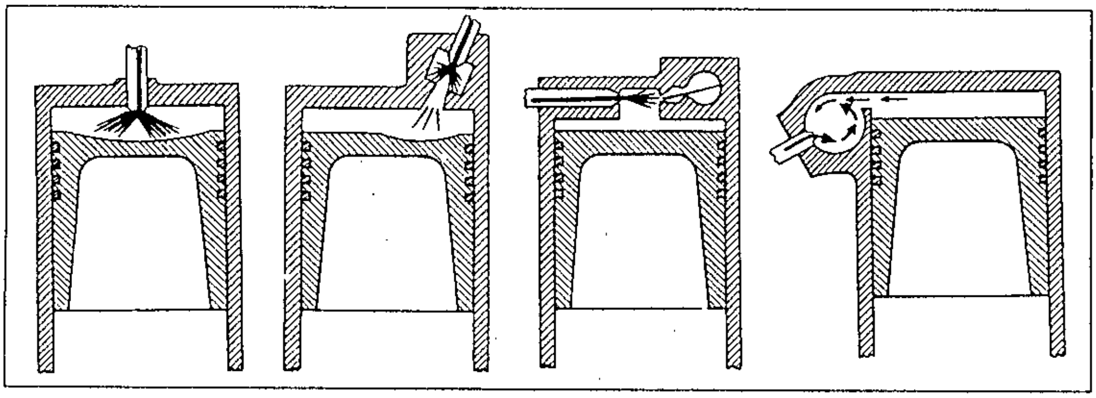

Figure 1.4: Combustion Chamber design for CI Engines (a) DI Engine (b) Precombustion chamber (c) Turbulence Chamber (d) Energy Cell [4]

In all IDI designs, an extra chamber for starting the combustion process is provided, and the combustion is continued in the main chamber as shown in fig. 1.4. Ignition delay is shorter with the IDI designs; only a small amount of fuel needs to accumulate in extra chamber before a combustible mixture is formed. Thus, IDI engines are quieter than DI engines and/or can be run on fuel with a lower cetane number e.g. vegetable oils. Also, IDI engines can use fuels with higher viscosity because the fuel does not need to be atomized as finely as in a DI engine.

1.4.1 Direct Injection Engines

An *open-chamber* or *direct chamber diesel* has an undivided combustion chamber formed between the piston and head into which fuel is injected. The task of mixing the fuel and air, controlling the combustion rate, falls upon the injection system.

In open chamber diesel engines cheap fuels can be burned and low combustion pressures can be held. They have the highest potential for maximum enthalpy efficiency because the combustion chamber offers the minimum wall area per unit of volume. The advantages of the open chamber design with a slow speed engine are as follows[2]:

1. The specific fuel consumption should be the lowest of all types of diesel engines.
2. Starting is relatively quick (because of low heat losses).
3. Less heat is rejected to coolant, and less energy in exhaust gases (because of the high enthalpy efficiency).
4. Quiet, relative freedom from combustion noise.
5. Residual fuel can be burned.

1.4.2 Precombustion Chamber

A divided-chamber diesel that depends upon a small antechamber to initiate combustion and to create a high secondary turbulence (or secondary swirl) for mixing and burning the major part of the fuel and air is called a *precombustion chamber diesel*. The precombustion chamber volume is about 20 to 30 per cent of the clearance volume, with one or more outlets leading to the main chamber. The outlets may be oriented to create primary turbulence in the prechamber.

The objective of the prechember design is to burn clearly in the small precup only a fraction of the injected fuel so that the resulting pressure rise will expel hot, vaporization but unburned fuel, more than partially burned fuel, at high velocity into the main chamber. So the duties of the injection nozzle are comparatively light. Moreover, high-cetane fuels may not be advantageous in a precup engine, since combustion begin too smoothly[2].

1.4.3 Swirl or Turbulence Chamber

A divided-chamber diesel that depends upon high primary swirl in a large antechamber to break up the fuel spray and initiate combustion, while forming essentially a homogenous mixture, is called a *swirl chamber* or a *turbulent-cell diesel*. Since the antechamber is connected to the main chamber by a restricted passageway, the shock of autoignition is confined within the swirl chamber to some degree. So,less mechanical stress rise and noise because of the lower rate of pressure rise and the lower maximum pressure in the main chamber. It also results in clean burning and able to achieve low levels of smoke, and NO_x, and unburnt hydrocarbons. The primary disadvantage of the swirl-chamber diesel is a greater specific fuel consumption than that of the open chamber type.

1.4.4 Air and Energy Cell

A divided-chamber diesel that depends upon a small antechamber to supply air and secondary turbulence to finish the combustion is called an *air cell diesel* . The rise in pressure with combustion in the main chamber forces additional air into the air cell (about 10 deg. a TDC). Later in the expansion stroke (about 20 deg a TDC), the pressure in the main chamber falls below that in the air cell; the air cell starts to discharge and so creates a light secondary turbulence (plus additional air) that helps, in some small degree, to complete the combustion process.

1.5 Requirements of a good CI fuel

The requirements for a good CI fuel cannot be as simply stated as were those for gasoline. This situation arises because of the added complexity of the CI engine from its heterogeneous combustion process, which is strongly affected by injection characteristics. However, the following general observations can be made:

1. *Knock Characteristics:* The present-day measure is the cetane rating - the best fuel, in general, will have a cetane rating sufficiently high to avoid objectionable knock.

2. *Starting Characteristics:* The fuel should start the engine easily. This requirement demands high volatility, to form readily a combustible mixture; and a high cetane rating, in order that the self-ignition temperature will be low.

3. *Smoking and Odour:* The fuel should not promote either smoke or odour from the exhaust pipe. In general, good volatility is demanded as the first

prerequisite to ensure good mixing and therefore complete combustion.

4. *Corrosion and Wear:* The fuel should not cause corrosion before combustion, or corrosion and wear after combustion. These requirements appear to be directly related to the sulphur, ash, and residue contents or the fuel.
5. *Handling Ease:* The fuel should be a liquid that will readily flow under all conditions that will be encountered. This requirement is measured by the pour point and the viscosity of the fuel. The fuel should also have a high flash point since an advantage of the CI engine is its use of fuels with low fire hazards.

1.6 Exhaust emissions of CI engines

1.6.1 Carbon Monoxide (CO) Formation:

Carbon monoxide emissions from CI Engines are controlled primarily by the fuel/air equivalence ratio ϕ. The CO concentrations in the exhaust increases with increasing equivalence ratio. Diesel engines always operate well on the lean side of stoichiometric, so CO emissions from diesel are low enough to be important.

1.6.2 NO_x Formation:

For both DI and IDI engines, the value of NO increases rapidly as the equivalence ratio ϕ increases at a fixed injection timing. The critical equivalence ratio for NO formation in high temperature and pressure combustion is close to stoichiometric. The critical time period is between the start of combustion and shortly after the occurrence of peak cylinder pressure (premixed combustion) and this is when burned gas temperatures are at a maximum. The decreasing temperature due to expansion and mixing of high temperature gas with air or cooler burned gas freezes the NO formation. As the injection timing is retarded, so the combustion process is retarded, NO formation occurs latter and concentrations are lower since peak temperatures are lower. At higher load with higher peak pressures and temperatures, the NO levels increase. In IDI engines, most of the NO forms within the prechamber and is then transported into the main chamber where the reactions freeze as rapid mixing with air occurs.

1.6.3 Hydrocarbon Emissions in CI Engines:

Hydrocarbons are the consequence of incomplete combustion of the hydrocarbon fuel. Engine exhaust gases contain a wide variety of reactive hydrocarbon compounds. Fuel composition can influence the composition and magnitude of the organic emissions. Fuels containing high proportions of aromatic and olefin produce relatively higher concentrations of reactive hydrocarbons. Oxygenates are present in engine exhaust and do take part in the formation of smog. Use of alcohol fuels increases oxygenate emissions. Flame quenching at the cylinder walls or at the entrance to a crevice is another source of hydrocarbon emissions. Oil layers on the walls also cause an increase in residual HC levels after combustion is complete.

1.7 Alternative Fuels for CI Engines

The last two decades have witnessed growing concern over the environmental impact and/or exhaustion of conventional fossil fuel energy sources in an environment that continuously increases its demand on liquid fuels. These concerns have highlighted the need for diversification and prompted increased research world wide into potential alternative sources of fuel energy for IC engines. It is implicit that the rate and character of development are strongly influenced by the availability, form and cost of fuel energy. One feature of alternative sources of fuel energy is that they are well suited for decentralized production (vegetable oil) to meet the needs for social and economic progress, especially in rural communities where conventional fossil fuels may be difficult or expensive to produce.

1.7.1 Alcohol as a CI Engine Fuel

Methanol which is produced from main raw material such as natural gas and coal is plentiful as a natural resource, so as ethanol, which is produced from agricultural products. For this reason, vigorous research has been conducted all over the world on alcohol cars and CI engines. As for example cars are run by NEET (100% methanol) in Brazil and gasohol (ethanol 10% and gasoline 90%) in United States.

When used in a CI engine, methanol poses a major problem owing to its very low cetane number of about 3. So it requires the addition of ignition accelerator to a amount of 10 to 20 per cent to methanol to raise the cetane number to about 33 [5]. An alternative system is to operate on diesel fuel at low load, with methanol added at high load to the injection pumps, direct to the injectors, or by aspiration. The last-named method gives part-load efficiency and lower smoke.

The use of ethanol as the principal fuel in a duel-fuel CI engine is reported where the alcohol supplying over 80 percent of the total energy requirement, and the remainder by a diesel oil injected under high compression for the purposes of pilot injection [6]. The alcohol is carburetted in with the air, and the maximum amount tolerated by the engine fixed by either misfire or diesel knock. The main problems encountered are long delay and slow, inefficient, combustion at low dual-fuel rates, and explosive combustion at high dual-fuel rates. In comparison with the use of diesel fuel alone, emissions of unburnt fuel with duel-fuel operation is increased by a factor of 2 to 5 due to lower efficiency, whereas NO_x is reduced by about 30 per cent due to the lower compression temperatures from the high enthalpy of vaporization of alcohol. Part load operation results in lower thermal efficiency and exhaust contain large volume of aldehyde and unburnt hydrocarbons [7].

1.7.2 Natural Gas as a CI Engine Fuel

Natural gas is available in many parts of the world and in a relatively high state of purity. There are two types of gas piston engines available. There are the dual-fuel engine and spark ignition engine. Compression ignition engines are used as dual fuel engines and have the advantage of providing high compression ratio, which is possible with natural gas or biogas due to their high octane numbers. The dual-fuel engine can be operated on either a mixture of a small quantity pilot fuel oil and gas, which constitutes the larger percentage of fuel or fuel oil alone[8]. The spark ignited gas engine can only be operated on gaseous fuel. The clean burning nature of natural gas does not create sludge and dilution of the lubricating oil, thus reducing the number of oil changes needed. It is leaves spark plugs and injectors carbon free for better performance.

1.7.3 Hydrogen as a CI Engine Fuel

Energy shortage and environmental problems are related very closely now a days. In recent years, Hydrogen as an energy source with a potential to solve these two problems simultaneously is attracting attention. Hydrogen becomes water when it is burnt, and is a clean fuel because it does not produce any air polluting substances other than nitric oxides generated by combustion heat. However, it is expensive and requires special safety measures for storage, it requires further R&D. Studies have shown that the generation of NO_x is greatly influenced by the way the Hydrogen mixture is formed. One possible method involves the premixing the hydrogen at the time of low load and by injection inside the high pressure hydrogen tube after the firing the premixed gas at the time of high load. According to a report [9], this system is effective in reducing NO_x far drastically than the simple method of injecting inside the high pressure hydrogen tube and is practically effective at low loads as shown in fig. 1.5.

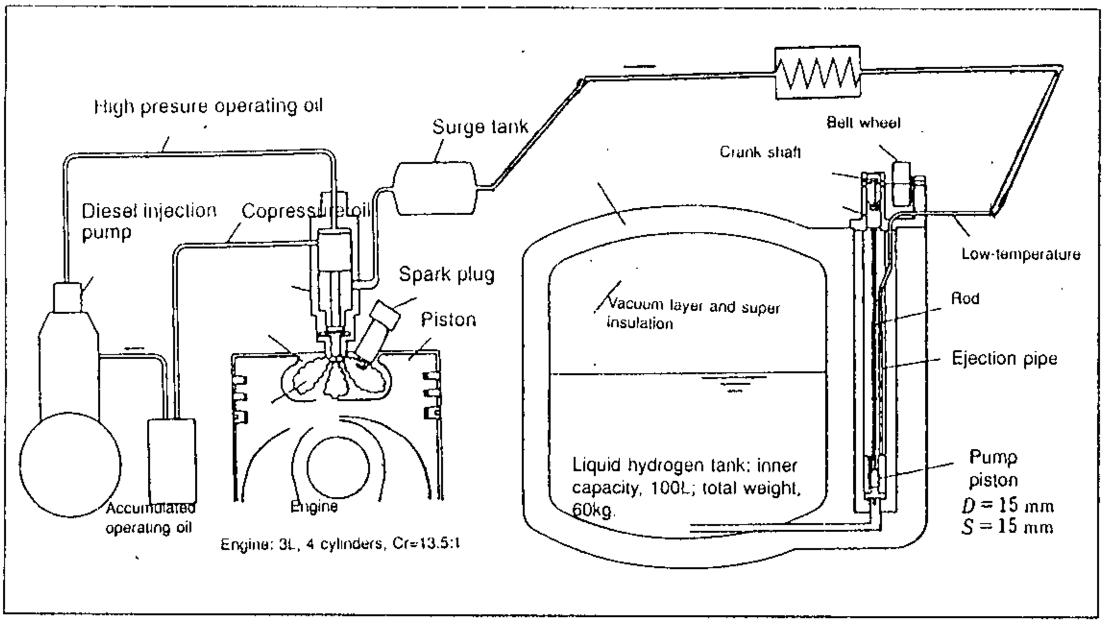

Figure 1.5: Liquid hydrogen storage system spark firing high pressure hydrogen injection engine system [9].

1.7.4 Biogas as a CI fuel

Biogas is produced from waste materials such as animal dung and crop. Biogas consists typically of 65 percent methane and 35 percent CO2 with small quantities of hydrogen sulphide and sulphur dioxide dependent on the characteristics of the raw sludge. Corrosive products of combustion are usually generated and these can result in corrosion when used in IC engines. The CO_2 can be removed from the biogas but this will involve additional cost. It is simpler to burn the biogas direct in an IC engine either as a dual fuel using pilot oil injection ignition[10] or spark ignition type.

1.7.5 Vegetable Oils as a CI fuel

The use of various vegetable oils as fuels for diesel engines is not a new concept. They have the advantage of being geographically widely produced, in a variety of products and are renewable in nature and thereby not contributing to the net atmospheric concentrations of the green house gas, CO_2. However, higher viscosity and lower volatility are identified as the main reasons for the unsuitability of vegetable oils as straight diesel fuel substitute.

Direct injection engines are much more dependent upon the ability of the injection system to accomplish a high degree of atomization of the fuel than are the IDI engines. Vegetable oils do not differ so much in specific gravity but all are 7-9 percent heavier than diesel fuel. The calorific value does not differ so much between vegetable oils. The viscosity of the vegetable oils are about 12 to 17 times higher than that of diesel fuel. Extensive research is going on in many countries to modify the vegetable oil properties to use them in diesel engines effectively and efficiently.

1.8 Substitution Techniques of Alternative Fuels in Internal Combustion Engines

Alternative fuels can be introduced into IC engines in several substitution techniques which can be classified as [11]:

1. Single injection system with alternative fuel.
2. Single injection system with alternative/diesel solution.
3. Single injection system with alternative/diesel fuel emulsions.
4. Single injection system with alternative (solid) /diesel fuel slurry.
5. Alternative fuel fumagation system with diesel injection.
6. Duel injection system.
7. Alternative fuel fumigation system with electrical assistance.

The substitution techniques are shown in fig.1.6.

1.8.1 Single Injection System with Alternative Fuels

When the alternative fuel is in liquid form and its properties are such that the diesel injection system can work properly with it, and the spontaneous ignition temperature of the fuel is less than the temperature at the end of the compression stroke, then the fuel can be introduced by this method. Some vegetable oil can be introduced by this method.

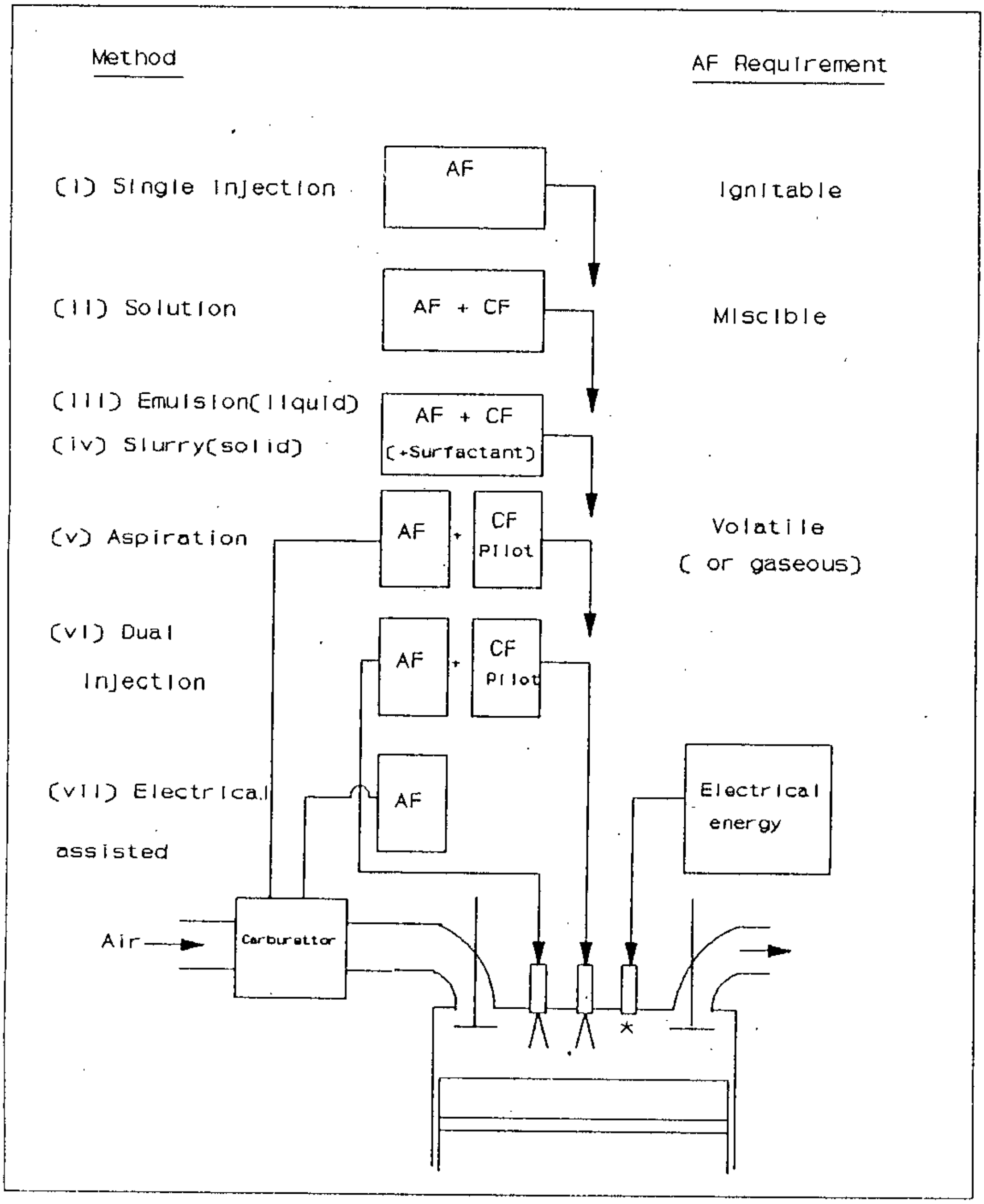

Figure 1.6: Methods of introducing alternative fuels into CI Engines. AF: Alternative Fuel CF: Conventional fuel [11]

1.8.2 Single Injection System with Alternative/Diesel Fuel Solution

When the alternative fuel is miscible with conventional gas oil, a solution can be made by blending the two fuels. Relatively few major component changes are necessary to use such solutions, though small timing and fuel volume adjustment may be needed to restore full power. This method is usually employed when the alternative fuel viscosity is much higher and blending with oils with less viscosity reduces the solution viscosity to an acceptable level.

1.8.3 Single Injection System with Alternative/Diesel Fuel Emulsion

When the highly viscose alternative fuel is immiscible in gas oil, the two liquid fuel can be emulsified mechanically and, if necessary, stabilized chemically. Emulsifiers also generally extend the blend's water tolerance relative to solutions without them. Emulsion's major drawbacks are their emulsifiers costs.

1.8.4 Single Injection System with Alternative (solid)/ Diesel Fuel Slurry

When the alternative fuel is in the solid form it can either pulverized or generated in the particulate form, and then slurred with the gas oil. The wide variety of solid fuels available as potential slurry components includes the starches and cellulose of biomatter, and the fossil based coals and cokes. This method is not yet popular as the presence of organic ash which promotes excessive engine wear[5]. The maximum concentrations of solid particulate in liquid fuels are generally limited by problems arising from physical stability and general pumpability, together with particulate burn-out time.

1.8.5 Alternative Fuel Fumigation System with Diesel Injection

Fumigation is a method by which alternative fuel is introduced by carburetted or vaporizer along with a separate fuel tank or gas cylinder (when the alternative fuel is in the gaseous form), lines, and controls. A pilot quantity of diesel is injected near the end of the compression stroke to ignite the mixture. Both gaseous and liquid alternative fuel can be used by this method. An advantage of such system is the possibility of switching from straight fumigation system to full diesel operation when alternative fuel supplies are cutoff[10].

1.8.6 Dual Injection System

Duel injection is a method by which the alternative fuel in directly injected into the engine cylinder, and the mixture is ignited by a pilot charge of diesel fuel. This method needs a second injection system, fuel tank, and fuel system. All types of alternative fuels including gaseous fuel can be used by this method. Disadvantages of dual injection include the complexity and cost.

1.8.7 Alternative fuel fumigation system with Electrical Assistance

A diesel engine can be converted to a spark-ignition engine by installing a spark plug into the engine cylinder and incorporating the ignition system. Alternative fuel can be introduced by carburation method.

1.9 Objectives

The objectives of this study are as follows:

1. To study the properties of some selected locally available vegetable oils. The properties selected are relevent to engine performance.
2. To study the modifications of the properties of vegetable oils when blended with kerosene.
3. To identify the deviations in the relevent properties of vegetable oils and their blends from diesel fuel.
4. To study the actual engine performance using two vegetable oil blends.
5. To study the variations in engine performance from diesel fuelled case.
6. To draw conclusions from the experimental values and results and to recommend for the future works.

Chapter 2

Literature Survey

Escalating prices and unreliability of supply of the petroleum oil have created the necessity for the developing countries to find alternative fuels for their requirements. Vegetable oils are a promising substitute as a fuel for diesel engines in some situations.

The use of vegetable oils as fuels for diesel engines is not a new concept and Dr. Rudloph Diesel used peanut oil to fuel one of his early engines at the Paris Exposition of 1900[12]. Vegetable oil fuels, however, were not acceptable because of their higher cost. Since Diesel's early experiments, the vegetable oil concept has been reintroduced usually during the crisis of petroleum fuels and in most cases the interest disappeared as soon as cheaper petroleum fuel were available. Now the interest for the vegetable oil as substitute to diesel fuel is enhanced because of the following two reasons [13].

1. Petroleum as a natural resource is limited, so eventually its supply is expected to run out, thereby making it necessary to find alternative fuels.
2. The exhaust emissions of CO_2 and NO_x is causing the destruction of the environment. It is considered necessary to develop CI engines which can

run on fuels with low environment destruction rates.

It is unfortunate that the emission specifications imposed in many countries is difficult to meet by the diesel engines. They are high-performance engines and generate less CO_2, but they generate great deal of NO_x and particulate materials (PM). It is true that SI engines also generate a great deal of SO_x and NO_x in a similar manner. But due to the development of high-performance ternary catalysis, the exhaust from SI engines hardly contain any of these harmful gases. So, diesel engines require modification for their survival[14]. A promising alternate is to use vegetable oils as emission caused by them is reported as very small[15].

As far as environmental factors are considered, two important points can be mentioned in favour of vegetable oils [16].

1. Unlike mineral oil, vegetable oil contains no sulphur, (or very negligible amount). So the environmental damages due to sulphuric acid is reduced.
2. Vegetable oil takes away from the atmosphere, for its production, more CO_2 contents of atmosphere.

Hassett and Hasan [17] conducted tests to determine if the fouling characteristics of methyl ester are significantly less than those of crude sunflower oil. The results presented show that the major problem of vegetable oils when used as diesel is the reactivity of the unburnt fuel. They noted that unburned or partly burned fuel in the cylinder is the cause of varnish and injector coking and can be improved by reducing fuel viscosity through esterification of vegetable oils. A finely atomized fuel completely burned will not gum up or foul any engine parts.

Quick, Wilson and Woodmore [18] in their findings concluded that coking of fuel injectors was a problem in unmodified diesel engines with long term operation. Short term tests with various vegetable oils as fuel gave results equivalent to diesel fuel.

Researchers have reported on the injection characteristics of various vegetable oils. Vegetable oil has a much smaller premixed combustion stage. In addition, the diffusion stage of combustion appears to be flatter (slower) for the sunflower oil than for diesel fuel which is reported by Ryan, Callahan and Dodge [19]. The results also indicated that sunflower oil both vaporizes and burns at a slower rate than diesel fuel. Crude soyabean and deodorized sunflower oils had the worst combustion characteristics and displayed the strongest tendencies to form deposits on the injector nozzle.

Tahir, Lapp and Buchanan [20] examined the fuel related physical properties and performance characteristics of vegetable oils in CI engines. They noted that the most detrimental parameter in the use of sunflower oil is its higher viscosity which is about 14 times that of diesel fuel at 38°C. This will lead to blockage of fuel lines, filters, higher nozzle valve opening pressures and poor atomization. The poor atomization leads to injector coking and contamination of the lubricating oil. Knocking and starting problem encountered on vegetable oil fuel engine were related to the low cetane rating and its high boiling points. The specific fuel consumption was higher due to its lower energy value whereas thermal efficiency was reported satisfactory when compared with diesel fuel. The oxidation of sunflower oil left heavy gum and wax deposits on the engine parts.

Yarbrough, Leport and Eugler [21] reported that the gums in vegetable oil were detrimental to diesel engine performance. Even degummed and dewaxed sunflower oil seriously contaminated the lubricating oil during engine operation.

They also compared sunflower oil and blends of sunflower oil with diesel fuel, to baseline resultsof three diesel engines. Overall, it was noted that engine performance on sunflower oil was comparable to operation on diesel fuel in short term tests. The Division of Agricultural Engineering, Republic of South Africa (1981) issued a news release reporting success in operating a diesel tractor for 2,300 hours on pure sunflower oil. The results were obtained with an indirect injection engine. Inspection after 1000 hours of operation showed that the engine was free of abnormal wear and injector coking.

Prydes [22] pointed out that one hundred percent vegetable oils cannot be used straightly in a direct injection diesel engine but can be used in an indirect injection, naturally aspirated and air cooled engine for long term operation. Long time usage resulted in injector coking, ring sticking, gum formation and lubricating oil thickening and gelation. It was stated that vegetable oils and their esters cannot meet ASTM specifications D975 for No. 2 diesel fuel for use in diesel engines.

The cetane number is a measure of self-ignition ability and the lower the cetane number of a fuel, the longer the ignition delay and the longer the period of fuel injection until self-ignition occurs[1]. During the ignition delay, a chain of processes leading to self-ignition develop - some physical in nature (eg fuel atomization, heating and mixing with air) and other chemical (eg fuel oxidation reaction). For petroleum products, the physical and chemical processes develop quickly as the fuel quantities are injected. When self-ignition occurs, there is enough fuel already prepared to sustain combustion, therefore rates of pressure rise in the cylinder are high. Vegetable oils on the other hand, have a different chemical structure closer to that of a pure substance. Viscosity is high and volatility is low therefore, the physical ignition delay should be much longer.

When self-ignition occurs, a smaller amount of fuel is ready for combustion and during the second phase of combustion, the pressure rise rate should be significantly lower. It is probable that the fuel accumulated in the cylinder during ignition delay burns initially slower and later faster. It has been shown that vegetable oils exhibit longer combustion duration with moderate rates of pressure rise, unlike the petroleum derived fuels of low cetane number[23],[24]. Peak pressures at the nozzle were higher with the alternative fuels due both to the fuel delivery rate at the pump and to the lower nozzle discharge rateas reported by [20] and [25].

Other reviews on fuel blend showed different results from researchers. Ziejewski and Kaufman[26] operated a diesel engine on 25/75 blend (vol/vol) of alkali refined sunflower oil and diesel fuel for 268 total hours. The major problems reported were abnormal build-up on the injection nozzle tips. The diameters of the nozzle were reduced and the needles showed excessive wear. Sporadic nozzle needle sticking, needle reopening and secondary injection were all reported. The lubricating oil consumption for the blend was slightly better compared to the run on diesel fuel. The piston- combustion chamber inspection revealed evidence of a dense fuel spray.

Pischinger and Falcon [27] studied the performance of methyl ester and its blends with diesel fuel. The results show that the low power and torque output together with high bsfc of vegetable oils in an unmodified IDI diesel engine relate mainly to their low net heating values. It was claimed that glycerol in the oils contributes to a certain extent to the formation of deposits in the combustion chamber and can be minimised by the use of esters.

The autoignition properties of vegetable oils are reported as similar to that of diesel fuels[28]. It is reported that vegetable oils can be used as a direct replacement for diesel fuel in existing engines with no modifications if used for short period[29],[30].

However, high viscosity and volatility are identified as the main reasons for the poor performance[28].The long term performance tests, following problems have been identified [31]:

1. Rapid choking-up of the injector nozzle and other parts such as piston heads, intake valves and exhaust valves.
2. Gumming up of the piston ring.
3. Higher lubrication oil consumption.
4. Effects on the fuel system i.e. fuel tank, pump and filters and supply lines.

Galloway [25] reported that the high viscosity of vegetable oil causes higher fuel line pressure compared with conventional fuel and the static pressure on vegetable oil is also higher. This is responsible for the reduction of the seating pressure of the injector needle valve and may create a situation where post injection dribble could occur. The primary cause is due to high viscosity and complete lack of leak back at the injector. The temperature is also reported to increase due to negligible leak back fuel and inhibited pressure relief. Carbon deposit on the injector is also reported to be as a result of the high nozzle temperature and thermal polymerization of some of the fuel trapped in the annular chamber in the nozzle tip.

Researches have indicated that vegetable oils in its pure form is not acceptable as a diesel substitute as modern diesel engine injection systems have been designed to their level of performance by using diesel fuel with controlled properties. Since vegetable oils have different physical and chemical properties than those of diesel fuel, it is expected that a direct injection diesel engine designed for diesel operation will perform differently when fuelled by vegetable oils. So, if existing engines are to be used, then vegetable oil properties are to be modified. Two excellent methods draw the attention of many researchers: one is to reduce the viscosity of the vegetable oil by blending with low viscosity fuels and the other one is to heat the vegetable oil before the injector nozzle as mentioned by Murayama et al.[32]. The later method reacquires modifications in then existing diesel injection system. So the blending method seems promising if no change in the engine design is desirable.

Studies by Kotsiopoulos et al.[15] have shown that, NO_x emission is reduced with vegetable oils blended with diesel but causes slightly higher HC and CO emissions. It is also reported that the maximum cylinder pressure was reduced but slightly higher bsfc. Yaginuma et al. [33] reported good efficiency and better smoke level with soyabin blended with kerosine. They also reported that multihole type nozzle improved performance under low pressure injection.

There have also been many investigations on fuel blending. Pischinger et al.[34] used emulsified fuels of methanol and gas oil blends, while Mori[35] used castor oil-ethanol-gas oil blends, both showing improved smoke and NO_x emissions. Fishinger et al.[36] investigated engine performance with soyabin oil-diesel blends, while Brasic et al.[28],Humke[37] and Ullman et al.[38] investigated particulate emission with vegetable oil-diesel fuel blends. Bari[39] used Rice bran oil blended with kerosene by 50% volume. They show somewhat different results, but general, deposit and particulate emissions increase with increases in vegetable oil content.

A DI diesel engine fuelled with 1:1 blend of viscous rapeseed and diesel oil is reported to run satisfactory for more than 300 hours at approximately 85%

of the full load without any major alteration of the engine[40]. Its performance deteriorated with the cumulative hours of operation, but could be restored to normal by decarbonizing exhaust manifold and fuel injector tip after every 100 hour of operation. Wear in various engine components is reported normal. Limited test of engine lubricating oil revealed no abnormality over the regular oil change period.

Experience with long-term use of plant oils for fuel is limited, but problems of coking and plugging of injector nozzles, sticking of piston rings, and polymerization of crankcase oil have been reported. Research is underway to attempt to understand and overcome these problems. Based on short-term demonstrations, the following conclusions on vegetable oil as alternative fuel can be reached[41]:

1. Certain precombustion chamber engines can handle vegetable oil fuels, neat or blended, more satisfactory thann can direct injection engines.
2. Most problems in engines resulting from the use of vegetable oils are due to improper combustion.
3. Crankcase lubrication failure by thickening will not occur under conditions of good combustion and regular oil change intervals.
4. Methyl and ethyl esters of vegetable oil operated well in either precombustion or direct injection engines but have cloud points from −2° to 4°C, which limits their climatic usefulness.
5. The heating value of neat and modified vegetable oil is close enough to the heating value of petroleum-based Diesel fuel so that no derating of tractor engines is necessary in the 75-80% power rating.

6. Microemulsions can reduce viscosity to near the range of petroleum-based diesel fuel. The emulsions have thermal stability, but the emulsifying chemicals are relatively expensive.

7. All vegetable oil should pass a 3 μm filter.

Long-term engine tests (1000 hours or more) are in progress. Research on VO chemical and physical properties is continuing to better match the fuel and the engine.

The use of the vegetable oils as CI fuel substitute are also studied from the point of view of economics. Economic comparison of vegetable oil and mineral oil are very difficult to make in absolute terms and will certainly vary from one country to another.

Signnificant factors for economic use are studied by Picken[42]:

(a) Local cost of mineral oil and refining per litre.

(b) Annual cost of a unit area of land for cultivation.

(c) Fuel used in cultivation and harvesting of land per unit area.

(d) Fuel used as fertilizer on land per unit area.

(e) Labour cost in cultivating of unit area.

(f) Cost of processing vegetable oil litre.

(g) Transportation and distribution costs per litre.

(h) Diesel oil equivalent of oil produced per unit area.

(i) Taxation system.

(j) Values of residue after oil extraction per unit area.

From this list the net energy gain per unit area of land can be computed as:-

(h-c-d) litters diesel oil equivalent/unit area neglecting energy used in processing and distribution.

The cost of cultivating this unit area of land is (b+e+f+g)

Thus, cost per litre diesel equivalent is: $\frac{b+e+f+g}{h-c-d}$.

To this must be added (i) taxation and (j) distribution costs, but letter will be similar to mineral based oil and the former is a variable which can reflect government policy.

For a fuel to be economically viable in real terms:

$$\frac{b+e+f+g}{h-c-d} \leq a$$

Consideration of the factors involved points to a likely difference between developed and developing countries.

(a) is likely to be similar

(b) is higher in developed countries

(c) is higher in developed countries

(d) is higher in developed countries

(e) is higher in developed countries

(f) is likely to be relatively low

(g) may be similar with labour costs balancing against greater distances involved

(h) are difficult to generate

(i) are difficult to generate

From a actual case study[43] it is seen that in the present situation vegetable is not economic as an alternative fuel. So it requires further research to use them economically as CI substitute.gines are designed to use diesel as a fuel and is design is based on the diesel properties. So, research is going on not only to modify the fuel properties, but also modified engine design to suit vegetable oils.

Chapter 3

Vegetable Oil as CI Fuel

In view of the energy crisis and emission problems, alternative fuels are promising substitute to the conventional petroleum fuels. Vegetable oils which have the advantage of being geographically widely produced, in a variety of products and are renewable in nature and thereby not contributing to the net atmospheric concentrations of the green house gas, carbon-di-oxide. At least 40 vegetable oils have shown they can fuel a Diesel engine.

3.1 Composition of Vegetable oils

Vegetable oils are mixtures of triglycerides- that is, glyceride esters of fatty acids. Vegetable oils are made up of chains of three fatty acid molecules connected to a glycerol molecule; such a combination is called a triglyceride. The most common fatty acids in vegetable oils are listed in Table 3.1.

Fatty acids can be divided into two classes: saturated and unsaturated. Each carbon atom along the chain has the ability to hold two hydrogen atoms. The fatty acids are saturated if all hydrogen atoms are in place. If two adjacent carbons are missing of hydrogen atoms, the carbons satisfy the loss by hooking

Fatty Acid		Vegetable Oil				
Name	Structure[1]	Sunflower	Soybean	Peanut	Cottonseed	Corn
Myristic	14	—	—	—	1	—
Palmitic	16	6	11	10	24	11
Stearic	18	5	4	3	2	2
Oleic	18:1	19	24	49	19	26
Linoleic	18:2	69	53	34	54	60
Linolenic	18:3	1	8	—	1	1
Arachidic	20	—	—	1	—	—
Behenic	22	—	—	3	—	—

[1] Carbon atoms:double bonds.

Table 3.1: Common fatty acids in vegetable oils[44].

Name	Structure[1]	Formula	Class
Palmitic	16	$CH_3-(CH_2)_{14}-COOH$	Saturated
Stearic	18	$CH_3-(CH_2)_{16}-COOH$	Saturated
Oleic	18:1	$CH_3-(CH_2)_7-CH=CH-(CH_2)-COOH$	Unsaturated
Linoleic	18:2	$CH_3-(CH_2)_4-CH=CH-CH_2-CH=CH$ $-(CH_2)_7-COOH$	Polyunsaturated
Linolenic	18:3	$CH_3-CH_2-CH=CH-CH_2-CH=CH$ $-CH_2-CH=CH-(CH_2)_7-COOH$	Polyunsaturated

[1] Carbon atoms:double bonds.

Table 3.2: Fatty acid composition of common vegetable oils[44].

to each other, creating a point of unsaturation. If there is more than one double bond, the fatty acid is polyunsaturated.

The relative amounts of several fatty acids for five different vegetable oils are shown in Table 3.2. Different fatty acids affect the stability and melting point of an oil. As the amount of unsaturation increases, so does the relative rate of oxidation as listed in Table3.3. A vegetable oil that has a high degree of unsaturation would tend to polymerize sooner in the crankcase of an engine than a vegetable oil that is highly saturated. Also, as the amount of unsaturation increase, the melting point on the other hand, decreases as shown in Table 3.4. Thus, a vegetable oil with a high degree of saturation tends to be a solid at room temperature. A compromise between a low melting point and a high oxidation

Fatty Acid	Structure[1]	Relative Oxidation Rate
Stearic	18	0.6
Oleic	18:1	6
Linoleic	18:2	64
Linolenic	18:3	100

[1] Carbon atoms:double bonds.

Table 3.3: Relative rates of oxidation of selected fatty acids[44].

Fatty Acid	Structure[1]	Melting Point (°C)
Myristic	14	57.0
Palmitic	16	63.5
Stearic	18	73.1
Oleic	18:1	5.5
Linoleic	18:2	−13.1
Linolenic	18:3	−24.2

[1] Carbon atoms:double bonds.

Table 3.4: Melting points of selected fatty acids[44].

rate must be made when selecting a suitable vegetable oil for use in Diesel engines.

3.2 Properties of Vegetable oils

3.2.1 Cetane Number

The cetane number of a Diesel fuel is a measure of the ignition delay period-that is, the time delay between the beginning of injection into the combustion chamber and the beginning of combustion. Fuel accumulates during this delay period and then ignites explosively to produce the characteristic Diesel knock. A short delay period, signified by a high cetane number, is desirable. Vegetable oils typically have cetane numbers of 35-40, whereas no. 2 Diesel fuel has a cetane number of about 45.

3.2.2 Heat of Combustion

The heat of combustion of a fuel is the amount of heat produced when the fuel is burned completely. A fuel of low- energy value yields less heat on combustion and, therefore, less power than the same amount of a fuel with high- energy value. The importance of this quality depends on whether the user purchases fuel on a weight or a volume basis.

Higher, or gross, heating values (HHV) refer to the heat content when the products of combustion are cooled to ambient temperature. A Bomb calorimeter is used to measure higher heating values. Lower, or net, heating values (LHV) are reported if the products of combustion are rejected at a high temperature such as an engine exhaust.

3.2.3 Pour Point and Cloud Point

The ability of a Diesel engine to operate in cold weather depends on the pour and cloud points of the fuel. The pour point is the lowest temperature at which fluid movement can be detected. The pour point is important since below that temperature the fuel will not flow to the outlet pipe in the fuel tank. The cloud point of a petroleum oil is the temperature at which paraffin wax or other solid substances begin to crystallize or separate from solution when the oil is chilled. The cloud point temperature is usually several degrees higher than the pour point. If the ambient temperature is below the cloud point, then the wax crystals will block the fuel filter. Both these measurements are highly significant when operating at low temperatures.

Many vegetable oils have some triglycerides with saturated fatty acids (e.g., soyabean oil), and such triglycerides have higher melting points than the triglycerides with mostly unsaturated fatty acids. Consequently, many vegetable oils have relatively higher cloud points than Diesel oil. If the high cloud point is undesirable, the vegetable oil can be winterized at 4°-5°C and then filtered to remove most of the saturated fat, or about 10% of the starting oil in the case of soyabean oil[41],[45].

3.2.4 Distillation Temperatures

American Society for Testing Materials (ASTM) D975 specifications require that the 90% point for distillation fall in the 282° – 338°C temperature range. Distillation of vegetable oils and esters will not take place at these temperatures at atmospheric pressure. Instead, decomposition (pyrolysis) will gradually begin at temperatures of 300°C, and the distillate will consist of decomposition products; the 90% point will never be reached[41]. In distilling a vegetable oil at atmospheric pressure, the first drop of distillate may occur at about 150°C; the first 10%, at 150°C – 300°C; and by the 80% point, a vapour temperature of more than 350°C will have been reached.

3.2.5 Flash Point

Flash point is the temperature to which fuel has to be heated to produce sufficient flammable vapour to flash when brought into contact with a flame. Vegetable oils and esters can be distilled only under reduced pressure. At atmospheric pressure, decomposition rather than volatilization will start at about 300°C. Thus, the flash points for vegetable oils and esters will be considerably higher than for Diesel oil. The presence of low-boiling solvents or additives will lower the flash point because of the greater volatility of the free fatty acids compared to the oil.

3.2.6 Viscosity

Viscosity may be described as a measure of a liquid's resistance to flow. The viscosity of Diesel fuel is important primarily because of its effect on handling of the fuel by the pump and injector system. Fuel viscosity exerts a strong influence on the shape of the fuel spray. High viscosities can cause poor atomization, large droplets, and high spray jet penetration. With high viscosities, the jet tends to be a solid stream instead of a spray of small droplets. As a result, the fuel is not distributed in, or mixed with, the air required for burning. This results in poor combustion, accompanied by loss of power and economy. In small engines, the fuel spray may impinge upon the cylinder walls, washing away the lubricating oil film and causing dilution of the crankcase oil. Such a condition contributes to excessive wear. Vegetable oils are much more viscous than Diesel fuel, especially at low temperatures. Many vegetable oils have viscosities in the same range as SEA 10 motor oil. Sunflower oil esters can be produced by the addition of ethanol or methanol and a catalyst. In this trans esterification process, the alcohol combines with the triglycerides to form glycerol and either ethyl esters or methyl esters. Then, the glycerol is removed by water extraction. Esterification has the effect of increasing the volatility and decreasing the viscosity of the oil, making it similar to Diesel fuel in these characteristics.

3.3 Production of Vegetable Oils

For farm-level extraction, a screw press is used to recover 60-80% of the oil from the meal. The screw press or expeller operation requires the following processes:

1. Cleaning the seed to free it of stones or metal pieces that could damage the expeller operation;
2. Dehulling to remove seed hulls to reduce the fibre content and increase the protein content of the meal, per given quantity of processed seeds;
3. Rolling the seed into flakes to increase the percentage of oil recover;
4. Cooking the seed prior to pressing for maximum oil recovery;
5. Pressing to separate the oil from the meal, which contains about 7-15% oil on a dry weight basis;
6. Filtering the oil to remove small seed particles.

The end product, crude oil, may need further processing to remove phosphatises and waxes.

Chapter 4

Test methods, instruments and experimental procedure

Experimental methods under this study consists of two steps: (a) testing of the properties of the fuel relevent to engine performance & (b) engine performance test. Fuel testing methods are discussed first which is followed by engine test procedure.

4.1 Fuel Testing

Testing is required for the determination of the actual fuel properties. Several fuel properties are evaluated under this programme and they are discussed briefly in the following sections.

4.1.1 Measurement of Kinematic-viscosity

In determining the fuel kinematic-viscosity, ASTM D-88-56 test procedure is followed. From the experiments we get the time value which is known as Saybolt Universal Second (SUS) and these valuse are converted to kinematic-viscosities using empirical formulas provided by SAE.

The ASTM standard D341-87 provides charts to permit fuel kinematic viscosity-temperature data to plot as a straight line. But charts provided by this standard is not suitable to plot. So, a kinematic viscosity-temperature chart is prepared using Freelance Graphics where Y-axis shows the value of loglog(Z) and the X-axis is Log T. The general relationship provided by ASTM D341-87 is :

$$\log\log \mathrm{Z} = \mathrm{A} - \mathrm{B}\log \mathrm{T}$$

where, Z is a function of kinematic-viscosity.

The values of A and B are determined from a number of data points using least square method to fit a straight line, minimizing the error. So, from the plotting of kinematic viscosity vs. temperature, other values of kinematic viscosity can be obtained for different temperatures.

4.1.2 Measurement of Volatility

ASTM D-86, and D482-87 are used for the determination of fuel volatility. With petroleum fuels, a maximum distillation temperature limit of 370°C is set to avoid cracking of heavier hydrocarbon molecules. In the distillation of vegetable oils, chemical decomposition and (pyrolysis) of fatty acids gradually begin at temperature of 300°C and the distillate contain the black decomposition products, which is observed visually during the experiment and a fall in the vapour temperature is also experienced. It is also experienced that 90% point is not achievable with vegetable oils.

4.1.3 Measurement of Calorific Value

The higher heating value of the fuels are measure using ASTM D240-87 test procedure. The water formed in the vegetable is difficult to measure and exact composition is also unknown. So, net heat of combustion is not calculated.

4.1.4 Measurement of Density

Fuel density at different temperatures are measured by direct method which involves the measuring of a sample contained in a density bottle (25 ml). The fuel temperature is measured by K-type thermocouple, connected to OMEGA digital thermometer.

4.1.5 Measurement of Carbon Residue

Carbon residue of fuel is measured following ASTM D189-81 test procedure, also known as Conradson method. This test method covers the determination of the amount of carbon residue left after evaporation and pyrolysis of fuel oil, and is intended to provide some indication of relative coke forming propensities.

4.1.6 Determination of Ash Content

Ash content of fuel is determined by following ASTM D482-87 test procedure.

4.2 Engine Performance Testing

Engine experimental set-up consists of engine test-bed, diesel and vegetable oil supply system, different metering and measuring systems of air, diesel and vegetable oil flow, with additional facilities of temperature measurement of various points as shown in Fig. 4.1.

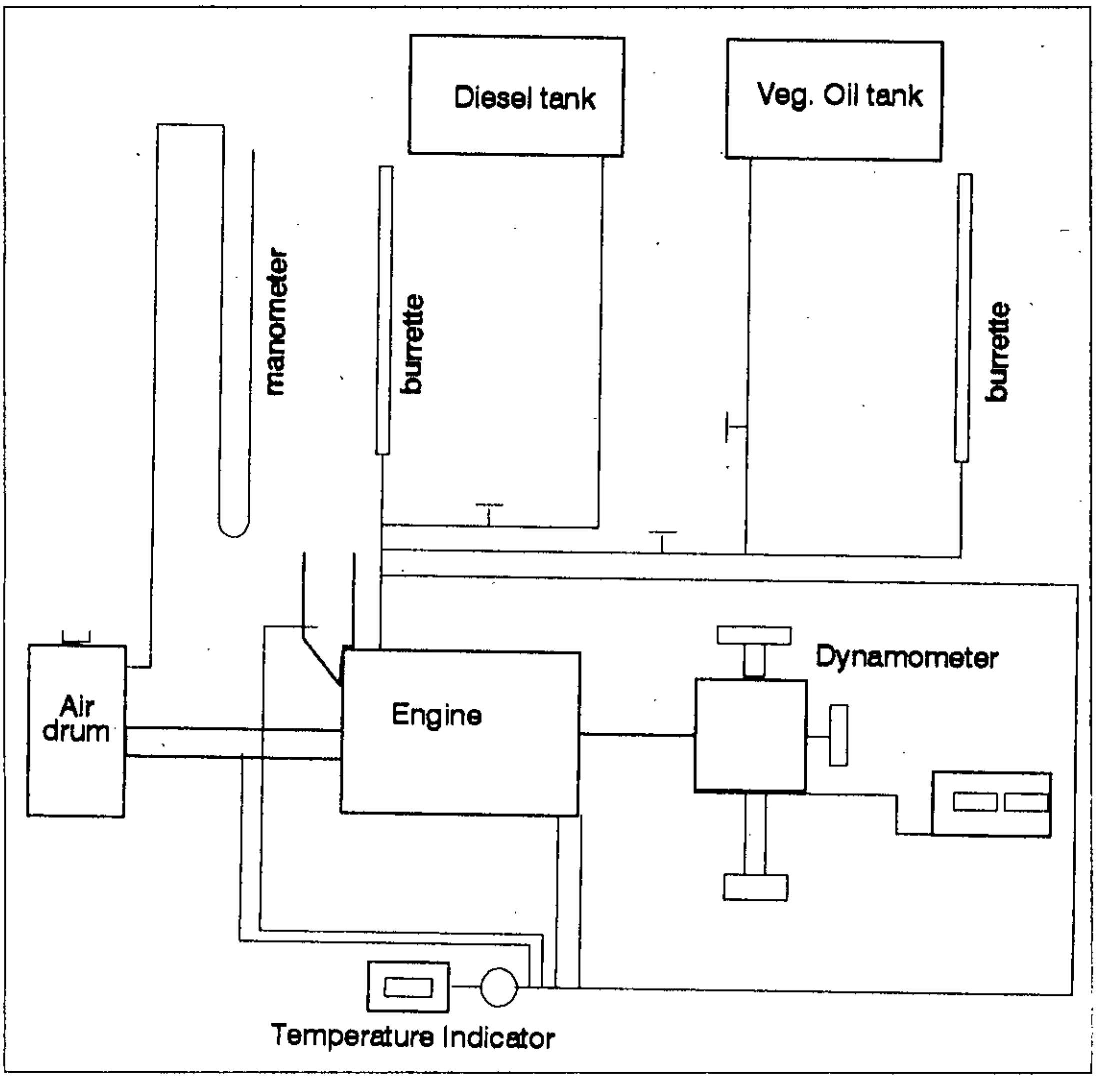

Figure 4.1: Schematic diagram of the experimental set-up showing major components.

The engine used is a Yanmar 2-cylinder, water cooled direct injection diesel engine. The name plate rated power of the engine is 16.4 kW at 2000 rpm and the output shaft speed is reduced to one about third of the engine speed.

4.2.1 Measurement of Engine Brake Power

A model no. TFJ-250L water brake type dynamometer is used to measure engine brake power. The dynamometer unit contains an electric load cell transducer to measure the force acting on the dynamometer and a magnetic type tachometer to measure the speed. Two LED displays are provided to show load and rotational speed readily. The engine is connected to the dynamometer assembly through a spline shaft and universal joints.

4.2.2 Measurement of Engine Speed

The engine speed is measured in revolution per minute by an magnetic type tachometer which is a part of the dynamometer. The speed shown by the dynamometer speed indicator is the the speed of the engine output shaft speed. The engine speed is also verified by a digital tachometer at the engine fly-wheel side.

4.2.3 Measurement of Temperature

The temperature of supplied diesel and vegetable oils as well as exhaust gas and inlet air temperatures are measured using K-type thermocouple which is connected to OMEGA-digital thermometer.

4.2.4 Measurement of Fuel Consumption Rate

The diesel and vegetable oil delivered to the engine injector pump under gravity are measured volumetric by a 50 cc barrette and stop watch.

4.2.5 Measurement of Air Flow Rate

The air supply line consists of a drum, which contains a parabolic nozzle at one end and the other one was connected to the inlet manifold through a flexible pipe connection. The parabolic nozzles used are of 0.75 inch diameter. A piezometric tube, placed on the air-drum is connected to a vertical manometer and water is used as the manometric fluid.

Chapter 5

Results and discussions

In this chapter, results obtained from fuel testing are presented which is followed by the engine performance results. Finally conclusions are drawn from these results and recommendations for future work are presented.

Prior to fuel testing, all the fuel samples are filtered using a heavy cloth (75 thread/cm). The blended vegetable oils were prepared by mixing 50% by volume of the oil with 50% by volume of kerosene. The mixture was left for 72 hrs and no separation of oils were observed. So, it was concluded that vegetable oils used under this programme (e.g. Rapeseed, Sesame, Soyabean and Linseed) are completely miscible in kerosene and can be stored for moderately long period of time. But storing for a long period may result in oxidation and gum forming of the fuel. Testing pure vegetable oils, diesels and kerosene were performed directly.

5.1 Results

In Fig. 5.1, variations of fuel density with temperatures are shown. It is found that pure vegetable oils have significantly higher density than the density of diesel fuel. However, when blended with kerosene, it is found that, their densities were reduced to a comparable figure. This occurs due to the complete miscibility of low density kerosene with heavier vegetable oils. From the graphs, it is seen that Soyabean has the highest density which is followed by Sesame, Rapeseed and Linseed. This trend is maintained in the densities of their blends also.

Fig. 5.2, shows the volatility of different fuels. From these graphs, it is seen that, for vegetable oils initial boiling points are lower than that of diesel, but later portion of the oils have higher evaporating temperatures than diesel fuels. However, when blended with kerosene, it is seen that the first 45% evaporation of vegetable oils occurs at lower temperatures than the diesel oils, due to the presence of 50% kerosene which have lower boiling temperatures. It is also observed that, at the end of 45% points, boiling temperatures rise significantly. The reason for this is, kerosene present in the blend evaporates first, exhibiting lower boiling temperatures. When the kerosene in the blend is exhausted, the boiling temperatures rise to a value of that of pure vegetable oils. It is also observed that the distillate is not collected beyond 80% evaporation because at that point boiling temperatures are more than 300°C. Above this temperature, fatty acids, a major component of vegatable oils, undergo chemical decomposition. The distillate after the 80% point consists of decomposition products and can be detected visually due to the change of colour to black.

In Fig 5.3, viscosities of oils are presented. It is also found that rapeseed oil has the highest viscosity, which is followed by the viscosities of linseed, soyabean and sesame. It is found that viscosities of pure vegetable oils are more than 10 times than that of diesel oils. So, pure vegetable oils are not usable as diesel fuel substitutes, as higher viscosity would result in poor atomization, poor combustion and worse emission. Moreover, carbon deposits in the engines would also be higher. But the blended vegetable oils show a significant reduction in viscosities.

At room temperature, blended vegetable oil viscosities are about 2 times that of diesel values. So, blended vegetable oils are usable as diesel fuel substitute with slightly reduced engine performance.

In Fig. 5.4, calorific values of different fuels are presented. It is seen that calorific values of pure vegetable oils are less than that of the calorific value of pure diesel on the mass basis. So, if same amount of fuel is supplied, a diesel engine fuelled by pure vegetable oil would provide less power. But, when blended with kerosene, the calorific values of vegetable oils are comparable to that of diesel. So, with blended fuels, similar amount of energy is supplied to the engine. In Fig 5.4, energy densities of the fuels are also presented which measures the energy contents per unit volume of fuel. The values found for all the fuels, (pure & blended) are close to each other. So, with vegetable oils, fuel energy available to the engine remain unchanged.

In Fig. 5.5, it is found that carbon residue of pure vegetable oils are less than that of diesel oils, but ash formed by vegetable oils are more than the corresponding diesel values. So, it requires that with vegetable oil fuelling, engines should be cleaned after certain period of operations. This is in line with the findings of Shyam [40], where it is suggested to clean the engine fuel system after every 100 hrs of operation.

The fuel properties measured are now compared with a PhD work as listed in table 5.1. It is found that the fuel properties obtained from this study is comparable to the findings of Nwafor[8].

On the basis of fuel properties, two vegetable oil blends of Sesame and Soyabean with kerosene were selected for engine testing. The rated speed of the engine was 2000 rpm. So, 2000 rpm was used as base speed. The engine was

	Rapeseed	Linseed	Soyabean	Sesame
Denisty ($\frac{Kg}{m^3}$)	911.5 (905.0)	923.6 (855.0)	911.8 (920.0)	913.3 (918.0)
Viscosity (cSt)	37.0 (45.0)	27.2 (41.0)	34.73 (40.0)	35.5 (39.5)
HCV ($\frac{MJ}{Kg}$)	39.71 (38.2)	39.31 (38.7)	39.39 (37.6)	39.35 (37.4)
Carbon residue (%)	0.30 (0.266)	0.22 (0.329)	0.27 (0.328)	0.25 (0.312)
Ash content (%)	0.01 (0.013)	0.01 (0.011)	0.01 (0.022)	0.01 (0.015)

Table 5.1: Comparison of the physical properties measured with a recent PhD work of Nwafor[8]. In this table values within the brackets are from the present study

also tested at speeds of 1500 and 1800 rpm to allow complete combustion of the vegatable oils which have higher ignition delays. So, three fuels e.g. diesel,blend of 50% kerosene & 50% Sesame , and blend of 50% kerosene & 50% Soyabean blend were tested at 3 different engine speeds of 1500, 1800 & 2000 rpm.

When the engine was tested with diesel it was started as usual. With vegetable oil, the engine was usually started with pure diesel fuel and then the fuel supply was switched to vegetable oil. Also before the engine was stopped, the engine was run with pure diesel oil for a short period (for few minutes) to flush off the oil line and the injector, otherwise clogging of the fuel line or injector might occur. All the engine brake power and fuel consumptions were derated using BS 5514:1982, standard.

In Fig 5.6, fuel consumption rates of the three fuels are presented at particular three speeds at different loads. It is seen that fuel consumption rate increases with increase in load. For the same fuel and same power, the fuel consumption rate is higher for higher speeds.

In Fig 5.7, fuel consumption rates of particular three fuels at 3 different speeds are shown. It is seen that, for same power and speed, diesel fuel consumption rate is less than those for sesame and soyabean blends. This effect is reflected in Fig 5.10 and 5.11, where bsfc for diesel is less than those for soyabean and sesame blends. The effect the variation of bsfc is also reflected in Fig. 5.12 and 5.13, where for same speed, diesel engine shows higher efficiency. It may also be noted that for same fuel and load, operation at lower speeds (1500 rpm) showed higher brake thermal efficiencies for all the cases. This is due to the availability of more time for the complete combustion of the fuels.

In Fig. 5.8, shows the air fuel ratios of different fuels at particular speeds. It is observed that when tested at same speed and load, air fuel ratios with diesel fuel is always higher than that of the blendings of sesame and soyabean fuelled cases. For a particular fuel, however, the air fuel ratio remains close at different speeds as shown in Fig. 5.9.

Fig 5.14 shows that for operation with each of the three fuels, the exhaust temperatures were very close at same loads. Specifically at 1800 rpm and 1500 rpm, they were almost identical. Fig 5.15 shows exhaust temperatures of the particular fuels at 3 different speeds. It is seen that at higher engine speeds, exhaust temperatures are higher. So, it may be concluded that the exhaust temperatures are moderately independent of fuel used and they depend on engine speeds and load. From this observation, it may be concluded that exhaust emission of NO_x are likely to be similar.

In the presentation of all engine performance data, it is seen that, all performance parameters of Soyabean & Sesame blends are very close to each other. Also, it is found that these blends require higher fuel consumption rate, resulting in higher bsfc and lower brake thermal efficiencies than diesel fuels. It is also observed that minimum bsfc's occur at relatively lower power with vegetable oil blends due to the incomplete combustions of the vegetable oil blends.

The engine performance results are compared with the results from Yaginuma et al. [33] whch are shown in Fig. 5.16. These values obtained are found very close to our results.

5.2 Discussions

The use of vegetable oils as CI engine fuel is not a new concept. Now-a-days CI engines are designed to operate on diesel fuels and their design is based on diesel fuel properties. So, difference in the fuel properties are responsible for the difference in the performance.

The major fuel properties that affect CI engine performance are density, viscosity, volatility, ignition quality, residue and calorific values of fuels. The calorific values of blended vegetable oils are found close to the diesel fuel values while densities of vegetable oils are higher. So, resulted energy density of vegetable oil blends are similar to diesel fuels. Moreover, several studies have shown that the autoignition characteristics of vegetable oils are similar to that diesel fuels[28]. So, in the point of view of ignition characteristics, CI engines fuelled by vegetable oils blends should operate efficiently without loosing power.

High viscosity & low volatility are identified as the main reasons for the poor engine performance. Higher viscosities of the pure vegetable oils make these fuels unsuitable for straight use as diesel fuel substitute. However, after the blending, although their viscosities are still higher, they are comparable to diesel fuel viscosities. These higher viscosities cause higher fuel line pressure compared with conventional fuel. This will reduce the required seating pressure of the injector needle valve creating a situation where post injection dribble may occur. This may result in complete lack of leak back in the injector and may result in injector nozzle temperature rise. Higher nozzle temperature is responsible for the carbon deposit on the injector due to the decomposition of the vegetable oils. Higher viscosity is also responsible for poor atomization which results in poor combustion and carbon deposit.

The volatility of pure vegetable oils are lower than diesel fuels. But the blended vegetable oils show lower boiling temperatures at first half fraction. So, lower T_{10} temperatures of blended fuel assures that sufficient amount of fuel will evaporate and allows the engine to start easily. The low T_{50} temperatures allow the engine to warm up and gain power quickly. A lower value of T_{50} helps to minimize diesel smoke and odour. It is found that T_{90} for blended vegetable oils are slightly higher than that of the diesel value. However, the problem due to higher T_{90} temperatures are eliminated due to the fact that when a droplet of vegetable oil blend is injected into the cylinder the high volatile fraction evaporates and ignites causing local temperature rise which assists the low volatile fractions to evaporate easily. It is also noted that the T_{90} temperatures obtained are not an indication of the actual significance as distillates of vegetable oils at this portion contain decomposed products and a decrease in temperature was also observed. So, if vegetable oil is modified in such a way that the oil evaporated at temperatures higher than 300°C are omitted, then the vegetable oil found would provide lower T_{90} temperatures. A lower T_{90} temperature will help to minimize crankcase dilution and improve fuel economy. The rejection of distillate of temperature higher than 300°C would eliminate the components which decompose at higher temperatures. This will reduce the carbon build up in the engine when operated with vegetable oils.

In the performance results it is seen that the all performance parameters for Soyabean and Sesame blend are close to each other. This was not unexpected because of the closeness of their physical & chemical properties. It may be mentioned here that, the calorific values, densities, viscosities & boiling temperatures of the blends of Sesame & Soyabean with kerosene are very close. So, it may be concluded that, vegetable oils may be substituted as No.2 Diesel fuel after modifying their properties, e.g. by reducing their density, viscosity & boiling temperatures.

Use of the vegetable oil blends in CI engines also require attention on some other factors such as corrosion and gum formation. Kerosene is highly corrosive. So, it is essential to study the effects of kerosen on engine corrosion. Another important factor is gum formation. This is due to the fact that vegetable oils contain phospholipides which can absorb atmospheric moisture to form gum in the fuel system and in the cylinder. However, these phosphatides can be removed by treatment with small amount of water, folloed by centrifugation[41].

Chapter 6

Conclusions and recommendations

6.1 conclusions

Based on the observations of the studies with vegetable oil blends, the following conclusions may be drawn:

1. Viscosities of pure vegetable oils are found significantly higher than that of diesel. So, vegetable oils are not suitable as straight diesel fuel substitute. However, after blending with kerosene, viscosities are reduced to a comparable figure. So vegetable oil blends are usable as diesel fuel substitute.
2. Blended vegetable oils yield low T_{10} & T_{50} temperatures. So, easy starting and warm-up are possible with vegetable oil blends.
3. Calorific values of vegetable oils are slightly less than diesel values. Calorific values and energy densities of vegetable oil blends are very close to diesel values. So, little chance of loosing power is there if fuelled with vegetable oil blends.

4. Performance parameters of Sesame and Soyabean blends are found very close. Their properties are also very close to each other. So, performance of CI engines fuelled by vegetable oils mostly depends on the properties of the fuels.
5. Engine performance with vegetable oil blends are close to diesel performances at lower speeds. So, vegetable oils can be successfully substituted for diesel fuels at low speed operations e.g. marine & agricultural purposes.
6. Exhaust temperatures are found independent of the fuel used. So, there is less possibility of generating more NO_x emissions.

6.2 Recommendations

For future work in this line, the author's recommendations are as follows:

1. The engine performance has been studied for only two vegetable oils (Sesame and Soyabean). So, other locally available oils may be studied.
2. In the present study, kerosene has been used to blend with vegetable oils. Other fuels such as diesel, alcohols may be blended with vegetable oils. The volume ratio in blending may also be varied to get optimum efficiency.
3. Since viscosity is a major problem with vegetable oil, studies may be undertaken to reduce viscosities of vegetable oils after preheating them.
4. Water may be emulsified with vegetable oil blends to improve combustion efficiency caused by micro explosions.
5. Exhaust gas analysis may be done to study the effect of vegetable oils exhaust emission.

Research in the field of vegetable oils as CI fuel substitute is going on in many countries of the world. It requires further extensive research to substitute CI fuel efficiently, economically without causing additional environmental pollusions.

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Graphs

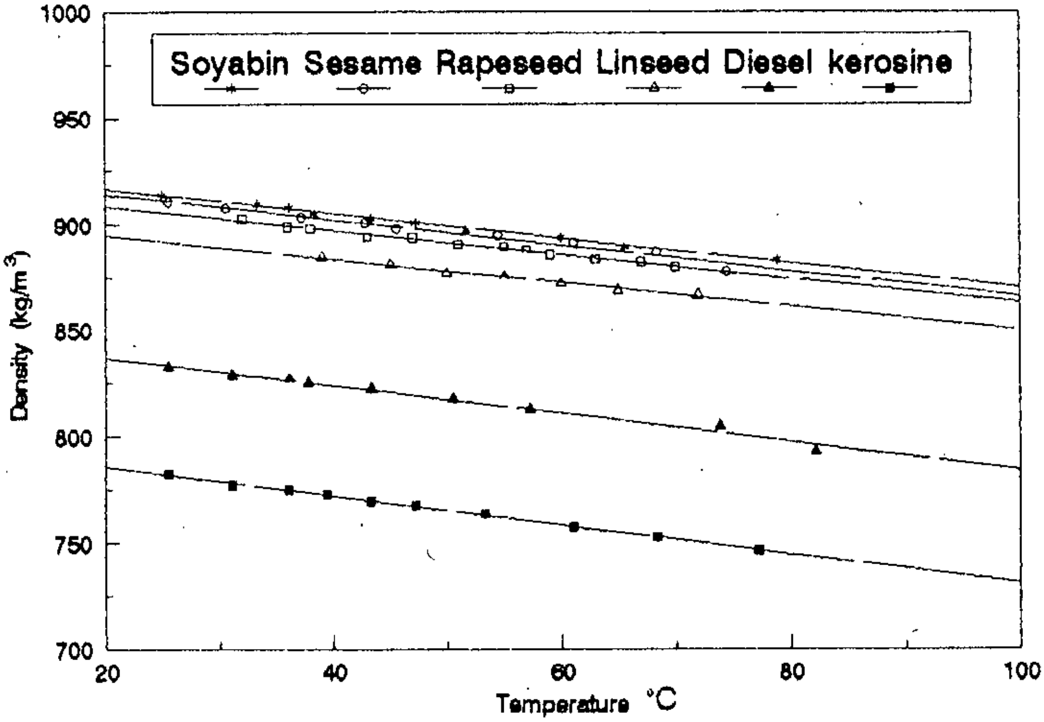

Figure 5.1(a): Variations of densities of pure oils with temperatures.

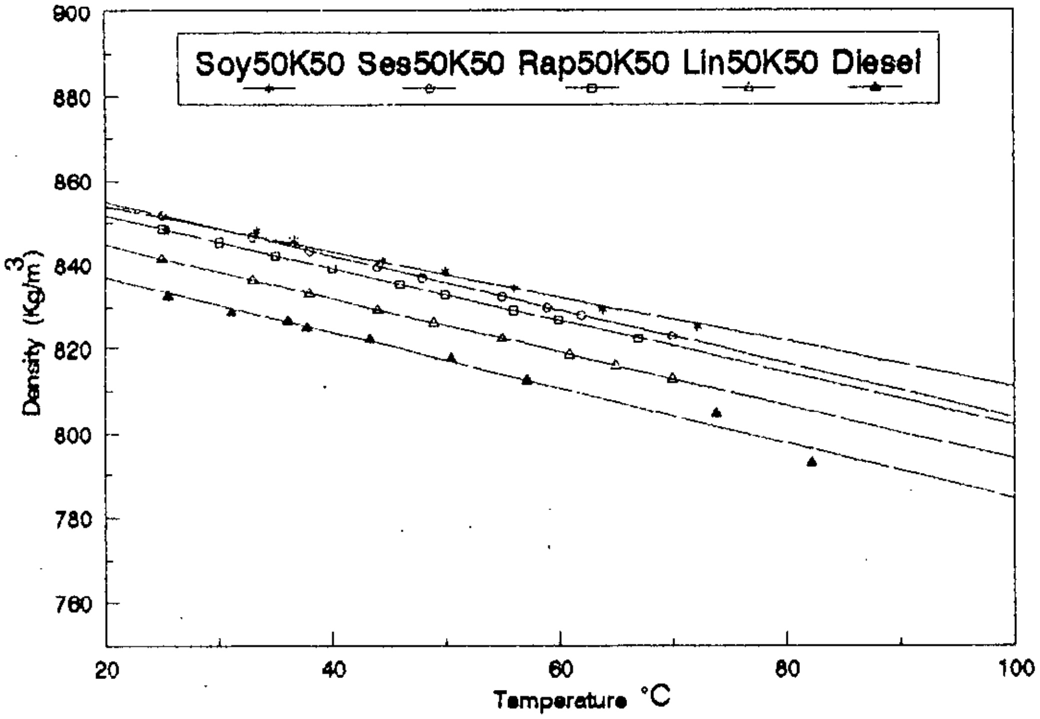

Figure 5.1(b): Variations of densities of blended oils with temperatures.

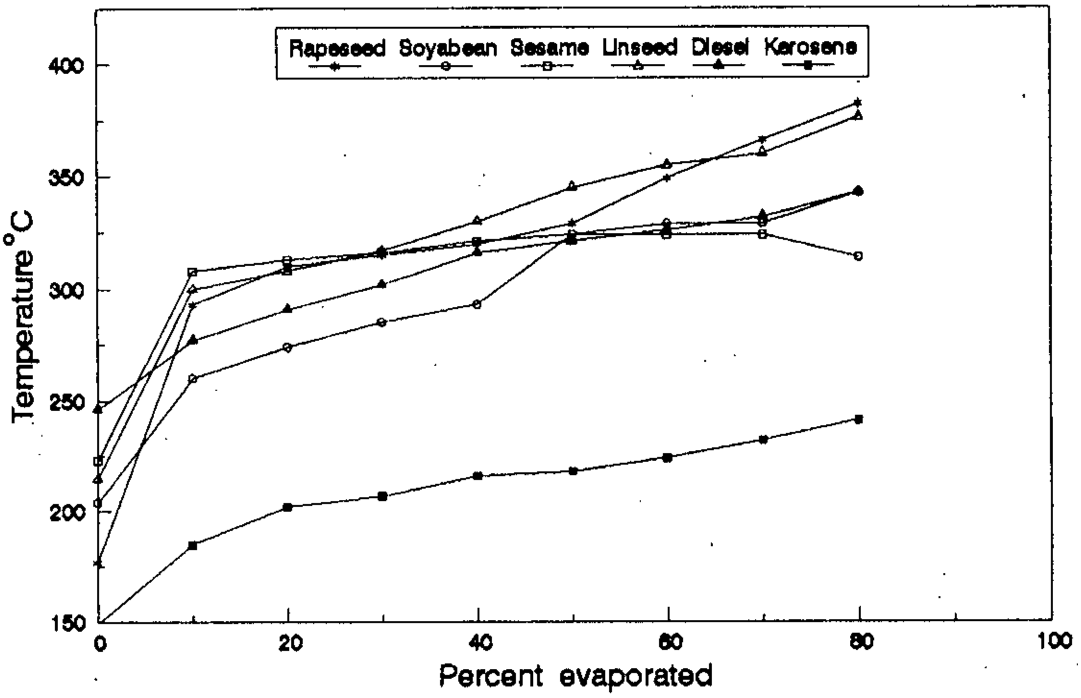

Figure 5.2(a): Variations of volatility of pure oils with temperatures.

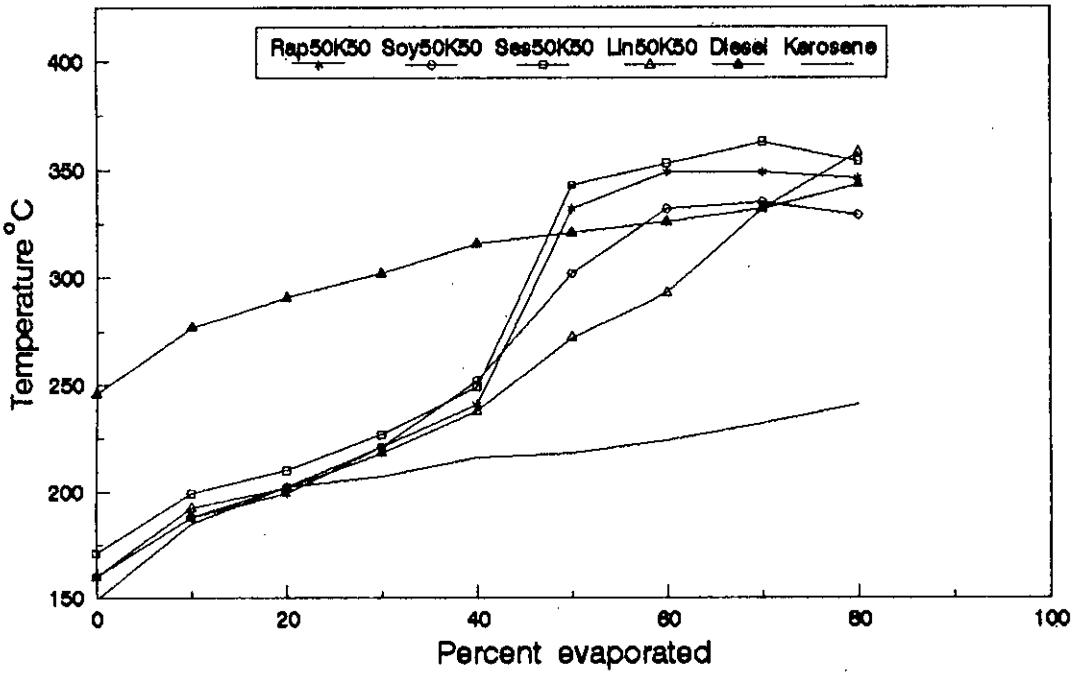

Figure 5.2(b): Variations of volatility of blended oils with temperatures.

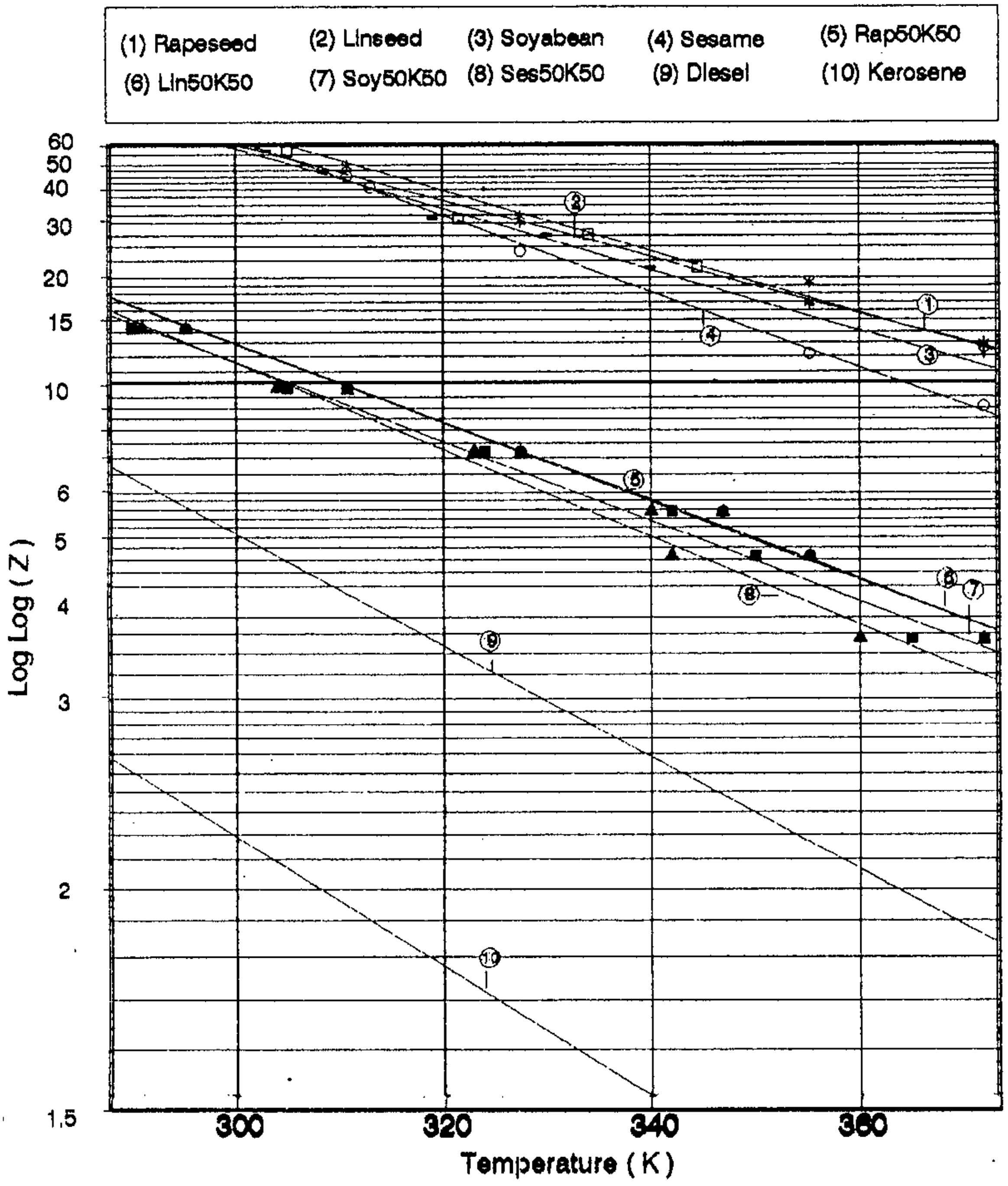

Figure 5.3: Effect of temperatures on the viscosities of fuels, pure and blended are shown.

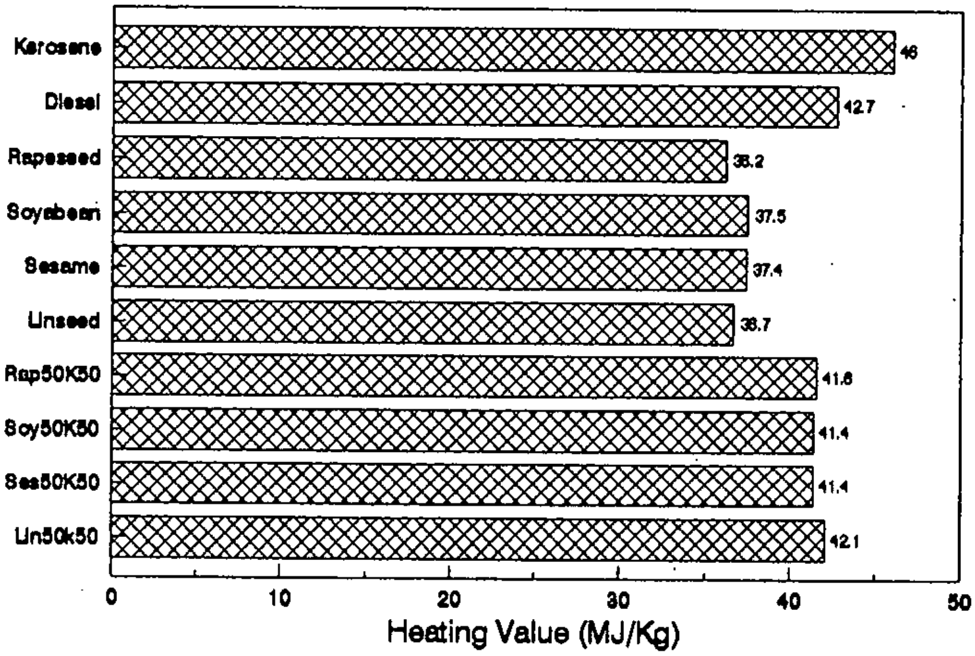

Figure 5.4(a): Calorific values of fuels, pure and blended.

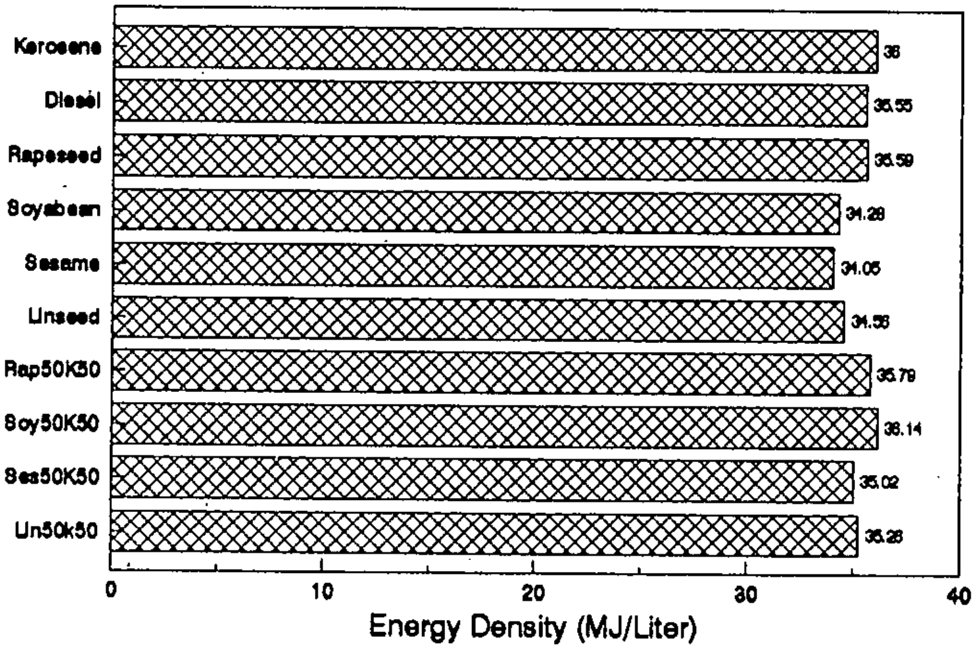

Figure 5.4(b): Energy densities of fuels, pure and blended.

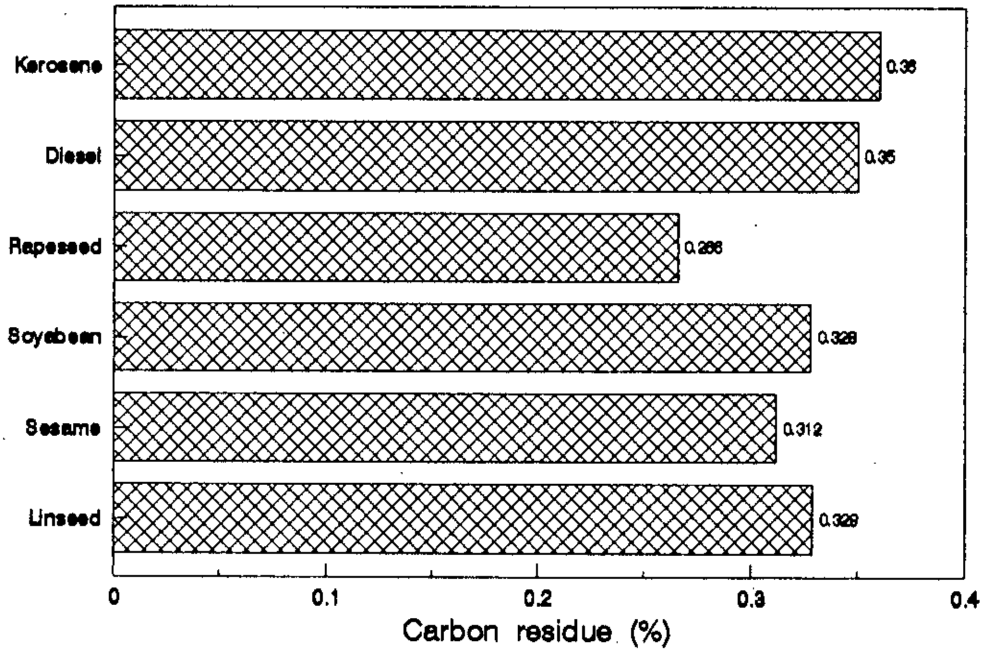

Figure 5.5(a): Carbon residue of oils.

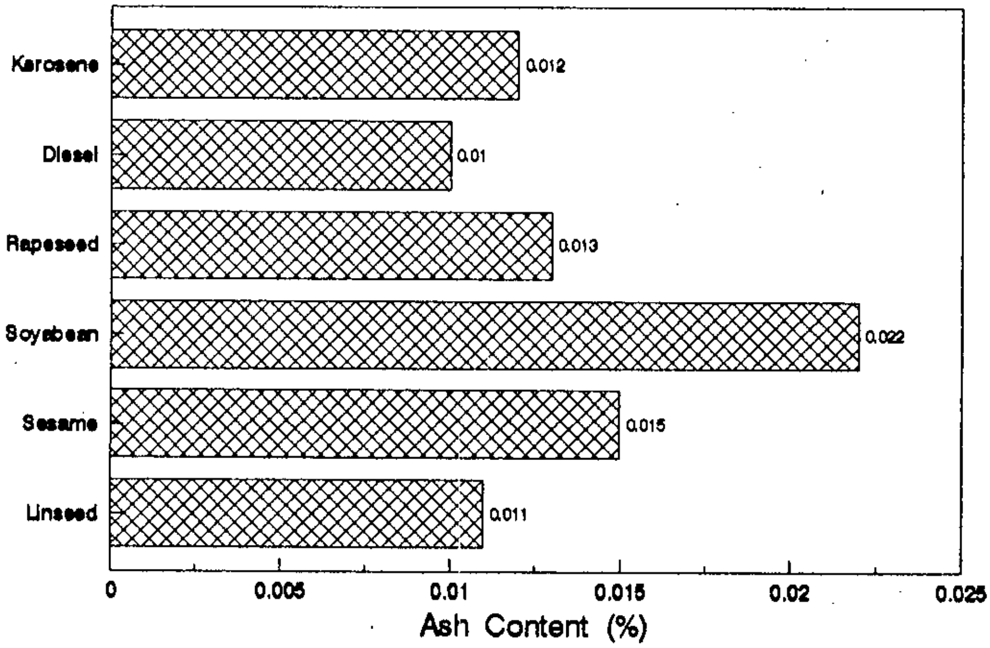

Figure 5.5(b): Ash contents of oils.

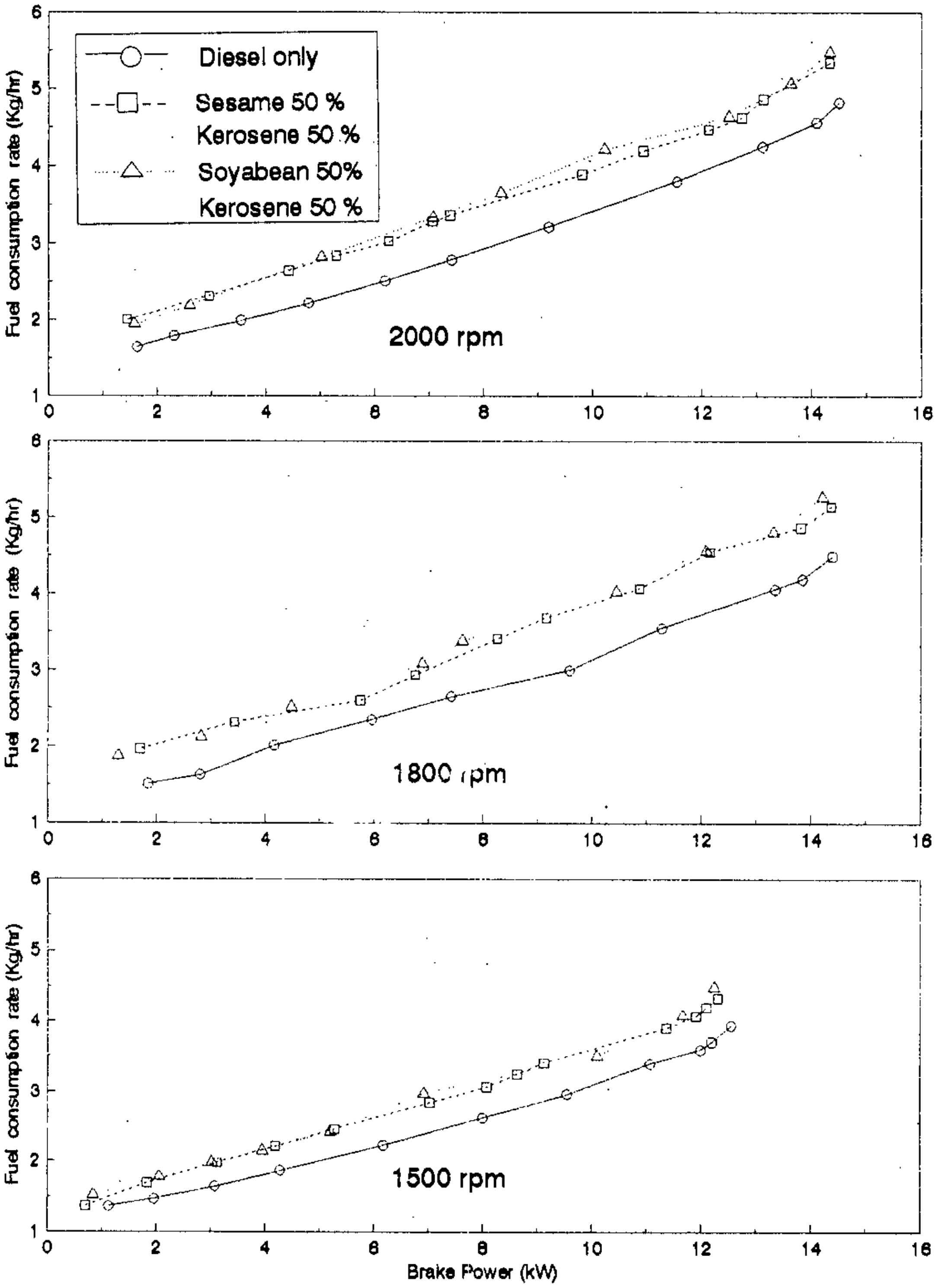

Figure 6.7: Comparison of the fuel consumption rates of different fuels at particular speed.

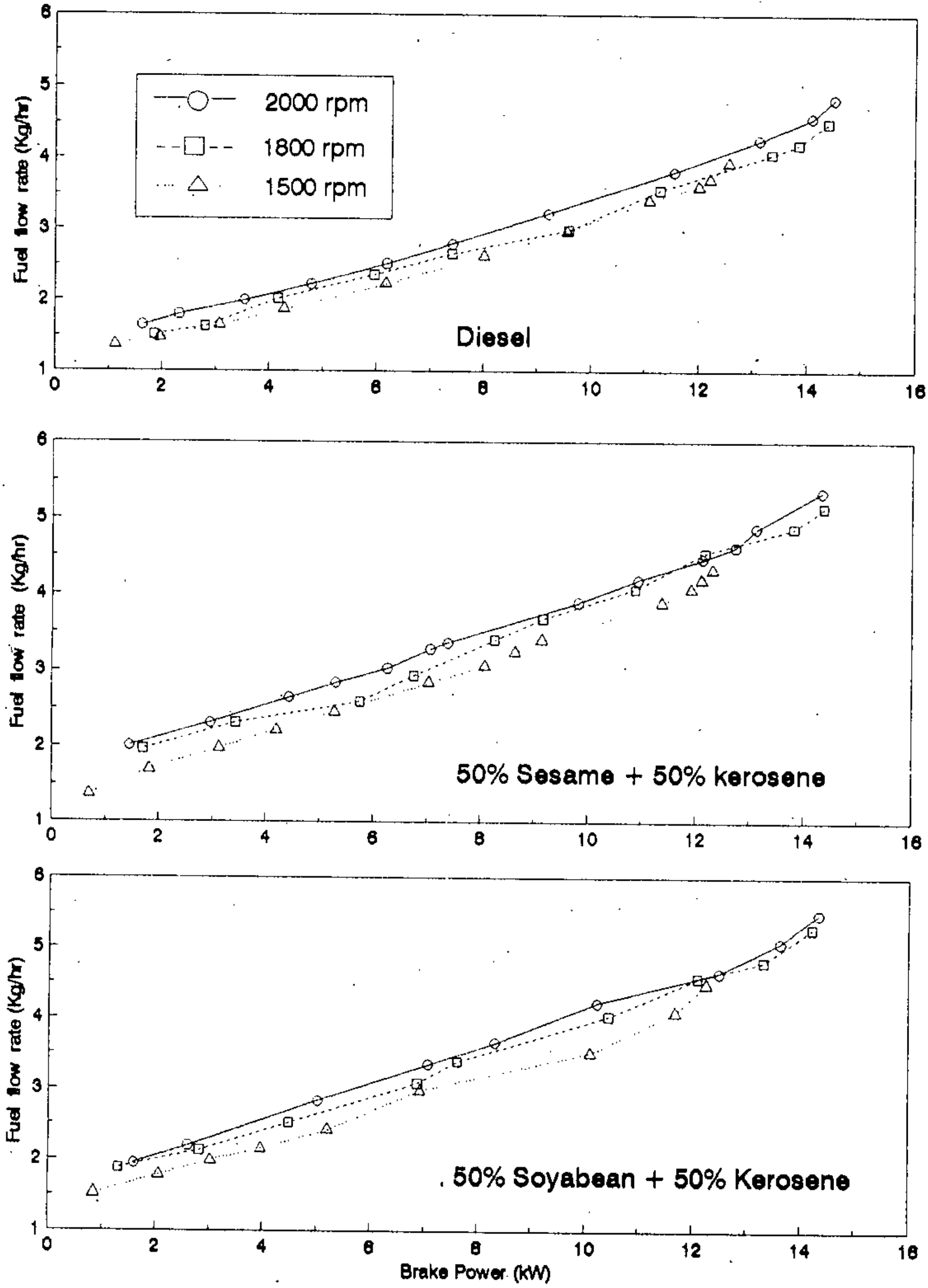

Figure 6.8: Comparison of the fuel consumption rates of particular fuels at different speeds.

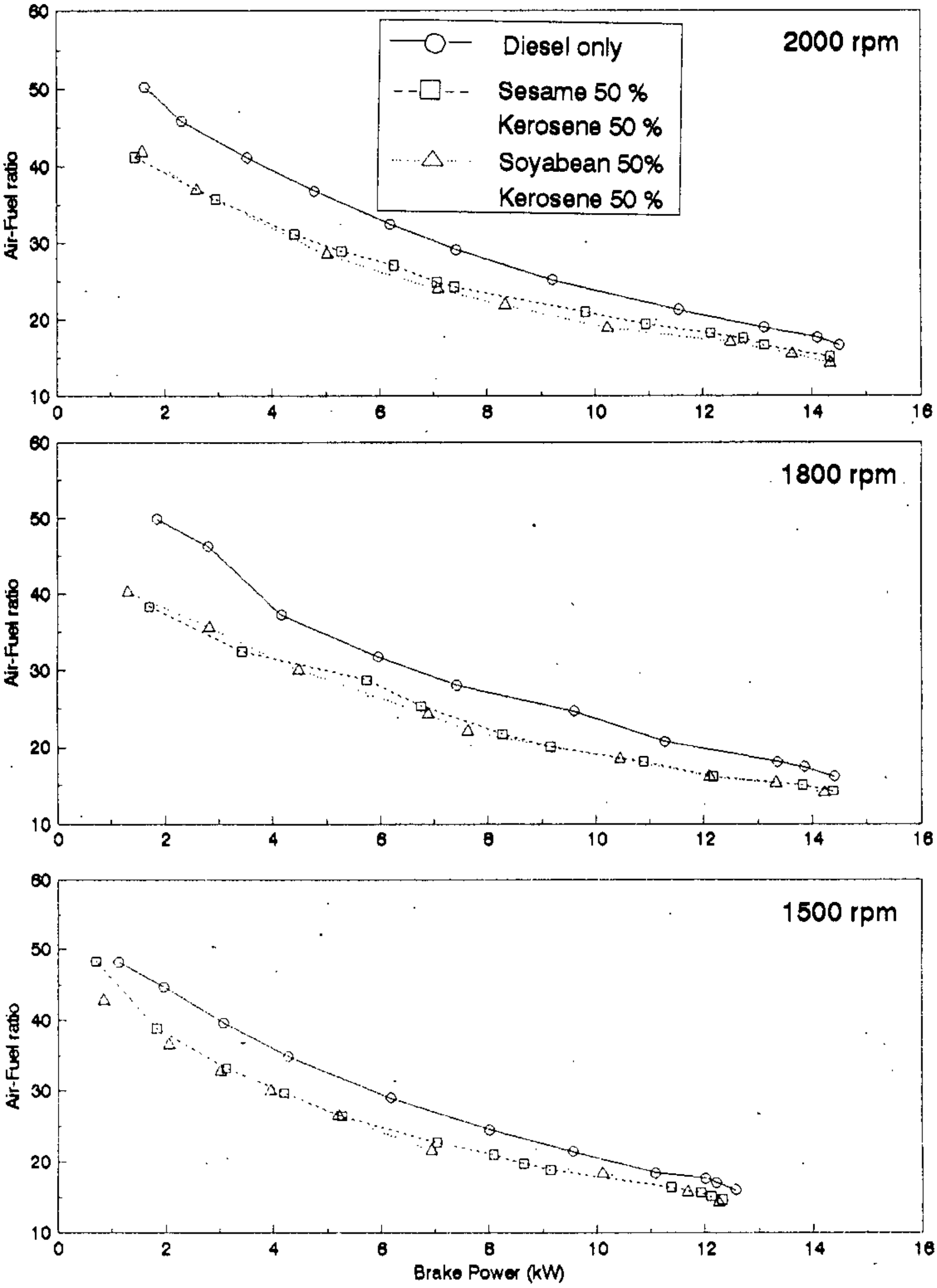

Figure 6.9: Comparison of the air fuel ratios of different fuels at particular speed.

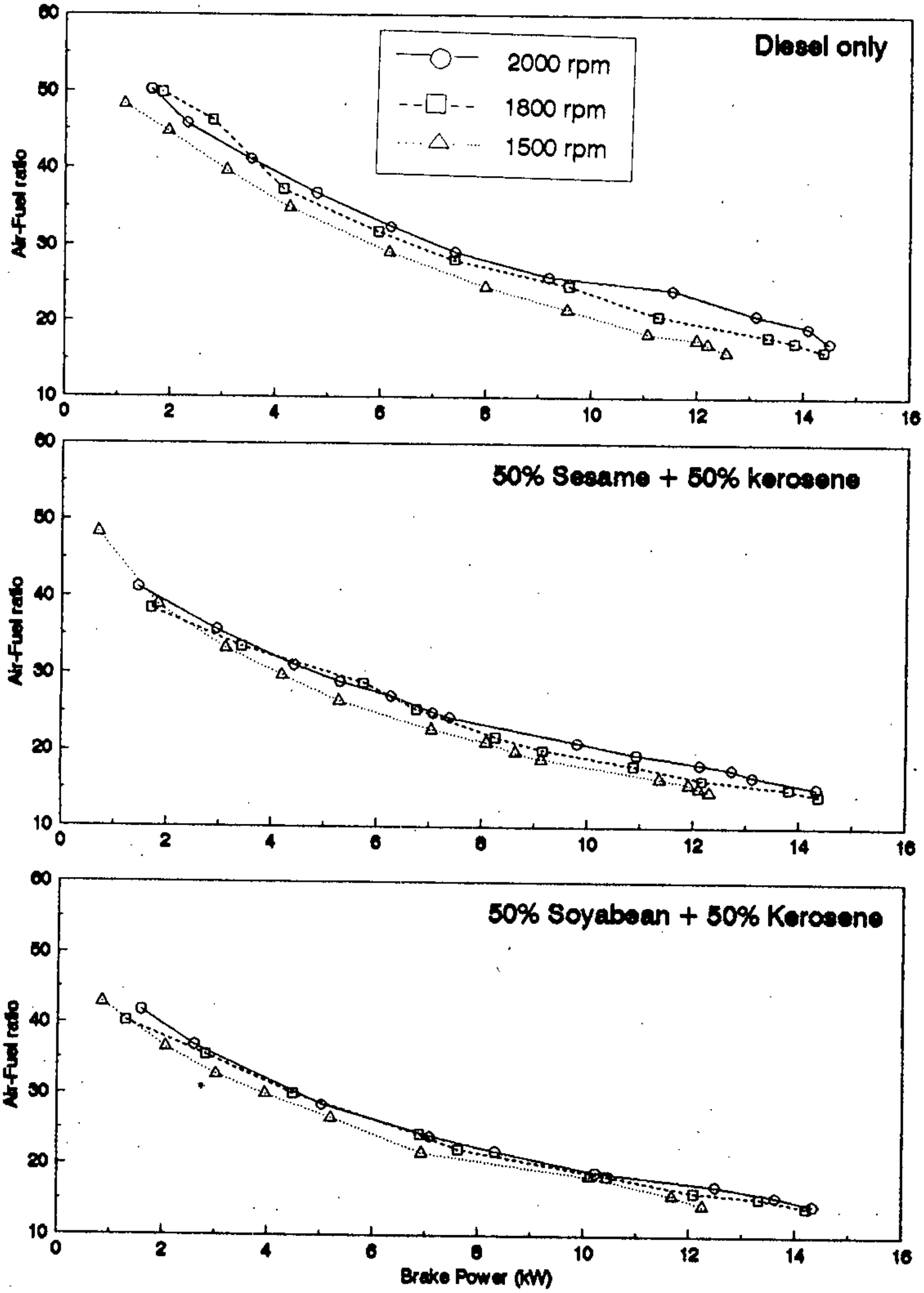

Figure 6.10: Comparison of the air fuel ratios of particular fuels at different speeds.

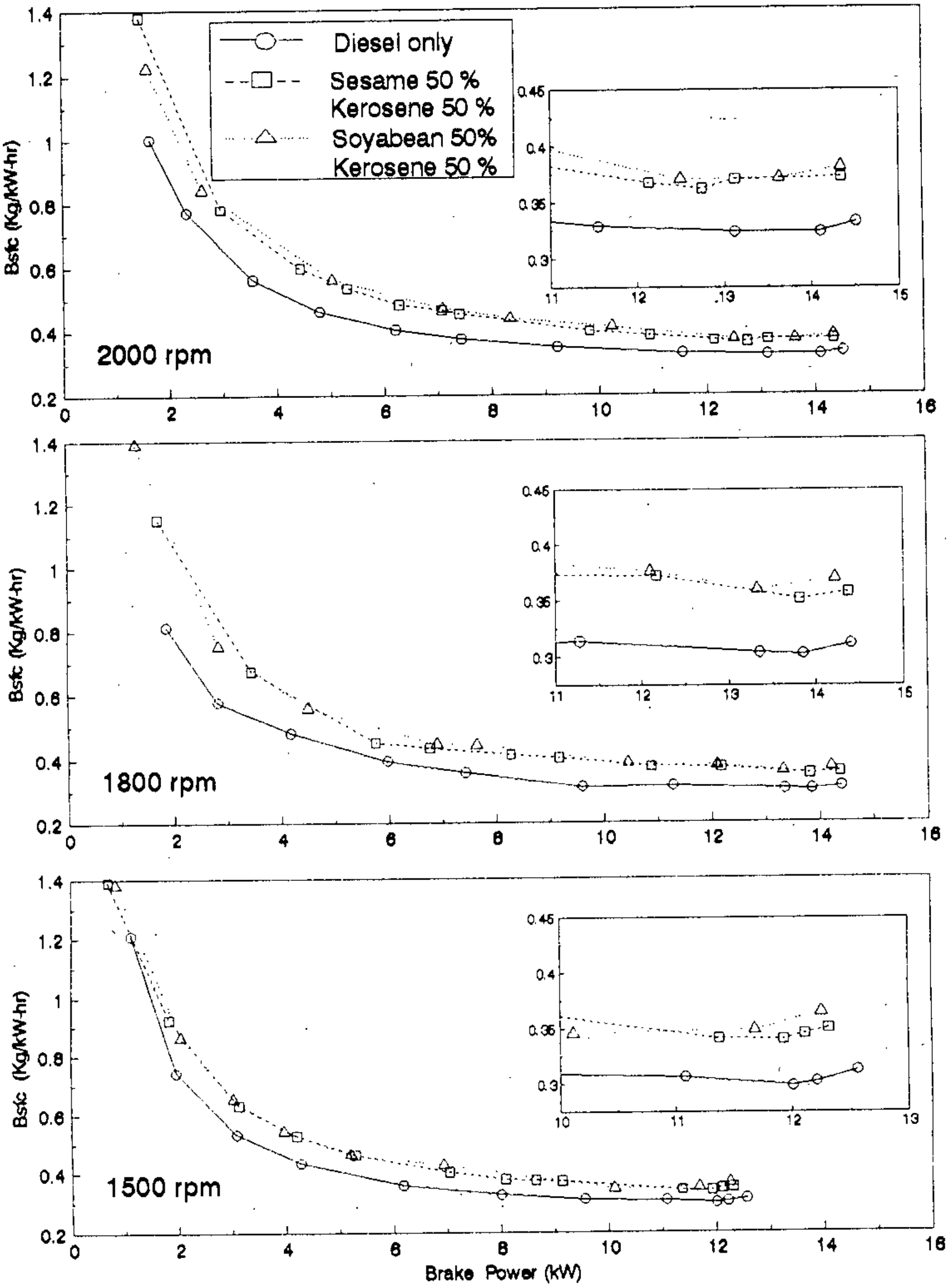

Figure 6.11: Comparison of the bsfc's of the different fuels at particular speeds.

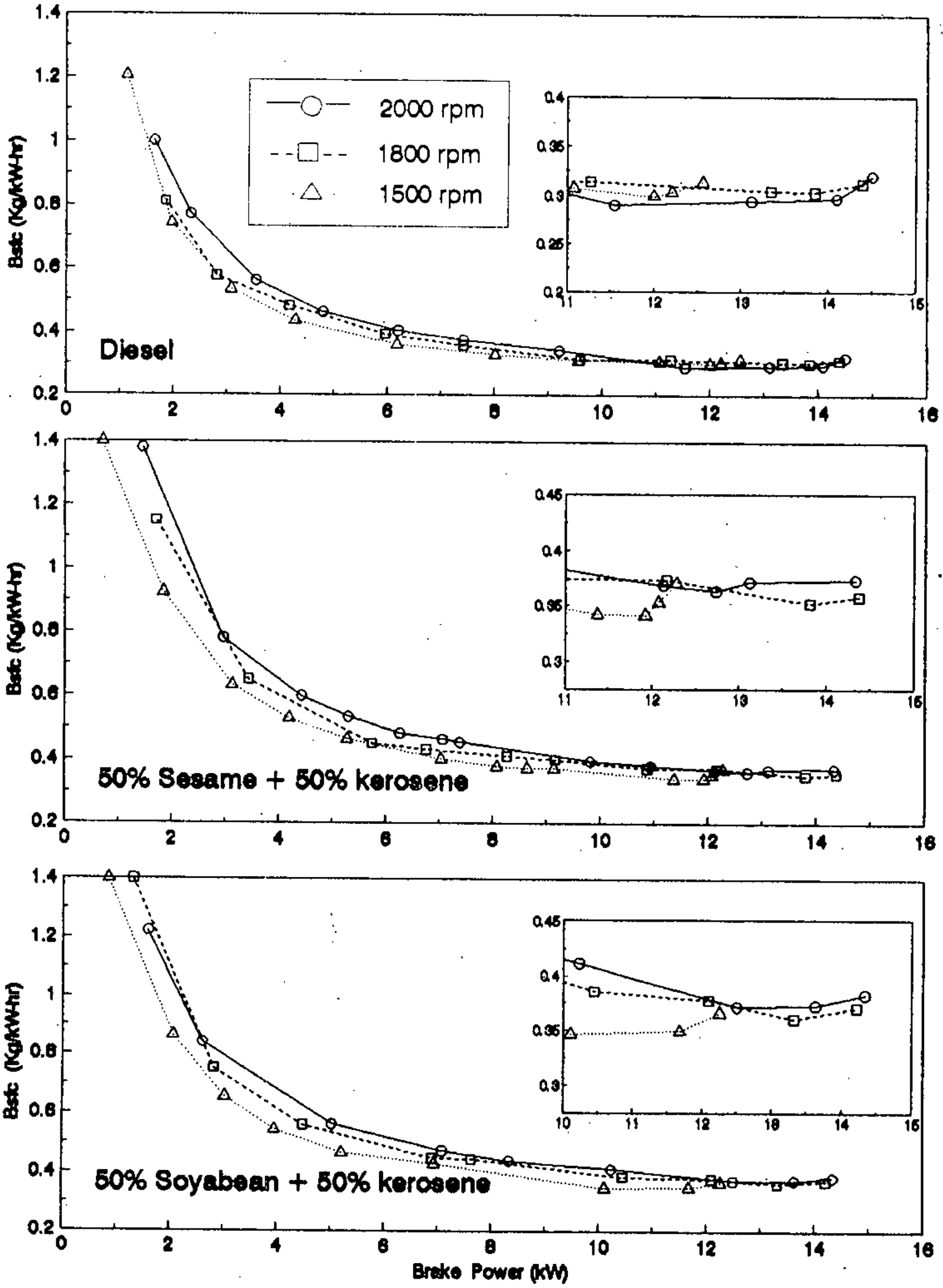

Figure 6.12: Comparison of the bsfc's of particular fuels at different speeds.

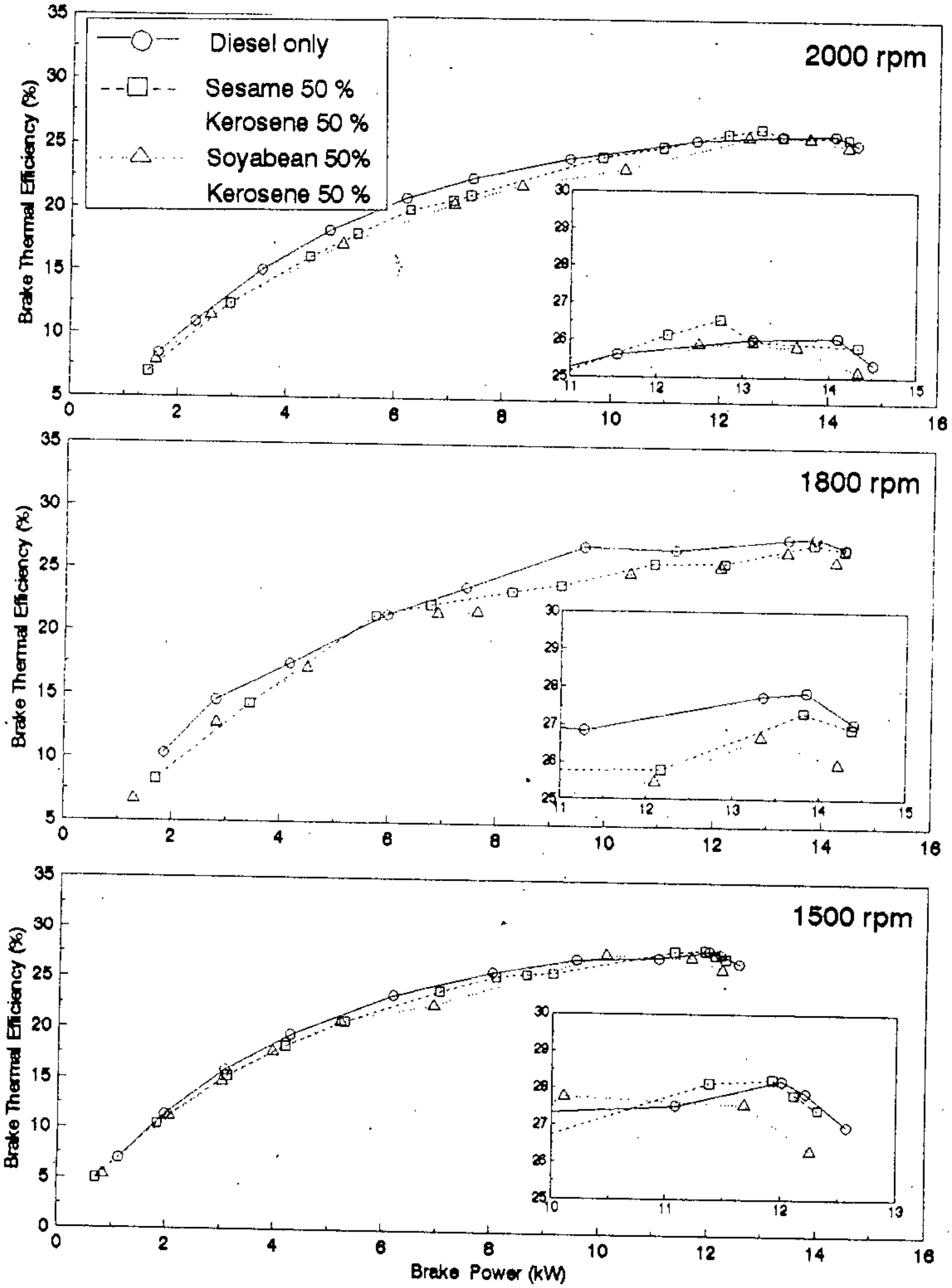

Figure 6.13: Comparison of the brake thermal efficiencies of different fuels at particular speeds.

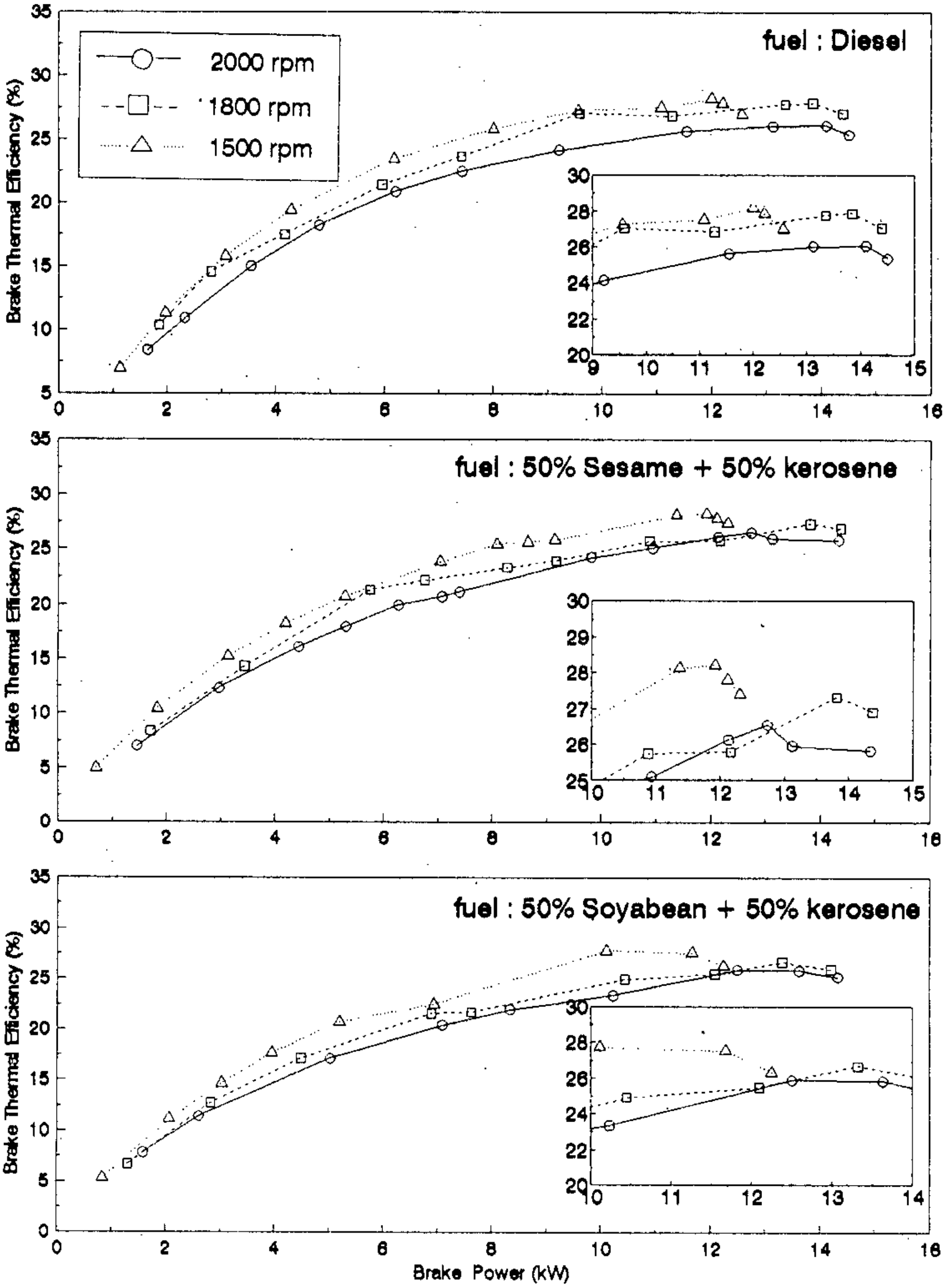

Figure 6.14: Comparison of the brake thermal efficiencies of particular fuels at different speeds

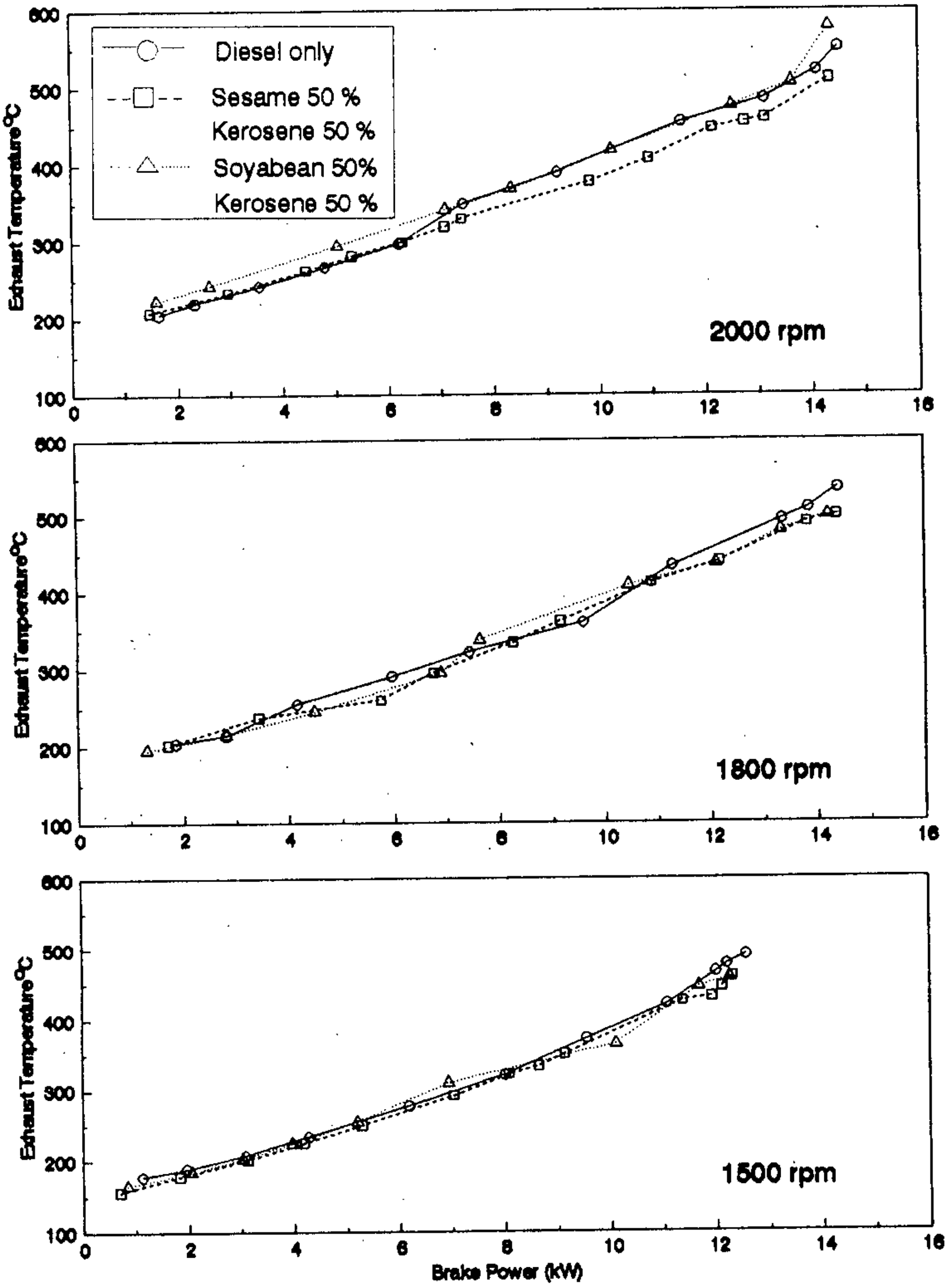

Figure 6.15: Comparison of the exhaust temperatures of different fuels particular

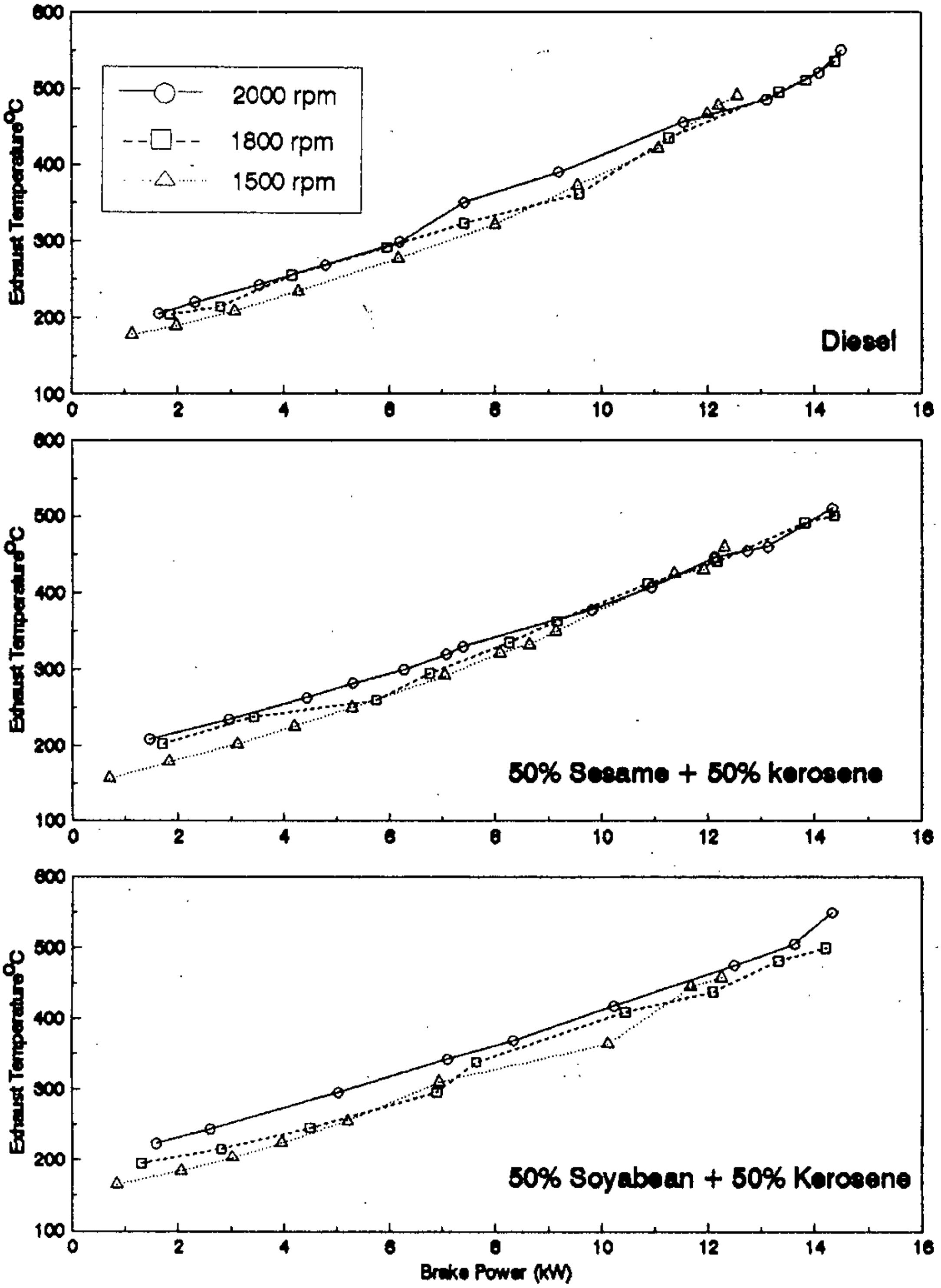

Figure 6.16: Comparison of the exhaust temperatures of particular fuels at different speeds.

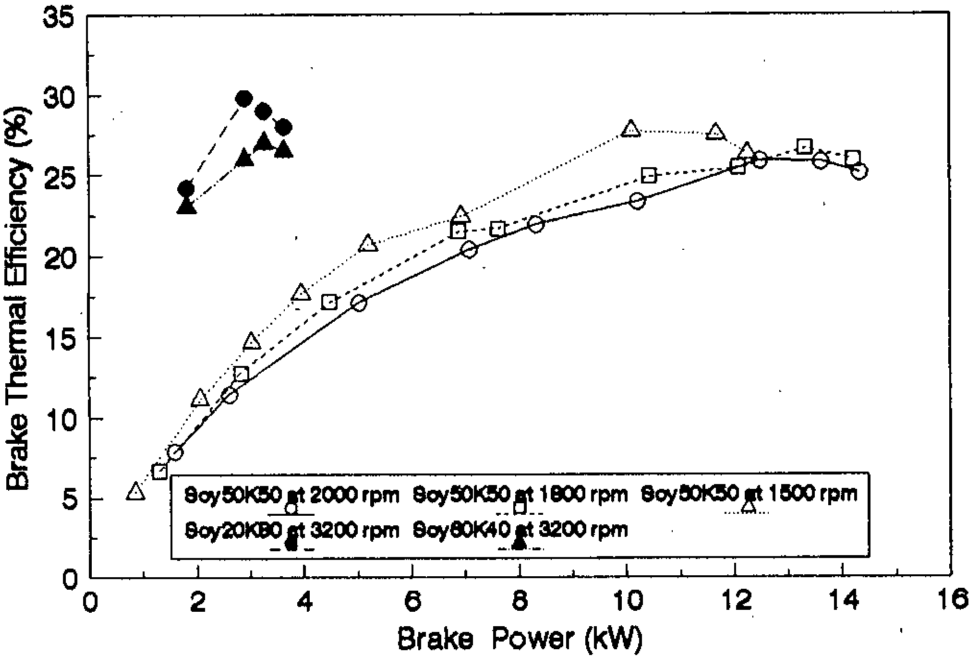

Figure 5.16: Comparison of Brake thermal efficiencies with results from Yaginuma et. al.[33]. Hence solid markers are used for the data from Yaginuma et. al.

Appendix A

Engine specifications

Brand name	: Yanmar Diesel	Model	: 2TGE
Engine no	: BTK 0231	Manufacturer	: Yanmar Diesel
Country of make	: Japan	No. of Cylinder	: Two
Rated rpm	: 2000	Rated power	: 22 HP
Lub Oil	: SAE 30	Fuel use	: Diesel
Lub. sys	: Forced feed	Cooling system	: Water cooled
Fuel filter	: present	Air chamber	: dry
Starting	: manual	Rotation	: clockwise
Fuel injection	: 10-12 btdc	Injection pressure	: 160 Kg/cm^2

Appendix B

Methods and sample calculations

B.1 Measurement of Kinematic-viscosity

In determining the fuel kinematic-viscosity, ASTM D-88-56 test procedure is followed. In this method, the efflux time in seconds of 60 ml of sample, following through a calibrated orifice, is measured under carefully controlled conditions. This efflux time, known as Saybolt Universal Second (SUS) is related to kinematic viscosity by empirical formula. The following empirical formulas used to convert SUS to kinematic viscosity which are taken from SAE handbook (1968):

$$\nu = \begin{cases} 0.224t - (185/t) & 35 < t < 115 \\ 0.223t - (155/t) & 115 < t < 225 \\ 0.2158t & t > 225 \end{cases} \tag{B.1}$$

where, ν = Kinematic viscosity (cSt)
t = Saybolt Universal Second (SUS)

The ASTM standard D341-87 provides charts to permit fuel kinematic viscosity-temperature data to plot as a straight line. The general relationship provided by ASTM D341-87 is :

$$\log\log \mathrm{Z} = \mathrm{A} - \mathrm{B}\log \mathrm{T} \tag{B.2}$$

where,

$Z = (\nu + 0.7 + C - D + E - F + G - H)$
ν = kinematic viscosity (cSt)
T = temperature K
A and B = constants
$C = \exp(-1.14883 - 2.65868\nu)$
$D = \exp(-0.0038138 - 12.5645\nu)$
$E = \exp(5.46491 - 37.6289\nu)$
$F = \exp(13.03458 - 74.6851\nu)$
$G = \exp(37.4619 - 192.643\nu)$
$H = \exp(80.4945 - 400.468\nu)$

The limits of applicability are listed below:

$Z = (\nu + 0.7)$	$2 * 10^7$ to 2.00 cSt
$Z = (\nu + 0.7 + C)$	$2 * 10^7$ to 1.65 cSt
$Z = (\nu + 0.7 + C - D)$	$2 * 10^7$ to 0.90 cSt
$Z = (\nu + 0.7 + C - D + E)$	$2 * 10^7$ to 0.30 cSt
$Z = (\nu + 0.7 + C - D + E - F + G)$	$2 * 10^7$ to 0.24 cSt
$Z = (\nu + 0.7 + C - D + E - F + G - H)$	$2 * 10^7$ to 0.21 cSt

It is found that for vegetable oils, the factors E, F, G and H are negligible. So, the general expression reduces to:

$$\log\log(\nu + 0.7 + C - D) = A - B\log T \qquad (B.3)$$

Sample calculation:

Sample : Rapeseed oil
Temperature : 40°C
SUS : 215 seconds

Using equation B.1
$$\begin{aligned} \nu &= 0.223t - \tfrac{155}{t} \\ &= 0.223 * 215 - \tfrac{155}{215} = 47.2 \text{ cSt} \end{aligned}$$

B.2 Measurement of Volatility

In contrast to as individual elemental or compound material exhibiting a single boiling point, a vegetable oil or vegetable oil blend, as in a commercial petroleum fuel, boils over a range of temperatures. An indication of the boiling points of different constituents can be gained by the simple ASTM batch distillation test in which a 100 ml sample is evaporated at a controlled rate by heating in a flask incorporating a slide arm, condensed in an condenser tube, and collected in a graduated cylinder.

Corresponding readings of vapour temperature and condensate recovery are plotted as a distillation curve showing the boiling temperatures of various components. The initial boiling point (ibp) is taken as the temperature observed at the fall of the first droplet of condensate, and the final boiling point (fbp) as the highest temperature reached during the test.

B.3 Measurement of Calorific Value

The calorific value of the fuels are measure using ASTM D240-87 test procedure. In this method, heat of combustion is determined by burning a weighed sample (1.000 gm) in an oxygen bomb calorimeter under controlled conditions. The heat of combustion is computed from temperature observations before, during and after combustion, with proper allowance for thermochemical and heat transfer correction. In the present study isothermal jacket calorimeter is used.

In this procedure, temperature rise, t, in an isothermal jacket calorimeter is computed from the following relationship.

$$t = t_c - t_a - r_1(b - a) - r_2(c - b) \tag{B.4}$$

where,

t = corrected temperature rise,
a = time of firing
b = time (to nearest 0.1 min) when the temperature rise reaches 60% of total temperature rise,
c = time at beginning of period in which the rate of temperature change with time has become constant (after combustion)
t_a = temperature at time of firing, corrected for thermometer error.
t_c = temperature at time, c, corrected for thermometer error.
r_1 = rate (temperature units per minute) at which temperature was rising during 5-min period before firing, and
r_2 = rate (temperature units per minute) at which temperature was rising during 5-min period after time c. If the temperature is falling, r_2 is negative and the quantity $-r_2(c - b)$ is positive.

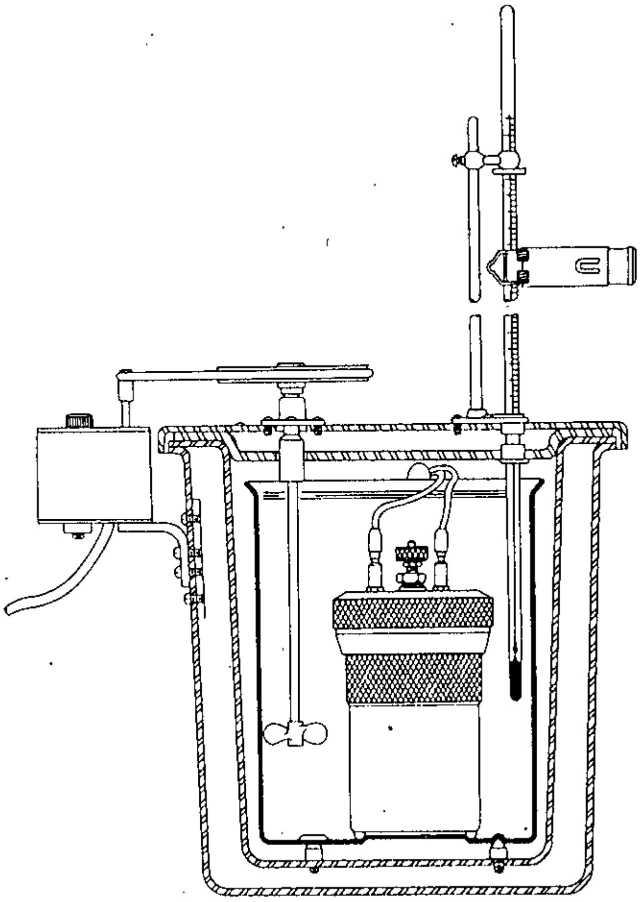

Figure B.1: Sectional view of a bomb calorimeter to measure the calorific value of a fuel[4]

Now, the gross heat of combustion, is measured by the following equation:

$$Q_g = \frac{tW - E}{w} \tag{B.5}$$

where,

Q_g = gross heat of combustion, at contact volume expressed as MJ/K

t = corrected temperature rise °C.

W = energy equivalent of calorimeter and added water KJ/°C.

E = correction of heat combustion of firing wire, KJ

= 0.96 * milimeters of chromel C wire consumed $/10^3$

w = wt of the sample in gm

Sample calculation:

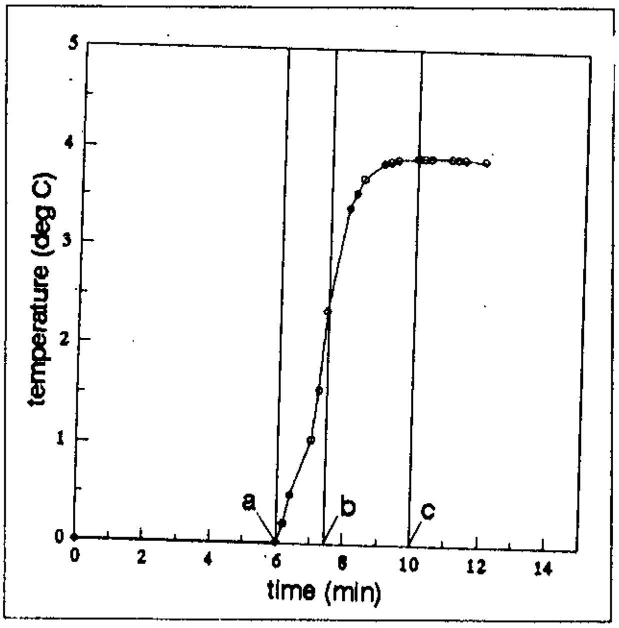

Figure B.2: Variation of temperature with time shown in Beckman themometer.

Sample : Rapeseed oil
With the help of Fig.B.2 :
a = 6
b = 7.4
c = 10
t_a = 0.01°C
t_c = 3.92°C
r_1 = 0.00167 °C/min
r_2 = −0.0050 °C/min
also,
W = $(1.999+0.432)*4.187 \frac{KJ}{°C}$
E = 0.96 x 5=4.8/10^3 KJ
w = 1.0044 gm

Using equations B.4 & B.4

$$
\begin{aligned}
t &= t_c - t_a - r_1(b-a) - r_2(c-b) \\
&= 3.92 - 0.01 - 0.00167 * (7.4-6) + 0.0050 * (10-7.4) = 3.9307°C
\end{aligned}
$$

$$Q_g = \frac{3.9307*2.332*4.187-0.0}{1000*1.004} = 38.2 \frac{MJ}{Kg}$$

B.4 Measurement of Density

Fuel density at different temperatures are measured by direct method which involves the measuring of a sample contained in a density bottle (25 ml). Hence density of fuels are calculated using the following relation:

$$\text{density} = \frac{W_t - W_b}{25} * 1000 \ \frac{g}{\text{liter}} \text{or} \ \frac{Kg}{m^3} \tag{B.6}$$

where, W_b = weight of the empty bottle
W_t = weight of the bottle filled with fuel

Sample calculation:

Sample : Rapeseed oil
W_b = 17.7779 gm
W_t = 40.3417 gm

density $= \frac{40.3417-17.7779}{25} * 1000 = 902.55 \ \frac{Kg}{m^3}$

B.5 Measurement of Carbon residue

Carbon residue of fuel is measured following ASTM D189-81 test procedure, also known as Conradson method.In this method, a weighed quality of sample (10 gm) is placed in a crucible and subjected to destructive distillation. The residue undergoes cracking and coking reaction during a fixed period of severe heating. At the end of the specified heating period, the test crucible containing the carbonaceous residue is cooled in a dedicator and weighed. The residue remained is calculated as a percentage of the original sample and reported as conradson carbon residue. The equation for calculation carbon residue is:

$$\text{Carbon residue} = \frac{A}{W} * 100 \tag{B.7}$$

where, A = mass of carbon residue, gm, &
W = mass of the sample, gm.

Sample calculation:

Sample : Rapeseed
A = 0.0266 gm
W = 10.0158 gm
Carbon residue (%) = $\frac{A}{W} * 100$
$= \frac{0.0266}{10.0158} * 100 = 0.266\%$

B.6 Determination of Ash Content

Ash content of fuel is determined by following ASTM D482-87 test procedure. In this test procedure, a suitable crucible is heated at 700 to 800°C for more than 10 minutes and cooled to room temperature and weighed to the nearest 0.1 mg using electronic balance. Then, a weighed amount of oil contained in the crucible is ignited and allowed to burn until only ash and carbon remain. The carbonaceous residue is reduced to ash by heating in a muffle furnace at 775°C, cooled and weighed. Now, the mass of the ash as a percentage of the original sample is calculated from the equation:

$$\text{Ash}(\%) = \frac{w}{W} * 100 \qquad \text{(B.8)}$$

where, w = mass of ash gm,
W = mass of sample, gm.

Sample calculation:

Sample : Rapeseed
w = 0.0013 gm
W = 10.0158 gm
Ash (%) = $\frac{w}{W} * 100$
$= \frac{0.0013}{10.0158} * 100 = 0.013\%$

B.7 Measurement of Engine Performance

A model no. TFJ-250L water brake type dynamometer is used to measure engine brake power.

The brake power of the engine is calculated using the following equations:

$$P(\mathrm{hp}) = \frac{WN}{2500} \tag{B.9}$$

$$P(\mathrm{kW}) = 0.7456 * P(\mathrm{Hp}) \tag{B.10}$$

$$F_{\mathrm{flow}} = \frac{V}{t} * \frac{60}{1000000} * \mathrm{density} \tag{B.11}$$

Hence,

$P(\mathrm{hp})$ = brake power in horse power
$P(\mathrm{kW})$ = brake power in kW
W = Load shown in the dynamometer
N = rpm of the shaft connected to the dynamometer
F_{flow} = fuel consumption rate in Kg/hr
V = fuel flow in ml in time t
t = time in minutes
density = density of fuel in $\frac{\mathrm{Kg}}{\mathrm{m}^3}$

$$P_{\mathrm{standard}} = \frac{P(\mathrm{kW})}{\alpha} \tag{B.12}$$

$$F_{\mathrm{standard}} = \frac{F_{\mathrm{flow}}}{\beta} \tag{B.13}$$

Hence,

P_{standard} = brake power after standardization
F_{standard} = fuel consumption rate after standardization in Kg/hr
α = power correction factor
β = fuel consumption correction factor

Power & fuel consumptions are derated using BS :5514:1982.

$$\eta_{\text{brake thermal}} = \frac{P_{\text{standard}} * 3.600}{F_{\text{standard}} * CV_{\text{fuel}}} * 100 \qquad \text{(B.14)}$$

Hence, $\eta_{\text{brake thermal}}$ = brake thermal efficiency (%)
CV_{fuel} = calorific value of fuel $\frac{MJ}{Kg}$

$$A_{\text{flow}} = C_d A \sqrt{2g \frac{h_{\text{manometer}} \rho_{\text{water}}}{\rho_{\text{air}}}} * 3600 \qquad \text{(B.15)}$$

C_d = coefficient of discharge of the nozzle
$h_{\text{manometer}}$ = manometer deflection
Hence, ρ_{water} = density of water $\frac{Kg}{m^3}$
ρ_{air} = density of air $\frac{Kg}{m^3}$
g = gravitional acceleration $\frac{m}{s^2}$

Sample calculation:

Date : 17.07.1995
Fuel : Diesel
T_{dry} = 31°C
T_{wet} = 29°C
P_{atm} = 754 mm
Relative humidity = 87 %

Using BS :5514:1982 α = 0.9735
β = 1.0045

Experimental data & values :
W = 17.4
N = 665
V_{fuel} = 50 ml
t = 1.26 min
$h_{\text{manometer}}$ = 38.5 cm =0.385 m
C_d = 0.92
A = $2.85^{-4} m^2$
ρ_{water} = $996 \frac{Kg}{m^3}$
ρ_{air} = $1.165 \frac{Kg}{m^3}$

Experimental Results :

$$P(hp) = \frac{17.4*665}{2500}$$

$$= 4.628 \text{ hp}$$

$$P(kW) = 0.7456 * P(hp)$$

$$= 3.45 \text{ kW}$$

$$F_{\text{flow}} = \frac{V}{t} * \frac{60}{1000000} * \text{density}$$

$$= \frac{50}{1.26} * \frac{60}{1000000} * 840 = 2.000 \frac{Kg}{hr}$$

$$P_{\text{standard}} = \frac{P(kW)}{\alpha}$$

$$= \frac{3.45}{0.9735} = 3.545 kW$$

$$F_{\text{standard}} = \frac{F_{\text{flow}}}{\beta}$$

$$= \frac{2.000}{1.0045} = 1.991 \frac{Kg}{hr}$$

$$\text{bsfc} = \frac{F_{\text{standard}}}{P_{\text{standard}}}$$

$$= \frac{1.991}{3.545} = 0.562 \frac{Kg}{kW-hr}$$

$$\eta_{\text{ brake thermal}} = \frac{P_{\text{standard}}*3.600}{F_{\text{standard}}*CV_{\text{fuel}}} * 100$$

$$= \frac{3.545*3.600}{1.991*42.7} * 100 = 15.01\%$$

$$A_{\text{flow}} = C_d A \sqrt{2g \frac{h_{\text{manometer}} \rho_{\text{water}}}{\rho_{\text{air}}}} * 3600$$

$$= 0.92 * 2.85^{-4} \sqrt{2 * 9.81 * \frac{.385*996}{1.165}} * 3600 = 75.86 \frac{Kg}{hr}$$

$$AFR = \frac{A_{\text{flow}}}{F_{\text{standard}}}$$

$$= \frac{75.86}{1.191} = 38.08 \frac{Kg \text{ of air}}{Kg \text{ of fuel}}$$