PRODUCTION AND PERFORMANCE EVALUATION OF BIODIESEL FROM *HIBISCUS SABDARIFFA* AND *HIBISCUS SURATTENSIS*

By

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DECLARATION

I hereby declare that the work in this thesis titled **"Production and Performance Evaluation of Biodiesel from *Hibiscus Sabdariffa a*nd *Hibiscus Surattensis*"** was carried out by myself in the Department of Mechanical Engineering, Ahmadu Bello University, Zaria, under the supervision of Dr D. S. Yawas and Professor P. B. Madakson.

Literature obtained and used from different sources has been has been duly acknowledged in the text and a list of references provided. No part of this work has been presented for another degree or diploma at any institution.

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CERTIFICATION

This thesis titled **"Production and Performance Evaluation of Biodiesel from *Hibiscus Sabdariffa* and *Hibiscus Surattensis*"** meets the regulations governing the award of the degree of Masters of Science of the Ahmadu Bello University, Zaria, Nigeria and is hereby approved.

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DEDICATION

This work is dedicated to the Almighty God; my source of inspiration and support and also to my mother- Mrs Celina Stephen, brothers: Lawrence, Kasa, Tsinvak, , Christian, Simon and my sister Mrs Philomena Istifanus.

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ABSTRACT

This work investigated the viability of using locally available vegetable seed oils to produce biodiesel. Two indigenous seeds- *Hibiscus Surattensis* (Hausa-rahma) and *Hibiscus Sabdariffa* (Hausa-yakwua) were used to carry out the research.

Biodiesel from oils derived from these seeds were produced by alkali catalyzed transesterification process. The physicochemical properties of the oils (such as viscosity, flash point, calorific value, relative density, acid value, ash content, carbon content, saponification value, iodine value and hydrogen content) and various blending ratios of biodiesel with diesel obtained from oils of these seeds were investigated and compared with standard diesel fuel. The methyl esters of the samples were comparatively analysed based on their performance characteristics in blends of 30:70, 40:60 and 50:50 using a Leyland Compression Ignition Engine coupled to a hydro-dynamometer. Parameters like speed of engine and fuel consumption were measured at different loads for pure diesel and various combinations of biodiesel blends. Torque, brake horse power and specific fuel consumption were calculated. The test results indicate that the biodiesel blends of 40:60 for *H. Sabdariffa has* Brake horse power- 12.44kW, Speed-2000rpm, and SFC 0.118 l /kW hr and; 30:70 for *H. Surattensis* has Brake horse power- 13.78kW, Speed-2000rpm, and SFC-0.332 l/kW hr while Diesel has Brake horse power- 10kW, Speed-2000rpm, and SFC-0.193 l/kW hr. Both *H. Sabdariffa* at 40:60 blend and *H. Surattensis* at 30:70 blend have brake horse power and SFC higher than diesel at the speed of 2000rpm hence H. *Sabdariffa*

blend of 40:60 and *H. Surattensis* blend of 30:70 blend can be recommended for use in diesel engines without making any engine modifications.

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SYMBOLS & ABBREVIATIONS

UNDP	United Nations Development Programme
MDG	Millennium Development Goals
CO_2	Carbon (IV) oxide
kW hr	Kilowatt Hour
N	Newton
SVO	Straight Vegetable Oil
ICE	Internal Combustion Engine
TDC	Top Dead Center
BDC	Bottom Dead Center
bp	Break Power
i.p	Indicated Power
P_i	Indicated Mean Effective Pressure (N/m^2)
A_c	Cross – sectional area of the Cylinder (m^2)
ω	Engine Speed (rev/sec)
n	Number of Cylinders
m	Metre
T	Torque (Nm)
F	Brake Load (N)
d	Torque Arm (m)
$\bar{P}$ (N/m^2)	Brake Mean Effective Pressure bmep
η_m	Mechanical Efficiency
η_{BT}	Brake Thermal Efficiency

M_f (kg/hr)	Mass of Fuel Consumed Per Unit Time
$Q_{net.\ v}$	Net Calorific Value of the Fuel (kJ/g)
η_{IT}	Indicated thermal efficiency
SFC	Specific fuel consumption (l/kW hr)
η_v	Volumetric efficiency
A	Constant = 0.25
B	Constant = 172
t	Time in seconds.
□	Kinematic Viscosity in mm^2/s
W_1	Weight of Empty Bottle (g)
W_2	Weight of Bottle Full of Water (g)
W_3	Weight of Bottle Full of Oil (g)
RD	Relative Density
a	Test titration
b	Blank titration
NaCl	Sodium Chloride
NaOH	Sodium Hydroxide
HCl	Hydrogen Chloride
H_2SO_4	Tetraoxosulphate (VI) acid
V	Rate of Fuel Consumption (l/hr)
v	Specific Fuel Consumption (l/kW hr)
V_s	Swept volume of engine (m)
K_2	Engine constant for 2 or 4- stroke engine

CHAPTER ONE

INTRODUCTION

1.0 BACKGROUND

Energy is central to sustainable development and poverty reduction efforts. It affects all aspects of development – social, economic, and environmental – including livelihoods, access to water, agricultural productivity, health, population levels, education, and gender-related issues. The United Nation Millennium Summit identified the most pressing global development needs. These were called Millennium Development Goals (MDGs) which were unanimously adopted by the international community in 2000.These MDGs are a list of human development objectives to be achieved by 2015 (UNDP, 2000). These goals include: poverty alleviation, universal basic education for all, promotion of gender equality and empowering of women, improved health conditions and environmental sustainability. None of the MDGs can be met without major improvement in the quality and quantity of energy services in developing countries. UNDP's efforts in energy for sustainable development support the achievement of the MDGs, especially MDG1, reducing by half the proportion of people living in poverty by 2015 (UNDP, 2000).

The present study is a research set out to investigate the viability of using some locally sourced vegetable seeds to produce biodiesel or methyl ester from the oils extracted from these local seeds. Different indigenous seeds namely: *Hibiscus Surattensis* and *Hibiscus Sabdiraffa* seeds were used to carry out the research work. The physicochemical properties of the biodiesel obtained from the oil of these seeds were investigated and

compared with standard diesel fuels. The fuels were used to run a diesel engine and the performance of the Diesel Engine was observed.

1.1 STATEMENT OF RESEARCH PROBLEM

1. Nigeria today is possibly facing the worst energy crisis ever to befall this nation. The country, by the government's admission, imports about 70% of refined fuel needed for domestic consumption. Despite the award of licenses to several private firms to build refineries, absolutely no investor has committed a farthing to construction (This Day Newspaper, 2007).

2. Numerous studies indicated that oil sources in the world will come to an end. As a result, new alternative energy sources will be required to substitute for Fossil diesel (Yücesu et al., 2006).

3. Due to rising dangers from the ongoing build up of human-related greenhouse gases produced mainly by the burning of fossil fuels and forests, it has become necessary to develop alternative fuels that will be environmental friendly.

A possible solution to a potential future energy shortage would be to use some of the world's remaining fossil fuel reserves as an investment in renewable energy infrastructure such as wind power, solar power, tidal power, geothermal power, hydropower, methanol, ethanol and biodiesel, or in an oil lamp; olive oil, canola oil, safflower oil, or sunflower oil which do not suffer from finite energy reserve but do not

have finite energy flow. The construction of sufficiently large renewable energy infrastructure might avoid the economic consequences of an extended period of decline in fossil fuel energy supply per capita.

1.2 PRESENT RESEARCH

The present study is a research set out to investigate the viability of using some locally sourced vegetable seeds to produce biodiesel or methyl ester from the oils extracted from these local seeds. Different indigenous seeds namely: *Hibiscus Surattensis* and *Hibiscus Sabdiraffa* seeds were used to carry out the research work. The physicochemical properties of the biodiesel obtained from the oil of these seeds were investigated and compared with standard diesel fuels. The fuels were used to run a diesel engine and the performance of the Diesel Engine was observed.

1.3 SIGNIFICANCE OF RESEARCH

The use of renewable fuels on a more significant scale than at present would reduce dependence on fossil fuels, thereby reducing the associated environmental impacts. Biodiesel, a renewable energy source, could supplement the energy needs of the economy, with relatively minimal impact on to the environment.

Recent survey has indicated that with the present rate of energy consumption, there is combined decline in quantity of crude petroleum which serves as source for diesel oil

production. Moreover, the rate of discovery of petroleum deposits is not proportional to the rate of consumption (George, 2005).

Through its environmental relations, the immediate and past impact effect of oil spillage and pollution has done much to destroy the live of the communities, vegetation and aquatic lives (George, 2005).

Also, Biodiesel improves lubricity and reduces premature wearing of diesel engine fuel pumps (Schumacher and Howell, 1994).

The above mentioned problems and other facts, necessitate further research or rather awakened new interest for vegetable oil improvement as alternative source. This potential energy source is renewable. It could reduce risk of unavailability of fossil diesel and could to a large extend reduce pollution effects resulting from their waste. Furthermore, there is no doubt that this will boost agriculture as more seeds will be required. A greater percentage of the populace live in the rural areas and as they cultivate these crops as raw materials for Biodiesel production, it will boost their economic power and poverty will be reduced thereby helping to achieve one of the MDGs.

1.4 AIM AND OBJECTIVES

The aim of this work is to establish the possibility of using *Hibiscus Surattensis* and *Hibiscus Sabdariffa* methyl esters as alternative fuels in diesel engine. The specific objectives are:

i. to investigate the physicochemical properties of vegetable oils from *Hibiscus*

Surattensis and *Hibiscus Sabdariffa* seeds.

ii. to convert the oils to biodiesel by the process of transesterification, and then compare their physicochemical properties with those of petroleum- based diesel.

iii. to test the performance of the biodiesel from these oils at various blend ratios with diesel using the Leyland Compression Ignition Engine.

iv. to establish the optimum blend of the biodiesel.

1.5 JUSTIFICATION

In the year 2000, there were about eight million vehicles around the world that ran on alternative fuels, indicating sustainability (Fight Global Warming, 2007).

The major environmental concern, according to an Intergovernmental Panel of Climate Change (IPCC) report, is that "most of the observed increase in globally averaged temperatures since the mid-20th century in due to the observed increase in anthropogenic greenhouse gas concentration" which is due to burning of fossil fuels (National Energy Information Center 2004).

Another concern is the peak oil theory, which predicts a rising cost of oil derived fuels caused by severe shortage of oil during an era of growing energy consumption. The demand for oil will exceed supply and this gap will continue to grow, which could cause a growing energy crisis starting between 2010 and 2020 (Hirsch, 2006).

Economic consideration- According to survey carried out in the US, biodieselers (people who brew biodiesel domestically) using waste oil feedstock make biodiesel for 50 cents

to US $1 per US gallon (http://journeytoforever.org). It still went further to report that most people in the US use about 600 gallon of fuel a year (about 10 gallon a week), costing about US$1,800 a year (mid-2007). Petro-diesel costs about three times more in the other industrialized countries (in UK in mid-2007 it cost the equivalent of US$7.37 for a US gallon of Petro-diesel) but those countries generally use less fuel than the US. This means that biodieselers will be paying $300-360 for their fuel (http://journeytoforever.org).

1.6 METHODOLOGY

This has to do with the methods used and the procedures adopted to extract each of the oils: the seeds collection, extraction of oils, their physicochemical properties, Transesterification, and experimentation based on the application of these samples in the diesel engine to test their performance characteristics.

1.7 SCOPE

The present work compares the performance of various biodiesels with fossil diesel using a Leyland four stroke Compression Ignition Engine (CIE) coupled to a hydro dynamometer. The goal of this work is also to determine the physicochemical properties of the vegetable oils and the biodiesel obtained from the oils which were then compared with that of standard petrol diesel. The performance will determine the suitability of these biodiesel fuels for use in a diesel engine.

CHAPTER TWO

LITERATURE REVIEW

2.0 HISTORICAL BACKGROUND OF BIODIESEL

"Biodiesel is a non-toxic, biodegradable diesel fuel made from vegetable oils, animal fats, and used or recycled oils and fats" and is used to run unmodified diesel engines – cars, buses, trucks, construction equipment, boats, generators and oil home heating units. Biodiesel is made using the process of transesterification (N. Stalin *et. al.*, 2004).

Transesterification is the process of using an alcohol (e.g. methanol or ethanol) in the presence of a catalyst, such as sodium hydroxide or potassium hydroxide, to chemically break the molecule of the raw renewable oil into methyl or ethyl esters of the renewable oil with glycerol as a by-product (Dincer,2008). Figure 2.1 presents a flow diagram for the production of biodiesel. It shows various processes involved in biodiesel production.

Biodiesel refers to the pure fuel before it is mixed with petro diesel. Biodiesel blends are denoted as "BXX" with "XX" representing the percentage of Biodiesel contained in the blend. For example, B20 is a blend of 20 percent by volume of Biodiesel and 80 percent by volume of petro diesel (Greenleaf Biofuels, 2008).

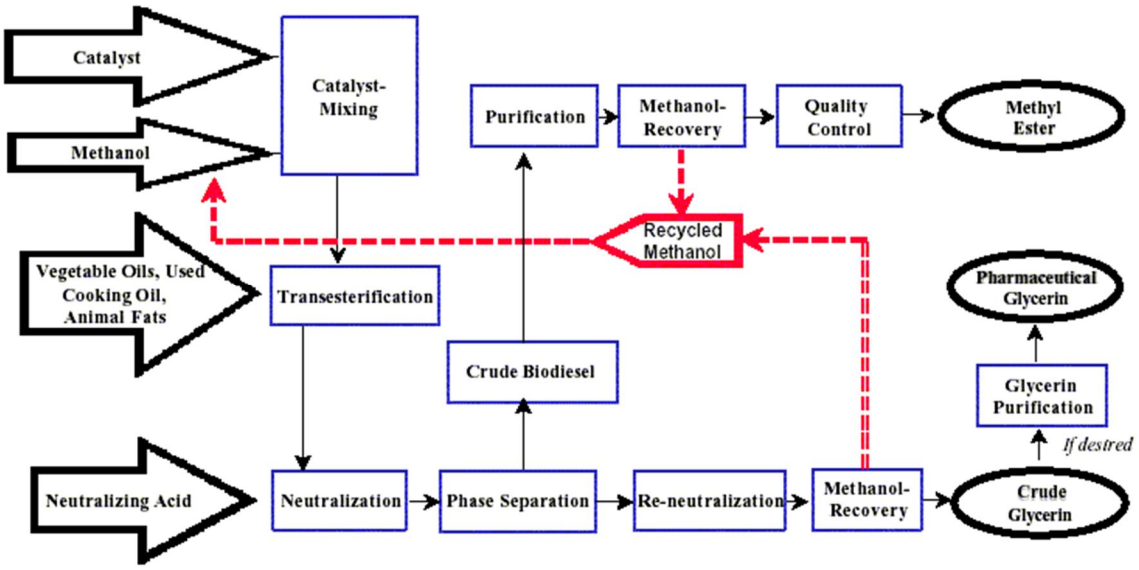


Figure 2.1: Flow Diagram for Biodiesel Production (Source: esru.strath.ac.uk).

The main purpose of fuel is to store energy in a form that is stable and can be easily transported from the place of production to the end user which helps in many ways such as transportation. Almost all fuels are chemical fuels that store chemical potential energy. The end user is then able to consume the fuel at will, and release energy, usually in the form of heat for a variety of applications, such as powering an engine or heating a building, such as a home.

The invention and widespread of internal combustion engines at the beginning of the 20th century caused a radical revolution in petroleum refining, Ever since then immense progress has been made to make diesel fuel better known and produced throughout the world, particularly the western world where the technology of petroleum refining has

enjoyed immense improvement through the use of modern science research and engineering applications. (Ajiwe et al., 2003)

Diesel engines are widely used as power sources for medium and heavy-duty applications because of their lower fuel consumption and they develop greater power compared with gasoline engines. For many years, the ready availability of inexpensive middle distillate petroleum fuel provided little incentive for experimenting with alternative, renewable fuels for diesel engine. However since the oil crisis of the 1970s, research interest has expanded in the area of alternative fuels. In recent years, the potential environmental benefits of alternative fuels have also attracted attention. Many researchers have concluded that vegetable oils hold promise as alternative fuels for diesel engine (Goerings et al.; 1982). Using raw vegetable oils in diesel engines can cause numerous engine-related problems. The increased velocity and volatility of vegetable engine oil lead to severe engine deposits, injector coking, and piston ring sticking (Perkins et al. 1991; Pestes and Stanislao 1984). However, these effects can be reduced or eliminated through transesterification of the vegetable oil to form a monoester, generally known "Biodiesel" (Perkins et al., 1991; Zhang et al., 1988). This process decreases the viscosity, maintains the heating value, and may actually increase the cetane number. It has been found that biodiesel can provide a substantial reduction in Hydrocarbon (HC), Carbon(II)oxide (CO) and particulate emissions, although often at the cost of an increase in Nitrogen (II)oxide (NO) emissions. (Larfogia et al., 1994; Cardone et al.; 1998; EPA, 2001).

Transesterification of a vegetable oil was conducted as early as 1853 by scientists E Duffy and J. Patrick, many years before the first diesel engine became functional. Rudolf Diesel's prime model, a single 10 ft (3m) iron cylinder with a flywheel as its base, ran its own power for the first time in Augsburg "International Biodiesel Day". (Knothe, 2001).

Rudolf Diesel demonstrated a diesel engine running on peanut oil (at the request of the French government) built by the French Otto Company at the World Fair in Paris, France in 1900,where it received the *Grand Prix* (highest prize) (Knothe, 2000).

This engine stood as an example of Diesel's vision because it was powered by Peanut oil --a biofuel, though not biodiesel, since it was not transesterified. He believed that the utilization of biomass fuel was the real future of his engine. In a 1912 speech Diesel said, "The use of vegetable oils for engine fuels may seem insignificant today but such oils may become, in the course of time, as important as petroleum and the coal-tar products of the present time" (Knothe, 2001).

On August 31st, 1937, Chavannes of the University of Brussels (Belgium) was granted a patent for a "Procedure for the Transformation of Vegetable Oils for their uses as Fuel" (fr. Procédé de Transformation d'Huiles Végétables en Vue de Leur utilization comme Carburants') Belgian patent 422,877 (Knothe, 2001). This patent described the alcoholysis (often referred to as transesterification) of vegetable oils using methanol and ethanol in order to separate fatty acids from the glycerol by replacing the glycerol by short linear alcohols. This appears to be the first account of the production of what is known as "biodiesel" today (Knothe, 2001).

Volkenrode (since late 1970s) in the German Federal Agricultural Research Centre (FAL) in Braunschweig, has been investigating the use of vegetable oils as fuel (George, 2005). Since 1982, an agricultural tractor powered by an unmodified four-stroke diesel engine has been running in practice exclusively on biodiesel at the FAL's experimental station without the occurrence of any technical problem due to this fuel (George, 2005).

Research into the use of transesterified sunflower oil, and refining it to diesel fuel standards, was initiated in South Africa in 1979 (SAE, 1983). By 1983, the process for producing fuel-quality, engine-tested biodiesel was completed and published internationally. An Australian company, Gaskoks, obtained the technology from the South African Agricultural Engineers; the company erected the first biodiesel pilot plant in November 1987 and the industrial-scale plant in April 1989 (with a capacity of 30,000 tons of rapeseed per annum) (SAE, 1983).

Some operational problems were reported due to the high viscosity of vegetable oils compared to petroleum diesel fuel, which result in poor atomization of the fuel in the fuel spray and often leads to the deposit and coking of the injectors, combustion chambers and valves. Attempt to overcome these problem included heating of the vegetable oil, blending it with petroleum-derived diesel fuel or ethanol, pyrolysis and cracking of the oils (Hofman, 2003).

Biodiesel has been defined as the monoalkyl esters of long-chain fatty acids derived from renewable feed stocks, such as vegetable oils or animal fats for use in compression ignition (diesel) engines. Biodiesel has become more attractive because of its

environmental benefits and the fact that it is made from renewable resources. It is the first and only alternative fuel to petroleum diesel to have a complete evaluation of emission results (Ma and Hanna, 1999; Bala, 2005).

2.1 REVIEW OF PAST WORK IN THE AREA

Carraretto et al., (2004) in their work showed that biodiesel produced from different vegetable oils, seems very interesting for several reasons: (i) it can replace diesel oil in boilers and internal combustion engines without major adjustments, (ii) only a small decrease in performances is reported, (iii) there is almost zero emission of sulphates, (iv) there is a small net contribution of CO_2 when the whole life cycle is considered, and (v) emission of pollutants is comparable with that of diesel oil. For these reasons, several campaigns have been planned in several countries to introduce and promote the use of biodiesel (Carraretto et al., 2004).

George, (2005) carried out an investigation on the physicochemical properties of some locally sourced vegetable seed oils namely Neem seed oil, mahogany seed oil, and locust beans oil. The oils were transesterified into methyl esters. Their physicochemical properties were compared with that of fossil diesel and then used to run the Leyland Compression Ignition Engine. Of the various blend proportions tested, the 40:60 blend of Neem oil and diesel fuel gave higher maximum torque and power than 100% diesel and the other oil samples, followed by 50:50 blend of sesame oil to diesel fuel. The most economical blend proportion in terms of fuel consumption and specific fuel consumption

was 50:50 Neemseed to Diesel, which gave 2.09litre/hr and 0.11 litre/kW hr which is slightly higher than the 1.3 litre/hr and. 0.09litre/kW hr obtained for diesel fuel. Experiment showed that Neem seed oil gave better performance than other sample oils when compared to the reference fuel (diesel).

More recently, the result of research carried out by Yawas and George, (2006) on methyl ester of vegetable seed oils namely Neem seed oil, Sesame seed oil Mahogany seed oil, and Locust beans oil was published. Experiment showed that Neem seed oil gave better performance than other sample oils when compared to the reference fuel (diesel).

Stalin et al. (2007) carried out a review of the alternative technological methods that could be used to produce Biodiesel. It was produced from *karanja* oil using alkali catalyzed transesterification process. Performance of IC engine using *karanj*a biodiesel blending with diesel and with various blending ratios was evaluated. The engine performance was studied with a prony brake-diesel engine set up. Parameters like speed of engine, fuel consumption and torque were measured at different loads for pure diesel and various combinations of dual fuel. Brake power, brake specific fuel consumption and brake thermal efficiency were calculated. The test results indicate that the dual fuel combination of B40 can be used in the diesel engines without making any engine modifications. Also the cost of dual fuel (B40) can be considerably reduced than pure diesel.

Emechebe (2008) carried out performance evaluation of Soy bean oil methyl ester as an alternative fuel for diesel engines. The quality of the methyl ester was verified by

carrying out viscosity, flash point and calorific value tests and comparing with the ASTM standard for biodiesel. The methyl ester was mixed at blends of B10, B20, B30,B40, B50 and B100.The physicochemical properties of the various blends were investigated and compared with that of conventional diesel fuel and then used to run a compression ignition engine (Leyland ignition compression engine) with hydraulic dynamometer. The brake horse power, fuel consumption, specific fuel consumption, exhaust gas temperature and oil pressure were determined for the various blends. A constant load of 20N was used throughout the entire experiment at engine speeds of 600, 1000, 1400 and 1800 rpm. From the performance results, the most suitable blends were the B10, B20 and B30 blends the best of which would be limited by production cost.

Atobatele (2009) carried out performance evaluation of Pear oil methyl ester as an alternative fuel for diesel engines. Ester conversion rates and fuel properties such as viscosity, relative density, Saponification value, acid value, ash content, flash point, calorific value and total and free glycerol were determined. The methyl ester was mixed at blends of B10, B20, B30, B40, B50 and B100 and analysed comparatively with conventional diesel fuel when burnt in a compression ignition engine. Based on this evaluation of engine performance, the studied vegetable oil (pear oil) gave best blend of 40:60 in terms of practicality and some fuel properties.

2.2 WAYS OF RUNNING DIESEL ENGINE WITH BIOFUEL

There are at least three ways to run a diesel engine on biofuel: using vegetable oils,

animal fats or both. All three are used with both fresh and used oils:

- Using the oil just as it is –usually called SVO fuel (straight vegetable oil) or PPO fuel (pure plant oil);

- Mix it with kerosene (paraffin) or petroleum diesel fuel, or with biodiesel, or blend it with a solvent, or with gasoline;

- Convert it to biodiesel.

The first two methods sound easiest, but, as so often in life, it's not quite that simple.

2.2.1 Mixing It

Vegetable oil is much more viscous (thicker) than either petro-diesel or biodiesel. The purpose of mixing it or blending it with other fuels is to lower the viscosity to make it thinner so that it flows more freely through the fuel system into the combustion chamber. Mixing vegetable oil with petroleum diesel or kerosene is still using fossil-fuel – cleaner than most, but still not clean enough, many would say. Still, for every gallon of vegetable oil used, that's one gallon of fossil fuel saved, and that much less climate-changing carbon dioxide in the atmosphere.

Various mixes, range from 10% Straight Vegetable Oil and 90% petro-diesel to 90% Straight Vegetable Oil and 10% petro-diesel. To do it properly is required what amounts to a proper SVO system with fuel pre-heating, anyway preferably using pure petro-diesel or biodiesel for starts and stops. In which case there's no need for mixes.

Blends of SVO with various solvents, and or with unleaded gasoline are "experimental at best" -- little or nothing is known about their effects on the combustion characteristics of the fuel or their long-term effects on the engine.

Higher viscosity is not the only problem with using vegetable oil as fuel. Vegetable oil has different chemical properties and combustion characteristics from the petro-diesel fuel that diesel engines and their fuel systems are designed to use. Diesel engines, especially the more modern, cleaner-burning diesels, are high-tech machines with precise fuel requirements). They're tough but they'll only take so much abuse.

There's no guarantee of it, but using a blend of up to 20% vegetable oil of good quality with 80% petro-diesel is said to be safe enough for older diesels, especially in summer. Otherwise using vegetable oil as fuel requires a professional SVO solution -- or conversion to biodiesel. This is not a likely problem in Nigeria being located in the tropics.

Mixes and blends are generally a poor compromise. But mixes can have one advantage in cold weather. As with biodiesel, some kerosene or winterised petro-diesel mixed with straight vegetable oil lowers the temperature at which it starts to gel. (ELSBETT, 2007; www.journeytoforever.org/biodiesel.html).

2.2.2. Straight Vegetable Oil

Straight vegetable oil fuel (SVO) systems can be a clean, effective and economical option. Unlike biodiesel, with SVO the engine has to be modified. The best way is to fit a professional single-tank SVO system with replacement injectors and glow plugs optimised for vegetable oil, as well as fuel heating. With the German Elsbett single-tank SVO system for instance, petro-diesel, biodiesel or SVO can be used, in any combination. Just start up and go, stop and switch off, like any other car.

There are also two-tank SVO systems which pre-heat the oil to make it thinner. Start the engine on ordinary petro-diesel (or biodiesel) in one tank and then switch to SVO in the other tank when the vegetable oil is hot enough, and switch back again to the petro-diesel tank before stopping the engine, or it will coke up the injectors (ELSBETT, 2007; www.journeytoforever.org/biodiesel.html).

2.2.3. Biodiesel or SVO?

Biodiesel has some clear advantages over SVO: it works in any diesel, without conversion or modifications to the engine or the fuel system. It also has better cold-weather properties than SVO (but not as good as petro-diesel). Unlike SVO, it's backed by many long-term tests in many countries, including millions of miles on the road. Biodiesel is a clean, safe, ready-to-use, alternative fuel, whereas it's fair to say that many SVO systems are still experimental and need further development.

The production of alternative fuels can have widespread effects. For example, the production of corn-based ethanol has created an increased demand for the feed stock, causing rising prices in almost everything made from corn. However, in a competitive free market, an increased supply of ethanol reduces the demand for conventional fuels, and thus lowers fuel prices. The ethanol industry enables agricultural surpluses to be used to mitigate fuel shortages (www.journeytoforever.org/biodiesel.html).

2.3 DEFINITION AND THEORY OF COMBUSTION ENGINE

2.3.1 Engines: - They are devices for converting heat energy into mechanical work. They are power-generating devices and are usually prime movers. Examples are hydropower plants; most of the engines are heat engines. A heat engine is one which operates in a cycle in which only heat works across its boundaries. Examples are steam power plant, automobile engines etc. They are also referred to as combustion engines and are of two types, viz:

(i) The Internal Combustion Engine (ICE)

(ii) The External Combustion Engine

2.3.1.1 The Internal Combustion Engine

The combustion of air and fuel produces the power directly. The combustion takes place inside the engine either at constant volume or at constant pressure or both. Examples are petrol, oil and gas engines, where the working agent is mainly air.

2.3.1.2 External Combustion Engine

Here, the energy is released from the fuel in a separated furnace by combustion, and is transferred to the working agent across a separating wall. Examples are steam engine and steam turbines, where the working agent is steam.

2.3.2 Compression Ignition Engine: - The compression ignition engine is an engine in which ignition of the liquid oil fuel injected into the cylinder is ignited by the heat of compression of the air charge. The oil fuel is introduced into the heated compressed air

charge by means of a fuel pump, which injects measured quantities of fuel to the cylinder in finely divided spray or mist to match the engine speed and loads.

There are two basic types of compression ignition engines namely: four stroke cycle and two stroke cycle engines.

(a) Four Stroke Cycle

Such an engine and its cycle of operation are shown diagrammatically in fig. 2. 1 .

Intake Stroke: During the intake or suction stage, air is induced into the cylinder as the piston moves from TDC to BDC. Due to the movement of the piston the pressure in the cylinder drops in value below atmospheric pressure and air flows through the induction system because of this pressure difference. The inlet valve closes when the piston has moved part way along the return stroke.

Compression Stroke: With both valves closed, the piston compresses the charge and, the fuel, as a finely atomized liquid, is injected shortly before the piston reaches TDC. The temperature of the compressed air is higher than the ignition temperature of the fuel, and the latter begins to burn without any outside means of igniting it.

Power Stroke: The hot, high-pressure gas expands pushing the piston down the cylinder. Slightly before BDC the exhaust valve begins to open, releasing the burnt gases to the atmosphere.

Exhaust Stroke: During this stroke the piston moves back towards the cylinder head and pushes the burned gases out through the exhaust valve (Eastop et al., 1995).

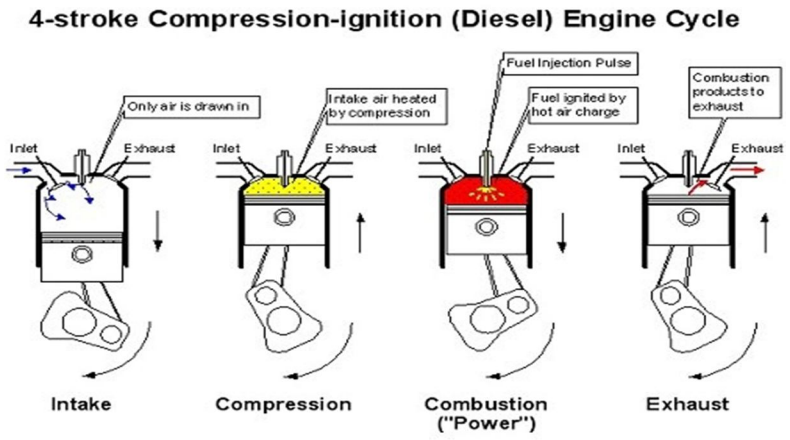


Fig. 2.2: Four – Stroke Cycle

(b) Two – Stroke Cycle

Two – stroke cycle diesel engines are very similar to four stoke cycle engines, except that they do not have separate intake and exhaust stokes, i.e., power stroke is completed in every revolution not in two revolutions as in four – stroke cycle engine. Instead, exhaust occurs at the end of the expansion, or power stoke and continues into the early part of the compression stoke. Intake occurs during the end of the expansion stroke and the early part of the compression stoke. To assist the intake process, the intake air is almost always boosted above atmospheric pressure, using supercharging or turbo charging. Air flow into the cylinder and exhaust gas flow out of the cylinder are controlled by conventional tappet valves in the cylinder head, ports in the cylinder wall, or the combination of both.

2.4 PERFORMANCE CRITERIA FOR INTERNAL COMBUSTION ENGINE

In selecting an engine for a particular application, two main factors are taken into consideration, which are power and speed characteristics. Also, in other that different engines of the same type may be compared, certain performance criteria must be defined (George, 2005).

2.4.1 Indicated Power (i.p)

Indicated power (i.p) is the power actually developed at the piston face as evaluated from an indicator diagram obtained from the engine. Fig. 2.3 below shows both the power and the pumping loops.

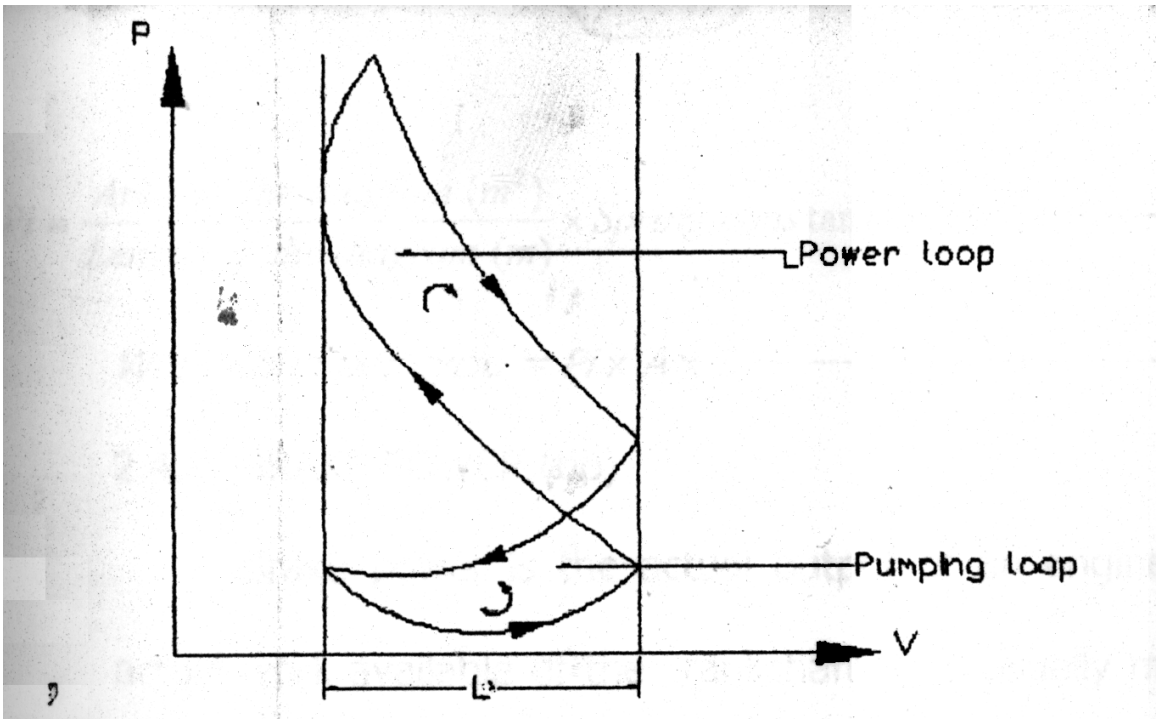


Fig. 2.3 Pressure Diagram for a Reciprocating Engine

The formula for i.p for four – stroke engine is given by (Eastop et al., 1995):

$$i.p = \frac{P_i A_c L \omega n}{2} \text{---------- (2.1)}$$

For two – stroke engine

$i.p = P_i A_c L \omega n$

Where, P_i – indicated mean effective pressure (N/m^2)

A_c – Cross – sectional area of the cylinder (m^2)

ω – The engine speed (rev/sec)

n – number of cylinders

2.4.2 Indicated Mean Effective Pressure (P_i)

Indicated Mean Effective Pressure P_i is the algebraic sum of the mean pressure acting on the piston during each stroke over one cycle. It is measured from the indictor diagram. The formula indicated mean effective pressure is given by (Eastop et al., 1995):

$$P_i = \frac{\text{Area of the diagram } (m^2)}{\text{Length of the diagram (m)}} \times \text{Spring Constant } (N / m^2) \text{ ---------- (2.2)}$$

Work done per cycle = $P_i \times A_c \times L$ ---------- (2.3)

2.4.3 Brake Power (b.p)

Brake power (b.p) is the actual of an engine or the actual work available at the crankshaft. It is usually measured using a dynamometer. The formula for brake power is given by (Eastop et al., 1995):

b.p = T x2πω ---------- (2.4)

Where T – torque = Fd---------- (2.5)

F = brake load, d = torque arm.

ω = engine speed

2.4.4 Brake Mean Effective Pressure (bmep)

The Brake Mean Effective Pressure (bmep) is the mean effective pressure which would have developed power equivalent to the brake power had it acted on the piston only (i.e. if the engine was frictionless).

For two – stroke engine, the bmep is given by (Eastop et al., 1995):

$$\text{Bmep} = \frac{bp}{L\text{Ac}\omega n} \quad \text{---------- (2.6)}$$

For four – stroke engine, the bmep is given by (Eastop et al., 1995):

$$\text{Bmep} = \frac{2bp}{L\text{Ac}\omega n} \quad \text{---------- (2.7)}$$

2.4.5 Friction Power (fp)

The Frictional Power (fp) is the difference between the indicated power and the brake power and is that power required to overcome the frictional resistance of engine part. It is given by (Eastop et al., 1995):

fp = ip – bp ---------- (2.8)

2.4.6 Mechanical Efficiency (η_m)

Mechanical Efficiency (η_m) is defined as the ratio of the brake power to the indicated power. It is given by (Eastop et al., 1995):

$$\eta_m = \text{bp / ip} \quad \text{---------- (2.9)}$$

The mechanical efficiency depends on bp and ip and therefore it is found by evaluating these experimentally.

2.4.7 Brake Thermal Efficiency (η_{BT}) and Indicated Thermal Efficiency (η_{IT})

Brake Thermal Efficiency (η_{BT}) is the power output of the engine obtained from the chemical energy of the fuel supplied. It is given by (Eastop et al., 1995):

$$= \frac{\text{Brake Power}}{\text{Energy Supplied}} = \frac{bp}{M_f \times Q_{net.v}} \quad \text{---------- (2.10)}$$

Where,

M_f = mass of fuel consumed per unit time

$Q_{net.\,v}$ = net calorific value of the fuel.

Indicated thermal efficiency (η_{IT}) is defined in a similar way to the brake thermal efficiency. It is given by (Eastop et al., 1995):

$$\eta_{IT} = \frac{i.p}{M_f \times Q_{net.\,v}} \quad \text{---------- (2.11)}$$

2.4.8 Specific Fuel Consumption (SFC) and Volumetric Efficiency.

Specific fuel consumption (SFC) is the mass flow rate of fuel consumed per unit power output. It is given by (Eastop et al., 1995):

$$SFC = M_f / b.p \times 3600 \quad \text{---------- (2.12)}$$

Volumetric efficiency, η_v, is the ratio of the volume of air induced, measured at the free air condition to the swept volume of the cylinder. It is given by (Eastop et al., 1995):

$$\eta_v = V/V_s \text{ ---------- (2.13)}$$

The power output of Internal Combustion Engine depends directly on the amount of charge, which can be induced into the cylinder and is also referred to as the breathing capacity of the engine.

2.5 TRANSESTERIFICATION

2.5.1 General Aspects of Transesterification

Transesterification is the general term used to describe the important class of organic reactions where an ester is transformed into another through interchange of the alkoxy moiety. When the original ester is reacted with an alcohol, the transesterification process is called alcoholysis and is given by Schuchard et al. in equation 2.14. In this review, the term transesterification will be used as synonymous for alcoholysis of carboxylic esters, in agreement with most publications in this field. The transesterification is an equilibrium reaction and the transformation occurs essentially by mixing the reactants. However, the presence of a catalyst (typically a strong acid or base) accelerates considerably the adjustment of the equilibrium.

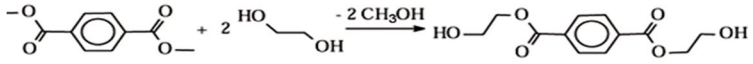
$$\text{RCOOR'} + \text{R"OH} \overset{\text{Catalyst}}{\rightleftharpoons} \text{RCOOR"} + \text{R'OH} \text{ ---------- (2.14)}$$

General equation for a transesterification reaction.

In order to achieve a high yield of the ester, the alcohol has to be used in excess. The applicability of transesterification is not restricted to laboratory scale. Several

relevant industrial processes use this reaction to produce different types of compounds (Schuchard et al.2000; Biodiesel Production Technology Overview).

An example is the production of PET (polyethylene terephthalate), which involves a step where dimethylterephthalate is transesterified with ethylene glycol in the presence of zinc acetate as catalyst is given by (Schuchard et al.,2000) in equation 2.15.

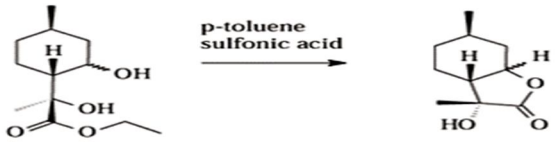


---------- (2.15)

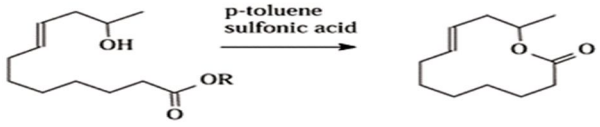
Transesterification of dimethylterephthalate with ethylene glycol.

Further, a large number of acrylic acid derivative is produced by transesterification of methyl acrylate with different alcohols, in the presence of acid catalysts.

If the alcohol and the ester groups are present in the same molecule simple lactones or macrocycles are formed by an intramolecular transesterification is given by (Schuchard et al., 2000) as follows:



---------- (2.16a)

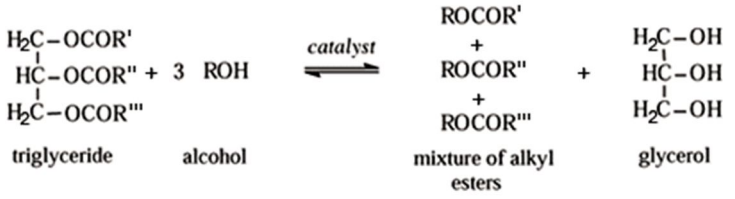


---------- (2.16b)

Examples of intramolecular transesterification reactions forming lactones or Macrocycles

2.5.2 Transesterification of Vegetable Oils

In the transesterification of vegetable oils, a triglyceride reacts with an alcohol in the presence of a strong acid or base, producing a mixture of fatty acids alkyl esters and glycerol as given by (Schuchard et al., 2000) in equation 2.17.



---------- (2.17)

Transesterification of vegetable oils

The overall process is a sequence of three consecutive and reversible reactions, in which di- and monoglyceride are formed as intermediates. The stoichiometric reaction requires 1mol of triglyceride and 3mol of the alcohol. However, an excess of the alcohol is used to increase the yields of the alkyl esters and to allow its phase separation from the glycerol formed. Several aspects, including the types of catalyst (alkaline or acid), alcohol/ vegetable oil molar ratio, temperature, purity of the reactants (mainly water content) and free fatty acid content have an influence on the course of the Transesterification and will be discussed below, based on the type of catalyst used (Schuchard et al.,2000).

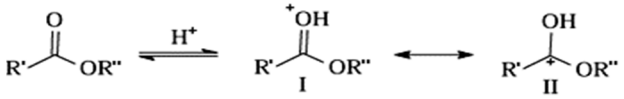
2.5.2.1 Acid – Catalyzed Processes

The transesterification process is catalyzed by *Brønsted* acids (a compound that donates hydrogen ion, H^+, to another compound –Petrucci et al., 2002; Miessler et al., 1998), preferably by sulfonic and sulfuric acids. These catalysts give very high yields in alkyl

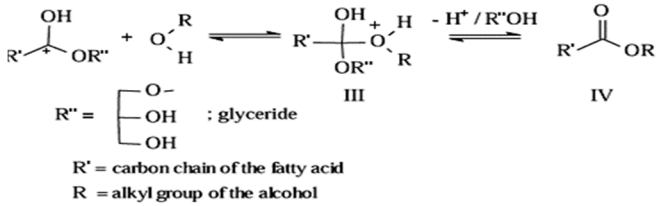
esters, but the reactions are slow, requiring, typically, temperatures above 100 ^{o}C and more than 3hrs to reach complete conversion (Freedman, Pryde and Mounts, 1984).

Pryde *et al*. (1984) showed that the methanolysis of soybean oil, in the presence of 1 mol% of H_2SO_4, with an alcohol/oil molar ratio of 30:1 at 65 ^{o}C, takes 50hrs to reach complete conversion of the vegetable oil (> 99%), while the butanolysis (at 117 ^{o}C) and ethanolysis (at 78 ^{o}C), using the same quantities of catalyst and alcohol, take 3 and 18hrs, respectively. The alcohol/vegetable oil molar ratio is one of the main factors that influence the transesterification. An excess of the alcohol favours the formation of the products. On the other hand, an excessive amount of alcohol makes the recovery of the glycerol difficult, so that the ideal alcohol/oil ratio has to be established empirically, considering each individual process.

The mechanism of the acid-catalyzed Transesterification of vegetable oils is given by (Schuchard et al., 2000) as follows for a monoglyceride:



---------- (2.18a)



---------- (2.18b)

Mechanism of the acid-catalyzed transesterification of vegetable oils.

However, it can be extended to di- and triglycerides. The protenation of the carbonyl group of the ester leads to the carbocation II which, after a nucleophilic attack of the alcohol, produces the tetrahedral intermediate III, which eliminates glycerol to form the new ester IV, and to regenerate the catalyst H+. According to this mechanism, carboxylic acids can be formed by reaction of the water, in order to avoid the competitive formation of carboxylic acids which reduce the yields of alkyl esters (Schuchard et al., 2000).

2.5.2.2 Base –Catalyzed Processes

The base – catalyzed transesterification of vegetable oils proceeds faster than the acid-catalyzed reaction. Due to this reason, together with the fact that the alkaline catalysts are less corrosive than acidic compounds, industrial processes usually favour base catalysts, such as alkaline metal alkoxides and hydroxides as well as sodium or potassium carbonates.

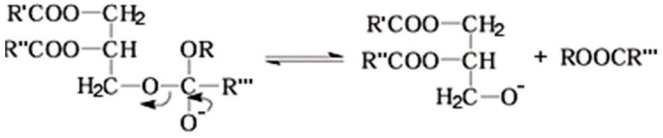
The mechanism of the base-catalyzed Transesterification of vegetable oils is given by (Schuchard et al., 2000) as follows:



---------- (2.19)



---------- (2.19b)



---------- (2.19c)

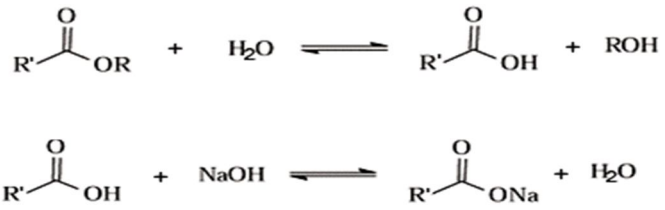


---------- (2.19d)

The first step (Equation 2.19a) is the reaction of the base with the alcohol, producing an alkoxide and the protonated catalyst. The nucleophilic attack of the alkozide at the carbonyl group of the triglyceride generates a tetrahedral intermediate (Equation 2.19b), from which the alkyl ester and the corresponding anion of the diglyceride are formed (Equation 2.19c). The latter deprotonates the catalyst, thus regenerating the active species (Equation 2.19d), which is now able to react with a second molecule of the alcohol, starting another catalytic cycle (Schuchard et al., 2000).

Diglycerides and monoglycerides are converted by the same mechanism to a mixture of alkyl esters and glycerol. Alkaline metal alkoxide (as CH_3ONa for the methanolysis) are the most active catalyst, since they give very high yields (>98%) in short reaction times (30 min) even if they are applied at low molar concentrations (0.5 mol %). However, they require the absence of water which makes them inappropriate for typical industrial processes (Schuchard et al., 2000).

Alkaline metal hydroxides (KOH and NaOH) are cheaper than metal alkozides, but less active. Nevertheless, they are a good alternative since they can give the same high conversions of vegetable oils just by increasing the catalyst concentration to 1 or 2 mol%. However, even if a water-free alcohol/oil mixture is used, some water is produced in the system by the reaction of the hydroxide with the alcohol. The presence of water gives rise to hydrolysis of some of the produced ester, with consequent soap formation given by (Schuchard et al., 2000) as follows:



---------- (2.20a)

R' = carbon chain of the fatty acid
R = alkyl group of the alcohol

---------- (2.20b)

This undesirable Saponification reaction reduces the ester yield and makes recovery of the glycerol considerably difficult due to the formation of emulsions (Freedman, et al., 1984).

Potassium carbonate, used in a concentration of 2 or 3 mo1% gives high yields of fatty acid alkyl esters and reduces the soap formation. This can be explained by the formation of bicarbonate instead of water which does not hydrolyse the esters as shown in equation 2.21(Schuchard et al., 2000).



R = alkyl group of the alcohol

---------- (2.21)

There are also other methods of base-catalyst transesterification of vegetable oils such as Heterogeneously Catalyzed Processes, Lipase-Catalyzed Processes, Lipase-Catalyzed Processes and, Non-ionic Base-Catalyzed Processes.

In this work the base-catalyzed transesterification of vegetable oils process was used due to the reasons stated above (Schuchard et al., 2000).

2.6 BRIEF DESCRIPTION OF THE SEED PLANTS

Two indigenous seeds, *Hibiscus Surattensis* and *Hibiscus Sabdiraffa*, were used to carry out the research work.

2.6.1 ***Hibiscus Sabdariffa L.*:** This plant is not indigenous to Nigeria. It has two botanical varieties recognized: var. *Sabdariffa*, a bushy branched sub shrub with red or green stems and red or pale yellow inflated edible calyces; var. *altissima* Wester, a tall, vigorous, practically unbranched plant, 10-16ft high (Purseglove, 1972). With fibrous, spiny, inedible calyces, grown for fibre. It is called *yakuwa* in Hausa. *H. Sabdariffa* is probably a native of West Africa and is now widely cultivated throughout the tropics (Purseglove, 1972). It has been in Asia for at least three centuries and was taken early to the New World by the slave trade, reaching Brazil in the 17th century. It was recorded in Jamaica in 1707 (Purseglove, 1972).

The red acid succulent calyces of var. *Sabdariffa* are boiled with sugar to produce sorrel drink (popularly known as zobo drinks). They are also made into jellies, sauces, chutneys and preservatives. The tender leaves and stalks are eaten as salad and as a pot-herb and are used for seasoning curry. The seeds contain oil. Var *altissima* is grown for fibre in India, Java and the Philippines. They are often found in farmlands and around village homes in Nigeria. (Purseglove, 1972).



(i) ***Hibiscus Sabdariffa L*** **plant**



(ii) **Dried (*Hibiscus Sabdariffa*) roselle calyces**

PLATE I: Hibiscus Sabdariffa L. Plant (Photo by Biriok, 2008)

2.6.2 *Hibiscus Surattensis*: *Hibiscus Surattensis* occurs in tropical Africa and tropical Asia. It is found in most countries of tropical Africa, including the Indian Ocean islands, and also in South Africa and Swaziland. It has been introduced in tropical America and is locally naturalized there (Purseglove, 1972).

It's a prostrate or climbing annual herb; stem prickly with recurved prickles, pubescent. The leaves alternate, and are simple; stipules are ovate, auriculate and amplexicaul, up to 1.5 cm x I cm. Fruit is an ovoid to globose capsule up to ovary superior, 1.5 cm long, densely pubescent, many – seeded. The seeds reniform, c.3 mm x 2 mm.

Hibiscus Surattensis occurs in grassland and at forest edges in lowland and at medium altitudes up to 1700 m, in regions with an average annual rainfall of 1000 – 1600 mm (Purseglove, 1972). It also occurs in marshes, abandoned fields and plantations, on waste ground near habitation, and in coastal habitats such as sand dunes. It is found on a wide variety of oil types. When cultivated, *Hibiscus Surattensis* is propagated by seed. The main management practice is weeding. However, this species is rarely cultivated and the

leaves are usually collected from the wild for use as a vegetable. Leaves of *Hibiscus Surattensis* are collected in the early flush of the rainy season. The leaves can be cooked immediately as a vegetable, or dried, pounded and kept for up to a year and used later in a similar way as fresh leaves. (Purseglove, 1972).



1. Leave 2. Plant 3. Pod
4. Seed

PLATE II: *Hibiscus Surattensis* (Purseglove, 1972).

2.7 DESCRIPTION OF OIL EXTRACTOR

Structure: The machine is composed of the grinding axis, front stand, pressing cage, gearbox and the framework as shown in Fig. 2.3. They function as follows: -

(i) Grinding Axis: This is where the screw shaft is situated. The front of the screw shaft is pushed into the driving gear axis bush of the gearbox. The running of the grinding shaft pushes the oil seeds into the pressing cage for pressing, so that the oil comes off from the pressing bar and the cakes from the cake outlet ring. The handle of the screw shaft is used for adjusting the thickness of the cake. Turning clockwise makes the cake to come out thick and vice versa. (See Fig. 2.4)

(ii) Front Stand: It consists of the nut stand and adjusting nut. These two parts connect with the gearbox, which upholds the machine's body and also the grinding shaft. The outside part of the adjusting nut is connected to the outside of the grinding shaft, and controlling this part controls the thickness of the cake.

(iii) Guiding Cage: It consists of the pressing cage, pressing bar, cake outlet ring etc. This is the main part of the machine where pressing takes place. The quality of installation of the pressing bar will directly affect the oil output rate.

And also the quality of installation of the parts of the pressing cage, front stand and gearbox will affect the usage of the main shaft. (See Fig. 2.5)

(iv) Gearbox: This consists of the gearbox, axis bush, big and small gears, driving axis, v-belt etc. The main function of this part is to uphold the front stand and to convey power to the machine. The power is generated from driving the small and big belt wheel driving axis, big and small gears and the axis bush, which is used in the operation of the of the grinding axis. And there is also a cake fork ahead of the axis bush which crushes the cake from the cake outlet ring.

(v) Framework: It consists of left and right motor stand and screw pole. This is to uphold and support the front stand, lower bracket and the installation of the motors.

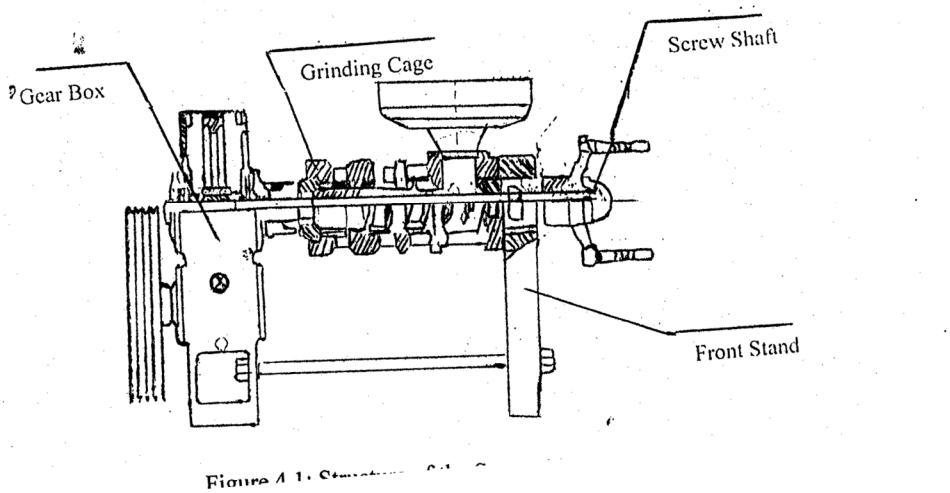


Figure 2.4: Structure of the Screw Oil Press Machine

(Courtesy: Ahmadu Mohammed Industrial Limited (AMIL) Kawo, Kaduna.)

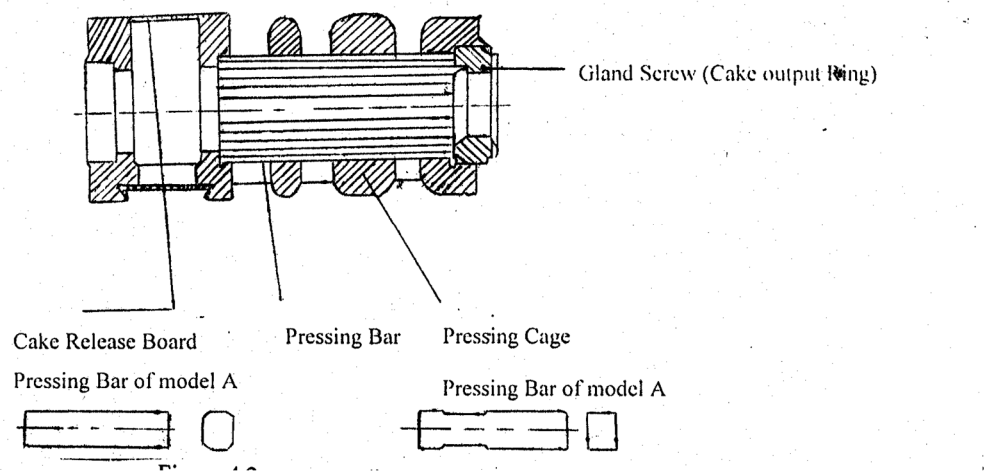


Figure 2.5: Structure of the Grinding Cage

(Courtesy: Ahmadu Mohammed Industrial Limited (AMIL) Kawo, Kaduna.)

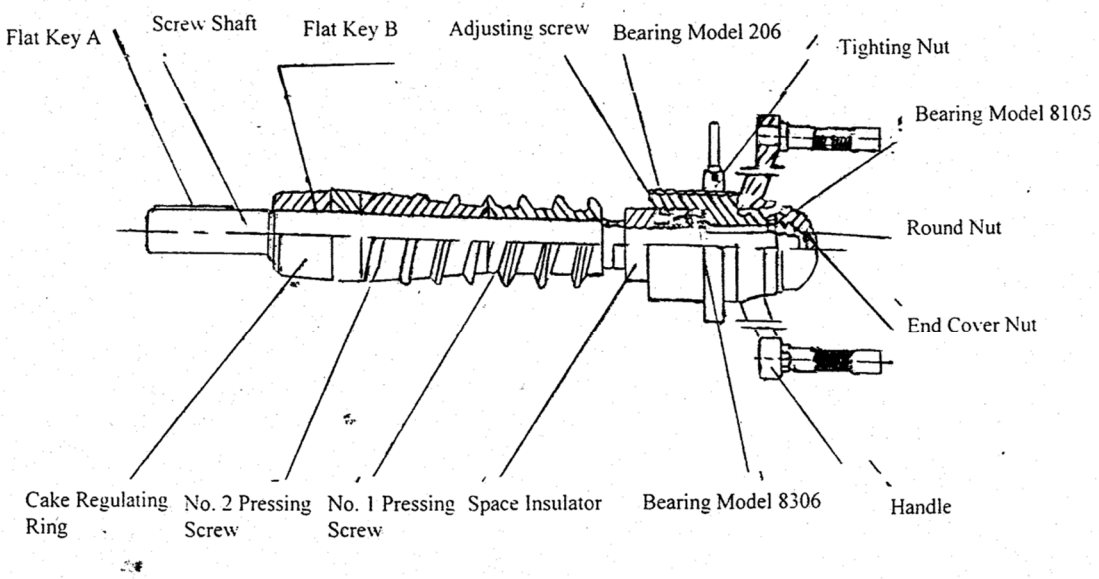


Figure 2.6: Structure Diagram of the Screw Shaft
(Courtesy: Ahmadu Mohammed Industrial Limited (AMIL) Kawo, Kaduna.)

2.8 TEST ENGINE

The engine used is a four stroke, four cylinders Leyland Compression Ignition engine type (compression ratio 21.5: 1). It was run using diesel and 30:70, 40:60 and 50:50 blends of diesel with *Hibiscus Surattensis* and *Hibiscus Sabdiraffa*. The engine has a bore of 84.16mm and a stroke of 101.6mm. The oil filter is externally fitted, full flow filter replaceable cartridge type. The valves are the over head type; push rod operation is by camshaft. The camshaft is driven by a duplex roller chain, which is automatically adjusted, to the correct tension by a hydraulic chain. The cooling system is a circulation of water assisted by impeller type pump, pressure relieve at 49kg/sq. cm. The engine was tested with hydraulic dynamometer in which resistance offered by the water to motion of the rotor reaction upon the casing, which tends to turn on the anti-friction roller supports. This tendency was counteracted by means of a lever arm terminating in a weighing device, which measures the torque. The Leyland Compression Ignition Engine used for the research is shown in Plate III.

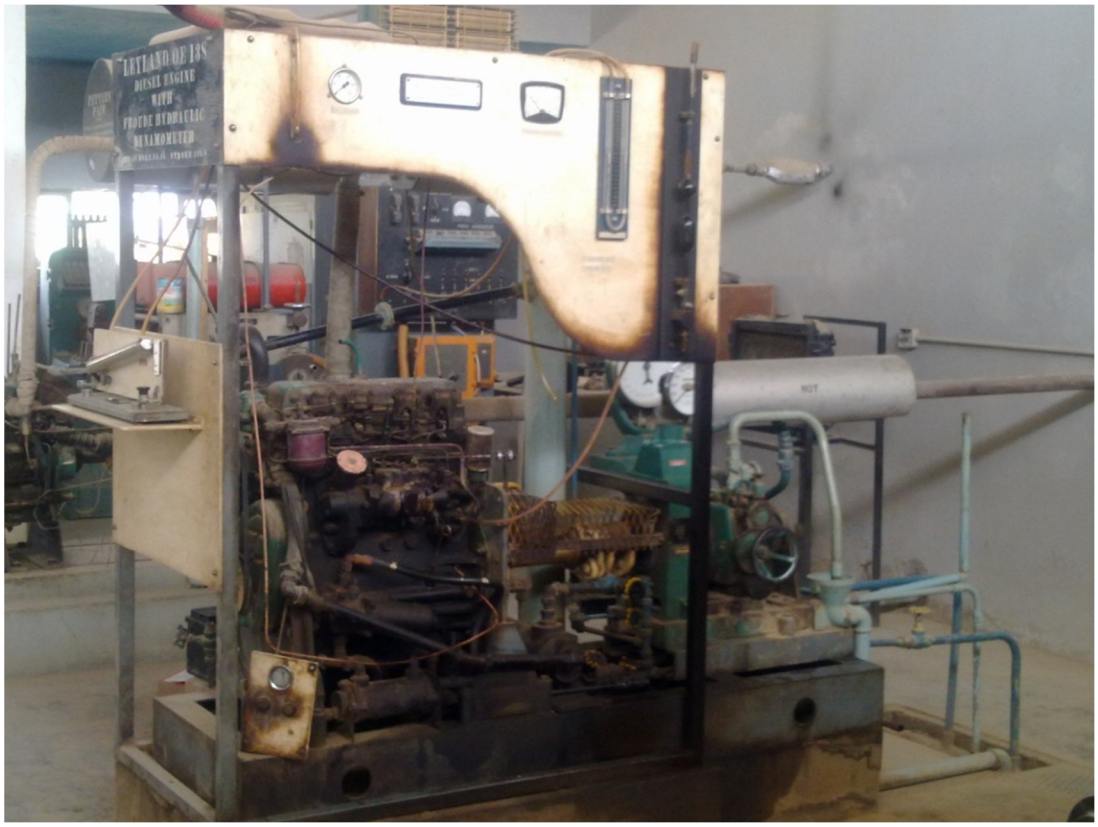


Plate III: Leyland Compression Ignition (Four Cylinders) Engine

CHAPTER THREE

MATERIALS AND METHODS

3.0 INTRODUCTION

A list of materials and methods used in the research is presented in this chapter.

3.1 EQUIPMENTS USED

The equipments used in this research are listed below:

3.1.1 Determination Of Physicochemical Properties:- The following equipments were used for:

3.1.1.1 Viscosity

A Redwood viscometer, stopwatch, Bunsen burner, thermometer, 50ml graduated viscosity flask and water.

3.1.1.2 Relative Density

Density bottle, analytical balance, thermometer.

3.1.1.3 Calorific Value

A Benthelot Mahler cook Bomb calorimeter, water, oxygen cylinders, stopwatch, Beckman thermometer, stirrer, electric motor, pipette, cotton thread, platinum ignition wire, magnifying eye piece, analytical balance and crucible.

3.1.1.4 Flash Point

A Pensky-Martens apparatus, thermometer, stirrer, Bunsen burner, injector burner.

3.1.1.5 Acid Value

Burette, pipette, conical flask, phenolphthalein indicator, potassium hydroxide, ethanol, clamp stand.

3.1.1.6 Saponification Value

Reflux flask, water bathe, burette, pipette, condenser, standard hydrochloric acid, ethanoic acid, potassium hydroxide and phenolphthalein indicator.

3.1.1.7 Ash Content

Silica crucible, oven, desicator, analytical balance, tongs.

3.1.1.8 Carbon Content

Crucible, desicator, analytical balance, tongs.

3.1.1.9 Iodine Value/Number

Glass-stopper bottle, glacial acetic acid, potassium iodide solution 10%, 0.1M sodium thiosulphate solution, Starch indicator, Carbon tetrachloride, Wij's solution.

3.1.1.10 Hydrogen Value

Erlenmeyer flask, Glass stopper, Acetic acid- chloroform solution 3:2, Saturated solution of potassium iodide, 0.1M sodium thiosulphate solution, Starch indicator (1%), Potassium iodide powder.

3.1.2 Oil Extractor

The machine used was a 6YL-78A Screw Oil Press. It has an external dimension of 1000 x 550 mm^2 and weighs about 210 kg; a prime mover is a 5.5kw, Y132-S electrical motor with rotational speed of 1400rpm. The power is transmitted to the machine via a Class A V-slotted pulley of four slots and diameter of 130mm on the motor and a Class A V-slotted pulley of four slots and diameter of 40mm on the machine respectively. It has a gearbox velocity ratio of 4.37 and grinding rotational speed of 100-120rpm. A typical Screw Oil Press is as shown in Appendix I.

3.1.3 Transesterification

Beakers, separating funnels, measuring cylinder, funnels, glass rods, evaporating dish, sodium hydroxide, sodium methanol, tetraoxosulphate (VI) acid and hydrochloric acid

3.2 SEED COLLECTION

The various seeds from which the vegetable oils were extracted were sourced for locally within the neighbourhood. These plants are available in large quantities in the neighbourhood. Some quantities were also purchased at the Kawo market in Kaduna North local government of Kaduna State.

3.3 METHOD OF EXTRACTION OF OIL

Before extraction of the oil commences, the machine was allowed to run for ten minutes for it to warm up. The seeds were then fed into the hopper, which was then pushed into the machine by screw No. 1 and No. 2 of the grinding screw shaft (refer to Fig. 2.5). As the No. 2 screw diameter became smaller the volume of the pressed seeds became smaller too. At the same time, the temperature in the cage increased so that under great pressure and temperature of the screw shaft and pressing of the cage on the seeds, the oil was drained off from the bar gap leaving cakes that come out through the cake outlet hole.

3.3.1 Oil Yield of Seeds

The Table 3.1 below shows the oil yield of the various oils used in this research.

Table 3.1: Oil Yield of Seeds used

Seed	Weight (kg)	Oil Quantity (ltr)	Oil Yield/kg
Hibiscus Sabdariffa	224.16	8.8	0.0393
Hibiscus Surattensis	115.65	4.5	0.0389

3.4 PHYSICO-CHEMICAL CHARACTERIZATION

The following properties of the samples were investigated and compared with those of petrodiesel:

3.4.1 Viscosity: This physical property is a measure of the resistance of fluid to streamline (i.e. non turbulent) flow. The viscosity of oil decreases rapidly with increase in temperature. The viscosity at the standard temperature of 37.8^0C is commonly accepted as a measure of the general viscosity of the fuel (George, 2005). The viscosity of a liquid hydrocarbon influences its suitability as a diesel engine fuel in several distinct ways:

i. High viscosity increases difficulties of transfer and delivery by gravity or pumping.

ii. High viscosity tends to reduce atomization and increase penetration of the fuel on injection and thereby causes incomplete combustion.

iii. Dirt and grit remain longer in suspension in viscous fuel, whereas they may have chance of settling through more fluid fuels.

iv. High viscosity is commonly associated with low ignition quality.

v. Very low viscosity fuels are deficient in lubricating properties which may give rise to wear in fuel pumps and injector parts, a tendency for fuel to leak in pumps and atomizers also accompany low viscosity.

3.4.2 Flash Point: This may be defined as the temperature at with oil give off sufficient inflammable vapours from its surface to ignite in the presence of a small flame. The flash points are measures of the risk of fire encountered when storing the oil and afford no indication of the behaviour of the oil in an engine.

3.4.3 Calorific Value: The (heating value) of a fuel is the amount of heat given by combustion. It is defined as the energy transferred as heat to the surroundings (cooling water) per unit quantity of fuel when burnt at constant volume and pressure with water product of combustion in the liquid or vapour state.

3.4.4 Relative Density: The relative density (specific gravity) of oil is defined as the ratio of the weight of any volume of it to the weight of an equal value of water. The property of gravity is as importance in the control of refinery operations or where large values of oil are being handled. It is also helpful in identifying unknown oils because the specific gravity of the oil gives a clue as to the type of crude from which it was made from.

3.4.5 Acid Value: It indicates the amount of free fatty adds present in oil or fat. The acid value of fat or oil is the number of milligrams of potassium hydroxide required to neutralize the free organic acids present in 1 gram of oil or fat.

3.4.6 Ash Content: This is a measure of the inorganic impurities present in the oil. It consist mainly of iron oxide, sand and sundry metallic salts, the composition of which varies with the origin of the oil, for example, some oils have an ash, which is soft and relatively harmless, but usually the ash is hard and gritty and consequently abrasive. A proportion, probably the greater part of the ash is ejected from the cylinder with exhaust gases, but some portion is held by the cylinder lubricating oil, causing wear of the liner and piston rings.

3.4.7 Carbon Content: Carbon content (coke value) is some measure of the carbon forming propensity of an oil and is the percentage residue remaining after the oil has been heated until all the volatile constituents have been burnt off.

3.4.8 Saponification Value: Saponification value is defined as the number of milligrams of potassium hydroxide, which are required for complete saponification of one gram of oil.

3.4.9 Iodine Value: is a measure of the total amount of unsaturated fatty acids in oil and is a measure of the number of grams of iodine which will combine with 100 grams of the oil.

3.4.10 Hydrogen Content: indicative of oxidation during early stages of oil or fat deterioration and is expressed as peroxide per gram.

Investigation of physicochemical properties of the oil samples was carried out in the Department of Food Science and Technology Research and development of the Ahmadu Bello University, Zaria in Kaduna State of Nigeria. The standard that was used for the test was that of the Association of Analytical Chemists (AOAC).

The procedures for investigating the physicochemical properties are outlined below:

A. Viscosity

The viscosities of the oils were determined using the following apparatus, materials and procedure.

Apparatus

A Redwood viscometer, stopwatch, Bunsen burner, thermometer, 50ml graduated viscosity flask and water.

Procedure

The sample oil was placed in the oil cylinder up to the point of the gauge and the temperature adjusted to that required by regulating the temperature of the surrounding bath. This was done by heating the water bathe using a Bunsen burner via the steel arm. The thermometer dipping into the oil cylinder was used as a stirrer. The oil was heated to the required temperature (35 ^{o}C), the plug was lifted and simultaneously a stopwatch was started. The time in seconds taken for 50ml to flow into a graduated receiving flask was noted. This was repeated for the oil at varying temperatures of 37.8^{o}C, 40^{o}C, 50 ^{o}C and 60^{o}C and time t, were tabulated as shown in Table 3.2. Results obtained were used to calculate viscosities for the oil at the temperatures given above (AOAC Standard). The procedure was repeated for the various blends of Biodiesel.

Table 3.2: Time taken to for 50ml of Sample Oil to Flow into a Graduated Receiving Flask

θ (^{o}C)	**t (sec)**
35	151.27
37.8	146
40	141.86
50	137
60	132.32

Sample Calculation

The standard equation using Redwood viscometer is given by (George, 2005):

$$\vartheta = At - \frac{B}{t} \text{ ---------- 3.1}$$

Where A & B are constants, 0.25 and 172 respectively.

t – time in seconds taken to fill 50ml flask.

□ – Viscosity in mm^2/s.

$$\vartheta = 0.25x151.27 - \frac{172}{151.27} = 36.68 mm^2/s$$

Calculated values for viscosities of sample oils and their Biodiesel blends were tabulated in Appendix II.

B. Relative Density

The relative densities of the oils were determined using the following:

Apparatus

Density bottle, analytical balance, thermometer

Procedure

The density bottle was weighed empty before pouring in the cooled sample (to about 15^oC) for both water and oil. When the bottle was filled, the ground glass stopper was inserted so that, the excess liquid rises and, through the hole, runs down. The procedure was repeated for each sample (AOAC Standard).

Sample Calculation

Equation for relative density is given by (George, 2005):

Relative Density = $\frac{\text{Weight of oil}}{\text{Weight of water}} = \frac{W_3 - W_1}{W_2 - W_1}$ ---------- 3.2

W_1--- weight of empty bottle = 30.0613

W_2--- weight of bottle full of water = 79.6041gm

W_3 --- weight of bottle full of oil = 75.1452

RD = $\frac{75.1452 - 30.0613}{79.6041 - 30.0613} = \frac{45.0839}{49.5428}$ = 0.91

Relative densities for the Sample Oils are tabulated in Appendix IV.

C. Calorific Value

The following procedure was used in the determination of the calorific value of the oils.

Apparatus:

A Benthelot Mahler Cook Bomb calorimeter, water, oxygen cylinders, stopwatch, Beckman thermometer, stirrer, electric motor, pipette, cotton thread, platinum ignition wire, magnifying eye piece, analytical balance and crucible.

Procedure:

Two grams of oil was measured out into the crucible and the crucible placed in position in the fitting provided in the bomb with the thread and platinum ignition wire partly immersed in the oil. 10ml of distilled water was placed in the bottom of the bomb. The cover was placed on the bomb, and the nut covered down tightly by hand using the hand spanner subsequently as necessary. The bomb was then connected to the oxygen cylinder by the copper tube, the pin valve opened and a steady flow of oxygen allowed to enter the bomb until a pressure of 25 atmospheres was attained. The valves were then closed in the

following order: (1) Oxygen cylinder, (2) Pin valve in bomb. The bomb was then detached and placed in the calorimeter vessel containing 2900ml of water. The calorimeter cover, on which reciprocating water circulator is fixed, was placed in the piston and the Beckman thermometer placed in the ebonite sleeve provided for the purpose. The water circulator was now started, and the temperature of the water noted at the intervals of a minute, this being continued for 5-10 minute in order to enable the bomb to acquire the temperature of the water and to determine the rate of increase (if the temperature of the water initially is below room temperature). The temperatures obtained were recorded and tabulated in Table 3.3. The terminals of the bomb were then connected to electrical supply and the oil ignited. The temperature was noted at 1 minute intervals until a maximum was reached, and then for a further similar period in order to determine the heat lost, the stirring of the water was regularly maintained throughout. The temperature rise over time was also presented in Table 3.4. When the test was completed, the bomb was removed from the calorimeter and the pin valve opened cautiously so as to allow the gases escape without any carry-over of water. The same procedure was repeated for various blends of Biodiesel (AOAC Standard).

Table 3.3: Bomb Water Temperature rise over time

Time	Temperature ^{o}C, T_1
0	0.7
1	0.695
2	0.695
3	0.695
4	0.695
5	0.695

Table 3.4: Temperature Rise Over Time after Firing of Oil Sample

Time	Temperature ^{o}C, T_2
1	1.9
2	3.43
3	4.03
4	4.39
5	4.3
6	4.48
7	4.45
8	4.509
9	4.505
10	4.492
11	4.489
12	4.475
13	4.46
14	4.45
15	4.38
16	4.3

Sample Calculation

The equation for calorific value is given by (George, 2005):

$$\text{Calorific Value} = \frac{(\text{Mass of Water} + \text{Water Equivalent}) \text{ x Rise in Temperature}}{\text{Weight of Oil Used}} \quad \text{---------- 3.3}$$

Temperature rise = 4.505 – 0.695 = 3.81

Mass of 2900ml of water = 2900g

Water equivalent = 475

$$\therefore \text{Calorific Value (CV)} = \frac{(2900+475)*3.81}{2}$$

= 6429.375Calories

= 6429.375 x 4.184J/g

= 26.9kJ/g

Calculations were carried out for the Sample Oils and Biodiesel blends and the results presented in Appendix III.

D. Flash Point

The flash points were determined using the following procedure:

Apparatus

A Pensky-Martens apparatus, thermometer, stirrer, Bunsen burner etc

Procedure

The oil was placed in the cup in such quantity as to just touch the prescribed mark on the inside of the cup. The cover was then fitted into position on the cup and heating of the apparatus by means of a Bunsen burner commenced. During heating, the oil was constantly stirred and as the oil approached the temperature of flashing with reference to the base diesel fuel, say about 65^0C, the injector burner was lifted and injected into the oil container at 12 seconds interval until a distinct flash was observed within the container. This was also done for each sample and results tabulated in Appendix III. (AOAC Standard).

E. Acid Value

The acid values of the samples were determined as follows:

Apparatus

Burette, pipette, conical flask, phenolphthalein indicator, potassium hydroxide, ethanol.

Procedure

1 gram of the sample was weighed into a conical flask and 10mls of ethanol was added and stired vigorously. A drop of phenolphthalein indicator was added to it and titred using potassium hydroxide against it. This was done for each sample and the results obtained tabulated in Table 3.5 and used for calculation.

Table 3.5: Titre Value for Determining Acid Value

Titration	**1st**	**2nd**	**3rd**	**Average**
Initial volume (ml)	25	25	25	25
Final volume (ml)	24.896	24.896	24.897	
Titre Value (ml)	0.104	0.104	0.103	0.1037

Sample Calculation

The equation for acid value is given by (George, 2005):

$$\text{Acid Value} = \frac{56.1 \times N \times V}{W} \text{ ---------- 3.4}$$

Where W – weight of sample

V – Volume of potassium hydroxide (KOH) in ml

56.1- Molecular weight of KOH

$$\therefore \text{Acid Value} = \frac{56.1 * 0.086 * 0.1037}{1} = 0.50 \text{mg/g}$$

The results are presented in appendix IV.

F. Saponification Value

The Saponification values were determined using the following:

Apparatus

Reflux flask, water bathe, burette, pipette, condenser, standard hydrochloric acid, ethanoic acid, potassium hydroxide and phenolphthalein indicator.

Procedure

Two grams of oil was weighed into a refluxing flask and pipette was used to pipette 25ml of ethanoic acid and potassium hydroxide into the oil. It was refluxed for 30 minutes in the water bath and shaken intermittently during refluxing. Immediately after refluxing and the solution was clear, 3 drops of phenolphthalein indicator were added and titration done using standard HCl against it and the titre recorded. This was done for each sample and the results obtained tabulated in Table 3.6 and used for calculation (AOAC Standard).

Table 3.6: Titre Value for Determining Saponification Value

Titration	1st	2nd	3rd	Average
Initial volume (ml)	50	50	50	50
Final volume (ml)	24.63	24.67	24.62	
Titre Value (ml)	25.37	25.33	25.38	25.36

Sample Calculation

Equation for Saponification value (for a semi-normal HCl) is given by (George, 2005):

$$\text{Saponification Value (S.V)} = \frac{56.1 \text{ x } (V_2 - V_1)}{2W} \quad \text{---------- 3.5}$$

Where V_1 – Volume of HCl used in test

V_2 – Volume of HCl used in blank

W- Weight of sample = 2g

$$\therefore \text{ S.V} = \frac{56.1*(38.2-25.36)}{2*2} = 180.1\text{mg}$$

Saponification values for the oils were tabulated in appendix IV.

G. Ash Content

The following steps were used to determine the ash content of the samples:

Apparatus

Silica crucible, oven, desicator, analytical balance, tongs.

Procedure

The ash content was determined by evaporating about 0.5grm of the oil in a weighed crucible and finally burning off all traces of carbon by heating the crucible to redness in an oven and, subsequently cooling in a desicator and reweighing (AOAC Standard). The process was repeated for the oil samples and recorded.

Sample Calculation

Equation for ash content is given by (George, 2005):

$$\text{Ash content (\%)} = \frac{W_3 - W_1}{W_2 - W_1} \text{ x } 100 \quad \text{---------- 3.6}$$

Where Weight of Crucible, W_1 = 28.46g

Weight of Crucible + Sample, W_2 = 28.96g

Weight of Crucible + Ash, W_3 = 28.4695g

$$\therefore \text{ Ash Content (\%)} = \frac{(28.4695-28.46)}{(28.96-28.46)}$$

$$= \frac{0.019}{0.5} * 100 = 1.91\%$$

Ash content was calculated and tabulated in appendix III.

H. Carbon Content

This was determined using the following apparatus, procedure and calculation:

Apparatus

Crucible, desicator, analytical balance, tongs, and reweighing.

Procedure

The carbon content was determined by burning out 0.5g of oil in a weighed crucible by heating it to a point where no more smoke was seen coming out of the crucible and subsequently cooled in a desicator and reweighed (AOAC Standard). The procedure was repeated for the other samples.

Sample Calculation

Equation for ash content is given by (George, 2005):

$$\text{Carbon Content (\%)} = \frac{(W_3 - W_1)\ x\ 100}{W_2 - W_1} = \frac{\text{wt of carbon x 100}}{\text{wt of sample}} \quad \text{---------- 3.7}$$

Where Weight of Crucible, W_1 = 28.46g

Weight of Crucible + Sample, W_2 = 28.96g

Weight of Crucible + Carbon W_3 = 28.462g

$$\therefore \text{Carbon Content (\%)} = \frac{(28.4621 - 28.46)x\ 100}{28.96 - 28.46} = \frac{0.0021}{0.5} * 100 = 0.42\%$$

Carbon content for the oils and their methyl ester blends were calculated and presented in Appendix III.

I. Iodine Value/Number

The Iodine values were determined using the following:

Apparatus

Glass-stoppered bottle, glacial acetic acid, potassium iodide solution 10%, 0.1M sodium thiosulphate solution, Starch indicator, Carbon tetrachloride, Wij's solution.

Procedure

A 0.5g sample of oil was accurately weighed into the glass (250 ml) stoppered bottle. A 10ml of carbon tetrachloride was added and content dissolved. A 20ml Wij's solution was added and the stopper inserted and content allowed to stand in subdued light for 30 minutes.

A 15ml of 10% potassium solution and 100ml of water were added. The solution was then titrated with 0.1M sodium thiosulphate using starch as indicator.

A blank determination was carried out commencing with 10ml of carbon tetrachloride (AOAC Standard). Results obtained were tabulated in Table 3.7.The procedure was repeated for the other samples.

Table 3.7: Titre Value for Determining Iodine Value

Sodium thiosulphate	1st	2nd	3rd	Average
Initial volume (ml)	25	25	25	25
Final volume (ml)	10.95	10.97	10.96	
Titre Value (ml)	14.05	14.03	14.04	14.04

Sample Calculation

The equation for Iodine Value is given by (George, 2005):

$$\text{Iodine Value} = \frac{(b-a) \times 1.269}{W} \quad \text{---------- 3.8}$$

Where; a = Test titration

b = Blank titration

W = Weight of sample gm

$\therefore$ I.V = $\frac{(48-14.04)x\ 1.269}{0.5}$ = 86.18mg

Iodine value for the oils were calculated and presented in Appendix IV.

J. Hydrogen Value

The following were used in the determination of the hydrogen value:

Apparatus

Erlenmeyer flask, Glass stoppered, Acetic acid- chloroform solution 3:2, saturated solution of potassium iodide, 0.1M sodium thiosulphate solution, Starch indicator (1%), and Potassium iodide powder.

Procedure

A 5gm oil sample was weighed into a clean dry 250ml glass stoppered Erlenmeyer flask and 30ml of the acetic acid- chloroform solution added. The flask was swirled until the sample dissolved in the solution then 0.5ml saturated solution of potassium iodide was added. The solution was allowed to stand with occasional shaking for 1min and then 30ml of distilled water was added.

The solution was then titrated with 0.1N sodium thiosulphate solution until yellow colour has almost disappeared then 0.5ml starch indicator solution was added and titration continued while shaking the flask near the end point. Sodium thiosulphte was added drop-wise until blue colour has just disappeared (AOAC Standard). The procedure was repeated for the oil samples and values obtained were tabulated in Table 3.8.

Table 3.8: Titre Value for Determining Hydrogen Value

Sodium thiosulphate	1st	2nd	3rd	Average
Initial volume (ml)	25	25	25	25
Final volume (ml)	22.894	22.897	22.894	
Titre Value (ml)	2.106	2.103	2.106	2.105

Sample Calculation

The equation for Hydrogen Value is given by (George, 2005):

$$H.V = \frac{S*N*1000}{W} \text{ ---------- } 3.9$$

Where; S = Titration of sample

N = Normality of Sodium thiosulphate, 0.1

W = Weight of Sample = 5gm

$$\therefore H.V = \frac{2.105*0.1*1000}{5} = 42.1mg$$

Results obtained are tabulated in appendix IV.

The values of the physicochemical properties obtained for both *Hibiscus Sabdariffa* and *Hibiscus Surattensis* oils were calculated and presented in Appendix IV. Appendix VI shows various International Standards for Biodiesel and, values obtained from properties obtained for both *Hibiscus Sabdariffa* and *Hibiscus Surattensis* oils, methyl esters and their blends compare with the various Standards.

3.5 METHYL ESTER PREPARATION (TRANSESTERIFICATION)

The transesterification was carried in the Chemistry Laboratory in the Chemistry Department, A B U, Zaria.

The oils were transesterified using the following:

APPARATUS

Beakers, separating funnels, measuring cylinder, funnels, glass rods, evaporating dish, sodium hydroxide, sodium methanol, tetraoxosulphate (VI) acid and hydrochloric acid.

Procedure

One litre of the oil was used to prepare soap. The soap was made by pouring 500 ml of NaOH (made by dissolving 158.3g NaOH in distilled water) into 1000 ml of the oil with vigorous stirring. The soap was redissolved in boiling water, salted out with brine (NaCl) and then redissolved in water and acidified with 1:1 HCl to produce the fatty acid mixture and then methylated with methanol in the ratio of 1 fatty acid mixture to 6 volumes of methanol in presence of 1:1 H_2SO_4. The methyl ester was formed after heating the mixture to boil for about 20 minutes. The oil ester was then separated using a separating funnel (AOAC Standard). This procedure yielded one litre of methyl ester.

3.6 DIESEL FUELS AND BLEND

The diesel fuel used in this research was obtained from MRS service station in Samaru, Zaria. The physicochemical properties of diesel as obtained from Kaduna Refinery and Petrochemical Company Kaduna was presented in Appendix V.

Table 3.9 below shows the composition of the various blends of biodiesel which was used in this research.

Table 3.9: Mixing Volumes of *Hibiscus Sabdariffa* and *Hibiscus Sabdariffa* blends

Blend	Vol. of Biodiesel (ml)	Vol. of Diesel (ml)	Total Vol. (ml)
B30	300	700	1000
B40	400	600	1000
B50	500	500	1000
Diesel	0	1000	1000

3.7 EXPERIMENTATION

3.7.1 Procedure for Engine Performance Test

The control valve of the over- head tank was opened for water to circulate through the engine. The dynamometer was checked to ensure that the static balance was correct. The water inlet valve for the engine and dynamometer were opened fully while the outlet valve was slightly opened. The engine was then started and run for five (5) minutes with diesel from the fuel tank.

The fuel supply from the tank was cut-off while the fuel from the consumption gauge was turned on so that fuel supply to the engine was directly from the gauge and not from the fuel tank (the gauge was filled well above the 50ml mark). The engine speed, ω, was then adjusted to a speed of 1000rpm and the load F, also adjusted from the dynamometer. The temperatures of the inlet and outlet water were obtained from the thermometer dipped in

the thermometer pocket on both inlet and outlet water pipes respectively. Timing was commenced with a stop watch when the fuel reached the first 50ml mark and stopped after 50ml of fuel was consumed (fuel level touched the second mark) and the time taken was recorded. Observation was made constantly on the cooling water, readings of inlet and outlet water temperatures, exhaust temperature, oil pressure and manometer were recorded each time the engine consumes 50ml of fuel.

The procedure was carried out with diesel fuel at engine speed of 1000, 1250, 1500 and 2000 rpm respectively. This procedure was then repeated with 30:70, 40:60 and 50:50 blends of the two methyl esters. The results obtained were presented in Appendix VII. The engine specification is presented in table 3.10.

Table 3.10 Engine Specification

Swept Volume	5651.91cm^2
Bore	84.16mm
Stroke	101.6mm
Number of cylinders	4
Compression	21.5: 1
Recommended maximum speed	3000rpm
Type of dynamometer	Hydro

3.8 EXPERIMENTAL CALCULATIONS

The readings obtained from the engine using 100% Diesel fuel is presented in table 3.11. These were used to calculate the engine parameters.

Table 3.11: Experimental Values of 100% Diesel Fuel

Diesel	Speed (r p m)	Load(N)	Coolant Inlet Temp.(°C)	Coolant Outlet Temp.(°C)	Exhaust Temp. (°C)	Vol. of Fuel Consumed (l/min)	Heat Loss to Coolant	Manometer Reading (mm)	Oil Pressure (psi)
100%	1000	29	32	54.5	100	50/2.42	22.5	1	44
	1250	27	32	52	95	50/2.92	20	1.5	48
	1500	24.5	32.5	52	95	50/2.38	19.5	2	50
	2000	22.5	32	55	120	50/1.47	23	4	53

The values obtained from the experiments were used to determine the various engine parameters as outlined below. These engine parameters were calculated for the 30:70, 40:60 and 50:50 methyl esters blends along with 100% Diesel.

(i) Torque: the equation for Torque, T is given by (George, 2005):

$$T = \frac{Fd}{1000} \quad \text{---------- 3.10}$$

Where, F = balance readings, (23N)

d= Torque arm length (in mm), 37cm = 370mm

$$\therefore\ T = \frac{29*370}{1000} = 10.73\text{Nm}$$

(ii) Brake Horse Power: Brake Horse Power, BHP is given by (George, 2005):

$$BHP = \frac{F*\omega}{K} \quad \text{---------- 3.11}$$

Where, F = 29N

ω= speed= 1000

K = Engine constant = 4500

$\therefore$ BHP = $\frac{29 * 1000}{4500}$ = 6.44kW

(iii) Rate of Fuel Consumption, V: the equation for rate of Fuel Consumption V, is given by (George, 2005):

V = $\frac{3600 * Vg}{t}$ ---------- 3.12

Where, Vg = calibrated volume of fuel gauge (litres) = 50ml = 50 x 10^{-3} litre

t = time taken to consume 50ml of fuel in seconds(s) = 145.3s

V = rate of fuel consumption (litres/ hour).

$\therefore$ V = $\frac{3600 * 50 * 10^{-3}}{145.3}$ = 1.2388 l /hr

(iv) Specific Fuel Consumption, v: the equation for Specific Fuel Consumption is given by (George, 2005):

v = $\frac{V}{BHP}$ ---------- 3.13

Where, V = fuel consumption = 1.2388 l/hr

BHP = Brake Horse Power = 6.44kW

v = Specific Fuel Consumption (l/kWh)

$\therefore$ v = $\frac{1.2388}{6.44}$ = 0.193 l/kWh

(v) Swept Volume, V_s: equation for Swept Volume is given by (George, 2005):

V_s = $\frac{\pi d^2 Sn}{4 * 10^6}$ ---------- 3.14

Where, d = cylinder diameter, (in mm) = 84.16mm

S = Piston stroke = 101.6mm

n = Number of cylinders = 4

$\therefore \quad V_s = \frac{\pi(84.16*)^2*101.6*10^{-3}*4}{4*10^6} = 0.00226m^3 = 2.26ltrs$

(vi) Break Mean Effective Pressure, $\bar{P}$: the equation for Break Mean Effective Pressure is given by (George, 2005):

$$\bar{P} = \frac{6*10^4*BHP*K_2}{\omega*V_s} \text{ ---------- 3.15}$$

Where, $\bar{P}$ = b.m e.p (kN/m^2)

V_s = Swept volume of engine = $0.00226m^3$

K_2 = constant = 2 for 4- stroke engine

$\therefore \bar{P} = \frac{6*10^4*6.44*2}{1000*0.00226} = 271.3kN/m^2$

(vii) Mechanical Losses, M (kW): the equation for Mechanical Losses is given by (George, 2005):

$$M = \frac{T\omega}{K} \text{ ---------- 3.16}$$

$$M = \frac{10.73*1000}{4500} = 2.38kW$$

(viii) Indicated Power, ip (kW): equation for Indicated Power is given by (George, 2005):

ip = BHP + M ---------- 3.17

i.p = 6.44 + 2.38 = 8.82kW

(ix) Mechanical Efficiency, η_{mech}: the equation for Mechanical Efficiency is given by (George, 2005):

$$\eta_{mech} = \frac{BHP}{BHP+M} = \frac{BHP}{i.p} \text{ ---------- 3.18}$$

$$= \frac{6.44}{8.82}$$

$$= 0.73$$

$$= 73\%$$

Values obtained for the engine performance were presented in Appendix VII.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.0 INTRODUCTION

This chapter illustrates the trend to which the experimental results of the blends of *Hibiscus Sabdariffa* and *Hibiscus Surattensis* oil esters respectively with diesel follow graphically. Values obtained from the experimentation and the results of calculations were used to plot the resulting graphs which were show in this section. The viscosities, torque, Brake horse power, fuel consumption and specific fuel consumption are discussed for diesel and the two methyl esters blends. The graphs plotted are analysed according to blend ratio.

4.1 RESULTS

Tables 4.2- 4.17 (see appendices I- VIII) and Figures 1-14 show the results obtained from the experiments conducted.

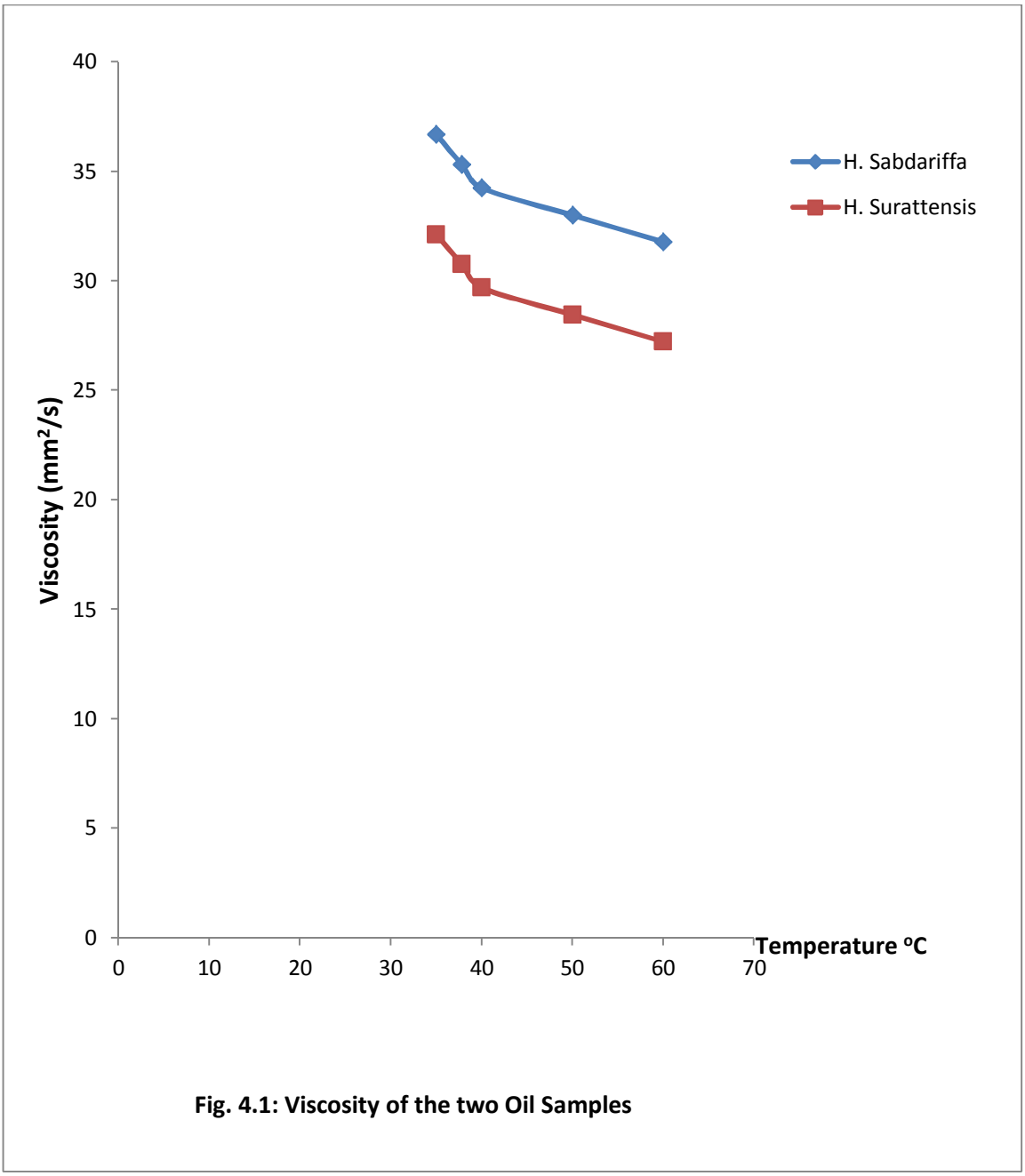


Fig. 4.1: Viscosity of the two Oil Samples

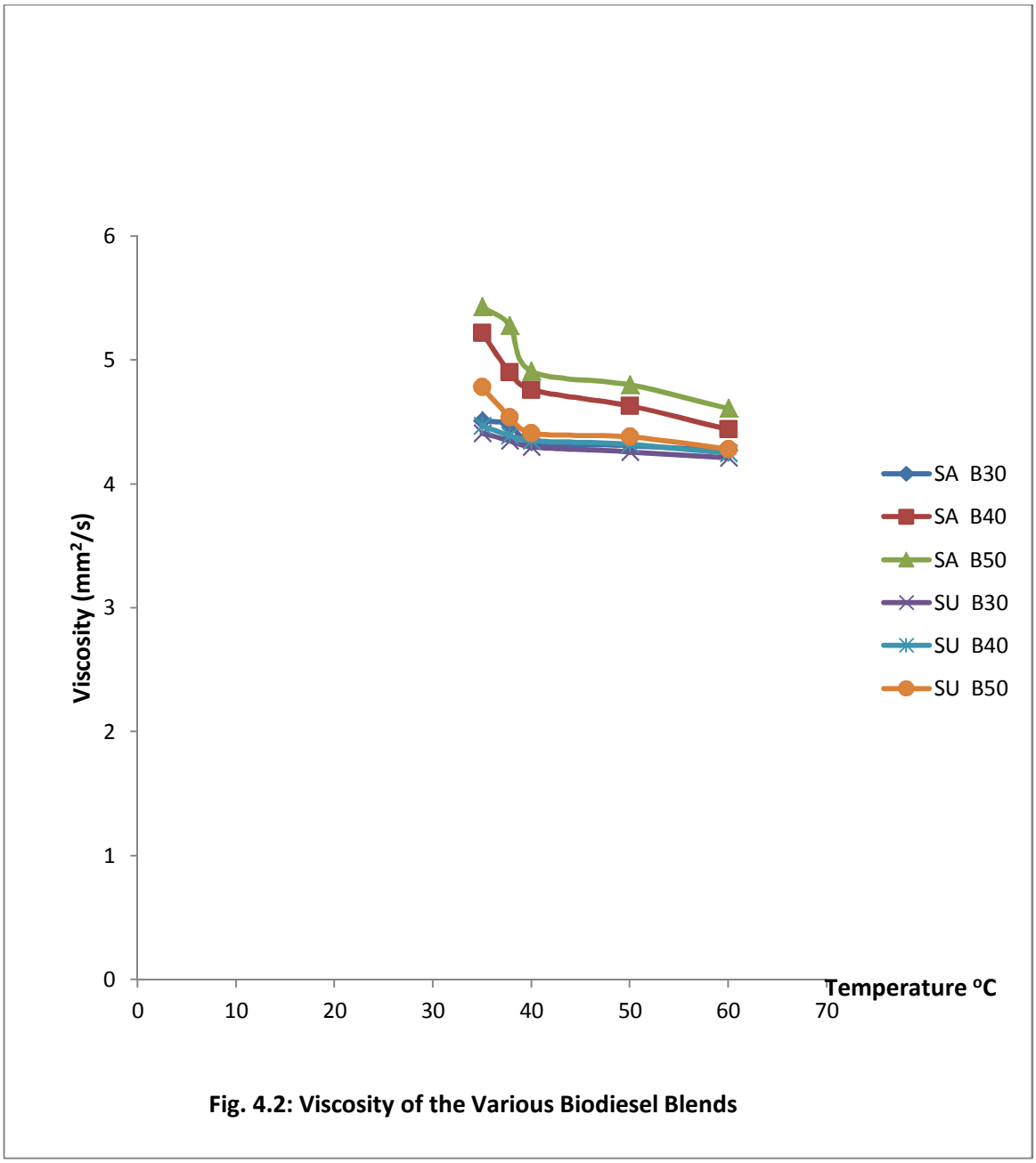


Fig. 4.2: Viscosity of the Various Biodiesel Blends

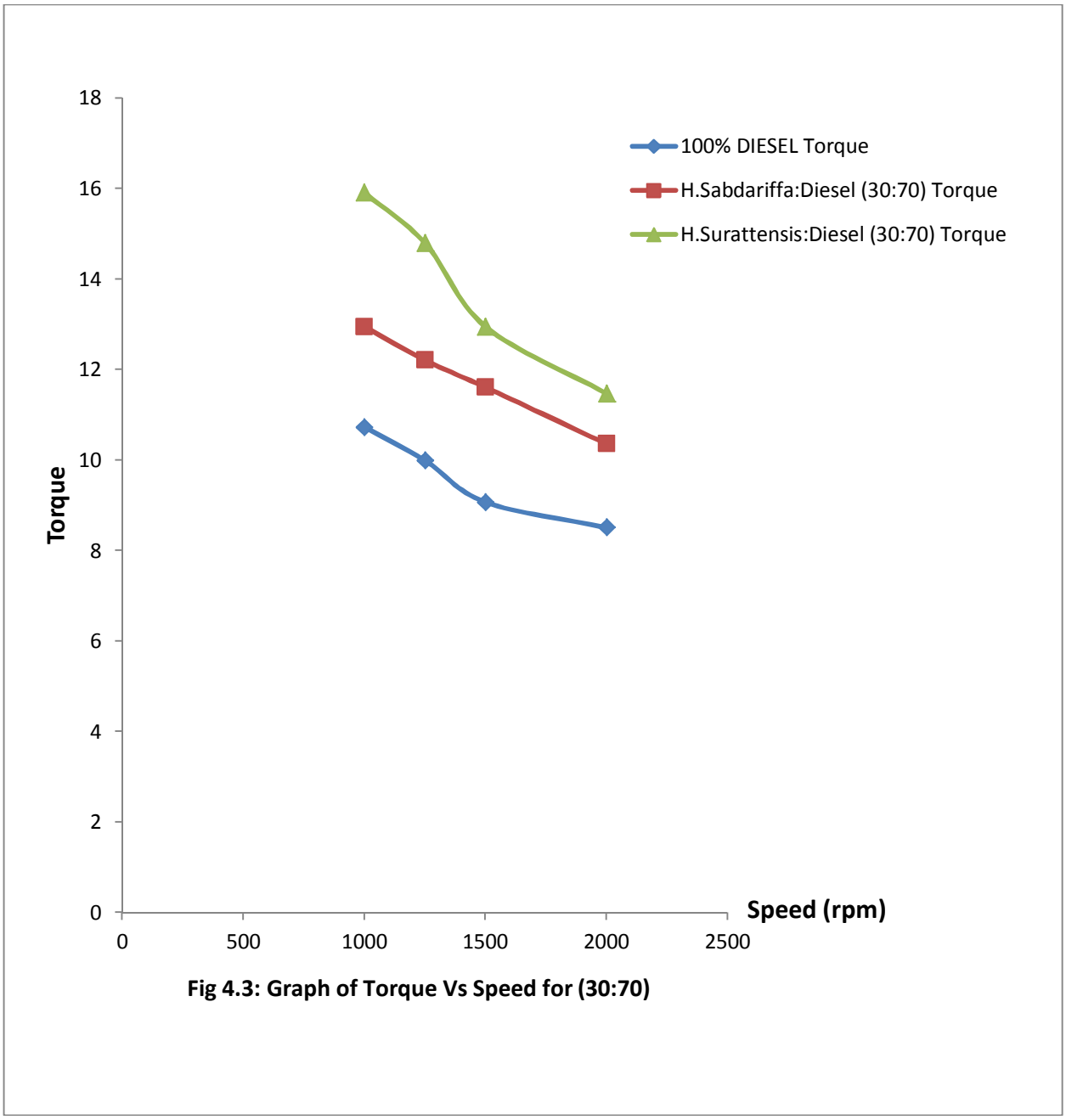


Fig 4.3: Graph of Torque Vs Speed for (30:70)

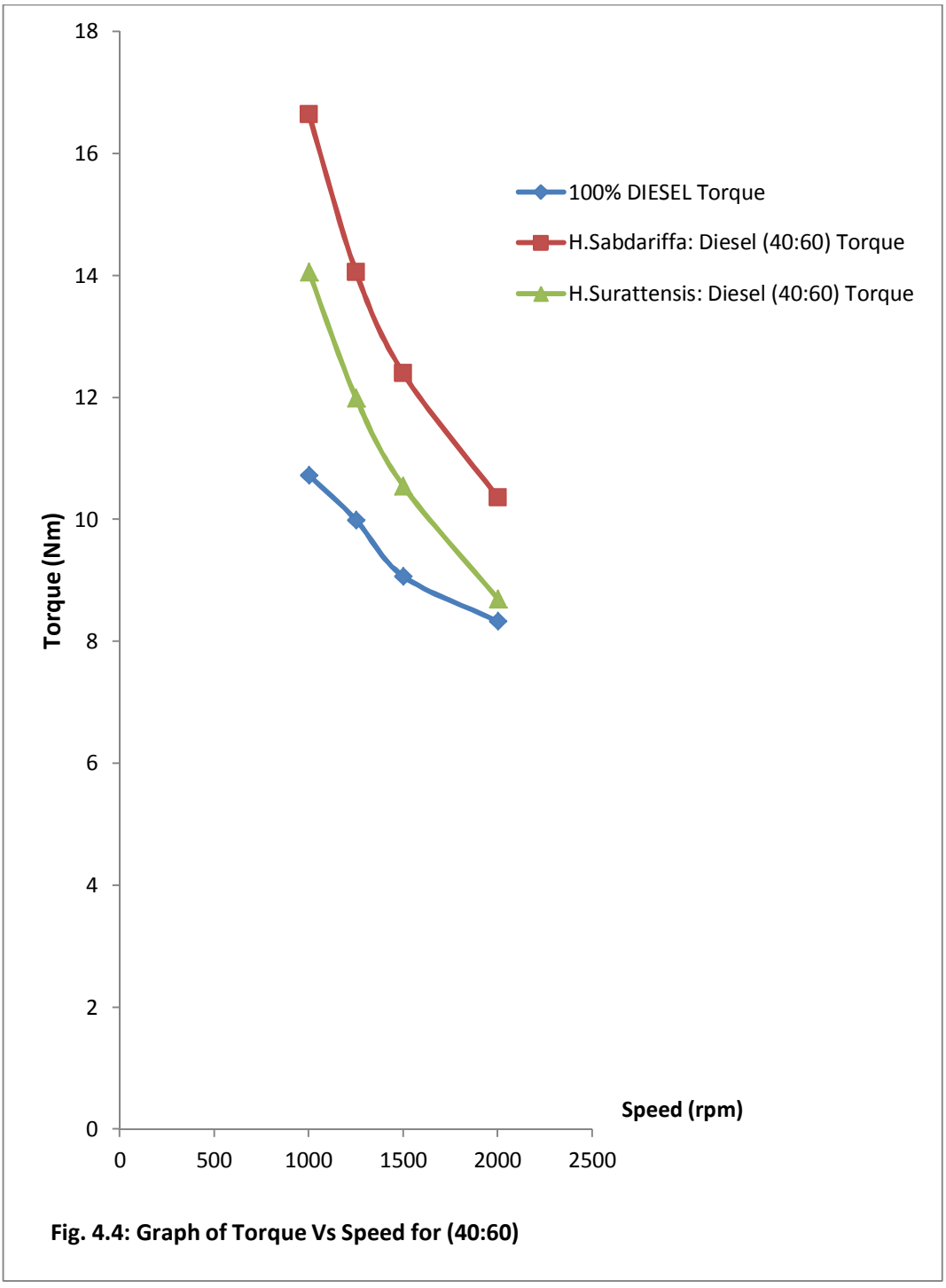


Fig. 4.4: Graph of Torque Vs Speed for (40:60)

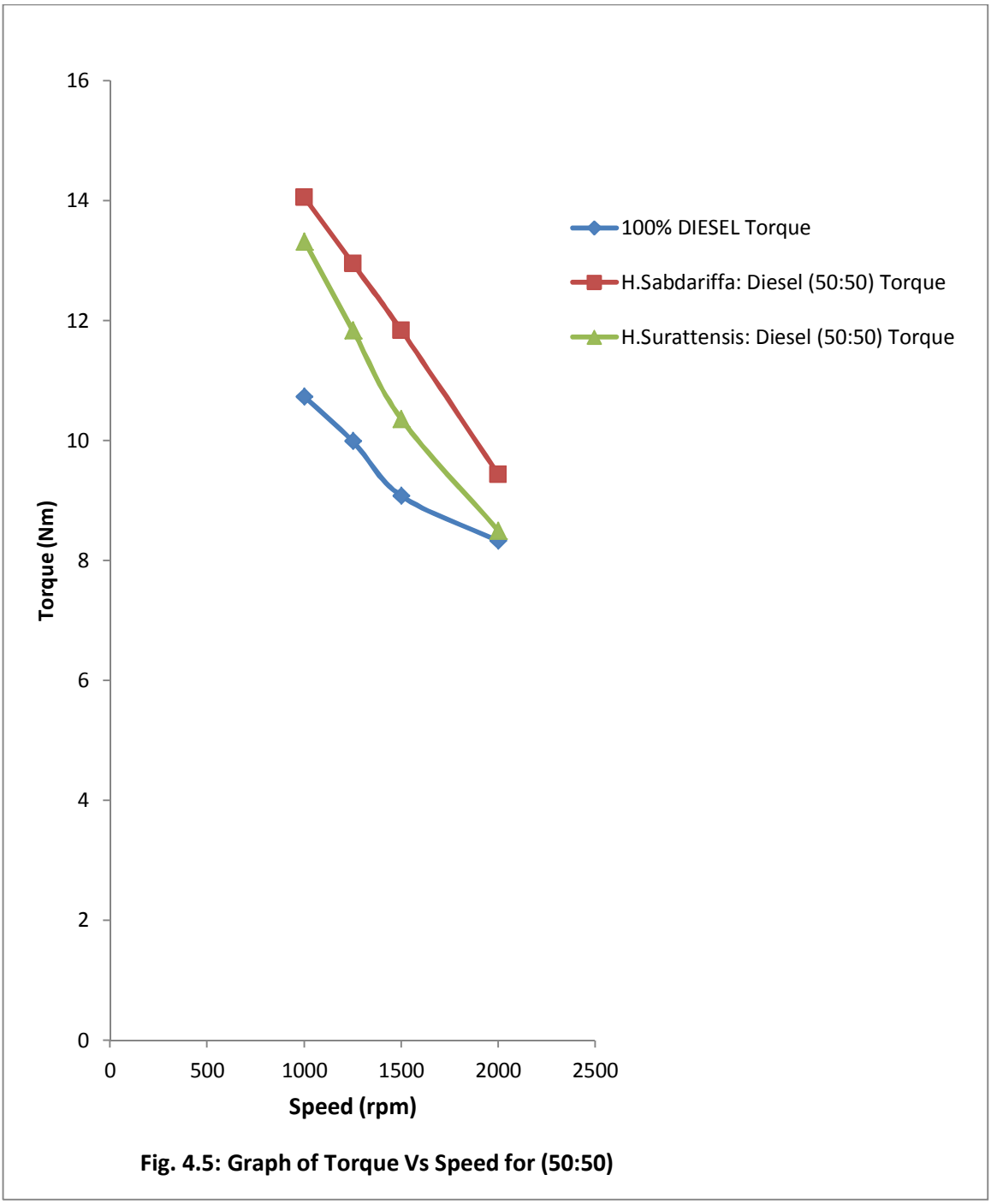


Fig. 4.5: Graph of Torque Vs Speed for (50:50)

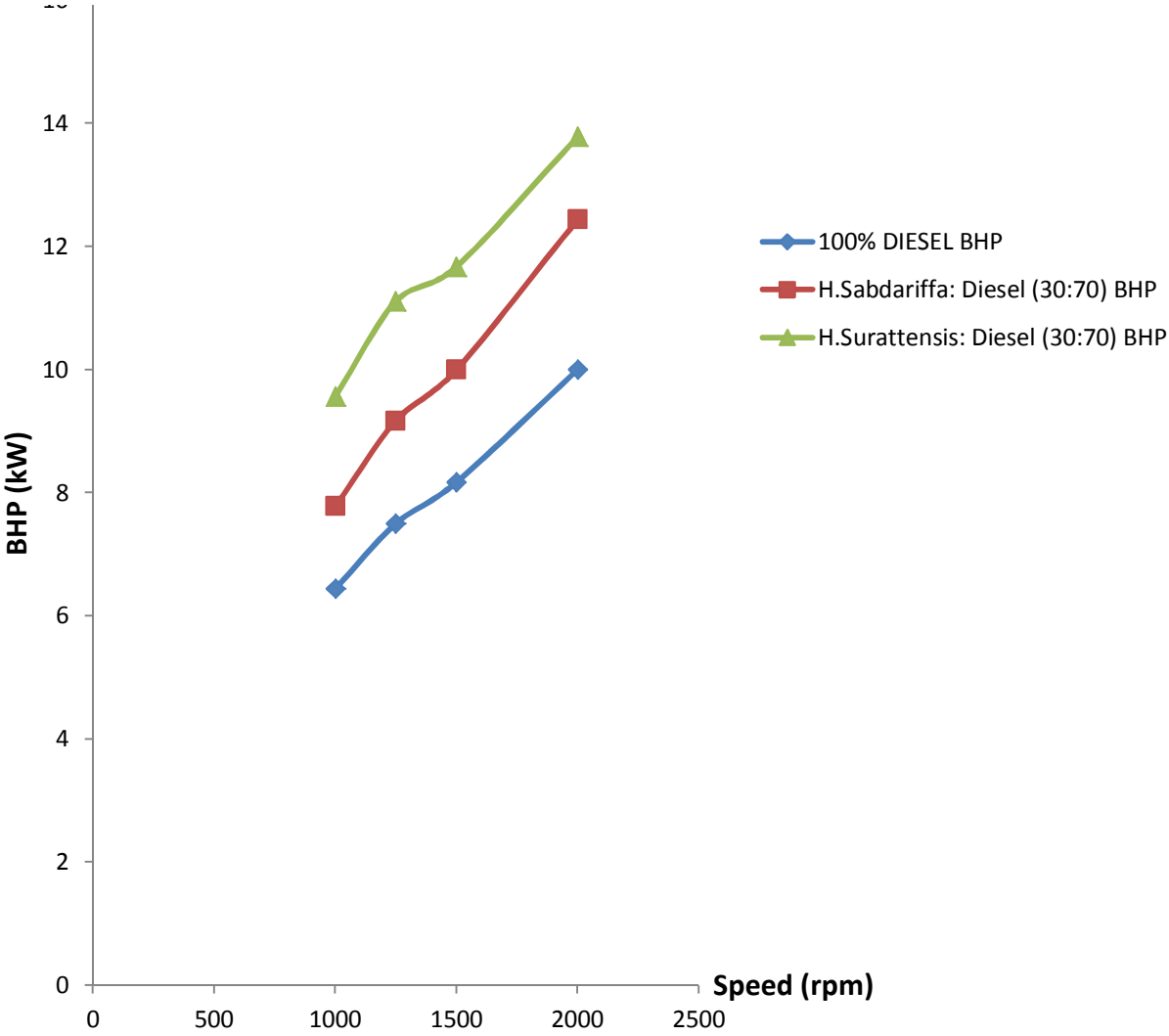


Fig. 4.6: Graph of BHP Vs Speed for (30:70)

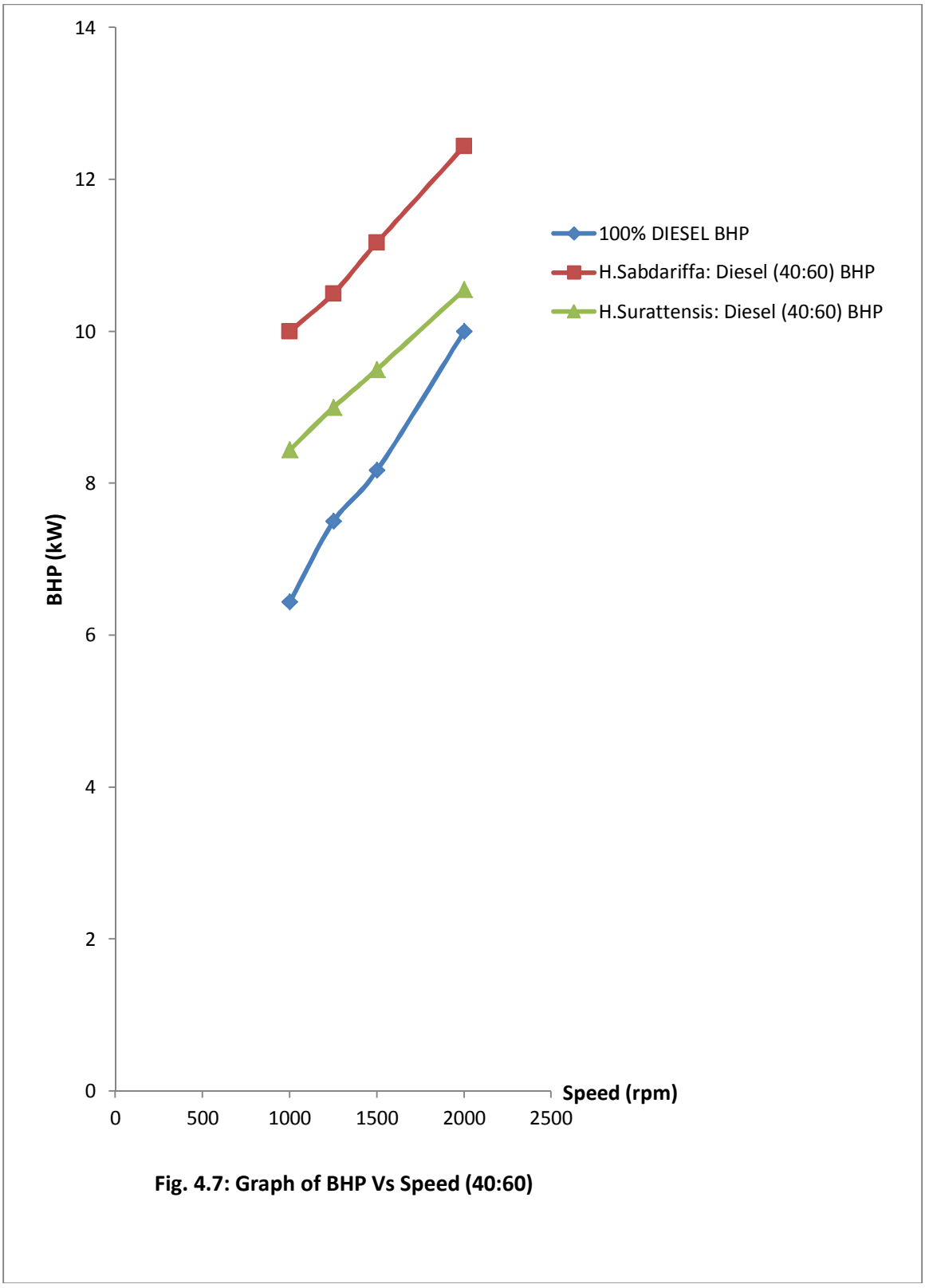


Fig. 4.7: Graph of BHP Vs Speed (40:60)

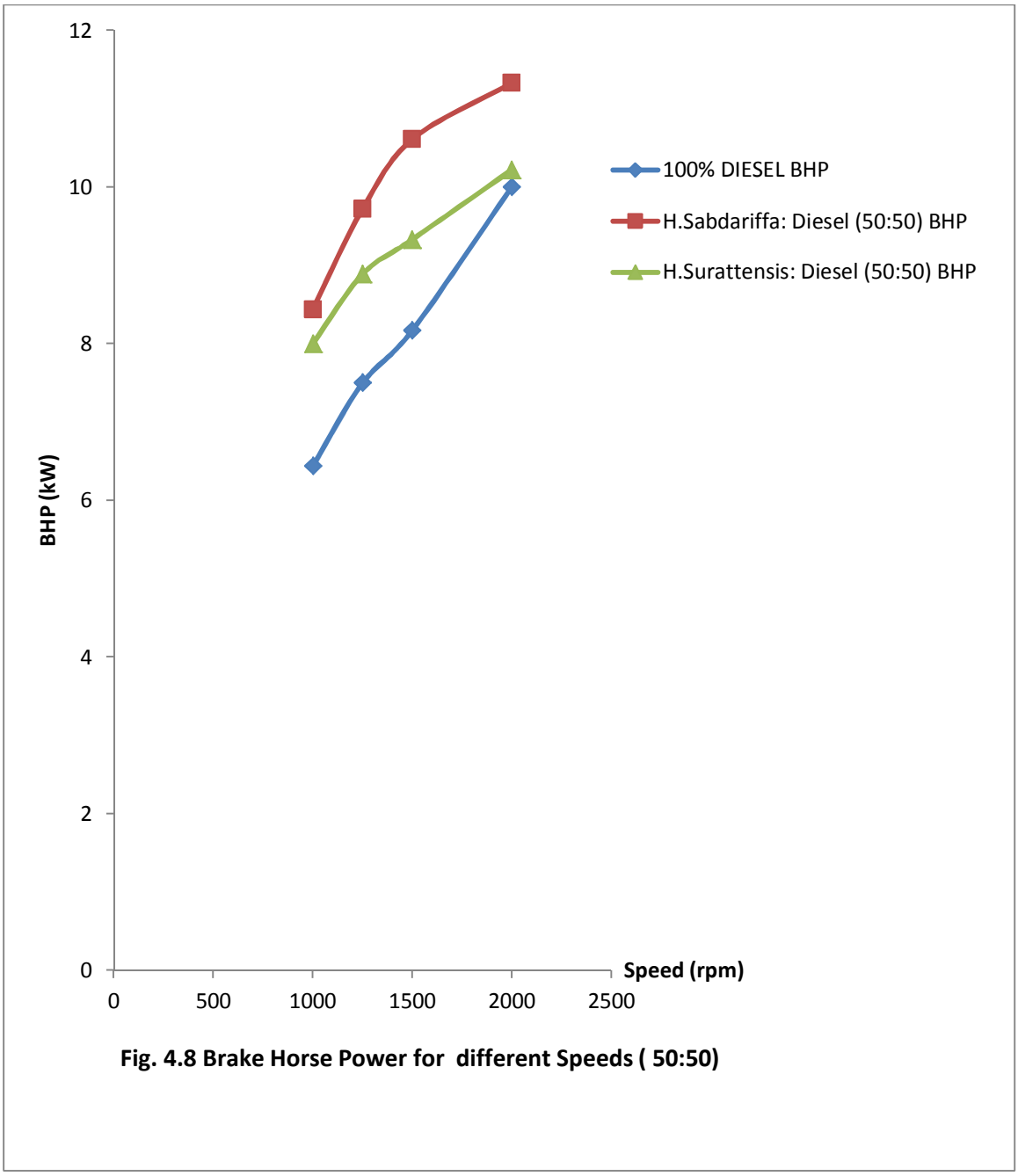


Fig. 4.8 Brake Horse Power for different Speeds (50:50)

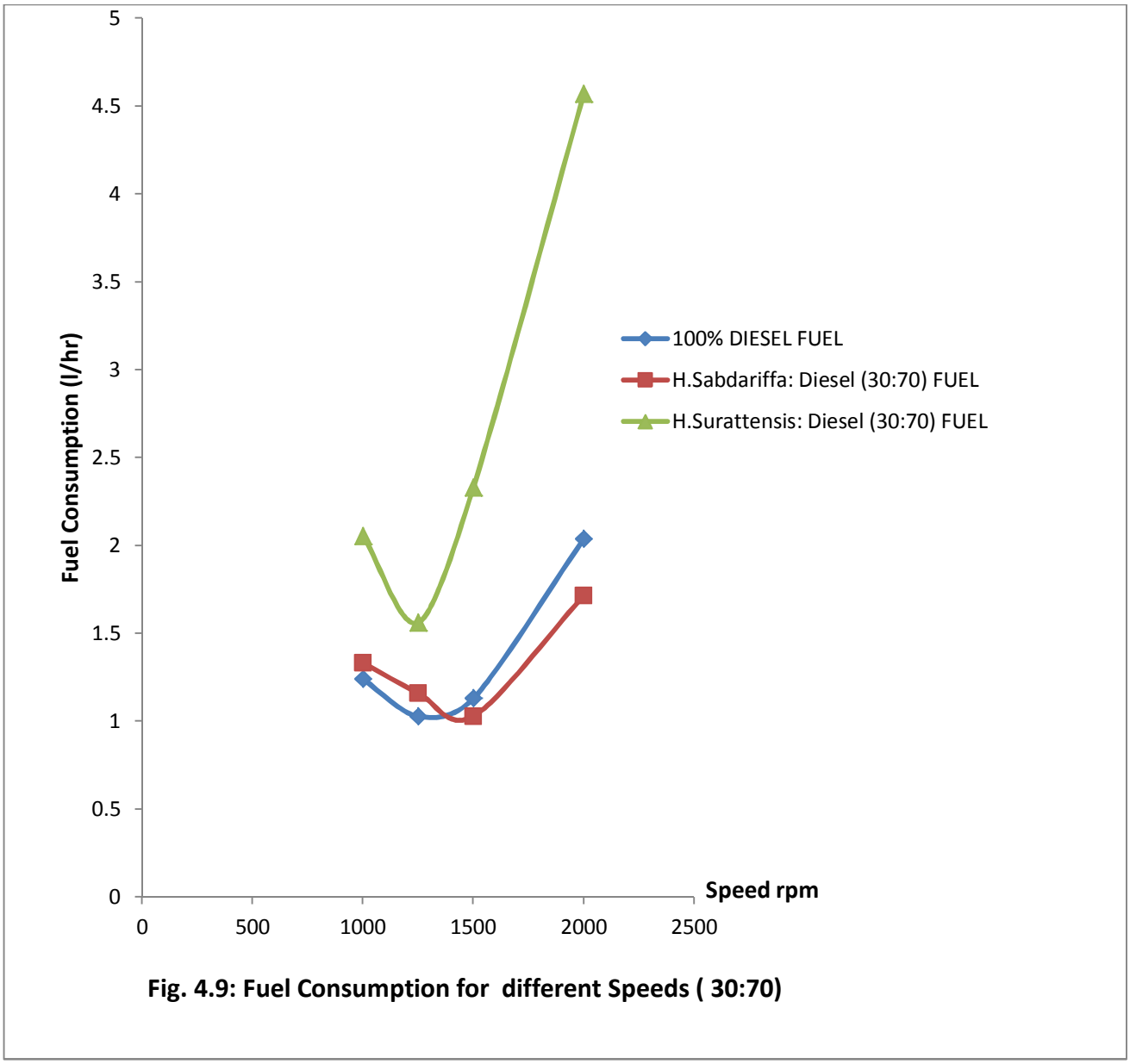


Fig. 4.9: Fuel Consumption for different Speeds (30:70)

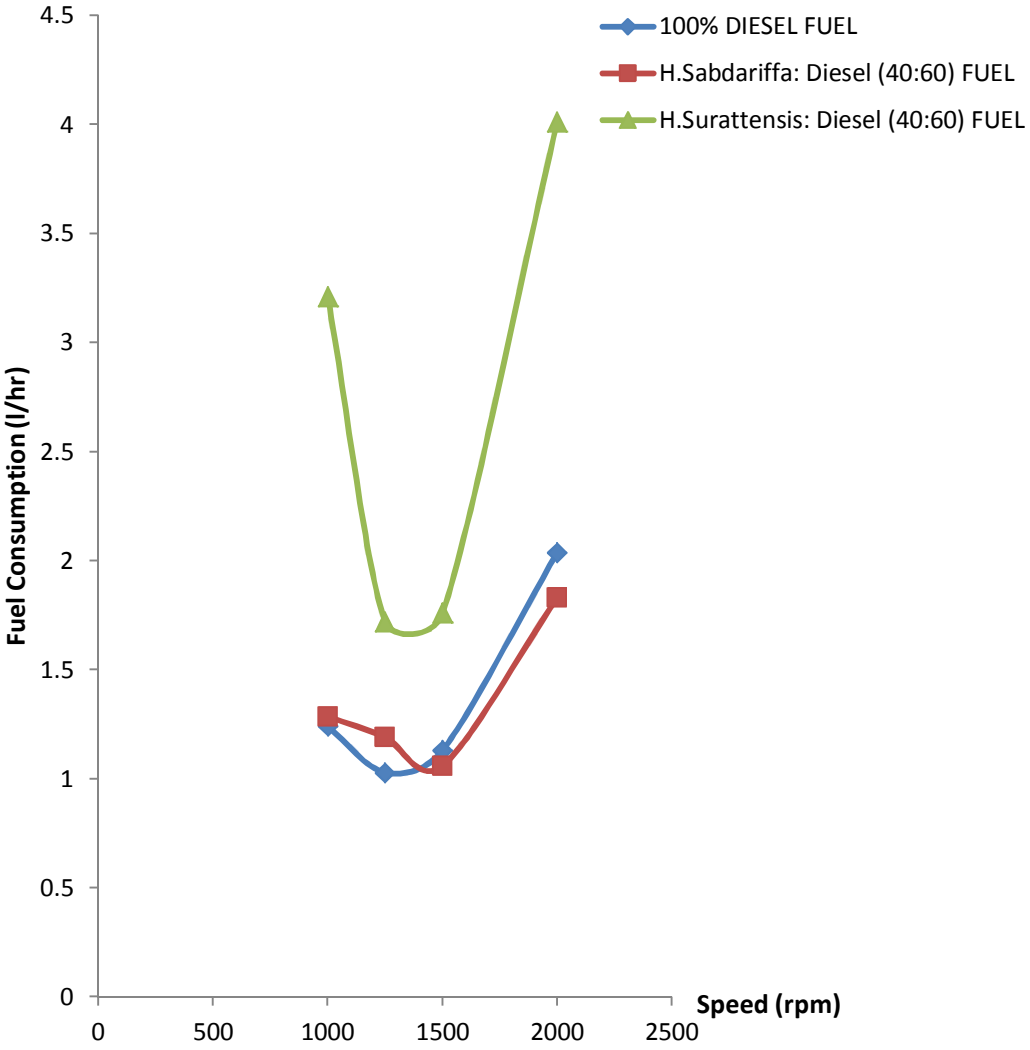


Figure 4.10: Fuel Consumption for different Speeds (40:60)

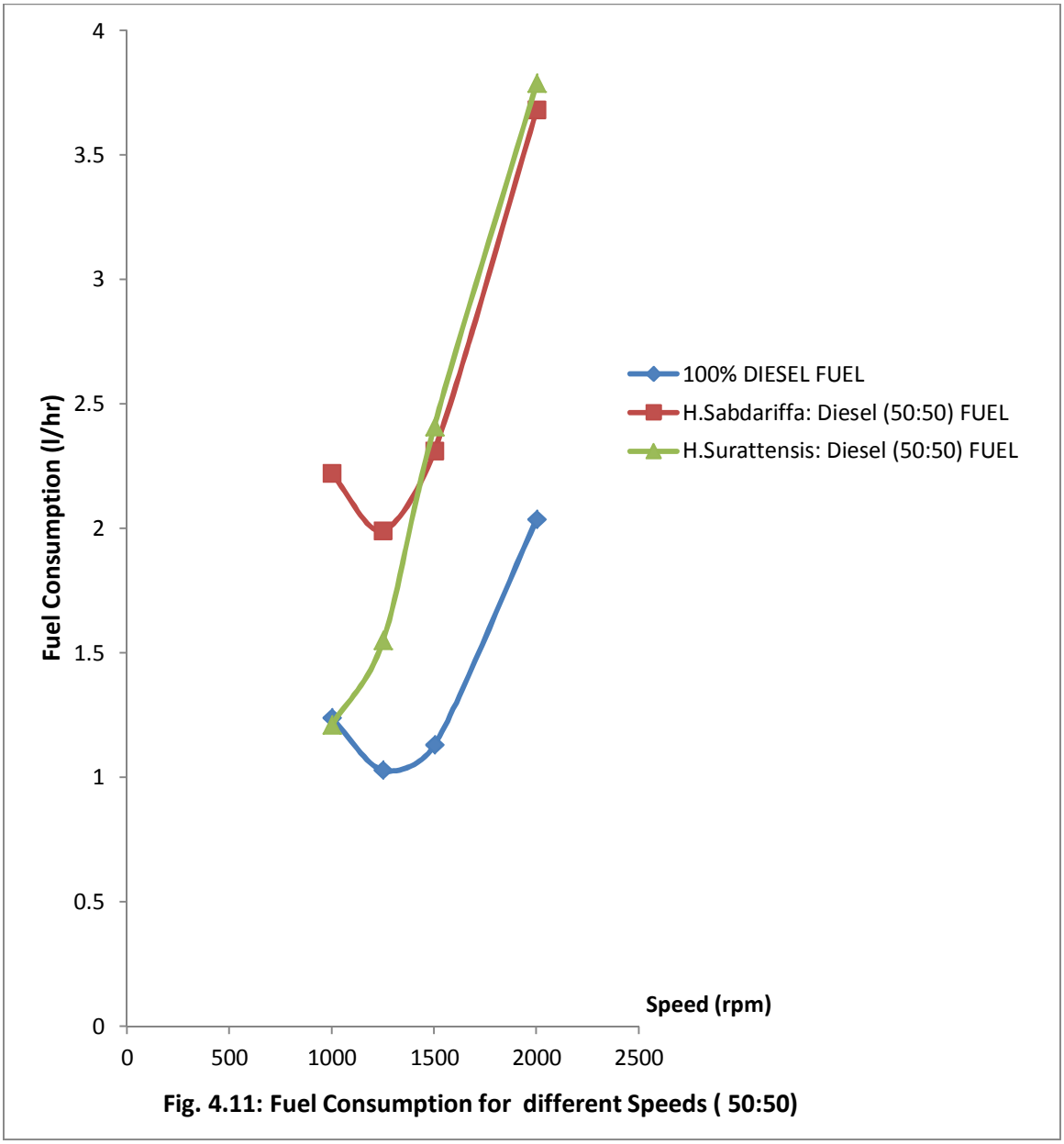


Fig. 4.11: Fuel Consumption for different Speeds (50:50)

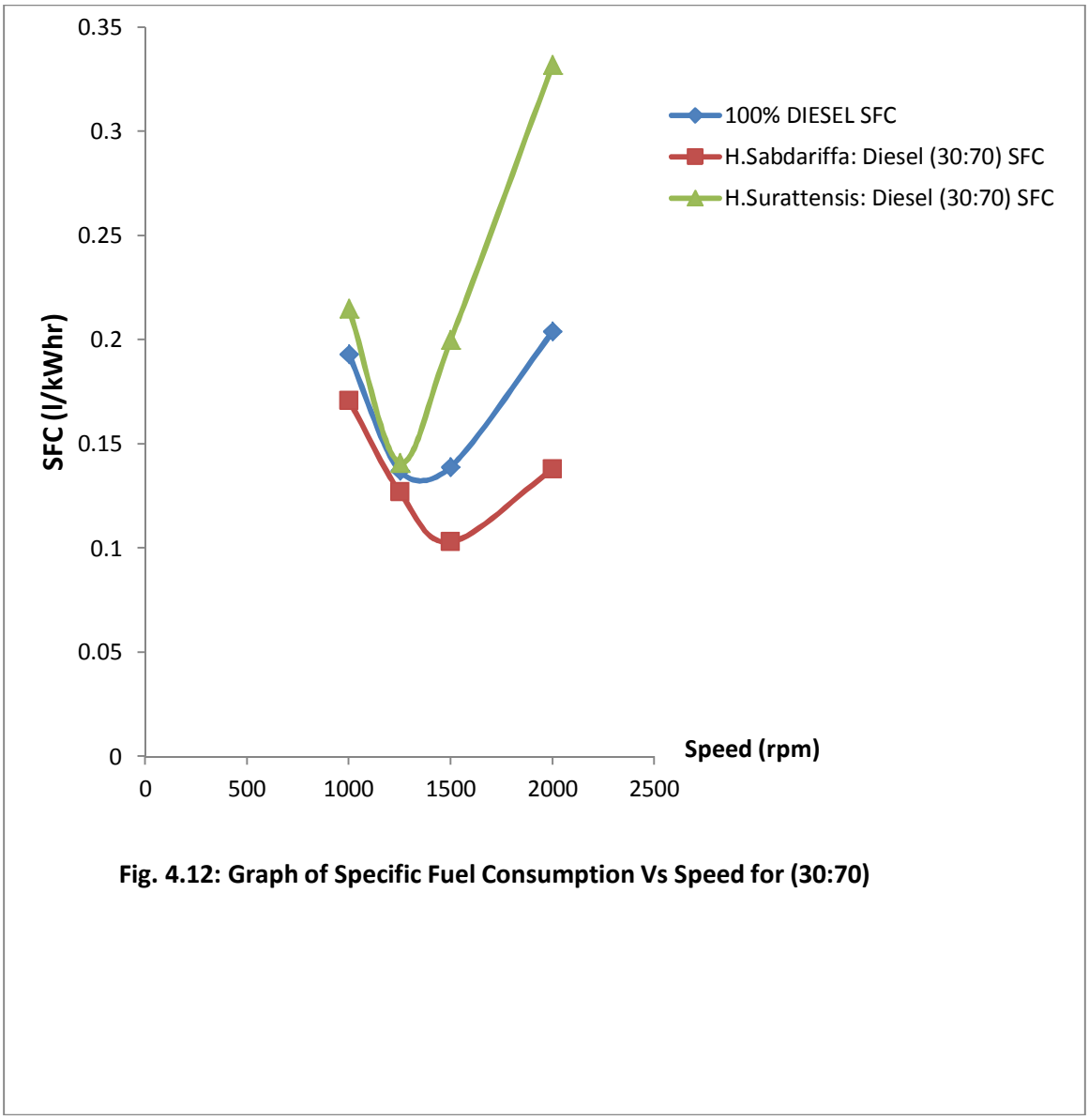


Fig. 4.12: Graph of Specific Fuel Consumption Vs Speed for (30:70)

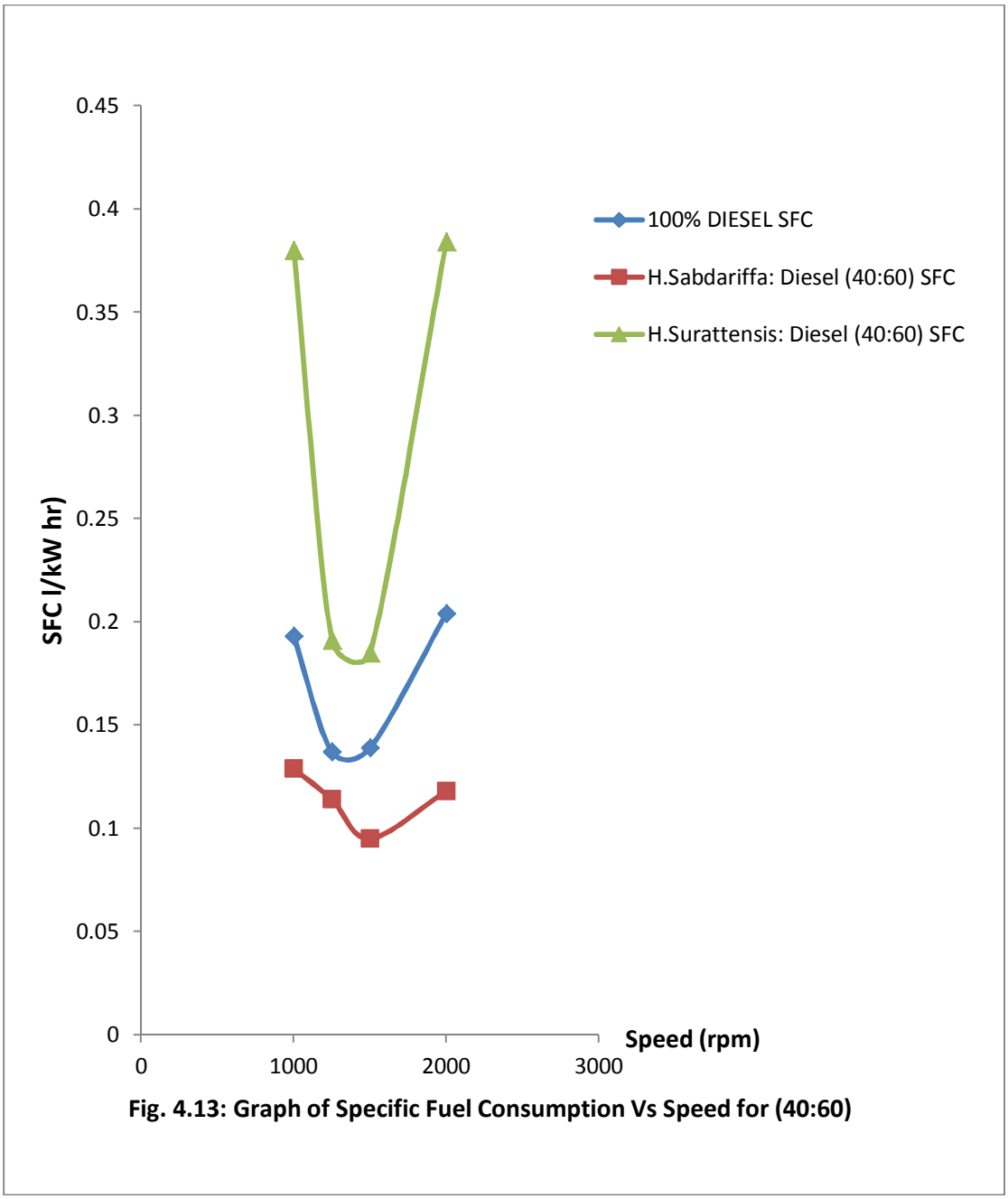


Fig. 4.13: Graph of Specific Fuel Consumption Vs Speed for (40:60)

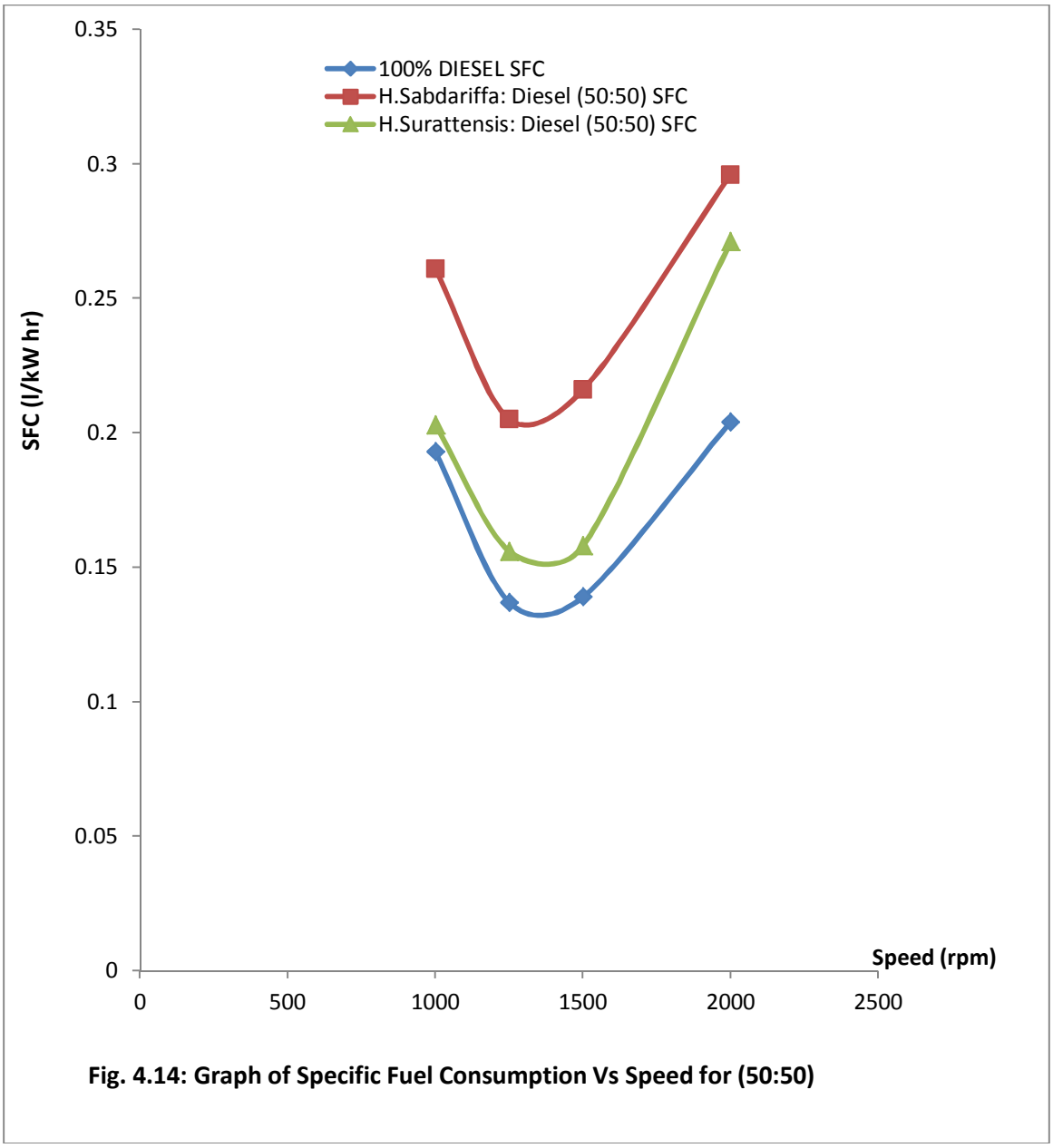


Fig. 4.14: Graph of Specific Fuel Consumption Vs Speed for (50:50)

4.2 DISCUSSION OF RESULTS

Below are the graphs for the performance characteristics of the Leyland Compression Ignition Engine. Those of interest in this research are the engine torque, brake horse power, fuel consumption and specific fuel consumption.

4.2.1 Viscosity

From the graph of viscosity (Fig. 4.1 and 4.2), it can be seen that viscosity decreases with increase in temperature. *H*. Sabdariffa seed oil is more viscous than *Hibiscus Surattensis*. Likewise *Hibiscus Sabdariffa* Biodiesel is more viscous than *Hibiscus Surattensis*. Viscosity increases from B30 blend to B50 blend. *Hibiscus* Sabdariffa B50 is the most viscous. This shows that this blend will give the longest ignition delay. Viscosity is a measure of a liquid's resistance to flow. High viscosity means the fuel is thick and does not flow easily. High viscosity fuel will increase gear train, cam and follower wear on the fuel pump assembly because of the higher injection pressure also, fuel atomizes less efficiently and the engine will be more difficult to start.

4.2.2 Torque

The relationship between torque and speed is shown in Figures 4.3, 4.4 and 4.5. The torque decreases for all the fuel samples to the minimum at the speed of 2000rpm. Comparing the torque produced by the engine at different loads and engine speeds for the diesel and various blends of fuel, it was observed that the torque increases steadily as load increased. The increase in torque is as a result of the higher calorific value of diesel followed by that of the biodiesel blends of B30 and B40, as well as complete combustion of fuels.

4.2.3 Brake Horse Power

The relationship between brake horse power (BHP) and speed is shown in Figures 4.6, 4.7 and 4.8. The brake horse power increases with increase in speed for all fuel samples to maximum at 2000rpm. Comparing the brake horse power produced by the engine at different loads and engine speed for various blends of Biodiesel, it was observed that the brake horse power increased steadily. Comparing brake horse power and different speeds for diesel and the different blends of Biodiesel, it was observed that the brake horse power is higher for blends of B30 and B40 than diesel. For B50 the brake horse power is not much more than diesel. Hence it can be concluded that the biodiesel blend of B40 of *Hibiscus Sabdariffa* and B30 *Hibiscus Surattensis* can be recommended for use in diesel engines without making any engine modifications.

4.2.4 Fuel Consumption

The relationship between Fuel Consumption and speed is shown in Figures 4.9, 4.10 and 4.11.The fuel consumption decreases with speed for the various blends of biodiesel to a minimum then increases continuously as the speed increased except for *H. Surattensis* at B50. Comparing the fuel consumption of the engine at various speeds and loads for the different blends tested, it was observed that fuel consumption is optimum for *Hibiscus Sabdariffa* blend of B30 at 1.029litre/hr. When fuel consumption is compared between the Biodiesel blends and diesel, it was observed that fuel consumption is optimum with diesel at the speed of 1250rpm while *Hibiscus Surattensis* has the least fuel consumption of 1.562litre/hr for B30 at speed of 1250rpm. This blend produces more BHP than *H. Sabdariffa* and diesel.

4.2.5 Specific Fuel Consumption

Figures 4.12, 4.13 and 4.14 show the relationship between Specific Fuel Consumption (SFC) and Speed. As Speed increases, specific fuel consumption decreases to the minimum at 1250rpm engine speed and then increases for all blends tested and diesel except for *Hibiscus Sabdariffa*. The specific fuel consumption for *Hibiscus Surattensis at* B30 is more or less equal to that of diesel at 1250rpm engine speed. The SFC for *Hibiscus Surattensis* is higher than that of Diesel. This can be due to the lower calorific value of biodiesel than diesel.

4.3 COST IMPLICATION

The cost of producing two of biodiesel from each of the oil sample is presented below in Table 5.1. The oil is not available off shelf and had to be produced from the seeds.

Table 4.1 Cost Implication of Biodiesel Production

S/No	Materials	Quantity (Litre)	Unit Price (Naira)	Total Price (Naira)
1	Diesel	4	160	640
2	H. Sabdariffa	2	8, 750	17, 500
3	H. Surattensis	2	8, 750	17, 500
4	Methanol	7.5	6, 000	18, 000
5	Chemicals	-	-	6, 500
6	Battery Rental	-	--	1, 500
7	Water Pumping	-	-	3, 200
8	Transportation	-	-	2, 500
9	Miscellaneous	-	-	24, 000
	TOTAL			**91, 340**

CHAPTER FIVE

SUMMARY, CONCLUSION AND RECOMMENDATION

5.0 SUMMARY

It was observed that torque decreases for all the fuel samples to the minimum at the speed of 2000rpm. Comparing the torque produced by the engine at different loads and engine speeds for the diesel and various blends of fuel, it was observed that the torque increases steadily as load increased. The increase in torque is as a result of the higher calorific value of diesel followed by that of the biodiesel blends of B30and B40, as well as complete combustion of fuels.

Comparing the brake horse power produced by the engine at different loads and engine speed for various blends of Biodiesel, it was observed that the brake horse power increased steadily. Comparing brake horse power and different speeds for diesel and the different blends of Biodiesel, it was observed that the brake horse power is higher for blends of B30 and B40 than diesel. For B50 the brake horse power is not much more than diesel. Hence it can be concluded that the biodiesel blend of B40 of *Hibiscus Sabdariffa* and B30 *Hibiscus Surattensis* can be recommended for use in the diesel engines without making any engine modifications. Comparing the fuel consumption of the engine at various speeds and loads for the different blends tested, it was observed that fuel consumption is optimum for *H. Sabdariffa* blend of B30 at 1.029litre/hr. When fuel consumption is compared between the Biodiesel blends and diesel, it was observed that fuel consumption is optimum with diesel at the speed of 1250rpm, while *Hibiscus Surattensis* has its least fuel consumption of 1.562litre/hr for B30. This blend produces less BHP as diesel.

The specific fuel consumption for *Hibiscus Sabdariffa at* B30 is more or less equal to that of diesel at 1500rpm engine speed. The SFC for *Hibiscus Surattensis* is higher than that of Diesel. This can be due to the lower calorific value of biodiesel than diesel.

5.1 CONCLUSION

From the results obtained and the discussion made the following conclusions can be drawn from the study:

1. For all the fuel samples tested, torque reached maximum values at 2000rpm while brake horse power reached minimum values at speed of 2000rpm.

2. The dual fuel combination of *H. Sabdariffa* blend of B30 and B40 and *H. Surattensis* blend of B30 can be recommended for use in the diesel engines without making any engine modifications.

3. By using this dual fuel combination (B30 and B40), emission of greenhouse gases would be reduced.

4. The possibility of using *Hibiscus Surattensis* and *Hibiscus Sabdariffa* methyl esters as alternative fuels in diesel engine has been established.

5. The physicochemical properties of vegetable oils from *Hibiscus Surattensis* and *Hibiscus Sabdariffa* seeds where investigated and found to be close to that of diesel.

6. The oils from *Hibiscus Surattensis* and *Hibiscus Sabdariffa* seeds were successfully convert to biodiesel by the process of transesterification, and their physicochemical properties compared with those of petroleum- based diesel and the performance of the biodiesels at various blend ratios with diesel were tested using the Leyland Compression Ignition Engine.

5.2 RECOMMENDATION

1. The Nigerian government should encourage the use of Hibiscus Sabdariffa and Hibiscus Surattensis methyl esters as fuels for alternative energy.

2. The cultivation of these seed crops on a large commercial scale should be encouraged by the government. This will increase their availability, boost agriculture and create employment for our teeming jobless youths.

3. The present menace of desertification and soil erosion facing this country will be checked or contained as these lands could be converted into farmlands for the cultivation of these seeds. We will therefore be contributing to ecological balancing – reducing the greenhouse gases- and helping to reduce the global warming.

4. Studies should be carried out on Moringa Oleifera, Caesalpinia Pulcherrima and Gmelina L. to ascertain the suitability of their methyl esters as alternative fuels for diesel engines.

5. The Screw Oil Press Machine should be procured by the Department to facilitate speedy extraction of oil from seeds by interested students who would want to carry out research on alternative fuel derived from vegetable oils since many of these oils are not readily available in the market.

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APPENDIX I

SCREW OIL PRESS MACHINE



(Courtesy Ahmadu Mohammad Industrial Limited (AMIL) Kawo Kaduna, Kaduna State.**)**

APPENDIX II

VISCOSITY OF OILS AND SAMPLES AT VARIOUS TEMPERATURES

Table 4.2: Viscosity at Various Temperatures for *Hibiscus Sabdariffa* And *Hibiscus Surattensis* Seed Oils

Temperature ^{o}C	Viscosity (mm^2/s)	
	Hibiscus Sabdariffa	***Hibiscus Surattensis***
35	36.68	32.12
37.8	35.32	30.76
40	34.25	29.69
50	33	28.46
60	31.78	27.22

Table 4.3: Viscosity at Various Temperatures for various blends of *Hibiscus Sabdariffa Biodiesel*

Temperature ^{o}C	Viscosity of Sample (mm^2/s)			
	B30	B40	B50	B100
35	4.51	5.22	5.34	5.81
37.8	4.78	4.9	5.28	5.60
40	4.34	4.76	5.91	5.40
50	4.31	4.63	4.80	5.20
60	4.27	4.44	4.61	5.00

Table 4.4: Viscosity at Various Temperatures for various blends of *Hibiscus Surattensis* Biodiesel

Temperature ^{o}C	Viscosity of Sample (mm^2/s)			
	B30	B40	B50	B100
35	4.41	4.47	4.78	5.16
37.8	4.35	4.39	4.54	4.88
40	4.30	4.35	4.41	4.69
50	4.26	4.32	4.38	4.47
60	4.21	4.25	4.28	4.36

APPENDIX III

TABLES OF PHYSICOCHEMICAL VALUES OF BLENDS

Table 4.5: Calorific Values for Oil, Diesel and blends of Hibiscus Sabdariffa Biodiesel

Sample	Mass (g)	$T_2(^oC)$	$T_1(^oC)$	$\Delta T(^oC)$	Calorific Value(kJ/kg)
B30	2	6.5046	0.693	5.8116	41 033
B40	2	6.4287	0.693	5.7357	40 487
B50	2	6.3649	0.693	5.6719	40 047
B100	2	6.1899	0.693	5.4969	38 811
Diesel	2	9.7578	0.648	9.1098	64 320
Oil	2	4.4893	0.695	3.7943	26 790

Table 4.6: Calorific Values for Oil, Diesel and blends of Hibiscus Surattensis Biodiesel

Sample	Mass (g)	$T_2(^oC)$	$T_1(^oC)$	$\Delta T(^oC)$	Calorific Value(kJ/kg)
B30	2	6.6477	0.685	5.9627	42 100
B40	2	6.5699	0.685	5.8849	41 551
B50	2	6.3991	0.685	5.7141	40 345
B100	2	6.3405	0.685	5.655	39 931
Diesel	2	9.7576	0.648	9.1098	64 320
Oil	2	4.505	0.695	3.8099	26 900

Table 4.7: Flash Point of Oils and their Methyl Esther Blends

	Flash Point	
Sample	**H. Sabdariffa**	**H. Surattensis**
B30	69	75
B40	71	85
B50	72	87
B100	144	174
Oil	64	70

Table 4.8: Carbon Content of Oils and their Methyl Esther Blends

Sample	Carbon Content	
	H. Sabdariffa	H. Surattensis
B30	3.12	3.16
B40	2.96	2.85
B50	2.72	2.81
B100	0.38	0.22
Oil	0.46	0.29

Table 4.9: Ash Content of Oils and their Methyl Esther Blends

Sample	Carbon Content	
	H. Sabdariffa	H. Surattensis
B30	0.97	1.76
B40	0.97	1.76
B50	0.97	1.76
B100	0.97	1.76
Oil	1.91	2.77

APPENDIX IV

PHYSIOCHEMICAL PROPERTIES OF DIESEL *HIBISCUS SABDARIFFA* AND *HIBISCUS SURATTENSIS* SEED OILS

Table 4.10: Physiochemical Properties of Diesel *Hibiscus Sabdariffa* and *Hibiscus Surattensis* Seed Oils

Oil Samples / **Properties**	**Diesel**	***Hibiscus Sabdariffa***	***Hibiscus Surattensis***
Relative density (15 ^{o}C)	0.85	0.91	0.93
Flash point (^{o}C)	65.5	64	70
Viscosity (mm^2/s)	1.6 - 5.5	35.32	30.76
Calorific value (MJ/kg)	65	26.9	26.79
Carbon Content (%wt)	4.4	0.42	0.29
Ash content (%wt)	0.01	1.91	2.77
Saponification Value (mg)	-	180.1	188.2
Acid value	-	0.5	1.1
Iodine Number	-	86.18	86.62
Hydrogen Value	-	42.1	38.64

APPENDIX V

PHYSICOCHEMICAL PROPERTIES OF REFERENCE DIESEL FUEL

Table 4.11: Physicochemical Properties of Reference Diesel Fuel from Kaduna Refinery and Petrochemical Company Kaduna

PARAMETER	VALUE
Specific gravity (15 ^{o}C)	0.85
Diesel Index	47 max
Distillation Temperature (^{o}C)	128
Recovery (357 ^{o}C % vol)	90 min
End boiling point (^{o}C)	385 max
Flash point (^{o}C)	65.5
Total sulphur content (%wt)	0.5max
Kinematic Viscosity (mm^2/s)	1.6 - 5.5
Cloud content (%wt)	4.4max
Ash content (%wt)	0.01max
Water (%wt)	0.05max
Sediment (%wt)	0.01
Calorific value (MJ/kg)	65max

APPENDIX VI

INTERNATIONAL STANDARDS FOR BIODIESEL

Table 4.12: International Standards for Biodiesel

Standard/ Specifications	Test Value	Unit	AUSTRIA	FRANCE	GERMANY	ITALY	SWEDEN	USA	MBTI
			ON C1191	Journal Official	DIN E 51606	UNI 10635	SS 15 54 36	D-6751~02	
Date			1 July 1997	14 Sep 1997	Sep 1997	21 April 1997	27 Nov 1996	10Jan 2002	August 03
Application			FAME**	VOME**	FAME**	VOME**	VOME**	FAME**	FAME**
Density	15ºC	g/cm^3	0.85 - 0.89	0.87 - 0.90	0.875 - 0.90	0.86 - 0.90	0.87 - 0.90	-	-
Viscosity	40ºC	mm^2/s	3.5 - 5.0	3.5 - 5.0	3.5 - 5.0	3.5 - 5.0	3.5 - 5.0	1.9 - 6.0	4.473
Distillation	I.B.P.	ºC	-	-	-	>300	-	-	339
Distillation	95%	ºC	-	<360	-	<360	-	-	357
Flashpoint		ºC	>100	>100	>110	>100	>100	>130	162
CFPP		ºC	<0/-15	-	<0/-10/-20	<0/-15	<-5	-	-
Pour point	summer	ºC	-	<10	-	-	-	-	-
Total Sulphur		% Mass	<0.02	-	<0.01	<0.01	<0.001	-	0.0004
CCR	100%	% Mass	<0.05	-	<0.05	-	-	0.050	0.04
CCR	10%	% Mass	-	<0.3	-	<0.5	-	-	-
Sulphate ash		% Mass	<0.02	-	<0.03	-	-	<0.02	-
(Oxide) Ash		% Mass	-	-	-	<0.01	<0.01	-	-
Water content		mg/kg	-	<200	<300	<700	<300	<300	0
Impurities total		mg/kg	-	-	<20	-	<20	-	0
Cetane Number		-	>49	>49	>49	-	>48	>47	52.9
Neutral No.		mg KOH/g	<0.8	<0.3	<0.5	<0.5	<0.6	<0.80	0.23
Methanol content		% Mass	<0.20	<0.1	<0.3	<0.2	<0.2	-	-
Ester content		% Mass	-	>96.5	-	>98	>98	-	-
Monoglycerides		% Mass	-	<0.8	<0.8	<0.8	<0.8	-	-
Diglyceride		% Mass	-	<0.2	<0.4	<0.2	<0.1	-	-
Triglyceride		% Mass	-	<0.2	<0.4	<0.1	<0.1	-	-
Free glycerol		% Mass	<0.02	<0.02	<0.02	<0.05	<0.02	0.020	0.003
Total glycerol		% Mass	<0.24	<0.25	<0.25	-	-	0.240	0.146
Iodine No.		-	<120	<115	<115	-	<125	-	<120
Phosphor		mg/kg	<20	<10	<10	<10	<10	<10	<10
Alkaline met.	NA/K	mg/kg	-	<5/5	<5	-	<10/10	-	-
**FAME: Fatty Acid Methyl Ester **VOME: Vegetable Oil Methyl Ester									

(Source: Indian BioFuel Awareness Forum by Satish Lele, satish.lele@gmail.com)

APPENDIX VII

EXPERIMENTAL VALUES

Table 4.13: Experimental Values of Blend of *Hibiscus Sabdariffa* Methyl Ester and Diesel Fuel

H/ Sabdariffa: Diesel	Speed (rp m)	Load(N)	Coolant Inlet Temp.(^oC)	Coolant Outlet Temp.(^oC)	Exhaust Temp. (^oC)	Vol. of Fuel Consumed (l/min)	Heat Loss to Coolant	Manometer Reading (mm)	Oil Pressure (psi)
30: 70	1000	35	35	56	120	50/1.75	21	3.3	56
	1250	33	34	45	97	50/2.92	11	1.2	51
	1500	30	35	40	95	50/2.25	5	0.5	46
	2000	28	30	42	97	50/2.58	12	0.5	48
40: 60	1000	45	42	57	100	50/2.52	15	2.0	52
	1250	38	42	64	100	50/2.55	22	2.5	52
	1500	33.5	41	57	100	50/2.33	16	1.5	50
	2000	28	45	75	140	50/1.43	20	2.5	58
50: 50	1000	38	42	63	120	50/1.58	21	3.2	42
	1250	35	42	61	120	50/2.93	19	2.5	46
	1500	32	40	56	97	50/2.3	16	1.5	46
	2000	25	40	58	97	50/2.5	18	2.0	48

Table 4.14: Experimental Values of Blend of *Hibiscus Surattensis* Methyl Ester and Diesel Fuel

H/Surattensis: Diesel	Speed (r p m)	Load (N)	Coolant Inlet Temp.(^oC)	Coolant Outlet Temp.(^oC)	Exhaust Temp. (^oC)	Vol. of Fuel Consumed (l/min)	Heat Loss to Coolant	Manometer Reading (mm)	Oil Pressure (psi)
30: 70	1000	43	48	61	140	50/1.46	13	2.0	46
	1250	40	44	58	140	50/1.06	14	2.0	54
	1500	35	45	64	170	50/1.21	19	2.5	59
	2000	31	46	58	120	50/1.2	12	2.5	49
40: 60	1000	38	42	60	120	50/1.27	18	2.5	49
	1250	32.4	38	60	100	50/1.48	22	2.0	50
	1500	28.5	42	63	120	50/1.19	21	2.0	49
	2000	23.5	34	57	100	50/1.01	23	1.5	48
50: 50	1000	36	44	58	141	50/1.85	14	3.5	54
	1250	32	48	63	140	50/2.16	15	2.5	54
	1500	28	44	65	150	50/2.04	21	3.5	54
	2000	23	42	58	120	50/0.93	16	2.0	49

APPENDIX VIII

PERFORMANCE RESULTS

Table 4.15: Performance Results of 100% Base Diesel Fuel

Parameter	Diesel			
Speed (rpm)	1000	1250	1500	2000
Load (N)	29	27	24.5	22.5
Torque (Nm)	10.73	9.99	9.07	8.33
BHP (kW)	6.44	7.5	8.17	10.0
Fuel Consumption (l/hr)	1.240	1.028	1.13	2.037
Specific Consumption (l/kW hr)	0.193	0.137	0.139	0.204
Swept Volume (l^3)	2.26	2.26	2.26	2.26
Break Mean Effective Pressure (kN/m^2)	341.95	318.6	289.2	265.5
Mechanical Loss (kW)	2.38	2.78	3.02	3.70
Indicated Power (kW)	8.82	10.28	11.19	13.70
Mechanical Efficiency (%)	73	72.95	73	72.99

Table 4.16: Performance Results of Blends of *Hibiscus Sabdariffa* Methyl Ester with Diesel

Parameter	***Hibiscus Sabdariffa* Methyl Ester : Diesel Fuel**									
	30: 70				**40: 60**				**50**	
Speed (rpm)	1000	1250	1500	2000	1000	1250	1500	2000	1000	1250
Load (N)	35	33	30	28	45	38	33.5	28	38	35
Torque (Nm)	12.95	12.21	11.1	10.36	16.65	14.06	12.4	10.36	14.06	12.95
BHP (kW)	7.78	9.17	10	12.44	10	10.5	11.17	12.44	8.44	9.72
Fuel Consumption (l/hr)	1.333	1.16 1	1.029	1.714	1.286	1.192	1.06	1.83	2.20	1.99
Specific Consumption (l/kW hr)	0.171	0.127	0.103	0.138	0.129	0.114	0.095	0.118	0.261	0. 205
Swept Volume (l^3)	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26
Break Mean Effective Pressure (kN/m^2)	413.1	389.5	354	330.3	531	446	395.4	330.3	448.1	412.9
Mechanical Loss (kW)	2.88	3.39	3.70	4.60	3.70	3.91	4.13	4.60	3.12	3.6
Indicated Power (kW)	10.66	12.56	13.70	17.04	13.70	14.41	15.30	17.04	11.56	13.32
Mechanical Efficiency (%)	72.98	73	72.99	73	72.99	72.87	73	73	73	72.97

Fuel

Table 4.17: Performance Results of Blends of *Hibiscus Surattensis* Methyl Ester with Diesel Fuel

Parameter	***Hibiscus Surattensis* Methyl Ester : Diesel Fuel**											
	30:70				**40: 60**				**50: 50**			
Speed (rpm)	1000	1250	1500	2000	1000	1250	1500	2000	1000	1250	1500	2000
Load (N)	43	40	35	31	38	32.4	28.5	23.5	36	32	28	23
Torque (Nm)	15.91	14.8	12.95	11.47	14.06	11.99	10.55	8.70	13.32	11.84	10.36	8.51
BHP (kW)	9.56	11.11	11.67	13.78	8.44	9.0	9.5	10.44	8	8.89	9.33	10.22

Fuel Consumption (l/hr)	2.055	1.562	2.33	4.57	3.21	1.72	1.76	4.01	1.21	1.55	2.41	3.79
Specific Consumption (l/kW hr)	0.215	0.141	0.20	0.332	0.380	0.191	0.185	0.384	0.203	0.156	0.158	0.271
Swept Volume (l^3)	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26	2.26
Break Mean Effective Pressure (kN/m^2)	507.6	472	413.1	365.8	448.1	382.3	336.3	277.2	424.8	377.6	330.3	271.3
Mechanical Loss (kW)	3.54	4.11	4.32	5.1	3.12	3.33	3.52	3.87	2.96	3.29	3.45	3.78
Indicated Power (kW)	13.10	15.22	15.99	18.88	11.56	12.33	13.02	14.31	10.96	12.18	12.78	14
Mechanical Efficiency (%)	73	73	73	72.99	73	72.99	72.96	72.96	73	73	76.6	73