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PERFORMANCE EVALUATION OF IDI SLOW SPEED DIESEL ENGINE ON PRE-HEATED JATROPHA OIL

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CERTIFICATE

It is to certify that the major dissertation entitled **"PERFORMANCE EVALUATION OF IDI SLOW SPEED DIESEL ENGINE ON PREHEATED JATROPHA OIL"** submitted by Mr. BEER BAHADUR KASHYAP, 01/THR/07 in partial fulfilment for the award of the Degree of Master of Engineering in Thermal Engineering, is an authentic record of student's own work carried out by him under my guidance and supervision.

It is also certified that this dissertation has not been submitted to any other Institute/University for the award of any degree or diploma.

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JUNE, 2009 **Beer Bahadur Kashyap**

ABSTRACT

Diesel Engines have proved its utility in agriculture and transportation, sector of India. Slow speed diesel engine helps in agriculture and rural electrification in developing countries. However, the concerns about long term availability of petroleum diesel and environmental degradation caused by burning of diesel fuel have mandated that renewable alternative to diesel fuel should be expeditely explored to overcome these twin problems. Vegetable oils have always been considered as a good alternative to diesel for last many decades and oil derived from Jatropha curcas plant has been considered as a sustainable substitute to diesel fuel.

Difficulties encountered with the use of straight vegetable oil in diesel engine are reported by various researchers. These problems are mainly attributed to high viscosity and low volatility of vegetable oil. The modification of Jatropha oil to biodiesel through process of transesterification is one of the most acceptable methods of overcoming the above problems however the transesterification process is a very complex phenomenon and not easily understandable to rural community for meeting their energy needs. The quality and other safety issues also preclude massive adaptation of transesterification method. Therefore, it is necessary that a system should be developed which could make use of heat of exhaust gases to pre-heat the Jatropha oil for reducing its viscosity for mass utilization in rural areas for decentralized energy production.

The present work aims at developing a dual fuel, slow speed diesel engine test rig with an appropriately designed shell and tube heat exchanger (with exhaust by-pass arrangement) for evaluation of potential suitability of preheated Jatropha oil as fuel in agricultural sectors. The bypass arrangement controls and gives the required fuel inlet temperature. The determination of performance and emission characteristics of the engine with pre-heated Jatropha oil was done and comparative assessment with baseline data of diesel fuel and unheated Jatropha oil was also made. The experimental results suggest that the brake thermal efficiency (BTE) of the engine was slightly lower and the brake specific energy consumption (BSEC) of pre-heated Jatropha oil was higher as compared to diesel fuel.

It was seen that as the temperature of Jatropha oil was increased, it resulted in improvement of brake thermal efficiency. However, a fuel inlet temperature higher than 100˚C could not be achieved during the trial. The emissions of nitrogen oxides (NO_x) from preheated Jatropha oil during the whole range of experiment were slightly lower than diesel fuel except at full load. The carbon monoxide (CO) and Hydrocarbon (HC) emission from the preheated Jatropha oil at 100˚C was found lower than diesel fuel during the full load condition. The results of the experiments suggest that straight Jatropha oil at a preheating temperature of 100˚C is a good substitute fuel for diesel engine in rural areas as far as decentralized energy production is concerned.

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NOMENCLATURE

@	At the rate
AC	Alternate Current
AN	Acid Number
ASTM	American Society for Testing and Materials
ATDC	After Top Dead Center
AVL-437	AVL-437 Smoke Meter
BIS	Bureau of Indian Standard
BMEP	Break Mean Effective Pressure
BP	Brake Power
BSEC	Brake Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
BTDC	Before Top Dead Center
^{o}C	Degree Celsius
Cc	Cubic centimetre
CI	Compression Ignition
cm^{-1}	Per Centimeter
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide

cSt	centi Stoke
CV	Calorific Value
DI	Direct Injection
DF	Diesel fuel
EOI	End of Injection
^oF	Degree Fahrenheit
FFA	Free Fatty Acid
FIT	Fuel Inlet temperature
FIP	Fuel Injection Pump
g/cc	Gram per cubic centimeter
HC	Hydrocarbon
H_2O	Water
HP	Horse Power
Hz	Hertz
IC	Internal Combustion
IDI	Indirect Injection
IS	Indian standard
JO	Jatropha oil (Unheated)
KOH	Potassium Hydroxide
KVA	Kilo Volt Ampere
Kw	Kilo Watt
kW-h	Kilo Watt Hour

JCL	Jatropha Curcas linn
Min.	Minute
Ml	Milliliter
Mt	Million Tonnes
Mtoe	Million Tonne of Oil Equivalent
NO	Nitric Oxide
Nos.	Numbers
NO_2	Nitrogen Di-oxide
NO_x	Oxides of Nitrogen
nPAH	Nitro Poly Aromatic Hydrocarbon
PAH	Poly aromatic Hydrocarbon
PM	Particulate Matter
Ppm	Parts Per Million
RPM	Revolutions Per Minute
SAE	Society of Automobile Engineering
Sfc	Specific Fuel Consumption
TDC	Top Dead Center
ULSD	Ultra Low Sulphur Diesel
UBHC	Unburnt Hydrocarbon
Vs	Versus
ρ	Density

CHAPTER-1

INTRODUCTION

Energy is the building block of any civilized society. Per Capita energy consumption reflects the prosperity of any country besides GDP. Now a day's most of the energy in the world is derived from fuels of fossil origin. The world is confronted with the twin crisis of fossil fuel depletion and environmental degradation due to indiscriminate use of these fuels. Renewable energy, energy conservation and management, energy efficiency and environmental protection have become very crucial for sustainable development in recent years. The diesel is used in large quantities in transport, agriculture, industrial, commercial and domestic sectors and increasing petroleum import bill has necessitated the search for liquid fuels as an alternative to diesel. For developing countries, fuels of bio-origin, such as alcohol, vegetable oils, biomass, biogas, synthetic fuels, etc. are becoming important. Such fuels can be used directly; while others need some sort of modification before they are used as substitute of conventional fuels. India will have to expedite its research on alternative diesel fuels to meet its future requirement. As diesel engines are considered as work horse in Indian economy, even substitution of a small fraction of total diesel requirement by alternative fuels will have a significant impact on the economy and the environment. Out of variety of alternative fuels, vegetable oils hold high potential in agriculture sector and transport sector.

1.1 Energy Crisis

An energy crisis is a great bottleneck in the supply of energy resources to an economy of any country. According to recent World Bank report Indian industry has the potential to save 20 to 30 % of total energy consumption. Energy conservation and efficiency improvement in the Indian power sector requires special attention since the sector has been suffering from a chronic supply shortage, lack of capital investment for new capacity addition and environmental problems. This resulted in an immediate, long term and multi-facet solution to the problems emerging from increased energy demands against short supplies. Energy management has also become the buzz word in industrial circles and 'energy' is considered as a major component in the production cost.

The above positive mindset has changed the pattern of energy use all over the world. Developed countries have increased their productivity while maintaining the same energy consumption levels. The world is moving towards a sustainable energy era with major emphasis on energy efficiency and use of renewable energy sources. The renewable sources of energy are very important and relevant in today's world. They cause lesser emissions and are available locally. Their use can, to a large extent, reduce chemical, radioactive, and thermal pollution. They stand out as a viable source of clean and limitless energy.

1.2 Energy Scenario

Energy has been affecting the geo-politics and always been an important issue in economic planning and international relations. India is rich in coal and abundantly endowed with renewable energy in the form of solar, wind, hydro and bio-energy, its hydrocarbon reserve is 0.7 billion tonnes (0.4 per cent of world's reserve).

Table 1.1: Primary energy consumption in India and World (2007) [1] (Mtoe)

Country	Oil	Natural Gas	Coal	Nuclear Energy	Hydro electric	Total
USA	943.8	595.7	573.7	192.1	56.8	2361.4
Canada	102.3	84.6	30.4	21.1	83.3	321.7
France	91.3	37.7	12	99.7	14.4	255.1
Russian Federation	125.9	394.9	94.5	36.2	40.5	692
United Kingdom	78.2	82.3	39.2	14.1	2.1	215.9
China	368	60.6	1311.4	14.2	109.3	1863.4
India	**128.5**	**36.2**	**208**	**4**	**27.7**	**404.4**
Japan	228.9	81.2	125.3	63.1	18.9	517.5
Malaysia	23.6	25.4	6.9	-	1.4	57.4
Pakistan	17.9	27.7	4.6	0.5	7.5	58.2
Singapore	47.4	5.9	-	-	-	53.4
Total World	**3952.8**	**2637.7**	**3177.5**	**622**	**709.2**	**11099.3**

The primary energy consumption in India and different countries is shown in table 1.1, which clearly reflects that most of the primary energy is met through fossil fuels and a small portion from nuclear or hydro. India accounted for 10.63 % of total primary energy consumption in Asia-Pacific region and 3.6 % of world primary consumption in 2007 [1]

Since the world's population is growing at the rate of 1.2 - 1.3 % Per annum or 75-80 million people per year. This means that in order to maintain today's world per capita energy use, we did have to build the equivalent of 1820 KGOE (Kilogram of oil equivalent) in 2008 which is shown in table 1.2, whereas per capita energy consumption of India is 510 KGOE, which is about 6 % of U.S.A. and 28 % of the world [2].

Table 1.2 Per capita energy consumption

Countries	Year 2005 (KGOE)	Year 2006 (KGOE)
U.S.A.	7915	7768
India	492	510
World	1797	1820

India's demand for petroleum products was 110.73 metric tonnes in 2001-02 which rose to around 155.78 metric tonnes in 2007-08 and India's self sufficiency in oil has consistently declined from 61.4% in 1990-91 to 21.89% in 2007-08 as shown in table 1.3**.** [3].

Table 1.3: India's petroleum production and demand scenario

Year	Domestic Production, (Mt)	Demand, (Mt)	Self Reliance, (%)
1990-91	33.02	53.72	61.4
1995-96	35.17	62.51	56.2
2000-01	32.43	106.523	30.4
2001-02	32.03	110.738	28.92
2003-04	33.38	123.815	26.96
2004-05	33.98	129.84	26.17
2006-07	33.99	144.85	23.46
2007-08	34.11	155.78	21.89

India is fourth largest economy of world and extensively uses energy to sustain its growth. As already elaborated India does not have huge reserves of petroleum products and mainly dependent upon the import of petroleum products to cater to its need for automobiles and other applications despite larger initiatives by government and exploration of new sources. India imported 121.67 million tons of crude petroleum and the Country spent Rs.2726.99 billion worth valuable foreign exchange in 2007-08. It is expected that India may have to import crude oil up to 85% of its requirement in 2010 which may even increase up to 92% in 2020[4 & 5]

1.3 Renewable Energy Sources

Renewable energy is energy obtained from sources that are essentially inexhaustible. The most important feature of renewable energy is that it can be harnessed without affecting the environment.

The potential for expanding the use of RETs (Renewable Energy Technologies) for energy generation is vast in India and awaits exploitation. Some of the Renewable energy potential and achievements is summarized on the table 1.4. These renewable energy technology are environmental benign. However, the high cost of these technologies has been a limiting factor in large scale adaptation.

Table 1.4: Renewable Energy Potential and Achievements in India as on 31.12.2007 [6]

S.No.	Sources/System	Estimated Potential	Cumulative Achievement
I.	Rural and Decentralized Energy System		
i)	Family Type Biogas Plants (nos.)	120 lakh	39.40 lakh
ii)	Solar Photovoltaic Programme	50MW/Sq. Km.	110 MWp
	a) Solar Street Lighting System	-	69,549 nos.
	b) Home Lighting System	-	3,63,399 nos.
	c) Solar Lantern	-	5,85,001 nos.
	d) Solar Power Plants	-	2.18 MWp
iii)	Solar Thermal Programme	-	
	i) Solar Water Heating System	140 million Sq. m. collector area	2.15 million Sq. m. collector area
	ii) Solar Cookers	-	6.17 lakh
iv)	Wind Pumps	-	1284 nos.
v)	Aero-generator/Hybrid Systems	-	675.27kW
vi)	Solar Photovoltaic Pumps	-	7068 nos.
II.	Remote villge Electrification	-	3368/830 Villages/ Hamlets
III.	Power from Renewables		
A.	Grid Interactive renewable Power		
vii)	Bio power(Agro residues & Plantations)	16,881	605.80 MW
viii)	Wind Power	45,195	7,844.52 MW
ix)	Small Hydro Power (up to 25 MW)	15,000	2,045.61 MW
x)	Cogeneration -bagasse	5,000	719.83 MW
xi)	Waste to Energy (Urban & Industrial)	2,700	55.25 MW
xii)	Solar Power		2.12 MW
	Total(in MW)	84,776	11272.13 MW
B.	Captive/CHP/Distributed renewable power		
xiii)	Biomass/Cogeneration (non- bagasse)		95.00 MW
xiv)	Biomass Gasifier	-	86.53 MW
xv)	Energy Recovery from Waste	-	23.70 MW
	Total	-	205.23MW
IV.	Other Programmes		
xvi)	Energy Parks	-	504 nos.
xvii)	Aditya Solar Shops	-	269 nos.
xviii)	Battery Operated Vehicle	-	270 nos.

1.4 Future Energy Scenario

The global primary energy demand is projected to increase by 1.6% per year between 2004 and 2030, reaching 17.1 billion tonnes of oil equivalent (btoe). Fossil fuels are projected to remain the dominant sources of primary energy globally.

They shall account for close to 83% of the overall increase in energy demand between 2004 and 2030 as shown in figure 1.1 [7]. The renewable energy technologies, including biofuels, wind, solar, geothermal, wave and tidal energy shall see the fastest increase in demand, but their share of total energy use still reaches only 1.7% in 2030 up from 0.5% in 2004. Over 70% of the increase in world primary energy demand between 2004 and 2030 comes from the developing countries.

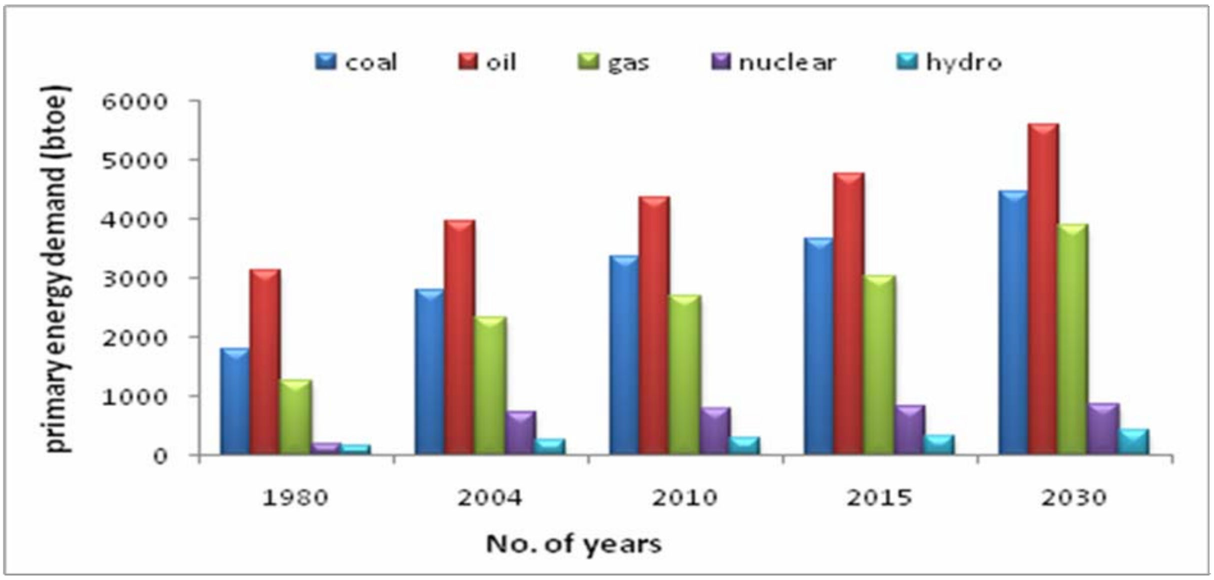

Figure 1.1: Fuel Shares in Primary Energy Demand

Global oil demand scenario has been drastically changed in recent years. In upcoming year 2015 and 2030, oil demand in India will be 3.7 mb/d and 5.4 mb/d respectively where as in world it will be 99.3 mb/d and 116.3 mb/d respectively. I.e. oil demand in India is expected to be 4 to 5 % of the world's demand in year 2015 to 2030 as shown in figure 1.2 [7].

In 1980, China and India together accounted for less than 8 percent of the world's total energy consumption. However, their share had grown to 18 percent in 2005. Even stronger growth is projected over the next 25 years, with their combined energy use more than doubling and their share increasing to one-quarter of world energy consumption in 2030 in the AEO (Annual Energy Outlook) 2008 reference case.

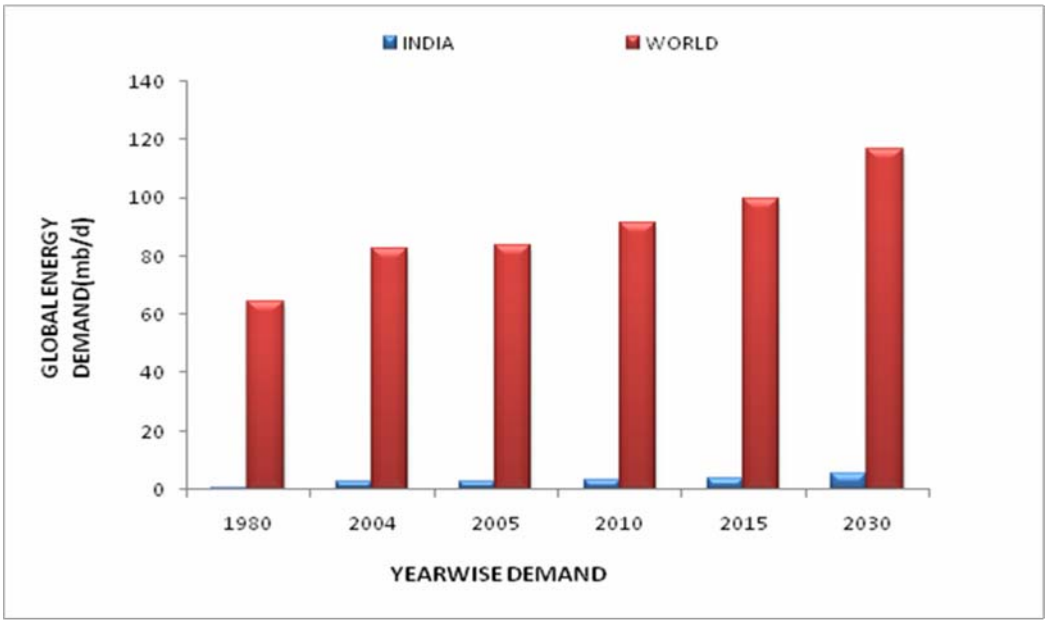

Figure 1.2: Future Global Energy Demand

The reference case clarifies that they will use as the starting point for pending and future analysis of proposed energy and environmental legislation. The development of an updated reference case is motivated primarily by the enactment of the American recovery & reinvestment act (ARRA) in mid February 2009. In contrast, the U.S. share of total world energy consumption is projected to contract from 22 percent in 2005 to about 17 percent in 2030[7].

1.5 Climate Change

Climate is referred to as the prevalent long-term weather conditions in a particular area. Human activities, particularly the combustion of fossil fuels, have made the blanket of greenhouse gases (water vapour, carbon dioxide, methane, ozone etc.) around the earth thicker. The resulting increase in global temperature is altering the complex web of systems that allow life to thrive on earth such as rainfall, wind patterns, ocean currents and distribution of plant and animal species. Climatic elements include precipitation, temperature, humidity, sunshine and wind velocity phenomena such as fog, frost, and hail storms. Climate change is caused by increases in the atmospheric concentration of so-called greenhouse gases (GHGs). These GHGs include: carbon dioxide (CO_2) (from burning fossil fuels), methane (CH_4), nitrous oxide (N_2O) (created by agriculture, land use and changes in land use where these gases are emitted), ozone (O_3) (generated mostly by fumes from car exhausts) and chlorofluorocarbons (CFCs). The increase of these GHGs in the atmosphere further prevents infrared radiation escaping from the earth's atmosphere into space, causing what is called 'global warming'. This acceleration of global warming by humans is referred to as the enhanced greenhouse effect or anthropogenic climate change [7]. Figure 1.3 depicts the green house effect in our atmosphere.

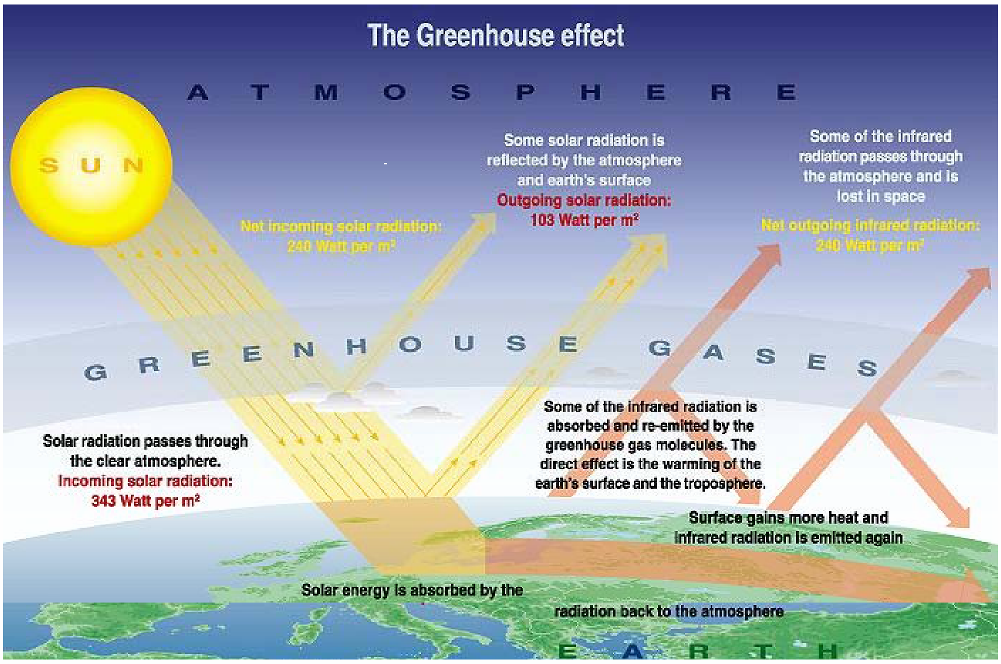

Figure 1.3: Green House Effect [8]

1.6 Effect of Global Warming

It is generally difficult to attribute specific natural phenomena to long-term causes, but some effects of recent climate change may already be occurring. Rising sea levels, glacier retreat, arctic shrinkage, and altered patterns of agriculture are cited as direct consequences, but predictions for secondary and regional effects include extreme weather events, an expansion of tropical diseases, changes in the timing of seasonal patterns in ecosystems, and drastic economic impact. Most of the world's endangered species (some 25 per cent of mammals and 12 per cent of birds) may become extinct over the next few decades as warmer conditions alter the forests, wetlands, and rangelands they depend on, and human development blocks them from migrating elsewhere.

1.7 CO_2 Emission Outlook

Carbon dioxide is responsible for 60 percent of the “enhanced greenhouse effect”. Only one part in 300 of the atmosphere is carbon dioxide. Currently, carbon dioxide levels in the atmospheric are rising by over 10 percent every 20 years. According to recent world database report Per capita CO_2 emission is 4.5 metric ton. Global energy-related carbon-dioxide (CO_2) emissions is expected to increase by 1.7 % every year over 2004-2030 [9]. They will reach 40.42 billion tonnes in 2030, an increase of 14.34 billion tonnes, or 55%, over the 2004 level as shown in table 1.5. By 2010, an emission has been raised up to 48% higher than in 1990’s.

Power generation is projected to contribute a little less than half the increase in global emissions from 2004 to 2030. Transport contributes one-fifth, with other uses accounting for the rest. Transport remains the second-largest sector for emissions worldwide, with its share of total emissions stable at around 20% throughout the projection period. [10].

Table 1.5: Global Increase in CO_2 by Different Sources

	1990	**2004**	**2010**	**2015**	**2030**	**2004-2030**
Power generation	6955	10587	12818	14209	17680	2.00%
Industry	4474	4742	5679	6213	7255	1.60%
Transport	3885	5289	5900	6543	8246	1.70%
Residential and services	3353	3297	3573	3815	4298	1.00%
Other	1796	2165	2396	2552	2942	1.20%
Total	**20,463**	**26,079**	**30,367**	**33,333**	**40,420**	**1.70%**

Charles Keeling began precise monthly measurements of the concentration of carbon dioxide in 1958 which has been shown in figure 1.4. He was the first to do so systematically and so his data have come to be known as the "The Keeling Curve." The measurements were made at the Mauna Loa Astronomical Observatory which is at the summit of an inactive volcano in Hawaii. Mauna Loa was chosen because it is far from major sources or sinks of carbon dioxide. Carbon dioxide concentrations measured at Mauna Loa are a good proxy for the average of the whole Earth.

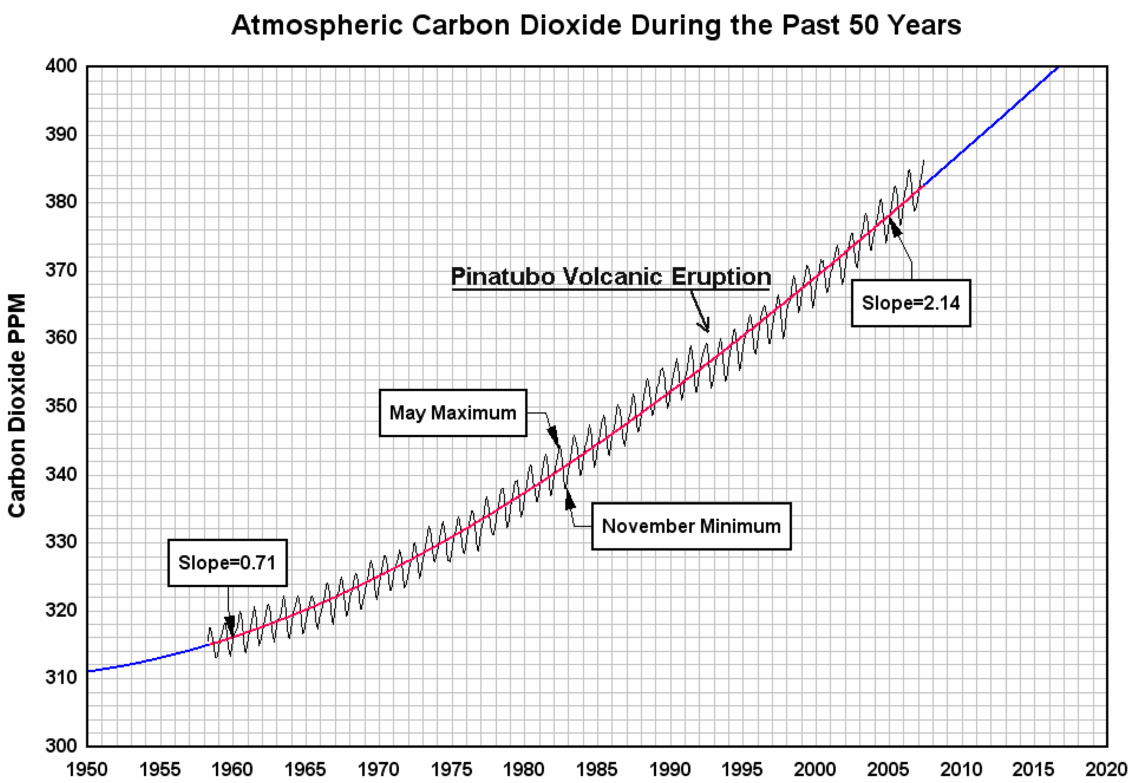

Figure 1.4: CO_2 Concentration in Atmosphere [11]

1.7.1 Interpretation of the Keeling curve

The black wiggles are a continuous record of the concentration of carbon dioxide in the Earth's atmosphere from 1958 to May 2008. The red line shows the same data but with the yearly variations removed. There are several ways this might have been done. Here, it was accomplished by fitting a curve called a 4th order polynomial data. The blue parts of the polynomial curve extend the record forward and backward in time. The red line is based on real data and the blue lines are plausible projections. Clearly the amount of carbon dioxide in the atmosphere is increasing. Equally clearly, the rate of increase is increasing. In 1960 the rate of increase per year was 0.71 PPM (parts per million). The 2005 rate of increase was 2.14 PPM per year. If the general trend continues, the concentration of carbon dioxide will be 400 PPM within ten years then it is hard to avoid this conclusion. The Pinatubo volcanic eruption of 1991 is credited with the slowing of the increase for a few years. The massive release of sulfur dioxide resulted in an increase in cloud cover which resulted in cooling which increased the solubility of carbon dioxide in sea water [11].

Developing countries shall account for over three-quarters of the increase in global CO_2 emissions between 2004 and 2030. The share of developing countries in world emissions shall rise from 39% in 2004 to 52% by 2030. China alone is responsible for 39% of the rise in global emissions. The CO_2 emissions due to oil shall remain as high as 25% in 2030 despite slight decline in its contribution since 2004. Table 1.6 summarizes the contribution of different fuels in global CO_2 emissions.

Table-1.6: Contribution of Different Fuels in Global CO_2 Emissions

	CO_2 emissions (Mt)				**Shares (%)**			**Growth (% p.a.)**	
	1990	**2004**	**2015**	**2030**	**2004**	**2015**	**2030**	**2004-2015**	**2004-2030**
Coal	401	734	1078	1741	67	67	68	3.5	3.4
Oil	164	314	450	645	29	28	25	3.3	2.8
Gas	23	54	92	157	5	6	6	5	4.2
Total CO_2 Emissions	**588**	**1,103**	**1,620**	**2,544**	**100**	**100**	**100**	**3.6**	**3.3**

1.8 Role of Diesel Engine in Indian Economy

Diesel Engine plays a very important role in Indian economy and also contributes to pollution significantly. These engines are used in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, underground mines equipment etc. The production of energy is carried through process of photosynthesis in which solar energy is converted into biomass. Agriculture in India is heavily based upon petroleum and its derived products such as fertilizers and pesticides. Energy sources used in agriculture are oil and electricity whereas indirect energy sources are chemical fertilizers and pesticides.

Oil and electricity are two major fuels which are used in agriculture sector. Because of mechanized farming the amount of energy consumed has increased multifold since independence in terms of oil and electricity.

1.9 Need of Alternative Fuels

An emphasized in preceding section, there is an urgent need to reduce dependence on petroleum derived fuels for better economy and environment. Adaptation of bio-origin fuels can address both these issues. These fuels are essentially non-petroleum and result in energy security and environmental benefits. This was the product of his dream an efficient internal combustion engine, powered by crude oil or even vegetable oil.

As our economic condition is concerned, we cannot afford such a heavy cost of diesel oil in rural areas where agriculture is a main source of income. Identification of alternative fuels for use in I.C. Engines has been subjected to studies throughout the globe. Performance tests have shown suitability of variety of alternative fuels such as hydrogen, alcohols, biogas, producer gas and various types of edible and non edible oils. However, considering the vast application of diesel in agriculture and transport sector in Indian, the bio-origin fuels such as vegetable oils derived fuels and biogas can significantly contribute towards the problems of fuel crisis and energy security.

CHAPTER 2

LITERATURE REVIEW

2.1 Vegetable oil as Potential Diesel Engine Fuel

The idea of using vegetable oil as a diesel engine fuel has been around for a long time and dates back to the beginning of last century when the diesel engine was invented. Only four years after Dr Rudolf Diesel produced his first functional prototype, diesel engines were being successfully run on straight vegetable oil (SVO). Straight vegetable oils do not contain any sulphur, aromatic hydrocarbons, metals or crude oil residues. The absence of sulphur means a reduction in the formation of acid rain by sulphate emissions which generate sulphuric acid in our atmosphere.

On a short term or emergency basis, many vegetable oils can be used directly as diesel fuel. The physical and chemical differences between unmodified vegetable oils and conventional diesel fuel, however, work against their long term use. In 1916, using the first diesel engine imported to Argentina, Gutierrez tested castor oil as an alternative fuel. In 1944, in Argentina, Martinez De Vedia described the duration runs with blends of vegetable oils and diesel fuel. The vegetable oils tested included sunflower, linseed, groundnut, cottonseed and turnip [12].The vegetable oils have comparable energy density, cetane number, heat of vaporization and stoichiometric air fuel ratio with mineral diesel fuel. [13]

Vegetable oils as alternative diesel engine fuels have received modest interest for several decades. However, economic factors have always favoured the use of petroleum based fuels. As already emphasized in preceding chapter, the uncertainties concerning adequate, stable supplies of petroleum fuels and environmental degradation have renewed interest in vegetable oils as diesel engine fuels [14]. Various crude or refined vegetable oils, low grade, non-edible, used vegetable oils, or oils recovered from other residues or wastes of chemical operations have been tested by numerous researchers for their utilization possibilities either straight or as diesel fuel extenders in C.I engines [15].

Vegetable oils fuels present promising ‘‘greener’’ substitutes for fossil fuels. Vegetable oils, due to their agricultural origin, are able to reduce net CO_2 emissions to the atmosphere along with import substitution of petroleum products. However, several operational and durability problems of using straight vegetable oils in diesel engines reported in the literature, which are because of their higher viscosity and low volatility compared to mineral diesel fuel [16].

Neat vegetable oil (Jatropha curcas) can be used safely in an indirect injection engine, but not in a direct injection engine due to the high degree of atomization required for this type. This problem is related to increasing droplet size on injection into the cylinder that results in poor combustion. This in turn, causes the formation of deposits in the combustion chamber, together with oil dilution due to introduction of unburnt fuel into the crankcase [17].

Vegetable oils are attractive and promising alternative to the diesel since they are renewable and can be produced easily in rural areas, where is there is acute demand of energy and can be used for developing decentralized energy sources. The significant use of vegetable oils as fuels in engines can be well judged by his two statements in the year 1911 and 1912 respectively.

"*The diesel engine can be fed with vegetable oils and would help considerably in the development of agriculture of the countries which use it.*"

"*The use of vegetable oils for engine fuels may seem insignificant today. But such products may in time become just as important as the kerosene and the coal tar products of the present time.*" [18]

2.2 Jatropha oil as a Diesel Engine Fuel

The concept of employing Jatropha oil as source for diesel fuel can be attractive for many developing countries because it can be grown on wasteland and infertile areas. In addition, the production of most vegetable oils including JO has a positive energy balance, and the use of these oils is environmentally neutral. As a locally grown fuel, vegetable oils are largely unaffected by world petroleum crises and indigenous production eases the foreign exchange concerns [19].

The Jatropha oil must meet the certain quality standard as a fuel [19]. It is important to note that the values of the free fatty acids, unsaponifiables, acid number and carbon residues vary in different oil samples. This indicates that the oil quality is dependent on the interaction of environment and genetics. The Jatropha oil contains more than 75% unsaturated fatty acid, which is reflected in the pour and cloud point of the oil.

The characteristics of variety of available vegetable oils fall within a fairly a narrow band and are closer to those of diesel oil. The Kinematic viscosity of vegetable oils varies in the range of 30 - 40 cSt at 38ºC. High viscosity of these oils is due to larger molecular mass and chemical structure. Vegetable oils have high molecular weights in the range of 600-900, which are three or more times higher than diesel fuel The flash point of vegetable oils are very high (above 200ºC).The heating value of these oils are of the range of 39 - 40 MJ/Kg which are low compared to diesel fuels (about 45 MJ/Kg).The presence of chemically bond oxygen in vegetable oils lower the heating value by about 10%. The cetane number is in the range of 32 to 40. The iodine value ranges from 0 to 200 depending upon un-saturation. The cloud and pour point of vegetable oils are higher than that of diesel fuel [20].

The high viscosity of vegetable oils deteriorates the atomization, evaporation and air fuel mixture formation characteristics leading to improper combustion and higher smoke emission, difficulty in engine starting, unreliable ignition and deterioration in thermal efficiency. In long-term use, durability problems like nozzle coking, carbon deposition in different parts of the engine and lubricating oil dilution are encountered .The methods adopted to decrease the viscosity of vegetable oils are (1) preheating, (2) mixing with other fuels and (3) converting to biodiesel [21].

It is very much necessary to evaluate the performance of vegetable oil in diesel engine before they could be adapted on large scale. The following literature review makes an attempt to examine the work carried by various researchers related to performance and emission of vegetable oil fuels.

2.3 Literature Review

Nwafor [22] investigated that 100% or neat vegetable oil can be used safely in an indirect injection engine, but not in a direct injection engine due to the high degree of atomization required for this type. The unheated plant fuel produced the highest brake thermal efficiency throughout the load range. There was no significant difference in BSFC between heated and unheated plant fuels at higher loading conditions. The heated fuel, however, offered a net reduction in BSFC at low engine speed operations.

Agrawal et al. [23] experimented on a single cylinder diesel engine on neat Karanja oil and its blends with and without preheating of oil and concluded that there was requirement of any modification in engine hardware. However, while using preheated fuel, engine efficiency improved slightly. Thermal efficiency of the engine with preheated oil blends was nearly 30% and for lower blends (unheated) such as K10, K20 and K50, it was 24–27%. The HC emissions from unheated and preheated lower blends (K10 and K20) were lower than mineral diesel. The emissions of NO_x from all blends with and without preheating are lower than mineral diesel at all load conditions. They concluded that the Karanja oil blends with diesel up to 50% (v/v) without preheating as well as with preheating have the potential to substitute diesel for running the CI engine for lower emissions and improved performance

Agrawal et al. [24] investigated on a similar study on Jatropha oil and found that thermal efficiency was lower for unheated Jatropha oil compared to heated Jatropha oil and diesel. CO_2, CO, HC, and smoke opacity were higher for Jatropha oil compared to diesel. BSFC and exhaust gas temperatures for unheated Jatropha oil was found to be higher compared to diesel and heated Jatropha oil.

Barsic et al. [25] found that it is essential to preheat the vegetable oil to 70–90 ºC to resolve the fuel filter clogging problem. They specified that a fuel inlet temperature requirement of 140ºC for acceptable viscosity for using vegetable as fuel for both direct injection and indirect injection engines. They found that heating the vegetable oils to 140ºC would-

(i) Reduce the viscosity to near that of diesel at 40ºC,

(ii) Increase the cetane rating,

(iii) Improve the Spray characteristics by increasing the penetration rate accompanied by a decrease in cone angle.

Bari et al. [26] experimented on increasing the fuel (vegetable oil) inlet temperature to 200ºC and concluded that it shall be effective in increasing the engine performance and reducing the carbon deposits build-up and piston ring sticking. They also used preheated Pongamia oil and Jatropha oil in both conventional and low heat rejection diesel engine. A decrease in the specific energy consumption and smoke emissions and an increase in NO_x emission were observed with preheated vegetable oil operation. It was also indicated that the injection system was not affected even by heating to 100ºC.

Nazar et al. [27] reported that the brake thermal efficiency with preheated vegetable oil was closer to that of diesel. They also used preheated karanja oil and neem oil as diesel fuel substitutes and found significant improvement in the engine performance with preheating.

Hiregoudar et al. [28] observed that the fuel injection system plays an important role in the efforts to achieve the reduction of engine emissions and fuel consumption, while keeping other engine performances at an acceptable level. A decrease in specific fuel consumption was reported using preheated vegetable oil. The high viscosity of vegetable oils creates operational problems like difficulty in engine starting, unreliable ignition and deterioration in thermal efficiency. In long-term use, durability problems like nozzle coking, carbon deposition in different parts of the engine and lubricating oil dilution are encountered

Hebbal et al. [29] concluded that the blends up to 25% without preheating and up to 50% with preheating can be substituted as fuel for diesel engine without any modifications in the diesel engine. Dilution of Deccan hemp oil with 75% of diesel has viscosity 7.658 cSt, which is very close to viscosity of diesel at 30ºC and does not require any heating prior to injection into combustion chamber. Blends containing 50%, 25% and 0% diesel require preheating up to 70, 80 and 95ºC, respectively.

The maximum brake thermal efficiency, minimum BSFC and BSEC of neat Deccan hemp oil are respectively 1.61% lower, 0.05 kg/kW-hr higher and 867.11 kJ/kW-hr higher compared to diesel. Smoke, unburnt HC and CO emissions at maximum load for neat Deccan hemp compared with diesel are higher by 3.08 Bosch No., 1.0 vol.%, and 50 ppm, respectively.

Alonso et al. [30] found that the vegetable oils (VO) used as fuel for heating. VO is one of the possible solutions for the problem of the increase in CO_2 emissions deriving from the burning of fossil fuels. Combustion produces CO_2, but when a fuel of vegetable origin is burnt, the carbon dioxide produced is compensated for that absorbed by the plants in the process of photosynthesis; it is a closed cycle.

Rakopoulos et al. [31] found the engine performance with the vegetable oil blends of various origins, was similar to diesel fuel having nearly the same brake thermal efficiency, showing higher specific fuel consumption for the high load and a minimum of it at the 10/90 blends for the medium load. A general practical conclusion found was that, with the exception of the slight concern for the little increase of emitted smoke with the vegetable oil blends, all the tested vegetable oil blends, can be used safely and advantageously in the Diesel engine, at least in small blending ratios with normal diesel fuel.

Banapurmath et al. [32] concluded that the high viscosity of vegetable oils leads to problem in pumping and spray characteristics. The inefficient mixing of vegetable oils with air contributes to incomplete combustion.

Pryor et al. [33] used neat crude soybean oil, crude degummed soybean oil in a three cylinder, 2600 series Ford Tractor engine. They observed that the engines running on soybean oil developed more or less same power as developed from diesel fuel. The brake specific fuel consumption was 11-13% greater than for diesel fuel at all loads.

Bacon et al. [34] reported that the initial engine performance tests using vegetable oils were found to be acceptable, while use of these oils continuously caused carbon build up in the combustion chamber. Continuous running of a diesel engine at part-load and mid-speeds caused rapid carbon deposition rates on the injector tips. Short 2 hr tests were used to visually compare the effects of using different vegetable oils in place of diesel fuel. The engine performance was found satisfactory and no irregularly was found.

Ryan et al. [35] characterized injection and combustion properties of several vegetable oils. They told that the atomization and injection characteristics of vegetable oils were significantly different from those of diesel fuel due to the higher viscosity of the vegetable oils. Engine performance tests showed that power output slightly decreased using vegetable oil fuel blends. Injector coking and lubricating oil contamination appeared to be a more dominate problem for oil-based fuels having higher viscosities.

Chauhan [36] evaluated the potential suitability of preheated Jatropha oil as a fuel. The experimental results suggest that the brake thermal efficiency (BTE) of the engine was lower and the brake specific energy consumption (BSEC) was higher when the engine was fuelled with Jatropha oil (Unheated and preheated) compared to diesel operation. The increase in fuel inlet temperature (FIT) resulted in increase of BTE and reduction in BSFC. He also observed that pre-heated Jatropha oil with the engine exhaust gases could be a good substitute fuel for diesel engine in the near future as far as decentralized energy production is concerned. The optimal fuel inlet temperature was found to be 80ºC considering the BTE, BSEC and gaseous emissions and durability and safe operation of the engine.

Tahir et al. [37] tested sunflower oil as a replacement for diesel fuel in agricultural tractors. Engine performance using the sunflower oil was found similar to that of diesel fuel, but due to relatively lower heating value of sunflower oil than diesel, more fuel was consumed and engine produced slightly less power when it was fuelled with sunflower oil.

Bruwer et al. [38] studied the use of sunflower seed oil as a renewable energy source. He ran the tractors with 100% sunflower oil instead of diesel fuel and reported that an 8% power loss occurred after 1000 hr of operation. The power loss was corrected by replacing the fuel injectors and injector pump. After 1300 hr of operation, the carbon deposits in the engine were reported to be equivalent to an engine fuelled with 100% diesel except for the injector tips, which exhibited excessive carbon build-up.

Worgetter [39] tested rapeseed oil as an alternative fuel in a 43 kW tractor engine. The test was aborted at about 400 hr due to unfavourable operating conditions. The use of rapeseed oil in the fuel resulted in heavy carbon deposits on the injector tips and pistons. Upon engine tear down, it was found that the heavy carbon deposits on the pistons were the cause of the noted power loss and not the fuel injectors.

Prateepchaikul et al. [40] made a comparison of refined palm oil and diesel oil in a small single cylinder in-direct injection diesel engine. They ran the engine more than 2000 hr. They concluded that during the 1000 hr of operation, the specific fuel consumption of the engine fuelled by refined palm oil was 15–20% higher and the black smoke density was not significantly different but wear in the compression rings of the engine, fuelled by refined palm oil was significantly higher as compared to the use of pure diesel

Nwafor [41] studied the effect of reducing viscosity by increasing the inlet temperature of vegetable oil fuel on combustion and emission characteristics of diesel engine. The test results showed that the CO production with heated fuel is a little higher than the diesel fuel at higher loading conditions. The CO concentrations in the exhaust were higher for unheated oil operation compared to other fuels. The heated oil showed marginal increase in CO_2 emissions compared to diesel fuel. The hydrocarbon emissions were significantly reduced when running on plant oils. The fuel consumption was a little worse when running on plant fuel. The ignition delay was longer for unheated plant fuel operation.

Reddy et al. [42] investigated the use of neat Jatropha oil on a single cylinder, constant speed, direct injection diesel engine. They changed injection timing, injector opening pressure, injection rate and air swirl level to study their influence on performance, emissions and combustion and compared results with neat diesel operation. Advancing the injection timing from the base diesel value and increasing the injector opening pressure increase the brake thermal efficiency and reduce hydro carbon (HC) and smoke emissions significantly. When the injection timing is retarded with enhanced injection rate, a significant improvement in performance and emissions was noticed. In this case emissions with Jatropha oil are even lower than diesel. Enhancing the swirl has only a small effect on emissions. The ignition delay with Jatropha oil is always higher than diesel under similar conditions. Improved premixed heat release rates were observed with Jatropha oil when the injector opening pressure is enhanced.

Silvico et al. [43] used heated palm oil as the fuel in a diesel generator. Studies revealed that exhaust gas temperature and specific fuel consumption were increased with an increase in charge percentage. The carbon monoxide emission was increased with the increase of load. Unburned HC emissions were lower at lower loads, but tended to increase at higher loads. This was due to a lack of oxygen resulting from the operation at higher equivalence ratios. Palm oil NO_x emissions were lower as compared to the diesel fuel.

Forson et al. [21] tested in a Lister model engine(single cylinder, air-cooled, direct injection, 4-stroke diesel engine) a blend of 2.6 % JCL oil and 97.4% fossil diesel by volume showed lowest BSFC and highest BTE in comparison to fossil diesel and blends with higher Jatropha oil portion..

2.4 Statement of the Problem

On the strength of the exhaustive review of work done by previous researchers, it can be found that there is no substantial work has been made on a slow speed diesel engine for accessing the potential suitability of variety of vegetable oils, either in neat or in blended form with and without preheating. However, it is evident that most of the work has been done on direct injection, high speed diesel engine. As high viscosity of vegetable oil has resulted in determinately effect on performance and durability, studies have also been made on pre-heating to decrease the viscosity at high temperature and alleviate the problem of high viscosity.

As Jatropha is becoming a sustainable source for diesel replacement in India, its high viscosity issue can be resolved by adapting two strategies; first to modify the engine to adapt to the fuel and the second for processing the fuel to adapt to the engine. The literature suggests that modifying existing diesel engines to preheat Jatropha oil to reduce viscosity and could achieve the first strategy. The adaptation of Jatropha oil in the diesel engine could also be done by blending the Jatropha oil with diesel or converting into biodiesel through transesterification process as a part of second strategy. As transesterification process requires expertise and equipments are not easily understandable to rural community and blending still require diesel, it shall be advisable to formulate the strategy in which neat Jatropha oil could be used in diesel engine without detrimental effect on engine health. As already mentioned, it was found that very little quantum of work has been done on potential suitability of Jatropha oil in slow speed diesel engine and no work has been reported on assessing the aptness of neat Jatropha oil or preheated oil in slow speed IDI Engine.

Therefore, in the present research work, following objectives were formulated.

1. Comprehensive literature survey.
2. Determination of important Physico-chemical properties of Jatropha oil.
3. Development of dual fuel, slow speed IDI diesel engine test rig.
4. Development of heat exchanger arrangement for pre-heating Jatropha oil
5. Determination of viscosity variation on elevated temperature
6. Conducting exhaustive experiments on the test rig to evaluate performance and emission characteristics of neat Jatropha oil and compare with base line data of diesel
7. Analysis of Results

CHAPTER 3

ENGINE SELECTION AND SYSTEM DEVELOPMENT

3.1. Introduction

A large number of factors have made energy derived from biomass as the matter of debate for policy maker and industry. Lower support prices of agricultural commodity, dependence on imported petroleum and environmental squalor have increased interest in energy produced from plant sources. The world community has realized the importance of vegetable oil based decentralized energy production and many of them have been successfully completed at the community level in the recent years. The qualities of this fuel, environmentally as well as technically, have pushed this fuel into fore front of final stages of commercialization in many countries. The major benefit of non edible oilseed production is that there is no need to adopt a particular oil seed bearing crop all over the world, rather, each country can have its own oil seed suited to their climate and economy. Large scale initiatives have been taken by different countries in this field after taking into consideration the above mentioned parameters.

3.2. Jatropha Curcas Plant Description and Cultivation

Re-forestation has a very important role in meeting the challenge of Climate Change. Several initiatives have been taken in recent years in different parts of the India to promote large scale cultivation of oilseed bearing plants. Amongst the various plant species, Jatropha Curcas has been found very suitable as a substitute to diesel fuel.

The Jatropha plant (Jatropha Curcas) is a shrub tree belonging to the genus Euphorbiaceae. The Jatropha plant originated from South America, but now the plant can be found worldwide in arid and semi arid tropical and sub-tropical countries. The Jatropha plant can be grown in almost all types of soils. It can even be grown in very poor soil and still produce a high average yield of seeds. However, light sandy soil is the most favourable. Jatropha can be found from sea level to 1800 m altitudes. The oil is pale yellow to brown in colour. The oil contains a toxic substance, in which they have a strong purging effect The Jatropha plant itself can be used in erosion control if planted across the hills and against the wind.

3.3 Jatropha oil as Possible Renewable Energy Source for Agriculture Sectors

Rural energy problems in developing countries are linked with other rural problems. These problems need an integrated approach to reach solutions. The Jatropha plant has four main contributions to rural development and poverty eradication, Renewable energy, promotion of women, poverty reduction and soil erosion control Furthermore, in the issue of poverty reduction, it provides a source of income in rural areas through the use of Jatropha oil as fuel and as raw materials for the soap making that earns more income for rural communities. The fruit hulls themselves are combustible and could be used to produce fire in villages. It could also be fermented to generate biogas. Jatropha oil could also be used as cooking fuel or lighting fuel in rural areas and the seed cake could also be used in anaerobic digester to produce biogas. The fact that the cash that was used to purchase petroleum products will remain in the village ensures more hard cash to be retained in the village that might help to meet other essential obligations. The Jatropha plant also provides a source of employment to many rural dwellers, which in turn helps to reduce urban migration in developing countries.

3.4. Jatropha as Toxic as well as Medicine

The leaves are used as a medicine and could also be used to develop Eri Silkworm. The leaves could also be used as an anti-inflammatory substance. In many places, the latex is used to heal wounds and as a medicine. The oil also contains an insecticide, which makes it possible for Jatropha oil to be used for medicinal purposes due to its strong purging effects. Apart from its use as a liquid fuel, the oil has been used to produce soap and biocides (insecticide, molluscicide, fungicide and nematicide).

The advantage is that the plant could not be browsed by animals and could act as an excellent fence. The disadvantage comes from the fact that the equipment, such as screw presses that are used to press Jatropha seeds, could not be used to press other edible seed oil from plants like sunflower unless a thorough cleaning is done which would take a lot of environmental resources. The main source of the toxicity is the phorbol esters contents of the seeds that could also promote tumours and inflammation. However, it has been observed that it is possible to detoxify the phorbol esters by deacidification and bleaching in order to use the seedcake for animal feed. The deacidification could reduce the phorbol esters up to 55%. The claims that there are some varieties of non-toxic Jatropha plants need more investigation.

From previous study it is clear that the viscosity is major problem to commercialize the Jatropha. The literature indicates that developing special engines like the Elsbett engine or modifying existing diesel engines to preheat Jatropha oil first to reduce viscosity and filter the fuel could achieve the first strategy. The modification of engines or manufacturing engines to run on straight Jatropha oil requires the addition of new injector, glow plugs, filter and heat exchanger to the old diesel engine design. The second option is modification of Jatropha oil to the existing engines. This option seems to be more practical since developing countries and rural community in particular shall not have enough funds to support the engine modification. The adaptation of Jatropha oil to the diesel engine could be done by using neat Jatropha oil by a dual tank approach, blending the Jatropha oil with diesel, producing methyl esters or ethyl esters through transesterification process that could be used straight instead of diesel or dual fuelling with diesel. However, it is very much essential to explore the possibility of using neat Jatropha oil in a dual tank mode before experimenting the other techniques since those techniques requires expertise and equipments such as transesterification process.

3.5 Selection of Engine

Diesel engines play an indispensable role in agriculture and transportation sector and as such diesel consumption is expected to increase multi fold in future. The diesel engine continues to dominate the agriculture sector in our country in comparison to spark ignition engine and have always been preferred widely because of power developed, specific fuel consumption and durability. In India, almost all irrigation pump sets, tractors, mechanized farm machinery and heavy transportation vehicle are powered by direct injection diesel engines. However, they are not considered suitable for vegetable oil adaptation on a long term basis. Considering the wide application of a small capacity diesel engine which has got great dominance in Indian agriculture sector, a slow speed, IDI, lister type, 4 stroke diesel engine was selected for the present study as the maintenance of this engine is very simple and due to its slow speed potential suitability of neat Jatropha oil is more in this kind of engine.

3.6 Development of Experimental Test Rig

The indirect injection (IDI) diesel engine used for this study is manufactured by Rolex Industries Engines Limited. It is widely used in India in agriculture for running the irrigation pump sets, running agriculture machinery and for driving different machines in industrial sector and shown in Plate 3.1.

Plate 3.1: Slow Speed Diesel Engine

It is a single cylinder, naturally aspirated, four stroke, vertical, water-cooled engine. It has a provision of loading electrically since it is coupled with single phase alternator through belt and pulley arrangement. The cylinder is made of cast iron and fitted with a hardened high-phosphorus cast iron liner. The lubrication system used in this engine is of splash system, and oil is delivered to the crankshaft. The inlet and exhaust valves are operated by an overhead camshaft driven from the crankshaft through two pairs of bevel gears. The fuel pump is driven from the end of camshaft. The engine can be hand started using decompression lever and is provided with spring loaded governor. The engine was started on diesel engine and after some time (10-15 minutes) it was switched on to the neat Jatropha mode where it again run on part load for more than half hour so that engine could achieve steady state and then the actual data were taken from no load to full load. The detailed technical specifications of the engine are given in table 3.1.

Table 3.1: Specifications of the slow speed diesel engine

Make	**Rolex**
Rated Brake Power (bhp/kW)	5 / 3.73
Rated Speed (rpm)	650
Number of Cylinder	Single
Bore X Stroke (mm)	114.3 x 139.7
Compression Ratio	17:1
Cooling System	Water Cooled
Lubrication System	Splash system
Cubic Capacity	1.432 Litre
Inlet Valve Open (Degree)	5˚ BTDC
Inlet Valve Closed (Degree)	15˚ ABDC
Exhaust Valve Open (Degree)	45˚ BBDC
Exhaust Valve Closed (Degree)	5˚ ATDC
Fuel Injection Timing (Degree)	20˚ BTDC

For conducting the desired set of experiments from the engine, it is essential to get the various instruments mounted at the appropriate location on the experimental setup. Apart from this, a dual fuel system has been developed for diesel and Jatropha oil.

The schematic diagram of the experimental setup along with all instrumentation is shown in figure 3.1. Overall pictorial view of the test rig along with instrumentation used in the present investigations is shown in plate 3.2.

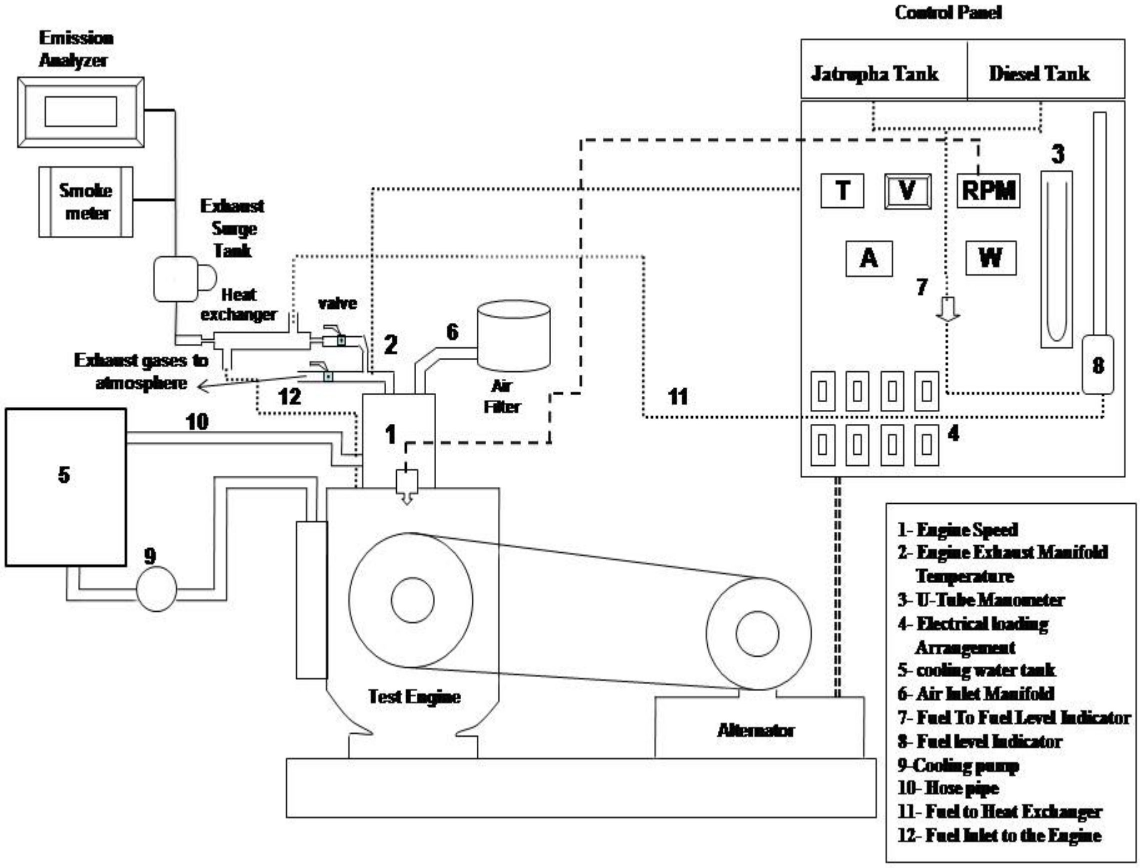

Figure 3.1: Schematic Block Diagram of Engine Setup

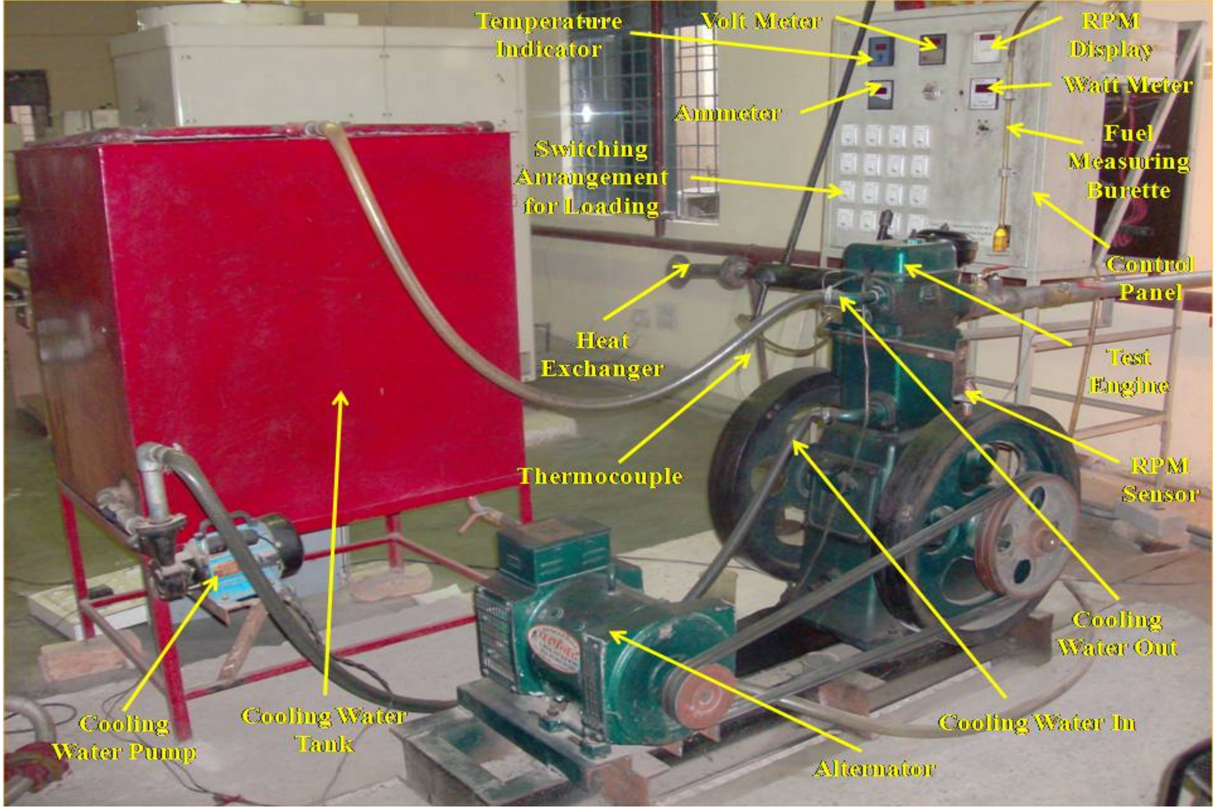

Plate 3.2: Photograph of the Test Rig

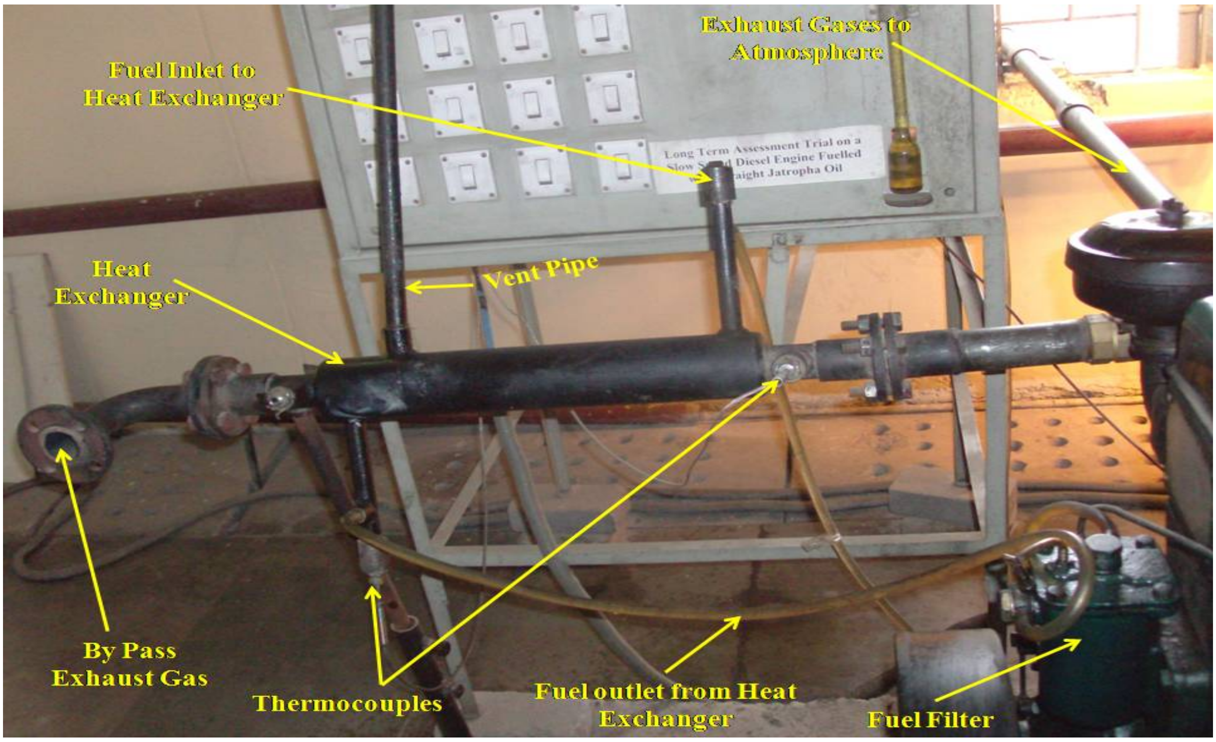

Plate 3.3: Photograph of Heat Exchanger Arrangement for Preheating by Exhaust Gases

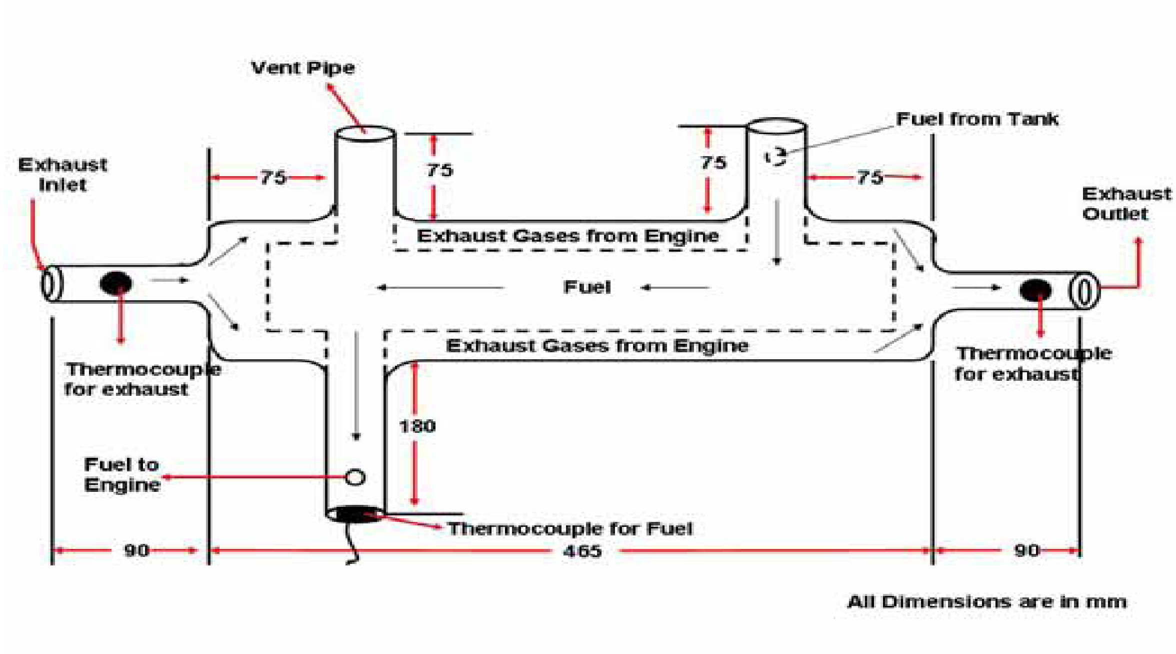

Figure 3.2 Schematic Diagram of the Counter flow Heat Exchanger

As already elaborated, higher viscosity is a major problem in using vegetable oil as fuel for diesel engines. In the present investigations, viscosity was reduced by heating the Jatropha oil. Viscosity of Jatropha oil was measured in the range of 40 to 100 ^{o}C (40 ^{o}C, 60 ^{o}C, 80 ^{o}C and 100 ^{o}C). For the present investigation, a shell and tube type, counter flow heat exchanger as shown in figure 3.2 was developed to preheat the vegetable oil using waste heat of the exhaust gases. In order to control the temperature of the Jatropha oil within a range of 40–100 ^{o}C, a bypass arrangement was provided in the exhaust gas line before the heat exchanger. This bypass valve reduces the amount of exhaust gases which controls the temperature of the Jatropha oil. Thermocouples were provided in the exhaust line to measure the temperature of the exhaust gases at the outlet and inlet section.

3.7 Installation of the Instrument Control Panel

After finalizing the procedures for data collection and procurement of the desired instruments, they were put on a panel. A MS Control panel was fabricated and Instruments such as voltmeter, ammeter, watt meter, speed counter, six channels digital temperature display was mounted on the front side of the control panel as shown in Plate 3.4. Electrical load bank, in which 7 bulbs of 500 watts, 1 bulb of 300 watts, 2 bulbs of 200 and a single bulb of 100 watt were mounted on the rear side of the control panel which is shown in Plate 3.5 and their switches provided on the front side of the control panel.

Plate 3.4: Control Panel

Plate 3.5: Load Bank

One 50ml burette with stop cocks was also mounted on the front side of the panel for fuel flow measurements of either diesel fuel or Jatropha oil. The two fuel tanks were mounted on the rear side of the panel at highest position with stop cocks as shown in plate 3.6.

Plate 3.6: Two Tanks System

A voltmeter, ammeter and wattmeter were connected between alternator and load bank. A nut was welded on the flywheel and the photo reflective sensor was mounted on a bracket attached to engine body. The thermocouples were mounted in the exhaust manifold to measure the exhaust temperature. The AVL 437 smoke meter and AVL Di Gas Analyzer were also kept in proximity for the measurements of various exhaust gas parameters.

Thus such a system was chosen to examine the practical utility of pre-heated Jatropha oil in such applications. Besides being a single cylinder system it was light and easy to maintain. The engine was provided with suitable arrangement, which permitted wide variation of controlling parameters. Being a water cooled engine it was also suitable for hot climate. The engine was cooled by providing a cooling water tank from where cold water was fed to the engine and hot water after cooling was pumped back to cooling water tank. Absence of radiator made the system more suitable for the tests.

3.8 Parameter Selection

The selections of appropriate parameters were essential for engine calculations, and parameters were selected very judiciously. The engine test was done as specified by IS: 10000. The main parameters desired from the engine are listed below.

1. Power produced by the engines
2. Engine speed (Rev/min)
3. Fuel consumption
4. Temperature
5. Speed of the engine
6. Gaseous emissions from engine such as CO, CO_2, HC, NO_X and smoke opacity.

With a view to calculate the parameters mentioned above, it was essential to pick up the following signals from the test bench.

1. Voltage generated by the alternator
2. Current generated by the alternator
3. RPM of the engine
4. Exhaust gas temperature at inlet and outlet of heat exchanger.
5. Jatropha fuel inlet and outlet temperature across heat exchanger
6. Fuel consumption rate
7. Smoke opacity from AVL 437 smoke meter.
8. CO, CO_2, HC, NO_X, from AVL Di Gas analyzer

Once the parameters were selected, the essential instruments required for sensing these parameters were installed at the appropriate points in the experimental set-up.

3.9. Measurement Methods

As already elaborated, the main components of the experimental setup are two fuel tanks (diesel and Jatropha oil), Fuel consumption measuring unit, electrical loading arrangement, voltmeter, ammeter, RPM meter, temperature indicator and emissions measurement equipments. The engine is started with diesel for at least 30 minutes and once the engine warms up, it is switched over to Jatropha oil. The two different stop cocks were provided in both the tanks. For switching the engine from diesel to Jatropha oil, the stop cock of diesel tank was shut whereas the stop cock of Jatropha oil was opened. With the help of this fuel measuring unit, the volumetric flow of the fuel can be easily measured. The fuel from the fuel measuring unit enters in to the fuel filter before entering to the engine.

3.9.1 Fuel Flow Measuring System

The fuel consumption of an engine is measured by determining the time required for consumption of a given volume of fuel. The mass of fuel consumed can be determined by multiplication of the volumetric fuel consumption to its density. In the present set up, volumetric fuel consumption was measured using a glass burette. The time taken by the engine to consume a fixed volume was measured using a stopwatch. The volume divided by the time taken for fuel consumption gives the volumetric flow rate. The test facilities were built up for measuring both diesel and Jatropha oil consumption rates as shown in the Plate 3.7.

Plate 3.7: Fuel Flow Measuring System

This test was carried out only after the preliminary run. After stable operating conditions were experimentally achieved, the engine was subjected to similar loading conditions. Starting from no load, observations were recorded at 20%, 40%, 60%, 80% and 100% of the rated load.

The brake specific fuel consumption was calculated by using the relationship given below:

$$bsfc = (Vcc \times \ell \times 3600) / (hp \times t) \tag{3.3}$$

and

$$bsec = bsfc \times CV \quad kJ/kW\text{-}h$$

Where,

bsfc	=	Brake specific fuel consumption, g/kW-h
Vcc	=	Volume of fuel consumed, cc
ℓ	=	Density of fuel, g/cc
hp	=	Brake horsepower, kW
t	=	Time taken to consume, cc of fuel, sec.

The brake thermal efficiency of the engine on different fuel blends at different operating conditions was determined using the equation as given below:

$$\eta_{th} = Ks / (HV \times bsfc) \tag{3.4}$$

Where,

η_{th}	=	Brake thermal efficiency, %
Ks	=	Unit constant, 3600
HV	=	Gross heat of combustion, kJ/kg
bsfc	=	Brake specific fuel consumption, g/kW-h

3.9.2 Rpm of the Engine

An 'MTC' make digital panel tachometer with proximity/photo reflective sensor was used for measurement of RPM. The instrument is capable of functioning in the range of 1 to 9,999 rpm with a sampling time of 1 second. For measurement, a nut was welded as shown in plate 3.8 on the flywheel face and sensor was mounted on a bracket near the flywheel in such a way that the distance was less than 5 mm. The display unit is digital and mounted on the panel board.

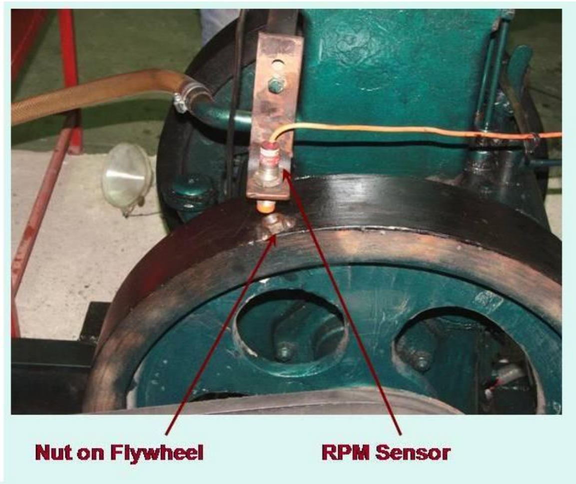

Plate 3.8: Engine Speed Measurement

3.9.3 Temperature Measurement

Chromel-Alumel K-type thermocouples as shown in plate 3.9 were connected to a 6 channel digital panel meter to measure temperatures of exhaust gases. Temperature of Jatropha oil is also observed at various points. The meter was calibrated by a millivolt source up to 800^{o} C.

Plate 3.9: Temperature Measurement Arrangement

3.9.4 Exhaust Emission Analysis

The exhaust gas analysis was done for exhaust smoke opacity, UBHC, CO, CO_2 and NO_X. For measuring the smoke opacity, AVL 437 smoke analyzer was utilized. This instrument gave reading in terms of percentage opacity. Of the light beam projected across a flowing stream of exhaust gases, a certain portion of light is absorbed or scattered by the suspended soot particles in the exhaust. The remaining portion of the light falls on a photocell, generating a photoelectric current, which is a measure of smoke density. The detailed technical specifications have been given in Appendix I.

For measurement of UBHC, CO, CO_2 and NO_X, an AVL4000 Light Di-Gas Analyzer was used. The detailed specification of AVL Di-gas Analyzer has been given in Appendix II. AVL 437 Smoke meter and AVL Di Gas Analyzer are shown in Plate 3.10.

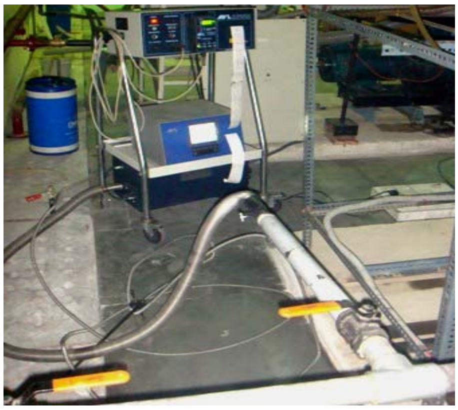

Plate 3.10: Smoke and Emissions Measuring System

CHAPTER-4

PHYSICO-CHEMICAL PROPERTIES AND EXPERIMENTAL PROCEDURES

4.1 Physico-Chemical Properties

4.1.1 Density

Density is the mass per unit volume. The measurement was made at room temperature. The density was measured with the help of a U-Tube Oscillating True Density meter. The density of Jatropha oil was measured and then compared with that of diesel fuel. The equipment used for density determination is shown in plate 4.1.

Plate 4.1: U-Tubes Oscillating True Density Meter

4.1.2 Viscosity

When a fluid is subjected to external forces, it resists flow due to internal friction. Viscosity is a measure of internal friction. The viscosity of the fuel affects atomization and fuel delivery rates. Absolute viscosity sometimes called dynamic or simple viscosity is the product of Kinematic viscosity and fluid density. Kinematic viscosity of liquid fuel samples were measured at 40˚C using Kinematic viscometer shown in plate 4.2 as per the specification given in ASTM D445.

To flow through the capillary. Efflux time was measured for calculating Kinematic viscosity using the formula given below:

$$v = c^* t \qquad \text{... (4.1)}$$

Where,

v = Kinematic viscosity, cSt or mm^2/sec

c = constant; mm^2/sec^2

t = time, second

Plate 4.2: Kinematic Viscometer

4.1.3 Flash and Fire point

Flash point is the minimum temperature at which the oil vapour, which when mixed with air forms an ignitable mixture and gives a momentary flash on application of a small pilot flame. The flash and fire point of the test fuels were measured as per the standard of ASTM D 93. The sample was heated in a test cup at a slow and constant rate of stirring for proper and uniform heating. The temperature at which these vapour catches flash is observed and called as the flash point of that liquid. Fire point is an extension of flash point in a way that it reflects the condition at which vapour burns continuously for at least for 5 seconds. Fire point is generally higher than the flash point by 5-8 ^oC. A Pensky Martens apparatus was used in the study for determination of flash point and is shown in plate 4.3.

Plate 4.3: Pensky Marten Flash Point Apparatus

4.1.4 Cloud and Pour Point

Cloud and Pour points are important for determining the feasibility of using the fuel in engine at lower ambient temperatures. Fuels with high pour points give flow problems at lower temperature, therefore it cannot be recommended for use in engine at low temperatures. Pour point for fuel oils, lubricating oils and diesel fuels is used as criteria in cold surroundings. The cloud and pour point of the fuel were measured as per the specification given of ASTM D2500 and ASTM D97 respectively. The cloud and pour point apparatus used for determination of these properties is shown in plate 4.4.

Plate 4.4: Cloud and Pour Point Apparatus

The pour point is determined by cooling a sample of the oil in a test jar, to a temperature when the jar is displaced from the vertical to the horizontal position, no perceptible movement of the oil will occur within the first 5 second.

4.1.5 Calorific Value

The calorific value is defined in terms of the number of heat units liberated when unit mass of fuel is completely burnt in a calorimeter under specified conditions. Higher calorific value of fuel is the total heat liberated in kJ per kg or m^3.

The calorific value of the fuel was determined with the Isothermal Bomb Calorimeter as per the specification given in ASTM D-240. The combustion of fuel takes place at constant volume in a totally enclosed vessel in the presence of oxygen. The sample of fuel was ignited electrically. The water equivalent of bomb calorimeter was determined by burning a known quantity of benzoic acid and heat liberated is absorbed by a known mass of water. Then, the fuel samples were burnt in bomb calorimeter and the calorific values of all samples were calculated. The Bomb Calorimeter used for determination of Calorific value is shown in plate 4.5.

Plate 4.5: Bomb Calorimeter

4.1.6 Cold Filter Plugging Point (CFPP)

Cold Filter Plugging Point (CFPP) is defined as the minimum temperature at the fuel filter does not allow the fuel to pass through it. At low operating temperature fuel may thicken and does not flow properly affecting the performance of fuel lines, fuel pumps and injectors. Cold filter plugging point of vegetable oils reflects its cold weather performance.

4.2 Experimental Procedure

The cooling water pump was started before cranking the engine, which is connected with cooling water tank through hose pipe. The engine was started at no load by pressing the exhaust valve with decompression lever and it was released suddenly when the engine was hand cranked at sufficient speed. Feed control was adjusted so that engine attains rated speed and was allowed to run for about 30 minutes till the steady state conditions were reached. With the fuel measuring apparatus and stop watch the time elapsed for the consumption of 10, 20 and 30 cc of fuel was measured and average of them was taken. Fuel Consumption, RPM, exhaust temperature, smoke density, CO, NO_x, HC , CO_2 and power output were also measured. The engine was loaded gradually keeping the speed with in the permissible range and the observations of different parameters were evaluated. Tests were also carried out on the engine with diesel to generate the base line data

Thermocouples were used to measure the temperature at the salient point of the diesel engine at running conditions. The output of the thermocouple was fed to the digital temperature indicator with variable junction to indicate the temperature readings. The thermocouple was mounted on the engine assembly through special arrangements. The engine was started on diesel fuel and after engine became sufficiently warm, it was switches over to Jatropha oil

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 Introduction

The present study was done on a slow speed diesel engine which was converted to run on a dual mode operation. The main objective of the study was to access the performance and emission characteristics of diesel engine with preheated straight Jatropha oil and result compared with baseline base line data on diesel and unheated Jatropha oil.

5.2 Comparison of Physico-Chemical Properties between Diesel and Jatropha Oil

Both the fuels; diesel oil and Jatropha oil were analyzed for several physical, chemical and thermal properties. Density, cloud point and pour point of Jatropha oil were found higher than diesel. The flash point of Jatropha oil was quite high compared to diesel. Hence, Jatropha oil is extremely safe to handle. Presence of oxygen in fuel improves combustion properties but reduces the calorific value of the fuel. Jatropha oil has approximately 80-90% calorific value compared to diesel. Nitrogen content of the fuel also affects the NO_x emissions (by formation of fuel NO_x). Higher viscosity is a major problem in using vegetable oil as fuel for diesel engines. The Viscosity of Jatropha oil can be improved by preheating the oil or blending it with mineral diesel. Viscosity of Jatropha oil was measured at 40°C and found to be very high as compared to mineral diesel. The Various Physico-chemical properties of Diesel and Jatropha oil are given in table 5.1.

Table 5.1: Physico-Chemical Properties of Diesel and Jatropha Oil

Property	Mineral Diesel	Jatropha Oil
Density(kg/m^3)	830	918
API gravity	37.15	22.81
Kinematic Viscosity at 40°C (cSt)	2.5	37
Cloud Point(°C)	-12	9
Pour Point(°C)	-17	4
Flash Point(°C)	70	238
Calorific Value(kJ/kg)	42700	37800
Carbon Residue Micro Method (%, w/w)	0.3	0.29
Ash Content(%w/w)	0.01	0.04
Carbon(%,w/w)	86.71	77.21
Hydrogen(%,w/w)	12.98	10.25
Nitrogen (ppm)	5	3
Oxygen(%,w/w)	0.31	12.52
Sulfur (ppm)	340	8

5.3 PERFORMANCE CHARACTERISTICS

The performance characteristic of the slow speed diesel engine on pre-heated Jatropha oil is summarized below.

5.3.1 Brake Thermal Efficiency

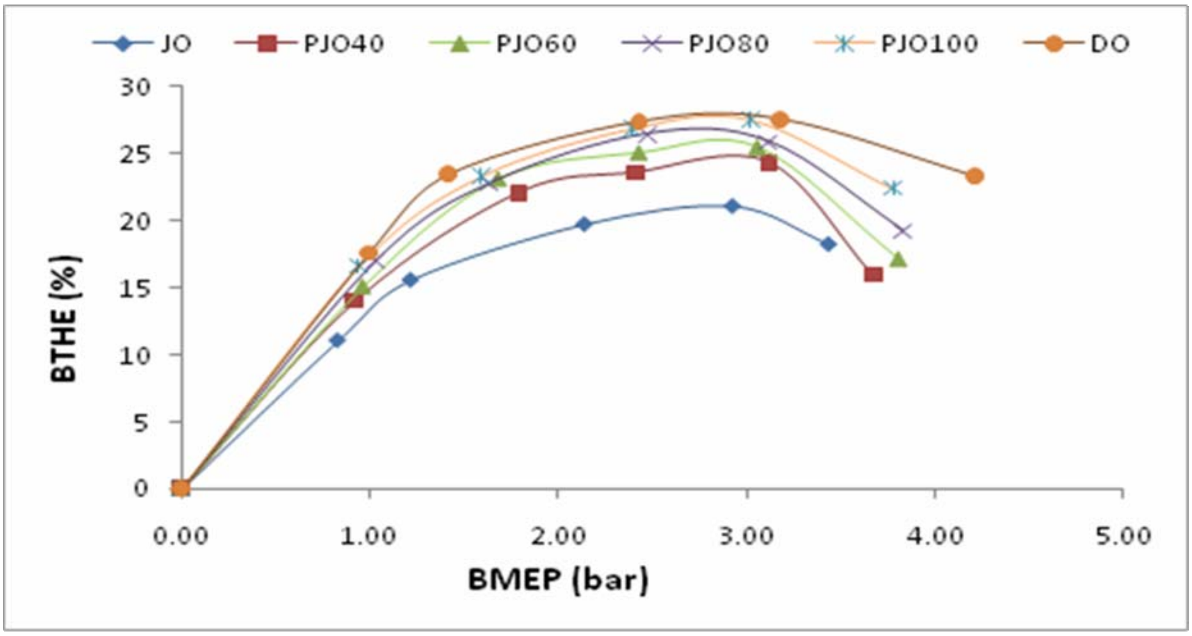

Figure 5.1: BTE Vs BMEP

The variation of brake thermal efficiency of the engine with pre-heated Jatropha oil at different temperature is shown in figure 5.1. It was observed that initially with increasing load, the brake thermal efficiency of all the fuels were increased and then tended to decrease with further increase in load. The brake thermal efficiency of the Jatropha oil (Unheated and pre-heated) were found to be lower than diesel fuel throughout the entire range. The possible reasons for this reduction are lower calorific value and high viscosity of the Jatropha oil as compared to diesel fuel. As the Jatropha oil is heated, the thermal efficiency increases. This is due to the fact that preheated Jatropha oil has lower viscosity and as viscosity reduces with increase in temperature it results in better atomization giving better thermal efficiency. The highest brake thermal efficiency was found in case of pre-heated Jatropha oil to 100˚C. The peak thermal efficiency for JO, PJO 40, PJO 60, PJO 80 and PJO 100 were 20.98 %, 24.83 %, 25.39 %, 26.46 % and 27.44 % respectively whereas the peak thermal efficiency of diesel was 27.48%.

5.3.2 Brake Specific Energy Consumption

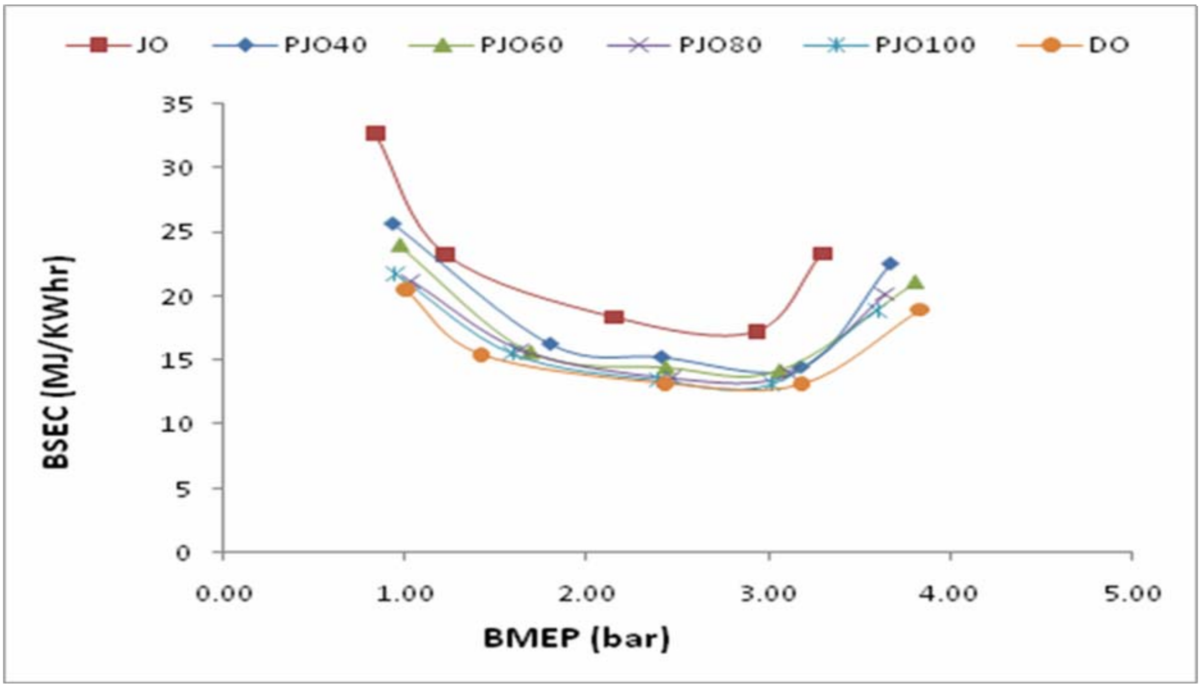

Figure.5.2: BSEC Vs BMEP

Brake Specific fuel Consumption is not a very reliable parameters to compare the performance of two different fuels because density and calorific value of both the fuel are significantly different. Therefore, brake specific energy consumption was taken as a parameter to compare the energy requirement for producing unit power in case of different test fuels. The variation of BSEC vs. BMEP for all the test fuels is shown in figure 5.2. It is clear from the figure that the brake specific energy consumption of Jatropha oil (either unheated or pre-heated) is higher than diesel which is due to high density, viscosity and low calorific value of the Jatropha oil. It is also observed that with the increase in degree of pre-heating, the brake specific energy consumption was found to be decreases. This was due to fact that higher fuel inlet temperature results in lower viscosity which causes better atomization and subsequent better combustion. This results in lower brake specific energy consumption for pre-heated Jatropha oil.

5.3.3 Exhaust Temperature.

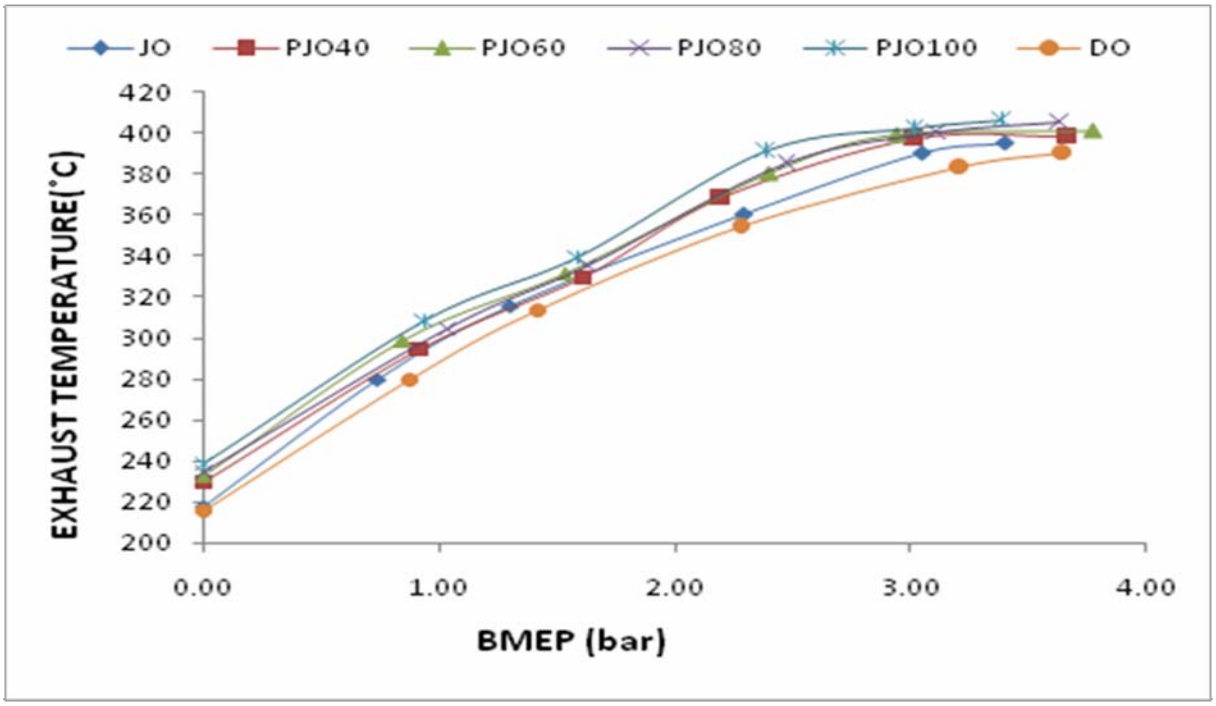

Figure 5.3: EXHAUST TEMPERATURE Vs BMEP

Figure 5.3 shows the variation of exhaust gas temperature with brake mean effective pressure for different test fuels. The result shows that the exhaust gas temperature increased with increase in load for all the test fuels. The highest value of exhaust gas temperature of 406°C was observed with the PJO 100 and the lowest was achieved with unheated Jatropha oil of about 218°C whereas the corresponding value for diesel was found to be 216°C. The exhaust gas temperatures were higher for Jatropha oil than diesel as JO contains constituents of poor volatility, which burn only during the late combustion phase. As we increase the inlet temperature of Jatropha oil it can be seen that the exhaust gas temperature was increased which may be due to the increase in the combustion gas temperature and the combustion process becomes better The results obtained are in accordance with Pugazhvadivu et al. [44] in which he has reported higher Exhaust temperature.

5.4 Emission characteristics

The emission characteristics of the test engine on pre-heated Jatropha oil and diesel are summarized below.

5.4.1 NO_x Emissions

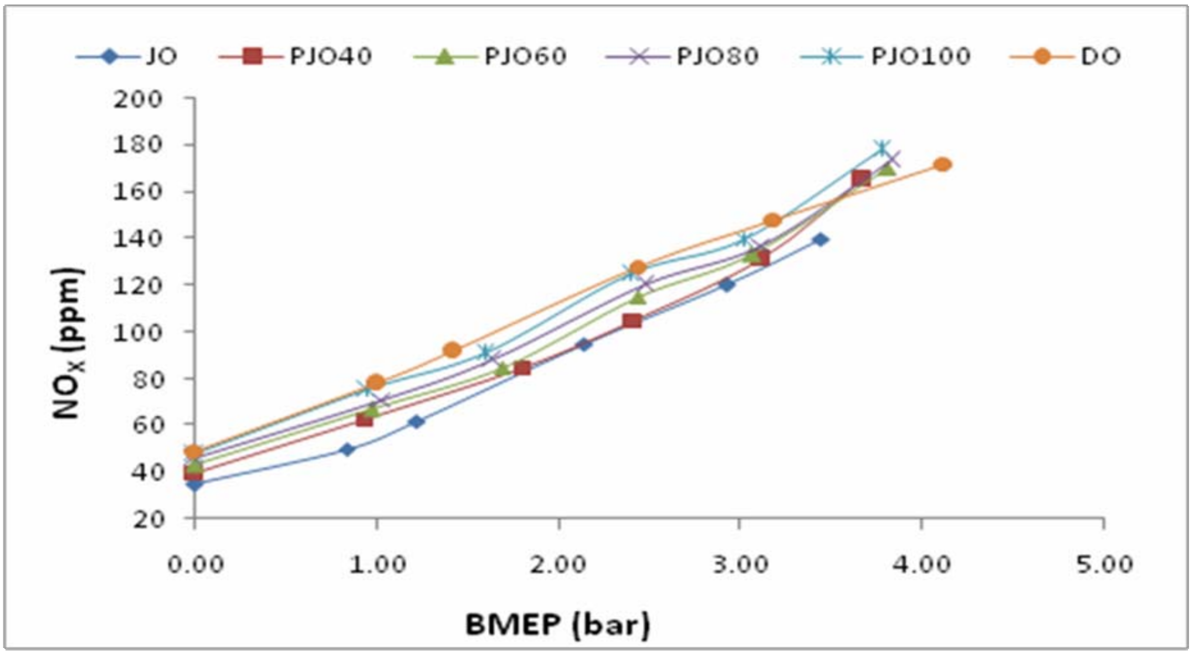

Figure 5.4: NO_x Vs BMEP

The variations of NO_x emissions for all the test fuels are shown in figure 5.4. NO_X formation is a temperature dependent phenomenon. It is clear from figure that, the NO_x emission was found to increase with increase in the fuel inlet temperature. The increase in NO_x with pre-heating may be attributed to increase in the combustion gas temperature with an increase in fuel inlet temperature. For diesel, the highest NO_x emission is 172 ppm whereas in case of PJO 40, PJO 60, PJO 80 & PJO 100, the highest values of NO_x are 165, 170, 173 & 178 ppm respectively. The results obtained are in agreement with the results of Agarwal et al. [24].

5.4.2 CO Emissions

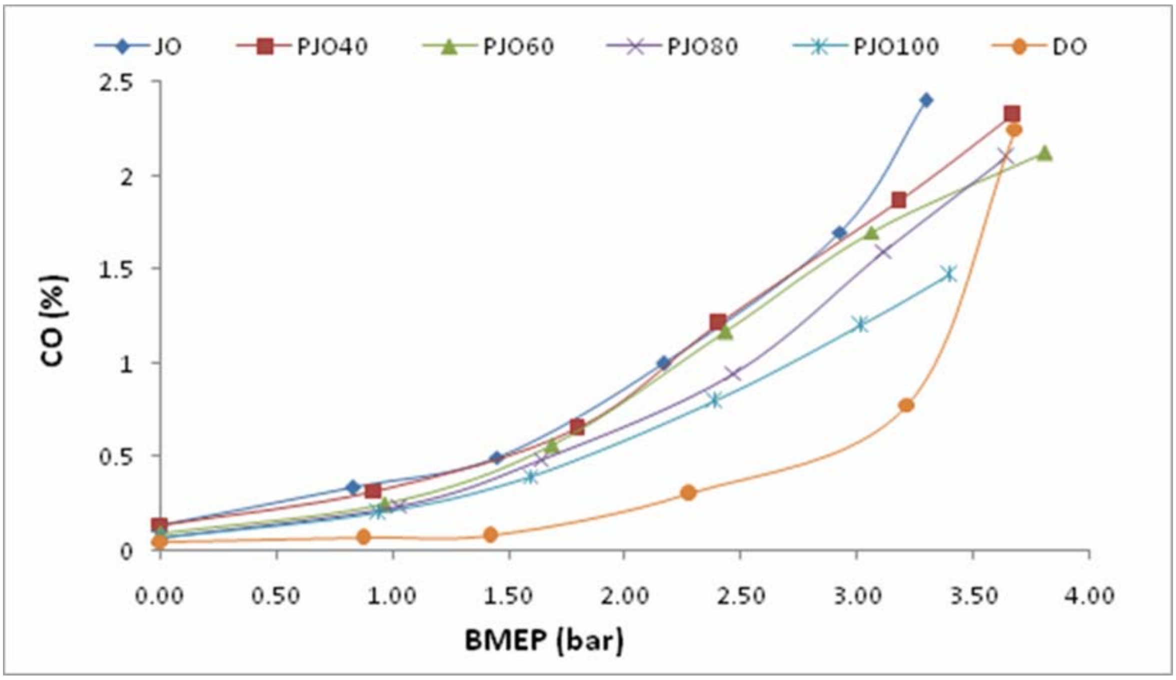

Figure 5.5: CO Vs BMEP

Figure 5.5 shows the comparison of the CO emissions for all the fuels at different engine load. As already stated, the viscosity of pre-heated Jatropha oil decreases with increase in temperature, so atomization of fuel droplets becomes better and CO emission was decreased due to improvement in spray characteristics and better air- fuel mixing. Within the experimental range, the CO emission from the unheated Jatropha oil is higher than that from diesel fuel. This is possible because of insufficient time in the cycle for combustion due to the high viscosity of vegetable oil. The higher the viscosity, poor will be the spray characteristics so the more difficult to atomize the vegetable oil and this resulted in locally rich mixtures in the engine cylinder. In consequence, it caused more carbon monoxide generated during the combustion, due to the lack of oxygen locally. The results are agreement with Agarwal et al. [24] and Pugazhvadivu et al. [44].

5.4.3 CO_2 Emissions

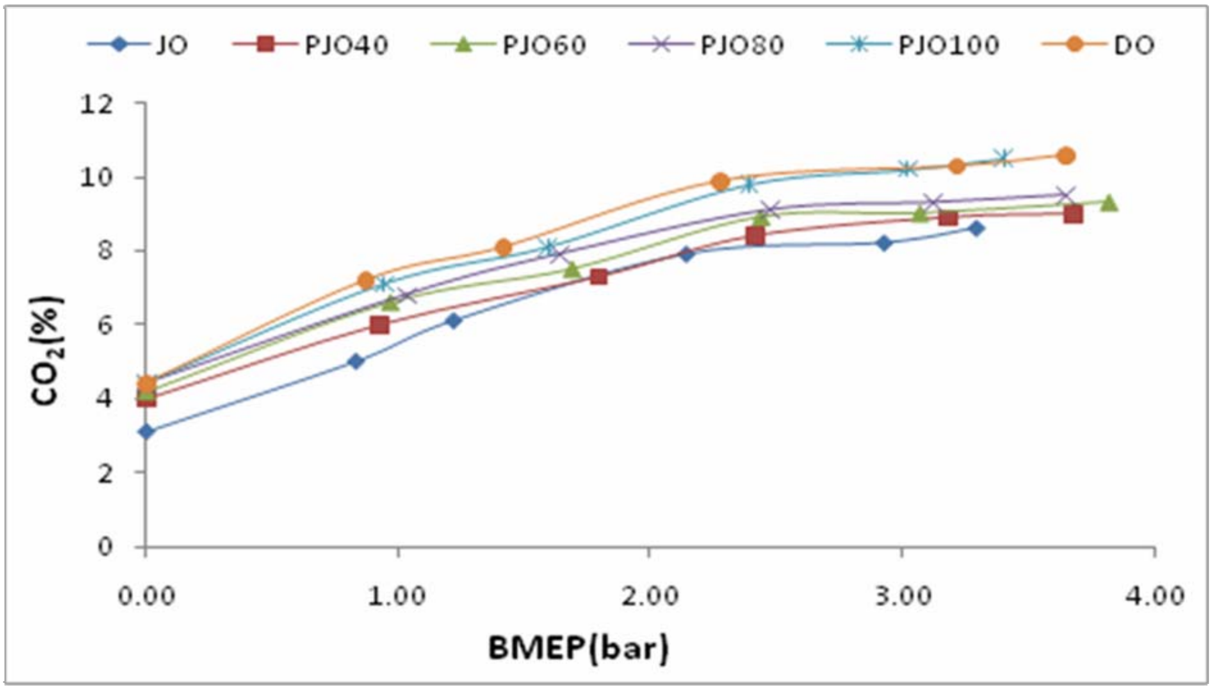

Figure 5.6: CO_2 Vs BMEP

The variations of CO_2 emissions of different fuels from the engine are shown in figure 5.6. The CO_2 emission of Jatropha oil is lower than that of the diesel fuels for all the test fuels. This is because of less volatility of vegetable oil, so the carbon content is relatively lower in the same volume of fuel consumed at the same engine load, but with increase in temperature of Jatropha oil, combustion inside the cylinder becomes better and these results are in agreement with Agarwal et al. [24] & Alonso et al. [30] in which he has reported increased CO_2 emissions. This better combustion results in increased value of CO_2. The highest value of CO_2 with diesel pre-heated Jatropha oil is 10.3% & 10.5 % respectively.

5.4.4 Un-burnt Hydro carbon Emissions

The variation of unburnt hydrocarbon (HC) emissions for diesel and pre-heated Jatropha oil are shown in figure. 5.7. The main reason of emission of HC is induction system design, combustion chamber design and flame quenching The HC emissions of all the fuels are lower at partial engine load, but increased at higher engine load. This is due to relatively less oxygen available for the reaction (incomplete combustion) when more fuel is injected into the engine cylinder at higher engine load.

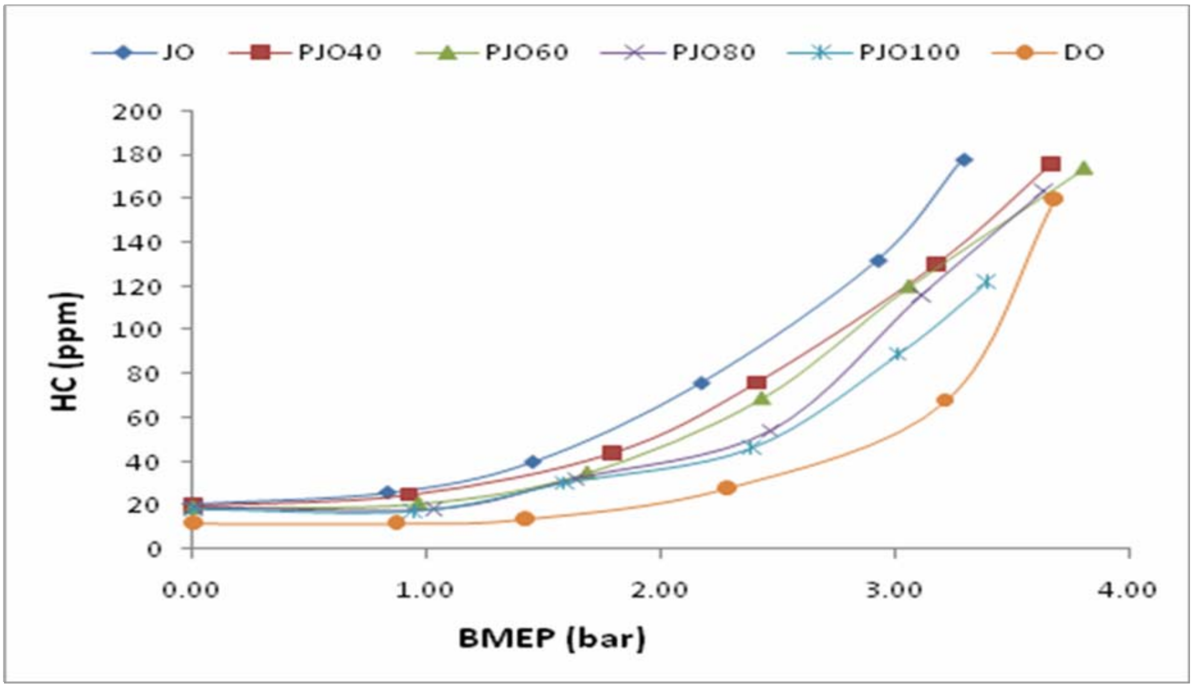

Figure 5.7: UBHC Vs BMEP

As temperature of Jatropha oil increases, the HC emissions decrease continuously because of proper combustion of preheated Jatropha oil. By increasing temperature, viscosity decreases thus proper atomisation takes place which leads to better combustion resulting in to lower HC emission.

HC emissions are lower at partial load, but tend to increase at higher engine loads for both the fuels. This is due to lack of oxygen resulting from engine operation at higher equivalence ratio and the results are agreement with Pugazhvadivu et al. [44].

5.4.5 Smoke opacity

Figure 5.8 shows the comparison of smoke opacity for all the test fuels at different load conditions. Within the experimental range, the smoke opacity for unheated Jatropha oil is significantly higher than diesel fuel. This may be due to the higher viscosity and poor volatility Jatropha compared to diesel. When the Jatropha oil pre-heated, the smoke opacity decreases with the increase in fuel inlet temperature. This may be due to lower viscosity at higher fuel inlet temperature and this leads to better atomization of pre-heated Jatropha oil. These results are agreement with the Rokopolous et al. [32] and Pugazhvadivu et al. [44].

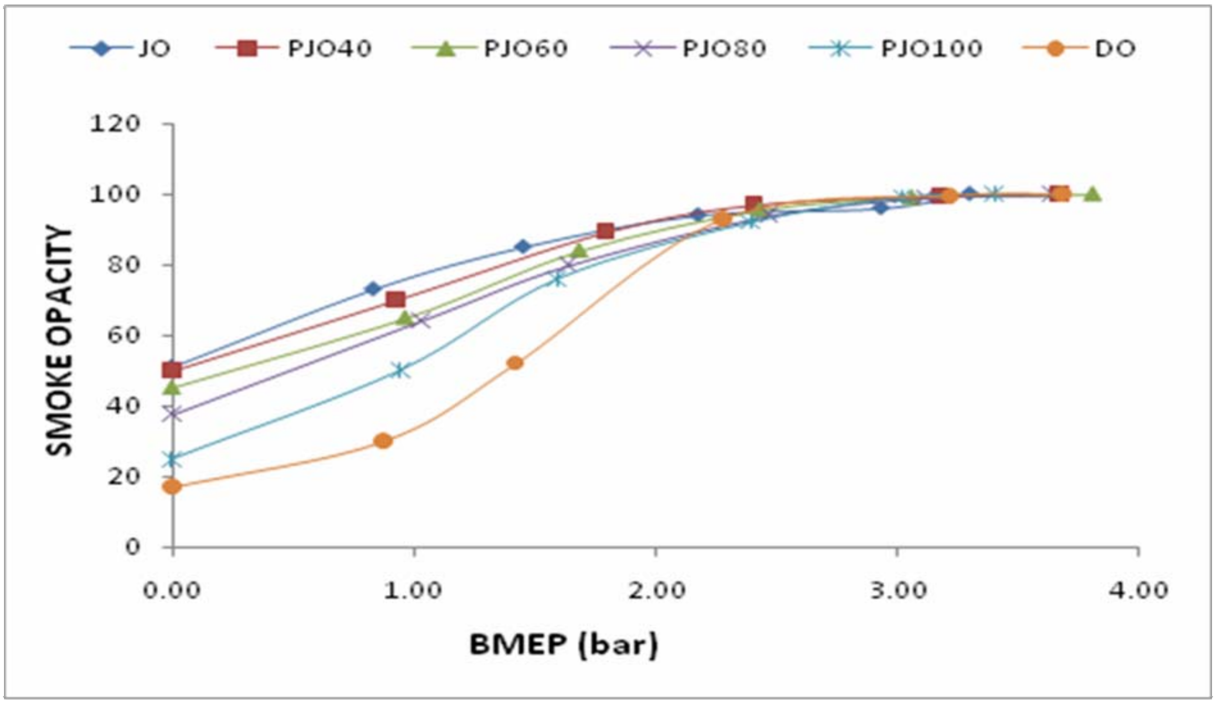

Figure 5.8: SMOKE OPACITY V_S BMEP

It is relevant to mention that with increase in fuel inlet temperature up to 100˚C, the brake thermal efficiency and all gaseous emissions are improved in comparison to unheated Jatropha oil. The maximum gain was achieved with PJO100 (pre-heated Jatropha oil at 100ºC). Therefore, it was found that fuel inlet temperature of 100ºC is good enough in reducing Kinematic viscosity to run the diesel engine without any adverse effect on engine.

CONCLUSIONS AND FUTURE SCOPE WORK

The present study was carried out keeping in mind for rural areas where diesel fuel is not readily available. During the project, an unmodified slow speed diesel engine was converted to run on a dual mode with arrangement of preheating of jatropha oil. The main objective of the present investigation was to evaluate suitability of pre-heated Jatropha curcas oil as a fuel for use in a slow speed diesel engine and to evaluate the performance and emission characteristics of the engine.

The experimental results show that the engine performance with pre-heated Jatropha oil is slightly inferior to the performance with diesel fuel. As the fuel inlet temperature of Jatropha oil is increased, the engine performance was improved. The thermal efficiency of the engine was lower and the brake specific energy consumption of the engine was higher when the engine was fueled with unheated Jatropha oil compared to diesel fuel. In case of preheated Jatropha oil, these parameters were superior to unheated Jatropha oil. The oxides of nitrogen (NO_x) from Jatropha oil during the whole range of experiment were lower than diesel fuel. However, for preheated Jatropha oil, the NO_x emissions were slightly increased and at 100˚ C it becomes comparable to diesel fuel. The NO_x emissions can be reduced by several methods such as EGR (Exhaust Gas Recirculation). The Carbon monoxide (CO), Hydrocarbon (HC) and CO_2 emission from the unheated Jatropha oil was found higher, during the whole experimental range. By increasing the Jatropha oil temperature, the value of Carbon monoxide (CO), Hydrocarbon (HC), smoke opacity were decreased as compare to unheated Jatropha oil whereas Carbon dioxide (CO_2) emissions was slightly increased and at 100˚ C it becomes comparable to diesel fuel.

It was also observed during the exhaustive trial that fuel inlet temperature higher than 100˚C could not be achieved. It can be concluded that at 100^{o}C of fuel inlet temperature, the performance and emissions were most favourable. The results from the experiments suggest that preheated Jatropha oil at 100˚C is potentially good substitute fuel for diesel engine and performance and emissions characteristics were found to be comparable to diesel fuel up to the 80 % load condition.

The long term assessment of engine durability and effect on engine performance with preheated Jatropha oil need to be examined for full load testing due to excess heating problem at full load condition.

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APPENDIX – I

TECHNICAL SPECIFICATION OF AVL Di-GAS ANALYZER

Measurement principle	CO, HC, CO_2	Infrared measurement
Measurement principle	O_2	Electrochemical
	NO (option)	measurement
Operating temperature	+5 ……. +45º C	Keeping measurement accuracy
	+1 ……. +50ºC	Ready for measurement
	+5 ……. +35º C	with integral NO sensor
		(Peaks of: +40ºC)
Storage temperature	-20 ….. +60º C	
	-20 ….. +50º C	With integrated O_2 sensor
	-10 ….. +45º C	With integrated NO sensor
	0 ….. +50º C	With water in filter and / or Pump
Air humidity	90% max., non-condensing	
Power drawn	150 VA	
Dimensions	432 x 230 x 470 mm (w x h x l)	
Weight	16 Kg	

APPENDIX –II

TECHNICAL SPECIFICATION OF AVL 437 SMOKE METER

Accuracy and Reproducibility	:	± 1% full scale reading.
Measuring range	:	0 - 100% capacity in %
		0 - ∞ absorption m^{-1}.
Measurement chamber	:	effective length 0.430 m ± 0.005 m
Heating Time	:	220 V …… approx. 20 min
Light source	:	Halogen bulb 12 V / 5W
Colour temperature	:	3000 K ± 150 K
Detector	:	Selenium photocell dia. 45 mm
		Max. Sensitivity in light,
		In Frequency range: 550 to 570 nm. Below 430 nm and above 680 nm sensitivity is less than 4% related to the maximum sensitivity.
Maximum Smoke	:	250ºC
Temperature at entrance		