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PERFORMANCE AND EMISSION STUDIES OF A AGRICULTURE DIESEL ENGINE ON PRE-HEATED JATROPHA OIL

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CERTIFICATE

It is to certify that the dissertation entitled **"PERFORMANCE AND EMISSION STUDIES OF A AGRICULTURE DIESEL ENGINE ON PRE-HEATED JATROPHA OIL"** submitted by Mr. Bhupender Singh Chauhan, 02/THR/06 in partial fulfillment 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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Abstract

Diesel Engines have proved its utility in transportation, agriculture and power sector of India. These engines also help in developing decentralized systems energy for rural electrification. However, the concerns about long term availability of petroleum diesel and stringent environmental norms have mandated that renewable alternative to diesel fuel should be expeditely explored to overcome these problems. Vegetable oils have always been considered as a good alternative to diesel for last many years and oil derived from Jatropha curcas plant has been considered as a sustainable substitute to diesel fuel.

Many researchers have reported difficulties encountered with the use of straight vegetable oil in diesel engine. These problems are mainly attributed to high viscosity of vegetable oil. The issue of high viscosity needs to be resolved for its long term utilization in diesel engine. Due to high viscosity, there are two strategies for using Jatropha oil as fuel for use in diesel engine. The first one is to modify the engine to adapt to the fuel and the second one is for processing the fuel to adapt to the engine. The literature suggests that modifying existing diesel engines to preheat Jatropha oil could be first strategy. The second option is modification of Jatropha oil to biodiesel through process of transesterification. The fuel modification process is a very complex phenomenon and not easily understable to rural community for meeting their energy needs. The quality and other safety issues also preclude massive adaptation of fuel modification methodology. Therefore, it is necessary that a system should be developed which could make use of heat of exhaust gases to increase the temperature of Jatropha oil for its large scale adaptation in diesel engine for attaining much needed energy security.

The present work aims at developing a dual fuel 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 a fuel. The bypass arrangement was such that it could give the desired fuel inlet temperature. The determination of performance and emission characteristics of the engine with Jatropha oil (Unheated and preheated) was done and comparative assessment with baseline data of diesel fuel was also made. 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 fueled 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. The emissions of nitrogen oxides (NO_x) from Jatropha oil during the whole range of experiment were lower than diesel fuel and with increase in FIT, it increased. The carbon monoxide (CO), Hydrocarbon (HC), Carbon dioxide (CO_2) emissions from the Jatropha oil was found higher than diesel fuel during the whole experimental range. However, with increase in FIT, a downward trend was observed.

The results from the experiments suggest 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.

CONTENTS

LIST OF FIGURES

LIST OF PLATES

LIST OF TABLES

NOMENCLATURE

@	At the rate
A/F	Air to Fuel
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
BSEC	Brake Specific Energy Consumption
BSFC	Brake Specific Fuel Consumption
BTE	Brake Thermal Efficiency
BTDC	Before Top Dead Center
^oC	Degree Celsius
cc	Cubic centimeter
CI	Compression Ignition
cm^{-1}	Per Centimeter
CN	Cetane Number
CO	Carbon Monoxide
CO_2	Carbon Dioxide
cSt	Centi Stoke
Cu	Copper
CV	Calorific Value
D100	Neat Diesel
DI	Direct Injection
DF	Diesel fuel
$dQ/d\Theta$	Apparent Net Heat transfer Rate
$dQ_{ch}/d\Theta$	Gross Heat Release Rate
$dQ_{ht}/d\Theta$	Heat Transfer across the cylinder walls, J/ºCA
EOI	End of Injection
EV	Electric Vehicle
ºF	Degree Fahrenheit

F/A	Fuel to Air
FFA	Free Fatty Acid
FIT	Fuel Inlet temperature
FIP	Fuel Injection Pump
FT	Fourier Transform
FTIR	Fourier Transform Infra red
g	Gram
g/cc	Gram per cubic centimeter
HC	Hydrocarbon
H_2O	Water
HP	Horse Power
Hz	Hertz
IC	Internal Combustion
IDI	Indirect Injection
IR	Infra Red
IS	Indian standard
JO	Jatropha oil (Unheated)
KOH	Potassium Hydroxide
KVA	Kilo Volt Ampere
kW	Kilo Watt
kW-h	Kilo Watt Hour
LSD	Low Sulphur Diesel
LPM	Liter per Minute
1M	1 Mole
Min.	Minute
ml	Milliliter
mm	Millimeter
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
O_2	Oxygen
PJO	Preheated Jatropha oil
PJO 40	Preheated Jatropha oil to 40^{o}C
PJO 60	Preheated Jatropha oil to 60^{o}C
PJO 80	Preheated Jatropha oil to 80^{o}C
PJO 100	Preheated Jatropha oil to 100^{o}C
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
THC	Total Hydrocarbon
ULSD	Ultra Low Sulphur Diesel
UBHC	Unburnt Hydrocarbon
Vs	Versus
v/v	Volume/ Volume
ρ	Density
%	Percent

CHAPTER 1

INTRODUCTION

1.0 ENERGY CRISIS

Energy has always played an important role in development of a country. It is considered as an index of economic growth and social development. Per capita energy consumption is considered as measure of prosperity of a country besides GDP and per capita income. The world has witnessed industrial revolution in the past century, and it has also faced serious problems of indiscriminate utilization of the energy resources. The ideology was related to more energy consumption for higher industrial development and never considered better and efficient use of energy. The US oil embargo and subsequent Gulf War were very crucial for both developed and developing countries. It was then the first time that crude petroleum importing nations felt the shock when the oil exporting countries bargained higher prices. This energy crisis forced the world to look for alternative sources of energy. This also resulted in efficient utilization of energy. The focus of country planners changed to ‘More efficiency, more productivity and reduced production cost’. This resulted in an immediate, long term and multi-facet solution to the problems immerging from increased energy demands against short supplies. Energy conservation and management has since 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 energy use pattern 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 to 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.

1.1 ENERGY SCENARIO

Energy has undergone a major transition from a general field of study of technologies to an important issue in economic planning and international relations.

Energy is the building block for socio-economic development of any country. Although 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 which are really very small (0.4 per cent of world's reserve). India accounted for 10.63 % of total primary energy consumption in Asia-Pacific region and 3.6 % of world primary consumption in 2007 [1]. Per capita energy consumption remains low as 491 KGOE (Kilogram of oil equivalent) compared with a world average of 1,796 KGOE in 2005 [2]**.** The distribution of primary energy in India vis a vis world in 2006 has been shown in Table 1.1.

Table 1.1. Distribution of Primary Energy in India and World (MTOE) [1]

	Oil	**Natural Gas**	**Coal**	**Nuclear Energy**	**Hydro Electric**	**Total**
India	128.5	38.6	208.0	4.0	27.7	404.4
World	3952.8	2637.7	3177.5	622.0	709.2	11099.3

India is fourth largest economy of world and has to extensively use energy to sustain its growth. Since India does not have huge reserves of petroleum products, it is heavily 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. Escalating prices, insufficient supply and limited reserves of petroleum have imposed an enormous burden on country's foreign exchange. In year 2006-07 the indigenous production of crude oil was 33.99 million tones where as consumption was 144.88 million tones forcing to import 110.89 million tones. The country is spending Rs.2199.91 billion [3] worth valuable foreign exchange towards import of crude petroleum which could otherwise be utilized for various other development works, that might ultimately prove to be more beneficial to Indian people. To improve the present energy crisis, future energy conversion in India should be sustainable which include increase share of renewable fuel, increase efficiency of fuel conversion, reduce environmental impacts, and increase knowledge. In this regard, the subsidy on traditional fossil fuels must be reduced in a phase manner and efforts must be put to develop and promote the use of renewable sources of energy to meet the energy requirement.

1.2 RENEWABLE ENERGY SOURCES

Table 1.2: Renewable Energy Potential and Achievements in India as on 31.12.2007 [4]

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.

Due to depleting fossil fuel resources, renewable energy sources such as solar, wind, biomass, small hydro power, etc. are emerging as alternative energy options. The potential for expanding the use of RETs (Renewable Energy Technologies) for energy generation is vast in India and awaits exploitation. The Renewable energy potential and achievements are summarized in table 1.2. These renewable energy technology are environmental benign. However, the high cost of these technologies has been a limiting factor in large scale adaptation.

1.3 THE FUTURE OUTLOOK

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) as shown in table 1.3.

Table 1.3: World Primary Energy Demand (Btoe)

	1980	2004	2010	2015	2030	2004 - 2030
Coal	1 785	2 773	3 354	3 666	4 441	1.8%
Oil	3 107	3 940	4 366	4 750	5 575	1.3%
Gas	1 237	2 302	2 686	3 017	3 869	2.0%
Nuclear	186	714	775	810	861	0.7%
Hydro	148	242	280	317	408	2.0%
Biomass and waste	765	1 176	1 283	1 375	1 645	1.3%
Other renewables	33	57	99	136	296	6.6%
Total	**7 261**	**11 204**	**12 842**	**14 071**	**17 095**	**1.6%**

Fossil fuels are projected to remain the dominant sources of primary energy globally. They account for close to 83% of the overall increase in energy demand between 2004 and 2030. Oil remains the single largest fuel in the primary fuel mix in 2030, though its share drops, from 35% now to 33% as shown in figure 1.1. The renewable energy technologies, including biofuel, wind, solar, geothermal, wave and tidal energy, 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 as shown in figure 1.1.

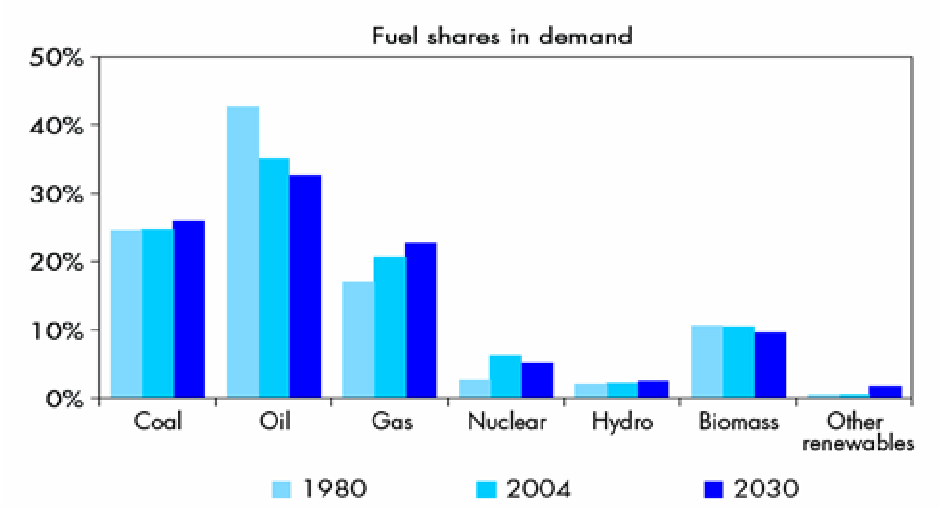

Figure 1.1: Fuel Shares in Primary Energy Demand

OECD countries account for almost one-quarter and the transition economies for the remaining 6%. The increase in the share of the developing regions in world energy demand results from their more rapid economic and population growth. Industrialization and urbanization boost demand for modern commercial fuels.

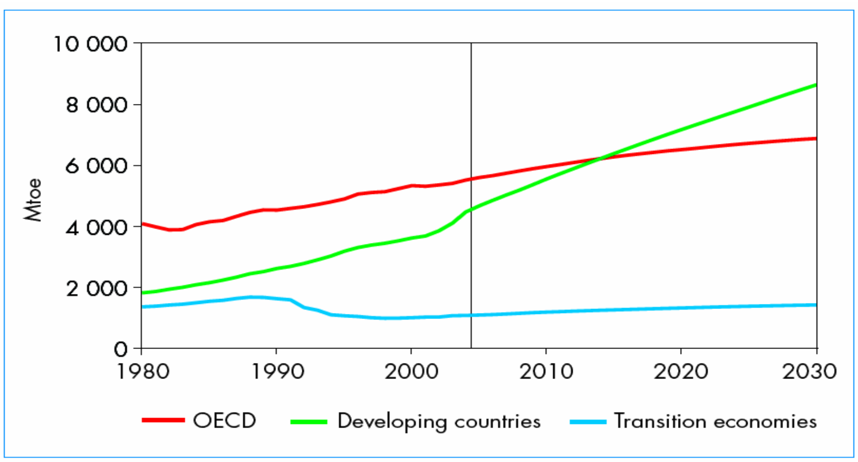

Figure 1.2: Region wise Primary Energy Demand

Global Oil demand is expected to continue to grow steadily at an average annual rate of 1.3%. It reaches 99 mb/d in 2015 and 116 mb/d in 2030, up from 84 mb/d in 2005 as shown in Table 1.4. Most of the increase in oil demand comes from developing countries, where economic growth – the main driver of oil demand– is highest (Figure 3.1). China, India and the rest of developing Asia account for 15 mb/d, or 46%, of the 33-

mb/d increase in oil use between 2005 and 2030, in line with rapid economic growth. At 3.0% per year on average, India shall require almost double of oil in 2030 as compared to 2005.

Table 1.4: Global Oil Demand

	1980	**2004**	**2005**	**2010**	**2015**	**2030**	**2005-2030**
OECD	**41.9**	**47.5**	**47.7**	**49.8**	**52.4**	**55.1**	**0.6%**
North America	21.0	24.8	24.9	26.3	28.2	30.8	0.9%
United States	*17.4*	*20.5*	*20.6*	*21.6*	*23.1*	*25.0*	*0.8%*
Canada	*2.1*	*2.3*	*2.3*	*2.5*	*2.6*	*2.8*	*0.8%*
Mexico	*1.4*	*2.0*	*2.1*	*2.2*	*2.4*	*3.1*	*1.6%*
Europe	14.7	14.5	14.4	14.9	15.4	15.4	0.2%
Pacific	6.2	8.2	8.3	8.6	8.8	8.9	0.3%
Transition economies	**8.9**	**4.3**	**4.3**	**4.7**	**5.0**	**5.7**	**1.1%**
Russia	n.a.	2.5	2.5	2.7	2.9	3.2	1.0%
Developing countries	**11.4**	**27.2**	**28.0**	**33.0**	**37.9**	**51.3**	**2.5%**
Developing Asia	4.4	14.2	14.6	17.7	20.6	29.7	2.9%
China	*1.9*	*6.5*	*6.6*	*8.4*	*10.0*	*15.3*	*3.4%*
India	*0.7*	*2.6*	*2.6*	*3.2*	*3.7*	*5.4*	*3.0%*
Indonesia	*0.4*	*1.3*	*1.3*	*1.4*	*1.5*	*2.3*	*2.4%*
Middle East	2.0	5.5	5.8	7.1	8.1	9.7	2.0%
Africa	1.4	2.6	2.7	3.1	3.5	4.9	2.4%
North Africa	*0.5*	*1.3*	*1.4*	*1.6*	*1.8*	*2.5*	*2.4%*
Latin America	3.5	4.8	4.9	5.1	5.6	7.0	1.5%
Brazil	*1.4*	*2.1*	*2.1*	*2.3*	*2.7*	*3.5*	*2.0%*
Int. marine bunkers	**2.2**	**3.6**	**3.6**	**3.8**	**3.9**	**4.3**	**0.6%**
World	**64.4**	**82.5**	**83.6**	**91.3**	**99.3**	**116.3**	**1.3%**
European Union	*n.a.*	*13.5*	*13.5*	*13.9*	*14.3*	*14.1*	*0.2%*

1.4 GLOBAL ENVIRONMENT DEGRADATION

The indiscriminate and inefficient energy utilization has also resulted in environmental degradation which needs to be adequately studied. The process of energy generation, transport and utilization leads to air pollutants. In-efficient use of energy has stretched the global environment to its limits as can be seen from the unprecedented and unpleasant responses of the nature in the past few years. Green house effect, global warming, acid rain, smog, deforestation, shift in climatic conditions etc. are some of the indications. Increase in the CO_2 Concentration is shown in Fig.1.3 which clearly represents that most of the CO_2 rise has taken place in post industrial revolution era. The curve of CO_2 concentration has been climbing exponentially (except in the mid 1990s when the economy of Eastern Europe and the Soviet Union collapsed).

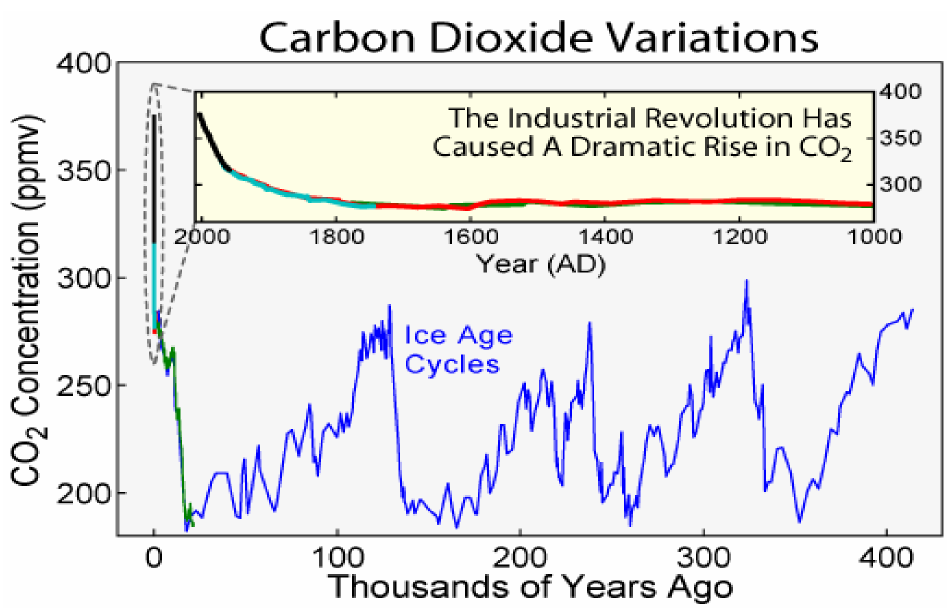

Fig. 1.3: Increase in CO_2 Concentration [5]

Scientists at the Mauna Loa observatory in Hawaii say that CO_2 levels in the atmosphere now stand at 387 parts per million (ppm), up almost 40% since the industrial revolution and the highest for at least the last 650,000 years. The figures, published by the US National Oceanic and Atmospheric Administration (NOAA) also confirm that carbon dioxide, the chief greenhouse gas, is accumulating in the atmosphere faster than expected. The annual mean growth rate for 2007 was 2.14ppm – the fourth year in the past six to see an annual rise greater than 2ppm. From 1970 to 2000, the concentration rose by about 1.5ppm each year, but since 2000 the annual rise has leapt to an average 2.1ppm. [6]

The amount of gas added to the atmosphere is doubling every 30-35 years [7]. Climate model projections summarized by the IPCC indicate that average global surface temperature will likely rise a further 1.1 to 6.4^{o}C during the twenty-first century

1.5 CO_2 EMISSION OUTLOOK

Global energy-related carbon-dioxide (CO_2) emissions is expected to increase by 1.7 % per year over 2004-2030. They shall reach 40.4 billion tonnes in 2030, an increase of 14.3 billion tonnes, or 55%, over the 2004 level as shown in table 1.5. By 2010, emissions shall be 48% higher than in 1990. However, the aggregate increase is much smaller for Annex I countries with commitments to limit emissions under the Kyoto Protocol. 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.

Table1.5: Increase in CO_2 by Different Sources

	1990	2004	2010	2015	2030	2004-2030
Power generation	6 955	10 587	12 818	14 209	17 680	2.0%
Industry	4 474	4 742	5 679	6 213	7 255	1.6%
Transport	3 885	5 289	5 900	6 543	8 246	1.7%
Residential and services	3 353	3 297	3 573	3 815	4 298	1.0%
Other	1 796	2 165	2 396	2 552	2 942	1.2%
Total	**20 463**	**26 079**	**30 367**	**33 333**	**40 420**	**1.7%**

Developing countries shall account for over three-quarters of the increase in global CO2 emissions between 2004 and 2030. They overtake the OECD as the biggest emitter by around 2012 as shown in figure. The share of developing countries in world emissions rises from 39% at present to 52% by 2030. This increase is faster than that of their share in energy demand, because their incremental energy use is more carbon-intensive than that of the OECD and transition economies. China alone is responsible for 39% of the rise in global emissions. China's emissions more than double between 2004 and 2030, driven by strong economic growth and heavy reliance on coal in industry and power generation. China overtakes the United States as the world's biggest emitter before 2010. Other Asian countries, notably India, also contribute heavily to the increase in global emissions.

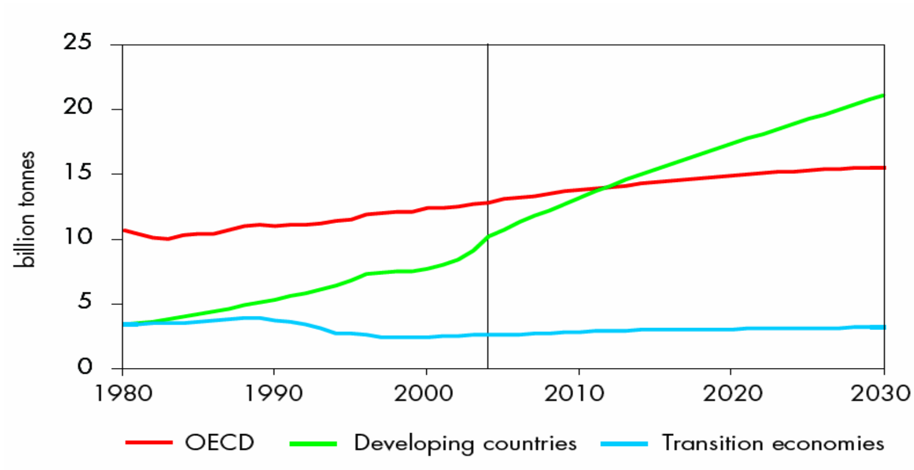

Fig.1.4: CO_2 emissions by OECD, Developing Countries & Transition Economies

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.

Table1.6: 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**
Total CO_2 emissions	**588**	**1 103**	**1 620**	**2 544**	**100**	**100**	**100**	**3.6**	**3.3**
Coal	401	734	1 078	1 741	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	5.0	4.2

1.6 CLIMATE CHANGE

Climate is referred to as the prevalent long-term weather conditions in a particular area. Climatic elements include precipitation, temperature, humidity, sunshine and wind velocity phenomena such as fog, frost, and hail storms. Thus, climate change can be defined as any change in climate over time, whether due to natural variability or human activity. The Reports by the United Nations Framework Convention on Climate Change (UNFCCC) define it as “a change of climate as attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods”. Climate change is caused by increases in the atmospheric concentration of so-called greenhouse gases (GHGs). The build-up of GHGs is rapidly changing how the atmosphere absorbs and retains energy. These GHGs include: carbon dioxide (CO2) (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 [8].

Mitigation of and adaptation to climate change are the two main pillars of climate change policy. Both pose significant analytical and policy challenges, and thus their respective discussions have evolved at different paces. On the one hand, mitigation of climate change refers to: “The stabilization of greenhouse gas (GHG) concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system which would enhance global warming. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, so as to ensure that food production is not threatened whilst at the same time enabling economic development to proceed in a sustainable manner”.

1.6.1 EFFECT OF GLOBAL WARMING

The predicted effects of global warming on the environment and for human life are numerous and varied.

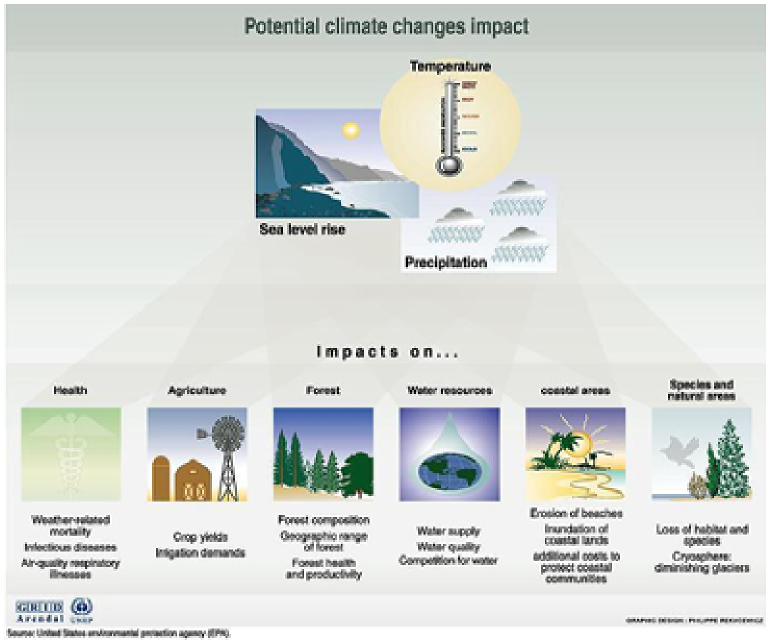

Fig. 1.5: Potential Climate Change Impact [9]

It is generally difficult to attribute specific natural phenomena to long-term causes, but some effects of recent climate change may already be occurring. Raising 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. Concerns have led to political activism advocating proposals to mitigate, eliminate, or adapt to it. The 2007 Fourth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC) includes a summary of the expected effects.

1.6.2 GREENHOUSE GAS EMISSION AROUND THE WORLD

Globally, 3% increase in carbon dioxide emissions has been experienced in 2007. With an 8% national increase, China's carbon dioxide (CO_2) emissions accounted for two thirds of last year's global carbon dioxide increase of 3.1%. China's CO_2 emissions are now estimated to be about 14% higher than those from the USA. With this, China tops the list of CO_2 emitting countries, having about a quarter share in global CO_2 emissions (24%), followed by the USA (21%), the EU-15 (12%), India (8%) and the Russian Federation (6%). Together, they comprise 71% of the total of global CO_2 emissions. Since population size and level of economic development differ considerably between countries, the emissions expressed per person show a largely different ranking: Top 5 CO_2 emissions in metric tons of CO_2 per person are: USA (19.4), Russia (11.8), EU-15 (8.6), China (5.1) and India (1.8). In USA, CO_2 emissions increased by 1.8% in 2007, compared to 2006 [10].

1.6.3 KYOTO PROTOCOL

The Kyoto Protocol is an agreement under which industrialized countries will reduce their collective emissions of greenhouse gases by 5.2% compared to the year 1990). The goal is to lower overall emissions of six greenhouse gases calculated as an average over the five-year period of 2008-12. National limitations range from 8% reductions for the European Union and some others to 7% for the US, 6% for Japan, 0% for Russia, and permitted increases of 8% for Australia and 10% for Iceland [11].

The five principal concepts of the Kyoto Protocol [12] are:

1. The heart of the Protocol lies in establishing commitments for the reduction of greenhouse gases that are legally binding for Annex I countries, as well as general commitments for all member countries.
2. In order to meet the objectives of the Protocol, Annex I countries are required to prepare policies and measures for the reduction of greenhouse gases in their respective countries. In addition, they are required to increase the absorption of these gases and utilize all mechanisms available, such as joint implementation, the clean development mechanism and emissions trading, in order to be rewarded with credits that would allow more greenhouse gas emissions at home.
3. Minimizing Impacts on Developing Countries by establishing an adaptation fund for climate change.
4. Accounting, Reporting and Review in order to ensure the integrity of the Protocol.
5. Compliance. Establishing a Compliance Committee to enforce compliance with the commitments under the Protocol.

India is a signatory to Kyoto Protocol and committed to adopt recommendation of this protocol. Government of India is looking for renewable, bio-origin fuel produced from locally available resources since these fuels can reduce the atmospheric CO_2 which shall ultimately help to clean the environment.

1.7 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 is used in heavy trucks, city transport buses, locomotives, electric generators, farm equipment, underground mine equipment etc [13, 14]. The dual problem of fast depletion of petroleum based fuels and air pollution can be judiously handled by switching from fossil fuel based economy to renewable source of energy. Our country is an agriculture based economy and agriculture is an energy transformation process as energy is produced and consumed in it. 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.

1.8 NECESSITY OF ALTERNATIVE FUELS

It is clear from the above discussions that India is facing the twin problems of fast depletion of fossil fuels and environmental degradation. There is an urgent need to reduce dependence on petroleum derived fuels for better economy and environment. Adaptation of bio-origin alternative fuels can address both these issues. These fuels are essentially non-petroleum and result in energy security and environmental benefits. These fuels are available either in one form or other for more than one hundred years. Before the introduction of gasoline as a motor fuel in the late 1800s, vehicles were often powered by what are now considered alternative fuels. The first internal combustion engine designed, built, and demonstrated by Rudolf Diesel at the 1900 Paris World's Fair ran on peanut oil. This was the product of his dream – an efficient internal combustion engine, powered by crude oil or even vegetable oil.

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, in Indian context, the bio-origin fuels like alcohols, vegetable oils, and biogas can contribute significantly towards the problems related to fuel crises.

1.8.1 BIO-FUELS

Bio-fuels are renewable liquid fuels coming from biological raw material and have been proved to be good substitutes for oil in the transportation and agriculture sector. Bio- fuels are gaining worldwide acceptance as a solution for problems of environmental degradation, energy security, restricting imports, rural employment and agricultural economy. The most promising biofuel, and closest to being competitive in current markets without subsidy, are ethanol, methanol, vegetable oils and biodiesel.

Ethanol is used as fuel or as oxygenate to gasoline. Raw material used for producing ethanol varies from sugar in Brazil, cereals in USA, sugar beet in Europe to molasses in India. Brazil uses ethanol as 100 % fuel in about 20% of vehicles and 25% blend with gasoline in the rest of the vehicles. USA uses 10% ethanol-gasoline blends whereas a 5% blend is used in Sweden. Australia uses 10% ethanol-gasoline blend. Use of 5% ethanol-gasoline blend is already approved by BIS and is dispensed in some Indian states.

Methanol could conceivably be made from grain, but its most common source is natural gas. Use of natural gas is better for reducing carbon dioxide production in comparison to other fossil fuels, but use of renewable fuels instead of natural gas would be still better. It can be made from coal or wood with more difficulty and lower efficiency than from natural gas.

Biodiesel is derivative of vegetable oils. Biodiesel is made from virgin or used vegetable oils (both edible & non-edible) and animal fats through a chemical process named transesterification. Biodiesel can be blended in any ratio with petroleum diesel fuel. Its higher Cetane number improves the combustion even when blended in the petroleum diesel. It can also be used as an additive to achieve the following objectives:

1. To reduce the overall sulfur content of blend,
2. To compensate for lubricity loss due to sulfur removal from diesel fuel,
3. To enhance the Cetane number of diesel fuel.

Emissions of CO_2, which translate into a greenhouse effect, are a feature of most fuels. If biomass energy is used instead of fossil fuels, however, there is normally a net reduction in CO_2 emissions. SO_2 emissions from using biomass energy tend to be considerably lower because relevant plants and trees contain only trace quantities of sulphur compared too much higher emissions from coal, gasoline, and even some natural gas. This drop in SO_2 is accompanied by a fall in the level of the other traditional motor pollutant emissions such as carbon monoxide, unburned hydrocarbons, and particulates, but these reductions are less easily quantifiable. However, there is an increase in the release of nitrogen oxides and aldehydes. There is no clear advantage to any one of the liquid biofuels, and choices between them will depend on local priorities.

1.8.2 RATIONALE OF BIOFUELS IN INDIA

The rationale of taking up a major Programme for the production of bio-fuels for utilization in I.C. Engines in our country lies in the context of:-

- Ethanol and biodiesel being superior fuels from the environmental point of view,
- Use of Bio-fuels becomes imperative in view of the stringent emission norms and court interventions,
- Need to provide energy security, specially for the rural areas,
- Need to create employment, specially for the rural poor living in areas having a high incidence of land degradation,
- Providing nutrients to soil, checking soil erosion and thus preventing land degradation, addressing global concern relating to containing Carbon emissions,
- Reducing dependence on oil imports,
- Usability of biofuel in the present engines without any major modification,

- Use of biofuel not requiring major or time consuming studies or research.

1.9 ALTERNATIVE FUELS FOR COMPRESSION IGNITION ENGINE

With the indispensable position gained by diesel engine in recent years, the demand for conventional fuel and environmental degradation caused by fossil diesel combustion can not be underestimated. As already elaborated, alternative fuels are immediately needed to deal the dual problem of fast depletion of fossil fuel reserves and environmental pollution. Such fuels should be renewable, should be suitable for use in existing engines and associated systems (such as fuel tank, pumps and hoses) as well other existing fuel storage, transportation and retail infrastructure. Since diesel engine plays an important and indispensable role in Indian economy and various sector of the country, fuels of bio-origin can provide a feasible solution to the problem.

Some of these fuels can be used directly while others need to be transformed to bring the relative properties close to the conventional fuels. Ethanol is an attractive alternate liquid source for I.C engines since it can be produced from renewable sources such as grains [15]. Given the widespread use of diesel fuels, in various sectors, the study on the performance of vegetable oils when used as a fuel in the neat or blended form is desirable [16**].** Since the viscosity of vegetable oils, hence of the fuel is of prime concern, the reduction in the viscosity is required which can be carried out by transesterification process [17].

1.10 ALTERNATIVE FUEL IMPUTES

There are some very important parameters which should be considered before adaptation of an alternative fuel in an existing engine. These includes: no or minimum modification required in design of engine, use of same storage and transportation infrastructure, biodegradable and non-toxic assuring safe handling and transportation, capability of being produced locally and low investment cost [18,19].

The economics of the fuels like vegetable oils, ethanol, and methanol etc. compared to the traditional petroleum resources are marginal. Public policies need to be revised to encourage the development of these resources. Land for production need to be explored, an extraction and transesterification plant would be required, distribution and storage facilities constructed and monitoring of major users for detection of problems in large scale use are all needed before the technology can be recommended for general use the magnitude of our energy needs provides an inexhaustible market of our total agriculture production capacity at the highest possible level. We could put the farm back to work providing for our food needs and also growing crops and livestock for energy. Energy is the only crop that we could never grow in surplus [20].

1.11 PRESENT WORK

In context to present work, a more elaborate discussion on adaptation of vegetable oils is made. Oil seed crops can provide a fuel grade product using relatively simple extraction and processing technology which could be performed on individual farms. Vegetable oils are promising fuels, particularly for diesel engines. The practicality of vegetable oils as diesel fuels has been sufficiently demonstrated to warrant further investigation of their effectiveness and to develop techniques that will permit their incorporation into agricultural operations, particularly in times of energy shortfall [21].

Vegetable oil returns about ten calories of output for each calorie of input. Numerous different vegetable oils have been tested as a fuel in engines. Often, the vegetable oils investigated for their use as a fuel are those which occur abundantly in the country of testing. Therefore, soybean oil is of primary interest in the United States while many European countries are concerned with rapeseed oil, and countries with tropical climate prefer to utilize coconut oil or palm oil. Other vegetable oils, including sunflower, safflower, etc., have also been investigated. In India, variety of non-edible oil has been used to fuel the engines. The current prices of vegetable oil in India are comparable with petroleum fuels. Some of the vegetable oils are available in India easily and in fact some of them under utilized whereas the potential of such oils are very high. If any particular vegetable oil amongst some 250 types of available in India , is to be used as energy crops , then the efforts must be put to increase the yield and oil content of that particular crop. The technologies should be developed to promote the use of vegetable oils as a replacement to fossil fuel which may result in increased crop production for energy.

CHAPTER 2

LITERATURE REVIEW

2.0 INTRODUCTION

As already elaborated in preceding chapter, rapidly increasing prices and uncertainties concerning petroleum availability let the scientists work on alternative fuel sources. Vegetable oil is a promising alternative because it has several advantages—it is renewable, environmental-friendly and produced easily in rural areas, where there is an acute need for modern forms of energy. Obviously, the use of non-edible vegetable oils compared to edible oils is more significant because of the issue of food security. The idea of using vegetable oils as fuel for diesel engines is not radically new. Rudolph diesel used peanut oil to fuel one of his engines at the Paris Exposition in1900. In recent years systematic efforts have been made by several researchers to use vegetable oils as fuel in diesel engines.

2.1 VEGETABLE OILS AS A POTENTIAL C. I. ENGINE FUEL

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 200º C).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 diesel fuel [22].

Petroleum based diesel fuels have different chemical structure than vegetable oil. The former contain only carbon and hydrogen atoms which are arranged in normal (straight chain) or branched chain structures as well as aromatic configurations. The normal structure is preferred for better ignition quality. Diesel fuel can contain both saturated and straight or unbranched chain unsaturated hydrocarbons, but the later are not present in large amounts to make oxidation a problem [23]. Vegetable oils consist of triglycerides to about 97%, the other 3% distribute among di- and monoglycerides and further more 3 fatty acids and the fat accompanying which are mostly removed with refining [29]. Structurally, a triglyceride is a reaction product of one molecule of glycerol with three fatty acid molecules to yield three molecules of water and one molecule of triglyceride [30].

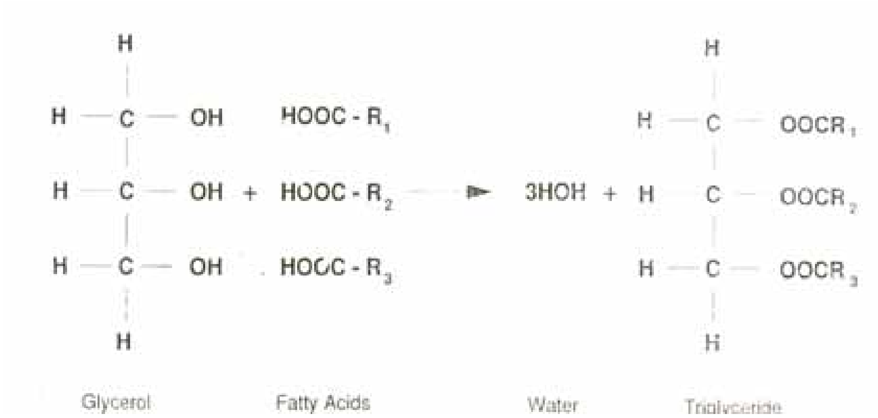

Fig.2.1 Chemical Structure of Vegetable Oils

where R, R' and R'' are the alkyl groups of different carbon chain lengths (varying between 12-18), and -COO- is an carboxyl group. Vegetable oils have different chemical structure as shown [22]: -

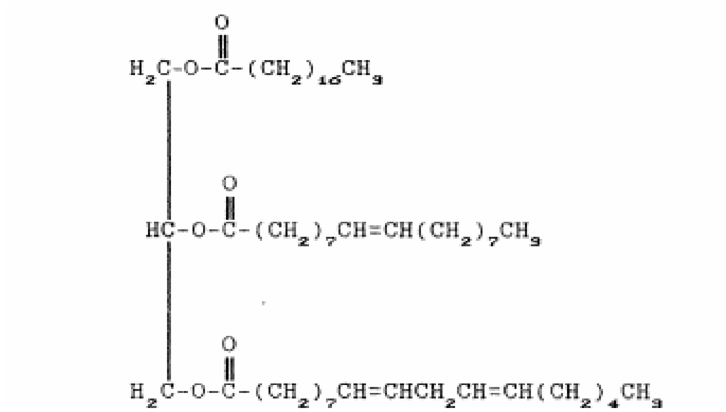

Fig. 2.2 Structure of a Typical Triglyceride Molecule

The large size of the vegetable oil molecules and the presence of oxygen in the molecules suggest that some fuel properties of the vegetable oils would differ markedly from those of hydrocarbon fuels [23].

Some of the properties of diesel and test methods required by ASTM are summarized in table 2.1.

Table 2.1: Tests and Limits for Fuel Properties [23]

Test	**ASTM Test**	**ASTM limits**
KinematicViscosity, mm^2/s	D445	1.9-4.1
Distillation Temperature, ^oC	D86	282-338 @ 90% pt.
Cloud Point, ^oC	D2500	*
Pour Point, ^oC	D97	4.4-5.5 ^oC
Flash Point, ^oC	D93	52 ^oC min
Water & Sediment, Vol %	D1796	0.05% max
Carbon Residue @ 10% residue	D524	0.35% max
Ash by Weight, %	D482	0.01% max
Sulphur by Weight, %	D129	0.5% max
Copper Strip Corrosion	D130	3 max
Cetane No.	D613	40 min

Cloud Point is not specified by ASTM. Satisfactory operation should be achieved in most cases if the cloud point is 6 ^oC above the tenth percentile minimum temperature for the area where the fuel will be used.

Advantages of the vegetable oils as engine fuels lie in their renewable nature and wide availability from the variety of sources. This is particularly attractive to countries lacking sources of liquid fossil fuels. They can also be produced on small scale, for on-farm operation to run tractors, pumps and small engines for power generation. There is a potential for a lower contribution, on combustion, to the atmospheric concentration of “Green house gas” carbon dioxide, than from the fixed carbon in fossil fuels.

It is clear that the use of the vegetable oils as fuels for diesel engines depends on their physical and chemical properties, and on their combustion characteristics as well as the type of engine use and the conditions of operation. They also have a higher Kinematic viscosity and density and lower cetane number, stoichiometric mixture ratio, and specific enthalpy of combustion than the diesel fuel. Though the properties vary from one type of oil to another this general comparison with the diesel fuel is valid for all [24].

The various vegetable oils are distinguished by their fatty acid compositions. Triglyceride molecules have molecular weights between 800 and 900 and are thus nearly four times larger than typical diesel fuel molecules [25]. Chemical structure of common fatty acids is given in table 2.2.

Table 2.2: Chemical Structure of Common Fatty Acids [22]

Fatty acid	**Systematic name**	**Structure**	**Formula**
Lauric	Dodecanoic	12:0	$C_{12}H_{24}O_2$
Myristic	Tetradecanoic	14:0	$C_{14}H_{28}O_2$
Plamitic	Hexadecanoic	16:0	$C_{16}H_{32}O_2$
Stearic	Octadecanoic	18:0	$C_{18}H_{36}O_2$
Arachidic	Eicosanoic	20:0	$C_{20}H_{40}O_2$
Behenic	Docosanoic	22:0	$C_{22}H_{44}O_2$
Lignoceric	Teracosanoic	24:0	$C_{24}H_{48}O_2$
Oleic	Cis-9-Octadecenoic	18:1	$C_{18}H_{34}O_2$
Linoleic	Cis-9,cis-12-octadecenoic	18:2	$C_{18}H_{32}O_2$
Linolenic	Cis-9,cis-12,cis-15-octadecatrienole	18:3	$C_{18}H_{30}O_2$
Erucic	Cis-13-Docosenoic	22:1	$C_{22}H_{42}O_2$

There are several problems associated with the use of vegetable oil. They can be categorized as operational and durability problems. The former included the ignition quality characteristics, e.g poor cold engine start-up, misfire, and ignition delay, and the latter include characteristics demonstrating incomplete combustion, e.g. nozzle coking, deposit formation, carbonization of injector tips, ring sticking and lubricating oil dilution and degradation [26].

Problems faced on using the neat vegetable oil

a) The increased viscosity of the neat vegetable oils leads to poor atomization and incomplete combustion with an unmodified fuel injection system.
b) The clogging of the fuel system.
c) Polymerization during storage.

d) Blow-by causing polymerization of the lubricating oil [27].
e) Thickening and Gelling of the lubricating oil as a result of contamination by the vegetable oil.
f) Oil ring sticking.
g) Carbon deposits around the nozzle orifice, the upper piston ring grooves and on the piston rings [28].

Because of the above stated problems, straight vegetable oil is not suitable as fuel for diesel engines; they have to be modified to bring their combustion related properties closer to diesel. This fuel modification is mainly aimed at reducing the viscosity to eliminate flow/atomization related problems. Four techniques can be used to reduce the viscosity of vegetable oils:

1) Heating/Pyrolysis,
2) Dilution/blending,
3) Micro-emulsion, and
4) Transesterification.

Undoubtedly, transesterification is well accepted and best suited method of utilizing vegetable oils in CI engine without significant long-term operational and durability issues. However, this adds extra cost of processing because of the transesterification reaction involving chemical and process heat inputs. In rural and remote areas of developing countries, where grid power is not available, vegetable oils can play a vital role in decentralized power generation for irrigation and electrification. In these remote areas, different types of vegetable oils are grown/produced locally but it may not be possible to chemically process them due to logistics problems in rural settings. Hence using heated vegetable oils as petroleum fuel substitutes is an attractive proposition. Keeping these facts in mind, a set of engine experiments were conducted using Jatropha oil on an engine, which is typically used for agriculture, irrigation and decentralized electricity generation. Heating was used to lower the viscosity of Jatropha oil in order to eliminate various operational difficulties.

Oil can be extracted from a variety of plants and oilseeds. Under Indian condition only such plant sources can be considered which is essentially non edible oil and available is in appreciable quantity and can also be grown on large-scale on wastelands.

Moreover, some plants and seeds in India have tremendous medicinal value, considering these plants for biodiesel production may not be a viable and wise option. Considering all the above options, probable biodiesel yielding trees or crops in India are [29]:

- Jatropha curcas or Ratanjot
- Pongamia pinnata or Karanj
- Calophyllum inophyllum or Nagchampa
- Hevea brasiliensis or Rubber seeds
- Calotropis gigantia or Ark
- Euphorbia tirucalli or Sher
- Boswellia ovalifololata.
- Orizya sativa or Rice bran oil

Of all the above prospective plant candidates as biodiesel yielding sources, Jatropha curcas stands at the top and sufficient information on this plant is already available. One hectare Jatropha plantation with 4400 plants per hectare under rain fed conditions can yield about 1500 liters of oil [29]. The residue oil cake after extraction of oil from Jatropha can be used as organic fertilizers. It is also estimated that one acre of Jatropha plantation could produce oil sufficient to meet the energy requirement of a family of 5 members and the oil cake left out when used as fertilizer could cater to one acre. The fact that Jatropha can be grown in any wastelands with less irrigation gives it a distinct advantage for consideration as the prime feedstock in Indian conditions.

One of the critical issues to be resolved for vegetable oil fuels as they seek status as replacements for petroleum diesel fuel is how they perform in a standard diesel engine. This literature review examines many of the tests that have been conducted in the past several years related to performance & emissions of vegetable oil fuels.

2.2 LITERATURE REVIEW

Humke et al. in tests with degummed crude soybean oil and crude soybean oil found that nozzle deposit formation after 10 hours caused engine performance to decrease and emissions to increase [30].

Rakopoulos et al conducted to evaluate and compare the use of a variety of vegetable oils of various origins as supplements to conventional Diesel fuel at blend ratios of 10/90 and 20/80 in a direct injection (DI) Diesel engine. They found that NO_x were reduced with use of vegetable oil in the diesel engine [31].

Pryor et al. 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 were more or less same as the power developed from diesel fuel. The brake specific fuel consumption was 11-13% grater than for diesel fuel at all loads [32].

Schlick et al conducted experiments on a direct injection diesel engine operating on mechanically expelled unrefined soybean oil and sunflower oil blended with diesel fuel on a 25:75 v/v basis. They evaluated that the power remained constant throughout 200 hrs of operation [33].

Hemmerlein et al. conducted experiments on naturally aspirated exhaust gas turbocharged air cooled and water cooled engines using rapeseed oil. Experiments were conducted using filtered rapeseed oil. It has been reported that the brake power and torque using rapeseed oil as fuel are 2% lower than that of diesel. The heat release rate is very similar for both fuels. With all the engines tested, maximum brake power was obtained with rapeseed oil. Also, lower mechanical stresses and lower combustion noise were observed. The emission of CO and HC are higher, whereas NO_x and particulate emission were lower in comparison with diesel fuel [34].

Rakopoulos reported use of olive fuel as a fuel supplement in DI and IDI Diesel Engines. He conducted an experimental study to evaluate 25/75 % and 50/50% blends of olive and commercial diesel fuel in four strokes DI and IDI Diesel Engines with swirl combustion chambers. The influence of the blends, for a large of loads, was examined on fuel consumption, maximum pressure, exhaust smoke, and exhaust gas emissions. A small penalty in sfc, and essentially unaltered maximum pressures and moderate increases in exhaust smoke were reported. There were moderate decreases in emitted NOx and increases in HC as well as negligible increases in CO [35].

Ziejewski et al. tested blends of 25% high oleic sunflower oil/75% diesel fuel and 25% high oleic safflower oil/75% diesel fuel and they evaluated that results from both the fuels were comparable with standard diesel fuel. The fuels were compared on the performance and emission results including , power output, fuel consumption, CO, CO_2 , NO_x and HC and the carbon and lacquer residue formation on the internal part of the engine. The results indicated no significant change in engine performance for the tested fuel, throughout the duration of the investigation. The carbon and lacquer deposits were within a normal range for both fuels in comparison to the results from the results of standard diesel fuel [36].

Nwafor et al prepared blends of neat rapeseed oil and diesel fuel in 25/75, 50/50, 75/25 % respectively and conducted the test run. There were no significant problems with engine operation using these alternative fuels. The test results showed increases in brake thermal efficiency as the amount of rapeseed oil in the blends increases. Reduction of power output was also noted with increased amount of rapeseed oil in the blends [37].

Ajiwe et al. tested the African pear seed to find out whether it possesses the physical and chemical properties enabling it to be used as a fuel in diesel engines [38].

Karaosmanoglu et al tested sunflower oil as a fuel in a single cylinder, direct injection air cooled diesel engine and concluded that no significant drop or increase in power and fuel consumption was observed. The engine didn’t display any fluctuations due to the change in the balancing force and the lubricating oil characteristics exhibited no remarkable change [39].

Machacon et al revealed the effects of pure coconut oil and coconut oil diesel fuel blends on the performance and emissions of a direct injection diesel engine. Operation of the test engine with pure coconut oil and coconut oil {diesel fuel blends) for a wide range of engine load conditions. The blends tested were 20{80}, 40{60}, 60{40} and 80{20} coconut oil {diesel fuel} (by volume ratios). The trial was shown to be successful even without engine modifications. They found that by increasing the amount of coconut oil in the coconut oil {diesel fuel blend resulted in lower smoke and NOx emissions. However, this resulted in an increase in the BSFC. This was attributed to the lower heating value of neat coconut oil fuel compared to diesel fuel [40].

Masjuki et al. to evaluated the performance, emission and wear characteristics of an indirect diesel engine fueled by blends of coconut oil and diesel fuel. The performance and emission characteristics results showed that 10–30% coconut oil blends produced a slightly higher performance in terms of brake power than that of diesel. All the coconut oil blends produced lower exhaust emissions including polycyclic aromatic hydrocarbons and particulate matter. The wear and lubricating oil characteristics results showed that coconut oil blends up to 30% produced similar results to that of diesel [41].

Silvico et al. 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 higher 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. They also reported that a diesel generator can be adapted to run with heated palm oil and would give better performance [42].

Abu-Quadis et al used shale oil in a single cylinder , direct injection diesel engine. They compared shale oil based fuels with petroleum based diesel oil in terms of performance, exhaust gaseous emission and particulate emission. They found that shale oil burned more efficiently than the baseline diesel fuel and therefore, resulted in higher thermal efficiency. The shale oil resulted in lower un-burnt hydrocarbon (HC) and less Carbon Monoxide (CO) than the diesel fuel. However the shale oil produced higher oxides of nitrogen (No_x) at lower load as compared to diesel fuel [43].

Al-Hasan extracted the oil from Pistachia Palestine fruits and tested its physical and combustion properties. The properties of a new energy resource of PP oil have been investigated. Pistachia Palestine (PP) tree forms a significant fraction of different forest trees in Jordan. The fruit of the PP tree is usually left without being utilized although it contains oil that may have a value if it is professionally processed. PP oil can be easily produced from PP fruits by oil pressing. PP oil is a promising source of fuel and an excellent additive to diesel fuel. The oil is flammable and special care must be taken when it is handled. Increasing the PP oil percentage in the fuel blends decreases the brake power and thermal efficiency, and increases the brake specific fuel consumption. Utilization of such oil helps in environmental protection against solid waste pollution [44].

Bari et al performed short term performance tests using crude palm oil as a fuel for diesel engine and found crude palm oil to be a suitable substitute, with a peak pressure about 5% higher and ignition delay about 3º shorter compared with diesel. Emissions of NO and CO were about 29 and 9% higher respectively for crude palm oil, However prolonged use of Crude palm oil as fuel caused the engine performance to deteriorate. After 5—hours cumulative running with CPO, the maximum power was reduced by about 20% and the minimum bsfc was increased by about 26% [45].

Yu et al conducted a study on waste cooking oil collected from the noodle industry. The oil was used as fuel in the engine without any further treatment. The performance and emission characteristics have also been compared with diesel fuel. The experimental results indicated that combustion characteristics were generally similar to that of diesel. The energy released at the late combustion phase was higher, which was due to heavier molecular weight materials present in the waste cooking oil. The engine performance was similar to that of diesel fuel. The emissions of CO, NO_x and SO_x were higher for waste cooking oil compared to that of diesel. At high temperatures, tar like substances were found to be depositing in the combustion chamber [46].

Pramanik analyzed performance of the engine using blends of diesel and jatropha oil in a single cylinder C.I. engine and compared with diesel. Significant improvement in engine performance was observed compared to vegetable oil alone. The specific fuel consumption and the exhaust gas temperature were reduced due to decrease in viscosity of the vegetable oil. Acceptable thermal efficiencies of the engine were obtained with blends containing up to 50% volume of jatropha oil. From the properties and engine test results it has been established that 40–50% of jatropha oil can be substituted for diesel without any engine modification. [47]

Forsen et al. tested 97.4%/2.6%; 80%/20%; and 50%/50% by volume blends of diesel and Jatropha oil on a single-cylinder direct-injection engine. They found carbon dioxide emissions were similar for all fuels, the 97.4% diesel/2.6% Jatropha fuel blend was observed to be the lower net contributor to the atmospheric level. The test further showed increases in brake thermal efficiency, brake power and reduction of specific fuel consumption for Jatropha oil and its blends with diesel generally, but the most significant conclusion from the study is that the 97.4% diesel/2.6% jatropha fuel blend produced maximum values of the brake power and brake thermal efficiency as well as minimum values of the specific fuel consumption. They also suggested the use of Jatropha oil as an ignition-accelerator additive for diesel fuel. [48]

Ramdhas et al. used rubber seed oil in a compression ignition engine and have reported that rubber seed oil blend fueled engine has higher carbon deposits inside combustion chamber than diesel-fueled engine. Utilization of blends required frequent cleaning of fuel filter, pump and the combustion chamber [49].

Reddy et al. 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 that of diesel under similar conditions. Improved premixed heat release rates were observed with Jatropha oil when the injector opening pressure is enhanced [50].

Above studies were conducted on either neat vegetable oils or blends of vegetable oil with diesel. The vegetable oil fuels were not subjected to any preheating arrangement. As already elaborated in preceding section, operational and durability problems have been experienced in diesel engine with vegetable oil as a fuel. The high viscosity of the vegetable oil has been the main reason behind these problems. The preheating of vegetable oil before introduction into the diesel engine either by exhaust gases or some other means has been found to be one option of utilizing vegetable oil in diesel engine since at high temperature viscosity of vegetable oil shall lower down. Some research has been done with preheated vegetable oils in diesel engine and some of the manor findings are summarized below.

Nwafor et. al. evaluated the effect of increasing fuel inlet temperature on viscosity and performance of a single cylinder, unmodified diesel engine. The overall results showed that fuel heating increased peak cylinder pressure and was also beneficial at low speed and under part-load operation. The high combustion temperature at high engine speed becomes the dominant factor, making both heated and unheated fuel to acquire the same temperature before fuel injection [51].

Agarwal et. al. conducted various experiments to study the effect of reducing Jatropha oil's viscosity by increasing the fuel temperature and thereby eliminating its effect on combustion and emission characteristics of the engine. The acquired data were analyzed for various parameters such as thermal efficiency, brake specific fuel consumption (BSFC), smoke opacity, and CO_2, CO and HC emissions. While operating the engine on preheated Jatropha oil performance and emission parameters were found to be very close to mineral diesel for lower blend concentrations. However, for higher blend concentrations, performance and emissions were observed to be marginally inferior [52].

Nwafor 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 [53].

2.3 STATEMENT OF THE PROBLEM

It is clear from the above literature review that vegetable oil can be used either as an extender or complete replacement to diesel fuel. Many researchers have reported difficulties encountered with use of vegetable oil in diesel engine. These difficulties are mainly attributed to high viscosity of vegetable oil. Jatropha is becoming a sustainable source for diesel replacement in India. However, its high viscosity issue is to be resolved for its long term utilization in diesel engine. Due to high viscosity, there are two strategies for using Jatropha oil as fuel for use in diesel engine. The first one is to modify the engine to adapt to the fuel and the second one is for processing the fuel to adapt to the engine. The literature indicates that modifying existing diesel engines to preheat Jatropha oil to reduce viscosity and could achieve the first strategy. The second option is modification of Jatropha oil to the existing engines. The adaptation of Jatropha oil to the diesel engine could be done by blending the Jatropha oil with diesel, producing methyl esters through transesterification process that could be used straight instead of diesel. However, it is essential to explore the possibility of development of a heat exchanger to preheat the neat jatropha oil with the help of exhaust gases before entry to diesel engine in a dual fuel tank mode because fuel modification techniques such as transesterification process requires expertise and equipments and not easily understable to rural community.

Therefore, the following objectives were envisaged for the present research work.

1. Comprehensive literature survey.
2. Determination of important Physico-chemical properties of jatropha oil.
3. Development of dual fuel mode experimental diesel engine test rig.
4. Development of heat exchanger and other 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 preheated jatropha oil and compare with base line data of diesel
7. Analysis of Results

CHAPTER 3

SYSTEM DEVELOPMENT & EXPERIEMNTAL PROCEDURE

3.0 INTRODUCTION

Diesel engines are amongst the most efficient prime movers and with the view of protecting global environment and concerns for long-term energy security, it has becomes necessary to develop alternative fuels with properties comparable to petroleum based diesel fuels. For the developing countries, fuels of bio-origin provide a feasible solution to the above twin crisis. Bio-fuels are getting a renewed attention because of global stress on reduction of green house gases (GHGs) and clean development mechanism (CDM). The fuels of bio-origin may be alcohol, vegetable oils, biomass, and biogas. Vegetable oils have comparable Physico-chemical properties with mineral diesel and they are biodegradable, non-toxic, and have a potential to significantly reduce pollution.

The qualities of this fuel, environmentally as well as technically, have pushed this fuel close to the final stages of commercialization in many countries. Each country can proceed in the production of particular oil, depending upon the climate and economy. Different countries have taken initiatives in this field and re-forestation has a very important role to play in meeting the challenge of Climate Change. Several initiatives have been taken in recent years in different parts of the country to promote large scale cultivation of oilseed bearing plants. Amongst the various plant species, oil extracted from seeds of Jatropha Curcus has been found very suitable as a substitute to diesel fuel.

3.1 JATROPHA PLANT DESCRIPTION

The Jatropha plant (Jatropha Curcas) or physic nut is a shrub or a small 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. It is claimed that probably the plant was distributed from South America by Portuguese seafarers via Cape Verde Islands and Guinea Bissau to Africa and Asia. 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 favorable. The Jatropha plant is a multiple use plant. The different uses of Jatropha will be presented in another section of this chapter. The root system of Jatropha plant comprises 3 – 4 lateral roots and a vertical one that reaches 5m down in the ground. The Jatropha Curcas is a drought resistant plant that can live up to 50 years. Jatropha Curcas tolerates a minimum annual rainfall of 250mm and a maximum annual rainfall of 3000mm. The minimum depends on the humidity, the higher the humidity the less the minimum rainfall Jatropha can tolerate. Jatropha can be found from sea level to 1800m altitudes. The tree grows to a maximum height of nearly 8m. The Jatropha fruit maturation takes 45 – 50 days. The plant starts producing yield 4 – 5 months after planting. The Jatropha trees produce a round fruit with a soft brownish skin, which have 1.5 – 3 cm in diameter and weigh 1.5 – 3 g. The seeds contain about 30-35% oil. The oil is pale yellow to brown in colour. The oil contains a toxic substance, curcas in that has strong purging effects.

The harvesting period of Jatropha seeds differ in different countries depending on the humidity of the weather. For instance, Jatropha seeds are only harvested once in most regions of Africa, during the period of August to September, while in Cape Verde the Jatropha seeds are harvested twice, in June or July and October or November. In general, fruits are picked from the plant or sometimes the fruits ripen in the tree and fall down, and thereafter are picked for processing.

3.1.1 The Cultivation of the Jatropha plant

Jatropha can be propagated from seeds as well as from cuttings. Seeds or cutting can be directly planted in the main field. Otherwise, seedlings grown in poly bags are transplanted in the main field.

3.1.2 Jatropha as a plant of many uses

Rural energy problems in developing countries and 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 in general: Renewable energy, promotion of women, poverty reduction and soil erosion control. The Jatropha Curcas has many products and potential contributions to rural community development. The products of the Jatropha plant are the plant itself, fruits, leaves, and latex. The fruits comprise of seeds and fruit hulls. The seeds produce seed oil, seed cake, and seed shells. The oil processes also produce sediments from oil purifications. Jatropha products and uses can be comprehensively presented as follows:

The Jatropha plant itself can be used in erosion control if planted across the hills and against the wind. The plant can also be used as firewood. The fact that it grows very fast means Jatropha could help to solve the problems of deforestation in many developing countries. The toxicity of the plant deters animal browsing. 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 fruits have seeds and also produce fruits hulls. The fruit hulls themselves are combustible and could be used to produce fire in villages. The fruit hulls also could be used as a green manure to add nutrients to the soil for agriculture. The fruit hulls could also be fermented to generate biogas. The Jatropha seeds can produce seed oil, seed cake and seed shells. The seed oil could be used as diesel or paraffin substitute or extender for diesel engines, cooking stoves, lightings and a lubricant. The oil and sediment from oil purifications can be used as base material for soap production. 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. The seed cake could be used directly in agricultural activities as fertilizer. The seed cake could also be used in anaerobic digester to produce biogas. The seed cake from non-toxic varieties of Jatropha could be used as a fodder. In the case of seed shells from the seeds, they can be combusted directly and produce energy in terms of fire.

The Jatropha plant also helps to control soil erosion and improve soil fertility. Jatropha plants facilitate the control of water erosion if it is planted parallel to store dams and could be used as a wind bleak. Since the plant roots grow closer to the ground surface, which forms bonds that slow the surface runoff during heavy rains, this helps the penetration of more water into the soil and makes the soil more productive.

Furthermore, in the issue of poverty reduction, the Jatropha plant 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. Other sources of income for Jatropha are; Sale of Jatropha seeds and more income from food crops; since the Jatropha hedge protects food crops against animals more production is ensured. 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.

3.1.3 Toxicity of the Jatropha plant

The toxicity of the Jatropha Curcas is an advantage on one hand and disadvantage on the other. The advantage emanates from the fact 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 ram 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.

3.1.4 Jatropha Oil as a Renewable Fuel for Road Transport

The history of using Jatropha oil instead of diesel goes back to the Second World War when Madagascar, Cape Verde and Benin used Jatropha oil as a diesel substitute. The recent tests of unmodified and modified Jatropha oil for diesel engines in Mali, Nicaragua and India make Jatropha oil a potential renewable fuel for road transport as a replacement or an extender of diesel fuels. Jatropha oil could also be used as cooking fuel or lighting fuel in rural areas. The focus of this study is for using Jatropha oil as a fuel for decentralized energy production. Jatropha oil is a very promising fuel for this application due to several advantages: Jatropha oil is a renewable fuel that could last for many years without any problem. Jatropha oil is environmentally friendly fuel and could be produced easily in rural areas. The major disadvantage of Jatropha oil as a fuel for road transport is the high viscosity of Jatropha oil that is due to the large molecular mass and chemical structure of Jatropha oil. Previous studies show that the high viscosity causes problems in pumping, combustion and atomization in injector systems of diesel engines. The literature further notes that in the long term the high viscosity may develop gumming, the formation of injector deposits, and ring sticking. Therefore, the reduction of viscosity in order for Jatropha oil to be used for road transport is paramount.

The greatest difference to be considered in using Jatropha oil as fuel for road transport or agriculture sector is the amount of viscosity, which could contribute to carbon deposit in the engines and the above-mentioned issues. The high viscosity could also cause incomplete fuel combustion and may result in reducing the life of an engine and have environmental drawbacks such as producing carcinogenic particles. However, the high cetane number and calorific value that is approximately equal to diesel fuel make it possible to use Jatropha oil in diesel engines. Additionally, the high flash point of Jatropha oil makes it safer to store, use and handle than petroleum diesel; 210ºC is the temperature at which it will ignite when exposed to a flame while diesel is only 45 – 55 ºC.

Due to the difference in viscosity and other differences noted above, there are two strategies for using Jatropha oil as fuel for road transport. The first one is to modify the engine to adapt to the fuel and the second one is for processing the fuel to adapt to the engine. 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 with the other techniques since those techniques requires expertise and equipments such as transesterification process.

3.2 PHYSICO-CHEMICAL PROPERTIES

3.2.1 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 3.1.

Plate 3.1: U-Tube Oscillating True Density Meter

3.2.2 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. It is an important property because if it is too low and too high then atomization and mixing of air and fuel in combustion chamber gets affected. Viscosity studies were conducted for different test fuels. 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 using Kinematic viscometer shown in plate 3.2 at 40^0 C as per the specification given in ASTM D445. A suitable capillary tube was selected, and then a measured quantity of sample was allowed to flow through the capillary. Efflux time was measured for calculating Kinematic viscosity using the formula given below:

$$\nu = c * t \qquad \ldots (3.1)$$

Where,

ν	=	Kinematic viscosity, cSt or mm^2/sec
c	=	constant; mm^2/sec^2
t	=	time, second

Plate 3.2: Kinematic Viscometer

3.2.3 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. A small pilot flame was directed into the cup through the opening provided at the top cover at the regular intervals. 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^o C.

A Pensky Martens apparatus used in the study for determination of flash point is shown in Plate 3.3.

Plate 3.3: Pensky Marten Flash Point Apparatus

3.2.4 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 3.4.

Plate 3.4: Cloud and Pour Point Apparatus

The cloud point is the temperature at which a solid material, usually paraffin waxes and similar compounds in the case of petroleum liquid begins to separate when the sample is cooled under carefully controlled conditions. Likewise, the pour point is the lowest temperature at which the liquid will flow in a specific way when cooled under controlled conditions. The cessation of flow results from an increase in viscosity or from the crystallization of wax from the oil. Fuel oils of wax bearing crude oils have much higher pour point then those derived from crude oils of low wax content. A low pour point is a desired property of oil in respect of handling in cold atmosphere.

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.

3.2.5 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. All fuels containing hydrogen in the available form will combine with oxygen and form steam during the process of combustion. If the products of combustion are cooled to it initial temperature, the steam formed as a result will condense. Thus maximum heat is abstracted. This heat value is called the higher calorific value.

The calorific value of the fuel was determined with the Isothermal Bomb Calorimeter as per the specification given in ASTM D240. 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 value of all samples were calculated. The Bomb Calorimeter used for determination of Calorific value is shown in plate 3.5.

Plate 3.5: Bomb Calorimeter

The heat of combustion of the fuel samples was calculated with the help of equation given below:

$$H_c = \frac{\Delta W_c T}{M_s} \qquad \ldots (3.2)$$

Where,

H_c = Heat of combustion of the fuel sample, kJ/kg

W_c = Water equivalent of the calorimeter assembly, kJ/ ^oC

ΔT = Rise in temperature, ^oC

M_s = Mass of sample burnt, kg

3.2.6 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. It defines the fuels limit of filterability. The apparatus for CFPP measurement is shown in plate 3.6.

Plate 3.6: Cold Filter Plugging Point Apparatus

3.3 ENGINE SELECTION

There is no difference of opinion that India is going to face a severe fuel crisis in future because fuel consumption has increased in all the vital sectors specially transportation and agricultural sector. As diesel engines plays an indispensable role in transportation and agriculture sector and as such diesel consumption will increase multifold in time to come. 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. A through description of combustion mechanism in diesel engine is beyond the scope of this study. However, it would be worthwhile to inform that the fuel is burnt in diesel engine by self ignition at higher temperature and pressure conditions of the order of 600°C and 40 bar, respectively. Diesel as a fuel is injected into the combustion chamber at the end of compression stroke and after certain ignition delay; it burns to give the motive power. In India, almost all irrigation pump sets, tractors, mechanized farm machinery and heavy transportation vehicle are powered by direct injection diesel engines. Keeping the specific features of diesel engine in mind, a typical engine system, which is actually used widely in the Indian agricultural sector, has been selected for the present experimental investigations.

3.4 DEVELOPMENT OF AN EXPERIMENTAL TEST RIG

A Kirloskar make, single cylinder, air cooled, direct injection, DAF 8 model diesel engine was selected for the present research work, which is primarily used for agricultural activities and household electricity generations as shown in Plate 3.7.

Plate 3.7: Test Engine

It is a single cylinder, naturally aspirated, four stroke, vertical, air-cooled engine. It has a provision of loading electrically since it is coupled with single phase alternator through flexible coupling. The engine can be hand started using decompression lever and is provided with centrifugal speed governor. 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 wet sump type, and oil is delivered to the crankshaft and the big end by means of a pump mounted on the front cover of the engine and driven from 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 detailed technical specifications of the engine are given in Table 3.1.

Table 3.1: Specifications of the Diesel Engine

Make	**Kirloskar**
Model	DAF 8
Rated Brake Power (bhp/kW)	8 / 5.9
Rated Speed (rpm)	1500
Number of Cylinder	One
Bore X Stroke (mm)	95 x 110
Compression Ratio	17.5:1
Cooling System	Air Cooled (Radial Cooled)
Lubrication System	Forced Feed
Cubic Capacity	0.78 Lit
Inlet Valve Open (Degree)	4.5 BTDC
Inlet Valve Closed (Degree)	35.5 ABDC
Exhaust Valve Open (Degree)	35.5 BBDC
Exhaust Valve Closed (Degree)	4.5 ATDC
Fuel Injection Timing (Degree)	26 BTDC

For conducting the desired set of experiments and together required data 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 with heat exchanger and 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 3.8.

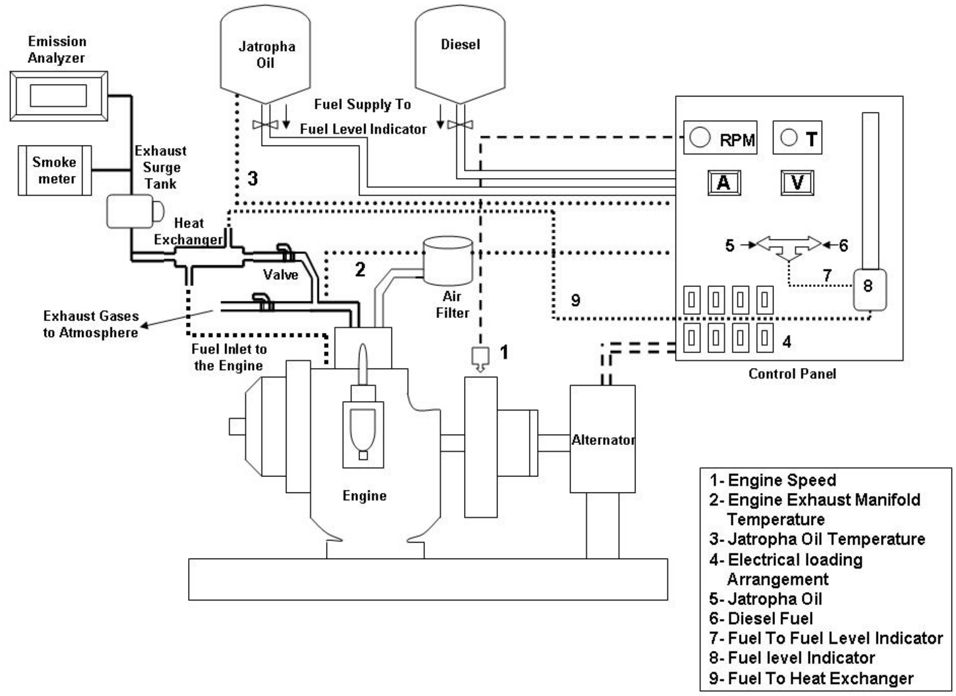

Fig. 3.1 Schematic Diagram of the Experimental Set Up

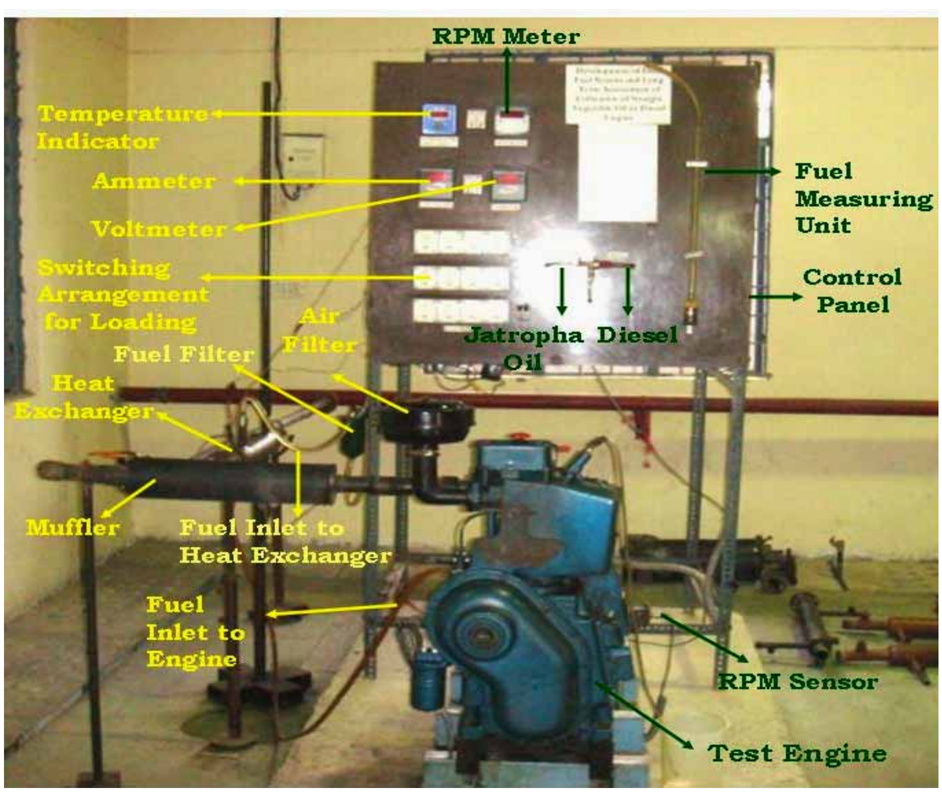

Plate 3.8: Photograph of the Experimental Set Up

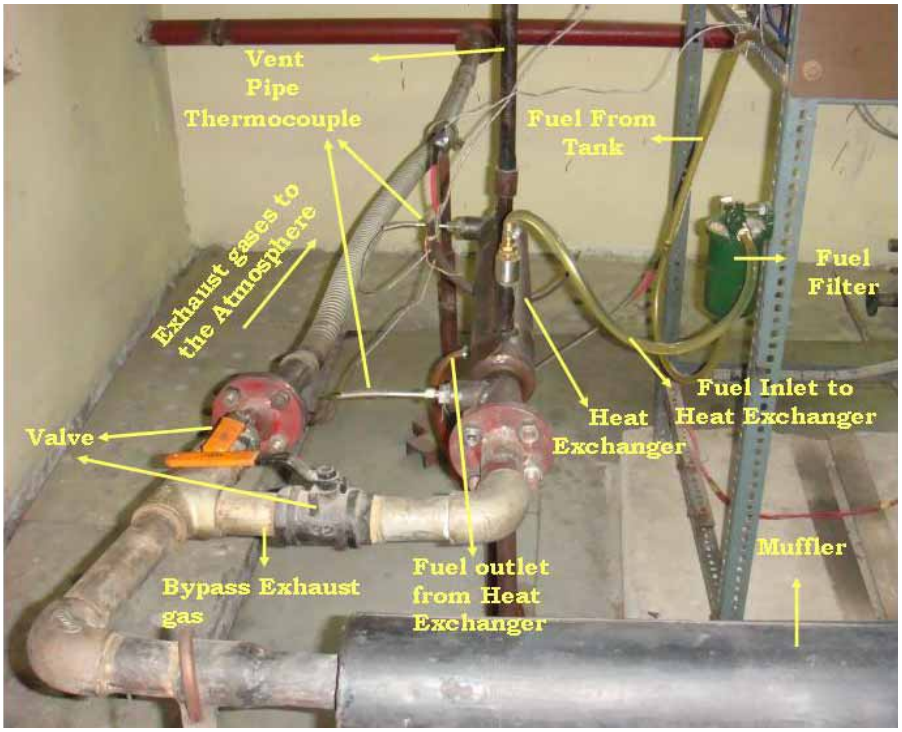

Plate 3.9: Photograph of Heat Exchanger Arrangement for Preheating by Exhaust Gases

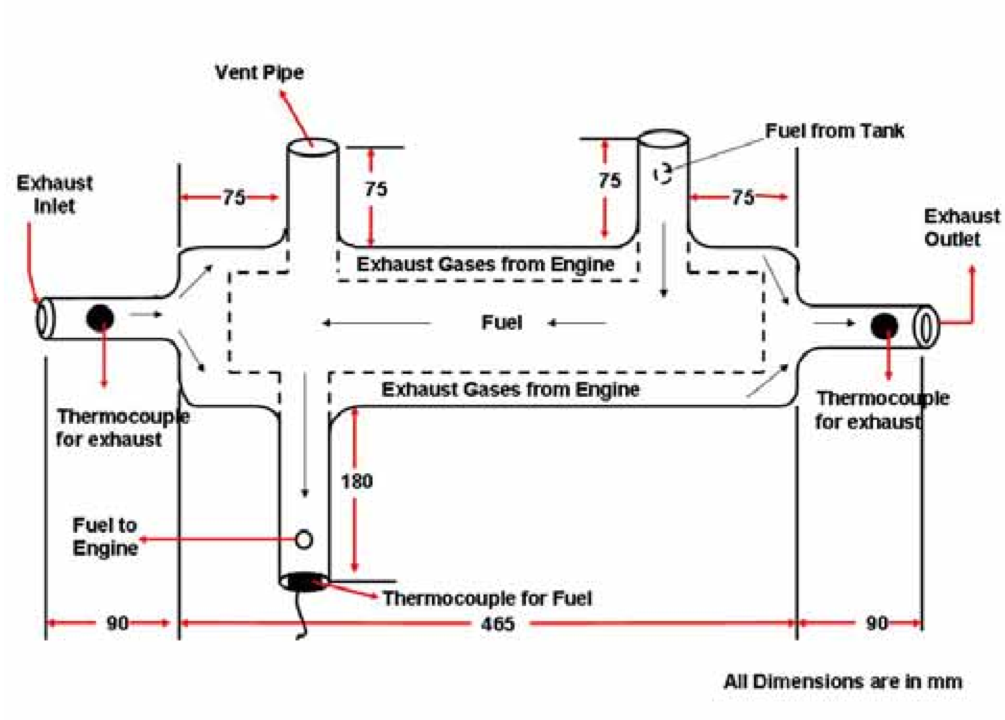

Fig. 3.2 Schematic Diagram of the Counterflow Heat Exchanger

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.

3.5 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 stand was fabricated and a 1020mm×850mm bakelite sheet of 3-mm thickness was mounted on it. Instruments such as voltmeter, ammeter, speed counter, six channels digital temperature display was mounted on the front side of the control panel (Plate 3.10). Electrical load banks, i.e., 12 bulbs each of 500 watts, were mounted on the rear side of the control panel which is shown in Plate 3.11 and their switches provided on the front side of the control panel.

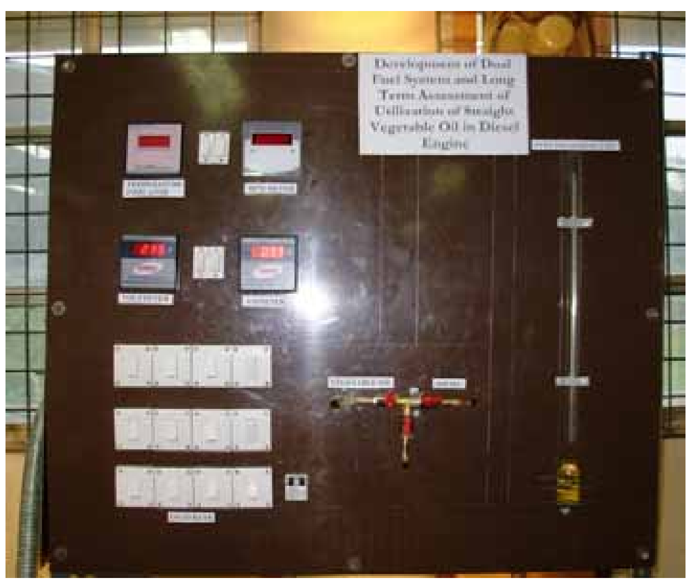

Plate 3.10: Control Panel

Plate 3.11: Load Bank

One burette with stop cocks and two way valves were also mounted on the front side of the panel for fuel flow measurements and selecting between either diesel fuel or jatropha oil. The two fuel tanks were mounted on the rear side of the panel at highest position as shown in plate 3.12.

Plate 3.12: 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 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 an air cooled engine it was suitable for hot climate. Absence of radiator, water body and pump made the system more suitable for the tests.

3.6 PARAMETERS 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

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. AVL 437 smoke meter
8. 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.

3.7 MEASUREMENT METHODS

As already elaborated, the main components of the experimental setup are two fuel tanks (Diesel and Jatropha oil), Heat Exchanger, bypass line, 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. For switching the engine from diesel to jatropha oil, a two way valve is provided on the control panel. Both the fuels from the two tanks can be feed to the engine through this valve separately. One end of the valve is connected to jatropha oil and the other end is connected to diesel. The fuel from the valve enters into the engine through this fuel measuring unit. 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 than enters in to the fuel filter before entering to the engine. In case of heat exchanger, the jatropha oil flows into the heat exchanger where it gets heated to the desired fuel inlet temperature before entering into the fuel pump and injectors to minimize their resistance to flow and for good atomization. The desired level of fuel inlet temperature of jatropha oil can be obtained by controlling the amount of exhaust gases passing through the heat exchanger with the bypass arrangement.

3.7.1 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. For this, two separate tanks, one burette, and a number of valves were provided on the panel as shown in the Plate 3.13.

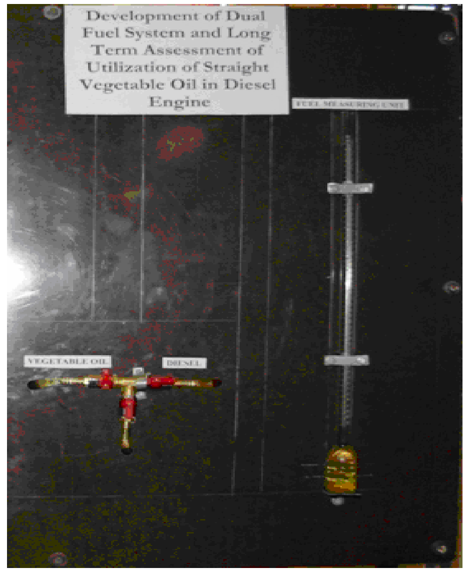

Plate 3.13: Fuel Flow Measuring System

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:

$$bsfc = (Vcc \times \ell \times 3600) / (hp \times t) \quad (3.3)$$

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:

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

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

3.7.2 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 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. The engine speed measurement arrangement is shown in plate 3.14.

Plate 3.14: Engine Speed Measurement

3.7.3 Temperature Measurement

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

3.7.4 Exhaust Emission Analysis

The major pollutants appearing in the exhaust of a diesel engine are the oxides of nitrogen. Exhaust gas analysis was done for exhaust smoke opacity, UBHC, CO, CO_2 and NOx. 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 technical detailed specifications have been given in Appendix I.

For measurement of UBHC, CO, CO_2 and NOx, AVL 4000 Light Di-Gas Analyzer was used. The detailed specification of AVL Di-gas Analyzer has been given in Appendix II.

Both the AVL 437 Smokemeter and AVL Di Gas Analyzer are shown in Plate 3.15.

Plate 3.15 Smoke and Emissions Measuring System

3.8 EXPERIMENTAL PROCEDURE

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. After feed control was adjusted so that engine attains rated speed and was allowed to run (about 30 minutes) till the steady state condition was reached. With the fuel measuring unit and stop watch, the time elapsed for the consumption of 10, 20 and 30cc 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. Fuel leakages from the injector were measured with small measuring cylinder. The engine was loaded gradually keeping the speed with in the permissible range and the observations of different parameters were evaluated. Short term performance tests were carried out on the engine with diesel to generate the base line data and subsequently neat Jatropha oil was used to evaluate its suitability as a fuel. The performance and emission characteristics of neat jatropha oil were evaluated and compared with diesel fuel. When the dual mode fuel engine was to run with preheated jatropha oil, a heat exchanger was used and is connected with the help of a bypass line of exhaust gases. The jatropha oil was heated to the different desired fuel inlet temperature and their performance and their performance and emission characteristics were evaluated. These data were than compared with both the diesel fuel and the unheated jatropha oil. The engine was always started with diesel as a fuel and after it was run for 20-25 minutes, it was switches over to jatropha oil. Before turning the engine off, the jatropha oil was replaced with diesel oil and it was run on diesel oil till all jatropha oil in fuel filter and pipe line is consumed.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.0 INTRODUCTION

The present study was done on an unmodified diesel engine which was converted to run on a dual mode operation. The main objective of the study was to fuel the diesel engine with preheated Jatropha oil using shell and tube heat exchanger and performance and emission studies on preheated Jatropha oil at different fuel inlet temperature and compare the results with baseline data.

4.1 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 was found higher than diesel. The flash 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 and emissions but reduces the calorific value of the fuel. Jatropha oil has approximately 89-90% 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 3.1

Table 4.1: Physico-Chemical Properties of Diesel and Jatropha Oil

Property	Mineral Diesel	Jatropha Oil
Density(kg/m^3)	810	920
Kinematic Viscosity at 40°C (cSt)	2.5	38
Cloud Point(°C)	2	9
Pour Point(°C)	-6	3
Cold Filer Plugging Point (CFPP) (°C)	-13	NA
Flash Point(°C)	70	235
Calorific value (kJ/kg)	42,200	37,500

From the above results it is clear that the Kinematic viscosity of Jatropha oil is much higher than diesel fuel which shall affect the engine performance. Therefore, Kinematic viscosity of jatropha oil at higher temperature was measured in Kinematic viscometer and results are summarized in figure 4.1.

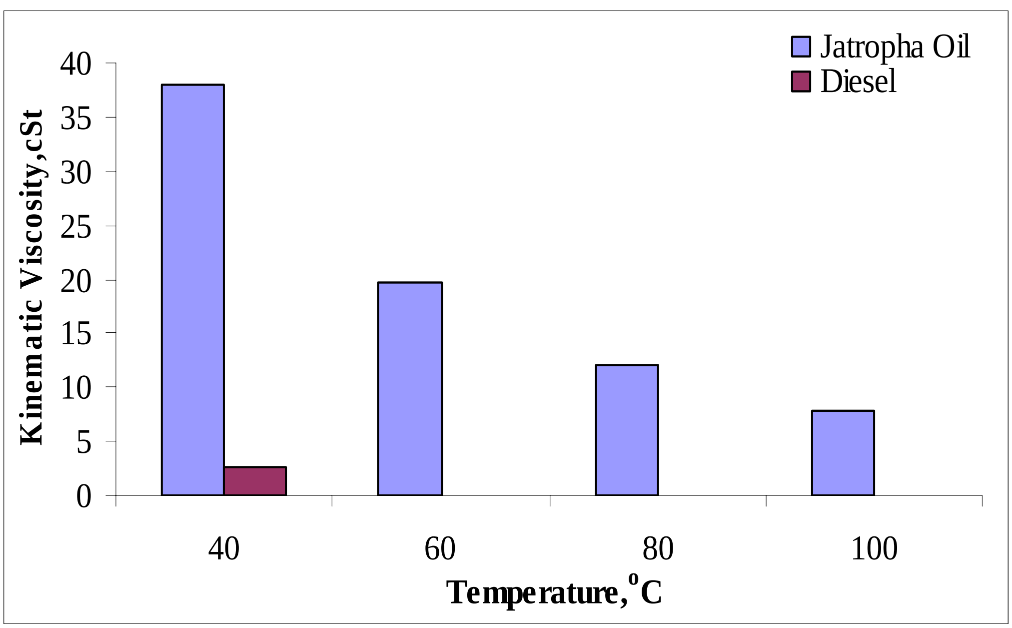

Fig. 4.1: Kinematic Viscosity of Jatropha Oil at Different Temperatures

From the above test results , it is clear that Kinematic viscosity of the fuel decreases with increase in temperature and at 100°C it is found that the viscosity of the oil come very near to diesel. Therefore, pre-heating of jatropha oil is a promising solution to decrease the viscosity and to alleviate problems associated with high viscosity. A series of experiments were conducted to select a range of fuel inlet temperature and based upon the results, 40°C, 60 °C, 80 °C and 100°C were selected as the pre-heating temperature at which subsequent tests shall be carried.

4.2 PERFORMANCE CHARACTERISTICS

The performance characteristics of the test engine on Diesel, Jatropha oil (Unheated and Preheated) are summarized below.

4.2.1 Brake Thermal Efficiency

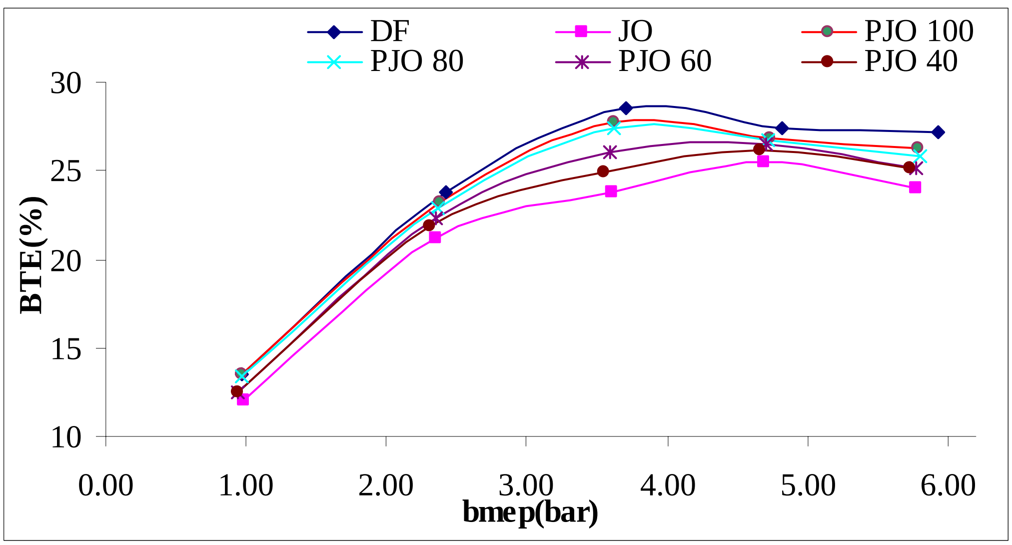

Fig.4.2 BTE Vs BMEP

The variation of brake thermal efficiency of the engine with pre-heated jatropha curcus oil at different temperature is shown in Figure 4.2 and compared with baseline data of diesel and unheated jatropha curcus oil. From the test results it was observed that initially with increasing brake power, the brake thermal efficiencies of all the fuels were increased and then tended to decrease with further increase in brake power. The brake thermal efficiencies of the Jatropha curcas 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. However, thermal efficiency of pre-heated jatropha oil was higher than unheated jatropha oil. This is due to the fact that preheated Jatropha oil has lower viscosity and with the rise in temperature, the viscosity reduces which result in increase in increase in Brake thermal efficiency. The highest brake thermal efficiency was found in case of pre-heated jatropha oil to 100ºC. The peak thermal efficiency for PJO 40, PJO 60, PJO 80 and PJO 100 were 26.17%, 26.44%, 27.4% and 27.69% respectively whereas the peak thermal efficiency of diesel was 28.51%.

4.2.2 Brake Specific Energy Consumption

Since Brake Specific Energy Consumption is not a very reliable parameters to compare the performance of two different fuels since density and calorific value of both the fuel are significantly different. Therefore, brake specific energy was taken as a parameter to compare the energy requirement for producing unit power in case of different test fuels.

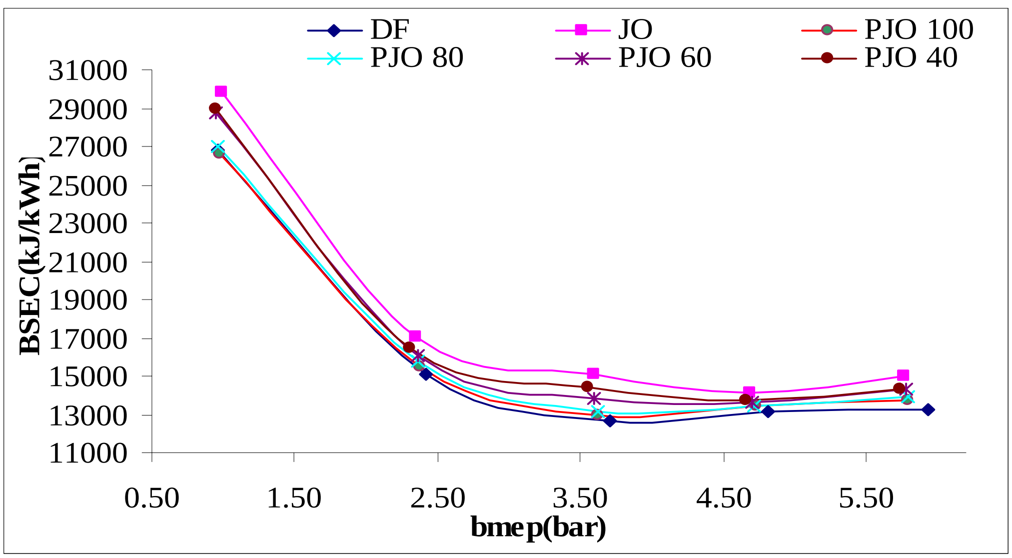

Fig.4.3 BSEC Vs BMEP

The variation of BSEC vs. BMEP for all the test fuels is shown in figure 4.3. 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 and low calorific value of the fuel. It is also observed that with the increase in degree of pre-heating, the brake specific energy consumption was found to be lower. 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.

4.2.3 Exhaust Temperature

Fig. 4.4 shows the variation of exhaust gas temperature with brake mean effective pressure for diesel, Jatropha oil (Unheated and Preheated). The results show that the exhaust gas temperature increased with increase in brake power in all cases. The highest value of exhaust gas temperature of 389°C was observed with the PJO 100 and the lowest was achieved with jatropha oil (JO) of about 345°C whereas the corresponding value with diesel was found to be 359°C. This is due to the poor combustion characteristics of the jatropha curcas oil because of its high viscosity. As the jatropha oil is heated with the help of a heat exchanger, its viscosity and density reduces. Also the jatropha oil is already heated before entering into the combustion temperature. Because of the above stated reasons, the combustion becomes good as compared with that of unheated jatropha oil which results in increased exhaust gas temperature.

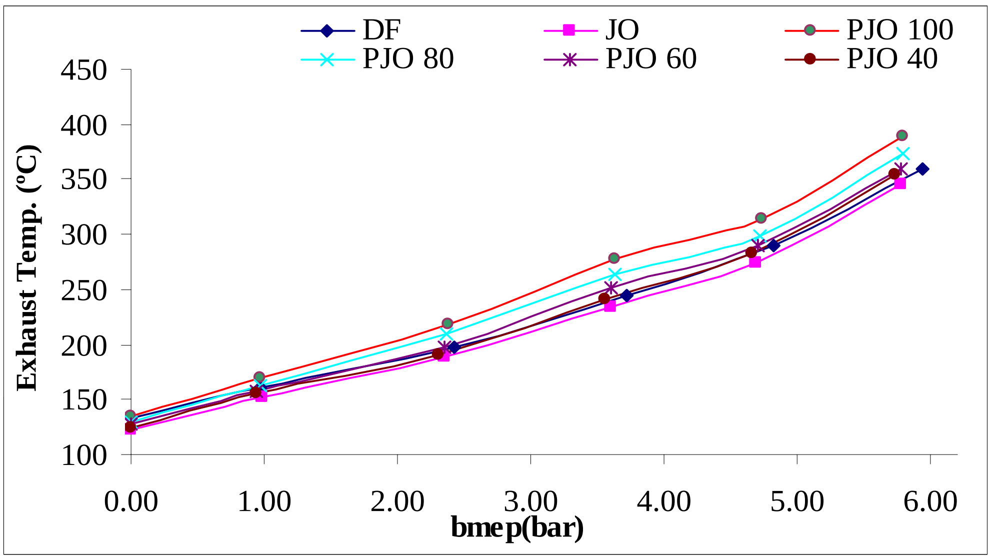

Fig.4.4 Exhaust Temperature Vs BMEP

The higher exhaust temperature with jatropha oil is indicative of lower thermal efficiencies of the engine. At lower thermal efficiency, less of the energy input in the fuel is converted to work, thereby increasing exhaust temperature. The results obtained are in accordance with Pramnik et al. [47] in which he has reported higher Exhaust temperature.

4.3 EMISSION CHARACTERISTICS

The emission characteristics of the test engine on jatropha oil (Unheated and Preheated) and diesel are given below.

4.3.1 NO_x Emissions

The variations of NO_x emissions for all the test fuels are shown in.Fig.4.5. The NO_x emissions increased with the increasing engine load, due to a higher combustion temperature. This proves that the most important factor for the emissions of NO_x is the combustion temperature in the engine cylinder and the local stoichiometry of the mixture. From Fig.4.5, it can be seen that within the range of tests, the NO_x emissions from the unheated jatropha oil are lower than that of diesel fuel but NO_x emissions increases as the fuel inlet temperature increased. Due to preheating of jatropha oil, the temperature inside the combustion chamber increases and this increase in temperature results in increased NO_x emissions in the exhaust gases. For diesel, the highest NO_x emission is 2046 ppm. With unheated jatropha oil (JO), the highest NO_x emissions are 1813 ppm. But in case of PJO 40, PJO 60, PJO 80 & PJO 100, the highest values of NO_x is 2079, 2495, 2612 and 2696 ppm respectively.

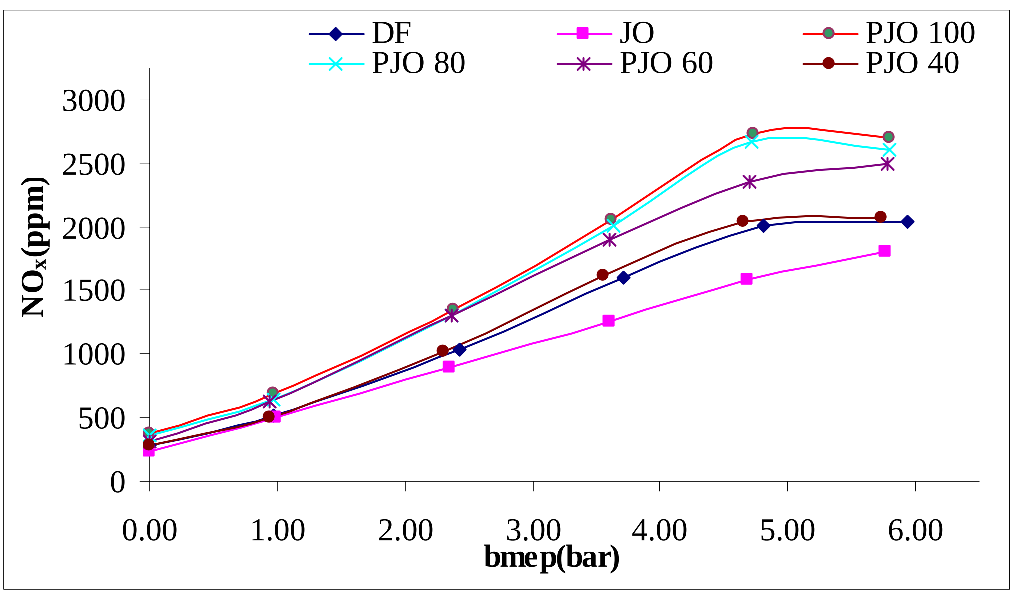

Fig.4.5 NO_x Vs BMEP

There is a considerable increase of NO_x from 1813 ppm to 2696 ppm for unheated jatropha oil and preheated jatropha oil respectively. The reason is possibly due to the smaller calorific value of vegetable oil. This is the most important emission characteristic of plant oil as the NO_x emission is the most harmful gaseous emissions from engines, the reduction of it is always the target for engine researchers and engine makers. This emission character of NO_x for plant oil is a very useful character for the application of plant oil to diesel engines as a kind of alternative fuel for the petroleum-based ordinary diesel fuel. The results obtained from the experiment clearly show that using plant oil in diesel engine reduces NO_x emissions and these results are in agreement with Wang et.al [54].

4.3.2 CO Emissions

Fig. 4.6 shows the comparison of the CO emissions for all the fuels at different engine load. Within the experimental range, the CO emission from the unheated jatropha oil is higher than that from pure diesel fuel. This is possible because of the high viscosity of vegetable oil. The higher the viscosity, the more difficult it is to atomize for the vegetable oil. This resulted in locally rich mixtures in the engine. In consequence it caused more carbon monoxide generated during the combustion, due to the lack of oxygen locally.

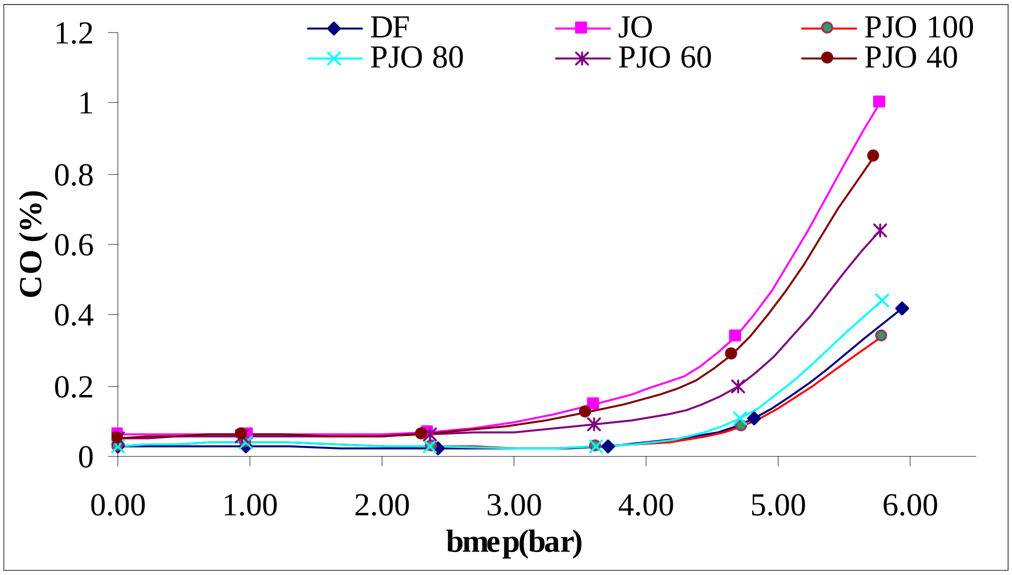

Fig.4.6 CO Vs BMEP

As already stated, the jatropha oil viscosity decreases with increase in temperature, atomization of fuel droplets becomes good enough to reduce the concentration of CO in the exhaust emissions. This reduces the value of CO from 1% to 0.34% at full load for unheated jatropha oil and preheated jatropha oil at 100^{o}C respectively. The highest value of CO for diesel fuel is 0.42%. The above results are in confirmation with the results obtained by Agarwal et al [52].

4.3.3 CO_2 Emissions

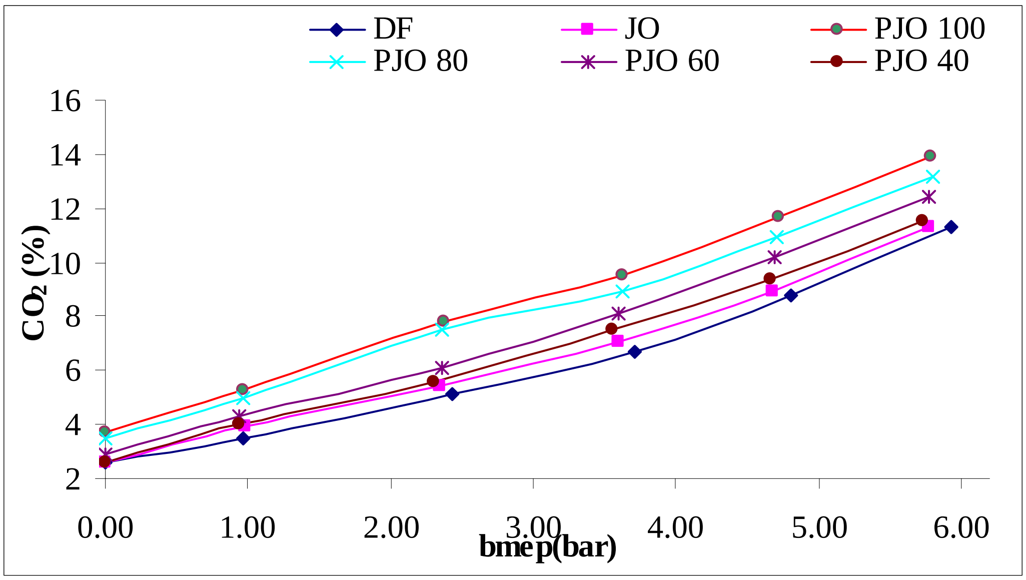

Fig.4.7 CO_2 Vs BMEP

The variations of CO_2 emissions of different fuels from the engine are shown in figure 4.7. In the range of whole engine load, the CO_2 emission of diesel fuel is lower than that of the other fuels. This is because vegetable oil contains oxygen element; the carbon content is relatively lower in the same volume of fuel consumed at the same engine load, consequently the CO_2 emissions from the vegetable oil and its blends are lower but with increase in temperature of jatropha oil, combustion inside the cylinder becomes better. This better combustion results in increased value of $CO_{2.}$ The highest value of CO_2 with diesel, unheated jatropha oil and preheated Jatropha oil at 100^{o}C were 11.3%, 11.6% and 13.9% respectively. The result shows that there was a slight increase in CO_2 emissions when using plant oil and these results are in agreement with Agarwal et al. [52] in which he has reported increased CO_2 emissions.

4.3.4 Un-burnt Hydro Carbon Emissions

The variation of unburnt hydrocarbon (HC) emissions for diesel and jatropha oil (Unheated and preheated) are shown in Fig. 4.8. The HC emissions of all the fuels are lower in partial engine load, but increased at higher engine load. This is due to relatively less oxygen available for the reaction when more fuel is injected into the engine cylinder at higher engine load. Fig. 4.8 shows that the HC emissions of unheated jatropha oil are higher than that of diesel fuel but with heated jatropha oil this value decreases and at a temperature of about 100^{o}C, it comes lower than that of diesel.

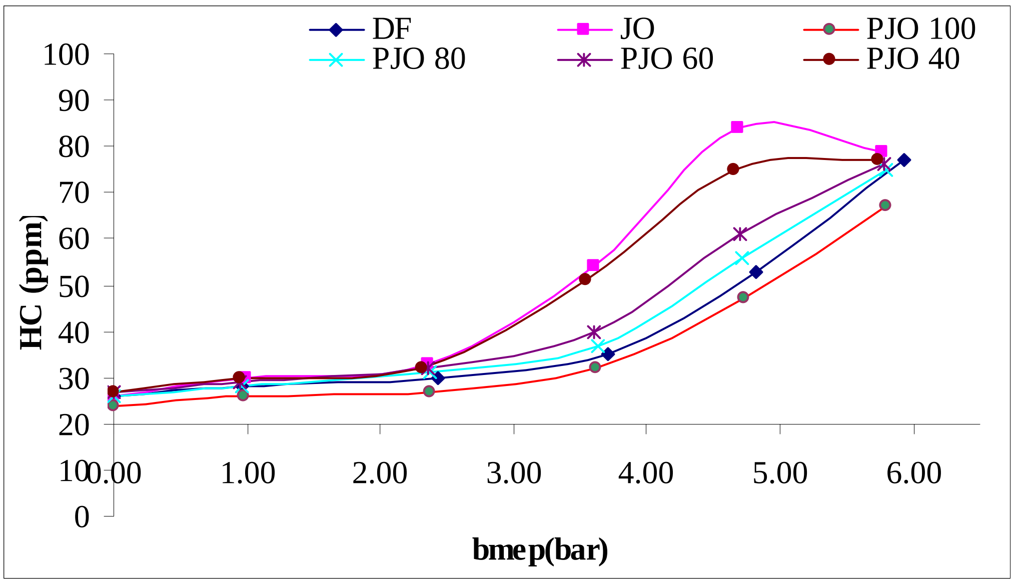

Fig.4.8 UBHC Vs BMEP

The value of unburned hydrocarbon emission from the diesel engine running at constant speed from no load to full load is high in case of straight vegetable oil and less for pure diesel. HC emissions are lower at partial load, but tend to increase at higher loads for both the fuels. This is due to lack of oxygen resulting from engine operation at higher equivalence ratio. These results are in accordance with Agarwal et. al.[52] in which he has reported increased HC emissions from no load to full load.

4.3.5 Smoke Opacity

Fig. 4.9 shows the comparison of smoke opacity for all the test fuels at different load conditions. Within the experimental range, the smoke opacity for jatropha oil (Unheated and pre-heated) is higher than diesel fuel for no load and medium load conditions. However, at full loads smoke opacity is found lower than diesel fuel. This may be due to the fact that higher load, oxygen content of jatropha oil may be responsible for better combustion and resulting into lower smoke opacity. This effect may be offset by high viscosity and density at lower load. When the fuel inlet temperature of jatropha oil is increased, the smoke opacity decreases with the fuel inlet temperature. This may be due to lower viscosity at higher fuel inlet temperature.

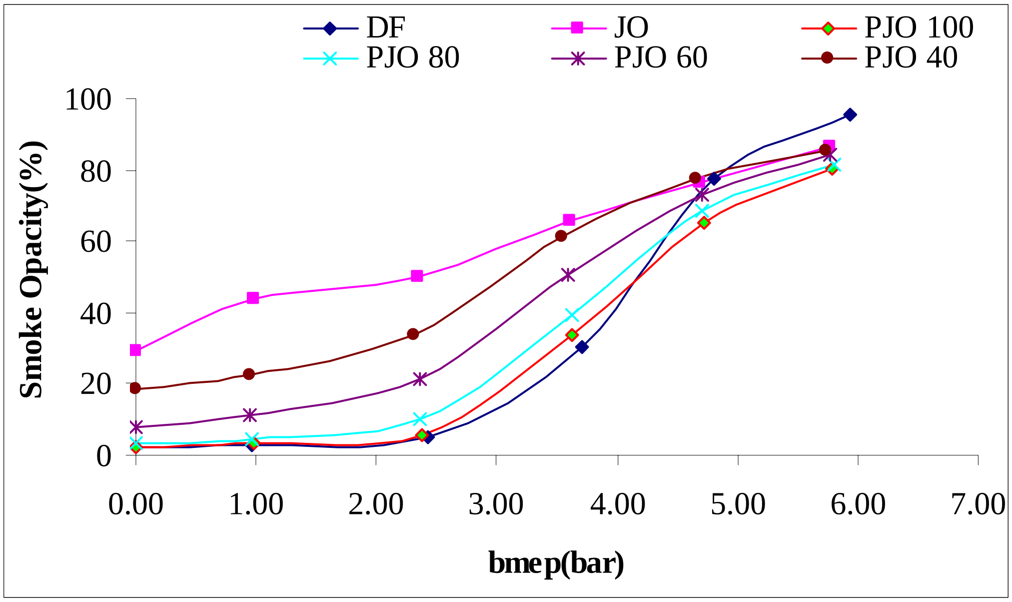

Fig.4.9 Smoke Opacity Vs BMEP

It is relevant to mention that with increase in fuel inlet temperature, the brake thermal efficiency improved and all gaseous emissions in comparison to unheated jatropha oil. The maximum gain was achieved with PJO100 (pre-heated jatropha oil to 100ºC). However, it was experienced during the course of investigation that lubricating oil started leaking from engine at pre-heated jatropha oil at 100ºC. Therefore, it was found that fuel inlet temperature to 80ºC is good enough in reducing Kinematic viscosity to run the diesel engine with out any adverse effect on engine

CHAPTER 5

CONCLUSIONS AND SCOPE FOR FUTURE WORK

The present study was carried on an unmodified diesel engine which was converted to run on a dual mode operation. The main objective of the present investigation was to evaluate suitability of Jatropha curcas oil (Unheated and Preheated) as a fuel for use in a C.I. engine and to evaluate the performance and emission characteristics of the engine. The experimental results show that the engine performance with unheated 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. However, 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. This is the most important gaseous emission characteristic of plant oil. However, for preheated jatropha oil, the NO_x emissions were increased. These NO_x emissions can be reduced by several methods such as EGR. The Carbon monoxide (CO), Hydrocarbon (HC), Carbon dioxide (CO_2) from the unheated jatropha oil was found higher than diesel fuel during the whole experimental range. With preheated jatropha oil, the value of Carbon monoxide (CO), Hydrocarbon (HC) and smoke opacity were decreased and Carbon dioxide (CO_2) emissions were slightly increased. From the results, it was seen that at 100^oC of fuel inlet temperature of jatropha oil, the performance and emissions were favorable. However, leakage of lube oil from the engine occurred. Therefore 80^oC was evaluated as the optimal fuel inlet temperature, considering the BTE, BSEC and gaseous emissions and durability and safe operation of the engine. The results from the experiments suggest that preheated jatropha oil (to a temperature of 80ºC) is potentially good substitute fuel for diesel engine and performance and emissions characteristics were found to be comparable to diesel fuel.

The long term assessment of engine durability and effect on lubricating oil with preheated jatropha oil need to be examined by the future researchers.

REFERENCES:

1. BP Statistical Review of World Energy, June 2008
2. World Development Indicator Database June 15, 2008,www.devdata.worldbank.org
3. Petstat, Ministry of Petroleum and Natural Gas, Government of India, www.petroleum.nic.in/petstat.pdf , accessed on June 15, 2008
4. http://mnes.nic.in , accessed on June 15, 2008
5. http://thinkearth.wordpress.com/2007/03/07/carbon-dioxide-concentration-in-atmosphere-in-last-400-thousand-years/ , accessed on June 15, 2008
6. http://www.guardian.co.uk/environment/2008/may/12/climatechange.carbonemissions, accessed on June 15, 2008
7. http://en.wikipedia.org/wiki/Global_warming#cite_note-grida7-0, accessed on June 15, 2008
8. http://edugreen.teri.res.in/explore/glossary.htm, accessed on June 15, 2008
9. http://www.grida.no/climate/vital/20.htm, accessed on June 15, 2008
10. http://www.mnp.nl/en/service/pressreleases/2008/20080613Chinacontributingt--wothirdstoincreaseinCO2emissions.html, accessed on June 15, 2008
11. http://www.answers.com/topic/kyoto-protocol?cat=biz-fin, accessed on June 15, 2008
12. http://www.onep.go.th/CDM/en/unf_kyoto_goal.html, accessed on June 15, 2008
13. Anjana Srivastava and Ram Prasad; Triglycerides-based diesel fuels; Renewable and Sustainable Energy Reviews; Vol.4, pp.111-133, 2000
14. J. Narayana Reddy and A. Ramesh; Parametric studies for improving the performance of a Jatropha oil-fuelled compression ignition engine; Renewable Energy; Vol. 31, pp. 1994-2016, 2006
15. T. K. Hayes, L. D. Savage and R. A. White; The effect of fumigation of different proofs on a turbocharged diesel engine; ASAE-880492, 1988

16. A. K. Aggarwal, L. M. Das; Biodiesel development and characterization for use as a fuel in C.I engine; ASME, Journal of Engineering for Gas Turbine & Power, Vol-123, pp 437-445, 2001
17. E. Larry, Wagner, J. Stanley and Clark; Effects of soyabean oils esters on the performance lubricating oil, and water of diesel engines ; ASAE-841385, 1984
18. Edward Crabbe, Nolasco-Hipolito Cirilo and Genta Kobayashi; Biodiesel production from crude palm oil and evaluation of butanol extraction and fuel properties; Process Biochemistry, Vol-37, pp 65-71, 2001
19. **Naveen Kumar**, Sachin Chugh and Vijay Kumar**;** Biodiesel – A Bridge for Sustainable Development for India; proceedings of International Conference on "Energy and Environment-Strategies for Sustainable Development", Jamia Milia Islamia, Delhi, 2004
20. C. L. Peterson, M. E. Casada, L. M. Safley and J. D. Broder; Potential Production of Agriculture Produced Fuels; Applied Engineering in Agriculture, Vol-11, pp 767-772, 1995
21. A. Farsaie, J. V. Debarhte and W. J. Kenworthy; Analysis of producing the vegetable oil as an alternate fuel; Energy in Agriculture, Vol-4, pp 189-205, 1985
22. K. A. Subramanian, S. K. Singhal, M. Saxena & S Singhal; Utilization of liquid biofuels in automotive diesel engine: An Indian perspective; Biomass & Bioenergy, Vol.29, pp 65-72, 2005
23. C. E. Goering, A. W. Schwab, E. H. Pryde, M. J. Gaugherty and A. J. Heakin; Fuel properties of eleven vegetable oils; ASAE , Vol 25, pp 1472-1477, 1982
24. J. Roy Crookes, Farriborz Kiannejad and A. A. Nazha Marouan; Systematic assessment of combustion characteristics of biofuels and emulsions with water for use as diesel engine fuel; Energy Conversion & Management, Vol-38, pp1785-1795, 1997
25. Yousaf Ali Hana and M. A. Khan; Alternative diesel fuels from vegetable oils, Bioresource Technology, Vol-50, pp 153-163, 1994
26. W Thomas Ryan and O. Maurin Bagby; Identification of chemical change occurring during the transient injection of selected vegetable oils; SAE-paper No. 930933, pp 201-210, 1993

27. S. M. Geyer, M. J. Jacobus and S. S. Lestz; Comparison of diesel engine performance and emissions from neat and transesterified vegetable oils; ASAE, Vol-27, pp 375-381, 1984

28. M. A. Fangrui and A Milford Hanna; Biodiesel Production: A Review; Bioresource Technology, Vol-70, pp 1-15, 1999

29. G. Knothe, R.O. Dunn and M. O. Bagby; Biodiesel: The use of vegetable oils and their derivatives as alternative diesel fuels. Biodiesel News Letter published by Central Pollution Control Board, New Delhi. ACS Symposium Series, 666, pp 172-208, 1997

30. A. L. Humke and N. J Barsia; Performance and emission characteristics of a naturally aspirated diesel engine with vegetable oil fuels; SAE paper 810955, 1981

31. C. D. Rakopoulos , K. A. Antonopoulos, D. C. Rakopoulos, D. T. Hountalas and E. G. Giakoumis; Comparative performance and emissions study of a direct injection Diesel engine using blends of Diesel fuel with vegetable oils or bio-diesels of various origins; Energy Conversion & Management, Vol.47, pp.3272–3287, 2006

32. Naveen Kumar and P.B. Sharma**;** Jatropha Curcus- A Sustainable Source for Production of Biodiesel; Special Issue of Journal of Scientific and Industrial Research (JSIR), Vol.64, pp. 883-889; 2005

33. M. L. Schlick; M. A. Hanna and J. L. Schinstock; Soybean and sunflower oil performance in a diesel engine; Transactions of the ASAE, Vol. 31, No. 5, pp. 1345-1349, 1988

34. Norbert Hemmerlein, Volker Korte and Herwig Richter; Performance, exhaust emissions and durability of modern diesel engines running on rape seed oil; Transactions of the SAE No. 910848, pp. 400-415, 1991

35. C. D. Rakopoulos; Olive oil as a fuel supplement in DI and IDI diesel engines; Energy, Vol-17, pp 787-790, 1992

36. Mariusz Ziejewski, Hans J. Goettler, Howard Hainees and Chor Huan; EMA durability tests on high oleic sun flower and safflower oils in diesel engines; Transactions of the SAE No. 961856, pp. 1963-1909, 96/7

37. O. M. I. Nwafor and G. Rice; Performance of rapeseed oil blends in a diesel engine; Applied Energy, Vol.54, No.4 , pp. 345-354, 1996

38. V. I. E. Ajiwe and A. E. Obika; African Pear seed oil: Potential alternative source to diesel oil; Fuel & Energy, Vol.14, pp. 112-116, 2000

39. F. Karosmanoglu, G. Kurt and T. Ozaktas; Long term CI engine test of sunflower oil; Renewable Energy, Vol. 19, pp. 219-221, 2000

40. Herchel T. C. Machacon, Seiichi Shiga, Takao Karasawa and Hisao Nakamura; Performance and emission characteristics of a diesel engine fueled with coconut oil diesel fuel blend; Biomass and Bioenergy, Vol. 20, Issue 1, pp. 63-69, January 2001

41. H. H. Masjuki, M. A. Kalam, M. A. Maleque, A. Kubo and T. Nonak; Performance, emissions and wear characteristics of an indirect diesel engine using coconut oil blended fuel; Proc. Instn Mech. Engrs, Vol.215, Part D, pp. 393-404, 2001

42. C. A. Silvio and de Almeida; Performance of a diesel generator fuelled with palm oil; Fuel 81, pp. 2097-2102, 2002

43. Moh'd Abu-Qudais and Mohamad I. Al-Widyan; Performance and emissions characteristics of a diesel engine operating on shale oil; Energy Conversion and Management, Vol.43, pp 673-682, 2002

44. M. Al-Hasan; Oil from Pistachia Palestine as a fuel; Biomass and Bioenergy, Vol.23 pp.381-386, 2002

45. S. Bari, C. W. Yu and T. H. Lim; Performance deterioration and durability issues while running a diesel engine with crude palm oil; Proceedings of Instn. of Mech. Engineers, Vol.215, Part D, pp.785-792, 2002

46. C. W. Yu, S. Bari and A. Amen; A comparison of combustion characteristics of waste cooking oil with diesel as fuel in a direct injection diesel engine; Proceedings of Instn. of mech. Engineers, Vol.215, Part D, pp 237-242, 2002

47. K. Pramanik; Properties and use of Jatropha Curcas oil and diesel fuel blends in C.I Engines; Renewable Energy, Vol-28, pp 239-248, 2003

48. F. K. Forson, E. K. Oduro and E. Hammond-Donkoh; Performance of Jatropha oil blends in a diesel engine; Renewable Energy, Vol 29, Issue 7, pp 1135-1145, 2004

49. A. S. Ramadhas, S. Jayaraj and C. Muraleedharan; Characterization and effect of using rubber seed oil as fuel in the compression ignition engines; Renewable Energy, Vol.30, pp.795–803, 2005

50. J. Narayana Reddy and A. Ramesh; Parametric studies for improving the performance of a Jatropha oil-fuelled compression ignition engine; Renewable Energy, Vol.31, Issue 12, pp. 1994-2016, 2006

51. O.M.I. Nwafor; The effect of elevated fuel inlet temperature on performance of diesel engine running on neat vegetable oil at constant speed conditions; Renewable Energy, Vol.28, pp.171–181, 2003

52. Deepak Agarwal and Avinash Kumar Agarwal; Performance and emissions characteristics of Jatropha oil (Preheated and blends) in a direct injection compression ignition engine; Applied Thermal Engineering, Vol. 27, pp 2314–2323, 2007

53. O.M.I. Nwafor; Emission characteristics of diesel engine running on vegetable oil with elevated fuel inlet temperature; Biomass and Bioenergy, Vol. 27, pp. 507 – 511, 2004

54. Y. D. Wang , T. Al-Shemmeri , P. Eames , J. McMullan , N. Hewitt , Y. Huang and S. Rezvani; An experimental investigation of the performance and gaseous exhaust emissions of a diesel engine using blends of a vegetable oil; Applied Thermal Engineering, Vol.26, pp 1684–1691, 2006

APPENDIX – I

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 Temperature at entrance	:	250ºC

APPENDIX – II

TECHNICAL SPECIFICATION OF AVL Di-GAS ANALYZER

Measurement principle	CO, HC, CO_2	Infrared measurement
Measurement principle	O_2 NO (option)	Electrochemical 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	