World Academy of Science, Engineering and Technology
International Journal of Mechanical and Mechatronics Engineering
Vol:2, No:2, 2008

Investigation on Performance and Emission Characteristics of CI Engine Fuelled with Producer Gas and Esters of Hingan (Balanites) Oil in Dual Fuel Mode

Samir J. Deshmukh, Lalit B. Bhuyar and Shashank B. Thakre

Abstract**—**Partial combustion of biomass in the gasifier generates producer gas that can be used for heating purposes and as supplementary or sole fuel in internal combustion engines. In this study, the virgin biomass obtained from hingan shell is used as the feedstock for gasifier to generate producer gas. The gasifier-engine system is operated on diesel and on esters of vegetable oil of hingan in liquid fuel mode operation and then on liquid fuel and producer gas combination in dual fuel mode operation. The performance and emission characteristics of the CI engine is analyzed by running the engine in liquid fuel mode operation and in dual fuel mode operation at different load conditions with respect to maximum diesel savings in the dual fuel mode operation. It was observed that specific energy consumption in the dual fuel mode of operation is found to be in the higher side at all load conditions. The brake thermal efficiency of the engine using diesel or hingan oil methyl ester (HOME) is higher than that of dual fuel mode operation. A diesel replacement in the tune of 60% in dual fuel mode is possible with the use of hingan shell producer gas. The emissions parameters such CO, HC, NO_x, CO_2 and smoke are higher in the case of dual fuel mode of operation as compared to that of liquid fuel mode.

Keywords**—**Esters, performance, producer gas and vegetable oil.

I. INTRODUCTION

THE world reserves of primary energy and raw materials are, obviously, limited. According to an estimate, the reserves will last for 218 years for coal, 41 years for oil, and 63 years for natural gas, under a business-as-usual scenario [1]. The fuels of bio-origin can provide a feasible solution to this worldwide petroleum crisis. Scientists around the world have explored several alternative energy resources, which have the potential to quench the ever-increasing energy thirst of today's population. Various biofuel energy resources explored include biomass, biogas, primary alcohols, vegetable oils, etc [2].

The use of plant oil as fuel for CI engine is not new. Dr. Rudolf Diesel (Inventor of diesel engine) demonstrated his engine in Paris in 1900 using groundnut oil as fuel. The plant oil fuels were not accepted much at that time, as they were more expensive. It was found that all properties of plant oils were close to FD except viscosity and volatility [3]. Various methods were adopted to overcome these problems. It included cracking of oil, blending of oils with FD, heating of plant oils before injecting into the combustion chamber of engine and esterification of plant oils [4]. Biodiesel has been reported as a possible substitute or extender for conventional diesel and is comprised of fatty acid methyl/ethyl esters, obtained from triglycerides by transesterification with methanol/ethanol, respectively. The resulting biodiesel is quite similar to conventional diesel fuel in its main characteristics [5] and [6]. The studies carried out on utilization of esters of hingan oil as CI engine fuel show that the important properties of hingan oil are quite closer to diesel, while CI engine performance with HOME as a fuel does not differ greatly from that of diesel. A slight power loss, combined with the increased fuel consumption due to lower heating value, was experienced with HOME [7].

In India, a large variety of biomass feedstock is available in huge amounts. As these are available locally, biomass gasifier-based power generation may be an appropriate option for decentralized power generation in many parts of the country. Biomass gasification is one such process where producer gas could be obtained from biomass feed stocks and in turn uses the producer gas for power generation purposes [8].

Gasification is the process of converting solid/liquid fuel into gaseous fuel. It involves the utilization and conversion of biomass in an atmosphere of steam and/or air to produce a medium or low calorific value gas. Gasification is a form of pyrolysis, carried out at high temperatures. The ratio of oxygen to biomass is typically around 0.3. The resulting gas, known as producer gas, is a mixture of carbon monoxide, hydrogen and methane, together with carbon dioxide and nitrogen. Biomass gasification is one of the upcoming biomass conversion technologies developed in order to produce a combustible gas mixture (called producer gas) using agro-

Samir J. Deshmukh is with the Department of Mechanical Engineering, PRM Institute of Technology & Research, Badnera, Amravati, 444607 M.S., India (phone:+91-721-2550731; fax: +91-721-2681329; e-mail: aryasamir@ yahoo.co.in).
Dr. Lalit B.Bhuyar, Prof. and Head, Department of Mechanical Engineering. PRMI T &R,.Badnera, Dist. Amravati,. 444607 M.S., India. (e-mail: lbbhuyar@gmail.com).
Shashank B. Thakre , Department of Mechanical Engineering. PRMI T &R,.Badnera, Dist. Amravati 444607. Maharastra. India, e-mail: sbthakre2007@gmail.com).

residues. It can be effectively utilized for decentralized power generation and thermal applications. Gasification of lignocelluloses biomass allows transforming its physical and chemical properties into a new fuel much more suitable to obtain mechanical energy in a process described a time ago [9].

Partial combustion of biomass in the gasifier generates producer gas that can be used for heating purposes and as supplementary or sole fuel in internal combustion engines. The utilization of producer gas in the diesel engine in dual fuel operation is an established technology for conservation of FD. Producer gas could be used in CI engine, without any modification in the engine. However, it cannot replace the FD completely. FD replacements up to 70–90% have been achieved in the dual fuel mode. Because of its poor ignition characteristics some minimum amount of FD is required to start the ignition [10]. On the other hand, increase in load on the engine, brake thermal efficiency of the dual fuelled engine starts decreasing drastically. Dual fuelled engine at higher loads emits more smoke. This is an indication of incomplete combustion of fuel. All the emissions such as CO, HC, NO_x and CO_2 from the dual fuel mode of operation are higher than that when diesel alone is used under all load conditions.

A typical composition of producer gas generated by biomass gasification on volumetric basis is given in Table I [10].

TABLE I
CONSTITUENTS OF PRODUCER GAS

Gas	Volume
Carbon monoxide	18-22%
Hydrogen	15-19%
Methane	1-5%
Hydrocarbons	0.2-0.4%
Nitrogen	45-55%
Water vapor	4%

In present study an attempt is made to utilize the biomass residue remaining after seed separation of hingan fruit as feedstock for biomass gasification. The producer gas along with diesel and esters of hingan oil are tried as a fuel in CI engine to analyze the engine performance. The diesel or biodiesel replacement with the use of producer gas is also analyzed.

II. MATERIALS AND METHOD

A. Hingan Fruit

Hingan tree, botanical name *Balanites Aegyptiaca(L.) Del;* family *Zygophyllaceac* is a multipurpose tree. The tree yields 100 kg of fruit annually. The fruit typically consists of outer skin, pulp, shell and kernel in the tune of 13%, 27%, 45% and 15% respectively. The fat content of the kernels is high, levels of 44-50% vegetable oil [11]. The oil obtained from the kernel of hingan is used for ester preparation by transesterification.

B. Characteristics of Fuels

Ester of hingan oil i.e. hingan oil methyl ester (HOME) was prepared by base catalyzed transesterification process and characterized as per the procedure recommended in [11]. The blend of HOME with diesel in the proportion 20% to 80% was prepared on volume basis termed as B20 is also used as liquid fuel in the present study. Characterization of liquid fuels, Diesel, hingan oil methyl ester (HOME) and B20 is carried out following ASTM standard test methods. The characteristics such as density, viscosity, gross calorific value are determined for diesel, HOME and B20.

Wood is the commonly used traditional fuel wherever heat generation is required. Wood is the well-known suitable biomass fuel because of its higher calorific value and low ash content. Small pieces of wood with approximate size of 5 cm in length and 3-4 cm in diameter are suitable to be used as gasifier feedstock. After removing the outer skin and pulp from the fruit, the nut covering the kernel is termed as shell of hingan fruit (SHF) is absolute woody material. The SHF is examined for development of producer gas in the down draft gasifier.

The proximate analysis of SHF is carried out to determine the characteristics such as moisture content, volatile matter, ash content, fixed carbon using Infra Red- Moisture Meter and Muffle furnace. The calorific value of SHF is determined using bomb calorimeter. SHF is used as a feedstock for gasifier in present study to generate producer gas. Diesel, HOME and B20 (liquid fuels) are used as fuels in single cylinder, CI engine to generate base line data. The CI engine used for the study was Kirloskar, single cylinder, four-stroke diesel engine. The engine is then run in dual fuel mode using liquid fuel and producer gas. The CI engine in liquid fuel and dual fuel mode is analyzed for its performance and emission analysis.

III. EXPERIMENTAL SETUP AND MEASURING DEVICES USED

A single cylinder, constant speed (1500 rpm), water cooled, direct injection with rated output of 3.7 kW, CI engine was used for the study. A down draft gasifier is selected in the study for generation of producer gas as the downdraft configuration reduces the amount of high molecular weight hydrocarbons and particles as compared to the updraft configuration [12].The schematic diagram of gasifier-engine assembly and experimental setup is shown in Fig.1. The experimental setup includes a diesel engine, biomass gasifier, gas filter, gas cooler, loading device. A downdraft gasifier is used for generation of producer gas. Small pieces of SHF, 20 - 30 mm in diameter and length were used as feedstock for gasification. The SHF is fed from the top of the gasifier at a regular interval. The partial combustion of biomass in the gasifier generates producer gas (PG), which enters the gas cooler. The dust particle in the gas is removed by passing through the gas filter. The valves are provided in the passage of gas to control the PG flow rate. Manometers are used to measure the air flow rate. The performance and emission tests are carried out in liquid mode and dual fuel mode at different load conditions. The dual fuel mode of operation is carried out by supplying the PG-air mixture to the combustion chamber of the engine through inlet manifold. The liquid fuel flow rate was measured on volumetric basis. AVL 444 digas analyser was used for the measurement of emissions concentration. A gas flow rate meter was used to measure the flow rate of PG. PG supply rate was controlled through a producer gas control valve (PG-valve). There was no control on aspirated air. To know the maximum intake of PG by engine, PG-valve is slowly opened till the engine started faltering. Later PG-valve is turned back slightly and the intake of PG at that point was taken as the maximum replacement in the engine for each operating condition. Experiments were carried out on the engine at five different loading conditions (0 %, 25%, 50 %, 75% and 98 %) using diesel, HOME, B20 blend, diesel + PG, HOME + PG and B20 + PG respectively as a fuel to the engine. The composition of producer gas was determined using 'Chimeto Gas-Chromatograph' and the calorific value of producer gas was calculated from the gas composition.

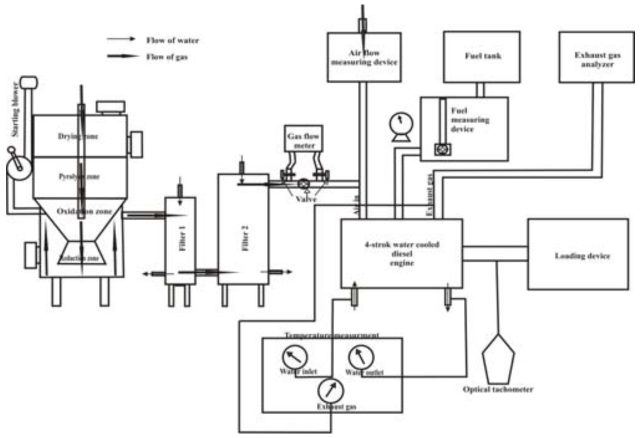

Fig. 1 Schematic diagram of the experimental setup for downdraft gasifier and C.I. engine

The performance parameters such as speed of engine, liquid fuel consumption rate (LFCR), PG flow rate(PGFR), thermal efficiency(BTE), specific energy consumption (SEC), % liquid fuel replacement (LFR) are calculated and compared. The emission of the engine was measured during these trials and compared with the base line data generated during the use of liquid fuels.

IV. Results and Discussions

A. Characterization of Liquid fuels

The important properties of HOME and B20 are quiet comparable with diesel as given in Table II [7].

TABLE II
PHYSICO-CHEMICAL PROPERTIES OF LIQUID FUELS

Property	HOME	B20	Diesel
Density, (Kg /m^3)	860	844	840
Viscosity, Cst(mm^2/s)	3.98	2.85	2.60
Calorific value, (MJ /kg)	39.65	41.92	42.5
Acid Value, (mg KOH/g)	0.34	0.20	--
Total sulphur content (%)	0.03	--	0.05
Carbon residue, (%)	0.19	--	0.15

B. The Proximate Analysis of Shell of Hingan Fruit (SHF)

The proximate analysis of SHF used as a feedstock for gasifier in this study is given in Table III. The ash content in used feedstock is very low i.e. 0.497% on dry basic, which indicate the good suitability of feedstock as a gasifier fuel. It is observed that the shell which is a woody material has 86% volatile matter and 5.5% moisture content. The woody SHF has good calorific value of 18 MJ/kg.

TABLE III
PROXIMATE ANALYSIS OF SHF

S.N.	Characteristic Parameter	Corresponding Value
1.	Volatile matter (% db)	86.00
2.	Ash content (% db)	0.497
3.	Moisture content (% db)	5.500
4.	Fixed carbon (% db)	8.003
5.	Calorific value (MJ/kg)	18.004

C. Composition and Calorific Value of Producer Gas (PG)

Based upon the producer gas composition, the calorific values are calculated and it is tabulated in Table IV. Average calorific value of 4.3844 MJ/m^3 observed for the producer gas is taken for further calculation. The calorific value of producer gas derived from wood chip and coir-pitch are 4.8MJ/kg and 3.5 MJ/kg respectively [9]. Hence it can be said that SHF is a suitable feedstock for gasification.

TABLE IV
COMPOSITION AND CALORIFIC VALUE OF PRODUCER GAS

Sample No.	Producer gas composition					Calorific value of PG (MJ/m^3)
	CO	H_2	CH_4	CO_2+other	Nitrogen	
1.	15.607	12.891	1.520	16.133	54.166	4.3844
2.	17.102	12.644	1.287	15.437	53.649	
3.	15.804	12.687	1.426	13.884	56.317	
Average	16.192	12.742	1.411	15.154	55.428	

D. Performance of CI Engine in Dual Fuels Mode (Liquid fuel and Producer Gas)

While operating the gasifier CI engine system, liquid fuel economy is one of the major factors. The engine performance with diesel, HOME, B20, Diesel + PG, HOME+PG and B20+PG is evaluated in terms of LFCR, BTE, BSEC, LFR and exhaust gas temperature(EGT) along with emission characteristics at 0, 25,50,75 and 98% loading conditions of the engine is discussed below.

1. *Brake Thermal Efficiency (BTE)*

It can be seen in Fig. 2 that the BTE of the dual fuel mode for engine is lower than that of diesel, HOME and B20. A considerable reduction in brake thermal efficiency is observed in dual fuel mode as compared to liquid fuel mode at all loading conditions. This is due to the lower calorific value of producer gas, which contains more combusted mixture that enters into the engine. Dual fuelled engine at higher loads emits more smoke. This is an indication of incomplete combustion of fuel which is due to the due to insufficient oxygen in the combustion chamber. This is due to the fact that producer gas evolved from the engine is at higher temperature and therefore density of producer gas is reduced, which in turn reduces the mass flow rate of PG and air required for combustion, resulting into lowering in oxygen level required for combustion.

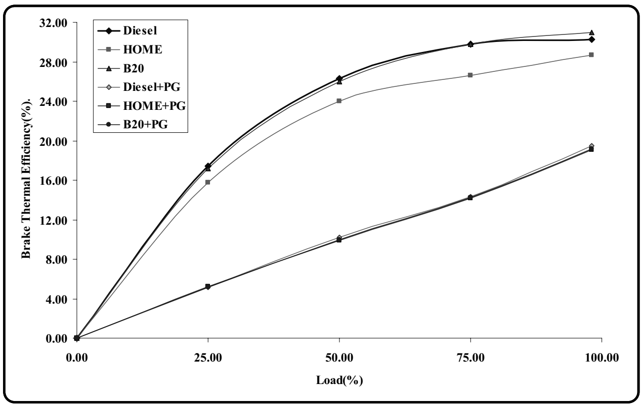

Fig. 2 Variation of BTE with applied load in liquid fuel and dual fuel mode

It is observed that difference in BTE value corresponding to liquid fuel mode and dual fuel mode, decreases with increase in load. This is due to reduction in producer gas flow rate (PGFR) at higher load as it is observed that detonation or knocking occurred when the engine is operated with a large fraction of the fuel energy from producer gas particularly at high load and hence the PGFR is restricted at high load.

2. *Liquid Fuel Replacement(LFR) and Liquid Fuel Consumption Rate (LFCR)*

Both the term LFR and LFCR are interrelated terms. The LFR in dual fuel mode operation is calculated as,

$$\%\ \text{Liquid fuel repalaceme nt(LFR)} = \frac{(\text{LFCR})_{\text{liquid}} - (\text{LFCR})_{\text{dual}}}{(\text{LFCR})_{\text{dual}}} \times 100$$

liquid: (Diesel, HOME and B20), dual: (Diesel + PG, HOME + PG and B20 + PG)

Fig. 3, explains the LFCR with liquid fuel and dual fuel mode. The liquid fuel consumption is more with HOME in comparison with diesel and B20. The considerable drop of LFCR is observed when the engine is operated in dual fuel mode. From Table 4.26, it can be easily seen that mean liquid fuel replacement of 46%, 50%, 55.5%, 60.36% and 26.24% is observed for 0, 25, 50, 75 and 98% loading respectively. Maximum LFR of in the tune of 59-61% is observed for all the dual fuel mode combinations.

With the increase in producer gas flow rates, the LFR increases. It can be seen that the maximum LFR has gone up to 60.91% in diesel + PG mode. The decrease in LFR is observed high load conditions. At high load operations, insufficient gas flow decreases the LFR. In order to reduce detonation, the intake of producer gas is reduced resulting in a low liquid fuel replacement at high load.

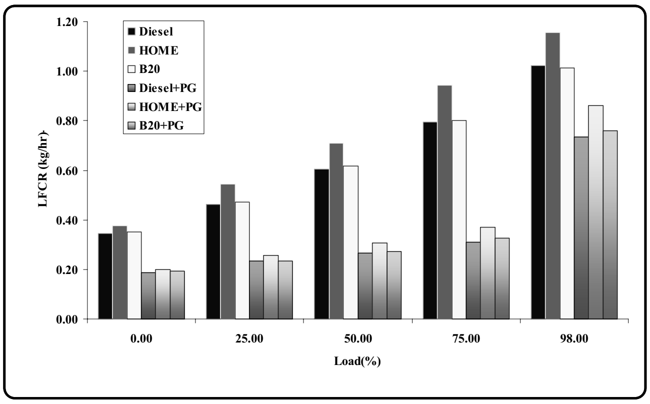

Fig. 3 Variation of LFCR with applied load in liquid fuel and dual fuel mode

3. *Specific Energy Consumption (SEC)*

Since the brake specific fuel consumption is not a very reliable parameter to compare the two fuels having different calorific values and density, brake specific energy consumption is preferred to compare the performance of CI engine. Specific energy consumption in dual fuel mode is calculated from the fuel consumption and calorific value of bio-diesel and producer gas. The specific energy consumption of the engine is higher at part load conditions irrespective of the fuel used Fig. 4. Specific energy consumption in dual fuel mode is higher than that of diesel mode at all load conditions.

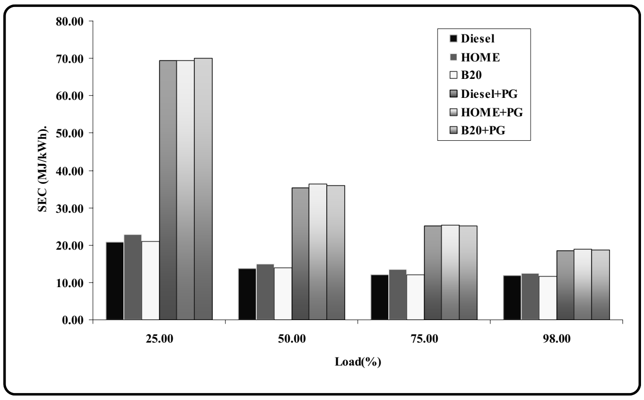

Fig. 4 Variation of SEC with applied load in liquid fuel and dual fuel mode

E. Emission Characteristics in Dual Fuel Mode

Emission characteristics of engine are important as far as environmental aspect is concerned. Also emission from the engine reflects the quality of combustion taking place inside the engine. The different emission parameters measured during liquid and dual fuel mode operation and discussed below.

1. Carbon monoxide (CO) emission

The variation of CO emission of the engine with various liquid fuel and dual fuel mode is depicted in Fig. 5.

With increase in load, an increase in CO emission is observed. Much higher values of CO emission are recorded in dual fuel mode as compared to liquid fuel mode. The higher concentration of CO emission in the dual fuel mode gives an indication of incomplete combustion. The mixture of high temperature PG and air flow to the engine reduces the amount of oxygen required for complete combustion. This creates incomplete combustion and increases CO emission.

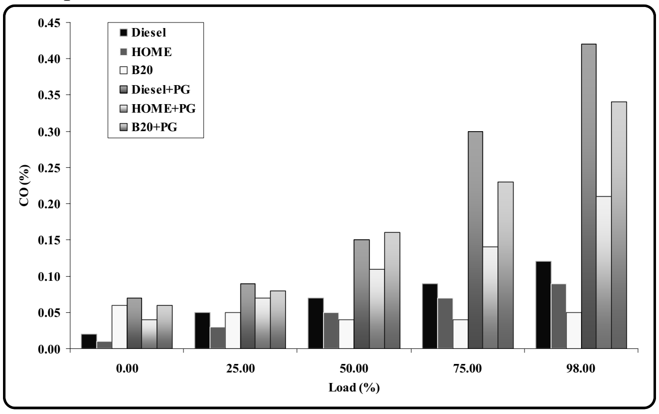

Fig. 5 Variation of CO emission with applied load in liquid fuel and dual fuel mode

2. Carbon Dioxide(CO_2), Hydrocarbon(HC) and Nitrogen Oxides(NO_x) emissions

Fig. 6, Fig. 7 and Fig. 8 illustrates the relationship between the % loading of the engine and the concentration of CO_2, HC and NO_x present in the exhaust gas respectively. As expected, with increase in load there is always an increase in CO_2, HC and NO_x emission.

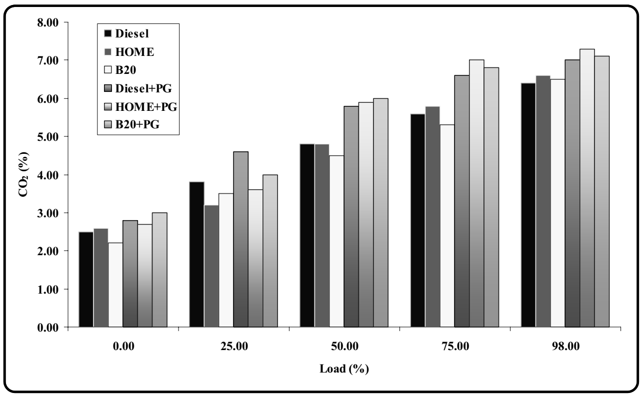

Fig. 6 Variation of CO_2 emission with applied load in liquid fuel and dual fuel mode

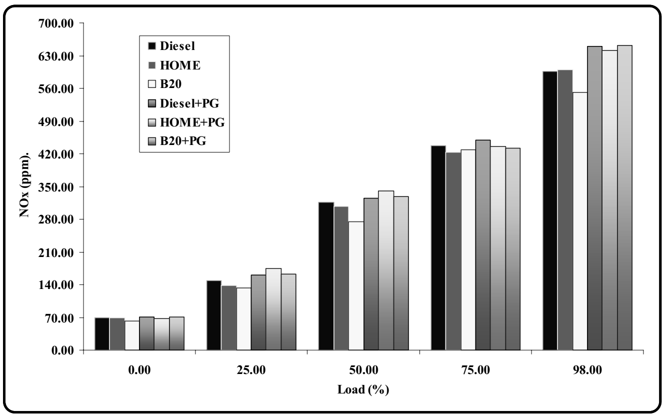

Fig. 7Variation of NOx emission with applied load in liquid fuel and dual fuel mode

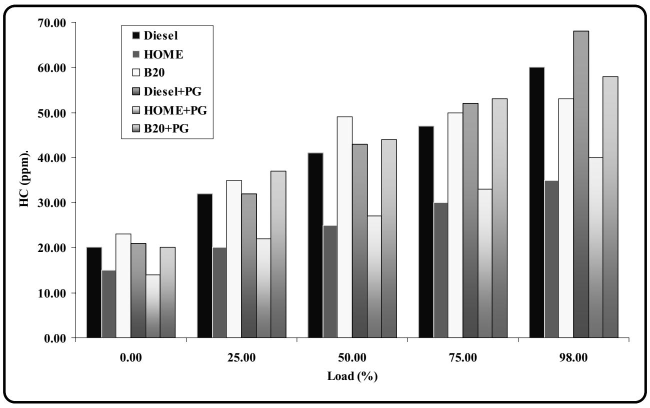

Fig. 8 Variation of HC emission with applied load in liquid fuel and dual fuel mode

In liquid fuel mode operation CO_2 emission is lower as compared to that of the dual fuel mode but insignificant difference in , HC and NO_x emission is observed in both liquid and duel fuel mode. Since the producer is a mixture of CO, HC, methane and CO_2, the combustion of producer gas increases CO_2 emission.

The NO_x emission depends upon combustion chamber temperature which in turn depends on the applied load. Insignificant difference in NO_x emission is recorded while operating the engine in liquid fuel mode and dual fuel mode. It was observed that the NO_x emission increases with increase in load for all the fuels tried on the engine. This is due to the lesser amount of oxygen available for combustion and hence NO_x formation. Also organic nitrogen from the air causes NO_x formation. Producer gas do not have organic nitrogen, it has only atmospheric nitrogen, which inorganic nitrogen [13].

3. Smoke Density

Fig. 9 illustrates the variation of smoke density with respect to load.

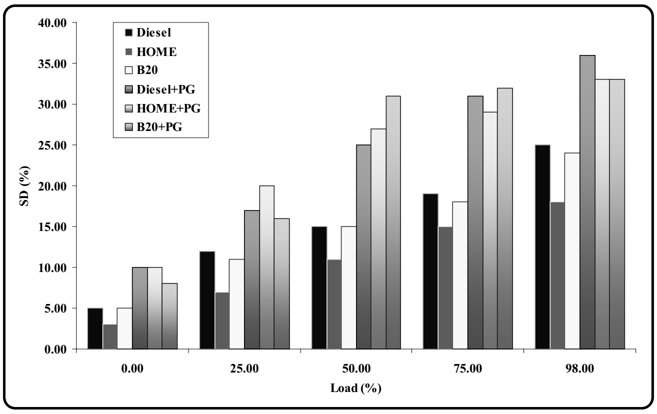

Fig. 9 Variation of smoke emission with applied load in liquid fuel and dual fuel mode

With the increase in load there is an increase in the smoke density. In liquid fuel mode operation the smoke density attained a maximum value of 25% with diesel fuel where as it is 36% in dual fuel mode for Diesel+PG at full load. In dual fuel mode of operation, the smoke density is observed to be higher than that of the diesel mode for all combination of PG.

This is due to the decreased amount of fresh air in dual fuel mode.

V. CONCLUSION

Some important findings on the engine performance and emission aspects of CI engine in dual fuel mode of operation while using SHF in the gasifier are highlighted in the present work. This study proved that the diesel engine is capable of successful running in dual fuel mode of operation with SHF as biomass in the gasifier. The important findings are listed below.

- Diesel engine shows similar performance and emission characteristics with all the three liquid fuels used in the study.
- The SHF is woody biomass having good calorific value and low ash content that makes it suitable feedstock for biomass gasification or can be used as firewood in rural households.
- This study proved that the diesel engine is capable of successful running in dual fuel mode of operation with the SHF as biomass in the gasifier.
- The SHF as biomass materials is suitable with little or no modification in the gasifier.
- The waste/low-cost biomass feedstock is used for producer gas generation. Hence, the power generation cost while using SHF as biomass is much cheaper than the conventional power generation cost.
- In dual fuel mode operation the engine performance decreases, with increased emissions at all load conditions.
- Carbon monoxide emission in dual fuel mode of operation is higher than that of liquid fuel operation.
- Other exhaust emission characteristics such as HC, NO_x and CO_2 are found to be closer irrespective of the fuel used and irrespective of mode of operation.
- In the dual fuel mode of operation, while using SHF, higher liquid fuel savings is achieved at part load conditions.
- Maximum liquid fuel replacement in the tune of 60% is achieved in all duel fuel mode operations, with no engine modification.

REFERENCES

[1] Kesse D G. “Global warming-facts, assessment, countermeasures.” J Pet Sci Eng. 26, pp 157-68, 2000.
[2] Murphy JD, McCarthy K. “The optimal production of biogas for use as a transport fuel in Ireland. Renew Energy.” 30, pp 2111-27, 2005.
[3] Agarwal AK. “Biofuels (alcohols and biodiesel) applications as fuels for internal combustion engines.” Progress in Energy and Combustion Science. 33, pp 233-71, 2007.
[4] Pramanik K. “Properties and use of Jatropha curcas oil and diesel fuel blends in compression ignition engine.” Renewable Energy. 28, pp 239-48, 2003.
[5] Sharma Y C, Sing B. “Development of biodiesel from karanja, a tree found in rural India.” J. Fuel. vol 87, pp1740-42. 2008.
[6] Otera J., “Transesterification” Journal Chem Rev. 93(4), pp1449-70, 1993.
[7] Deshmukh S J, Bhuyar L B. “Transesterified Hingan (Balanites) oil as a fuel for compression ignition engines.” Biomass and Bioenergy. Article in press, 2008 http://www.elsevier.com/locate/biombioe.
[8] Sridhar G, Paul PJ, Mukunda HS. “Biomass derived producer gas as a reciprocating engine fuel -an experimental analysis.” Biomass and Bioenergy. 21, pp 61-67, 2001.
[9] Ramadhas AS, Jayaraj S, Muraleedharan C. “Power generation using coir-pith and wood derived producer gas in diesel engines.” Fuel Processing Technology. 87, pp 849-53. 2006.
[10] Mohod AG, Gadge SR, Mandasure VN. “Liberation of carbon monoxide through gasifier I.C. engine system.” I.E. (I) Journal I.D. 84, pp27–29, 2003.
[11] Abdel R, Saadany E, Wasif M. “Chemical and physical studies on Balanite aegyptiaca oil.” Grasas Y Aceites. 37(2), pp 81-85, 1986.
[12]] P. McKendry. “Energy production from biomass (part 2): conversion technologies.” Bioresource Technology. 83, pp 47–54, 2002.
[13] R.N. Singh, S.P. Singh, B.S. Pathak. “Investigations on operation of CI engine using producer gas and rice bran oil in mixed fuel mode.” Renewable Energy. 32, pp1565-1580, 2007.

Samir J. Deshmukh was born on January 13, 1973, at Buldana, Maharashtra, India. He did his primary and secondary education from Daryapur(M.S.) in India. He received his Bachelor degree in Mechanical Engineering and Masters degree in Thermal Engineering from Amravati University, Amravati, M.S. India in 1994 and 2002 respectively. He is interested in alternate fuels and rural renewable energy.

Presently he is working as Assistant Professor in Mechanical Engineering Department, PRM Institute of Technology & Research, Badnera, Amravati. He is working on bidiesel and alternate fuels and its utility in rural area as an energy source. He is in the teaching and research field from last 12 years.

Samir is a member of ISTE and IE (I).