Effect of Hydrogen Enrichment on the Performance and Emissions of a Complete Bio-Fueled Diesel Engine

R.Prakash[1], Gandhi Pullagura[2], R.K.Singh[3] and S. Murugan[4]

Abstract— Esters of vegetable oil by esterification and bio oil produced by pyrolysis of various biomass resources have greater scope as alternative fuels for the future in power and transportation sectors. Experiments were conducted to evaluate the performance and emission parameters of a compression ignition engine on a dual fuel mode. Hydrogen was inducted in small quantities in a diesel engine whereas an emulsion of bio-oil and methyl ester of karanja was injected into the cylinder as a main fuel. The results were compared with diesel fuel operation and presented in this paper. The percentage increase in the brake thermal efficiency was 11.8%, 27.6% and 34.4% for WPO-MEK without hydrogen operation, WPO-MEK with 2lpm of hydrogen and WPO-MEK with 4lpm of hydrogen respectively at full load. The BSEC is 2.5% higher for WPO-MEK operation when compared to diesel. In case of WPO-MEK with hydrogen 2lpm and 4lpm, the BSEC values reduced by 18.7% and 29.3% respectively. There is about 51.2%, 64.4% and 72% increase in NO emissions for WPO-MEK, WPO-MEK with 2lpm, 4lpm of hydrogen induction respectively. Smoke density decreases by 14.6%, 26.2% and 31% respectively for WPO-MEK, WPO-MEK with 2lpm, 4lpm of hydrogen induction.

***Keywords*—** biomass, bio-oil, bio-diesel, emissions, emulsion, hydrogen enrichment.

I. Introduction

The world is presently confronted with two major issues; fossil fuel depletion and environmental degradation. Indiscriminate extraction and high consumption of fossil fuels have led to reduction in crude oil resources. The search for an alternative fuel, which promises a harmonious correlation with sustainable development, energy conservation, management, efficiency, and environmental preservation, has become highly pronounced in the present context. Biomass is organic matter produced by plant, both terrestrial (those grown on land) and aquatic (those grown in water) and their derivatives.

It includes forest crops and residues, crops grown especially for their energy content on ‘energy farms’ and animal manure. Unlike coal oil, and natural gas, which takes millions of years to form, biomass can be considered a renewable energy source because plant life renews and adds to itself every year. By pyrolysis process the biomass can be converted into useful energy [1]. Pyrolysis of biomass yields solid, liquid and gaseous products like char, pyrolytic oil and pyrogas [2]. Experiments have been carried out to determine the feasibility of flash pyrolysis oil in diesel engines [3]-[5]. Injection system failure and faster erosion on steel components in the engine were noticed from the results. Major problem with the wood pyrolysis oil is its miscibility with diesel fuel. The problem of immiscibility can be rectified by up gradation of pyrolysis oil by emulsification process [6]. Emulsion is one of the techniques used while a fuel has to be mixed with another fuel of hydroscopic nature. Stable wood pyrolysis oil emulsions were prepared using two surfactants namely hypermer and CANMET [7]. It was observed that the viscosity was found to reduce when the emulsion was prepared with a maximum of 20% pyrolysis oil. Emulsion prepared with an addition of Tween 20 surfactant 2% by volume with six different percentages of water as fuels were tested in a diesel engine [8]. It was observed from the results that the 5% by volume of water diesel emulsion gave an optimum brake power and a brake thermal efficiency compared with the other water diesel emulsions. Since vegetable oils usually produce high smoke emissions from diesel engines, dual fuel operation can be adopted as a method for improving their performance.

Some researchers have reported that dual fuel operation is useful to reduce smoke and increase the thermal efficiency of the diesel engines [9]-[10]. Dual fuel operation of a diesel engine was studied by many researchers using different pilot fuels such as jatropha, rubber seed, mahua oil and their methyl

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esters and inducted fuels such as hydrogen, biogas[9]-[12]. Therefore an attempt was made to investigate the performance and emissions of a single cylinder four stroke air cooled direct injection diesel engine running on dual fuel mode. An emulsion of wood pyrolysis oil and methyl ester of karanja was used as primary fuel in the engine, whereas, hydrogen was admitted into the diesel engine at 2lpm and 4lpm in the suction along with the air.

II. METHODS AND MATERIALS

A. Production of wood pyrolysis oil

In the present investigation, pyrolysis oil from waste wood was obtained by vacuum pyrolysis process. The production process and the characteristics of wood pyrolysis oil were studied by Prakash et al[13].

B. Methyl ester of karanja oil

Karanja methyl ester used in this investigation was obtained from the transesterification process of karanja oil.

C. Properties of wood pyrolysis oil and methyl ester of karanja oil

The properties of wood pyrolysis oil are compared with diesel fuel and karanja methyl ester and given in Table 1.

TABLE I
PROPERTIES OF FUELS COMPARED

Properties	Diesel Fuel	KME	WPO
Specific gravity at 15 °C	0.83	0.88	1.1560
Net calorific value[MJ/kg]	43.8	38,416	20.584
Flash point[°C]	50	230	98
Fire point[° C]	56	258	108
Pour point[°C]	30	-3	2
Carbon residue[%]	0.1	0.71	12.85
Kinematic viscosity at 40 °C[cSt]	2.58	27.84	52.3
Cetane number	50	57.6	-
Moisture content (wt %)	0.025	0.034	15-30
Ash (wt%)	0.13	0.04	0.01

D. Emulsification of WPO

In this investigation, the water in oil emulsion was prepared by adding the surfactant Span-20 having HLB number 8.6 to emulsify the wood pyrolysis oil with karanja methyl ester. WPO fuel emulsion was prepared from wood pyrolysis oil 10% and karanja methyl ester 90% with the addition of surfactant Span-20 1% by volume. The resultant mixture was shaken vigorously for about 30 minutes. The emulsion produced was observed visually by about eight hours and found that the emulsion made with 10% WPO was stable.

III. EXPERIMENTAL PROCEDURE

The engine used for the present investigation is a single cylinder, four strokes, air cooled, direct injection, diesel engine. The photographic view of the experimental setup is shown in Fig.1 and the engine specification is given in Table 3.

Fig.1 Photographic representation of the engine experimental set up

Initially the engine was operated with neat diesel and the performance, emission parameters were evaluated. Then the engine was allowed to run with the WPO-MEK emulsion. For dual fuel operation, hydrogen fuel, at a constant flow rate of 2lpm and 4lpm were supplied through a flame arrester and flame trap and finally it was admitted into the intake pipe (at a distance of 40 cms from the intake manifold) where it mixed with air and this hydrogen-air mixture was inducted into the engine cylinder. The emulsion on volume basis was allowed from the fuel tank and then injected into the cylinder. The performance and emission parameters were measured and compared with that of diesel baseline readings. AVL444 exhaust gas analyzer was used to measure nitric oxide emission (NO) whereas AVL437C smoke meter was used to measure the smoke values of the exhaust.

TABLE II
TEST ENGINE SPECIFICATION

Make/Model	Kirloskar TAF 1
Brake power, kW	4.4
Rated speed, rpm	1500
Bore [mm]	80
Stroke [mm]	110
Compression Ratio	17.5:1
Cooling System	Air cooling

IV. RESULTS AND DISCUSSION

A. Performance parameters

i) Brake Thermal Efficiency

The variation of brake thermal efficiency with brake power is shown in Fig.2. The brake thermal efficiency is 28.64% and 32.02%` with diesel and WPO-MEK emulsion respectively at full load. Methyl ester of karanja oil has less viscosity and better volatility compared to diesel which causes better injection, mixing and evaporation characteristics results in a increasing in brake thermal efficiency. The brake thermal efficiency was 36.7%, 38.5% with 2lpm and 4lpm hydrogen enrichment at full load. The high flame velocity of hydrogen contributed to better mixing of methyl ester with air which leads to improvements in thermal efficiency [9]. The maximum thermal efficiency was recorded with 4lpm hydrogen enrichment.

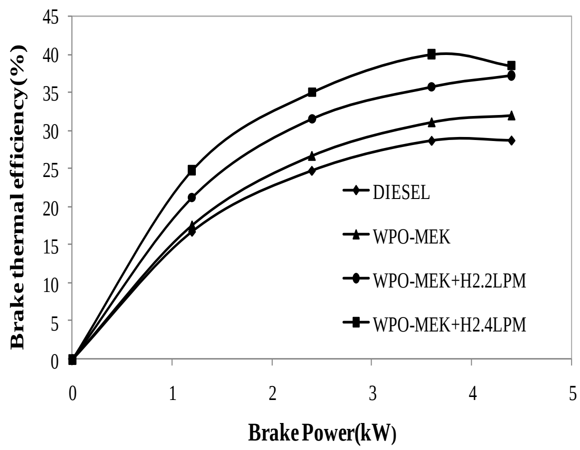

Fig. 2 Variation of brake thermal efficiency with brake power

ii) Brake specific energy consumption

Variation of brake specific energy consumption with brake power is shown in the Fig.3.

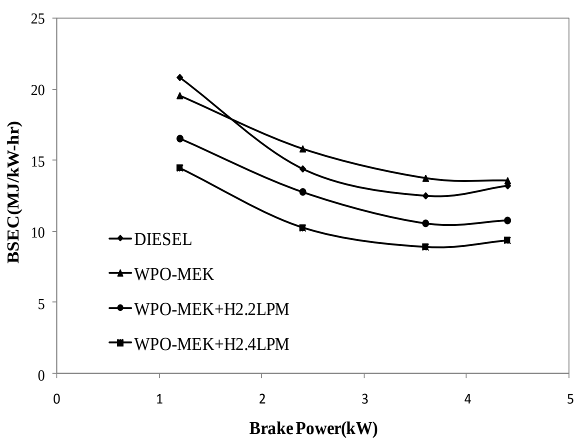

Fig. 3 Variation of BSEC with brake power

It was found that brake specific energy consumption fuel decreased as hydrogen enrichment increased. The BSEC decreased at high load is due to the premixing of hydrogen fuel with air. The BSEC values are 13.23 (MJ/kWh) and 13.57 (MJ/kWh) with diesel and WPO-MEK operation respectively at full load. Higher BSEC at WPO-MEK operation may be due to lower calorific value of the fuel emulsion. The BSEC was 10.75 (MJ/kWh) and 9.35 (MJ/kWh) with 2lpm and 4lpm hydrogen enrichment at full load. The diffusivity and uniform mixing of hydrogen with air leading to near complete combustion of the fuel and its high flame speed will enhance the thermal efficiency [10].

B. Emission parameters

i) NO emissions

The variation of oxides of nitrogen and smoke density with respect to the brake power is shown in Fig. 4.

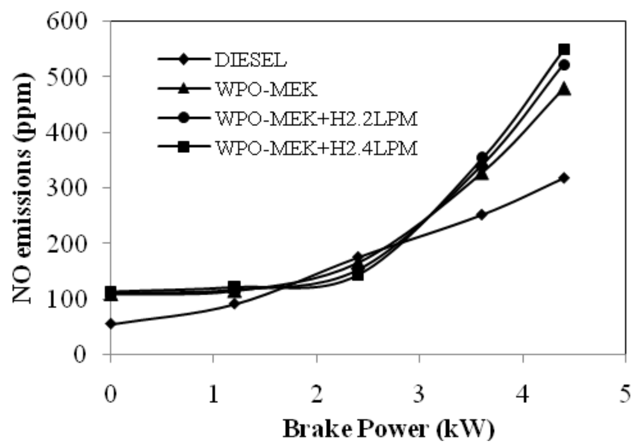

Fig. 4 Variation of oxides of nitrogen with the brake power

The formation of oxides of nitrogen is due to the peak combustion temperature, oxygen concentration in the combustion chamber and the residence time of high temperature gas in the cylinder [14]. The NO values were 318 ppm and 481 ppm with diesel and wpo10-methyl ester of Karanja oil operation respectively at full load. The NO values were 523 ppm and 550 ppm with 2lpm and 4lpm hydrogen enrichment at full load. Hence there is 51.2%, 64.4% and 72% increase in NO emissions for WPO-MEK, WPO-MEK with 2lpm, 4lpm of hydrogen induction respectively. Oxygen concentration in WPO-MEK may be reason for increased NO emissions. The enhanced combustion rate increases the cycle temperature leads to higher NO emissions when hydrogen is inducted in small quantities [10].

ii) Smoke density

With WPO-MEK operation smoke emission is higher at all the loads due to poor atomization of the fuel. Variation of smoke density with brake power is shown in Fig. 5.

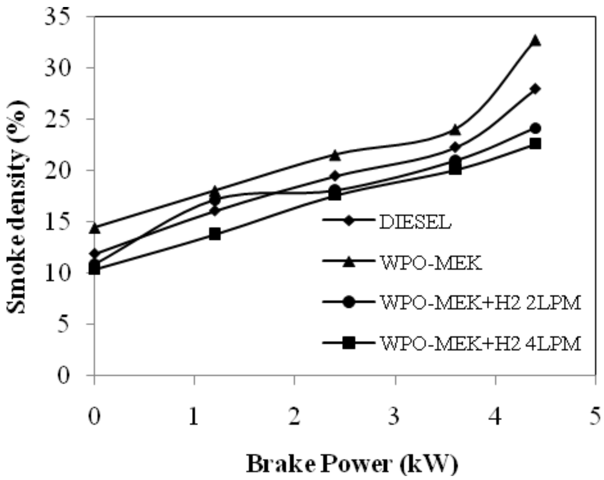

Fig. 5 Variation of smoke density with the brake power

The smoke density is 32.8% with WPO-MEK at peak power output. However, there is a significant reduction of smoke emission in dual fuel operation. It is reduced by 26.2% and 31% when operated along with hydrogen quantities 2lpm and 4lpm respectively. The introduction of hydrogen reduces the quantity of injected fuel and lowers the smoke level at all power outputs. Further, it can be observed that the inducted hydrogen forms a homogeneous mixture that burns more rapidly and the overall mixture contains less carbon from which smoke can form [9].

V.CONCLUSIONS

The following conclusions are drawn from the results of the investigation on the performance and emissions of a single cylinder four stroke air cooled direct injection diesel engine fueled with karanja methyl ester wood pyrolysis oil emulsion on dual fuel mode;

- The percentage increase in the brake thermal efficiency was 11.8%, 27.6% and 34.4% for WPO-MEK, WPO-MEK with 2lpm of hydrogen and WPO-MEK with 4lpm of hydrogen respectively at full load.
- The BSEC is 2.5% higher for WPO-MEK operation when compared to diesel. For WPO-MEK with hydrogen 2lpm and 4lpm the BSEC values reduced by 18.7% and 29.3% respectively.
- There is 51.2%, 64.4% and 72% increase in NO emissions for WPO-MEK, WPO-MEK with 2lpm, 4lpm of hydrogen induction respectively.
- Smoke density decreases by 14.6%, 26.2% and 31% respectively for WPO-MEK, WPO-MEK with 2lpm, 4lpm of hydrogen induction.

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