UTILIZATION OF HYDROGEN IN A BIODIESEL-PRODUCER GAS FUELLED COMPRESSION IGNITION ENGINE OPERATING ON DUAL FUEL MODE

V.S. Yaliwal[1], M.D. Malipatil[2], Sushruth Halewadimath[3], N.R. Banapurmath[4]
[1, 2] Department of Mechanical Engineering,
[1, 2] S. D. M. College of Engineering and Technology, Dharwad, Karnataka, India
[3, 4] B. V. B. College of Engineering and Technology, Dharwad, Karnataka, India

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Abstract-In this present work influence of hydrogen on the performance and emission characteristics of four stroke direct injection water cooleddiesel engine developing 3.7 kW at 1500 rpm operating on dual fuel mode using Honge oil methyl ester (HOME) and producer gas (PG) has been studied. Hydrogen was added to PG during suction stroke through the intake manifold at 5 lpm and 8lpm. Experimental resultsshowed that the addition of H_2 to PG showed significant improvements in the combustion of PG. Hydrogenof 8 lpmaddition to PG resulted in greater brake thermal efficiency (BTE) by 3.21%, decreased carbon monoxide (CO), hydrocarbon (HC) emissions by 15-20% while smoke and nitric oxide (NOx) emissions were found to be lesser compared to the biodiesel-PG dual fuel operation.

Keywords: Dual fuel engine, Honge oil methyl ester (HOME), Producer gas, Hydrogen, Emissions.

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1. Introduction

Biodiesels can be operated on single fuel mode in diesel engines more conveniently. Gaseous fuels such as PG and H_2 can also be used in diesel engines and they actas potential alternative fuels. However, CI engines cannot be operated using PG and H_2 without the injection of a small quantity of pilot fuel, because the gaseous fuel will not burnbecause of lower temperature and pressure. Therefore dual fuel operation needs small quantity of liquid fuel to commence the combustion [1, 2]. Among alternative fuels, biodiesels derived from non-edible vegetable oils, PG obtained from solid combustible fractions of babul wood and [3-6]. Biomass derived fuels like producer gas and biodiesels greatly contribute to sustainable energy with an aim of eliminating complete use of fossil fuels. Gasification is a technological option that is available for utilizing woody biomass and may deliver gaseous fuels. Power production using these alternative fuels through low cost technology is more appropriate for hilly and rural applications [7-9].

In view of this, investigators have tried toimprove the combustion of producer gas fuelled dual fuel engines [1-9]. It is reported that indirect (IDI) engines operating in dual fuel mode with producer gas and diesel showed significant improvements in thecombustion due to better mixture formation caused by the higher air turbulence. Moreover, PG can be well suited for slow speed engines and can be recommended for producer gas operation [2]. Compression ignition (CI) engine operating on DF engine with different fuel combinations showed reduced combustion with reduced smoke and nitric oxide emissions [1-10]. Various optimum engine parameters such compression ratio, injection timing, injector opening pressure, nozzle and combustion geometry leading to enhanced performance of dual fuel engine. Further, investigators studied the producer gas production using different gas combinations and used in diesel engines operated on dual fuel mode [6, 8]. PG has very low a low calorific value hence improvement in its energy content by adding hydrogen significantly PGproperties. This can lead to variations in the combustibility range andreducedpilot fuel utilization. Since the hydrogen is a carbon free and clean burning gaseous fuel and has higher energy content and flame velocity; therefore, use of H2 into a PG fuelled CI engineshowed into changes in the performance and emission levels [10-12].Spray characteristics,Combustion chamber geometry and compression ratio effect on the diesel engine performance, combustion and emission levels has been reported [13, 14].

1.1 Present work

Hydrogen addition to producer gas operating on dual fuel mode is less investigated. In view of this, an effort has been made to evaluate the effect of hydrogen in a Honge oil methyl ester (HOME) and producer gas fuelled diesel engine. Experiments were conducted on a single-cylinder, four stroke, direct injection diesel engine operated under a dual-fuel mode using biodiesel, PG and with and without addition of H_2. Optimum parameters such as compression ratio, advanced IT and increased injectionpressure have been reported in previous studies [4].

2. Characterization of waste biomass and producer gas

Honge oil was procured from the local suppliers and was subsequently converted into its respective biodiesel called HOME. PG derived from babul woody biomass was generated using downdraft gasifier and was used as an inducted primary fuel while the renewable liquid fuel HOME was used as an injected fuel. The characteristics of the fuels are shown in Tables 1. Properties of wood were measured at Bangalore Test House, Bangalore, India. Table 2characterizes hydrogen fuel.

3. Experimental setup and procedure

The gasifier-engine system consists of a diesel engine, downdraft gasifier, gas cooler-cleaner set up, coupled to an eddy current dynamometer for loading arrangement and is shown in Fig. 1. The specification of the engine and gasifier is given in Table 3. The engine was coupled to an eddy current dynamometer. The injector opening pressure and the static injection timing were 230 bar and 27^0 before top dead centre (BTDC), respectively. A piezoelectric pressure transducer was mounted flush with the cylinder head surface to measure the cylinder pressure. Further to enhance the performance of producer gas fuelled engine, a high calorific value and carbon free gas i.e., hydrogen (5 and 8 lpm) was added during the combustion. Experiments were conducted on the CI engine in dualfuel fuel mode using HOME – Producer gas with 5 and 8 lpm hydrogen. Suitable accessories used are shown in Figure 1.

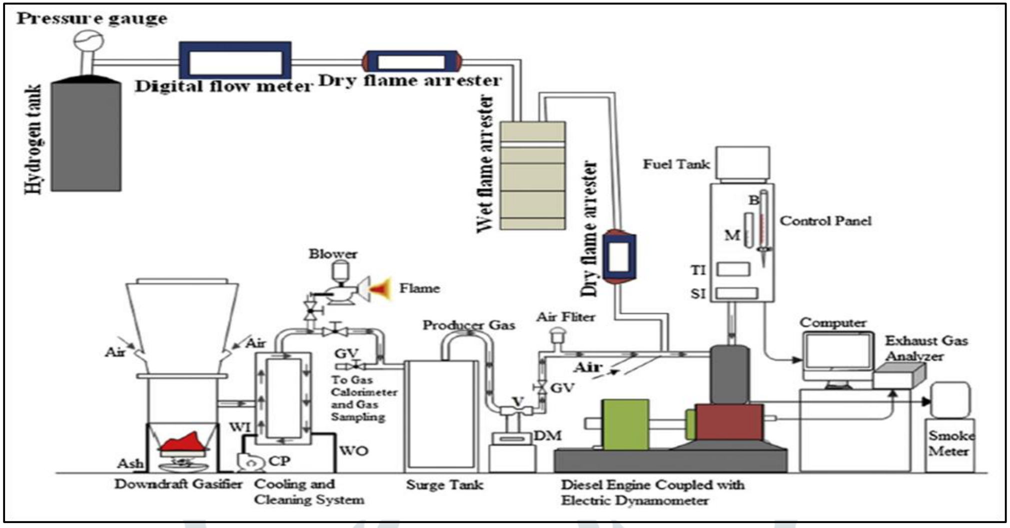

Fig 1. Schematic view of the experimental set up for dual fuel operation

Table 1 Properties of diesel, Honge (Karanja) oil, HOME and babul wood

Sl No	**Properties**	**Diesel**	**Honge oil**	**HOME**	**Properties**	**Babul Wood**
1	Viscosity @ 40 ^{0}C (cst)	4.59	44.850	5.6	Moisture content, % w/w	11.3
2	Flash point ^{0}C	56	270	163	Ash content, %, w/w	0.79
3	Calorific Value in kJ / kg	45000	35800	36,010	Volatile matter, %, w/w	85.8
4	Specific gravity	0.830	0.915	0.870	Fixed carbon, %, w/w	13.4
5	Density Kg / m3	830	915	890	Sulphur, %, w/w	0.05
---	---	---	---	---	Nitrogen as N, %, w/w	0.30
---	---	---	---	---	Carbon, %	52.4
---	---	---	---	---	Hydrogen, %	6.1
---	---	---	---	---	Oxygen, %, w/w	50.25
---	---	---	---	---	Calorific value, KJ/Kg	20,575.8
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Table 2 Properties of Hydrogen [12]

Sl.No	Properties	Hydrogen
1	Density of liquid at 20^0C, kg/m3, 1 bar	0.081
2	Lower calorific value, kJ/kg	120,000
3	Limits of flammability in air, vol. %	4.0-75.0
4	Auto ignition temp, K	857
5	Viscosity [mPa.s] (1 bar, 20 ^{0}C)	8.75
6	Octane number	130
7	Flame velocity, cm/sec	350
8	Stoichiometric A/F, kg of air/kg of fuel	34.40

Table 3: Specification of CI Engine

	Diesel engine		**Down draft gasifer**	
Sl No	**Parameters**	**Specification**	**Parameters**	**Down draft gasifier**
1	Type of engine	Kirlosker Single cylinder four stroke direct injection diesel engine	Supplier	AnkurSci. Energy Tech. Pvt. Ltd., Baroda.
2	Nozzle opening pressure	200 to 205 bar	Rated capacity Rated Gas flow	62735 kJ/h 15 Nm^3/h
3	Rated power	5.2 KW (7 HP) @1500 RPM	Average gas calorific value	5-5.6 J/m^3
4	Cylinder diameter (Bore)	87.5 mm	Rated woody biomass consumption	5-6 kg/h
5	Stroke length	110 mm	Hopper storage capacity	40 kg
6	Compression ratio	17.5 : 1	Typical conversion efficiency	70-75%

4. Results and discussions

This section presents experimental results obtained by conducting experiments on a CI engine test set-up converted to operate in tri-fuel mode using diesel/biodiesel as injected fuel and H2- PG mixture as inducted fuel. Measurements were made for different load conditions. The results of investigation obtained from H2-PG and HOME combination, and base line data (diesel-PG) were compared and analyzed. Air-gas mixture at stoichiometric ratio was ensured by applying suitable carburettors.

4.1. Performance characteristics

Brake thermal efficiency of dual and tri-fuel operation at different brake power was presented in Fig. 2. The increase in BTE was observed with continuous H2 induction and is revealed to be higher at high loads. Results showed that, BTE of an engine operated on HOME-PG with and without hydrogen addition is revealed to be lower compared to diesel-PG operation. BTE for HOME-PG operation without hydrogen addition are found to be 15.3% and for hydrogen addition to the HOME-PG are found to be 14.64%, 16.27% for 5 lpm and 8 lpm of hydrogen addition compared to 20.24% for diesel-PG operation at 80% load. Low volatility and higher viscosity of HOME, an increased ignition delay of HOME-PG as well as lower air/fuel equivalence ratio due to low energy content of HOME and PG are main causes of this observed performance. For the same injected fuels with 8 lpm flow rate of H2, BTE was increased closer to that of diesel-PG operation. Also for higher flow rates of H2 beyond 8 lpm, the fuel energy was not effectively converted to mechanical work.

4.2. Emission characteristics

Emission characteristics of engine operation at different conditions were presented in the following section.

The effect of brake power on the smoke opacitywas presented inFig. 3. HOME-PG operation with and without hydrogen resulted inhigher smoke levels in the exhaust compared to diesel-PG operation.This is because properties of HOME have dominating effect during DF combustion. Heavier molecular structure of the injectedbio-diesel caused by the presence of free fatty acids, improper spraypattern and poor soot oxidation leading to incomplete combustion.However, the reduction in smoke opacity was observedwith continuous H2 induction and is revealed to be increased athigher loads. However, the smoke opacity for neatHOME-PG operation is 30% higher than diesel-PG and 26.4% higherthan HOME-PG operation with H_2 of 8 lpmhydrogen addition at 80% load. This reduction of smoke levels for HOME-PGoperation with hydrogen addition is mainly due to high combustiontemperature associated with optimum utilization of availableoxygen and use of higher flame velocity andcarbon free hydrogen fuel.

HC and CO emissions for diesel-PG and HOME-PG derived from MSW with and without H2 addition are displayed in Figs. 4 and 5. HOME-PG has higher HC and CO emissions compared to diesel-PG combination. Incomplete combustion is due to poor atomization caused by the high content of long chain fatty acids in biodiesel, relatively low adiabatic flame temperature of the PG, low energy content of HOME and PG as well as high viscosity and density of HOME. Also, replacement of air by PG and presence of CO in the PG leads to incomplete burning of HOME-PG combination. In addition, higher CO content was observed in the exhaust at partial load could be due to too lean mixture for combustion. However addition of H2 to low calorific value gas leads to lower HC and CO emission due to better combustion of fuel combination

The NOx emission levels for various fuel combinations are presented in Fig. 6. It can be seen that diesel-PGoperation led to increasedNOx emissions compared to HOME-PG operation with and without hydrogen addition over the entire load range. HOME and PG operation at 80% load and a H2 flow rate of 5 lpmand 8 lpm resulted in 25% and14.5% loweredNOx emissions compared to the diesel-PG operation and 29.1% compared to neat HOME-PG operation. It is linked with higher heat release during premixed combustion phase because of higher calorific value of diesel and comparatively better atomization. Following the addition of H2, NOx emission increases. That is because the addition of H2 advances the combustion time and increases the premixed combustion and combustion temperature, which promotes the production of NOx.

4.3. Fuel substitution

The fuel substitution for DF operation at various power outputs is displayed in Fig. 7at different brake power. It depends on fuel's physico-chemical properties of the fuels usedand engineconfiguration. A fuel substitution value for diesel-PG operation isincreased by 20.1% compared to HOME-PG operation. However H2 addition toHOME-PG at flow rate of 5 and 9lpm increases fuel substitutionby 16.5 and 9.2% compared to HOME-PG operation.

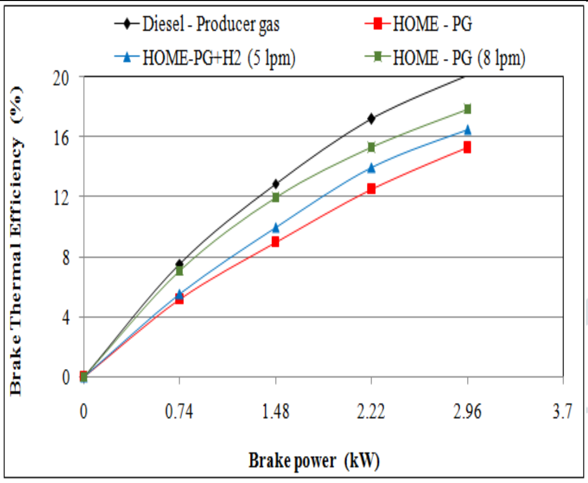

Fig 2. Variation of break thermal efficiency with break power

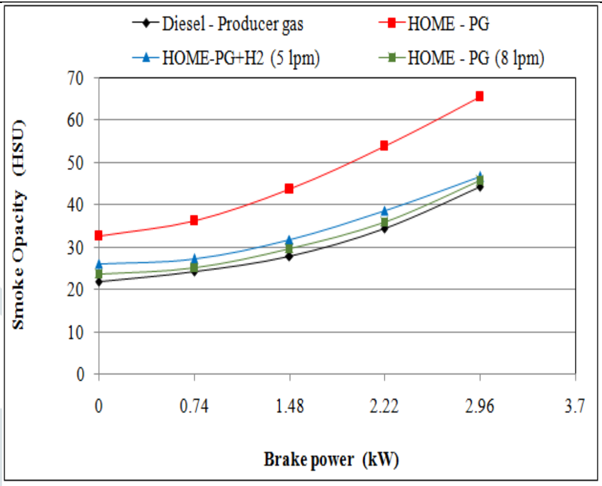

Fig 3. Variation of smoke opacity with break power

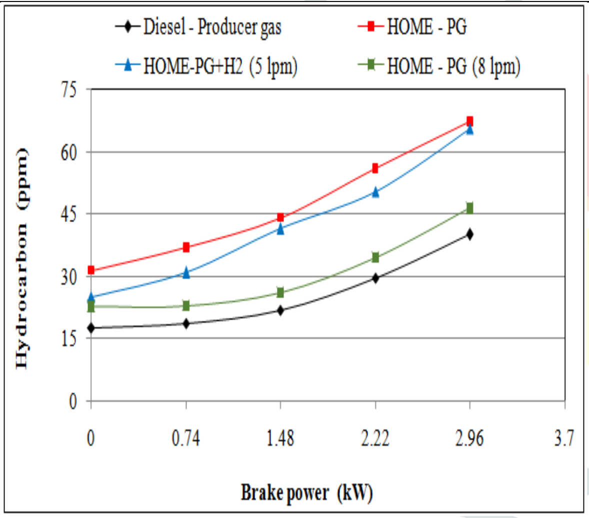

Fig 4. Variation of hydrocarbon emission with break power

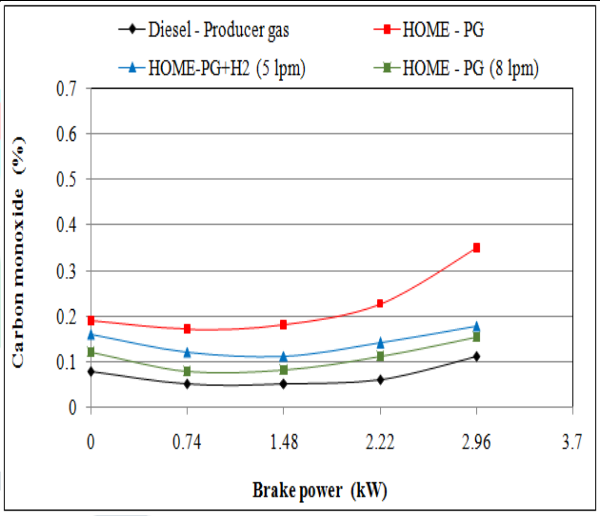

Fig 5. Variation of carbon monoxide emission with break power

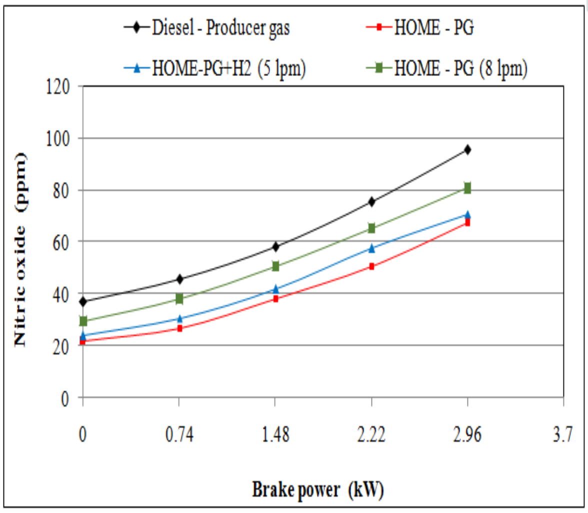

Fig 6. Variation of nitric oxide emission with break power

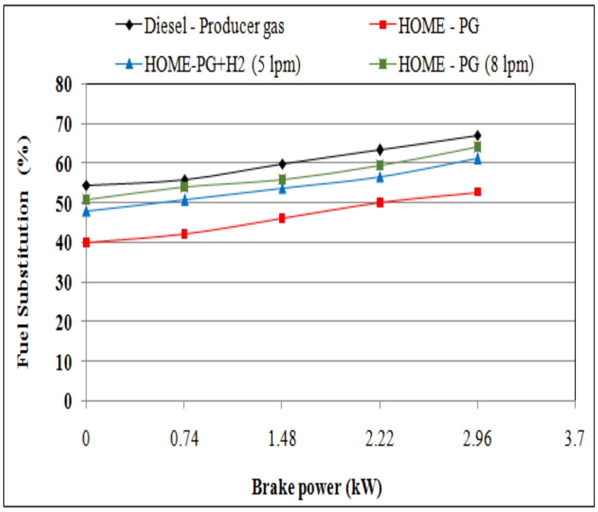

Fig 7. Variation of fuel substitution with break power

Conclusions

1. BTE of dual fuel engine is higher with H_2 compared to HOME-PG operation.
2. BTE for HOME-PG operation without hydrogen addition are found to be 15.3% and for hydrogen addition to the HOME-PG are found to be 16.84%, 17.87% for 5 lpm and 8 lpm of hydrogen addition compared to 20.14% for diesel-PG operation at 80% load.,
3. HC and CO levels in the engine exhaust were higher for HOME based dual fuel operation.
4. HOME and PG operation at 80% load and a H2 flow rate of 5 lpm and 8 lpm resulted in 25% and14.5% lowered NOx emissions compared to the diesel-PG operation and 29.1% compared to neat HOME-PG operation
5. Fuel substitution about 66% for the diesel–producer gas operation and for HOME–producer gas wit 5 and 8 lpm were found to be 16.5 and 9.2% compared to HOME-PG operation respectively at 80% load.

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