Development of Carburetor for Optimum Performance of Producer Gas Fueled Dual Fuel Compression Ignition Engine

N.R.Banapurmath¹, V.S. Yaliwal², K. J. Noolageri³, P.G. Tewari⁴ Professor^{1, 4}, Assistant Professor², Application Engineer³,

^{1, 4} B.V.B. College of Engineering and Technology, Hubli 580031, Karnataka, India

²S.D.M. College of Engineering and Technology, Dharwad 580 002, Karnataka, India

³Onward Technologies Ltd. Pune, Maharastra, India

E-mail addresses: nr_banapurmath@rediffmail.com, vsyaliwal2000@yahoo.co.in

Abstract

Alternative fuels have numerous advantages compared to fossil fuels as they are renewable, biodegradable; provide energy security and foreign exchange savings besides addressing environmental concerns, and socio-economic issues. With regard to stringent emission legislation in the automotive sector and need to save fossil fuel for other developmental and research activities over the coming decades, this research work is directed at developing diesel engine-gasifier integrated systems to operate on renewable fuels such as Honge oil methyl ester [HOME] and Producer gas with specially designed carburetor. The raw Honge oil was obtained from Honge seeds and then it was subsequently converted into its respective biodiesel i.e., HOME. Further the branches of the Honge tree were used as the biomass feed stock in the downdraft gasifier for the producer gas generation. This work mainly aims at total substitution for fossil fuel by respective renewable fuels and is a step towards energy security and sustainability.

The producer gas generated in the downdraft gasifier was then passed through a suitably fabricated carburetor supplying a mixture of producer gas and air at stoichiometric ratio. In this proposed research work different carburetor shapes were identified and developed to maximize the gasifier-engine performance. The developed producer gas carburetor was further analyzed for its mixing performance with a subsequent CFD modeling. The model is a mixing chamber having essential orifices for air and producer gas inlets to generate stoichiometric mixture at near to ambient conditions with required driving pressure differential for the flow. The carburetors were drawn from Y - shape and with parallel gas entry. Preprocessing has been done in GAMBIT and solver FLUENT has been used for analysis. From the study it was found that parallel flow gas entry carburetor resulted in better mixing of air and producer gas.

The diesel engine developing 3.7 kW was finally operated in dual fuel mode using HOME and producer gas with different carburetors. The dual fuel engine provided with parallel flow gas entry carburetor showed 3 to 4 % increased brake thermal efficiency with reduced smoke, HC and CO emission levels. The experimental results were found to be in good agreement with CFD analysis.

Key words: Honge oil Methyl ester, Producer gas, Carburetor, Emissions, Sustainability, energy security.

1.0 Introduction

Alternative fuels have numerous advantages compared to fossil fuels as they are renewable, biodegradable; provide energy security and foreign exchange savings besides addressing environmental concerns, and socio-economic issues. Conventional liquid fuels are the major contributor for these energy sources and if these are used extensively, they might get extinct. With declining fossil fuel resources and increased demand for their products, there is an urgent need to develop economical, environment friendly, energy-efficient processes and resources for the production of fuels and chemicals. In this context, many researchers have studied different alternative fuels for dual fuel engines [5 - 17]. Such alternative fuels are biodiesels and producer gas. Hence a promising need to identify an alternative to petroleum products, that is indigenous and renewable energy source has become all that important along with well designed gasifier based diesel engine system. With regard to stringent emission legislation in the automotive sector and need to save fossil fuel for other developmental and research development to over the coming decades, this research work is directed at developing diesel engine-gasifier integrated systems to operate on renewable fuels such as Honge oil methyl ester [HOME] and Producer gas with specially designed carburetor.

A carburetor is a fuel-air mixing device provides a suitable air - fuel mixture for producer gas operated dual fuel engine. The design of carburetor plays a very important role in achieving better performance with reduced emission levels from a dual fuel engine [1, 2, 3, 4]. Therefore, it is very much essential to supply well defined air-gas mixture under all circumstances to the engine cylinder. Carburetors are the air – fuel mixing devices where a flow induced pressure drop forces a fuel flow into the air stream [2, 3, 18]. An ideal carburetor would provide a mixture of appropriate air-fuel (A/F) ratio to the engine over its entire range of operating conditions. To ensure proper performance, carburetors should be designed in such a way that, it must be reproducible and have unequivocal adjustment procedures [2,3, 19].

A mixture of fuel and air contains just enough amount of air for complete combustion of fuel is called stoichiometric ratio. A mixture which has less air than the required amount for complete combustion is termed as rich mixture and mixture which contains more air than required for complete combustion is termed as lean mixture [1]. Venturi type gas induction device was designed and incorporated in the gas pipe line shown in Figure 1. The engine was operated under dual fuel mode in which gas and liquid fuel supply being adjusted manually for maximum diesel replacement at each load. The producer gas flow resistance should be as low as possible in order to reduce loss of peak power capacity and to keep efficiency of the engine at its best. Optimum mixture under all the operating conditions is necessary to achieve high fuel efficiency and low emissions. This can be obtained by using suitably developed carburetor for dual fuel engines. The changes in the engine operations could be the results of variations in the composition of producer gas, air – fuel ratio and

engine operating conditions. Some literatures were highlighted the use of carburetors [20 - 26]. Mitsubishi Motors Corporation has presented an empirical formulation with algebraic expression to arrive at the air - fuel ratio knowing the exhaust gas composition [20]. Spindt *et al.* [21] have attempted to compare various air/fuel ratio calculation methods for consistency in results. Tung - Ching *et al.* [22] have presented work on adaptive air/fuel ratio controllers for spark ignition engine throttle transients. Piero Azoni *et al.* [23] have developed an air - fuel ratio controller using the throttle angle information along with some other signals. Ohyama [24] has presented work on air/fuel control using an upstream model in the intake system. A generalized model of the air/fuel ratio control during transient conditions in highly supercharged direct injection systems with a complex air induction system. Berggren et al. [25, 26] have developed an air/fuel ratio controller using the throttle angle information along with some other signals. The main objective has been to evaluate the possibility of achieving finer air - fuel ratio control, especially during transient conditions that involve sudden variations in the physical conditions inside the intake manifold due to fast throttle opening and closing.

In this present work, an attempt has been made to develop a suitable carburetor for the dual fuel engine operating on HOME and Producer gas. The carburetor was suitably designed and tested air – producer gas mixing through CFD modeling and experiments were conducted to check the carburetor for optimum performance of dual fuel engine.

2.0 Producer Gas supply system with Carburetor

In the case of producer-gas dual fuelling, it is difficult to ensure uniform gas quality as it is affected by flow conditions through the gasifier system, the pressure drop across the gasifier system and the gas temperature at the gasifier outlet, varying with both engine design and operating conditions. Small gasifier systems operating on engine suction encounter pulsating gas flow to the engine. Such pulsations of gas flow depend upon engine design, especially its operating speed, stroke to bore ratio and the extent of damping provided by the gas cooling and cleaning system [1, 12, 13]. The carburetor used for mixing air and gaseous fuel consists of air and gaseous fuel inlets and outlet. The out let of carburetor is attached to the intake manifold of an engine as shown in Figure 1. The carburetor used must be developed in such a way that, it should give air and producer gas mixture at stoichiometric and at an ambient conditions for a particular engine depending on engine operating conditions (load and speed conditions). In design and development of carburetor, simplicity, ruggedness and cost are considered as a basic requirement to achieve ease of handling, easy adjustment and reproducible performance.

Experiments with use of different gas carburetors for dual fuel engine applications were reported [1, 2, 3, 5, 19]. Even though, standard carburetor for mixing producer gas and air are still not available for producer gas operated dual fuel engines, but carburetors for dual fuel engines operating

with natural gas, biogas and landfill gas and air mixing are readily available. However, stoichiometric air-to-fuel ratio for natural gas, biogas and landfill gas was reported in the literature [1, 2, 3, 5, 19]. The required air-to-fuel ratio for natural gas is 17:1, whereas for producer gas is 1.3:1. The carburetors available for gaseous fuels such as natural gas, Biogas and landfill gas is unsuitable due to widely different stoichiometric air to fuel requirement [3]. Therefore different carburetor is required for producer gas operated engines. The carburetor designed for producer gas must have an ability to maintain the required air-to-fuel ratio (1.2 to 1.5:1) with varying load conditions, smooth operation with minimal pressure loss and on-line provision for air/fuel tuning during the operation [3].

The above-mentioned feature was incorporated in the gas carburetor development. The carburetor is simple in design and does not have any moving components. The carburetor is designed to operate in conjunction with the venturimeter (connected to the producer gas line before the inlet of carburetor) designed for the flow measurement. Figure 1 shows the producer gas line with Y –shaped carburetor, venturimeter and digital gas flow meter. A suitable ball valve was provided at the entrance of the carburetor for adjusting the flow rate of producer gas. Similarly another port of the carburetor is connected to the air line, which also has a ball valve and orifice plate. Measurement of air and gas flow rates gives an indication of the air-fuel ratio. The down stream of the venturimeter was connected to the carburetor and the gas accelerates with the air as it is introduced into the carburetor.

During the operation, the producer gas and air pressure are kept identical and the producer gas pressure was kept slightly higher (a few mm above atmospheric pressure) than that of air pressure. This arrangement ensures proper producer gas – air mixture irrespective of any load on the engine. However, the experiments were carried out by varying the flow rate of producer gas at different engine loads and at constant engine speed. The equivalence ratio at 80% load were found to be 0.69, and 0.82 for Y – shaped, and parallel flow gas entry carburetors respectively. The supply of producer gas was adjusted manually to obtain the maximum percentage of diesel displacement. The steady flow of the gas and air mixture in the down stream of the carburetor was ensured by having large diameter with no bends in the carburetor and intake manifold. In the carburetor, if inlet convergences were smoother than outlet divergences, the mixture get more homogenous, the reason of that is in increasing turbulence in outlet divergence. During the experiment, a reduction in the consumption of diesel fuel was observed when operated on dual fuel mode, but there was a reduction in brake thermal efficiency, Smoke opacity and NO emission levels were found to be low in HOME – producer gas operation compared to Diesel - Producer gas operation which is a great advantage of dual fuel operation and CO and HC emission for dual fuel mode was found to be higher than Diesel – Producer gas operation.



Fig. 1 Schematic of Producer Gas Y – shaped carburetor with venturimeter connection

The air and fuel flow rates were individually measured over a range of engine operating conditions. However, the composition of producer gas and homogeneity of the air and gas mixture is not addressed. The A/F ratio was reasonably constant beyond a specified mixture flow rate, with relatively rich mixture at low mixture flow rates. This characteristic is desirable from the viewpoint of engine operation, rich mixture for engine start-up and no-load

operations, relatively leaner mixture during part load operation. The results obtained with venturi gas induction were encouraging and are only presented in this section.

3.0 Characterization of Fuels tested

Honge tree is also called as Karanja oil. This tree is chiefly found along the banks of streams and rivers or near the seacoast. It is not exacting in its soil and climatic requirements and grows in dry places and attaining heights of 15 - 18 m. It is often grown as roadside avenue tree all over India. The expected life of this tree is 40 - 50 year and potential yield on maturation is about 5000 kg per hectare.

The producer gas can be generated by partial combustion of biomass in a gasifier. The resulting producer gas consisting of CO, H_2 , CO₂, Nitrogen and Methane. The laminar burning velocity for producer gas (at 0.1 MPa, 300 K) is about 0.5 m/s [1], which is about 30% higher than methane. There is a general perception that producer gas being a low-density energy fuel, the extent of derating in power would be large when compared to high-energy density fuels like natural gas and liquefied petroleum gas. This could be misleading because what need to be accounted for in comparison is the mixture energy density and not the fuel energy density. The producer-gas lower

calorific value is lower than that of diesel, which is 42.5 MJ/ kg, natural gas at 45 MJ/kg, and biogas at 23.6 MJ/kg. The engine derating is enormous in the case of a producer-gas run engine [1, 8, 9]. The different properties of the fuels used are determined at our college laboratory. The data were generated three times and averaged out readings are shown in Table 1 and 2. Table 1 shows the properties of liquid fuels and proximate and ultimate analysis of biomass feed stock used in the present study. The composition of producer gas derived from these biomass feed stock is shown in Table 2.

Sl.No	Properties	Diesel	HOME	Description	Babul wood
1	Viscosity @ 40 [°] C (cst)	4.59 (Low)	5.6	Moisture Content, % wlw	10.3
2	Flash point ⁰ C	56	163	Ash Content, % wlw	0.79
3	Calorific Value in kJ / kg	45000	36,010	Volatile Matter, % wlw	85.8
4	Specific gravity	0.830	0.870	Fixed Carbon % wlw	13.4
5	Density Kg / m3	830	890	Sulphur, % wlw	0.05
6	Type of oil	Fossil	Non edible	Nitrogen, as N % wlw	0.30
7				Gross Calorific value, Cal/g	5631.O
/				Gross Calorific value, kJ/ kg	23575.8
8				Density, kg/m ³	380
9				Phosphorus % w/w	
10				Potassium	

Table 1 Properties of liquid fuels and Proximate and ultimate analysis of biomass feed stocks

 Table 2 Composition of producer gas

Туре	CO	H ₂	Meth	HC	N ₂	Water	CO ₂	Calorific	Density
of	0/	0/	ane	0/	0/	Vapour	0/	value	kg/m ³
wood	%	%	0/	%	%	0/	%	NIDI 3	
			%			%		MJ/Nm [*]	
Babul	18-	15-	1-5	0.2-	4.5-		8 -		
Duoui	2201	100/		0.2	5.50/	4	1.00/	5.6	360
wood	22%	19%	%	0.4%	5.5%		10%		

4.0 Experimental setup

Experimental investigations were conducted on four-stroke single cylinder direct injection water cooled compression ignition engine shown in Figure 2. The specification of the engine is given in Table 3. The engine was always operated at a rated speed of 1500 rev/min. The engine was having a conventional fuel injection system. The injection nozzle had three holes of 0.3 mm diameter with a spray angle of 120⁰. The fuel consumption was measured with burette and stopwatch. The injector opening pressure and the static injection timing as specified by the engine manufacturer were 205 bar and 23⁰ before top dead centre (BTDC), respectively. However, for the present study, the injection timing and injection pressures of 27⁰ BTDC and 230 bar was used with dual fuel operation. The engine had been provided with a hemispherical combustion chamber with overhead valves operated through push rods. Engine-Soft is software used to communicate the data between test rig and data acquisition system through a control panel. Engine Soft can serve most of the engine testing application needs including monitoring, reporting, data entry, data logging. The software evaluates power, efficiencies, and fuel consumption and heat release and pressure - crank angle diagram. It is configurable as per engine set up. Cooling of the engine was accomplished by circulating water through the jackets of the engine block and cylinder head. A piezoelectric pressure transducer was mounted flush with the cylinder head surface to measure the cylinder pressure. The cylinder pressure was measured with Piezo electric transducer fitted in the cylinder head as shown in Figure 3. Tables 4, 5 and 6 show the specifications of pressure sensor, exhaust gas analyzer and Hart ridge Smoke meter used to measure HC, CO, CO2, NOx and smoke. All the readings were repeated for three times and averaged out readings were used for analysis. Figure 4 shows parallel flow gas entry carburetor for producer gas induction fitted to the engine. Figure 4 shows the parallel gas entry carburetor for producer gas induction fitted to the engine. Figures 5 and 6 shows Y – shaped and parallel flow gas entry carburetors.



Fig. 2 Overall view of Experimental Setup



Fig. 3 Views of Pressure Sensor fitted to engine cylinder



Fig. 4 Parallel gas entry carburetor for producer gas induction fitted to the engine



Fig. 5 Y- shaped carburetor



Fig. 6 Parallel flow gas entrycarburetor

Table 3 shows specification of experimental test rig

Sl No	Parameters	Specification
1	Machine Supplier	Apex Innovations Pvt Ltd, Sangli. Maharastra State.
2	Engine Type	Single cylinder four stroke water cooled direct injection TV1 compression ignition engine with a displacement volume of 662 cc, compression ratio of 17:1, developing 5.2 kW at 1500 rev/min TV1 (Kirolsker make)
3	Software used	Engine Soft
4	Nozzle opening pressure	200 – 225 bar
5	Governor type	Mechanical centrifugal type
6	Cylinder diameter (Bore)	0.0875 mtr
7	Stroke length	0.11 mtr
8	Combustion camber	Open Chamber (Direct Injection) with hemispherical cavity
9	Eddy current dynamometer:	Model :AG – 10, 7.5 KW at 1500 to 3000 RPM and Water flows through dynamometer during the use

Make	PCB Piezotronics
Model	HSM111A22, Piezoelectric
Measurement range	0 to 344 bar
Sensitivity	0.145 mV / kpa
Resolution	0.69 kPa
Non - Linearity	\leq 2.0 % FS
Temperature Range	$-73 \text{ to} + 135^{\circ}\text{C}$

Table 4 Specifications of Pressure Pick-Up

le 5 Specification of exhaust	gas analyzer
-------------------------------	--------------

Model	Gasboard-5020,		
Sensor Type	Infrared (NDIR) gas sensor.		
Measure gas concentration	CO, HC, CO2, O2, NO		
Display	LCD display. English display screen		
Interface	Oil temperature and RPM interface. RS-232		
	interface.		
Measurement range:	HC: 0 – 9999 PPM, CO: 0 – 10%, CO2 : 0 –		
	20%, O2: 0 – 25% and NO: 0 -5000 PPM		
Error	HC: ±12ppm or ±5% (relative) CO: ±0.06% or		
	$\pm 5\%$ (relative) CO2: $\pm 0.5\%$ or $\pm 5\%$ (relative) O2:		
	$\pm 0.1\%$ or $\pm 5\%$ (relative) NO: ± 25 ppm or $\pm 4\%$		
	(relative)		
Resolution	HC: 1 ppm, CO: 0.01 %, CO2:0.01 %, O2:0.01		
	%, NO: 1 ppm		
Response time and warming up	Less than10s (NDIR) and 10min		
Power and Weight	AC220V $\pm 10\%$, 50HZ ± 1 HZ and 6.5kg		
Dimension	266mm (width) x 360mm (depth) x 183mm		
	(height)		

Table 6 Specifications of Smoke meter

Туре	Hartridge smoke meter
Object of Measurement	Smoke density
Measuring range opacity	0-100 %
Accuracy	+ / -2 % relative
Resolution	0.1 %
Smoke length	0.43 m
Ambient Temperature Range	-5° C to $+45^{\circ}$ C

5.0 Downdraft gasifier

For the experimentation, down draft gasifier was used because it reduces the amount of high molecular weight hydrocarbons and particles compared to updraft gasifier [*Deshmukh et al* (2008), **Banapurmath** *et al* (2008)]. To operate a dual fuel engine, the gasifer was coupled to the diesel engine. Figure 7 depicts photographic view of a downdraft gasifier, Figure 8 shows flaring for

checking quality of producer gas. Table 7 shows the specification of down draft gasifier. Gasifiers are the reactors in which gasification of solid fuel takes place giving Producer gas. The internal diameter in most downdraft gasifiers is reduced in order to create throat. Air inlet nozzles are commonly set radially round the throat to distribute air as uniformly as possible. The pyrolysis zone is above the combustion zone and the reduction zone below it. Fuel is fed from the top and the air flows in the downward direction through the combustion and reduction zones. Movement of air is in the same direction as that of the fuel. The downdraft gasifier is so designed that tars in the pyrolysis zone are drawn through the combustion zone wherein a high amount of them will be cracked and reduced to non-condensable gaseous products before leaving the gasifier. As and when the high molecular weight fractions pass through the high temperature zone, they are cracked. Rate of oxidation and reactions like tar cracking are interrelated through the temperature parameter. The oxidation zone products are products of combustion, cracked and uncracked pyrolysis products and water vapour. These products pass then through reduction zone, where reduction reactions were taking place. Sometimes the gasifier jacket is cooled by incoming air which heats the incoming air and boosts production of CO. The narrow air stream, entering into the gasifier causes a small zone of the fuel pile to burn very quickly at very high temperature 1600°C-1800°C. This generates producer gas rapidly.



Fig. 7 Photographic view of a Downdraft Gasifier.



Fig. 8 Flaring for checking quality of producer gas

Туре	Down draft gasifier
Rated capacity	15000kcal/hr
Rated gas flow	15Nm ³ /hr
Average gas calorific value	1000kcal/m ³
Rated woody biomass consumption	5-6kg/hr
Hopper storage capacity	40kg
Biomass size	10mm (Minimum)
	50mm (Maximum)
Moisture content (DB)	5 to 20%
Typical conversion efficiency	70-75%

Table 7 Specification of the downdraft gasifier

6.0 Optimization of Carburetor for Dual Fuel operation: Computational approach

For the modeling and analysis, five different carburetors shapes were developed and tested for air fuel mixing through CFD software package. The detailed explanation is discussed below.

6.1 Boundary conditions

The inlet boundary conditions for air and Producer gas are mass flow rate and pressure were applied and no buoyancy steady state condition. The initial condition of flow rate through the air inlet with ideal mass fraction as 0 is considered and mass fraction of Producer gas is 1. The results obtained for different carburetor shapes were given in the Table 8. The CFD analysis was carried out on a different carburetor shapes are given below. Three - dimensional model has been used to simulate the air and producer gas analysis. Producer gas mass fraction across a selected plane, velocity streamlines and velocity vectors were explained in the subsequent paragraphs.

(a) Y-shape carburetor

The contour of the mass fraction of the producer gas has its color scale with red for 1 (100% Producer gas) and blue for 0 (100% air). The Figure 8 (a) and (b) shows Y – shaped carburetor model.

Figure 9 (a) and (b) shows cut-sectional view contour plot of producer gas and air mixture showing mass fraction. It is observed that air and Producer gas and air mixing in a pipe and at the outlet. The area weighted average of mass fraction of Producer gas at outlet found to be 0.56. The velocity at outlet is 12 m/s shown in Figure 10.



Fig. 9 Contours of producer gas (a) cut- sectional view

(b) Isometric view



Fig. 10 (a) Velocity streamlines



(b) Parallel flow carburetor

The Fig 11 represents the most optimal configuration considered, that shows a three dimensional view of contour plot mass fraction of producer gas. Fig. 12 shows structured mesh. This type is improved configuration that has enhanced the mixing of Producer gas and air as compared to the other version of carburetors. The area weighted producer gas mass fraction at outlet is 0.50. This is the one, which gives optimum mixing at out let for combustion. The velocity at outlet was found to be 39 m/s, The Fig. 13 and 14 represents velocity stream lines in mixing chamber and more turbulence flow occurred. It helps in proper mixing of air and Producer gas as compared to other carburetors. The mixing of both air and producer gas mixing can be seen in Fig. 15.







Producer gas and air flow mixture analysis









Fig. 14 Velocity streamlines (a) Isometric view

(b) Side view



Fig. 15 Velocity vectors

Carburet or type	Inlet dia, mm	Outlet dia. mm	Descripti on	Producer gas mass fraction	Air mass fraction	Velocity at outlet m/s	Equiva -lence ratio
Y-shape carburetor	50.8	50.8	135000 with nodes structured mesh	0.56	0.44	12	0.62
Parallel flow gas enrty	31.75	25.4	Structured hex with mesh1566 77	0.50	0.50	39	0.8

 Table 8 Results of CFD analysis for different carburetors

7.0 Experimental Investigations of dual fuel operation

The effect of injection timing and injection opening pressure on brake thermal efficiency, exhaust gas temperature, smoke opacity, hydrocarbon emissions, carbon monoxide emissions and nitrogen oxide emissions were reported in the literatures [1, 6]. During the experiment, optimum parameters in terms of injection timing and injection opening pressure were kept constant as given in the literature [1, 6, 7]. The injection timing and injection opening pressure were kept constant at 27°BTDC and 230 bar respectively. Compression ratio of 17.5 and babul wood as biomass feed stock was used for the experimentation.

7.1 Performance Characteristics:

This section presents the results of investigation carried out on a single cylinder, DI engine operating on HOME and producer gas in dual fuel mode of operation with different types of carburetors namely Y, and parallel flow gas entry carburetors. The speed of the engine is maintained constant at 1500 rpm.

7.1.1 Brake thermal efficiency:

The brake thermal efficiency (Figure 16) is found to be higher for producer gas-diesel dual fuel mode of operation compared to HOME-Producer gas operation over the entire load range. Producer gas being common, properties of the injected fuel has a major effect on the engine performance. The bio-diesel injected fuel has higher viscosity than diesel which makes atomization difficult and also has lower calorific value, which together result in lower brake thermal efficiency. Of

the two carburetors, parellel flow gas entry carburetor gives better performance compared with Y degree gas entry carburetors. The brake thermal efficiency values at 80 % load with HOME – Producer gas operation and Y, and parallel flow gas entry carburetors were found to be 12.24, and 17.2 % and 19.1 % for diesel –Producer gas operation with parallel flow gas entry carburetor respectively.



Fig. 16 Variation of BTE with brake power

7.1.2 Exhaust gas temperature

Exhaust gas temperature at different power outputs in dual fuel mode of operation is presented in Figure 17. The Exhaust gas temperature was found to be higher for HOME -Producer gas and lower for Diesel- Producer gas operation. It may be due to the incomplete combustion of gaseous fuel with the injected biodiesel fuel and most of the fuel burns during diffusion combustion phase. Results were showed that the parallel flow gas entry carburetor gives lower exhaust gas temperature compared with other carburetors tested. The Exhaust gas temperature values at 80 % load with HOME – Producer gas operation and Y, and parallel flow gas entry carburetors were found to be 510, and 460 degree centigrade and 370 degree centigrade for diesel –Producer gas operation with parallel flow gas entry carburetor respectively.



Fig. 17 Variation of EGT with brake power

7.2 Emission Characteristics:

Emission Characteristics of engine are important as for as environmental aspects is concerned. The emission from the engine indicates the combustion quality taking place inside the engine. Researchers have reported comparable results of engine emissions. This is due to the variation of producer gas composition and type of liquid fuel, engine type, design and operating parameters, engine choice (indirect/direct injection and brand), fuel inlet temperature, high or low load and speed operation, instrumentation accuracy, method of conducting the experiment, lack of feedstock homogeneity and ambient conditions. The emission levels with producer gas operation under dual fuel mode were measured under steady state conditions, using well calibrated instruments. The different emission parameter measurements during the dual fuel mode operation are discussed below.

7.2.1 Smoke opacity

The effect of brake power on smoke opacity is shown in Figure 18. The smoke opacity was lower for diesel- Producer gas dual fuel operations compared to HOME - Producer gas over the entire load range. The presence of free fatty acid and its heavier molecular structure of the injected biodiesel fuel compared to diesel results in higher smoke levels. Of the two carburetors, parallel flow gas entry gives better performance compared with Y gas entry with reduced smoke opacity. It could be due to the better air and gas mixing results complete combustion of gaseous fuel. The smoke opacity values at 80 % load with HOME – Producer gas operation and Y, and parallel flow gas entry carburetors were found to be 72, and 62 HSU and 40 HSU for diesel –Producer gas operation with parallel flow gas entry carburetor respectively.



Fig. 18 Variation of smoke opacity with brake power

7.2.2 HC emissions

The variation of HC emission levels with brake power is shown in Figure 19. The presence of free fatty acid and its heavier molecular structure of the injected bio-diesel fuel compared to diesel results in higher HC emissions. This is because the parallel flow gas entry carburetor ensures stoichiometric mixture of air and producer gas compared to other carburetors tested and this ensuring better combustion as well. Hydrocarbon emissions were observed in the range of 65 to 73 ppm for neat diesel – Producer gas operation and 46 to 64 ppm for HOME-Producer gas dual fuel operation throughout the load range at the optimum parameters. At lower loads, HC level were found to be higher and decreased at higher loads. The HC emission values at 80 % load with HOME – Producer gas operation and Y, and parallel flow gas entry carburetors were found to be 72, and 62 PPM and 40 PPM for diesel –Producer gas operation with parallel flow gas entry carburetor respectively.



Fig. 19 Variation of HC emission with brake power

7.2.3 CO emissions

The effect of brake power on CO emissions for diesel-Producer gas and HOME - Producer gas dual fuel operation is shown in Figure 20. Higher concentration of CO in the exhaust is a clear indication of incomplete combustion of the pre-mixed mixture. The CO levels were higher for dualfuel operation due to already presence of CO in the producer gas and combustion inefficiencies. It may also due to the mixture of Producer gas-air flow to the engine reduce the amount of oxygen required for complete combustion and this creates incomplete combustion and increase in the CO emission levels. At lower loads, the mixture being leaner results in greater extent of incomplete combustion and hence higher CO concentration. This puts a lower load limit for the dual fuel operation. At higher loads, the CO levels in the exhaust may slightly reduced to lower extent compared to lower loads because of increased combustion temperature. Higher emission of CO levels in the exhaust could be attributed to lower heating value of Producer gas, lower adiabatic flame temperature and lower mean effective pressures. However, the CO emission levels were found to be lower with parallel flow carburetor compared to other carburetors tested. This could be due to better mixing of gaseous fuel with air and leads to slightly better combustion. The CO emission values at 80 % load with HOME – Producer gas operation and Y, and parallel flow gas entry carburetors were found to be 72, and 62 % and 40 % for diesel -Producer gas operation with parallel flow gas entry carburetor respectively.



Fig. 20 Variation of CO emission with brake power

7.2.4 Nitrogen oxide emissions

The effect of brake power on nitrogen oxide emissions for both Diesel- Producer gas and HOME - Producer gas dual fuel mode of operation is shown in Figure 21. The NOx emissions were found to be higher for Diesel - Producer gas dual fuel operations compared to HOME - Producer gas over the entire load range. This is because the higher heat released during premixed combustion with Diesel- Producer gas dual fuel operation, results in higher BTE associated with higher NOx. This may also be due to the lower adiabatic flame temperature of Producer gas and absence of organic nitrogen in Producer gas. Results were indicate that the parellel flow gas entry carburetor gives higher NOx compared with other carburetors tested because of higher heat release during premixed combustion. The nitric oxide emission values at 80 % load with HOME – Producer gas operation and Y, and parallel flow gas entry carburetors were found to be 72, and 62 PPM and 40 PPM for diesel –Producer gas operation with parallel flow gas entry carburetor respectively.



Fig. 21 Variation of NOx with brake power

7.3 Fuel substitution

Figure 22 presents the fuel substitution for dual fuel operation at different power outputs. Fuel substitution values were higher for Diesel- Producer gas operation compared to HOME-Producer gas combinations. Injected fuel properties such as cetane number, viscosity and calorific value may be considered as responsible for the observed trend. However 30^{0} gas entry carburetors give higher fuel substitution. Substitution is higher at lower loads and found to decrease with load. The fuel substitution values in percentage at 80 % load with HOME – Producer gas operation and Y, and parallel flow gas entry carburetors were found to be 72, and 62 % and 40 % for diesel –Producer gas operation with parallel low gas entry carburetor respectively.



Conclusions:

Following are the conclusions made out based on the present work,

- Three dimensional CFD computations on producer gas carburetor made have been able to capture the detailed functional features of fluid flow in the carburetor configurations considered and the results on engine are found to be consistent at different engine operating conditions. Turbulent model based on k-ε theory with the CFD predictions of the producer gas mass fraction and the carburetor flow analysis has been evaluated leading to an optimal design of the Producer gas carburetor that is used for prototype testing and real-time engine testing.
- 2. The experimental results from gasifier engine system tests showed that parallel flow gas entry carburetor was found to be optimum compared to Y carburetor shape.
- 3. Operating the Gasifier engine system with optimum carburetor, and HOME and Producer gas makes the system completely independent from fossil fuel use.
- 4. Optimized carburetor shape improves the dual fuel engine performance with reduced HC and CO emission levels.

References:

- 1. Banapurmath N.R., Tewari P.G., Comparative performance studies of a 4-stroke CI engine operatedon dual fuel mode with producer gas and Honge oil and its methyl ester (HOME) with and without carburetor, Renewable Energy, 34 (2009) 1009–1015.
- Anil T.R., Ravi S.D., Shashikanth M., Rajan N.K.S., Tewari P.G., CFD Analysis of a Mixture Flow in a Producer Gas Carburetor, International Conference On Computational Fluid Dynamics, Acoustics, Heat Transfer and Electromagnetics CFEMATCON-06, July 24-25, 2006, Andhra University, Visakhapatnam – 530003, INDIA.
- Sridhar G., Sridhar H. V., Dasappa S., Paul P. J., Rajan N. K. S., Mukunda H. S., Development of Producer Gas Engines.
- Banapurmath N.R., Tewari P.G., Hosmath R.S., Experimental investigations of a four-stroke single cylinder directinjection diesel engine operated on dual fuel mode with producer gas as inducted fuel and Honge oil and its methyl ester (HOME)as injected fuels, Renewable Energy 33 (2008) 2007–2018.
- Srivastava A, Prasad R. Triglycerides-based diesel fuels. Renewable and sustainable Energy Reviews 2000, 4:111–33.
- Vellguth G., Performance of vegetable oils and their monoesters as fuels for diesel engines. SAE 1983, Paper No.831358.
- Gajendra Babu MK, Chandan Kumar Das LM. Experimental Investigations on a Karanja Oil Methyl Ester Fuelled DI Diesel Engine. SAE 2006-01-0238, 2006.

- Deepak A., Kumar A.A., Performance and emission characteristics of a Jatropha oil (preheated and blends) in a direct injection compression ignition engine. International Journal of Applied Thermal Engineering 2007;27:2314–23.
- Scholl KW, Sorenson SC. Combustion analysis of soyabean oil methyl ester in a direct injection diesel engine. SAE 1993;930934.
- 10. Nwafor OMI. Effect of advanced injection timing on the performance of rapeseed oil in diesel
- Banapurmath N.R., Tewari P.G., Yaliwal V.S., Satish Kambalimath , Basavarajappa Y.H., Combustion characteristics of a 4-stroke CI engine operated on Honge oil, Neem and Rice Bran oils when directly injected and dual fuelled with producer gas induction, Renewable Energy 34 (2009) 1877–1884.
- 12. Vyarawalla F, Parikh PP, Dak HC, Jain BC. Utilization of biomass for motivepower generation: gasifier engine system. Biomass 1984;3:227–42.
- Parikh PP, Bhave AG, Kapse DV. Shashikantha. Study of thermal and emission performance of small gasifier dual fuel engine systems. International Journal of Biomass 1989;19:75–97.
- Bhattacharya SC, Hla SS, Pham H-L. A study on a multi-stage hybrid gasifierengine system. International Journal of Biomass and Bioenergy 2001;21:445–60.
- 15. Sridhar G, Dasappa S, Sridhar HV, Paul PJ, Rajan NKS. Gaseous emissions using producer gas as fuel in reciprocating engines. SAE 2005-01-1732 2005.
- Uma R, Kandapal TC, Kishore VVN. Emission characteristics electricity generation system in diesel alone and dual fuel modes. International Journal of Biomass and Bioenergy 2004;27:195– 203.
- Bridgwater AV, Toft AJ, Brammer JG. A techno-economic comparison of power production by biomass fast pyrolysis with gasification and combustion. International Journal of Renewable and Sustainable Energy Reviews 2002;6:181–248.
- Klimstra J., Carburetors for Gaseous Fuels –on Air to Fuel ratio, Homogeneity and Flow restriction. SAE paper 892141
- Vinay S.S., Ravi S.D., PremaKumar G., Rajan N. K.S., Numerical and Experimental Modeling of Producer Gas Carburettor, Proc. of the International Conference on 'Advances in Mechanical Engineering, 2008, S.V. National Institute of Technology, Surat – 395 007, Gujarat, India, pp 1 – 9.
- 20. Fukui T, Tamura Y, Omori S, Saitoh S. Accuracy of A/F calculation from exhaust gas composition of SI engines. Mitsubishi Motors Corp, SAE Paper 891971.
- 21. [Spindt RS. Air fuel ratios from exhaust gas analysis. SAE 1965;650507.
- Tseng TC, Cheng WK. An adaptive air/fuel ratio controller for SI engine throttle transients. Massachusetts Institute of Technology 1999-01-0552; 1999.

- 23. Azzoni P, Minelli G, Moro D. Air-fuel ratio control for a high performance engine using Throttle angle information. SAE paper 1999;011169.
- 24. Ohyama Y. Air/fuel ratio control using upstream models in the intake system. SAE Paper 1999;0857(vol. 1).
- Berggren P, Perkovic A. Cylinder individual lambda feedback control in an SIengine. Technical Presentation at Lynkoping, Reg: LiTH-ISY-EX-1649; 1996.
- Douglas G. Janisch patented work on producer gas carburetor; US Patent 5070851 December 10 1991, <u>www.freepatentsonline.com</u>