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Effect of venture design on the performance of CNG and biogas operated dual fuel engine with jamun seed oil methyl ester blends

In the present work, effect of mixing gas venture (GV) on the performance of modified dual fuel (DF) engine with effective utilization of biodiesel and gaseous fuel combinations is reported. Biodiesel prepared jamun seed oil called jamun seed oil methyl ester (JAMUNME B100) and its B20 blend (JAMUNME B20) are used as pilot injected fuels while the biogas and compressed natural gas (CNG) are used as the inducted fuels in the modified DF engine. Hence, the present research focus on the enhancing of engine performance of DF engine fuelled with liquid and gaseous fuel combinations. Meanwhile, the effect of GV on modified DF engine performance is investigated. Higher brake thermal efficiency (BTE), lower carbon monoxide (CO), hydrocarbon (HC) and smoke emissions besides higher NO_x emissions are observed with higher methane content gas. Combustion parameters such as ignition delay (ID), and peak pressure (PP) are analysed. The DF engine operated on renewable fuel combinations in DF mode can cover the way for partial substitution of fossil fuel along with reduction in greenhouse gas emissions. Increasing the number of orifices in GV will improve the gas-air mixing ratio.

Keywords: *Jamun seed oil methyl ester (JAMUNME); CNG; Biogas; manifold induction, emissions; peak pressure and ignition delay.*

1.0 Introduction

Internal combined effect of pollution and depleting fossil fuels all over the world had forced the researchers to discover for substitute fuel that could be used in diesel engines. Currently, researchers and experts studied that biodiesel injection with gaseous fuels could be an effective solution for present conditions. The research on DF engines had addressed that biodiesel injection with gaseous fuels could support for improvement of performance and exhaust emissions in diesel engine [1]. Biogas usage in case of internal combustion (IC) engines represents many benefits. The carbon dioxide (CO_2) content in the diesel fuel affects negatively on the process of combustion thereby reducing stability and speed of the combustion process. More amount of hydrogen (H_2) present in the biogas helped to increase the combustion characteristics of engine [2]. By using lower flow rates of biogas and methane fraction exhibited higher BTE and lower HC emissions. Homogeneous charge compression ignition (HCCI) mode of operation presented low smoke and NO_x emissions. Preheating of intake fuel resulted in superior performance and emissions but along with that amplified the knock tendency [3]. IT and exhaust gas recirculation (EGR) powerfully influence the process of combustion in diesel engines when operated with acetone-butanol-ethanol (ABE)/ diesel fuel. IT and EGR strategies significantly affected on the emissions of NO_x, HC, CO and soot in diesel engine operated with ABE/diesel fuel [4]. The addition of H to the biogas increased the flame speed and ID [5]. Combustion duration (CD) decreased with increment of energy ratios (ER) and advanced direct injection timing (DIT). There was an improvement of BTE about 19.45% by increasing ER and advancing DIT. With the increase of ER emissions of NO_x, HC, CO, and soot were decreased along with emissions of CO increased [6]. The speed of combustion was decreased by the retarded DIT which resulted into reduction of NO_x emissions and increase of HC and CO emissions [7]. At fixed DIT the BSFC slightly reduced with increment in di-methyl-ether (DME) quantity. At fixed quantity of DME the lowest BSFC was found with DIT of 7°CA BTDC. With increase in DME quantity CO and HC increased along with smoke reduced [8]. Late IT was better technique to suppress the

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TABLE 1: PROPERTIES OF DIESEL, CEIBA PENTANDRA OIL, BIODIESEL AND ITS BLENDS WITH DIESEL

	Properties	Diesel	Jamun seed oil	JAMUNME B100	JAMUNME B20
1	Chemical formula	$C_{13}H_{24}$	-	-	-
2	Density (kg/m^3)	830	926	886	864
3	Calorific value (kJ/kg)	43,000	38,722	38,915	39818
4	Flashpoint (^oC)	54	204	148	112
5	Cetane number	45-55	50	-	47
6	Kinematic viscosity (mm^2/s)	2.3	42.66	4.9	4.56

engine knock than early IT due to more transfer of heat from cylinder wall to the gases. Increased volumetric efficiency along with reduction of CD was found at early IT conditions [9]. BTE remained stable at low methanol to diesel ratio (MDR), but resulted in minor decrement at high MDR. The emissions of NO_x and soot were reduced as MDR increased meanwhile emissions of HC and CO significantly increased [10]. A study of the impact of range of cooled EGR on engine performance and gaseous emissions was carried out at different engine speeds, loads and injection timings. NO_x reductions were achieved with higher EGR fractions, but the rate of reduction was significantly reduced. Engine performance and efficiency were not significantly affected except at very high EGR fractions [11].

2.0 Materials and methods

2.1 BIODIESEL

In the present work biodiesel obtained from jamun seed oil termed as jamun seed oil methyl ester (JAMUNME) and its B20 blend (JAMUNME B20) are used as pilot injected fuels while the biogas and CNG is used as the inducted fuel in the modified DF engine. The fuels chosen for engine applications have a significant impact on engine efficiency and emissions. Jamun seed oils being nonedible, can be effectively used as feasible fuels for diesel engine applications.

The weight of the Jamun fruit is about 10.88 to 7.10 gm and seed about 1.85 to 1.43 gm. Both seed and fruit contain polyphenol in higher quantity, besides tannin and anthocyanin. Biodiesel from jamun seed oil is prepared by well-established transesterification process. The chemical reaction is sustained for 2 hours at constant temperature of 60^{o}C with a stirring speed of 700 rpm. Upper layer of crude biodiesel separated is washed with equal volume of warm distilled water repeatedly to obtain JAMUNME. B20 blend of biodiesel (JAMUNME B20) is obtained by mixing 80% of diesel with 20% biodiesel. The fuel properties used in the present work are shown in Table 1.

Biogas and CNG are used as inducted fuels in the modified dual fuel engine. Tables 3 and 4 shows the properties of biogas and CNG used in the study.

TABLE 2: SHOWS THE FATTY ACID COMPOSITIONS OF NON-EDIBLE OIL AND ITS BIODIESEL RESPECTIVELY

	Fatty acids	Jamun seed oil vol%	Jamun seed biodiesel vol%
1	Palmitic C16:0	32.18	4.7
2	Stearic C18:0	-	6.5
3	Oleic C18:1	21.09	32.2
4	Linoleic C18:2	26.04	16.1
5	Linoleic C18:3	24.80	21

TABLE 3: PROPERTIES OF BIOGAS

Properties	Purified biogas
Composition % (v/v)	CH_4–93% CO_2–4% H_2–0.06% N_2–2.94% H_2S–20 ppm
Lower heating value (MJ/kg)	42.62
Relative density	0.714
Flame speed (cm/s)	-
Auto-ignition temperature	-

TABLE 4: PROPERTIES OF NATURAL GAS

Properties	Natural gas
Boiling range (K@101325Pa)	147
Density (kg/m³) at 1 atm. and 15^{o}C	0.77
Flash point (K)	124
Octane number	130
Flammability limits range Rich Lean	 0.5873 1.9695
Flame speed (cm/s)	33.80
Net energy content (MJ/kg)	49.5
Auto ignition temperature (K)	923 (650^{o}C)
Combustion Energy (KJ/m³)	24.6
Vaporization energy (MJ/m³)	215-276
Stoichiometric A/F (kg of air/kg of fuel)	17

3.0 Experimental set up

Tests are carried on single cylinder compression ignition (CI) diesel engine with 17.5 compression ratio, producing 5.2 kW power at speed of 1500 rpm modified to operate in DF mode using both liquid and gaseous fuels respectively. Fig.1 shows the DF engine test rig. Eddy current dynamometer is used for engine loading. Piezoelectric pressure sensor is used to acquire pressure signals with crank angle. Various sensors are

Fig.1: DF engine test rig

Fig.2: Gas supply arrangement

Fig.3: Biogas induction system with mixing ventures of varied orifice

utilized for measurement of fuel flow, air, load and temperatures. Injection timing (IT) and injection pressure (IP) as noted by the maker respectively is 23°BTDC and 205 bar. Fig.2 shows the gas supply arrangement to the DF engine. Fig. 3 shows the biogas and CNG induction system along with mixing ventures used in the study.

4. Results and discussion

In this section experimentation on DF mode with biogas-biodiesel, CNG-biodiesel and diesel-CNG induction through four ventures each having 12 holes of 3, 6, 9 and 12 mm hole size is discussed.

Ventura type effect on BTE is presented in Fig.4. It is observed that BTE is higher for diesel-CNG gaseous combination compared to JAMUNME biodiesel and its B20 blend due to high flame velocity and high energy content in diesel. However, thermal efficiency for all fuel combinations is improved with 9 mm size venture compared to other ventures tried. This may be caused by homogeneous mixing of air and inducted gases of biogas and CNG (fuel) with nearly stoichiometric condition. Biodiesel and gaseous fuels being common with same venture and varied size of the venture orifice is the main influencing parameter on engine performance. JAMUNME B100 and JAMUNME B20 with biogas combination inducted fuels have lower calorific value and lower flame velocity than with CNG gas combination which results into lower energy release rate leading to lower BTE. However, JAMUNME B20 with CNG shows more BTE

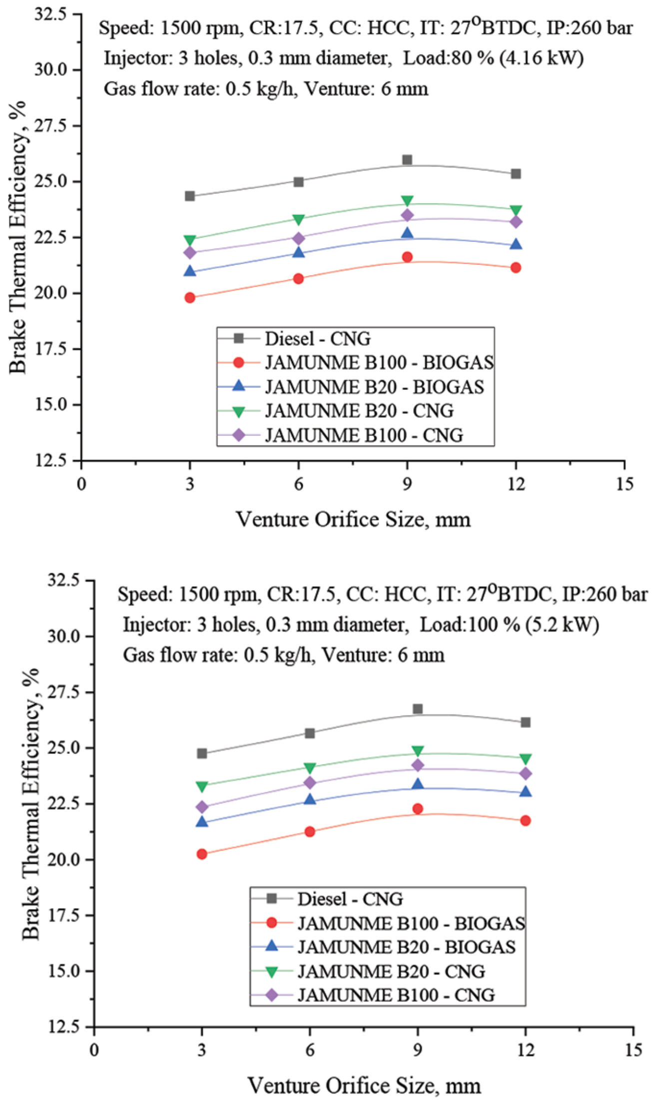

Fig.4: Effect of venture orifice size on BTE at 80 and 100% loads

than JAMUNME B100 and this is due to blending of diesel with biodiesel which improves the fuel properties. Among all the ventures tried, 9 mm size gas entry venture resulted in improved performance due to complete combustion caused by the proper air-fuel mixing and improved equivalence ratio.

Fig.5 shows venture size effect on smoke opacity of dual fuel engine fuelled with biodiesel-biogas and biodiesel-CNG combination. 9 mm venture resulted in lesser smoke opacity than other ventures tested. It may be due to improved air and gas mixing resulting in superior combustion. In addition, differences in the gaseous fuel properties may lead to differences in the smoke levels. Higher smoke levels have been observed for JAMUNME and biogas inducted operation compared to CNG operated dual fuel mode operation. This could be due to difference in the methane content of biogas as compared to purified biogas. Gaseous fuels being common, JAMUNME B20 shows lesser smoke as compared to B100 due to more fuel burning characteristics in premixed combustion phase and improved fuel property of JAMUNME B20.

HC emission were found to be lower using 9 mm venturi compared to other ventures tested as shown in the above Fig.6. Combustion of marginally viscous biodiesel JAMUNME along with gaseous fuel results in to higher HC emissions. Lower HC emission were observed with 9 mm venturi compared to other ventures for all fuel combinations in dual fuel mode. It may be caused by the fact that 9 mm venturi ensures required air-fuel ratio (stoichiometric mixture) compared to other ventures tested. This factor may lead to better combustion as well. For 2 and 6 mm venturi, HC emission was larger than 9 mm. In appropriate air-fuel mixing and subsequent decreased burning rate of the fuel combinations occurring with 2 and 6 mm venturi could be the reasons for the same. Between JAMUNME B100 and B20 with CNG shows lesser HC level compared to JAMUNME B100

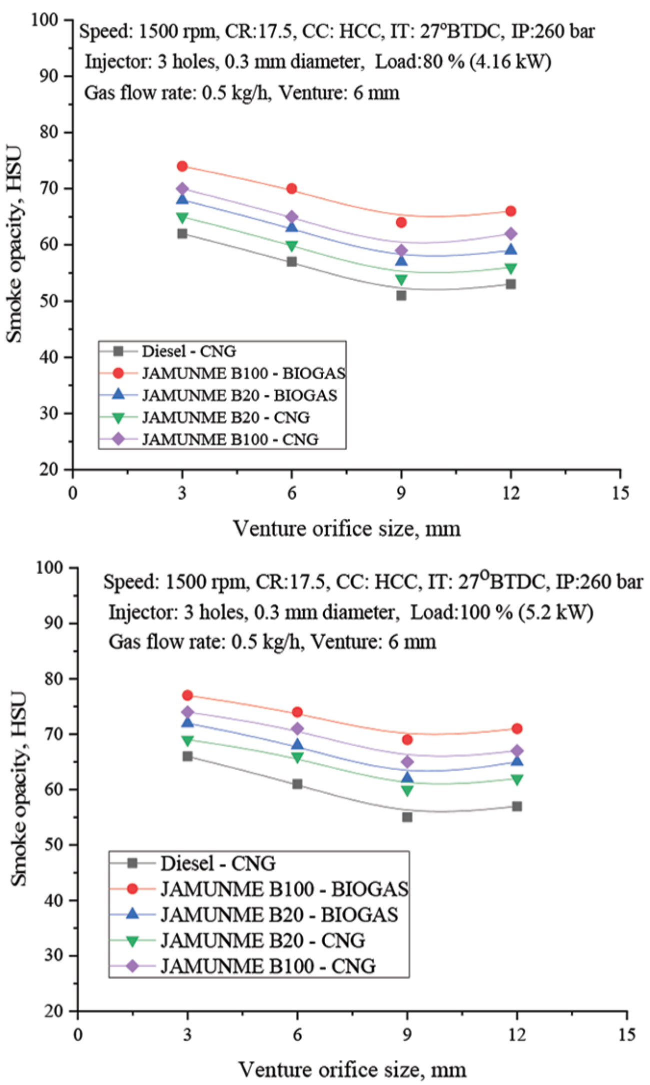

Fig.5: Effect of venture orifice size on smoke opacity at 80 and 100% loads

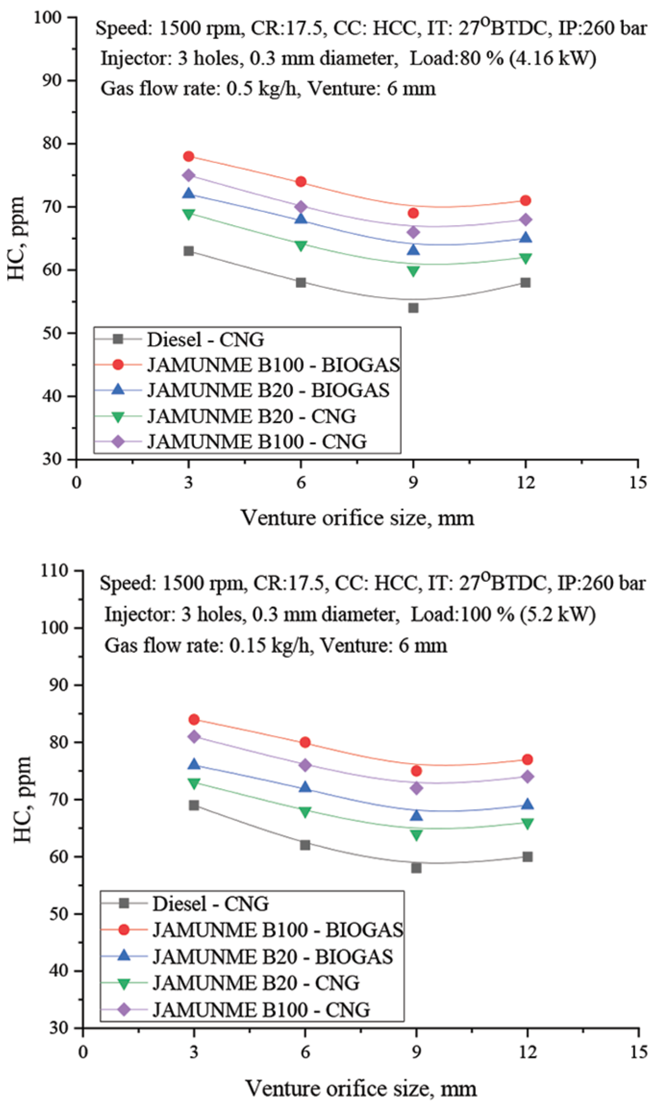

Fig.6: Effect of venture orifice size on HC emission at 80 and 100% loads

and B20 with biogas and this is due to varied fuel properties of gaseous fuel combinations. Diesel-biogas combination shows least HC emission compared to biodiesel and gaseous fuel combinations due to higher viscosity and lower energy content of biodiesel compared to diesel.

Fig.7 shows the effect of venturi size (type) on CO emission with biodiesel-biogas and biodiesel-CNG dual fuel operation. Higher CO are observed with JAMUNME - biogas and may be due to partial burning of the pre-mixed air-fuel mixtures and improper utilization of gaseous fuel during combustion of gaseous fuel compared to CNG operation due to combustion inefficiencies. Lower equivalence ratios and quality of fuel-air mixture prevailing inside engine cylinder significantly affects the combustion. However, substitution of gaseous fuel may lessen the quantity of oxygen required for complete combustion hence incomplete burning of gaseous fuel occurs. Between JAMUNME B20 and B100 with biogas combination shows higher per cent of CO emission compared to JAMUNME and B100 with CNG this is due to higher calorific value and better combustion with CNG than biogas. Lower CO emissions were observed with 9 mm venturi compared to other ventures tested for all the fuel combinations in dual fuel mode. Comparatively improved air mixing with gaseous fuel may cause slightly improved combustion. Gaseous fuels being common, JAMUNME B20 shows lower percentage of CO than JAMUNME B100 and may be due to improved fuel property and blending with diesel improves combustion efficiency.

The effect of venture on the NO_x levels is shown in Fig.8. For all the dual fuel operation using 9 mm venturi shows higher NO_x emission levels compared to 2 mm and 6 mm venturi. Higher heat release rate during premixed combustion for dual fuel operation using 9 mm venturi provides enhanced BTE with increased NO_x levels. This could also be due to enhanced heat release rate (HRR) during premixed combustion compared to diffusion combustion phase. JAMUNME B20

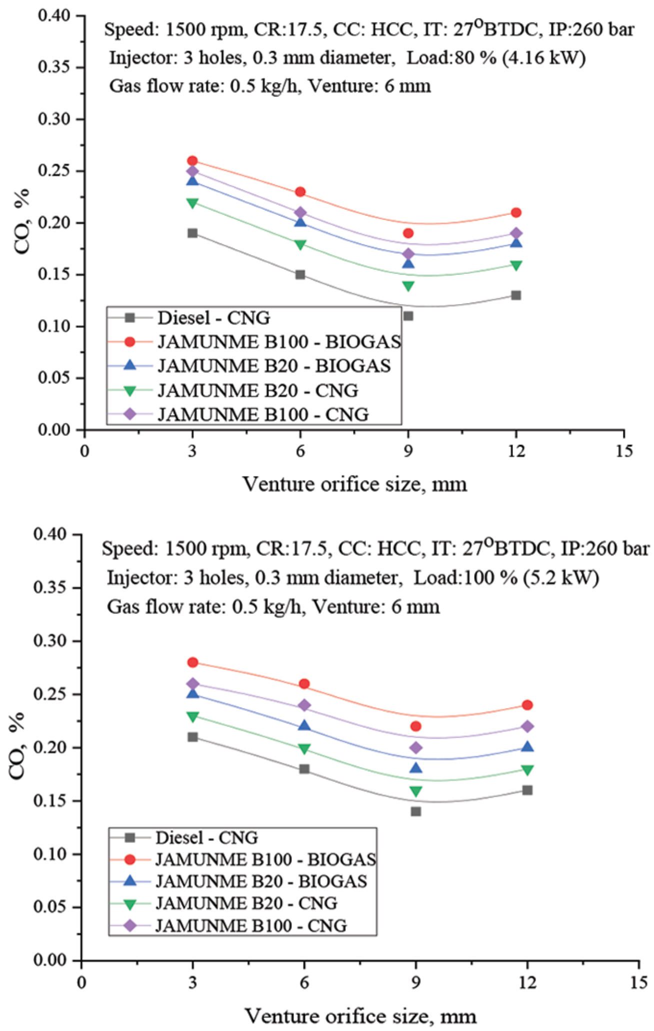

Fig.7: Effect of venture orifice size on CO emission at 80 and 100% loads

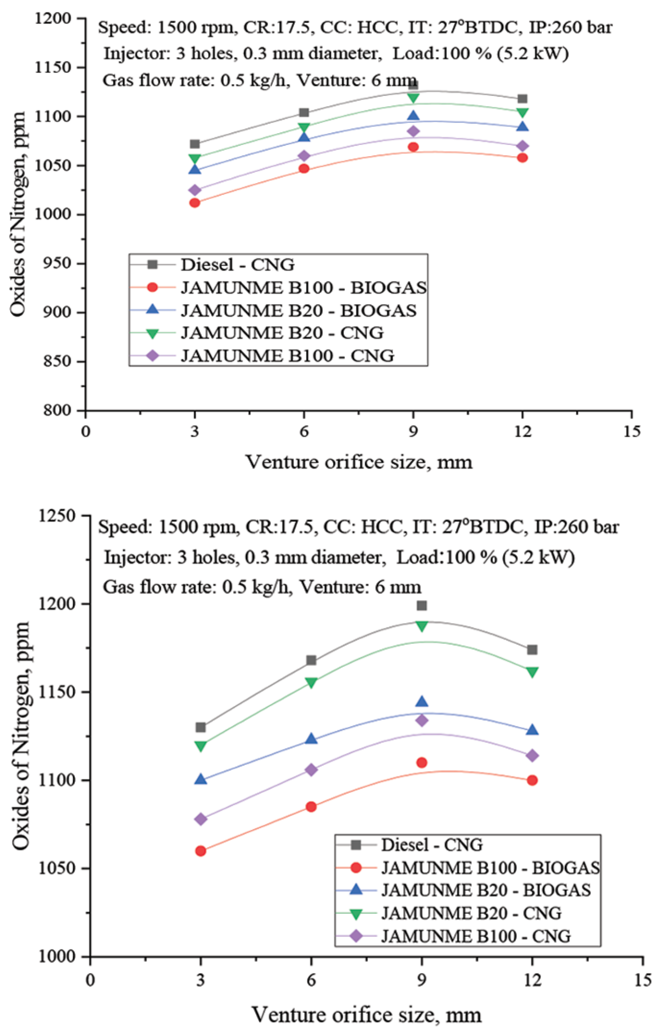

Fig.8: Effect of venture orifice size on NO_x emission at 80 and 100% loads

and B100 with CNG shows higher NO_x levels compared to biogas due to higher calorific value of CNG which improves combustion and increases the engine temperature. Gaseous fuels being common JAMUNME B20 shows higher NO_x level due to blending with diesel which improves fuel property and increase engine temperature and heat release rate.

Fig.9 shows the effect of venturi on ID of DF engine fuelled using biogas and CNG with JAMUNME biodiesel and its B20 blend respectively. As the number of holes on venture increases the ID period decreases. Biodiesel-biogas DF engines show higher delay period as related to biodiesel-CNG fuel operation due to higher methane content of latter gas with higher in-cylinder pressures. Gaseous fuels show lower ID with JAMUNME B20 compared to JAMUNME B100 due to higher calorific value of the former fuel. Also, biogas and biodiesel combinations show comparatively higher IDs.

Fig.10 shows the effect of venture on the PP of DF engine operated with induction of biogas and CNG gases and injecting JAMUNME and its blend as pilot fuels. As the number of holes on venture increases the PP increases. Higher BTE of the dual fuel engine results into higher PP with increasing holes on gas mixing venture. Biodiesel-biogas DF engine show higher delay period as related to CNG dual fuel operation due to higher methane content and calorific value of latter gas. Biogas and CNG being same JAMUNME B20 show higher PP compared to JAMUNME B100 due to higher calorific value of the former fuel. Also, biogas and biodiesel combinations show comparatively lower PP.

5. Conclusions

- BTE for different fuel combinations were improved with 9 mm size venturi compared to other ventures tried. This may be caused by homogeneous mixing of air and inducted gases (fuel) with nearly stoichiometric air-gas ratio.
- More smoke emission for the pilot fuels is observed with B100 blends when compared to B20 fuels due to lower viscosity and higher calorific value of the latter fuel.

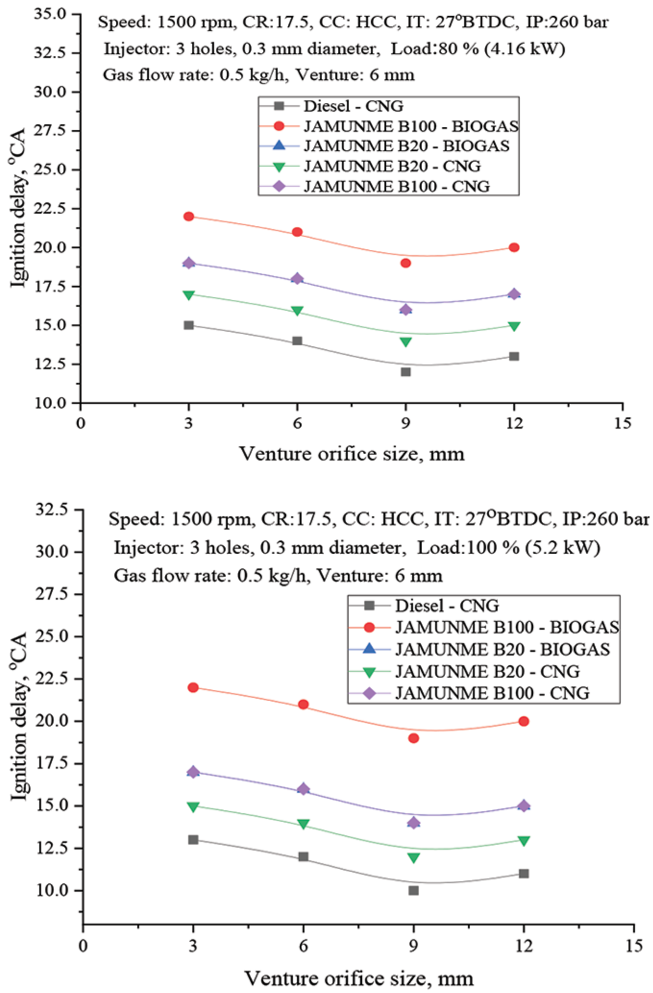

Fig.9: Effect of venture orifice size on ignition delay emission at 80 and 100% loads

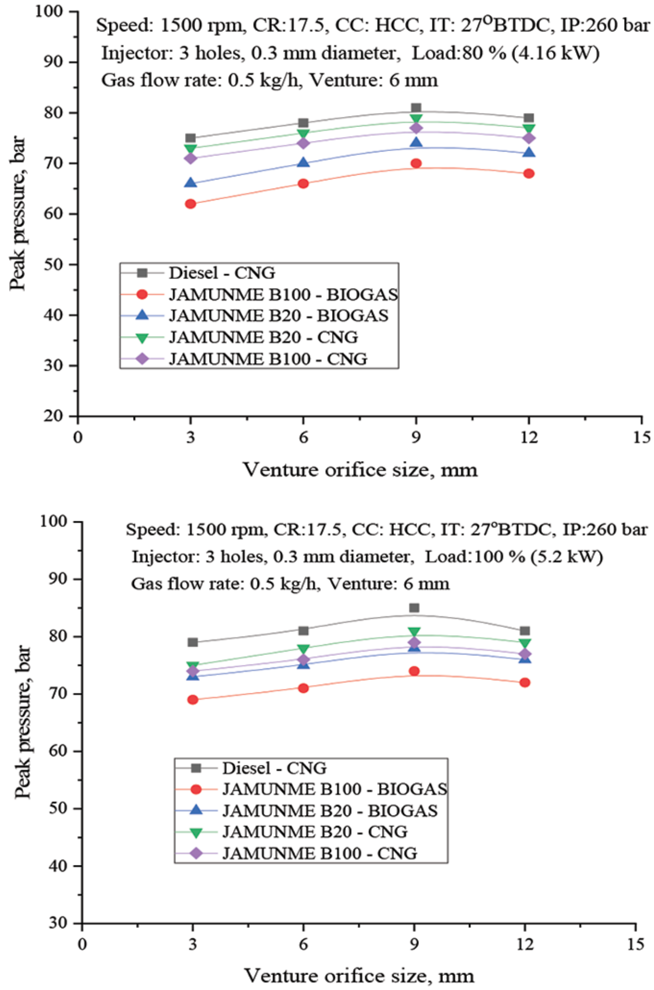

Fig.10 Effect of venture orifice size on peak pressure at 80 and 100% loads

- JAMUNME B20 shows lower HC emissions as compared to JAMUNME 100 for both CNG and biogas dual fuel engine operation.
- Lower CO emissions were observed with 9 mm venturi compared to other ventures tested for all the fuel combinations in dual fuel mode.
- Between gaseous fuels of biogas, CNG shows more NO_x emissions due to lowered combustion temperature.
- ID period decreases as the number of holes on venture increases.
- JAMUNME being same CNG show higher PP compared to biogas due to higher calorific value of the former fuel.

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