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Effects of butanol blending ratio in biogas-biodiesel dual fuel engine

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Abstract: By the rise in population, the usage of non-renewable fuels is increasing. It led to the depletion of fossil fuels and other environmental issues. Reducing the usage of fossil fuel, enhancing performance and reducing emissions are the key areas in this research. In this experiment, a conventional single cylinder CI engine is used in dual fuel mode. In dual fuel mode, biogas is used as primary fuel and biodiesel (Palm oil) with various butanol blending ratios (10%, 20% and 30%) is used as pilot fuel. Various properties like flash and fire point, cloud and pour point, viscosity, density, calorific values are measured. Biogas flow rate and applied load are varied for each blending ratio. The effects of load, butanol blending ratio and biogas flow rate on BTE, BSFC, HC, CO and NOx emissions are analyzed and compared with diesel-only mode. Biodiesel with 30% butanol blend in dual fuel mode shows better brake thermal efficiency at 12 lpm flow rates. All test cases prove 12 lpm is better than 16 lpm biogas flow rates. Increase in biogas flow rate reduces NO_x emissions. However, it increases HC and CO emissions. And this investigation proposes to intervene in the dual fuel biogas-biodiesel engine at 12 lpm biogas rate of flow.

1. Introduction

Fuel: A one among many of our regular life's rapidly dwindling need that has been under severe consideration to preserve from its depletion. Retrofitting the existing systems that consume fossil fuels would require sufficient duration in years. Henceforth, attenuating the consumption of fossil fuels with alternate class of fuels leads to a possible solution for sustainable development. In this context, it is believed to be very essential to orient the transportation sector towards environment friendly operations since it contributes a major portion of fuel consumption. Sharma et al. [1] found that the biogas, under dual fuel mode, would mostly reduce the brake thermal efficiency (BTE). However, BTE can be improved by possible methods such as enhanced injection time [2], mixing other pilot fuels in to biogas [3], achieving high compression ratio (CR) in dual fuel mode [4], and maintaining low flow rates of biogas at high loads [5]. Knocking, a threat to the safe engine operation would decrease in dual fuel mode, which could be due to the low flame speed [6, 7]. Fuels with low and high octane numbers adjust the air-fuel mixture's octane number to prevent the knock without penalising the engine's performance under dual fuel mode [8]. Low flame speed, low combustion temperature and early occurrence of the peak pressure are rooted due to decrease in BTE [9].

Butanol, a primary solvent based on alcohol family, shows much impact on NOx emission and the soot products are found to decrease with an increase in butanol blends [7]. Butanol with biogas in dual fuel mode increases CO emissions [10]. NOx emissions in biogas-fuelled engines are witnessed to be much lower due to the decreased combustion temperature [11]. In the dual fuel engine, the hydrocarbon (HC) emissions were found to be more than with diesel-only mode due to lower biogas flame velocity leading to reduced flame propagation [12]. Nevertheless, butanol provides leaning effect which in further decreases the output power [13 & 14]. Apart from broadening the fuel applicability, duel fuel combustion additionally ensures it to be clean in high-efficiency engines [15]. At a full load diesel-only and diesel-biogas modes showcases same performance, yet at low loads, the diesel-only mode shows better performance [16]. In the present study, effects of butanol blending ratio in biodiesel and biogas flow rate are studied on various performance and emission indices.

2. Methodology

In the present study, the load, biogas flow rate and butanol fractions in the biodiesel are considered to be the variable input parameters, which all reflect the operating range of the engine. The load is varied from 5 N-m to 20 N-m which accounts for 20 to 90% of engine load respectively. Two biogas flow rates say 12 & 16 lpm are adopted for the work. The maximum biogas energy substitution is 60%. Bu10 (10% of butanol in biodiesel), Bu20 and Bu30 are taken as an important input parameter in the study. Table 1 shows various input parameters involved in the present study.

Table 1: Description of input parameters

Parameters	**Parameter label**	**Levels**			
Biogas flow rate (lpm)	A	12	16	-	-
Butanol fraction (%)	B	10	20	30	-
Engine load (N-m)	C	5	10	15	20

2.1. *Experiment setup*

A 4-stroke single cylinder compression ignition (CI) engine with water cooling system is used in for the present experimental work, whose specifications are provided in Table 2. Figure 1 shows the schematic diagram of the experiment setup. The engine is coupled (crankshaft) with a dynamometer, which is the source for varying the engine load. The mixture of methane and carbon dioxide is used as a simulated biogas, a primary fuel, which is inducted with air through engine's intake manifold. A flow control device is used for adjusting the Methane (CH_4) and Carbon dioxide (CO_2) flow rates. Biodiesel and butanol mixture is the secondary fuel for the experiments and the mixture is injected into the cylinder from a 20 L fuel tank. Biogas is prepared by mixing CH_4 and CO_2 in the fraction of 3:2. The filtered air was supplied from the airbox as an intake to an engine. To study the exhaust gases like HC, CO and NO_x emissions, AVL 5-gas emission analyzer is used.

Table 2. Engine specification

Parameters	Values
Bore & stroke	87.5 mm, 80 mm
Compression ratio	17
Cubic capacity	481 cm^3
Peak pressure	75 bar
Output power	8 hp
Nozzle pressure	200 MPa

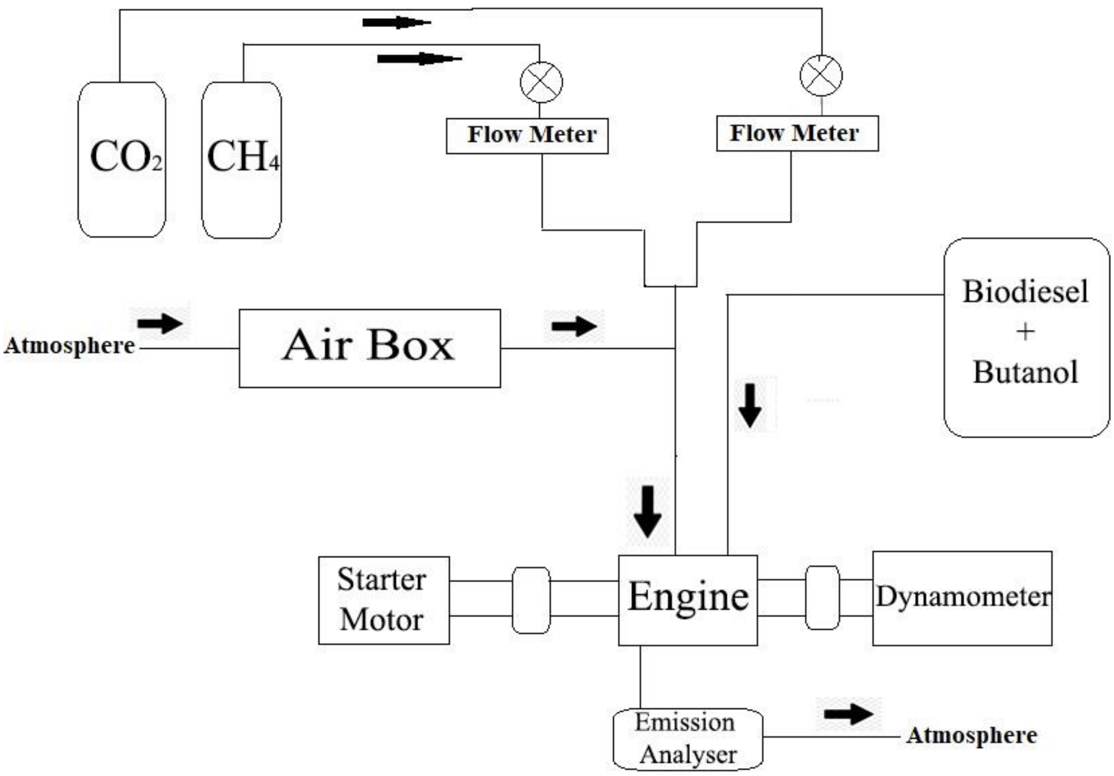

Fig. 1: Schematic of the Experimental Setup

2.2. Preparation of modified fuel:

In this study, 20% palm oil based biodiesel and 80% pure diesel is used as the biodiesel, which is termed as B20. 90% of B20 and 10% of butanol is given with the name Bu10. For instance, 1 *litre* of Bu10 contains 900 *ml* of B20 and 100 *ml* of butanol. And the same procedure is followed to prepare Bu20 and Bu30. The properties of various blends are provided in Table 3.

Table 3: Properties of fuel

Properties	Values			
	B20	Butanol10+B20	Butanol20+B20	Butanol30+B20
Flash point (^{o}C)	80	83	79	76
Fire point (^{o}C)	91	91	86	83
Cloud point (^{o}C)	6	5.5	4	2.3
Pour point (^{o}C)	-7	-7	-7	-8
Kinematic viscosity at 40 ^{o}C (mm^2/s)	4.32	4.11	4.32	4.42
Calorific value(kJ/kg)	39312	39420	38318	37684

3. Results and discussion

3.1. Brake thermal efficiency

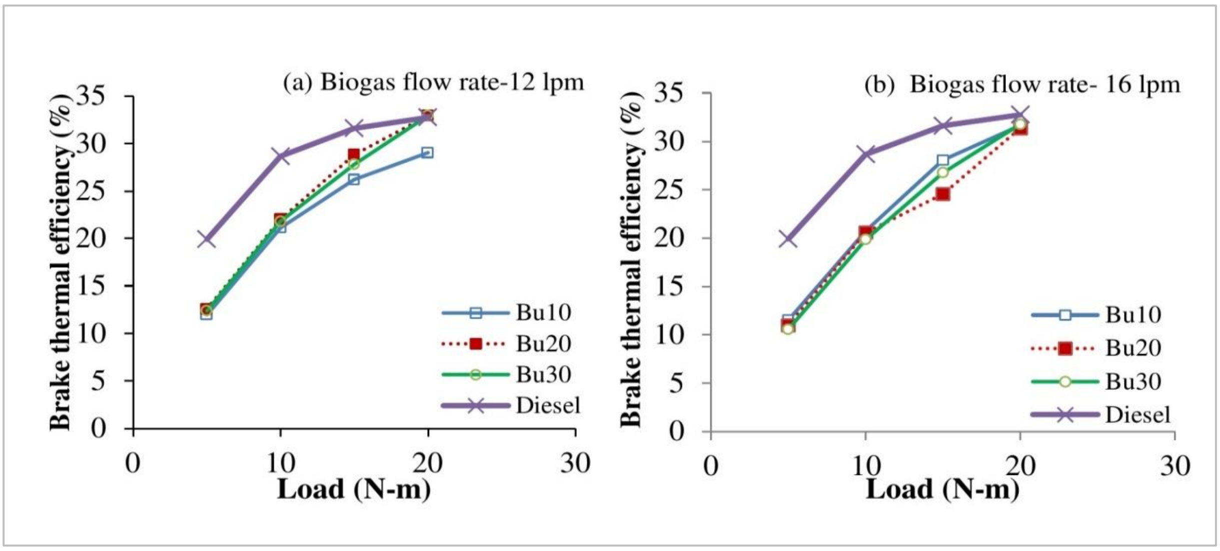

Fig. 2. Effect of butanol blend ratio on BTE

BTE of an engine helps to analyse how well the heat content of fuel is transformed into mechanical energy by the engine. Fig. 2 shows the effect of butanol blending ratio in dual fuel mode on BTE at different loads and biogas flow rates. BTE increases at the two biogas flow rates (12 and 16 lpm) with increase in the loads, which could be due to an increase in power and reduction in heat loss. Gaseous nature of biogas and its low flame velocity leads to have a reduced BTE compared to diesel-only mode. Low biogas flow rate provides high efficiency because of high flame velocity. The maximum BTE is obtained at Bu30 for the flow rate of 12 lpm at high load. The reason behind this trend could be due to the oxygen content in butanol, which resulted a better combustion and in further high combustion efficiency. Due to high pilot fuel consumption and improvement in biogas combustion, dual fuel mode shows better BTE at high load compared to diesel-only mode.

3.2. Brake specific energy consumption

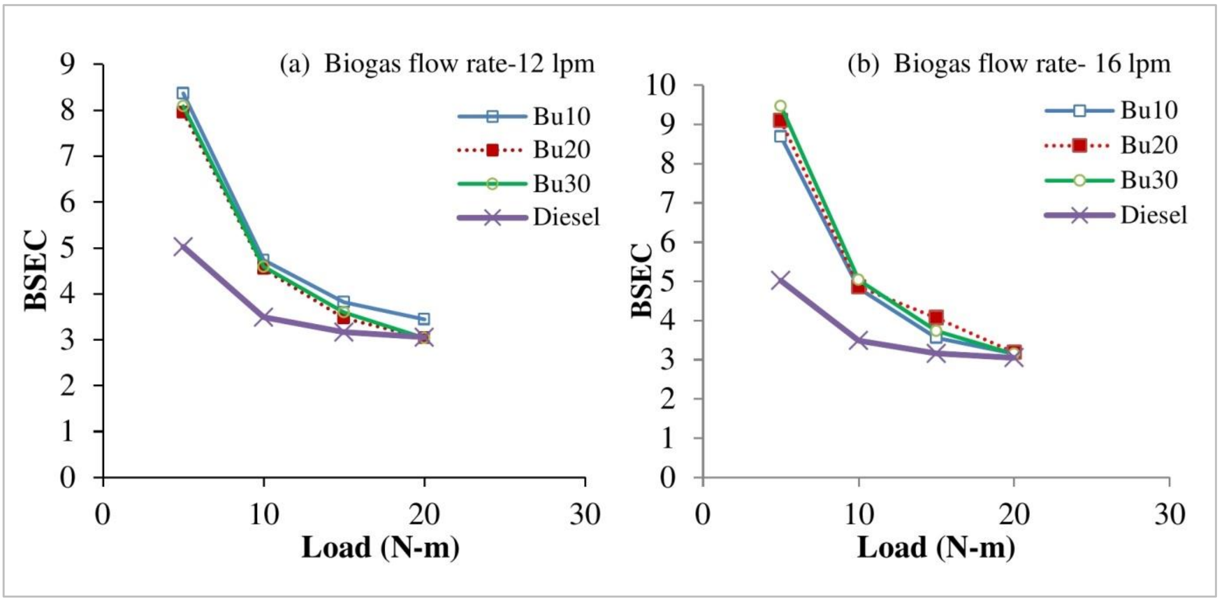

Fig. 3. Effect of butanol blend ratio on BSFC

Fig. 3 depicts the variations in BSEC for various butanol blend ratio and biogas flow rates. At low loads, BSEC is found to be low for diesel-only mode compared to the dual fuel mode, due to the presence of high ignitable diesel. However, at higher loads, BSEC in dual fuel mode got better due to improvement in biogas combustion because of high combustion temperature available in the combustion chamber [17]. As it can be witnessed from the figures (Fig. 3), BSEC gradually decreases with the increase in engine load. At 12 lpm of biogas, BSEC decreases with the increase in the butanol concentration since butanol possesses a lower heat value, and lower air-to-fuel ratio for stoichiometric mixtures.

3.3. HC emissions

Effect of butanol blend ratio for various biogas flow rates on HC emissions is provided in Fig. 4. Reduction in HC emission is observed with an increase in load for both 12 and 16 lpm biogas flow rates. At high load, pilot fuel consumption will be high which makes combustion temperature to increase. This results in reduction of HC emissions since HC emissions increases primarily because of incomplete combustion at high flow rates. Bu10 blend releases less amount of HC emission among the other fuel blends taken in the present work. At 12 lpm of biogas, the minimum values for HC emissions are 140, 178, 188 ppm for Bu10, Bu20, Bu30 respectively. Butanol has a low cetane number which threatens the ignition properties of blends and encourages quenching effect in the cylinder. Hence, increase in butanol content increases HC emission in the blends.

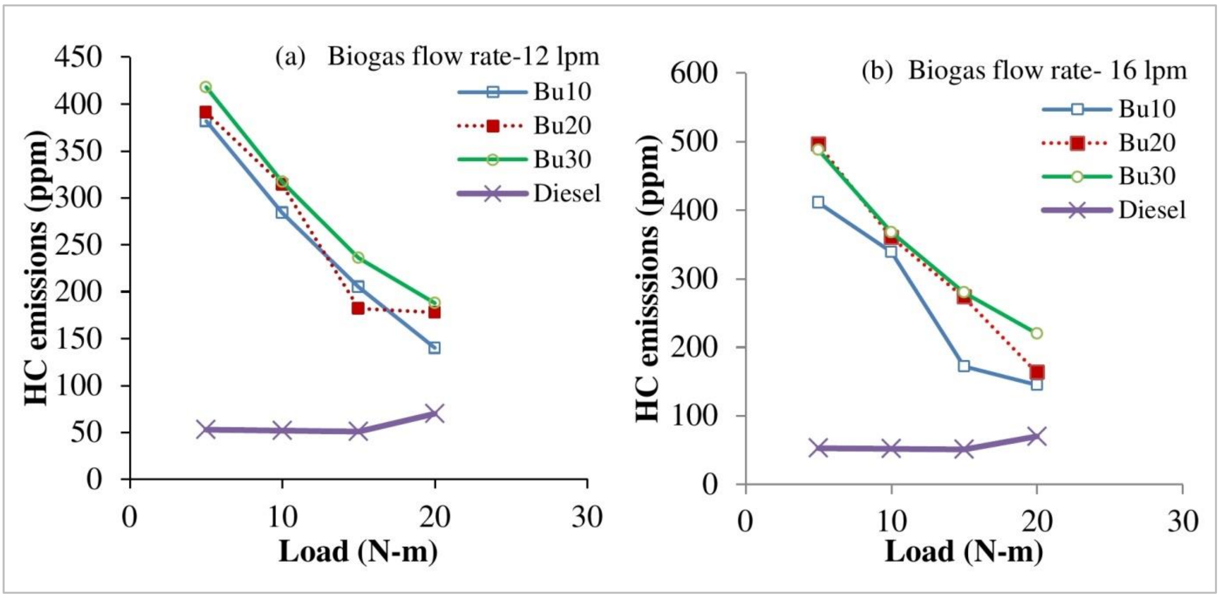

Fig. 4. Effect of butanol blend ratio on HC emission

3.4. *Carbon monoxide emissions*

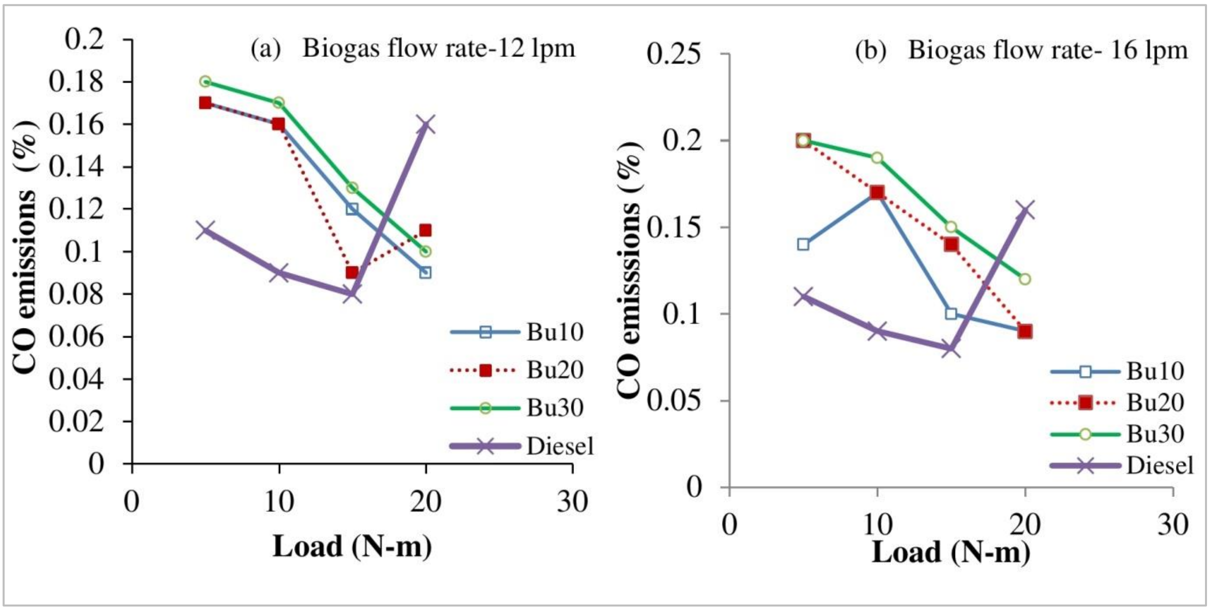

Fig. 5. Effect of butanol blend ratio on CO emission

CO emission is a result of incomplete combustion in the chamber. Increase in load caused a reduction in CO emissions at the two considered flow rates of biogas in the present work as shown in Fig. 5. CO concentration increases with an increase in butanol blending ratio in the fuel, and hence Bu30 has high CO emissions at the two biogas flow rates (12 and 16 lpm). CO emissions are lowed in diesel-only mode as compared to butanol blended dual fuel mode due to a low stoichiometric flame speed of biogas when compared with diesel-only mode. Increase in butanol blending ratio increases CO emissions due to lower cetane number of butanol. Additionally, lower cetane number in a fuel increases the ignition delay. The minimum values of HC emission are 0.09, 0.11, 0.1 % for Bu10, Bu20, Bu30 fuels respectively at 12 lpm of biogas and 0.09, 0.09, 0.12 % for Bu 10, Bu20, Bu30 fuels respectively at 16 lpm of biogas.

3.5. Nitrogen oxides emissions

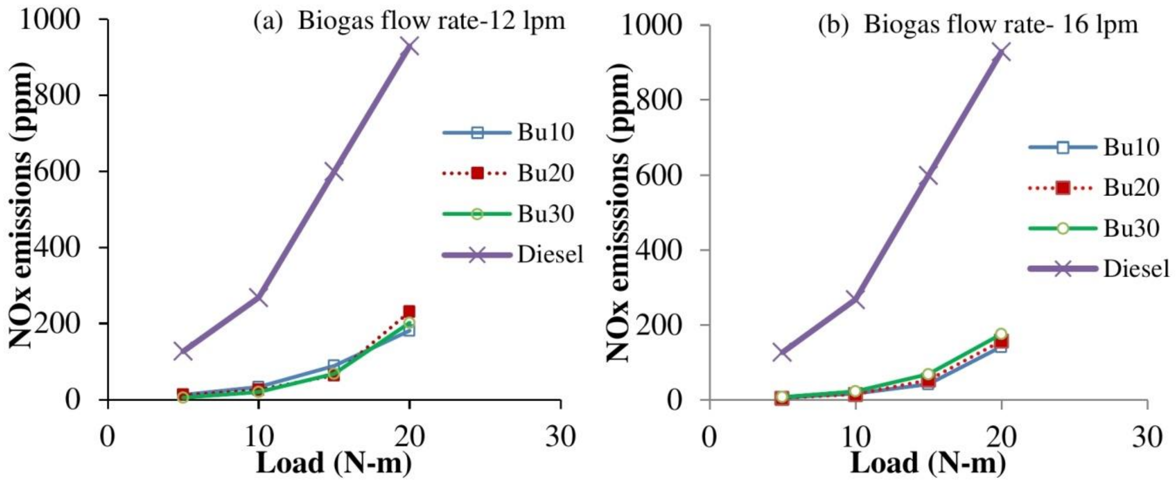

Fig. 6. Effect of butanol blend ratio on NOx emission

Nitrogen oxide (NO_x) is a chemical compound of oxygen and nitrogen bonds that are formed during the combustion stage due to high temperature inside the cylinder. NOx concentration increases with increase in load for 12 and 16 lpm flow rates as shown in Fig. 6. This is due to the higher combustion temperature and higher degree of fuel blending. The maximum NOx values found from the present experiments are 181, 231, 202 ppm for Bu10, Bu20, Bu30 respectively at 12 lpm of biogas. And 142, 157, 176 ppm for Bu10, Bu20, Bu30 respectively at 16 lpm of biogas. Diesel-only mode produces more NO_x emissions than biogas, due to high combustion temperature. Bu10 has the lowest NOx emissions in both 12 and 16 lpm flow rates. Mixing butanol to biodiesel increases NO_x emissions and there will be a promotion in NO_x as the concentration of the butanol rises. Butanol increases the amount of oxygen content and decreases the cetane number of fuel blends. Additionally, biogas is found to reduce the secondary fuel consumption and also a reduction in NO_x emission is observed.

4. Conclusion

The present experiments are conducted to discover the effects of 10%, 20% and 30% of butanol in biodiesel on performance and emission characteristics by varying loads and biogas flow rates in dual fuel mode. The butanol addition to the biodiesel slightly increases the pile of emission produced. Based on the results we can conclude that 12 lpm biogas flow rate is more efficient than 16 lpm biogas flow rate. In emissions, Bu10 releases less concentration of harmful gases within butanol blends, and this fuel produces very less NOx compared to diesel. CO emissions are lower in butanol blends than in diesel at higher loads of engine. Similarly, Bu30 shows efficient results in performance characteristics within butanol blends. In performances, both diesel and butanol blends show similar results at a higher load (20 N-m). However, alternative fuels with various ratios needed to be explored to achieve optimized performance, combustion and emissions in dual fuel modes.

References

[1] Sharma, A., Ansari, N. A., Pal, A., Singh, Y., & Lalhriatpuia, S. (2019). *Renewable Energy*, **141**, 657–668.

[2] Khayum, N., Anbarasu, S., & Murugan, S. (2020). *Fuel*, **262**, 116505.
[3] Dhanasekaran, C., & Mohankumar, G. (2016). *International Journal of Hydrogen Energy*, ***41*(1)**, 713–721.
[4] Bora, B. J., Saha, U. K., Chatterjee, S., & Veer, V. (2014). *Energy Conversion and Management*, **87**, 1000–1009
[5] Feroskhan, M., & Ismail, S. (2017). *Biofuels*, **11(4)**, 441–449.
[6] da Costa, R. B. R., Valle, R. M., Hernández, J. J., Malaquias, A. C. T., Coronado, C. J. R. & Pujatti, F. J. P. (2020). *Applied Energy*, **261**, 114438.
[7] Zheng, Z., Xia, M., Liu, H., Shang, R., Ma, G., & Yao, M. (2018). *Fuel,* **226***,* 240–251.
[8] Kassa, M., Hall, C., Ickes, A., & Wallner, T. (2016. *International Journal of Engine Research*,**18(8)**, 797–809.
[9] Yoon, S. H., & Lee, C. S. (2011). *Fuel Processing Technology*, **92(5)**, 992–1000
[10] Goga, G., Chauhan, B. S., Mahla, S. K., Dhir, A., & Cho, H. M. (2019). *Journal of Thermal Analysis and Calorimetry*, **140(6)**, 2817–2830.
[11] Huynh, T. T., Le, M. D., & Duong, D. N. (2019). *International Journal of Energy and Environmental Engineering*, **10(4)**, 483–492.
[12] Deheri, C., Acharya, S. K., Thatoi, D. N., & Mohanty, A. P. (2020). *Fuel*, **260**, 116337.
[13] Rl, C. S. T. K. (2015, October 17). *OMICS International. Oil Gas Res* **1**: 101. doi:10.4172/2472-0518.1000101
[14] Elfasakhany, A. (2014). *Energy Conversion and Management*, **88**, 277–283.
[15] Han, X., Zheng, M., and Wang, J. Fuel **109** (2013) 336-349, DOI:10.1016/j.fuel.2013.01.049
[16] N.N. Mustafi, R.R. Raine, S. Verhelst. Fuel **109** (2013) 669–678.
[17] Feroskhan M., Ismail S., Gosavi, Tankhiwale P. and Khan Y. (2019). *Proc. Inst. Mech. Eng. D* **233(5)** 1178-1193