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Emission characteristics of diesel engine fuelled with biogas and *n*-propanol-biodiesel-diesel blend under dual fuel mode

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Abstract : Experimental work focuses on utilizing *n*-propanol-biodiesel-diesel blend as pilot fuel for biogas operated dual fuel diesel engine. The engine performance and emissions characteristics of dual fuel mode were analysed and compared with conventional diesel fuel. It is inferred from the test results that NO_x-smoke opacity emission were drastically reduced under dual fuel mode as compared to diesel. The higher HC emission level was noticed with biogas-diesel under dual fuel mode as compared to diesel operation. The utilization of oxygenated additives such as *n*-propanol and biodiesel improves the emissions characteristics from diesel engine. However, BTE were found to be lower under dual fuel mode as compared to diesel mode.
Keywords : Biogas; HC; dual fuel; NO_x; CI engine; emission.

1. Introduction

Diesel engines are widely used in transportation, agricultural appliances and construction machines owing to their high fuel efficiency and durability. However, the $NO_x$and smoke emissions are the main exhaust emissions of diesel engines and there is a trade-off relationship between them [1-3].Stringent environmental policies, reduction in underground fossil fuel, escalating prices and increased demand for energy have triggered interest in more advanced and novel combustion technologies that use renewable and alternative fuels as energy sources. There is continuous pressure on emission control through periodically tightened regulations throughout the world. In this situation, there is an urgent need to promote use of alternative fuels as substitutes for diesel engine [2-4].

Biogas run dual fuel diesel engines can be a panacea to the problem of acute power shortage particularly in rural areas in India. As is known to all, conventional diesel engine owns the benefit of much higher thermal efficiency than SI engine at the expense of high NO_x and soot emissions. Hence, the utilization of biomass fuel in CI engines will improve the emissions and maintain high efficiency, which will promote the application of biomass fuel [3-5].Moreover,gaseous fuels are considered good for internal combustion engines, because of their good mixing characteristics with air. The high self-ignition temperature enables them to operate with lean mixtures and higher compression ratios, resulting in an improvement in the thermal efficiency and reduction in emissions. Biogas is a good renewable gaseous fuel, and is produced by the anaerobic digestion of cow dung, non-edible seed cakes, animal waste, food waste, agricultural waste, municipal waste, sewage sludge etc [6-8].

Numerous research work on experimental and theoretical investigations concerning the dual fuel diesel-natural gas operating mode have been reported over the last decades but a very few work has been reported with biogas as primary fuel. Porpatham *et al.*[9,10] investigated the effect of methane concentration in biogas based on a SI engine and found that with rising volume percent of methane, HC emissions decreased significantly while NO_x emissions maintained almost fixed. Thermal efficiency also increased while the ignition timing was needed to be postponed as a strategy to control the cyclic variation.

Propanol is a potential fuel additive for use in diesel engines and posses several advantages such as higher cetane number, high calorific value, lower heat of vaporization and better miscibility with diesel [14]. To achieve favorable conditions for ignition, *n*-propanol requires fewer heat and lower intake air temperature because it has low heat of vaporization. Moreover, its blends with biodiesel are to improve solubility and reduce viscosity to aid flowability [15]. Overall, *n*-propanol has physical properties close to diesel thus, *n*-propanol is an important additive or alternative fuel for use in CI engines [ ].

From the open literature, it was found that none of the research study has been done on utilizing *n*-propanol/biodiesel-diesel blend combination as pilot fuel for biogas operated diesel engine. The author's first time reported the utilization of *n*-propanol/biodiesel-diesel as potential pilot fuel for biogas operated dual fuel engine. Finally, the results obtained from the dual fuel operation were compared with those of diesel operation and presented in this paper.

2. Materials and Methods

The low sulphur diesel fuel was procured from the local retail petrol pump of Indian oil Corporation Limited. All the required chemicals such as methanol (Merck, 99.5%), *n*-propanol (Merck, 98%) and potassium hydroxide (KOH) of analytical grade were purchased from Lobachemie Pvt. Ltd. India. Biodiesel from waste cooking oil were produced by transesterification reaction. For transesterification, 1 litre of waste cooking oil was heated to65 ^oC in a round bottom flask. Catalyst (NaOH-0.5% w/w_{oil}) was dissolved in methyl alcohol(270 ml), and this was poured into the round bottom flask containing the heated waste cooking oil while stirring the mixture continuously for 1 h in a biodiesel reactor.

A temperature of 55 ± 1 ^oC was maintained for 1 h, and the reaction products were allowed to settle under gravity for 6 h in a separating funnel. The products of the transesterification process, i.e. waste cooking oil methyl ester (biodiesel) and glycerol form the upper and lower layers, respectively. The bottom layer of glycerol was removed, and the upper layer of biodiesel was mixed with warm distilled water (10% v/v) in order to remove the impurities like unreacted methanol, unreacted oil and catalyst. The mixture was again allowed to settle under gravity for 6 h, and the lower layer of water containing impurities was drained out.

The physio-chemical properties of the tested fuels were analyzed as per international ASTM specifications given in Table 1. The pilot fuel blends consisting of combination of waste cooking oil biodiesel-diesel/*n*-propanol were denoted as D80–B10–P10 and D60–B20–P20 on volume basis. The pilot fuel blends were obtained by mixing on magnetic stirrer to ensure homogeneity of fuel blends. The biogas was procured from the School of Energy and Environment, Thapar University, Patiala. The biogas composition is shown in Table 2 and the test engine specifications are shown in Table 3.

Table 1 Fuel Properties

Properties	Diesel	Test Method	Biogas	Test Method	WCO Biodiesel	Test Method
Chemical composition	$C_{12}H_{26}$	———	60% CH_4, 40% CO_2 (volume)	———	RCO_2R'	ASTM D 5291
Density (kg/m^3)	840	ASTM D 4052	1.1	ASTM D 3588	922	ASTM D 1298
Lower calorific value (MJ/kg)	42	ASTM D 4809	20.67	ASTM D 1945	40.3	ASTM D 3338
Cetane number	45-55	ASTM D 613	———	ASTM D 2699	63.8	ASTM D 613
Auto-ignition temperature (K)	553	ASTM D 93	1086	ASTM E 659	———	———
Stoichiometric air fuel ratio	14.92	———	10	ASTM D 4891	13.8	———

Table 2 Composition of biogas

Components	**Amount (%)**
Methane (CH_4)	50-70
Carbon Dioxide (CO_2)	30-40
Hydrogen (H_2)	5-10
Nitrogen (N_2)	1-2
Water Vapour (H_2O)	0.3
Hydrogen Sulphide (H_2S)	Traces

Table 3 Technical specifications of the test engine

Engine parameter	**Specification**
Engine model	FCD Ltd.
Number of cylinders	1
Cylinder bore/stroke	102/110 mm
Displacement volume	898.84 cc
Compression ratio	17.5 : 1
Maximum power	6 kW
Rated speed	1500 rpm
Fuel injection pressure	210 bars
Fuel injection system	Direct injection
Cooling system	Forced air cooled

3. Results and Discussion

The following section illustrated the results of performance and emission characteristics of the diesel engine fuelled with the biogas and n-propanol-biodiesel-diesel blend as pilot fuel under different load conditions. The effects of pilot fuel blend were analysed on the basis of performance and emission characteristics at different engine operating loads at constant speed of 1500 rpm.

3.1. Brake thermal efficiency (BTE)

It was observed that the BTE under different biogas-diesel dual fuel mode of operation with both pilot fuels was lower than conventional diesel fuel. The poor gaseous fuel utilization was due to a very lean fuel-air mixture, which maintains low combustion chamber temperature [36]. The longer ignition delay and low combustion temperature close to the point of fuel injection results in slower flame propagation [37]. This can be explained by the presence of biogas residuals, higher fuel consumption and low combustion chamber temperature.At full load the BTE of dual fuel mode with P10B10D80 and P20B20D60 were 23.4% and 22.4% when compared to diesel fuel (26.4%) and B20 (25.5%).

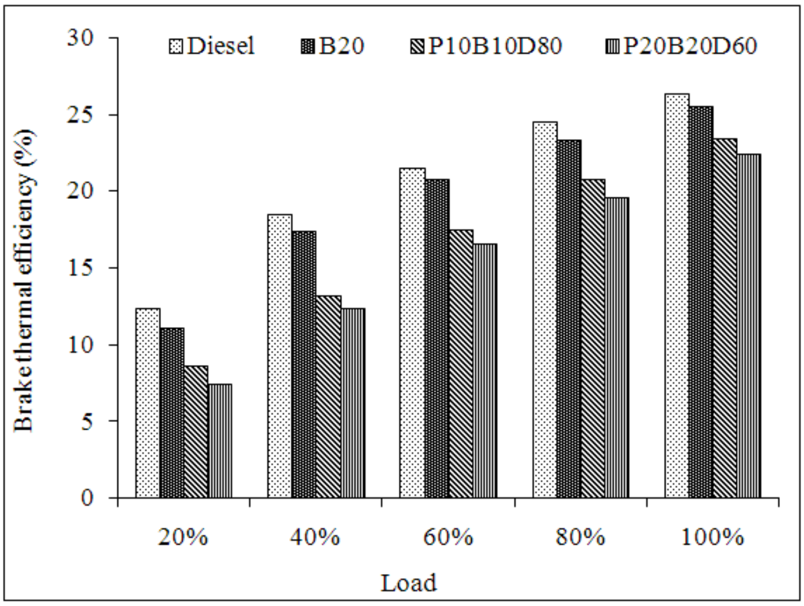

Figure 1 Variation of brake thermal efficiency with engine load

3.2. Oxides of Nitrogen (NO_x)

The NO_x concentration under biogas fuelled dual fuel engine is lower than diesel mode. With increasing *n*-propanol concentration, the NO_x formation slightly increases at all engine load conditions. This can be attributed to the increase in level of oxygen content of the *n*-propanol-biodiesel blended fuel. In the biogas fuelled dual fuel operation the presence of inert gases such as CO_2, having higher specific heat dilutes the cylinder charge and significantly reducing the peak combustion temperature and oxygen availability [39,40]. The presence of oxygen content in the biodiesel fuel plays a vital role in increasing NO_x emission from biodiesel operated diesel engine [42].

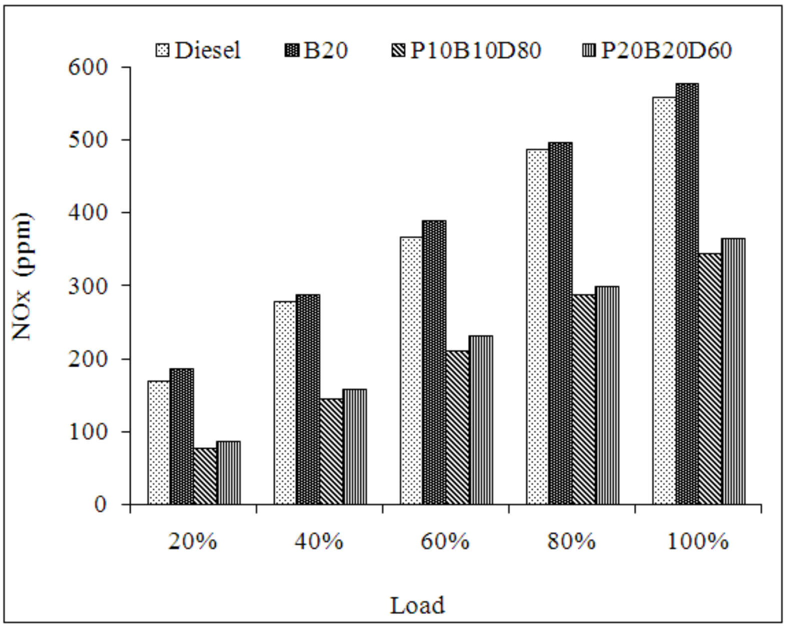

Figure 2 Variation of NO_xemissionwith engine load

3.3. Smoke opacity

It is revealed from the Figure 4 that biogas fuelled diesel engine gives lower smoke emissions due to reduction in flame temperature because of the available CO_2 in biogas[43]. Another reason may be the presence of methane in biogas, as the main constituent, i.e. the lower member of the paraffin family and have a very small tendency to produce soot [44,45]. The addition of *n*-propanol in the pilot fuel blend under biogas fuelled dual fuel engine is very effective in controlling smoke opacity in the engine exhaust. The most significant feature is that with increasing *n*-propanol concentration, the smoke opacity decreases at all engine loads. The smoke is mainly associated with burning of pilot liquid fuel. The reduction of smoke opacity with biogas fuelling is mainly caused by reduced soot formation and enhanced soot oxidation [46]. The presence of oxygen content in *n*-propanol and biodiesel blended fuel plays vital role in enhanced oxidation of the fuel.

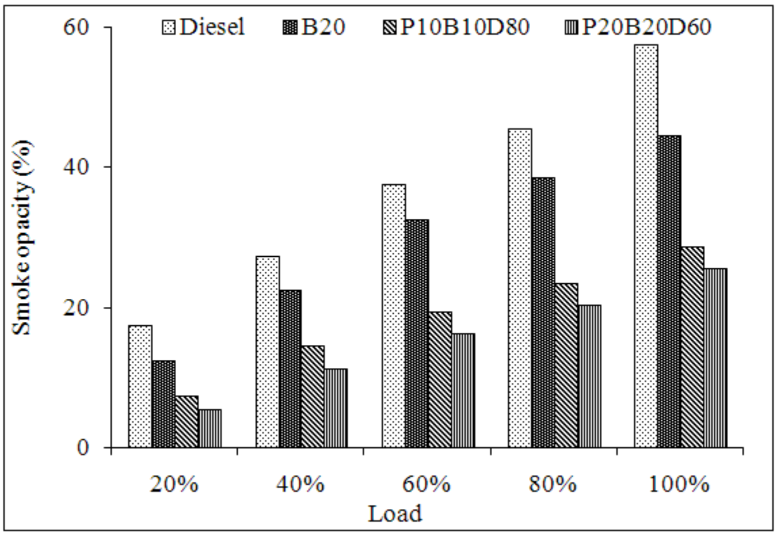

Figure 3 Variation of smoke opacity emission with engine load

3.3. Hydrocarbon (HC)

The biogas fuelled dual fuel mode of operation with both pilot fuels was higher than diesel fuel at all loads. At low to intermediate load condition, the higher hydrocarbon emissions in the dual fuel mode are due to the very lean premixed charge, lower combustion temperate and slower flame propagation leads to the higher amount of hydrocarbons emitted in exhaust [49].At higher loads, due to higher combustion chamber temperature, more complete oxidation takes place which subsequently reduces the level of hydrocarbon emission than lower loads under dual fuel mode [50]. The addition of *n*-propanol concentration helps in improving the enhanced oxidation of fuel under dual fuel mode.

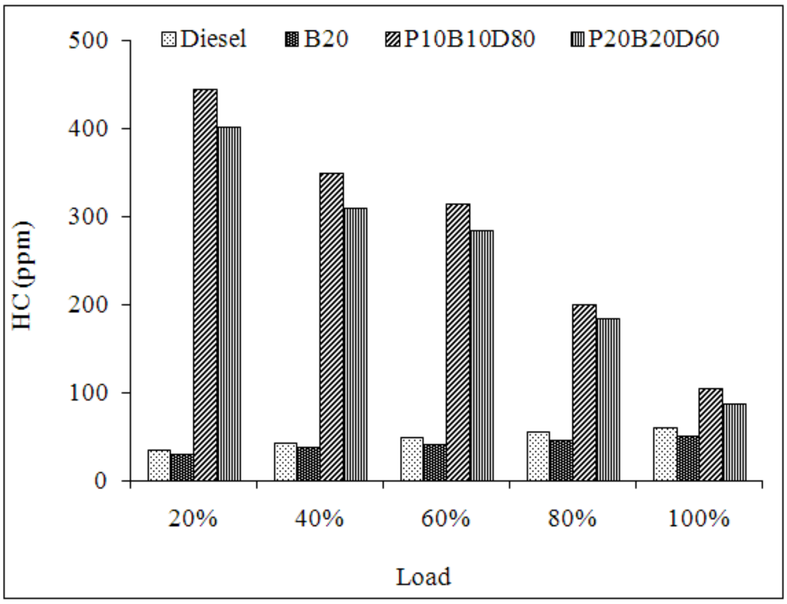

Figure 4 Variation of HCemissionwith engine load

4. Conclusions

The present experimental investigation explores and highlights the potential of *n*-propanol-biodiesel blend as pilot fuel for biogas dual fuel diesel engine. The oxygenated feature of n-propanol and biodiesel improves the emission characteristics by drastically reducing the well known trade-off of NO_x-smoke opacity from biogas dual fuel diesel engine. The brake thermal efficiency was lower under dual fuel mode as compared to diesel at all engine load patterns. The emission of unburned hydrocarbon is higher under biogas dual fuel mode as compared to diesel. Hence, the usage of n-propanol-biodiesel-diesel blend as pilot fuel under biogas dual fuel operation is a promising alternative fuel for diesel engine in terms of performance and emissions characteristics.

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References

1. Liu, J.; Yao, A.; Yao, C. Effects of diesel injection pressure on the performance and emissions of a HD common-rail diesel engine fueled with diesel/methanol dual fuel. *Fuel*2015, *140*, 192-200.
2. Jindal, M.; Rosha, P.; Mahla, S.K.; Dhir. A. Experimental investigation of performance and emissions characteristics of waste cooking oil biodiesel and propanol blends in a compression ignition engine. *RSC Adv*. 2015, *5*, 33863-33868.
3. Chandra, R.; Vijay, V.K.; Subbarao, P.M.V.; Khura, T.K. Production of methane from anaerobic digestion of Jatropha and Pongamia oil cakes.*Appl. Energy* 2012, *93*, 148-159.
4. Hashizume, T.; Miyamoto, T.; Akagawa, H.; Tsujimura, K. Emission characteristics of a MULDIC combustion diesel engine: effects of EGR.*JSAE Rev.* 1999, *20*, 428-430.
5. Jingura, R.M.; Matengaifa, R. Optimization of biogas production by anaerobic digestion for sustainable energy development in Zimbabwe.*Renew Sustain Energy Rev.* 2009, *13*, 1116-1120.
6. Karim, G.A. Combustion in gas fueled compression: ignition engines of the dual fuel type. *J. Eng. Gas Turbines Power* 2003, *125,* 827-836.
7. Namasivayam, A.M.; Korakianitis, T.; Crookes, R.J.; Bob-Manuel, K.D.H.; Olsen, J. Biodiesel, emulsified biodiesel and dimethyl ether as pilot fuels for natural gas fuelled engines. *Applied Energy* 2010, *87,* 769-778.
8. Bob-Manuel, K.D.H.; Crookes, R.J.; Olsen, J. Renewable fuelling of a diesel engine in single and dual fuel operation. In: TechnischeAkademie Esslingen (TAE) 6th international colloquium fuels. 10 and 11 January 2007.
9. Porpatham, E.; Ramesh, A.; Nagalingam, B. Investigation on the effect of concentration of methane in biogas when used as a fuel for a spark ignition engine.*Fuel*2008, *87,*1651.
10. Bora, J.; Bhaskor; Saha, K. U. Comparative assessment of a biogas run dual fuel diesel engine with rice bran oil methyl ester, pongamia oil methyl ester and palm oil methyl ester as pilot fuels. *Renew. Energy* 2015, *81,* 490-498.
11. Barik, D.; Murugan, S. Investigation on combustion performance and emission characteristics of a DI (direct injection) diesel engine fueled with biogas-diesel in dual fuel mode. *Energy* 2014, *72,* 760-771.
12. Mustafi, N.N.; Raine, R.R.; Verhelst, S. Combustion and emissions characteristics of a dual fuel engine operated on alternative gaseous fuels. *Fuel* 2013, *109*, 669-678.
13. Lu, X.C.; Yang, J.G.; Zhang, W.G.; Huang, Z. Effect of cetane number improver on heat release rate and emissions of high speed diesel engine fueled with ethanol–diesel blend fuel. *Fuel*2004, *83,* 2013-2020.
14. B. Rajesh Kumar, T. Muthukkumar, V. Krishnamoorthy and S. Saravanan. A comparative evaluation and optimization of performance and emission characteristics of a DI diesel engine fueled with *n*-

propanol/diesel, *n*-butanol/ diesel and *n*-pentanol/diesel blends using response surface methodology. RSC Adv. 2016, 6, 61869.

15. Thomas Walther, Jean Marie François. Microbial production of propanol.Biotechnology Advances 2016, 34: 984-996.
16. Sahoo, B.B.; Sahoo, N.; Saha, U.K. Effect of engine parameters and type of gaseous fuel on the performance of dual-fuel gas diesel engines– a critical review. *Renew Sustain Energy Rev.* 2009, *13*, 1151-1184.
17. Papagiannakis, R.G.; Hountalas, D.T. Combustion and exhaust emission characteristics of a dual fuel compression ignition engine operated with pilot Diesel fuel and natural gas. *Energy Convers Manage* 2004, *45*, 2971-2987.
18. Imran, S.; Emberson, D.R.; Diez, A.; Wen, D.S.; Crookes, R.J.; Korakianitis, T. Natural gas fueled compression ignition engine performance and emissions maps with diesel and RME pilot fuel. *Appl. Energy* 2014, *124*, 354-365.
19. Liu, J.; Yang, F.; Wang, H.; Ouyang, M.; Hao, S. Effects of pilot fuel quantity on the emissions characteristics of a CNG/diesel dual fuel engine with optimized pilot injection timing. *Appl. Energy* 2013, *110*, 201-206.
20. Graves, B.; Patychuk, B.; Dastanpour, R.; Rogak, S. Characterization on particulate matter morphology and volatility from a compression-ignition natural-gas direct-injection engine.*Aerosol Sci. Technol.* 2015, *49*, 589-598.
21. Porpatham, E.; Ramesh, A.; Nagalingam, B. Effect of compression ratio on the performance and combustion of a biogas fuelled spark ignition engine.*Energy Convers Manage* 2012, *95*, 247-256.
22. Banapurmath, N.R.; Tewari, P.G.; Hosmath, R.S. Combustion and emission characteristics of a direct injection, compression-ignition operated on Hongeoil, HOME and blends of HOME and diesel. *Internat. J. Sustainable Engineering* 2008, *1*, 80-93.
23. Bagi, Z.; Acs, N.; Balint, B.; Hovrath, L.; Dobo, K.; Perei, K.R., Rakhely, G.; Kovacs, K.L. Biotechnological intensification of biogas production.*Appl. Microbiol. Biotechnol.*2007, *76*, 473-482.
24. Nijaguna, B.T. Biogas Technology. New Age International Publishers.2006.
25. Weiland, P. Biogas production: current state and perspectives.*Appl. Microbiol. Biotechnol.*2010, *85*, 849-860.
26. Sahoo, B.B. Clean development mechanism potential of compression ignition diesel engines using gaseous fuel in dual fuel mode (Ph.D thesis), Centre for Energy, IIT Guwahati, India, 2011.
27. Bedoya, I.D.; Arrieta, A.A.; Cadavid, F.J. Effects of mixing system and pilot fuel quality on diesel and biogas dual fuel engine performance.*Bioresour.Technol.* 2009, *100*, 6624-6629.
28. Palash, S.M.; Masjuki, H.H.; Kalam, M.A.; Atabani, A.E.; Fattah, I.R.; Sanjid, A. Biodiesel production, characterization, diesel engine performance, and emission characteristics of methyl esters from aphanamixispolystachya oil of bangladesh. *Energy Convers.Manag.*2015, *91*, 149-157.
29. Obed, A.M.; Rizalman, M,; Gholamhassan, N.; Yusaf, T.; Ardebili, S.M.S. Optimization of biodiesel-diesel blended fuel properties and engine performance with ether additive using statistical analysis and response surface methods. *Energies*2015, *8*, 14136-14150.
30. Zhu, L.; Cheung, C.S.; Zhang, W.G.; Huang, Z. Combustion, performance and emission characteristics of a DI diesel engine fueled with ethanol-biodiesel blends. *Fuel*2011, *90*, 1743-1750.
31. Papagiannakis, R.G.; Hountalas, D.T.; Rakopoulos, C.D. Theoretical study of the effects of pilot fuel quantity and its injection timing on the performance and emissions of a dual fuel diesel engine. *EnergyConversManage*2007, *48*, 2951-2961.
32. Kyunghyun, R. Effects of pilot injection pressure on the combustion and emissions characteristics in a diesel engine using biodiesel-CNG dual fuel.*E0nergyConversManage*2013, *76*, 506-516.
33. Barik, D.; Murugan, S. Simultaneous reduction of NO_x and smoke in a dual fuel DI diesel engine.*Energy Convers Manage* 2014, *84*, 217-226.
34. Papagiannakis, R.G.; Rakopoulos, C.D.; Hountalas, D.T.; Rakopoulos, D.C. Emission characteristics of high speed, dual fuel, compression ignition engine operating in a wide range of natural gas/diesel fuel proportions. *Fuel*2010, *89*, 1397-1406.
35. Hyun, Y.S.; Sik, L.C. Experimental investigation on the combustion and exhaust emission characteristics of biogas-biodiesel dual fuel combustion in a CI engine.*FuelProcessTechnol.*2011, *92*, 992-1000.
36. Prakash, R.; Singh, R.K.; Murugan, S. Experimental investigation on a diesel engine fueled with bio-oil derived from waste wood-biodiesel emulsions. *Energy*2013, *55*, 610-618.

37. Pullen, J.; Saeed, K. Factors affecting biodiesel engine performance and exhaust emissions Part I: Review. *Energy*2014, *72*, 1-16.
38. Xue, J.; Grift, T.E.; Hansen, A.C. Effect of biodiesel on engine performances and emissions. *Renew. Sustain. EnergyRev*. 2011, 15, 1098-1116.
39. Bora, B.J.; Debnath, B.K.; Gupta, N.; Sahoo, N.; Saha, U.K. Investigation on the flow behaviour of a venturi type gas mixer designed for dual fuel diesel engines. *Int. J. Emerg. Technol. Adv. Eng*. 2013, *3*, 202-209.
40. Debnath, B.K.; Sahoo, N.; Saha, U.K. Adjusting the operating characteristics to improve the performance of an emulsified palm oil methyl ester run diesel engine. *EnergyConvers.Manag*.2013, *69*, 191-198.
41. Gnanamoorthi, V.; Devaradjane, G. Effect of compression ratio on the performance, combustion and emission of DI diesel engine fueled with ethanol diesel blend. *J. EnergyInst*. 2015, *88*, 19-26.
42. Duc, P.M.; Wattanavichien, K. Study on biogas premixed charge diesel dual fuelled engine.*EnergyConvers.Manag*.2007, *48*, 2286-2308.
43. Cheng-qiu, J.; Tian-wei, L.; Jian-li, Z.A study on compressed biogas and its application to the compression ignition dual-fuel engine.*Biomass*, 1989,*20*, 53-59.
44. Bari, S. Effect of carbon dioxide on the performance of biogas/diesel dual-fuel engine. *Renew. Energy*1996, *9*, 1007-1010.
45. Wu, H.W.; Wang, R.H.; Chen, Y.C.; Ou, D.J.; Chen, T.Y. Influence of port-inducted ethanol or gasoline on combustion and emission of a closed cycle diesel engine. *Energy*2014, *64*, 259-267.
46. Al-Dawody, M.F.; Bhatti, S.K. Optimization strategies to reduce the biodiesel NO_x effect in diesel engine with experimental verification. *EnergyConversManage*2013, *68*, 96-104.
47. Chandra, R.; Vijay, V.K.; Subbarao, P.M.V.; Khura, T.K. Performance evaluation of a constant speed IC engine on CNG methane enriched biogas and biogas. *Appl.Energy*2011, *88*, 3969-3977.
48. Lounici, M.S.; Loubar, K.; Tarabet, L.; Balistrou, M.; Niculescu, D.C.; Tazerout, M. Towards improvement of natural gas-diesel dual fuel mode: an experimental investigation on performance and exhaust emissions. *Energy*2014, *64*, 200-211.
49. Papagiannakis, R.G.; Hountalas, D.T. Combustion and exhaust emission characteristics of a dual fuel compression ignition engine operated with pilot diesel fuel and natural gas. *EnergyConversManage*2004, *45*, 2971-2987.

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