International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-9 Issue-1, October, 2019

The Effect of Nozzle-Opening Pressure on the Performance and Emission Parameters of a Diesel Engine Operated on Aphanizomenonflos Biodiesel-Titanium Dioxide (TiO_2) Nanofluid-Diesel Blend

G.Jayabalaji, P.Shanmughasundaram

Abstract**: *In the present investigation, titanium dioxide (TiO_2) nano-fluid (5%, 10%, and 15%) was blended with AphanizomenonFlos (AF) biodiesel (20%)-diesel (80%) blend. Among all blends, AFD-10TiO_2 blend was optimum, as per the authors earlier investigation. Hence, to find the optimum operating parameter of AFD-10TiO_2, the nozzle opening pressure of the existing diesel engine was varied in the range of 160 bar to 220 bar in steps of 20 bar. AFD-10TiO_2/200 gave optimized results compared to other test fuels. BSFC forAFD-10TiO_2/200 decreased with an increase in injection pressure of AFD-10TiO_2.The BTE of the engine increased about 1.5% to 5.5% more than in the case of diesel, and AF-D blend respectively. The tailpipe emissions for AFD-10TiO_2/200such as CO, HC, smoke reduced by about 16%, 12%, and 18% respectively. The NO_x emission forAFD-10TiO_2/200increased by about 14% more than that for diesel.***

Keywords* : *Diesel engine; Biodiesel; AphanizomenonFlos Biodiesel; Titanium Dioxide; Nano-fluid

I. INTRODUCTION

The need of non-edible biodiesel has significantly increased in developing countries as a substitute to mineral diesel. When the true potential, and the clean emission of liquid fuel derived from the non-edible, feedstock-based biodiesel was realized,the battle against feedstock scarcity also came to an end as researchers from various corners explored the use of biodiesel prepared from various indigenous feed stocks in diesel engines to reduce the pressure on a specific feedstock such as Jatropha and Karanja especially in India. In this regard, research on biodiesel from algae is a potential choice. There are many algae species available for the production of biodiesel. Among them, Aphanizomenon Flos (AF) is a prime choice, because it has the highest growth rate, contains more amount of lipid, and needs a low cost culture medium. This AF species can sustain extreme salinity condition and pH to survive. Algae-based biofuels, considered greener, help in waste management and do not have a negative impact on the food supply as they are derived from sources, which are not used by humans.

The addition of nano-particles in the biodiesel-diesel blend can decrease the delay in ignition, and may increase the evaporation of the fuel, when injected into the cylinder combustion chamber. Among nano particles titanium dioxide (TiO_2) is better, because this oxygen buffer for aphanizomenonflos (AF) biodiesel during the combustion stage. Keskin*et al*. [1] dopped Mn and Mo nano metal oxides with diesel, and they observed an increase in flash point and fire point. They also reported that, 37% reduction of CO and 4% reduction of NO. Another researcher Khond and Kriplani [2] reported that, titanium dioxide in biodiesel blend could reduce the emission and increase the performance of diesel engines.Sadhik Basha [3] reconnoitered the effect of using alumina nano particles with biodiesel-water emulsion and reported about 22% decrease in CO and 16% decrease in HC emission. Another research group Yang *et al.* [4] used nano-organic additives in biodiesel and reported a drastic decrease in NO, CO, and smoke emission. Researchers Balaji *et al.*[5] investigated the use of zinc oxide nano-fluid in Karanja biodiesel and used the blend in a single cylinder diesel engine and observed a reduction of all emission parameters except NO. Also, their investigation reported an increase in BTE of the engine in all the operating load conditions. The use of AF biodiesel with $T_iO_2$nano-fluid could give added advantage in performance and emission, if the existing diesel-operated engine was modified according to the AF biodiesel-TiO_2nano-fluid-diesel blends behavior because, diesel engines were generally fashioned to operate best on diesel. In this regard, the optimization of injection pressure was a righteous choice, because the influence of TiO_2nano particles on the injector nozzle might lead to poor spray formation, and incomplete mixing of fuel and air, which might decrease the efficiency, increase the fuel consumption, and increase the tail pipe emissions. Yesilyurt [6] experimentally investigated the effect of fuel injection pressure in the range of 170-220 bars on diesel engine fueled by waste cooking oil biodiesel. He suggested that, fuel injection pressure up to 210 bar would give an increase in BTE and engine torque.

Revised Manuscript Received on October 30, 2019.
* Correspondence Author
G.Jayabalaji*, Department of Mechanical Engineering, Karpagam Academy of Higher Education, Coimbatore - 641021, India.
Email: Jayabalaji91@gmail.com
P.Shanmughasundaram, Department of Automobile Engineering, Karpagam Academy of Higher Education, Coimbatore - 641021, India.
Email: sunramlec@rediffmail.com

Also, he documented that an increase in injection pressure led to decrease in the emission of CO, HC and smoke. Agarwal*et al.* [7] reported that the increase in injection pressure for biodiesel operation led to an increase of BTE. Another research group Gumus*et al.* [8] reported that, NO emission decreased with an increase in injection pressure, but this was not significant in all experiments. Kuti*et al.* [9] experimentally investigated the spray characteristics of the engine operated with Palm biodiesel with different injection pressure. They observed that, the BTE of the engine increased with drop in BSFC, CO, HC, and smoke emissions. Similarly, Suh and Lee [10] optimized the fuel injection pressure of the engine operated with 5% soybean biodiesel in a common rail diesel engine. They documented that, with the increase in injection pressure, the combustion quality of the fuel increased and decreased the emission of CO, HC, smoke respectively. But, the NO emission and BTE of the engine increased.

In the present investigation, titanium dioxide (TiO_2) nano-fluid was blended with Aphanizomenon Flos (AF) biodiesel (20%)-diesel (80%) blend. AFD-TiO_2 blends were prepared, and investigated. Among all blends AFD-10TiO_2 was optimum. The nozzle-opening pressure of the existing diesel engine varied in the range of 160 bar to 220 bar in steps of 20 bar, to find the optimum operating parameter of AFD-10TiO_2. The results of AFD-10TiO_2 with different injection pressure were investigated and documented.

II. METHODS AND MATERIALS

2.1 Fuel Preparation

The fuels and additives used in the analysis were diesel, Aphanizomenon Flos (AF) biodiesel, and titanium dioxide (TiO_2) nano-particles. The AF biodiesel and TiO_2nano-particles were purchased from the local chemical trader and mixed in the author's laboratory to prepare the blends. The physicochemical properties of diesel, AF biodiesel, and AFD-10TiO_2 blend are provided in Table 1. The properties of TiO_2 are given in Table 2.

Table 1 Properties of diesel, and AFD-10TiO_2.

Properties	Test method, ASTM	Diesel	AF biodiesel	AFD-10TiO_2
Density, kg/m^3	-	831	835	831.4
LHV, MJ/kg	D 4809	43.6	39.8	42.7
Ignition temperature, °C	E 659	212-348	170-320	198-336
Cetane number	D 613	51	48	50.7
C, wt.%	-	85.3	65.74	76.47
H, wt.%	-	13.19	10.04	10.4
N, wt.%	-	1.21	1.11	0.4
S, wt.%	-	0.3	0.01	0.21
O, wt.%	-	-	23.1	12.52

Table 2 Properties of TiO_2.

Parameter	Property
Particle size, nm	20
Molecular weight, g/mol	82
Color	White
Type	Powder

2.2 Engine setup

The outline of the engine setup is shown in Figure 1. The specifications of the engine are provided in Table 3

Table 3 Specifications of the engine.

Make	Kirloskar, VCR
Type	1cyl., 4S, CI
Injection	Direct
Power, kW	3.7
Speed, rpm	1500
Cooling	Water
Volume, cm^3	551
Standard IP, bar	180
IT ,ºCAbTDC	23
CR	17.5

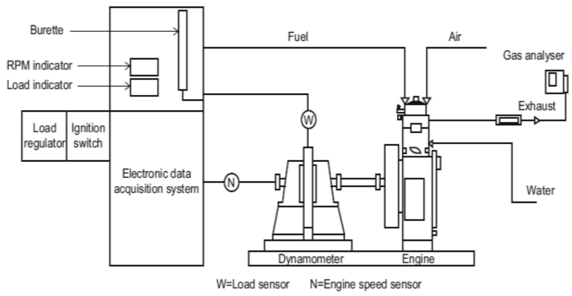

Figure 1. Experimental setup

The engine used for the current experiment is a single cylinder, water-cooled type fitted with a dynamometer. The dynamometer measures the load. The injection pressure was changed by adjusting the nozzle-opening pressure of the injector. AVL 444 gas analyzer measured the emissions. K-type temperature measurement thermocouples were installed at various locations on the engine to record the temperature of inlet water, outlet water, exhaust gas temperature and suction air temperature.

Table 4 Text matrix.

Fuel Used	Parameter			Acronym
	IT, ºCAbTDC	IP, bar	CR	
Diesel	23	180	17.5	Diesel
Aphanizomenon Flos-diesel	23	180	17.5	AF-D
AFD-10T_iO_2	23	160	17.5	AFD-10TiO_2 /160 bar

AFD-10T$_i$O$_2$	23	180	17.5	AFD-10 TiO$_2$/180 bar
AFD-10T$_i$O$_2$	23	200	17.5	AFD-10 TiO$_2$/200 bar
AFD-10T$_i$O$_2$	23	220	17.5	AFD-10 TiO$_2$/220 bar
AFD-10T$_i$O$_2$	23	220	17.5	AFD-10 TiO$_2$/220 bar

The engine was equipped with a vertical burette for measuring the consumption of fuel during every load and speed conditions. The ambient condition of temperature and pressure during the experiment was about 28 ºC and, 1 bar respectively. The experimental matrix is provided in Table 4

III. RESULTS

3.1 Performance

3.1.1 BSFC

Figure 2 shows the difference of BSFC, with load for diesel, AF-D, AFD-10 TiO$_2$/160, AFD-10TiO$_2$/180, AFD-10 TiO$_2$/200, and AFD-10TiO$_2$/220. A decreasing trend for BSFC is observed with increase in load for all fuels. This is due to the gradual increase in cylinder temperature with the rise in load. The value of BSFC, for diesel and AF-D blends is 0.276 kg/kWh and 0.291 kg/kWh respectively. The BSFC decreases for the AF-D blends with the increase in TiO$_2$ percentage. The BSFC at full load, for AFD-10TiO$_2$/160, AFD-10TiO$_2$/180, AFD-10TiO$_2$/200, and AFD-10TiO$_2$/220 are 0.284 kg/kWh, 0.273 kg/kWh, 0.256 kg/kWh, and 0.261 kg/kWh respectively. This decrease in BSFC, with the increase in injection pressure may be due to good spray droplet formation, which may give complete combustion, and decrease fuel consumption [11]. The maximum drop in BSFC is observed for the case of AFD-10TiO$_2$/200

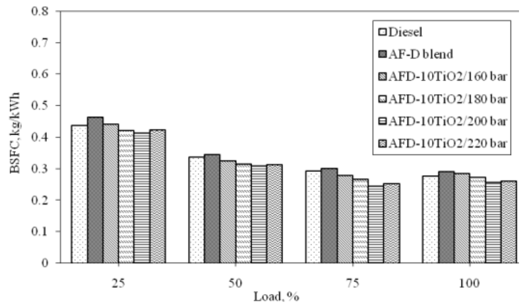

Figure 2 BSFC, with load for diesel, AF-D blend, and AFD-10TiO$_2$ blends with different injection pressure.

3.1.2 BTE

The difference of BTE, with load for diesel, AF-D, AFD-10TiO$_2$/160, AFD-10TiO$_2$/180, AFD-10TiO$_2$/200, and AFD-10TiO$_2$ /220 is shown in Figure 3. The BTE of the engine increased with the increase in injection pressure of the fuel. The BTE of diesel and AF-D is 31.3% and 26.8%respectively. The drop in BTE for AF-D is due to the lower calorific value of the AF-D blend in comparison to diesel. The BTE for AFD-10TiO$_2$ increases with increase in injection pressure. The BTE for AFD-10TiO$_2$ /160, AFD-10TiO$_2$/180, AFD-10TiO$_2$/200, and AFD-10TiO$_2$/220 is found to be 28.8%, 30.4%, 32.2%, and 31.7% respectively. This increase in BTE with the increase in injection pressure may be due to complete combustion of fuel and a good air-fuel mixture formation [12].

3.2 Emission analysis

3.2.1 CO

Figure 4 shows the deviation of CO, for diesel, AF-D blend, AFD-10TiO$_2$/160, AFD-10TiO$_2$ /180, AFD-10TiO$_2$ /200, and AFD-10TiO$_2$/220. Generally CO emission is due to the partial burning of fuel in the combustion chamber. The CO for AF-D blend is 0.013 % vol., which is much lower than that for diesel, at full load. The decrease in CO for AF-D blend is due to the existence of oxygen pockets in the fuel. The addition of TiO$_2$nano particles with AF-D blends, drastically decreases the CO emission. This may be due to the occurrence of improved combustion rate which increases the heat transfer rate of fuel during combustion owing to the catalytic activity of TiO$_2$ [13], 14] . The CO emission shows a decreasing trend with an increase in nozzle-opening pressure. The CO emission for AFD-10TiO$_2$/160, AFD-10TiO$_2$/180, AFD-10TiO$_2$/200, and AFD-10TiO$_2$/220 are 0.0127 % vol., 0.0124 % vol., 0.0119% vol., and 0.0122% vol. respectively, at full load. The decrease in CO is due to the better atomization of fuel

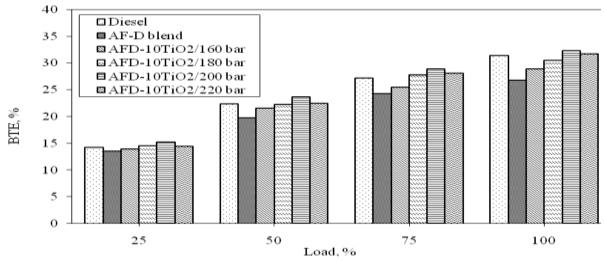

Figure 3 BTE for diesel, AF-D blend, and AFD-10TiO$_2$ blends with different injection pressure.

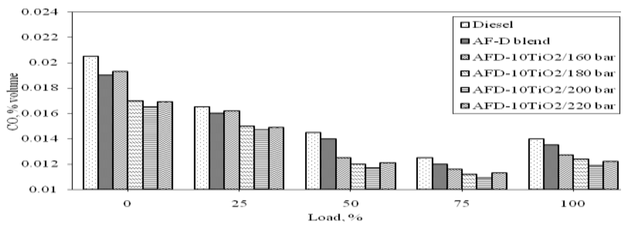

Figure 4 CO, with load for diesel, AF-D blend, and AFD-10TiO$_2$ blends with different injection pressure.

3.2.2 HC

The difference of HC, with load for diesel, AF-D, AFD-10TiO$_2$/160, AFD-10TiO$_2$/180, AFD-10TiO$_2$/200, and AFD-10TiO$_2$/220 is shown in Figure 5. HC decreases withan increase of load. This is due to high temperature combustion at high loads. HC for AF-D blend and AFD-TiO$_2$ blends are lower compared to that for diesel. This may be due to the existence of oxygen in AF biodiesel [15-16]. Another reason for lower HC formation is TiO$_2$nano particles, which shares additional oxygen molecules and improve the rate of combustion. The HC emission for AFD-10TiO$_2$ /160, AFD-10TiO$_2$/180, AFD-10TiO$_2$/200, and AFD-10TiO$_2$/220 are 5.12 ppm, 4.41 ppm, 4.11 ppm, and 4.42 ppm respectively. The decrease in HC, with higher injection pressure may be due to the reduction in wall impeachment and flame quenching [5].

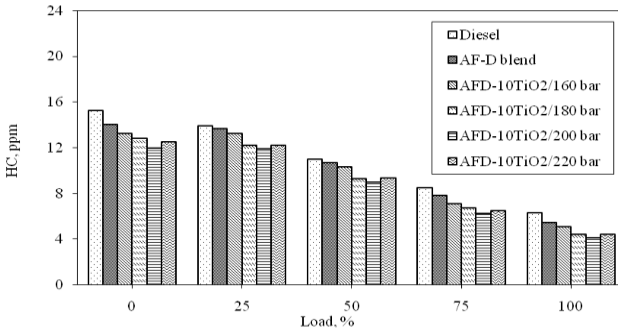

Figure 5 HC, with load for diesel, AF-D blend, and AFD-10TiO$_2$ blends with different injection pressure.

3.2.3 NO

The difference of NO, with load for diesel, AF-D, AFD-10TiO$_2$/160, AFD-10TiO$_2$/180, AFD-10TiO$_2$/200, and AFD-10TiO$_2$ /220 is shown in Figure 6.In general NO is formed due to high temperature combustion of fuel and higher availability of oxygen radicals in the fuel. The NO emission shows an increasing pattern throughout the load spectrum, irrespective of fuels tested. The increase in NO emission may be due to the rapid burning of fuel in the pre-mixed combustion phase, because of good atomization and dissolved oxygen in the fuel blend [8]. The NO emission for AFD-10TiO$_2$/160, AFD-10TiO$_2$/180, AFD-10TiO$_2$/200, and AFD-10TiO$_2$/220are 329 ppm, 340 ppm, 357 ppm, and 375 ppm respectively.

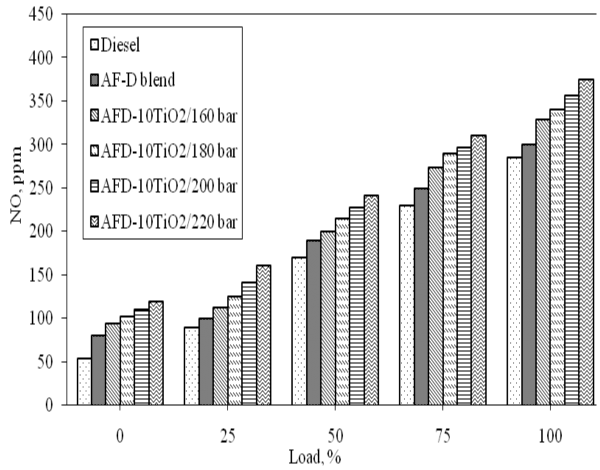

Figure 6 NO, with load for diesel, AF-D blend, and AFD-10TiO$_2$ blends with different injection pressure.

3.2.4 Smoke

The difference of smoke, for diesel, AF-D, AFD-10TiO$_2$ /160, AFD-10TiO$_2$ /180, AFD-10TiO$_2$ /200, and AFD-10TiO$_2$ /220is shown in Figure 7.Smoke emission for AF-D blend is less compared to that for diesel in every load. This is due to the buffered oxygen in the AF biodiesel. The smoke emission for AFD-10TiO$_2$ /160, AFD-10TiO$_2$ /180, AFD-10TiO$_2$ /200, and AFD-10TiO$_2$ /220blends, decreases, throughout the test load. This may be due to the formation of free radicals due to the action of TiO$_2$, and formation of short bonds between carbon and hydrogen molecules [9]. Apart from this, TiO$_2$nano-particles increase the air-fuel mixture and reduce smoke emission. Another possible reason for low smoke is improved mixture formation and formation of multiple ignition centers inside the combustion chamber.

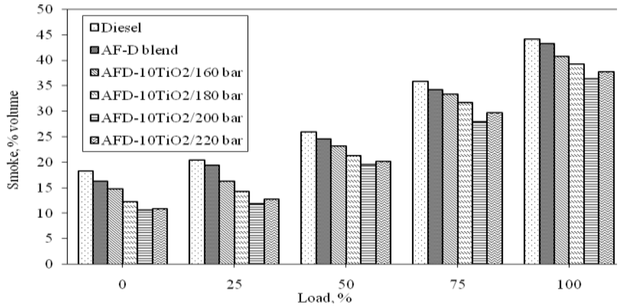

Figure 7 Smoke, with load for diesel, AF-D blend, and AFD-10TiO$_2$ blends with different injection pressure.

IV. CONCLUSIONS

This investigation revealed the effects of using blends of TiO$_2$nano-particles with variation in injection pressure from 160 bar to 220 bar in steps of 20 bar. AFD-10TiO$_2$/200 gave optimum results in terms of performance and emission. The brief conclusions of the present investigation are given s below:

- BSFC decreased withan increase in injection pressure of AFD-10TiO$_2$.
- The BTE of the engine increased by about 1.5% and 5.5% than in the case of diesel, and AF-D blend.
- The tailpipe emissions for AFD-10TiO$_2$/200such as CO, HC, smoke reduced by about 16%, 12%, and 18% respectively.
- The NO for AFD-10TiO$_2$/200increased by about 14% than that for diesel.

Nomenclature

AF	Aphanizomenonflos
AF-D	Aphanizomenonflos-diesel
AFD-5TiO$_2$	Aphanizomenonflos-diesel blend with 5% of titanium dioxide
AFD-10TiO$_2$	Aphanizomenonflos-diesel blend with 10% of titanium dioxide
AFD-15TiO$_2$	Aphanizomenonflos-diesel blend with 15% of titanium dioxide
ASTM	American society for testing and materials
BSFC	Brake specific fuel consumption
BTE	Brake thermal efficiency
C	Carbon
CI	Compression Ignition
CNG	Compressed natural gas
CO	Carbon monoxide
CR	Compression ratio
EGT	Exhaust gas temperature
H	Hydrogen
HC	Hydrocarbon
IEA	International energy agency
IP	Injection pressure
IT	Injection timing
LHV	Lower heating value
N	Nitrogen
NO	Nitrous oxide
O	Oxygen
S	Sulphur

TiO_2 Titanium dioxide

Acknowledgement

I would like to extend my sincere thanks to Karpagam Academy of Higher Education, Coimbatore – 641021 for providing all the necessary support and facilities to carry out this research work

REFERENCES

1. Keskin A, Guru M, Altiparmak D. Influence of tall oil biodiesel with Mg and Mo based fuel additives on diesel engine performance and emission. Bioresour Technol. 2008;99(14):6434–8.
2. Khond VW, Kriplani VM. Effect of nanofluid additives on performances and emissions of emulsified diesel and biodiesel fueled stationary CI engine: a comprehensive review. Renew Sust Energy Rev. 2016;59:1338–48.
3. Sadhik Basha J. An experimental analysis of a diesel engine using alumina nanoparticles blended diesel fuel. SAE Tech Pap Ser. 2014;. doi:10.4271/2014-01-1391.
4. Yang WM, An H, Chou SK, Vedharaji S, Vallinagam R, Balaji M. Emulsion fuel with novel nano-organic additives for diesel engine application. Fuel. 2013;104:726–731.
5. Balaji S, Kapilan N, Saravanan R. Influence of propyl gallate antioxidant on performance and emissions of a ci fuelled with neem oil biodiesel. J Biofuels. 2016;7(2):62.
6. Murat Kadir Yesilyurt. The effects of the fuel injection pressure on the performance and emission characteristics of a diesel engine fuelled with waste cooking oil biodiesel-diesel blends. Renewable Energy 2019; 132: 649-666.
7. Agarwal AK, Dhar A, Gupta JG, Kim WI, Lee CS, Park SW. Effect of fuel injection pressure and injection timing on spray characteristics and particulate size-number distribution in a biodiesel fuelled common rail direct injection diesel engine. Appl Energy 2014;130:212-221.
8. Gumus M, Sayin C, Canakci M. The impact of fuel injection pressure on the exhaust emissions of a direct injection diesel engine fueled with biodiesel diesel fuel blends. Fuel 2012;95:486–94
9. Kuti OA, Zhu J, Nishida K, Wang X, Huang Z. Characterization of spray and combustion processes of biodiesel fuel injected by diesel engine common rail system. Fuel 2012; 11.
10. Suh HK, Roh HG, Lee CS. Spray and combustion characteristics of biodiesel/diesel blended fuel in a direct injection common-rail diesel engine. J Eng Gas Turbines Power 2008;130(3):1-9.
11. Park SH, Yoon SH, Lee CS. Effects of multiple-injection strategies on overall spray behavior, combustion, and emissions reduction characteristics of biodiesel fuel. Appl Energy 2011;88:88-98.
12. Sun J, Caton JA, Jacobs TJ. Oxides of nitrogen emissions from biodiesel-fuelled diesel engines. Prog Energy Combust Sci 2010;36:677-795.
13. Lapuerta M, Armas O, Fernàndez JR. Effect of biodiesel fuels on diesel engine emissions. Prog Energy Combust Sci 2008;34:198-223.
14. Debabrata Barik, Asit Kumar, S. Murugan. Effect of Compression Ratio on Combustion Performance and Emission Characteristic of a Direct Injection Diesel Engine Fueled with Upgraded Biogas-Karanja Methyl Ester-Diethyl Ether Port Injection. Energy & Fuels 2018,32:5081-5089.
15. Debabrata Barik, S. Murugan, N.M. Sivaram, E. Baburaj, P. Shanmuga Sundaram. Experimental investigation on the behavior of a direct injection diesel engine fueled with Karanja methyl ester-biogas dual fuel at different injection timings. Energy 2017;118:127-138.
16. S. Dinesh, A review on different parameters affecting the vehicle emission gases of different fuel mode operations, Research Journal of Science and Engineering Systems, 4 (Issue 4), (2018)146– 157.

AUTHORS PROFILE

Mr. G.Jayabalaji born in Tharamangalam,Salem, Tamilnadu, India, received his B.E (Bachelor of Engineering) degree in Mechanical Engineering from Sri Ramakrishna Engineering College, Coimbatore. He received Master's Degree M.Tech (Automotive Engineering) from AmritaVishwa Vidhyapeetham India. . He has an experience of about 5 years in teaching various subjects of Mechanical and Automobile Engineering. Pursuing Ph.D course in Mechanical Engineering in Karpagam Academy of Higher Education Coimbatore.

Dr.P.Shanmughasundaram born in Kalangal, Coimbatore, Tamilnadu, India, received his A.M.I.E (India) degree in Mechanical Engineering and A.M.I.E (India) degree in Production Engineering from Institution of Engineers (India). He received Master's Degree M.E (Refrigeration and Air conditioning) from Coimbatore Institute of Technology, India. He obtained Doctoral degree in the Mechanical Engineering from PSG College of Technology, Anna University, Chennai. He has an experience of about 20 years in teaching various subjects of Mechanical and Automobile Engineering. He has produced 5 PhDs and he is guiding 8 PhD scholars. To his credit, he has 60 International peer reviewed Scopus and SCI Journal publications. He has authored a book chapter in Elsevier publication. He is the reviewer of more than 25 Scopus and SCI International Journals. His areas of interest are Metal Matrix Composites, Tribology and Optimization techniques. He has organized 1 International Conference, 6 National conferences and 15 National level workshops. He is a member of Society of Automotive Engineers (SAE), Fellow of Institution of Engineers (India), life member of Indian Society for Technical Education and Tribology Society of India.