EFFECT OF THREE AND FIVE HOLES NOZZLE ON THERMAL EFFICIENCY AND EMISSION CHARACTERS OF DI-CI DIESEL ENGINE WITH LEMONGRASS BIODIESEL AS ALTERNATE FUEL

by

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The performance and emissions characters of Diesel engine behavior depend largely on several criteria, fuel injection nozzle plays a vital role in the proper combustion of Diesel engines. This research analyzes the impact of a nozzle hole configuration on the features of a biodiesel-fuelled Diesel engine. Therefore, the causes are dependent on the modification that the nozzle hole was selected from three-hole and five-hole nozzles, while the engine characteristics of the lemongrass biodiesel blend with diesel were examined. Lemongrass biodiesel with 20% blend, LGB B20, has been investigated experimentally with different engine loads with respect to brake power, three-hole, and five-hole nozzles. The experimental investigation showed an improvement in peak i.e. highest heat release rate of 12.5% for three- and five-hole nozzle and brake specific fuel consumption of 15% is increased in single hole nozzle and it is observed it's diminished in three- and five-holed nozzle. Further, the brake thermal efficiency is increased in the five-hole nozzle in comparison to the three-hole nozzle at full load condition. Furthermore emission characteristics like HC, CO, and smoke are decreased with an increase in the number of nozzles, at the penalty of increase in NO_x *emissions has been observed.*

Key words: *lemongrass, three-hole, five-hole, performance and emission*

Introduction

In Diesel engines, the main pollutants are NO_x and PM. Likewise, their burning items are causing worldwide issues, for example, the impact on the ozone layer, which is presenting an incredible risk for this condition the absolute survival of our planet. Diesel engines are being long used for heavy-duty applications, whereas in the last few decades, they gained popularity even in light-duty applications because of their increased fuel efficiency. The Diesel engine's higher fuel efficiency is achieved through the use of higher compression ratios and a relatively higher oxygen concentration inside the combustion chamber. These factors, however, contribute to the high NO_x emissions produced by Diesel engines. The emission characteristics have been critical in focusing on and developing more environmentally friend-

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ly internal combustion engines. Additionally, the resulting products of combustion contribute to global issues like the acid rain, greenhouse effect, pollution, and ozone depletion, all of which pose a serious threat to our environment. Many researcher are focused on different biodiesel Kapok [1], castor oil methyl ester [2], pongamia oil methyl ester [3], on modification of different nozzle hole condition. Based on historical studies, the use of 20% biodiesel it has been recorded that diesel is conducive to unmodified usage Diesel engines [4]. In fact to provide to minimize imports of fuel and, in order of becoming a self-confident oil industry, India has started to use renewable energy such as biodiesel in the past several decades [5]. Nozzle hole geometry and injector pressure are modified to determine (optimise) Diesel engine performance, and optimised engine parameters are used to conduct additional research on the impact of piston bowl geometry on Diesel engines [6]. The CI engine was studied with vegetable biodiesel and a turbulence-induced piston in order to enhance performance and decrease emissions. It is worth noting that biodiesel from castor oil is investigated using a variety of parameters, including molar ratio, reaction temperature, catalyst, and nozzle hole, in order to optimise the performance along with the emission characteristics [7, 8]. Studies on DI type Diesel engine with non edible oil-pongamia oil methyl ester fueled to reduce harmful emissions, the nozzle hole technique is used [9]. In wild conditions, this plant is well suited to arid environments and is capable of withstanding long periods of drought [10]. After analyzing the emission parameters, it was concluded that palm oil methyl ester blended with diesel blends have been made use in CI Diesel engines. According to experimental results, palm methyl ester blends satisfy the emission criteria. The efficiency specification of the Diesel engine is carried with different nozzle hole [11]. Many researchers has performed using castor methyl ester with different hole nozzle and concluded blend 20% is helpful in improving the performance of engine [12]. Additionally, it demonstrated that biodiesel extracted from cooking oil can be used in conjunction with diesel along with the presence of a potassium hydroxide (KOH) catalyst in the form of a substitute fuel in Diesel engines [13]. The lemongrass biodiesel is used with different compression ratios such as 16:1, 17:1, and 18:1 to produce better engine performance with minimum emission of 20% blended [14]. Three- and five-hole nozzle analyzed for different blend ratios of vegetable oil the result shows the lower engine performance and decreased emission such has CO and HC [13, 15]. Dual fuel with different nozzle hole studied with different wide range speed to meet the standard emission [14]. Nanoparticle as additive with methyl ester with varying nozzle injector reduces the harmful environmental pollution [16]. By varying three- and five-hole nozzle injectors [17, 18] is concluded that the brake thermal efficiency (BTE) performance is enhanced while the emission of CO, HC, and smoke opacity is decreased. In order to achieve optimal power and fuel economy, any engine must have efficient fuel and air mixing. In a Diesel engine, employing multi-hole injectors instead of single-hole injectors allows for smaller holes, which results in better fuel atomization and more complete fuel/air mixing, resulting in higher efficiency [19, 20]. According to the literature, the best nozzle design is one that allows the most liquid fuel to be burnt while leaving the least amount of liquid fuel unburned. A nozzle with more than five-holes theoretically meets these criteria for emerging jets engines. All of the nozzles were tested, and the findings revealed that the five-hole nozzle had the greatest results in simulation and performance for all engine speeds [21, 22]. Based on the previous discussion, many researchers is focused on the nozzle injector design modification, nozzle hole geometry and air fuel mixture were take the strategy for the higher blended biodiesel are studied. In these previous studies, the lemongrass biodiesel was optimized with different nozzle injector is not performed. In this work, the testing was carried out in a single-cylinder type Diesel engine with regular engine load, timing and compression ratio at that same rated speed of 1500 rpm using diesel and lemongrass biodiesel B20 blend with three- and five-hole nozzle to investigate emission and performance characteristics.

Materials and methods

Biodiesel now a days become more attractive because of its environmental friendly and produced from renewable sources rather than non-renewable sources. Now a days biodiesel manufacturers are produced Lemon grass biodiesel its available are cheaper than edible oil seeds like sunflower, saffola, *etc.* The development of Lemongrass biodiesel is transesterification from lemongrass oil is a tropical perennial plant which yields aromatic oil. Sweet-smelling or fundamental oils are exceptionally focused optional metabolites of various works in plant framework. They create a variety of natural mixtures, such as benzenoids, natural sulphur, and nitrogenous mixtures, that work on a variety of levels. Lemongrass oil methyl ester is currently being delivered using lemon grass oil. Lemongrass (Cymbopogan flexuosus) is actually a fragrant tall sedge that grows throughout tropical and subtropical southeast Asia and Africa. They grows to about 2 m in height with red base stems. Lemongrass oil is used to mix it for about 15 minutes at 850 °C, leaving an undesirable natural problem to deal with for 30 minutes. The characteristics of the test fuel are listed in tab. 1.

Table 1. Properties of diesel and lemongrass biodiesel

Properties	ASTM Standard	Diesel	LGB
Density [kgm^{-3}]	D4052	840	830
Kinematic viscosity at 40 °C [cSt]	D445	3.2	4.34
Specific gravity	D1298	0.83	0.87
Calorific value [$MJkg^{-1}$]	D240	43	38.79
Flash point [ºC]	D93	55	50
Fire point [ºC]	D93	63	58
Cetane number	D976	48	64

Experimental engine set-up

Through a load cell, the engine was connected to an eddy current dynamometer. The engine set-up are shown in fig. 1.

Each experiment was carried out at a constant temperature and pressure. The engine is integrated with a data acquisition system for the purpose of storing data for offline analyzis. The AVL smoke metre is used to determine the intensity of smoke, while the gas analyzer is used to determine various emissions such as NO_x, CO, and HC. Figure 2 shows the specification of engine.

Test procedure

In this work, the testing was carried out in a single-cylinder type Diesel engine with regular engine load, timing and compression ratio at that same rated speed of 1500 rpm using diesel and lemongrass biodiesel B20 blend to investigate emission and performance characteristics. Then the engine fully cleaned with dry the balance oil with finishing point, which leads some time taken to cool the engine normal room temperature. Then the new set-up single nozzle hole is changed to three- nozzle to repet the test again. Now, the test engine reprocessed to the same cleaning technology the three-hole nozzle is changed to five-hole nozzle to repeat the test. Overall in the set-up with single hole, three-hole and five-hole nozzle, the test parameters such has performance and emission characteristics were examined and discuss in result and discussion. Specification of the test engine is illustrated in tab. 2.

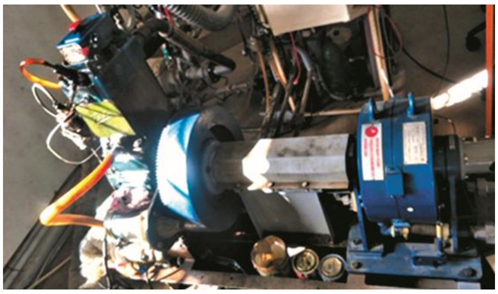

Figure 1. Engine set-up

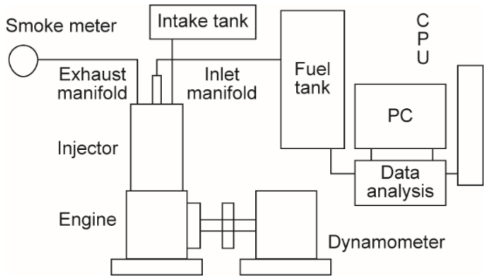

Figure 2. Block diagram of VCR Diesel engine

The list of instruments and their range, accuracy and uncertainty are given in tab. 3. Lower level blends B20 is a common biodiesel blend for Diesel engine in all over the world. It is popular because it represents a good balance of cost, low emissions levels, cold-weather performance, materials compatibility, and ability to act as a solvent. Using lower level of biodiesel blends does not require engine modifications. Engines operating on B20 have closer performance and emission level when compared to diesel. However, biodiesel still offers better GHG benefits compared to conventional diesel fuel. The three- and five-hole nozzle are shown in fig. 3.

Table 2. Specifications of the test engine

Engine	Specifications
Number of cylinder	1
Number of strokes	4
Engine make	Kirloskar
Model	TV1
Rated power	5.2 KW at 1500 rpm
Compression ratio	17.5:1
Orifice diameter	20 mm
Dynamometer arm length	185 mm

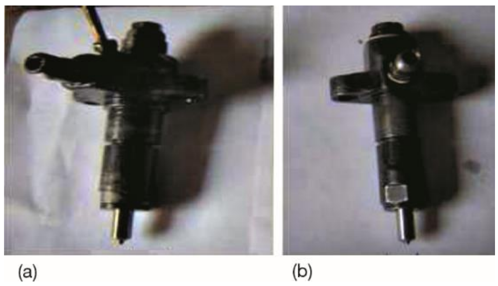

Figure 3. Three-hole (a) and five-hole nozzle (b)

Result and discussion

Performance and emission characters for diesel, lemongrass biodiesel with 20% blend, three- and five-hole nozzle are experimented with different load condition. For three- and five-hole nozzles, the HRR for diesel and LGB B20 mix was investigated. When compared to diesel, the peak value for HRR for diesel and LGB B20 is 12.5% higher, and it occurs earlier than diesel fuel conditions. This might be attributed to improved fuel-borne oxygen combustion. In comparison to diesel and LGB B20 mix, the combination of high pressure

Table 3. List of instruments and their range, accuracy and uncertainty [2]

Instrument	Measurement	Range	Accuracy	Uncertainty
AVL DI gas 444 five gas analyzer	CO CO_2 HC O_2 NO_x	0-10 vol.% 0-20 vol.% 0-20000 ppm 0-22 vol.% 0-5000 ppm	±0.03% ±0.% ±10 ppm ±0.1% ±50 ppm	±0.2% ±0.15% ±0.2% ±0.5% ±1%
AVL 437 smoke meter	Opacity [%] Absoption [m^{-1}]	0-100 0-99.9	0.1 0.01	±1% ±1%
AVL GH14d/AH1 pressure transducer	Pressure	0-100 bar	±0.1 bar	±0.15%
AVL 365C angle encoder	Crank angle	0-720°	±1%	±0.2%

combustion and reduced oxygen concentration during the combustion period may have resulted in delayed formation and propagation of flame rates, resulting in lower HRR.

Peak cylinder pressure

Figure 4 depicts the peak *i.e.* highest cylinder pressure for diesel, lemongrass biodiesel with 20% blend. Three- and five-hole nozzle are experimented with different load condition. Peak HRR of 12.5% for three- and five-hole nozzle as improved at all load condition. The maximum peak cylinder pressure is observed in lemongrass biodiesel with five-hole nozzle. At all condition the three- and five-hole nozzle are increased it's due the properties of lemongrass biodiesel. It is observed the increasing nozzle hole applies to increase in peak cylinder pressure. This peak pressure is obtained for diesel and LGB B20 with single hole nozzle is 62 bar and 59 bar, respectively. The higher peak cylinder pressure is obtained for LGB B20 with three- and five-hole nozzle is 64 bar and 65 bar, respectively. These experimental results are observed with kapok biodiesel are similar [1]. This reduction is may be due to dilution, chemical, thermal and ignition delay effect.

Brake thermal efficiency

Figure 5 denotes the brake thermal efficiency (BTE) for diesel, lemongrass biodiesel with 20% blend, three- and five-hole nozzle are experimented with different load conditions. It is observed that BTE of diesel and LGB B20 is 31.5% and 28% for the full load condition. The BTE is reduced because the properties of the biodiesel such as calorific value and viscosity of biodiesel blend. At this condition is noted that the three- and five-hole nozzle are increased it's due the properties of lemongrass biodiesel. The increase in BTE LGB B20 three-

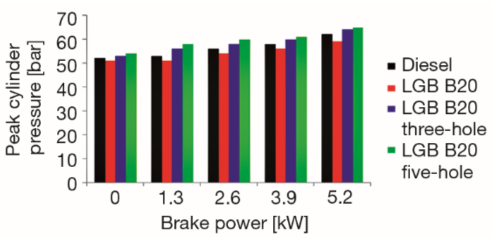

Figure 4. Peak cylinder pressure *vs.* break power
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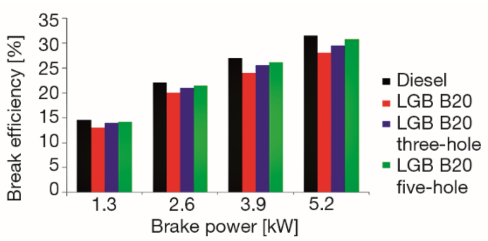

Figure 5. The BTE *vs.* break power
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and five-hole nozzle is 29.5% and 30.8%, respectively. The BTE is increased due to the efficient of atomization of biodiesel high air fuel mixture and a high spray characteristic which leads increase the combustion process.

Brake specific fuel consumption

Figure 6 shows the brake specific fuel consumption (BSFC) of diesel, lemongrass biodiesel with 20% blend, three- and five-hole nozzle are experimented with different load conditions. The BSFC with brake power it observed that its increase in loads as well as is increased in blended biodiesel. The consumption of brake specific fuel obtained for diesel and biodiesel is 0.22 kg/K and 0.25 kg/K, respectively, also it is observed at all condition load the biodiesel blend is increased. It is because of better combustion of air and mixture of fuel with enhanced atomization of fuel. However for the varying nozzle hole such as three- and five-hole nozzle is 0.20 kg/K and 0.22 kg/K, respectively, the observed value is decreased compare to the lemongrass biodiesel blend.

The CO emission

Figure 7 depicts the variation of CO emission with the brake power for diesel lemongrass biodiesel with 20% blend, three- and five-hole nozzle. The CO emission for diesel and LGB B20 is 0.8% and 0.68%, respectively, at full load condition. More oxygen present normally in lemongrass biodiesel which leads to increase the CO emission. In biodiesel more oxygen contents which react with air fuel combustion process may be due to more oxygen it promotes to decrease the carbon. It also observed that is emission value is decreased with increase the number of nozzle holes. The three- and five-hole nozzle for lemongrass biodiesel is 0.58% and 0.50%, respectively. It better mixing of air fuel mixture leads to decrease the CO emission effects.

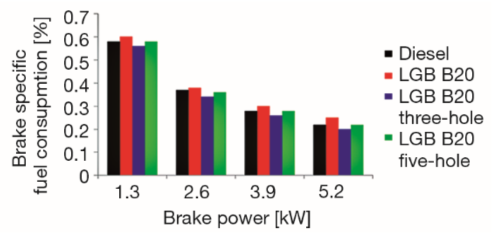

Figure 6. The BSFC *vs.* break power
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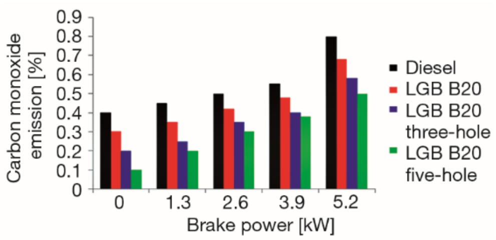

Figure 7. The CO *vs.* break power
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The HC emission

The HC emission of B20 blend with in relation to brake power for diesel lemongrass biodiesel, three- and five-hole nozzle as given in fig. 8. It is seen with increase in the engine load, the HC emission decreases when compared to the diesel. For full load condition the HC emission for diesel and LGB B20 is 46 ppm and 43 ppm, respectively. This is because of high density and viscosity properties content its mixed shows of LGB B20 blend, due to that it reduced the evaporation rate and its leads to decrease the HC emission. The HC emission which also observed for three- and five-hole nozzle is decreesed by 13.5% and 16% as compared with the diesel at full load condition. The HC emission for three-hole nozzle is 40 ppm and five-hole nozzle is 38 ppm, respectively. From this observed value the emission of HC is reduced due to the viscosity and density of the lemongrass biodiesel, as well has the nozzle hole which also enhanced to reduce the combustion process to reduce the HC emission.

The No$_x$ emission

The NO_x emission is increased has compared to other emission such has CO and HC. The NO_x emission is increased progressively which increase the nozzle holes and its is observed high NO_x emission in five-hole nozzle. The NO_x emission of B20 blend in relation with brake power for diesel lemongrass biodiesel, three- and five-hole nozzle as shown in fig. 9. In full load condition the NO_x emission for diesel and LGB B20 is 494 ppm and 520 ppm, respectively. The oxygen content present in the lemongrass biodiesel which leads with air/fuel mixture has increased the pressure of the cylinder enhanced to increase the NO_x emission also. Due to the increase of nozzle hole the spray of fuel and mixture of air-fuel is increased its occurred the homogenous lead to improvement of the NO_x emission. The NO_x emission for three-hole nozzle is 540 ppm and five-hole nozzle is 561 ppm, respectively. The oxygen content and air fuel mixture of nozzle hole which leads to increase the NO_x emission.

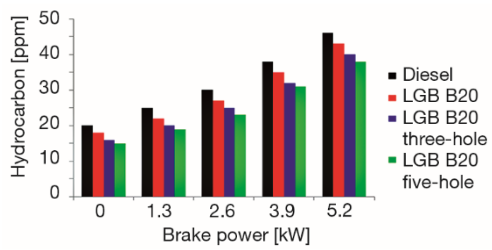

Figure 8. HC *vs.* break power
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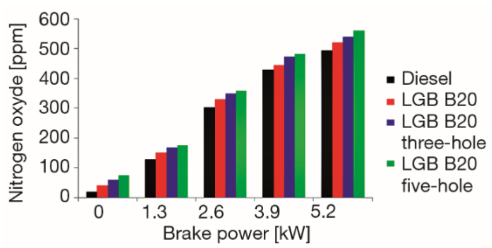

Figure 9. The NO_x *vs.* break power
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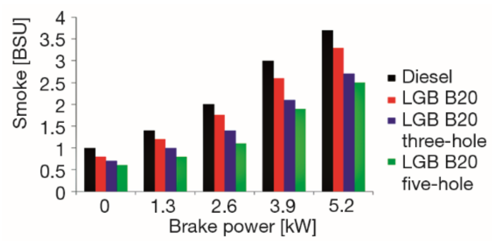

Figure 10. Smoke *vs.* break power
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Smoke opacity

Figure 10 represents the variation of smoke opacity in relation with brake power for diesel lemongrass biodiesel with 20% blend, three- and five-hole nozzle. The smoke formation is due to fuel rich zones and lack of oxygen for combustion. The smoke opacity for diesel and LGB B20 is 3.7 BSU and 3.3 BSU, respectively, while in full load condition. The smoke opacity obtained for three- and five-hole nozzle is 2.7 BSU and 2.5 BSU, respectively. This reduction in smoke opacity could be related to more oxygen ions found in biodiesel, which improve the combustion of fuel and air. Further the smoke opacity is decreased with increasing number of nozzle holes.

Conclusions

The performance and emission characteristics for diesel, lemongrass biodiesel with 20% blend, three- and five-hole nozzle experiment with different load conditions and the following conclusion were drawn.

- The peak HRR of 12.5% for three- and five-hole nozzle is increased when compared to the diesel value, the maximum peak cylinder pressure is observed in lemongrass biodiesel with five-hole nozzle. The consumption of brake specific fuel of 15% is increased for single hole nozzle and it is observed its diminished in three-hole as well as five-hole nozzle. Further, the BTE increased in the five-hole nozzle compared to the three-hole nozzle while in full load condition.

- The CO emission for diesel and LGB B20 is 0.8% and 0.68%, respectively, for full load condition. At full load condition the emission of HC for diesel and LGB B20 is 46 ppm and 43 ppm, respectively. The NO_x emission is increased progressively which increase the nozzle holes and its is observed high NO_x emission in five-hole nozzle. The smoke formation is due to fuel rich zones and lack of oxygen for combustion. The smoke opacity for diesel and LGB B20 is 3.7 BSU and 3.3 BSU, respectively.
- The emission CO, HC, and smoke opacity is diminished with increasing the nozzle hole injector, however the NO_x emission is increased when compare to the diesel and lemongrass biodiesel.
- Blended 20% lemongrass biodiesel is made use of, in Diesel engine with no modification. Furthermore is to focus to reduce the NO_x emission by using different design parameters.

References

[1] Nandakumar, C., *et al.*, Effect of Nozzle Hole Geometry on the Operation of Kapok Biodiesel in a Diesel Engine, *Fuel*, *276* (2020), Sept., 118114
[2] Reddy, N., *et al.*, Investigation of Influence of Injector Opening Pressure and Nozzle Geometry on the Performance and Emission Characteristics of DI Diesel Engine with CAOME, *European Journal of Sustainable Development Research*, *3* (2019), 4, em0093
[3] Prakash, S., *et al.*, Experimental Analyzis of Diesel Engine Behaviours Using Biodiesel with Different Exhaust Gas Recirculation Rates, *International Journal of Ambient Energy*, On-line first, https://doi.org/10.1080/01430750.2020.1712251, 2020
[4] Javed, T., *et al.*, Combustion-Based Transportation in a Carbon-Constrained World: A Review, in: *Pollutants from Energy Sources*, (eds. Agarwal, R., *et al.*), Springer, Singapore, 2019, pp. 7-34
[5] Thiagarajan, C., *et al.*, Heat Transfer Analyzis and Optimization Of Engine Cylinder Liner Using Different Materials, *Materials Today: Proceedings*, *33* (2020), Part 1, pp. 778-783
[6] Channappagoudra, M., *et al.*, Comparative Study of Standard Engine and Modified Engine with Different Piston Bowl Geometries Operated with B20 Fuel Blend, *Renew Energy*, *133* (2019), Apr., pp. 216-232
[7] Aboelazayem, O., *et al.*, Biodiesel Production from Castor oil in Egypt: Process Optimisation, Kinetic Study, Diesel Engine Performance and Exhaust Emissions Analyzis, *Energy*, *157* (2018), Aug., pp. 843-852
[8] Barajas Forero, C. L. *et al.*, Biodiesel from Castor Oil: A Promising Fuel for Cold Weather, *The Renewable Energy & Power Quality Journal*, *1* (2005), 3, pp. 59-62
[9] Prabhahar, M., *et al.*, Investigation of Pine Oil Methyl Ester Blends with Diesel on a Compression Ignition Engine to Control Oxides of Nitrogen and Soot Particles, *Rasayan Journal of Chemistry*, *10* (2017), 4, pp. 1075-1079
[10] Arunkumar, M., *et al.*, Experimental Studies on Engine Performance and Emission Characteristics Using Castor Biodiesel as Fuel in CI Engine, *Renewable Energy*, *131* (2019), Feb., pp. 737-744
[11] Saravana Kumar, B., *et al.*, Performance and Emission Analyzis of Four Stroke Diesel Engine by Varying its Fuel Injection Nozzle Holes on a VCR Engine, *International Journal of Engineering Research & Technology*, *7*, (2019), 11, pp. 1-4
[12] Prakash, S., *et al.*, Experimental Studies on the Performance and Emission Characteristics of an Automobile Engine Fueled with Fish Oil Methyl Ester to Reduce Environmental Pollution, *Energy Procedia*, *160* (2019), Feb., pp. 412-419
[13] Cenk Sayin, M. G., *et al.*, Influence of Injector Hole Number on the Performance and Emissions of a DI Diesel Engine Fueled with Biodiesel-Diesel Fuel Blends, Elsevier Publications, *Applied Thermal Engineering 61* (2013), 2, pp. 121-128
[14] Prabhu, L., *et al.*, Performance and Emission Characteristics of a Diesel Engine Using Nanoparticle as Additive with Biodiesel 250 ppm , *International Journal of Applied Engineering Research*, *9* (2014), 23 pp. 18759-18770

[15] Thirunavukkarasu, R., *et al.*, Investigation on Single, Four and Five Holes Fuel Injector Nozzle on Performance and Emission Characteristic of Diesel on A VCR Engine by Using Ceramic Coating Material on the Piston Crown, *Materials Today: Proceedings, 5* (2018), 2, pp. 7577-7585
[16] Alabbad, M., *et al.*, Autoignition of Straight-Run Naphtha: A Promising Fuel for Advanced Compression Ignition Engines, *Combust Flame, 189* (2018), Mar., pp. 337-346
[17] Attard, W. P., *et al.*, Spark Ignition and Pre-Chamber Turbulent Jet Ignition Combustion Visualization, SAE Technical Papers, 2012-01-0823, 2012
[18] Bunce, M., *et al.*, Sub-200 g/kWh BSFC on a Light Duty Gasoline Engine, SAE Technical Paper, 2016-01-0709
[19] Cui, H., *et al.*,China‘s New Energy Vehicle Mandate Policy (Final Rule), Policy update, ICCT report 11, 2018
[20] Som, D. E., *et al.*, Effect of Nozzle Orifice Geometry on Spray, Combustion, and Emission Characteristics Under Diesel Engine Conditions, *Fuel, 90* (2011), 3, pp. 1267-1276
[21] Schmidt, D. P., *et al.*, The Internal Flow of Diesel Fuel Injector Nozzles: A Review, *Int. J. Engine. Res., 2* (2001), 1, pp. 1-21
[22] Ranz, W. E., Some Experiments on Orifice Sprays, *Can. J. Chem. Engng., 36* (1958), 4, pp. 175-181

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