

Combined Effect of EGR and SiO₂ Nanoparticles on CI Engine Fuelled with Waste Cooking Oil Biodiesel

Channakeshava B C¹, Dr. Ramesha D K²

¹Research scholar, Department of Mechanical Engineering, University Visvesvaraya College of Engineering, India.

²Professor, Department of Mechanical Engineering, University Visvesvaraya college of Engineering, India.

Email: Sheelakeshava2014@gmail.com

Abstract

In this paper, the effect of exhaust gas recirculation (EGR) and Silicon oxide (SiO₂) nanoparticles on performance, combustion and emission characteristics of diesel engine fueled with waste cooking oil biodiesel is presented. Waste cooking oil (WCO) biodiesel was derived by transesterification process. Methyl ester was prepared by mixing diesel and biodiesel oils as 20% by volume. SiO₂ nanoparticles was blended with biodiesel at concentration of 100 ppm to enhance the physicochemical fuel characteristics to obtain clean and efficient combustion performance. An experimental setup was incorporated into a diesel engine to investigate the influence of these nano-materials on engine performance, combustion and emissions characteristics using WCO biodiesel-diesel mixture. Enriching methyl ester mixture with 100 ppm SiO₂ (B20+100ppm SiO₂) increased the break thermal efficiency (BTE), heat release rate (HRR) and peak pressure are increased by 5.51%, 4.02% and 8.98% respectively. Emissions of unburned hydrocarbons (UBHC), carbon monoxide (CO), nitrogen oxides (NO_x) and smoke opacity are decreased by 30%, 6.93%, 23.25% and 10% respectively as compared to B20. With the incorporation of 10% EGR, BTE, HRR and peak pressure increased by 1.29%, 0.71% and 1.28% respectively as compared to B20. Emissions of UBHC, CO, NO_x and smoke opacity are decreased by 2.6%, 2.32%, 11.42% and 0.52% respectively as compared to B20 at full load. Due to the significant reduction in emissions, improvement in combustion and performance characteristics, EGR- SiO₂ nano additives can be used as an effective formula for diesel engines fueled with biodiesel.

Keywords: Biodiesel; Nanoparticles; Silicon oxide; EGR; Performance; Combustion; Emission.

1. Introduction

Fossil fuels play a crucial role in starting engines for electricity generation and domestic purposes [1], however, its combustion product and the increase in automobile use create negative effects on the environment. Therefore, people are promoting low-carbon living in today's world [2]. The consequences of using fossil fuels cause dangerously increased levels of unburned hydrocarbons (UBHC), carbon monoxide (CO) and nitrogen oxides (NO_x), resulting in adverse ecological changes. In addition, flue gases cause air pollution and the released gases contribute greatly to the climate by trapping heat [3]. As a non-renewable resource, the oil as a fuel is running out and its price is unstable because of the increment in its use for power generation and transportation and the rapid increase in energy demands [3]. Therefore, the current scenario of fossil fuel depletion and rising fuel prices, the challenges facing the current global plan for low-carbon living and the identification of extent of energy and the challenges that is associated with the contamination caused by burning process of fossil fuels have motivated to research clean and sustainable energy sources. Furthermore, it has become very important to examine the possibility and outlook of harnessing technically attainable, readily obtainable and globally suitable renewable energy sources as an alternative fuel [4,5]. More important again, the environmental crises linked with the combustion of fossil oil have also alerted the researchers to look for strategies that can deal with the excessive worrying air pollution levels and its potential consequences. Among the various alternative fuels, biofuels have received much attention as the most desirable backup fuels for the field of transportation [6]. This is because these energy carriers are capable of powering machines by themselves while their harmful such as NO_x, HC and CO are substantially lower than those of the fossil fuels.

2. Materials and methods

This section describes the biodiesel preparation procedure, properties of tested fuels and Experimental set up.

2.1. Transesterification

Transesterification process consists of 2 steps namely Acid Transesterification and Base Transesterification. In acid transesterification, waste cooking oil (WCO) is heated up to 50°C. Then Methanol is added to preheat WCO. After this reaction the bottom deposit is detached from the reaction (Base Transesterification). The obtained mixture is heated for 45–55 min in the presence of KOH (Potassium Hydroxide) and methanol. Once the reaction is completed, the products are permitted to distinct into two deposits. The bottom deposit, which contained glycerol, is removed. The ester (WCOME) left overs in the upper deposit. Fig. 1 demonstrates the complete operation of the Transesterification method. The fuel properties of Diesel, WCOME with and without SiO₂ were determined and tested to meet the ASTM standard requirement. All the properties of verified biofuels are tabulated in Table 1.

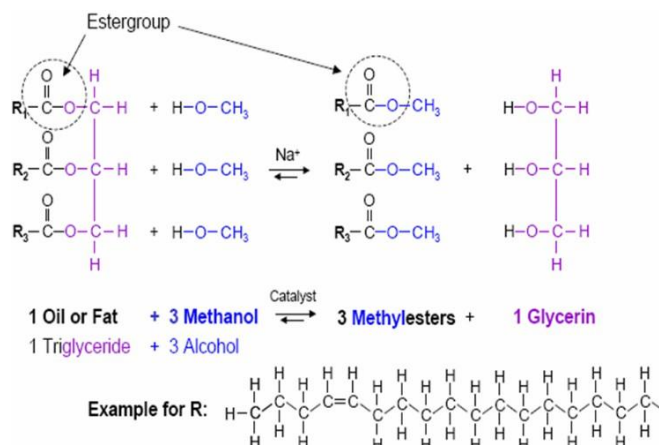


Figure 1: Transesterification process.



Figure 2: Engine setup.

2.2. Error analysis and uncertainty

The experimental results will certainly have error and uncertainties, which can rise from the incorrect calibration of instruments due to excessive handling and mishandling, surrounding conditions, experimental test conditions and planning, surveillance and reading. The errors which are gotten become a hindrance to obtain accurate results. Thus to nullify these errors, tools and methods from mathematics and statistics are used. Generally, the method used is repetition of the taking data from the experimentation (at least 3 times) and finding the mean in order to minimize the error that may occur. Measurements of uncertainties were calculated and results are shown in Table 4. The uncertainty of the experiment was 1.8445%.

Table 1.Properties of fuels.

Properties	ASTM	Diesel	WCO	WCOME	B20	B20+100PPM SiO ₂
Kinematic viscosity (40°C,Cst)	19.6	3.05	43	5.83	4.01	4.02
Density (Kg/m ³)	870-900	828	914	874	826	825
Heat value (MJ/Kg)	-	42.6	29	37.2	39.2	41.8
Flash point (°C)	>130	60	307	150	98	102
Cetane number	40-55	40	53	51.48	51	53.1

Table 2.Nanoparticle Properties.

Parameters	Silicon oxide(SiO ₂)
Manufacturer	Nano Research Lab
Chemical Name	Silicon oxide
Form Color	Powder white
Particle Size	25–50 nm
Specific Surface Area	250 m ² /g
Molecular Weight	60.08 g/mole

Table 3.Error analysis and uncertainty.

Measurements	Accuracy	Uncertainty
Speed	±3 RPM	± 0.3%
BSFC	±3 kg/KWh	± 0.35%
Power (KW)	±0.3KW	± 0.40%
CO	±0.02%	± 1.0%
NOx	±7 ppm	± 0.7%
In cylinder pressure	±0.1 bar	± 0.2%
Temperature	±1°C	± 0.1%
Torque	± 0.1Nm	± 1%

Table 4.The specification of engine.

Parameters	Specifications
Engine	Four Stroke Single Cylinder
Make	Kirloskar
Number of cylinder	One

Speed	1500 rev/min
Bore	85 mm
Stroke length	110 mm
Compression ratio	17.5:1
Starting	Cranking
Working length	four Stroke
Method of cooling	Water cooled
Method of ignition	Compression ignition
Dynamometer	Eddy current

3. Exhaust gas recirculation

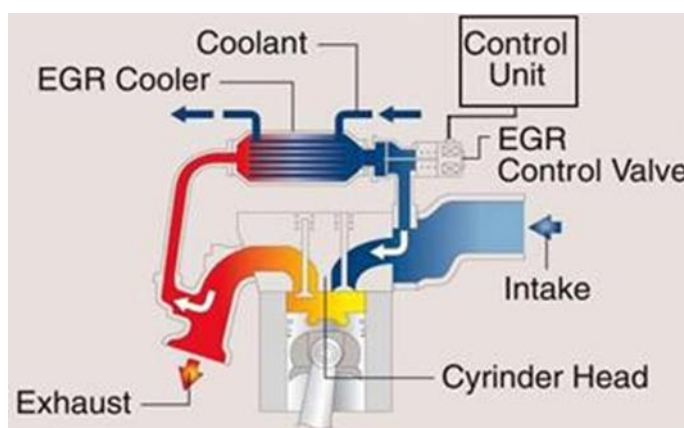


Figure 3: Exhaust gas recirculation.

The most effective way of reducing NO_x emissions is to hold combustion chamber temperatures down. Although practical, this is a very unfortunate method in that it also reduces the thermal efficiency of the engine. We have been taught since infancy in our first thermodynamics course that for maximum engine thermal efficiency, Q_{in} should be at the highest temperature possible. Probably the simplest practical method of reducing maximum flame temperature is to dilute the air-fuel mixture with a non-reacting parasite gas. This gas absorbs energy during combustion without contributing any energy input. The net result is a lower flame temperature. Any non-reacting gas would work as a diluent. Those gases with larger specific heats would absorb the most energy per unit mass and would therefore require the least amount; thus less CO₂ (carbon dioxide) would be required than argon for the same maximum temperature. However, neither CO₂ nor argon is readily available for use in an engine. Air is available as a diluent but is not totally non-reacting. Adding air changes the AF and combustion characteristics. The only non-reacting gas that is available to use in an engine is exhaust gas, and this is used in all modern automobile and other medium-size and large engines.

4. Results and discussion

Exhaustive experimentation has been made with varied load and the readings have been tabulated and plotted in graphs.

4.1. Engine performance

4.1.1. Brake thermal efficiency

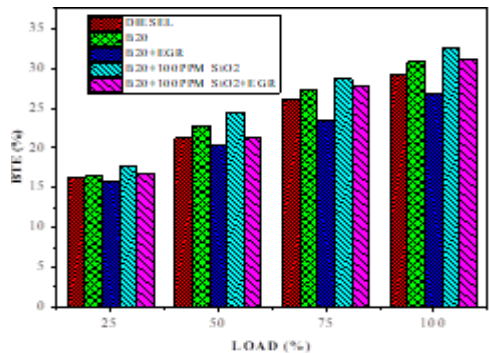


Fig 4: Variation of BTE with load.

Fig. 4 shows the variation of BTE with Load. Brake thermal efficiency increases for Nano additive biodiesel than the diesel. Addition of Nano particle improves the combustion activity and more useful work is obtained from the fuel, due to improvement in surface area to volume ratio increases the power attribute by enhancing the heat transfer rate inside the engine cylinder. Addition of Nano particle minimizes the ignition delay period and provides better atomization of fuel from the fuel injector's cause's rapid evaporation indeed increases the thermal efficiency. At higher loading condition, BTE of B20+ SiO₂ increased by 5.51% and BTE of B20+ SiO₂+EGR increased by 1.29% compared to B20.

4.1.2. Break specific fuel consumption (BSFC)

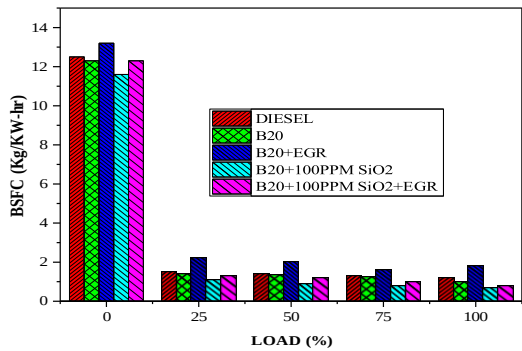


Fig 5: Variation of BSFC with load.

Fig. 5 shows the variation of BSFC with Load. BSFC decreases as the loading increases. Addition of nano particles to biodiesel improves the quality of the fuel. Due to lesser size and homogenous mixing of nano particles with biodiesel prevents the clogging of the fuel and increases the atomization property. Nano particle have higher reactive surface area causes increases in the catalytic property, which improves the combustion with minimum fuel consumption. Oxide will enhances the secondary atomization causing increases in combustion uniformly. At higher loading condition, BSFC of B20+ SiO₂ decreased by 30% and BSFC of B20+ SiO₂+EGR decreased by 20% compared to B20.

4.2. Combustion parameters

4.2.1. HRR (heat release rate)

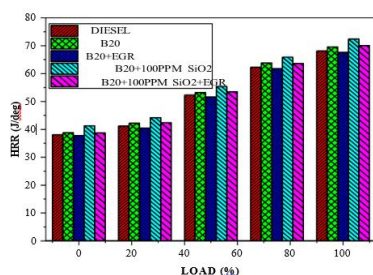


Fig 6: Variation of HRR with load.

Fig. 6 Portray the association of HRR (J/Deg) with Load (%). Experiment reveals that as the addition of Nano products to diesel and biodiesel fuel increases the HRR. Adding Nano particles to biodiesel increases the catalytic activity in the biodiesel fuel thus encouraging the full combustion causes increases in HRR. At higher loading condition, HRR of B20+ SiO₂ increased by 4.02% and HRR of B20+ SiO₂+EGR increased by 0.71% compared to B20.

4.2.2. Peak pressure

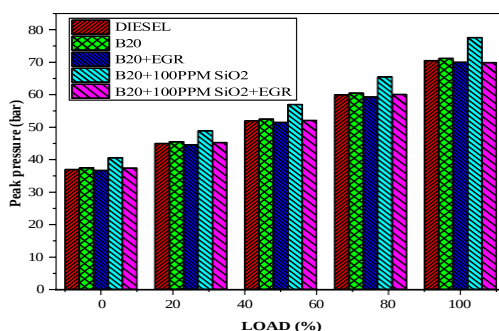


Fig 7: Variation of peak pressure with load.

Fig. 7 depict the relation between Peak pressure (bar) and Load (%), Due to improved combustion efficiency, the ignition delay time decreases for the Nano fluid biodiesel blends compared to diesel fuel and Nano particles also provide sufficient area to volume for the catalytic operation of the fuel leads to increased combustion, thereby Nano fluid biodiesel exhibits higher peak pressure compares to diesel fuel. At higher loading condition, Peak pressure of B20+ SiO₂ increased by 4.02% and Peak pressure of B20+ SiO₂+EGR increased by 0.71% compared to B20.

4.3. Emissions parameters

4.3.1. Unburned hydrocarbons (UBHC)

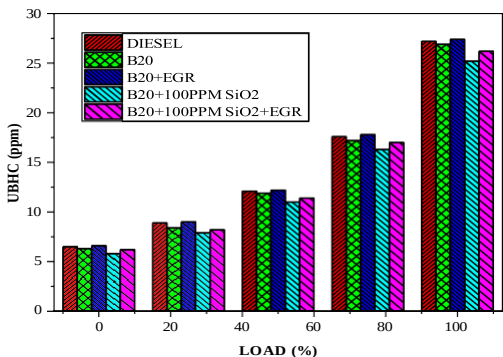


Fig 8: Variation of UBHC with load.

Fig. 8 shows the variation of HC with Load. HC decreases as the load increases were observed. When load increases availability of oxygen gradually decreasing due to fuel injection is more. But for the biodiesel contains oxygen molecules in fatty acid chain hence HC formation for the biodiesel is decreases due to more combustion than diesel will be observed. As the addition of the nano particles to biodiesel blends increases the atomization of fuel and decreases the viscosity of the fuel leads to improvement in the vaporization of particles. Furthermore improved mixing quality of air fuel increases combustion phenomena resulting n reduction in HC formation. Presences of oxygen in the chain increase the combustion rate with lesser combustion duration. Another reason as the addition of nano particles decreases the temperature of carbon combustion and enhances the catalytic activity of oxygen. At higher loading condition, UBHC emission of B20+ SiO₂ decreased by 6.93% and UBHC emission of B20+ SiO₂+EGR decreased by 2.6% compared to B20.

4.3.2. Carbon monoxide (CO)

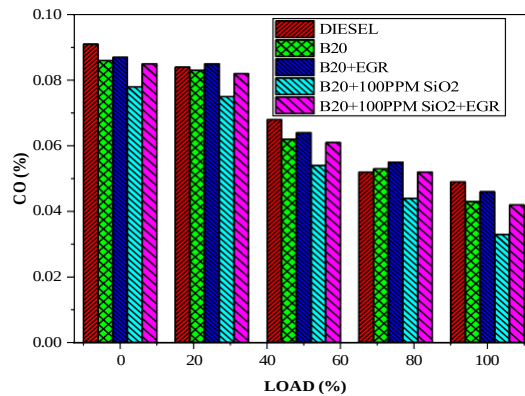


Fig 9: Variation of CO emission with load.

Fig. 9 shows the variation of CO with respect to engine load. A reduction in CO emission significantly due to presence of more oxygen atoms present in the biodiesel blends than the diesel. The oxygen atoms boots up the combustion activity. Nano particles improve the air fuel mixture quality due to higher area to volume ratio which leads burning rate for the complete combustion. Decrease in the viscosity of the biodiesel improves the atomization this plays a vital role in the reduction of CO emission. Nano particles decreases the homogeneity of the biodiesel composition there by increases the breakup rate during injection of fuel from the fuel injector At higher loading condition, CO emission of B20+ SiO₂ decreased by 23.25% and CO emission of B20+ SiO₂+EGR decreased by 2.32% compared to B20.

4.3.3. Nitrogen oxides (NO_x)

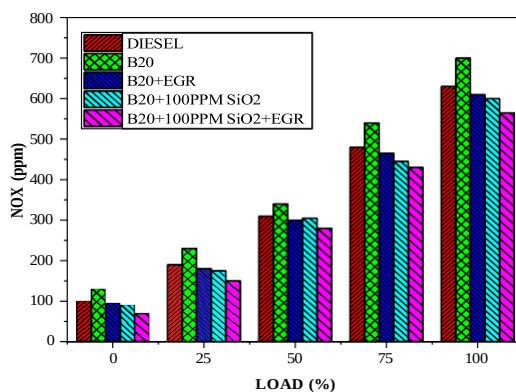


Fig 10: Variation of NO_x emission with load.

Fig. 10 shows the NO_x and load relation. NO_x emission will be higher for the biodiesel for all loading condition than the diesel fuel. NO_x shows higher emission with increase loading

condition due to higher adiabatic flame and cylinder temperature. Ignition delay, higher combustion temperature and higher availability of oxygen conditions favor the formation on NO_x with higher rate. Due to presence of oxygen, content in the biodiesel shows higher NO_x. As the dosing of metal based nanoparticle to biodiesel causes complete combustion. In this condition, peak pressure and HRR will be maximum but due to shorter ignition delay of nanoparticles decreases the cylinder combustion temperature and leads to less NO_x formation will be achieved due to thermal breakdown of the hydrocarbons. At higher loading condition, NO_x emission of B20+ SiO₂ decreased by 14.28% and NO_x emission of B20+ SiO₂+EGR decreased by 19.28% compared to B20.

4.3.4. Smoke opacity

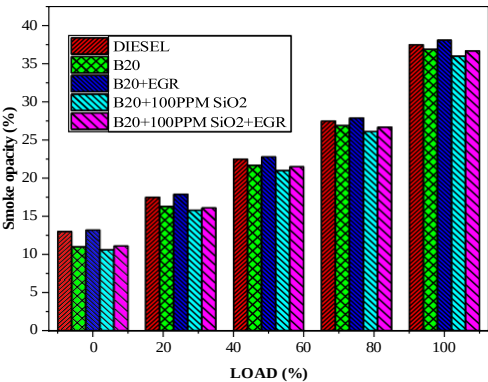


Fig.11: Variation of smoke opacity with load.

This is due to the advanced surface area -to - volume ratio of SiO₂ and greater cetane number causing complete combustion. Higher oxygen content in the blend enhances combustion and results in lowering of smoke emissions. Also due to improved Sulphur and oxygen content of the nanoparticle, blended fuel there is reduction of Smoke opacity. At higher loading condition, Smoke opacity of B20+ SiO₂ decreased by 2.43% and Smoke opacity of B20+ SiO₂+EGR decreased by 4% compared to B20.

5. Conclusions

The following are the conclusions drawn from the experimental results.

With respect to B20+100ppm SiO₂,

- BTE increased by 5.51% and 11.64% compared B20 and diesel respectively.
- BSFC decreased BY 30% and 41.6% compared B20 and diesel respectively.
- HRR increased by 4.02% and 6.31% compared B20 and diesel respectively.
- Peak pressure increased by 8.98% and 10.07% compared B20 and diesel respectively.
- UBHC decreased by 6.93% and 7.35% compared B20 and diesel respectively.

- CO decreased by 23.35% and 32.65% compared B20 and diesel respectively.
- NO_x decreased by 14.28% and 4.76% compared B20 and diesel respectively.
- Smoke opacity decreased by 2.43% and 4% compared B20 and diesel respectively.

With respect to B20+100ppm SiO₂+EGR,

- BTE increased by 1.29% and 6.84% compared B20 and diesel respectively.
- BSFC decreased by 20% and 30% compared B20 and diesel respectively.
- HRR increased by 0.71% and 2.93% compared B20 and diesel respectively.
- Peak pressure increased by 1.82% and 2.93% compared B20 and diesel respectively.
- UBHC decreased by 2.6% and 3.67% compared B20 and diesel respectively.
- CO decreased by shows 2.32% and 14.28% compared B20 and diesel respectively.
- NO_x decreased by 19.28% and 10.31% compared B20 and diesel respectively.
- Smoke opacity decreased by 0.54% and 2.13% compared B20 and diesel respectively.

References

- [1] J. Lv, S. Wang, B. Meng, The effects of nano-additives added to diesel-biodiesel fuel blends on combustion and emission characteristics of diesel engine: a review, *Energies* 15 (3) (2022) 1032.
- [2] T. Cai, et al., Evaluation of NO_x emissions characteristics in a CO₂-Free micro-power system by implementing a perforated plate, *Renew. Sustain. Energy Rev.* 145 (2021) 111150.
- [3] H. Venkatesan, et al., A comprehensive review on the effect of nano metallic additives on fuel properties, engine performance and emission characteristics. *International Journal of Renewable Energy Research (IJRER)* 7 (2) (2017) 825–843.
- [4] M.E.M. Soudagar, et al., An investigation on the influence of aluminium oxide nano-additive and honge oil methyl ester on engine performance, combustion and emission characteristics, *Renew. Energy* 146 (2020) 2291–2307.
- [5] M.E.M. Soudagar, et al., The effect of nano-additives in diesel-biodiesel fuel blends: a comprehensive review on stability, engine performance and emission characteristics. *Energy Conversion and Management* 178 (2018) 146–177.
- [6] M. Mohadesi, Z. Hojabri, G. Moradi, Biodiesel production using alkali earth metal oxides catalysts synthesized by sol-gel method, *Biofuel Research Journal* 1 (1) (2014) 30–33. [7] K. Heydari-Maleny,
- [7] Ramesha D K, PremaKumara K, Abhishek Jain C, AkashN, Babu Reddy B, Kallappa R, Kammara M(2015) Experimental investigation on combustion, performance and emission characteristics of plastic oil and biodiesel as a substitute fuel in diesel engine. *IRJET* 02
- [8] Mani M, Nagarajan G, Sampath S (2013) Characteristic and effect of using waste plastic oil and diesel fuel blends in compression ignition engine. *Energy* 36:212–219
- [9] Madheshiyaa AK, Vedrtname A (2018) Energy-energy analysis of biodiesel fuels produced from waste cooking oil and mustard oil. *Fuel* 214:386–408
- [10] AvinashA, SasikumarP, MurugesanA (2018) Understanding the interaction among the barriers of biodiesel production from waste cooking oil in India: an interpretive structural modeling approach. *Renew Energy*.
- [11] Amit Kumar, Harveer Singh Pali, "Evaluation of waste plastic and waste cooking oil as a potential alternative fuel in diesel engine", <https://doi.org/10.1016/j.nxener.2024.100181>.

- [12] Medhat Elkelawy, E. A. El Shenawy, Hagar Alm-Eldin Bastawissi, "Predictive modeling and optimization of a waste cooking oil biodiesel/diesel powered CI engine: an RSM approach with central composite design". Article number: 30474 (2024).
- [13] Maroa, Samwel Semakula, "The Effects of Exhaust Gas Recirculation (Egr) on the Performance of Diesel Engine". 217081370.
- [14] M.S.Gad, MostafaM. AbdelAziz, Hatem Kayed, "Impact of different nano additives on performance, combustion, emissions and exergetic analysis of a diesel engine using waste cooking oil biodiesel". <https://doi.org/10.1016/j.jprr.2022.04.004>.
- [15] M.Mofijur, M.G.Rasul., "Role of biofuel and their binary (diesel-biodiesel) and ternary (ethanol-biodiesel-diesel) blends on internal combustion engines emission reduction". *Renewable and Sustainable Energy Reviews* 53(2016) 265-278
- [16] Md.Mofijur Rahman, Masjuki Hj. Hassan, Performance and emission analysis of Jatropa curcas and Moringa oleifera methyl ester fuel blends in a multi-cylinder diesel engine. *Journal of Cleaner Production* 65(2014) 304-310
- [17] Ramhari Poudal, Pavel Loskot., Mitigating the current energy crisis in Nepal with renewable energy sources. *Renewable and Sustainable Energy Review* 116(2019)109388.
- [18] Licia Pietrosemoli, Carlos Rodriguez-Monroy., The Venezuelan energy crisis: Renewable energies in the transition towards sustainability. *Renewable and Sustainable Energy Reviews* 105 (2019) 415-426.
- [19] Eyasu Shumbulo Shuba, Demeke Kifle., Microalgae to biofuels: 'Promising' alternative and renewable energy, review. *Renewable and Sustainable Energy Reviews* 81 (2018) 743-755.
- [20] P. Tamilselvan, N. Nallusamy., A comprehensive review on performance, combustion and emission characteristics of biodiesel fuelled diesel engines. *Renewable and Sustainable Energy Reviews* 79 (2017) 1134-1159.
- [21] Ahmad Abbaszaadeh, Barat Ghobadian., Current biodiesel production technologies: A comparative review. *Energy Conversion and Management* 63 (2012)138-148.
- [22] V.K. Shahir, C.P.Jawahar., Comparative study of diesel and biodiesel on CI engine with emphasis to emissions— A review. *Renewable and Sustainable Energy Reviews* 45 (2015)686-697.