Combined effect of 'biodiesel, ethanol, exhaust gas recirculation and magnetization of fuel' on the performance and emission parameters of diesel engine.

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ABSTRACT

Utilization of biodiesel as alternative fuel results in higher emission of oxides of nitrogen (NOx) and reduced performance parameters. Exhaust gas recirculation (EGR) is a great technology to control the emission of NOx, but use of EGR reduces the performance parameters of diesel engines. Oxidative addition and magnetization of fuel help to make the combustion complete. In the present investigation, Jatropha biodiesel has been used with diesel in the form of a blend having 20% biodiesel (BD20) as fuel in 4-stroke, direct ignition, diesel engine. 5% Ethanol (E5) has been used as additive along with biodiesel blends and 10% EGR. The magnetization of fuel (MF) has been done with the help of a permanent magnet having strength of 3000 gauss. The results of this investigation show that BD20 is beneficial as fuel for reducing emissions like Carbon Mono-oxide, Hydro-Carbon, and smoke but it reduces Brake Power and Brake Thermal Efficiency. BD20E5 gives better performance parameters than the BD20, but the emission of HC

increases slightly. 10% EGR reduces NOx emission with a small cost of performance parameters but with MF performance and emission parameters were improved.

Keywords: Biodiesel; Diesel Engine; Ethanol; Exhaust gas recirculation; Fuel Magnetization.

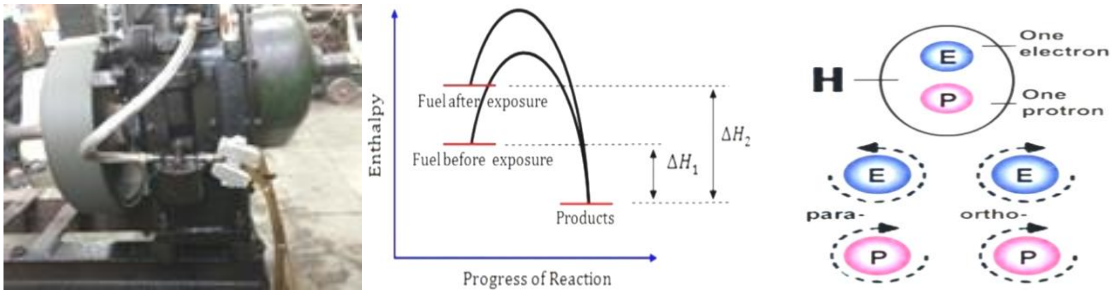
INTRODUCTION

All nations of the world are confronting the issues of exhaustion of petroleum fuel and contamination of the atmospheric air because of the creation of hurtful gases (Bhale *et al.*, 2009; Madiwale *et al.*, 2018; Srinidhi *et al.*, 2018). Looking for elective fuel biodiesel can turn into a key factor to full fill the world's vitality request and diminish the toxic outflows (Madiwale *et al.*, 2018; Kumar *et al.*, 2018; Srinidhi *et al.*, 2019; Srinidhi *et al.*, 2020; Srinidhi *et al.*, 2021). Biodiesels are methyl ester or ethyl ester of plant oil, for the most part delivers from transesterification of eatable and non-eatable oil (Bhale *et al.*, 2009; Kumar *et al.*, 2018; Srinidhi *et al.*, 2020). With the utilization of biodiesel as fuel in compression ignition engine execution factors were diminished somewhat, while outflows of HC, and CO reduces when contrasted with 100% diesel (D) yet emanation of NOx increases (Ashok *et al.*, 2017; Ashok *et al.*, 2018; Srinidhi *et al.*, 2018; Srinidhi *et al.*, 2019; Srinidhi *et al.*, 2020; Srinidhi *et al.*, 2021). As per some investigation outflow of Carbon di Oxide (CO_2) is additionally higher with biodiesel as fuel in a compression ignition engine, when contrasted with diesel (Srinidhi *et al.*, 2021).

Ethanol is one of the most common fuel additive, which provide improved mixing of fuel -air blend and promote the combustion of Jatropha biodiesel. Blends of alcohol and biodiesel try to modify the thermo-material properties of methyl ester (Srinidhi *et al.*, 2020). Ethanol has been used to reduce density and viscosity of biodiesel blends, ethanol is also rich in oxygen content which makes the atomization of biodiesel better due to it's good evaporative characteristic. (Imtenan *et al.*, 2014). Utilizing ethanol or bioethanol as an added substance with biodiesel brings about higher BTE, BSFC, and HC outflow while lower CO, NOx, and smoke emanation when contrasted with biodiesel (How *et al.*, 2014; Imtenan *et al.*, 2014; Misra and Murthy, 2011).

Recirculation of exhaust gases is a procedure to lessen unsafe emanations, explicitly for decreasing the discharge of oxides of nitrogen (NOx). In this, part of fumes is sent back to the inlet channel, which blends in with incoming air, and oxygen contained in it and utilized for the burning of fuel (Srinidhi *et al.*, 2019; Srinidhi *et al.*, 2020). When EGR is utilized with ethanol as added substance, while utilizing biodiesel mixes as fuel, BTE is lower and BSFC is higher (Yasin *et al.*, 2015; Sakhare *et al.*, 2016; Solaimuthu *et al.*, 2015). The outflows of HC, CO, and CO_2 are seen as marginally higher with the utilization of EGR and biodiesel as fuel (Yasin *et al.*, 2015; Yasin *et al.*, 2017; Srinidhi *et al.*, 2019).

When the charge is made to enter the burning chamber, then mixing and realignment of molecules with oxygen are left. The realignment of hydrocarbon chains with oxygen and ionization of particles are necessary conditions for improved combustion. This can be achieved by the application of magnetic field on fuel piping, before the ignition chamber as shown in fig. 1 (a) (Sahoo and Jain, 2019). Magnetization changes the hydrocarbon molecules from the larger bundles to the smaller group with higher space for oxygen needed for improved combustion, which improves the combustion and declined outflow of NOx and CO for the most part (Wahhab *et al.*, 2017; Sahoo and Jain, 2019). Application of magnetic field on fuel makes the bond between oxygen and hydrocarbon much stronger and increases the enthalpy of combustion as shown in fig. 1 (b) (Wahhab *et al.*, 2017). Hydrogen atom is having dipole moment and charged positive or negative with the presence of proton and electron respectively. Due to the nucleus rotation under the effect of magnetic field hydrogen becomes paramagnetic or diamagnetic as shown in fig.1 (c). Polarization of fuel brings higher BTE and lower BSFC with the lower emanation of HC, CO, CO_2, and NOx (Wahhab *et al.*, 2017; Sahoo and Jain, 2019).



(a) (b) (c)

Figure 1.(a) Fuel Magnetization (Sahoo and Jain, 2019), (b), Effect of Magnetization on Combustion Energy (Wahhab et al., 2017) (c) Atomic Orientation (Wahhab et al., 2017)

MATERIALS AND METHODOLOGY

In the present investigation fuel used is the blend of biodiesel of jatropha oil and diesel. Jatropha methyl ester has been collected from Hindustan biodiesel Ujjain, Madhya Pradesh, India. Fuel blends prepared for this experimentation are Pure diesel (D), 80% diesel with 20% biodiesel (BD20) and 75% diesel + 20% biodiesel + 5% ethanol (BD20E5). Ethanol has been taken from Mahakal Institute of Pharmacy Ujjain, Madhya Pradesh, India.

Test Fuel

Density and viscosity of ethanol match with those of biodiesel and it is highly soluble in biodiesel (Bhale, *et al.*, 2009). In this research firstly, ethanol was blended with biodiesel and mixed properly. After that this blend of ethanol and biodiesel were blended with diesel and mixed again. No surfactant was used in this investigation. Table 1 shows the important chemical properties of fuel blends used during this investigation.

Table 1. Properties of Fuel Blends.

Properties	D	BD20	BD20E5
Density (kg/m3)	850	852.12	851.75
Calorific Value (kJ/g or MJ/kg)	43.400	41.83	40.95
Viscosity (@ 40 °C, mm2/s)	3.5	3.72	3.65
Latent Heat of Vaporization (kJ/kg)	250	240	270
Cetane No	47	47.8	45.81

Experimental Setup

The experimental setup consists of a four-stroke, single cylinder, vertical diesel engine having a constant compression ratio of 17.5. The schematic diagram of the complete set up used for this investigation is shown in fig. 2.

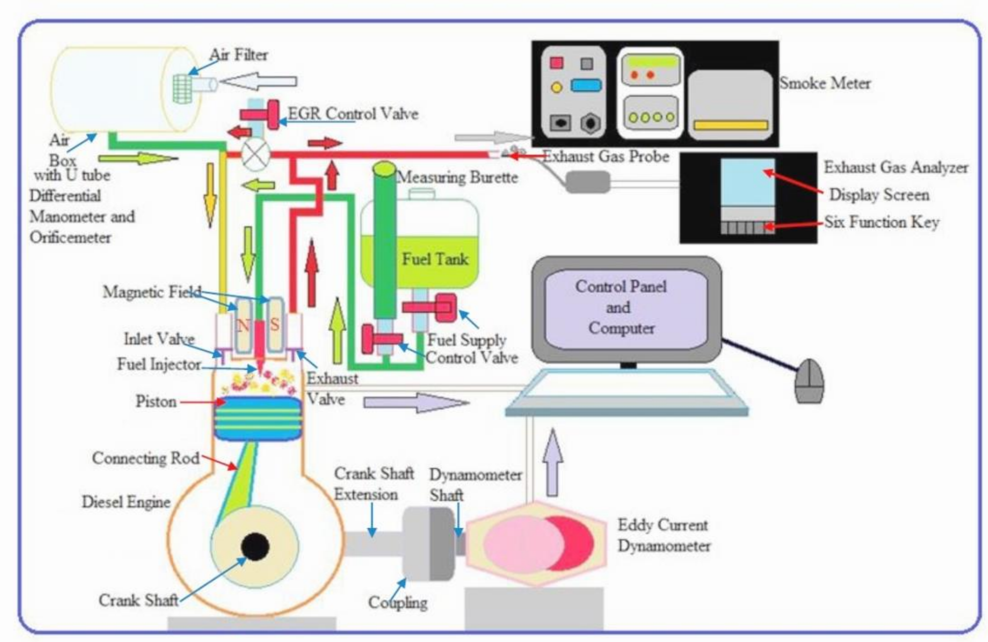
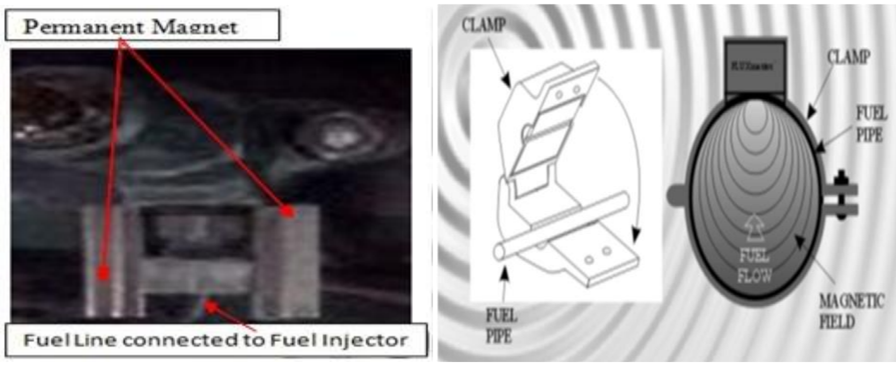


Figure 2. Schematic diagram of the experimental setup

No governor has been used in this research. Speed was changing with change in load and can be measured with the help of Tachometer. Maximum and minimum speeds were noticed between 1300 and 1600 RPM respectively. Brake power depends upon speed and torque produced, which is the reason behind the change in BP and given by:

BP=2πNT/60 (Solaimuthu, *et al.*, 2015)

Where N is speed in RPM and T is the torque produced in N-m.



(a) (b)

Figure 3.(a) Fuel Magnetization, (b) Magnetization of fuel (Wahhab, *et al.*, 2017)

Magnetization of fuel has been done by attaching permanent magnet on fuel line, just before injection of fuel blend into the cylinder as shown in fig. 3(a). Magnetic field can also be produced with the help of electric magnet as shown in fig. 3(b) (Wahhab, *et al.*, 2017, Sahoo and Jain 2019).U tube differential manometer and orifice meter have been used for flow measurement of air. Readings for the consumption of fuel is taken from the attached burette. Thermocouples have been used for temperatures at different points and temperatures were shown on the control panel. Air-box, air filter, eddy current dynamometer and magnet of 3000 gauss are the devices used in this study. Rota-meters have been used for the discharge calculations of cooling water for engine and dynamometer. Observations have been taken with no load, 5kg, 10kg, 15kg and 20kg load with various fuel blends and with various conditions. Table 2 shows the specifications of the diesel engine. Table 3 shows the uncertainties in the measurements of various parameters calculated by Root Sum Square method (Sahoo and Jain, 2019). Calculated value of overall uncertainty is 3.76.

Table 2. Technical specifications of the Diesel Engine.

Engine	Kirloskar tv1
Bore x stroke	87.5mm x110mm
Cubic Capacity	661 cm3
Compression Ratio	17.5:1
Rated output:	5.2kw at 1500 rpm
Fuel injector pressure	20-25Mpa
Injection timing	23 degree before Top Dead Centre (TDC)
No of valves	2
Valve timing	4.5 degree
Inlet valve opens before TDC	35.5 degree
Inlet valve opens After Bottom Dead Centre (BDC)	35.5 degree
Exhaust valve opens before BDC	4.5 degree
Governor type	Mechanical, centrifugal type
Fuel injection type	Mechanical individual pump

Table 3. Uncertainty Analysis of various measuring parameters

Device/ Parameter	Range	Accuracy	Uncertainty
Carbon Monooxide	0 to 10% by vol.	0.01% by vol.	±0.2
Carbon Dioxide	0 to 20% by vol.	0.1% by vol.	±1
Oxides of Nitrogen	0 to 4000 ppm vol.	1 ppm vol.	±2
Hydrocarbon	0 to 20000 ppm vol.	1 ppm vol.	±0.3
Exhaust Gas Temperature	0 to 500°C	±1°C	±1.4
Flow Meter	1 to 20 cc	±0.1 cc	±0.6
Piezo sensor	0 to 5000 psi	±1 bar	±1.2
Smoke	0 to 100% opacity in %	±1% full scale reading	±1.5
Engine speed	250 to 8000 rpm	10 rpm	±0.1
Time (Stop watch)	999 minutes/59.9 s	±0.1 s	±1
U-tube manometer	0 to 500 mm	±1 mm	±1
Burette	0 to 100 cc	±1 cc	±1

RESULT AND DISCUSSION

Performance Parameters

Fig. 4 (a), (b) and (c) show the variation in performance parameters like BP, BTE and BSFC with various blends and conditions. BP and BTE are slightly lesser with BD20 as compared to diesel fuel. BP is lower due to lower calorific value, higher density and higher viscosity of BD20 than D, which reduces atomization and combustion efficiency (Ahmed *et al.*, 2014; Imtenan *et* *al.*, 2014). Reductions in BP and BTE have been reduced by using BD20E5 due to imroved atomization and combustion efficiency (Misra and Murthy, 2011; Imtenan *et al.*, 2014). BTE further increases with BD20E5 + MF as compared to BD20. Fuel Particles are dispersed and devided finely, which results in active interlocking of oxygen with fuel molecules and increases the degree of complete combustion (Sahoo and Jain, 2019). Maximum decrease in BTE with BD20, BD20E5, BD20+MF and BD20E5+MF with respect to diesel are 11.60%, 10.83%, 10.83% and 6.52% respectively. But with the use of EGR, BP and BTE are lower than all tried blends and techniques, due to insufficient oxygen present in the combustion chamber resulting in incomplete burning (Yasin *et al.*, 2015). The highest reduction in BP and BTE with BD20E5+10%EGR noticed are 7.88% and 22.68% respectively with reference to diesel. These decreases in BP and BTE have been reduced with BD20E5+10%EGR+MF to 6.22% and 17.72% respectively. Presence of ionized particles in combustion chamber improves the combustion hence increases the brake power (Barna and Lelea, 2017).

It can be seen that BSFC increases with the use of BD20 due to lower heating value of BD (Ashok, et al. 2017). BSFC further increases with the use of EGR due to lower oxygen content during combustion (Yasin *et al.*, 2015). The highest relative increase in BSFC is 19.52% at medium load with BD20 as compared to diesel. With BD20E5, BD20+MF and BD20E5+MF this increase is 16.02%, 15.35% and 9.53% respectively as compared to BD20. Improved atomization and combustion quality result in slight decrease in BSFC with additive (Imtenan *et al.*, 2014). But as 10% EGR is utilized along with BD20E5 this increment goes up to 18.01%. Utilizing BD20E5+10%EGR+MF brings down this increase to 11.75%. Reduced surface tension and increased energy with magnetic field are the reason for reduced BSFC with fuel magnetization (Wahhab *et al.*, 2017).

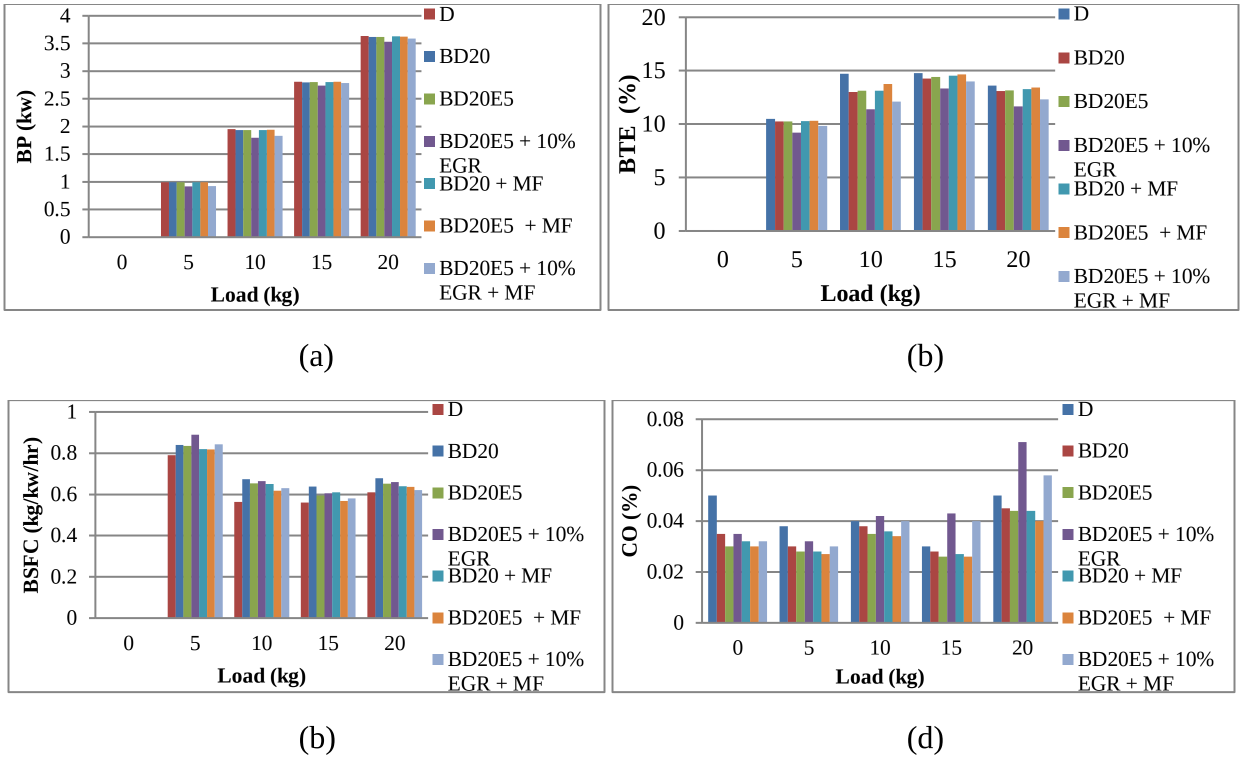


Figure 4. Variation in (a) BP, (b) BTE, (c) BSFC and (d) CO emission with various blends and operating conditions.

Emissions

Fig. 4 (d), Fig. 5 (a), (b), (c) and (d) show the variations in emissions of CO, HC, NOx, CO_2 and smoke with various blends and operating conditions. Emission of CO decreases with the use of BD20 as compared to diesel due to higher cetane number and inherent oxygen content (Ashok et al., 2017), CO emission further reduces with the use of BD20E5 due to increased level of oxygen in fuel blend (Imtenan *et al.*, 2014). There is a decrease in HC outflow with the use of BD20 and BD20E5 as compared with diesel. But HC emission is a little higher with BD20E5 than with BD20 and these results are inline with Bhale *et al.*, 2009. CO emission is much lower with the use of BD20E5+MF due to inrceased oxygen availability and improved combustion (Sahoo and Jain, 2019). But the emissions of CO and HC increase with the use of EGR due to replacement of oxygen by exhaust gases and incomplete combustion (Yasin *et al.*, 2015) and controlled by MF verified with Sahoo and Jain, 2019. Maximum decrease in CO with BD20, BD20E5, BD20+MF and BD20E5+MF as compared to diesel are 30%, 40%, 36% and 40%. The maximum increase in CO and HC emissions with BD20E5+10%EGR are 40% and 23.40%, which were brought down to 36% and 14.89% with the use of BD20E5+10%EGR+MF.

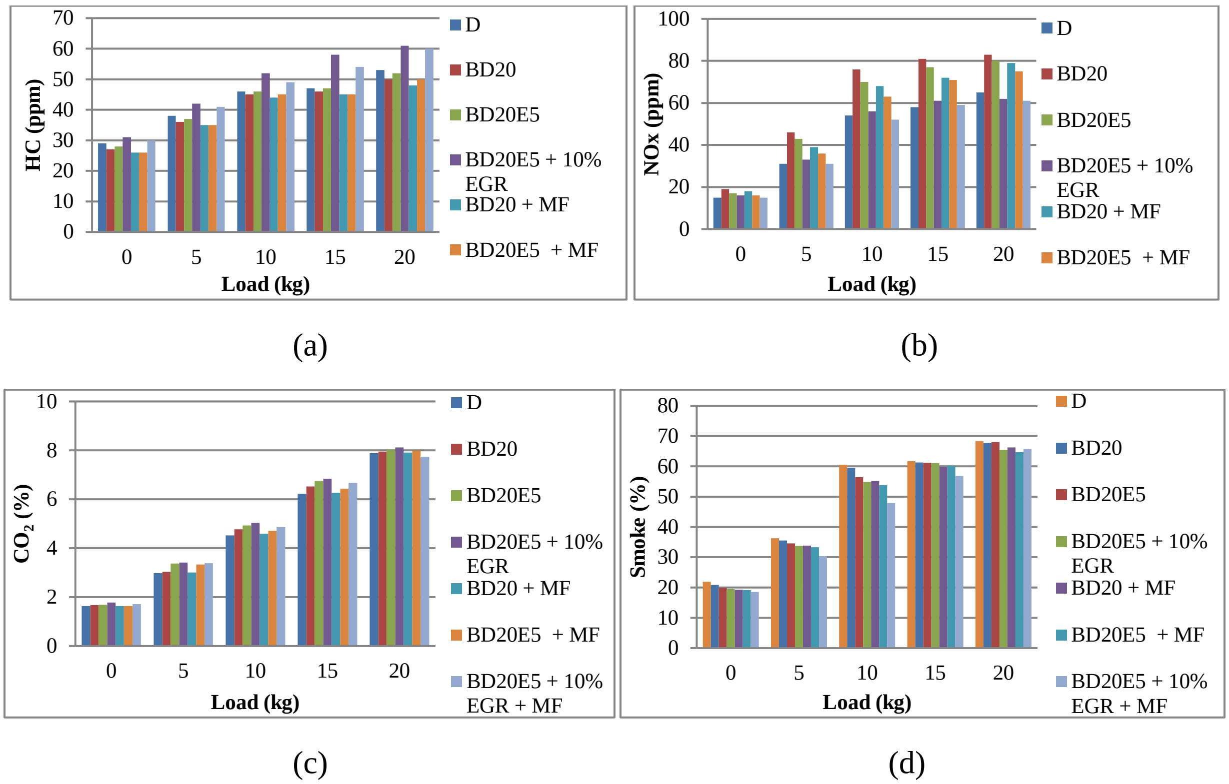


Figure 5. Variations in (a) HC, (b) NOx, (c) CO_2 and (d) smoke emission with various blends and operating conditions.

The emission of NOx increases with the use of biodiesel up to 48.38% due to higher oxygen content in BD, which results in elevated oxidation, increased EGT and higher NOx emission (Ahmed *et al.*, 2014). EGR reduces the temperature by increasing total heat capacity of gases in combustion chamber (Yasin *et al.*, 2015). At higher loads with BD20E5+10%EGR, a decrease of 4.61% in the relative percentage of NOx has been noted. Ethanol addition reduces the average temperature of working gas due to higher latent heat of vaporization and lower heating value (Imtenan *et al.*, 2014). NOx is further reduced upto 6.15% using BD20E5+10%EGR+MF with the dispersed fuel arrangement achieved by fuel magnetization validated with Wahhab *et al.*, 2017.

The emission of CO_2 is a little higher with various blends as compared to diesel, due to the complete combustion of fuel and conversion of CO into CO_2 verified with Yasin et al. 2015 and 2017. The highest percentage of CO_2 increase goes up to 14.76% with BD20E5+10%EGR at a lower load. This increase has been brought down to 13.75% with the use of BD20E5+10%EGR+MF verified with Sahoo and Jain 2019. With biodiesel and ethanol, smoke emission reduces due to present of higher oxygen to burn fuel (How *et al.* 2014). Effect of producing higher smoke with EGR was suppressed with ethanol and fuel magnetization. It may be due to proper mixing and improved combustion takes place with high oxygen content and ionization of fuel molecules (Thiyagarajan et al., 2018).

CONCLUSION

Use of biodiesel introduces penalty in the form of lower BP, lower BTE, higher BSFC, and higher NOx emission. Using biodiesel also reduces emissions like CO, HC and smoke outflow as compared to diesel. The average decrease in BP, with BD20E5+10%EGR+MF blend was 3.10%, average increase in BSFC was 4.80%, average decrease in BTE was 7.75%, average decrease in CO emission was 1.54%, average increase in HC emission was 9.19%, average decrease in emission of NOx was 1.62% and the average decrease in smoke outflow was 12.86% as compared with diesel. Based on the results and discussion conclusion can be made, that Biodiesel, ethanol and EGR could be used in lower quantity to maintain optimum level of performance and emission parameters along with fuel magnetization.

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