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Influence of magnetized waste cooking oil biodiesel on performance and exhaust emissions of a diesel engine

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Abstract : Continuous fuel consumption increase and harmful exhaust emissions led to intensive search about alternative fuels and techniques for fuel saving. Waste cooking oil (WCO) biodiesel was derived from WCO by transesterification process. Biodiesel properties were within acceptable limits of ASTM standards. Biodiesel blends were prepared from diesel and WCO biodiesel in volume percentages of 10 and 20% as B10 and B20. A comparative study of performance and exhaust emissions of a diesel engine burning biodiesel blends under magnetic field effect. The magnetic field was mounted along the fuel line before fuel injector. The magnetic field was produced from a permanent magnet of 4000 Gauss. Influence of magnetic field on performance parameters such as specific fuel consumption, thermal efficiency, exhaust gas temperature and air- fuel ratio of a diesel engine was studied at different engine loads. Exhaust emissions such as CO, CO_2, HC and NO_x for a diesel engine burning biodiesel blendsB10 and B20 under the effect of magnetic field were studied. Applying the magnetic field to fuel line increased thermal efficiencies for crude diesel, waste cooking oil biodiesel blends B10 and B20 by 2, 4 and 11 %, respectively. There were decreases in CO emissions by 3, 3.5 and 4 for diesel oil and biodiesel blends B10 and B20, respectively under magnetic field. Decreases in HC emissions for diesel, B10 and B20 fuels were 6, 11 and 8%, respectively. Decreases in NOx emissions by 3, 1.5 and 2% for diesel and biodiesel blends B10 and B20, respectively were shown with the effect of fuel magnet.
Keywords : WC, Biodiesel, Magnetic field, Performance, Emissions.

1. Introduction

The increase of fossil fuel demand and harmful emissions in human life, transportation and power generation led to intensive search about alternative fuels. Fossil fuel resources are non renewable and depletable in the near future. Greenhouse gases effect, harmful emissions, and global warming caused environmental impact. Biodiesel is an alternative fuel derived from the transesterification of vegetable oils and waste cooking oil [1, 2, 3]. Injector coking problems, oil dilution, deposits in various parts of engine were produced due to its higher viscosity [4]. Repeated use of edible vegetable oil led to higher free fatty acid [5].

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WCO causes disposal problems as river water pollution and drainage choking. Transesterification was used to produce biodiesel from waste cooking oil by [6]. Characteristics of WCO biodiesel are similar to diesel oil. Thermal efficiency, carbon monoxide, unburned hydrocarbon and smoke opacity were lower compared to diesel fuel. Oxides of nitrogen and specific fuel consumption of WCO biodiesel blends are higher than diesel oil [7].

Applying the magnetic field to fuel line of a single cylinder diesel engine led to a decrease in specific fuel consumption by about 8%at higher load. The fuel consumption reduction was about 8% at higher load condition due to magnetic field influence. The reductions of NO_x, HC and CO_2 emissions were up to 27.7, 30 and 9.72%, respectively at part load [8]. CO emissions were reduced at higher engine loads. NO_X, HC, CO_2 emissions reductions were up to 27, 32 and 11%, respectively [9].There is an increase in the thermal efficiency due to fuel consumption reduction and exhaust emissions reductions for petrol engine under the effect of magnetic field. The reductions in CO, NO and HC emissions were up to 12, 11 and 19 %, respectively. Hydrogen particle is arranged in two isomeric forms para and ortho. There are different opposite nucleus spins. The ortho state of hydrogen has effectiveness about Para state for efficient combustion[10].

Magnetic field effect on performance of a diesel engine was studied. There is a thermal efficiency increase. The fuel consumption reduction was up to 12%. The reductions in CO and HC emissions were range up to 11, 27 %, respectively. The variation of permanent magnet strength led to improvement of engine performance. The viscosity of the hydrocarbon fuel decreased under applying of magnetic field. Hydrocarbon fuel molecules declusteringled to better atomization, better mixing of fuel-air mixture and improvement of thermal efficiency [11, 12].Application of permanent magnet in fuel line of a diesel engine improved the engine performance and reduced fuel consumption at higher engine loads. CO, NO, and CH_4 emissions were reduced by the effect of magnetic fuel energizer [13]. Hydrocarbon fuel molecules contain a number of atoms which consist of number of nucleus and electrons that orbit about their nucleus. Without the effect of magnetic field, fuel molecules have not the ability to be aligned and the molecules are not actively interlocked with oxygen molecules during combustion. The forces between molecules are reduced with the effect of magnetic field. Molecules had positive and negative electrical charges under magnetic field effect. Fuel molecules had been realigned during combustion. Hydrocarbon molecules are arranged in clusters. Strong permanent magnetic breaks down the clusters and there is an acquired maximum space available for oxygen molecules to combine with fuel molecules. The magnetic field resulted in better fuel economy and reduction of exhaust emissions [14].

If the magnetic field intensity increased, specific fuel consumption would be decreased and thermal efficiency would be improved in petrol engines. CO and HC emissions decreased with magnetizing the fuel before entering the engine cylinder. Fuel consumption reduction was up to 15% due the effect of magnetic field. CO, NO and CH_4 reductions at idling speed were up to 7, 30 and 40%, respectively [15, 16]. The reduction in fuel consumption was between (9-14) %. The percentages reductions of CO and HC emissions were 30 and 40%, respectively [10].Experimental tests were run on a petrol engine by using magnets of intensities 2000, 4000, 6000, and 8000 Gauss at constant speed of 1500 rpm. Increase of magnetic intensity led to increase of thermal efficiency and decrease of specific fuel consumption. Engine output brake power increased with increase in magnetic field intensity. Fuel consumption reduced up to 14% under the effect of magnetic field [18]. Performance and exhaust emissions were investigated for Motorcycle by applying the magnetic field to the fuel line before carburetor. A strong permanent magnet with strength of 3000Gauss was applied to fuel line. The average increase is 10% at 50 km/h. The reductions in CO and HC are about 36 and 13%, respectively. Fuel magnetism dissolves the carbon build up in carburetor jets, fuel injectors and combustion chambers [19].

Applying the magnetic field to fuel line before the burner of the boiler was studied. The magnetic field was applied by mounting two permanent magnets of 2000 Gauss intensity for each one. Subjecting the magnetic field led to a decrease in fuel consumption, CO and HC emissions by about 3.675, 38.04 and 21.89%, respectively. There were increases in CO_2 and exhaust gas temperature by about 3.432 and 4.34%, respectively [20].Magnetic field has a significant effect on engine performance. Magnetic field was applied by permanent and electromagnetic coils on different fuels such as gasoline, natural gas and diesel fuels. There were no significant changes in specific fuel consumption and air- fuel ratios for diesel fuel subjected to magnetic field. There were reductions in fuel consumption, CO and HC emissions for gasoline fuel subjected to magnetic field by about 15.5, 61.5 and 53 %, respectively. There were reductions in specific fuel consumption, CO and HC emissions for natural gas fuel subjected to magnetic field by about 13.8, 20 and 19 %, respectively [21]. Performance and emissions were analyzed of magnetic fuel energizer for motorcycles. A strong permanent magnet of 3000 gauss intensity was applied on fuel line before carburetor. There were reductions in CO and HC emissions by about 36 and 13%, respectively [22].Fuel consumption reduction under magnetic field effect was about 31.53% by using a wire magnet with diameter of 0.35 mm and number of winding 5000 turns [23].Magnetic field achieved a percentage of 28% reduction in fuel consumption and reductions in HC, CO and CO_2 emissions. This was due to realignment of hydrocarbon molecules, converting para to ortho rotation hydrogen molecules interlocked with oxygen during combustion to produce complete combustion [24].

Increase of the spray atomization by magnetic field effect reduced the viscosity of the fuel. This gave a wide A great surface area of the spray droplets per volume was produced to react with the oxidizer. This increases evaporation and mixture formation, reduction of particulate matter and increase of engine efficiency [25, 26]. Magnetic fuel conditioner increased the molecular internal energy to obtain complete combustion. A higher engine output, better fuel economy and reductions of HC and CO emissions. Magnetic fuel conditioner increased 10-40% mileage of vehicle. Magnetic fuel conditioner reduces clogging problems in engine. Magnetic fuel conditioner provides 30% extra life for expensive catalytic converter and reduces engine maintenance [27]. Fuel ionization caused better combustion of air-fuel mixture. Improper mixing of hydrocarbon and oxygen led to incomplete combustion. Fuel is ionized due to the magnetic field by electromagnets. This makes alignment and orientation of hydrocarbon molecules and better atomization of fuel. Electromagnet in fuel lines improved mileage and reduced emissions of vehicle [28].

The impact of magnetic field on diesel engine performance was shown. The magnetic field intensities were changed to 7000, 9000 and 18000 Gauss. A reduction in specific fuel consumption in diesel engine was up to 15.71%. Reductions in CO, NO_x, HC and CO_2 were 10.25, 7.40, 29.82 and 33.04%, respectively [29].The magnetic fuel ionizer improved fuel burning, increased thermal efficiency and reduced emissions. The magnetic fuel ionization decreased specific fuel consumption and smoke levels [30]. Magnetic field alters the structure of fuel. A reduction in exhaust emissions was shown by applying magnetic [31].CO_2, HC and CO emissions are decreased by 30.57, 97 and 30.57% respectively at 8000 gauss magnetic field. Fuel magnet of 8000 gauss capacity is more suitable than 4000 gauss [32]. The magnetic field reduced exhaust emissions and fuel consumption. Magnetization is economically to reduce exhaust emissions and fuel consumption [33]. Incorporating a magnetic tube in diesel engine fuel line on performance and emissions was studied. Reductions in specific fuel consumption and fuel consumption were about 3.5% and 15%, respectively. Improvement in thermal efficiency about 3.5%.Reductions in CO, HC and CO_2emissions were in the range of 21.9–33.3%, 5.4–11.3%, 29.4–64.7% and 2.68–4.18%, respectively [34]. Magnets applied to fuel reduce fuel consumption, improve emissions and improve engine operation [35, 36]. The application of magnetic field makes biodiesel molecules to ionize with oxygen and decluster HC molecules. The magnetic flux density is from 1400 to 1800 Gauss. Magnets can be used with biodiesel blends to improve the performance and emission of diesel engine [37].

The purpose of this study is to study the effect of magnetic field on biodiesel derived from waste cooking oil in diesel engine on exhaust emissions and performance. Transesterification process was used to produce biodiesel. WCO biodiesel was blended with diesel oil by volume percentages of 10 and 20%. Testing was used on a diesel engine at variable loads and constant engine speed at 1500 rpm. Thermal efficiency, specific fuel consumption, air- fuel ratio, CO, HC, CO_2 and NO_x emissions were recorded for biodiesel blends and compared to diesel oil.

2. Methodology and experimental set up

2.1. Biodiesel production process

Waste cooking oil was provided and collected from food factories, hotels and restaurants. Waste cooking oil had been filtered to avoid clogging and depositing on fuel nozzles. Waste cooking oil was used to derivemethyl ester by transesterification method. Biodiesel production was carried out in a conical flask has condenser and hot plate with magnetic stirrer. The flask was supplied with the oil and preheated to 65˚C. Sodium hydroxide catalyst (NaOH) by weight 1% was added to methanol solution of 6:1 molar ratio. Methoxide produced solution was put in the flask and the reaction was timed (1.5 hours). Then mixture was left to separate glycerol from biodiesel. Biodiesel was washed many times with water. The residual methanol, catalyst and water were separated from biodiesel by rotary evaporator at 80°C. WCO methyl ester was dried at 100°C.Mixing of biodiesel with diesel oil was done at different proportions of 10 and 20% by volume. Physical and chemical properties of biodiesel blends were agreed with ASTM standards of diesel oil and were arranged in Table 1.

Table 1: Chemical and physical properties of waste cooking oil biodiesel compared to diesel fuel.

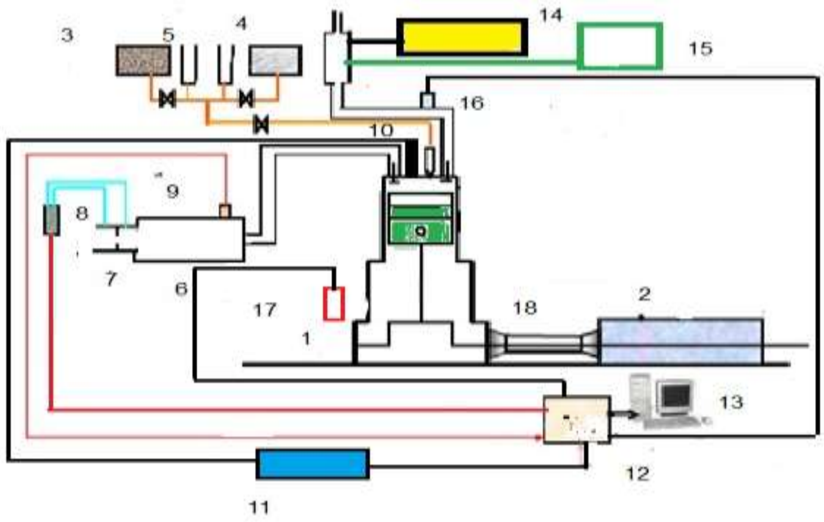
Properties	**D100**	**B100**	**B20**
Density at 15 °C , kg/m^3	834	892	855
Dynamic viscosity at 40°C, cst	2.7	4.5	3
Lower heating value, MJ/kg	44.49	42.83	43.95
Flash point , °C	160	75	62
Cetane number	55	65	58

3. Experimental Setup and instrumentation

Experimental tests were carried out on a diesel engine with a maximum power of 5.775 kW at rated speed of 1500 rpm**.** Table 2 shows the technical specifications of test engine. Figure 4 is shown schematic diagram of experimental engine. The test engine is coupled directly to AC generator of maximum power 10 kW for engine output brake power measurement. A sharp edged orifice mounted in one side of the air box to measure the air flow rate. Temperature measurements in intake air manifold and exhaust gas were done using thermocouple probes of type K. Fuel flow measurements. was made using one burette with stopcock and two way valves. MRU DELTA 1600-V gas analyzer and OPA 100 smoke meter were used for smoke and exhaust emissions measurements. The experimental work was carried out by engine load variation from zero to full load at constant speed of 1500 rpm.

Table 2.Test Engine Specifications.

Engine parameters	**Specifications**
Type	DEUTZ F1L511
Number of cylinders	1
Cooling type	Air cooled
Bore (mm)	100
Stroke (mm)	105
Compression ratio	17.5:1
Fuel injection advance angle	24º BTDC
Rated brake power (kW)	5.775 at 1500 rpm
Injector opening pressure (bar)	175



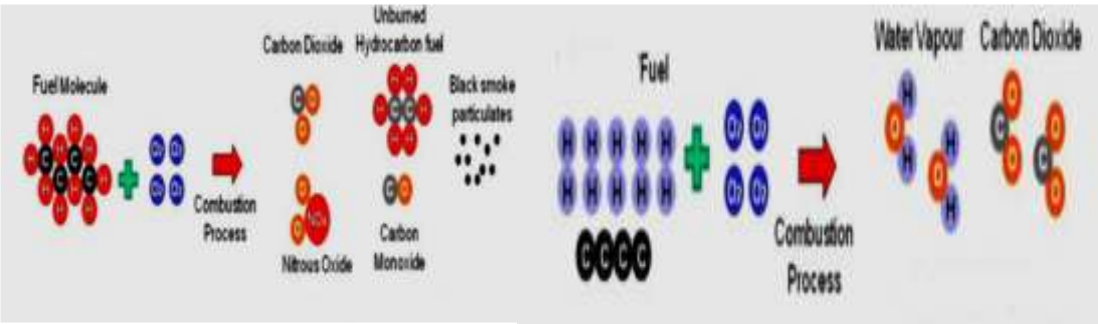
1.	Diesel engine	10- Piezo pressure transducer
2.	AC generator	11- Charge amplifier
3.	Diesel tank	12- Data acquisition card
4.	Biodiesel tank	13- Personal computer
5.	Burette	14- Exhaust gas analyzer
6.	Air surge tank	15- Smoke meter
7.	Orifice	16- Exhaust gas temperature thermocouple
8.	Pressure differential meter	17- Proximity switch
9.	Intake air temperature thermocouple	18- Cardan shaft

Fig.1. Schematic Diagram of a diesel Test Engine fueled with Magnetized biodiesel fuel.

4. Effect of magnetic field on fuel

Atoms of hydrocarbon fuel consist of nucleus and electrons that orbit about their nucleus. Fuel molecules cannot be aligned and cannot actively interlock with oxygen molecules during combustion without the effect of magnetic field and the intermolecular forces between molecules are reduced. Molecules had positive and negative electrical charges with the effect of magnetic field. Magnetic field makes spinning electrons absorb the energy and flip into alignment. Hydrocarbon fuel molecules are arranged in clusters. If Strong permanent magnetic breaks down the clusters, viscosity decreases, disperse molecules and acquired maximum space available for oxygen molecules to combine with fuel molecules. The ionization of fuel under the effect of magnetic field dissolves the carbon build up in the combustion chambers and fuel injectors and keeping the engine in cleaner condition as shown in Fig.2 [25, 26].

Hydrogen is in two distinct isomeric forms para and ortho. Different opposite nucleus spins are produced from hydrogen. Ortho state of hydrogen is better for combustion because it is more effective than para state. Strong magnetic field produced ortho state along the fuel line. Strong permanent magnets changes the fuel orientation (para to ortho) and its change their configuration as shown in Fig.3. Fuel particles become finely divided and easy to combine with oxygen [14]. Nuclear alignment makes hydrocarbons fuel to flow easily and burn more efficiently. Positive ionization leads to attract and bond with negatively charged oxygen and causes efficient combustion [16]. This led to fuel better atomization and better fuel-air mixing. Fuel economy, less fuel consumption and emissions reductions under the effect of magnetic field [7].



(a) Without magnet **(b) With magnet**

Fig. 2: Effect of magnetic field on hydrocarbon fuel.

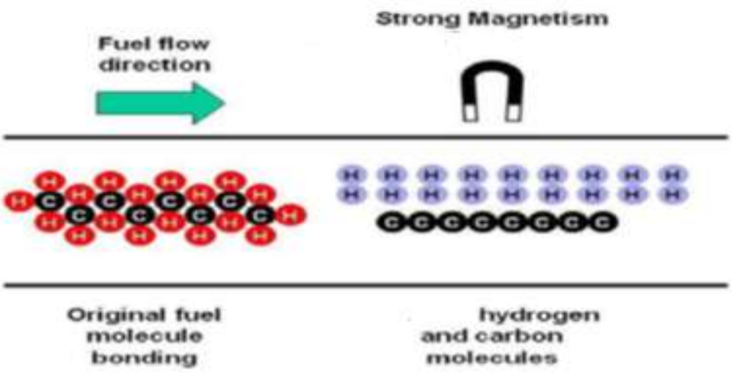


Fig. 3: Effect of strong magnet on hydrocarbon fuel.

5. Results and Discussion

5.1 Effect of fuel magnetism on specific fuel consumption

Effect of engine load on specific fuel consumption for WCO biodiesel blends and diesel fuel under magnetic field is shown in Fig.4. Waste cooking oil biodiesel blends showed higher specific fuel consumptions at all loads compared to diesel fuel. B10 and B20 showed increases in fuel consumption proportional to biodiesel volume percentage of biodiesel. Biodiesel heating value is about 14.88% lower than that of diesel fuel. More fuel was consumed compared to diesel fuel to develop the same power. Magnetization of biodiesel blends reduced fuel consumption and specific fuel consumption. Fuel particles become finely divided and easy to combine with oxygen. Hydrocarbon fuel flows easily and burns more efficiently. This led to fuel better fuel-air mixing, atomization and fuel consumption under the effect of magnetic field. There are decreases in specific fuel consumptions for magnetized biodiesel blends about demagnetized biodiesel blends B10 and B20. Specific fuel consumption for diesel fuel is 0.264kg/kW.hr at full load. WCO biodiesel blends B10 and B20 specific fuel consumptions are 0.309 and 0.367 kg/kW.hr, respectively at full load. Decreases of specific fuel consumptions for magnetized diesel oil, WCO biodiesel blends B10 and B20 about demagnetized fuels are 2, 4 and 11 %, respectively at full load [27, 28, 34].

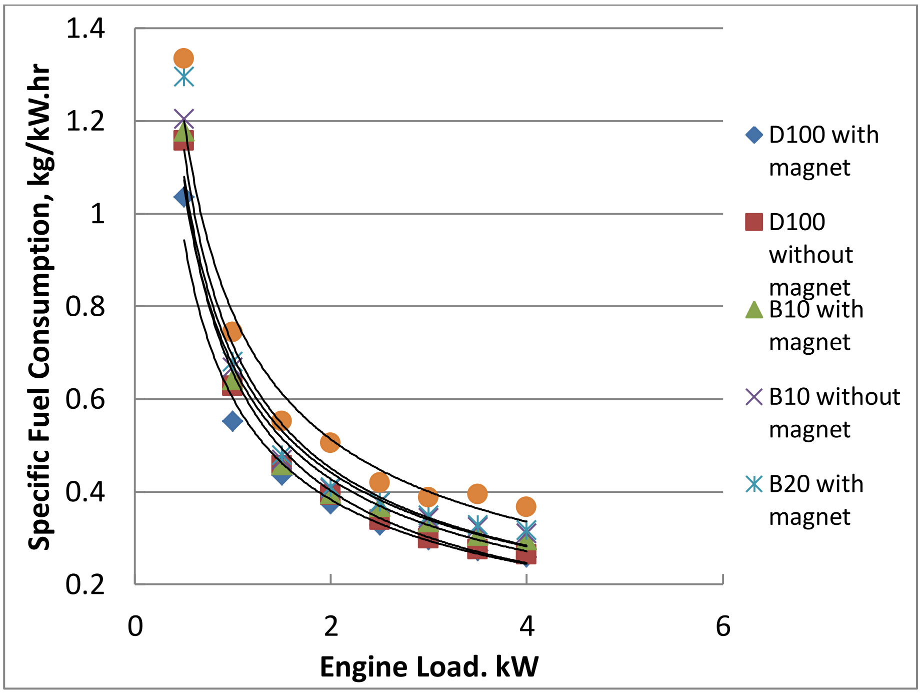


Fig.4: Values of specific fuel consumptions at engine loads for biodiesel blends with and without magnet.

5.2 Effect of fuel magnetism on thermal efficiency

Figure 5 portrayed thermal efficiency variation with engine load for biodiesel blends in the ratio of 10 and 20% with diesel fuel subjected to magnetic field. Thermal efficiency of WCO biodiesel blends increases with increase of engine load. The heat release in the cylinder increases and the thermal efficiency increases as the brake power increases. Lower thermal efficiencies were shown for B10 and B20 compared to diesel fuel at all loads due to poor combustion characteristics, lower heating value, higher viscosity and poor volatility compared to diesel fuel. Magnetization of biodiesel blends reduced fuel consumption and specific fuel consumption. Hydrocarbons fuel to flow easily and burn more efficiently and led to fuel better atomization, better fuel-air mixing and better fuel consumption under the effect of magnetic field. Magnetic field improved mixture formation due to the reduction in surface tension and viscosity of the fuel. A great surface area of the spray droplets per volume was produced to react with the oxidizer. There is increase in thermal efficiencies for magnetized biodiesel blends about demagnetized B10 and B20. Increases of thermal efficiencies for magnetized diesel oil, WCO biodiesel blends B10 and B20 about demagnetized fuels are 2, 4, and 11 %, respectively at full load [27, 28, 34].

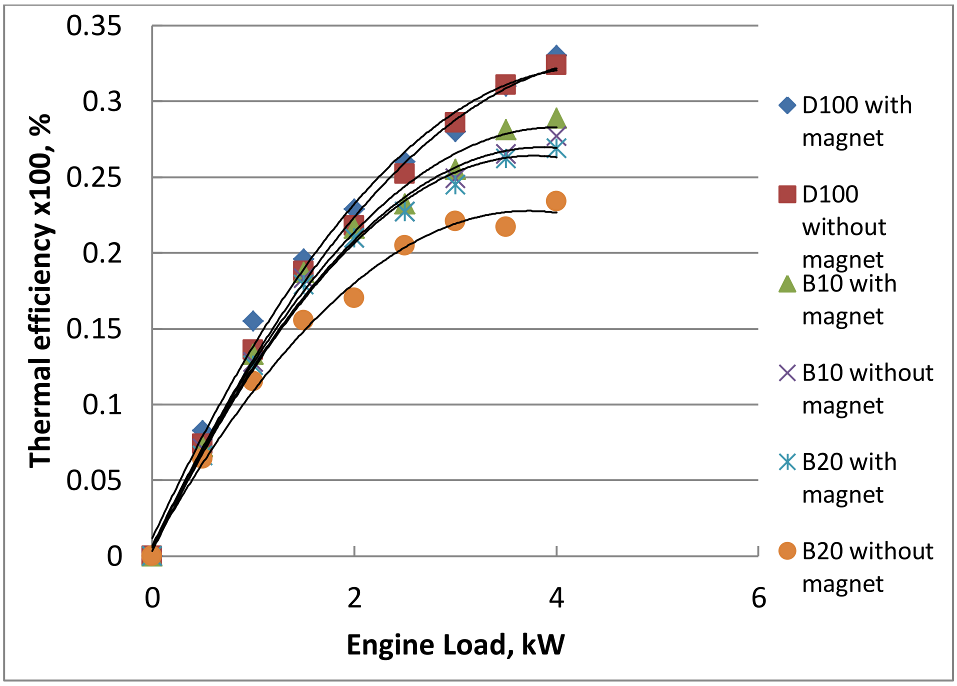


Fig.5: Thermal efficiency at different loads for biodiesel blends with and without magnet.

5.3 Effect of fuel magnetism on air-fuel ratio

Air- fuel ratios of biodiesel blends under magnetism effect were investigated in Fig.6. Decrease of air-fuel ratios with engine load increase due to fuel consumption increase and the richer mixture. Biodiesel blends produced higher fuel consumptions and lower air- fuel ratios compared to diesel fuel. Air- fuel ratios decreased with biodiesel percentage due to increase in fuel consumption. Fuel magnetization led to a reduction in fuel consumption. Air- fuel ratios increased for magnetized biodiesel blends about demagnetized biodiesel blends due to decrease in fuel consumption. Fuel better atomization, better fuel-air mixing and better fuel consumption under the effect of magnetic field were shown. Reduction of the viscosity and surface tension of the fuel under magnetic field effect improved mixture formation. Air- fuel ratios of biodiesel blends B10 and B20, respectively are 20.99, 17.94 and 15.14 at full load. Air- fuel ratios for magnetized diesel oil, WCO biodiesel blends B10 and B20 are 22.3, 18.69 and 16.47 %, respectively at full load.

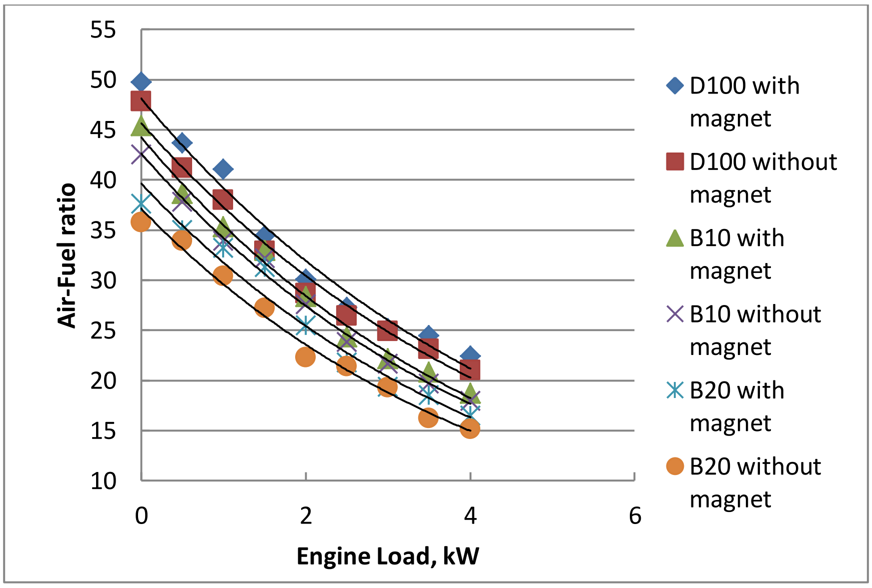


Fig.6: Influence of biodiesel blends with and without magnet. on air- fuel ratio at different loads

5.4 Effect of fuel magnetism on CO emission

Figure 7 shows CO emission trend for WCO biodiesel blends at different engine loads under magnetism effect. CO emission decreases from part load to . CO emissions are reduced by use of biodiesel blends. Biodiesel percentage Increase led to CO reduction. The decrease in CO emission for biodiesel blends is attributed to oxygen content in biodiesel blends and led to better combustion. Subjecting the fuel lines to magnetic field led to more efficient combustion. Fuel molecules were realigned, the intermolecular forces were reduced, easier to interlock with oxygen and producing a complete combustion. Hydrocarbon fuel molecules are arranged in clusters. Magnetism breaks down the clusters, viscosity decreases, disperse molecules and acquired increased space available for oxygen molecules to bond with fuel molecules. This led to fuel improved atomization, better fuel-air mixing and reduction of carbon monoxide emission under the effect of magnetic field. Fuel magnetism led to reductions in CO emissions for diesel oil and waste cooking oil biodiesel blends B10 and B20 about 3, 3.5and 4%,respectively at full load [26, 27, 28, 34].

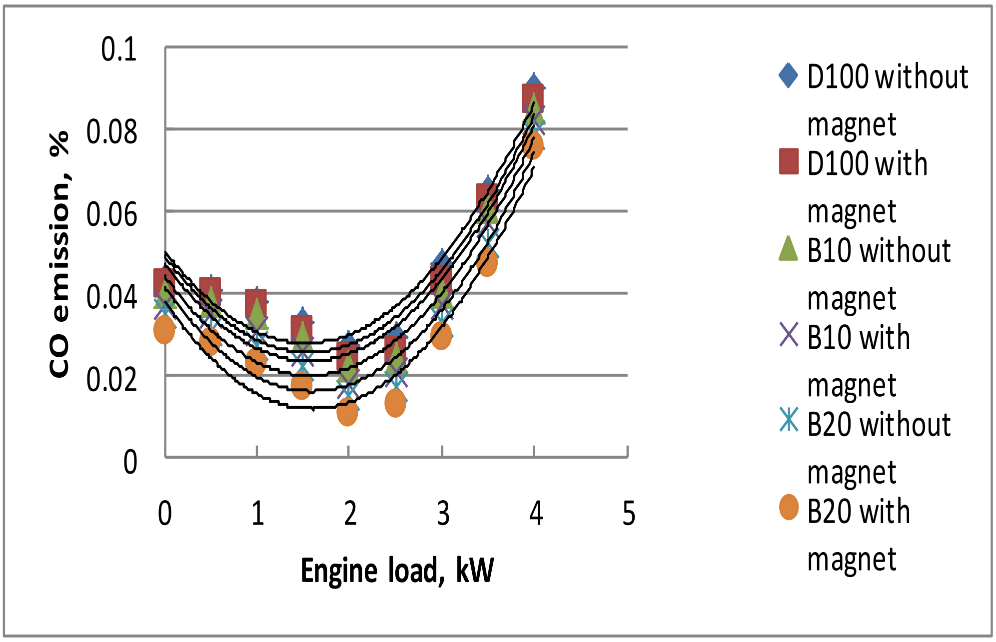


Fig.7 :CO emissions values at different engine loads for biodiesel blends with and without magnet.

5.5 Effect of fuel magnetism on CO_2 emission

Effect of magnetized and demagnetized WCO biodiesel blends on CO_2 emissions was shown in Fig.8. CO_2 emissions are higher for biodiesel blends compared to diesel fuel. CO_2 emission increased with engine load increase because of higher fuel consumption. Biodiesel blends produced CO_2 emissions higher than diesel oil and it increased with increase in percentage of biodiesel. CO_2 emission increased because of higher oxygen content in biodiesel blends. Subjecting biodiesel blends to magnetic field led to more complete combustion. Under effect of magnetism, fuel molecules were realigned, easier to interlock with oxygen and producing complete combustion. Ionization leads to fuel attraction and bonding with negatively charged oxygen and causes more complete combustion under magnetic field effect. This led to fuel better atomization, better fuel-air mixing and reduction of carbon dioxide emission. Applying fuel magnetism to diesel oil and WCO biodiesel blends led to increase in CO_2 emission about 5, 4 and 2%, respectively at full load [28, 34].

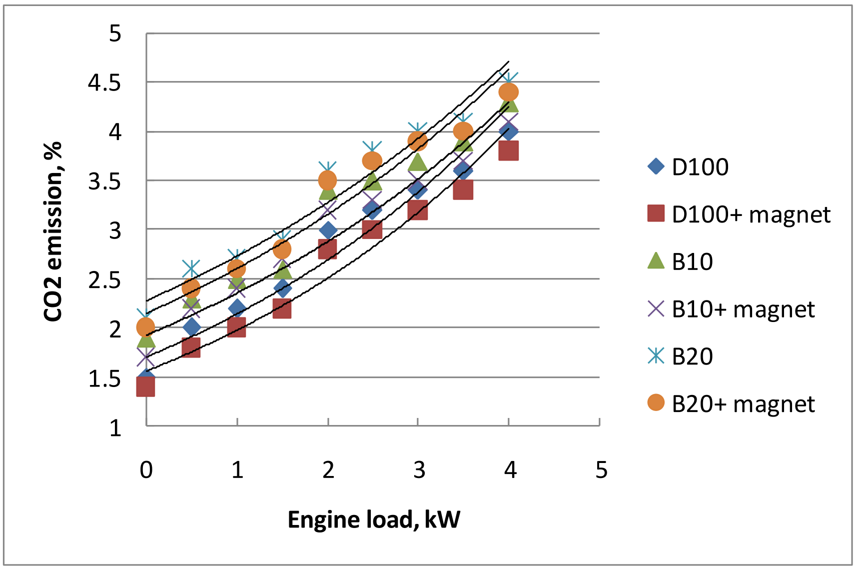


Fig.8 : CO_2 emissions at different engine loads for biodiesel blends with and without magnet.

5.6 Effect of fuel magnetism on HC emission

Figure 9indicatesthe effect of WCO biodiesel blends subjected to fuel magnetism on HC emissions. HC emission is lower at engine part load and increase for all the fuels as the load increases because of fuel rich mixture presence and oxygen content resulting at higher engine load. Higher percentage of oxygen leads to lower HC emissions at higher engine brake power. Biodiesel blends produced reductions in HC emissions compared to diesel fuel due to oxygen content resulting in better combustion and higher cetane number. Fuel magnetism breaks down the clusters, viscosity decreases, disperse molecules and acquired maximum space available for oxygen molecules to combine with fuel molecules. The ionization of fuel under the effect of magnetic field dissolves the carbon build up in the combustion chambers and fuel injectors. Ionization causes more complete combustion under magnetic field effect and led to fuel better atomization, better fuel-air mixing and reduction of carbon dioxide emission. Applying magnetic field to diesel oil and WCO biodiesel blends B10 and B10 led to reductions of HC emissions by about 6, 11 and 18%, respectively at full load [26, 27, 28, 34].

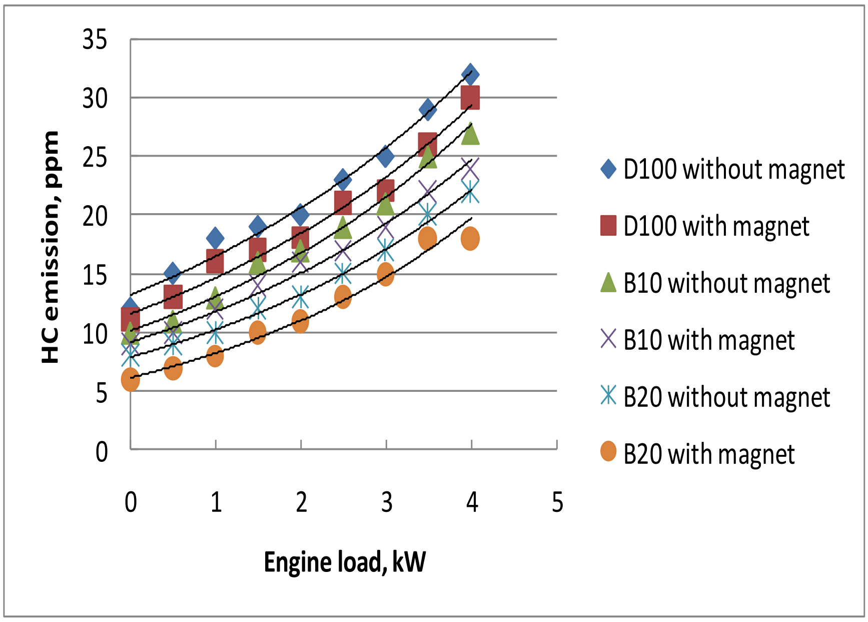


Fig.9: HC emission variation with engine load for biodiesel blends with and without magnet.

5.7Effect of fuel magnetism on NO_x emission

Effect of fuel magnetism on NOx emissions variations of WCO biodiesel blends from zero to full load is described in Fig.10. NOx emissions increased with engine load increase for all fuels. The fuel consumption increase with engine load results in increase of the cylinder temperature in the combustion chamber which led to thermal (Zeldovich) NOx formation. NOx emissions of WCO biodiesel blends are higher than diesel fuel. This may be due to the adiabatic flame temperature and oxygen content in biodiesel which help for complete combustion,higher cylinder temperature and NOx emission. Shorter ignition delay and the increased of biodiesel percentage undergoing premixed combustion led to higher cylinder pressure and temperature. The values of NOx emission for diesel oil, B10 and B20 are 300, 310 and 322 ppm respectively, at full load. Increase of biodiesel percentage produced increase in NO_X emission. Fuel magnetism led to decrease of NOx emissions. Applying magnetic field to diesel oil and waste cooking oil biodiesel blends B10 and B20 led to decrease of NOx emissions by about 3, 1.5 and 2%, respectively at full load [26, 27, 28, 34].NO_x concentration decreased when using fuel magnet. Fuel molecules had been realigned and were interlocked with oxygen during combustion. The fuel magnetism makes the fuel is more receptive to oxygen and producing a leaner combustion which causes less cylinder temperature and NO_x emission. Ionization allows fuel to attract and bond with negatively charged oxygen and causes more complete combustion under magnetic field effect. This led to fuel better atomization, better fuel-air mixing.

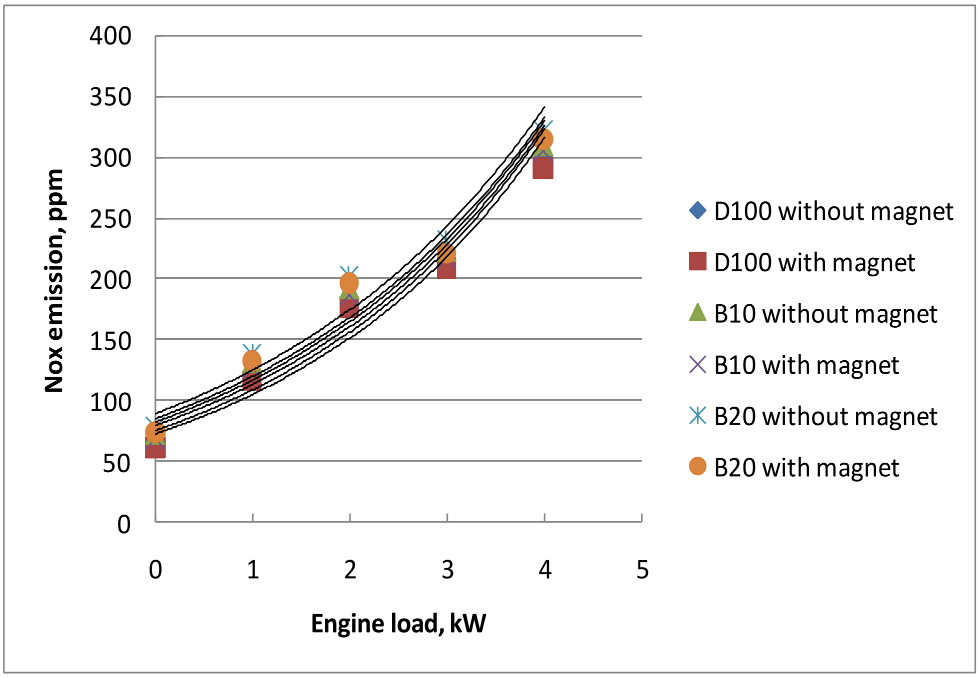


Fig.10: NO_x emission at different engine loads for biodiesel blends with and without magnet.

6. Conclusions

The experimental tests are run on a diesel engine at different loads. WCO biodiesel was produced from oil by transesterification process. It was mixed with crude diesel oil in different volume percentages of 10 and 20% as B10 and B20. The magnetic field has effects on engine performance and exhaust emissions and is summarized in these points:

1. The magnetic field reduced specific fuel consumptions by about 2, 4 and 11 % at full load for diesel oil, biodiesel blends B10 and B20, respectively.
2. The magnetic field increased the thermal efficiency by about 2, 4 and 11 % for diesel oil, biodiesel blends B10 and B20, respectively.
3. HC emissions were decreased by about 6, 11 and 8% at full load for diesel oil, biodiesel blends B10 and B20, respectively under magnetic field effect.

4. Magnetic field produced decreases in CO emission for diesel oil, biodiesel blends B10 and B20, respectively by about 3, 3.5 and 4 % at full load.
5. Decreases in NO_x emission were about 3, 1.5 and 2% at full load for diesel oil, biodiesel blends B10 and B20, respectively under magnetic field effect.

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