Effect of Fuel Magnetism on Industrial Oil Burner Performance Burning Waste Cooking Oil

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Abstract-- **Due to continuous consumption, depletion, increasing energy demand and harmful exhaust gases of fossil fuels in transportation and power generation, all these led to search about alternative fuels. Waste cooking oil is considered a new alternative fuel with lower price and solved the problem of getting rid of it. The chemical and physical properties of waste cooking oil were measured and analyzed according to ASTM standards. Waste cooking oil was preheated to 90°C before oil nozzle. A magnetic field was applied to the fuel line to magnetize the fuel before the burner. The magnetic field used in this study is coming from a permanent magnet of 4000 Gauss. Performance, exhaust emissions and combustion characteristics comparative study of a swirled oil burner burning diesel and waste cooking oil was done. Applying the magnetic field to fuel line decreased fuel consumption by 21 and 22 % for waste cooking and diesel oils, respectively. Exhaust gas temperatures for diesel and waste cooking oils decreased under fuel magnet effect. There were improvements in combustion efficiency by 8 and 12 % for diesel and waste cooking oils, respectively. There were decreases in CO_2 by 28 and 31%, HC by 29 and 25 %, CO by 30 and 37% for diesel and waste cooking oils, respectively under magnetic field. Increases in NO_x emissions by 40 and 48% and oxygen concentration by 21 and 12% for diesel and waste cooking oils, respectively were shown with the effect of fuel magnet. There were decreases in radial inflame temperatures distributions by the effect of magnetic field on diesel and waste cooking oils.**

Index Term-- **Oil burner, Waste cooking oil, Magnet, Inflame temperature, Combustor, Exhaust emissions.**

NOMENCLATURE

GC	Gas chromatography
L	Axial distance between burner exit and the end of flame length, m.
LDO	Light Diesel Oil.
R	Measured radial distance from the centerline axis of combustor, m
R_0	Radius of cylindrical section of combustor, m.
R/R_0	Relative distance, dimensionless.
WCO	Waste Cooking Oil.
X.	Measured axial distance from the burner exit, m.
X/L	Relative distance, dimensionless.

1. INTRODUCTION

The energy consumption is inescapable for human race on our planet. There are some reasons which encourage us for searching about alternative fuels that is technically suitable, environmentally acceptable, economically competitive, and readily available. The increase of demand for fossil fuels in all sectors of human life, transportation and power generation led to intensive search about alternative fuels. Fossil fuel resources are non-renewable and they will be depleted in the near future. Environmental impact causing greenhouse gases effect, harmful emissions, and global warming. The price instability of fuels and taxation of energy products and all these led to search about alternative fuels [1].

Vegetable oils and animal fats are triglycerides attached to glycerol. Vegetable oil is biodegradable, carbon neutral, and does not produce hazardous toxic exhaust gases. Waste cooking oil have attracted a lot of concerns to all scientists and researchers because it represents some problems in its conversion and disposing it away from harming human or the environment [2, 3]. Waste cooking oil is used in food preparation, frying, cooking and semi product preparation such as fish, potatoes and vegetables. Using of recycled waste cooking oil is healthy harmful and it is not environmental to environment. Using of waste cooking oil as an energy supply for heating purposes is a vital solution to reduce the intensive dependence on diesel fuel [4, 5].

Burning of diesel oil produced higher concentrations of CO emissions compared to diesel fuel. NO_x and CO emissions were affected significantly by the fraction of the total air used for atomization. Fuel properties have an effect on NO_x and CO emissions [6]. Waste cooking oil has the advantages of lower cost. Little amount of oxygen is needed for complete combustion due to its oxygen content [7]. NOx and CO emissions decreased for vegetable oils about diesel oil. Zeldovich thermal mechanism was responsible for the formation of nitric oxide in the flames [8]. Lower emissions of CO and NO_x were produced for vegetable oils compared to diesel oil [9]. Vegetable oils have higher percentage of oxygen, higher density and viscosity. Vegetable oils should be preheated before using in oil burners [10, 11].

Applying the magnetic field to fuel line in a single cylinder diesel engine led to a decrease in fuel consumption by about 8% at higher load condition. Applying the magnetic field on diesel fuel line has effects on exhaust emissions, CO emission reduced at higher engine load. The reduction of HC emissions was up to 30%. CO_2 emission reduced up to 9.72% at part engine loads [12]. An experimental investigation of engine exhaust emission on a single cylinder diesel engine under the effect of magnetic field was made. CO emissions were reduced at higher engine loads. HC and CO_2 emissions reductions were up to 32 and 11%, respectively [13]. There is an increase in the thermal efficiency due to fuel consumption reduction. Exhaust emissions such as CO and HC reduced in spark ignition engine under the effect of magnetic field. The reductions in fuel consumption, CO and HC emissions were up to 12, 11 and 19 %, respectively. Hydrogen particle in fuel is arranged in two isomeric forms para and ortho. The ortho state of hydrogen has effectiveness about Para state for efficient combustion. The ortho state is applied by introducing strong magnetic field to the fuel line [14].

Performance of a single cylinder, four stroke diesel engine under the effect of magnetic field was studied. Reduction of fuel consumption was up to 12%. The reductions in CO and HC emissions were up to 11 and 27 %, respectively. Variation of permanent magnet strength led to improvement in engine performance. Viscosity of the hydrocarbon fuel decreased under applying magnetic field to fuel line. Hydrocarbon fuel molecules declustered and this led to better fuel atomization, better fuel-air mixing, reduction of unburned hydrocarbons and thermal efficiency improvement. Lower fuel consumptions and improvement of fuel economy in engines help in complete combustion of the fuel and reduction of CO emission [15, 16]. Application of permanent magnets in fuel line of a single cylinder diesel engine improved engine performance parameters and reduced fuel consumption at higher engine loads. Exhaust gas emissions such as CO and CH_4 were reduced by the effect of magnetic fuel energizer [17].

Hydrocarbon atoms consist of number of nucleus and electrons and electrons 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. Movements due to magnetic field exist in the molecules and they had positive and negative electrical charges. The fuel molecules had been realigned and were interlocked with oxygen during combustion. Hydrocarbon molecules are arranged in clusters. If permanent magnetic device is strong enough to break down the clusters, there will be an acquired maximum space available for oxygen molecules to combine with fuel molecules. The magnetic field resulted in better fuel economy and reductions of exhaust emissions such as hydrocarbons and carbon monoxide [18, 19]. Effect of the magnetic field for fuel line on engine performance in spark ignition engine was investigated. As the magnetic field intensity increased, specific fuel consumption decreased and thermal efficiency was improved. CO and HC emissions decreased with magnetizing the fuel before entering the engine cylinder. Fuel consumption reduction was up to 15%. CO and CH_4 reductions at idling speed were up to 7 and 40%, respectively [20, 21, 22].

Experimental tests were run on a four stroke, single cylinder petrol engine by using magnets of Intensities 2000, 4000, 6000, and 8000 Gauss at constant speed of 1500 rpm. Fuel ionization led to specific fuel consumption reduction and complete combustion was occurred. 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 [23]. Performance and exhaust emissions were investigated under effect of magnetic fuel energizer for motorcycle was by applying the magnetic field along the fuel line before carburetor. Strong permanent magnet with strength of 3000 Gauss was applied to fuel line. The percentage of decrease in fuel consumption is 10% at 50 km/h, the percentage reductions in CO and HC emissions are about 36 and 13%, respectively. Fuel magnetism dissolves the carbon build up in carburetor jets, combustion chambers, fuel injectors and combustion chambers and this increase combustion efficiency [24].

A magnetic field was applied on the fuel line to magnetize the fuel before the burner of the boiler. The magnetic field was applied by mounting two permanent magnets of 2000 Gauss for each one. Subjecting the magnetic field to fuel line led to a decrease in fuel consumption, CO and hydrocarbon emissions by about 3.675, 38.04 and 21.89%, respectively. There were increases in CO_2 emission and exhaust gas temperature by about 3.432 and 4.34%, respectively [25].

Magnetic field has a significant effect on engine performance. Magnetic field was applied by mounting 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 [26]. Magnetic field saved fuel consumption about 31.53% which uses diameter of wire 0.35 mm and number of winding 5000 turns, for copper core in road testing [27].

Fuel magnet improved the performance of four strokes petrol engine. Magnetic field achieved 28% reduction in fuel consumption and reductions in HC, CO and CO_2 emissions. Magnetic field changes orientation and molecule change of fuel. This was due to realignment of hydrocarbon molecules, converting para to ortho rotation hydrogen molecules interlocked with oxygen during combustion to produce complete combustion [28].

Magnetic field in the fuel line gave an improvement in mixture formation by increasing the atomization process of the spray due to the increasing rate of disintegration of the droplets by reduction in the viscosity and surface tension of the fuel. This gave a wide surface area of the spray droplets per volume to react with the oxidizer. This increases evaporation and mixture formation, reduces of particulate matter and increases of engine efficiency [29]. 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 in the exhaust emission were shown. Magnetic fuel conditioner increased from 10 to 40% mileage of vehicle. Magnetic fuel conditioner reduces clogging problems in engine. Magnetic fuel conditioner is eco-friendly, provides 30% extra life for expensive catalytic converter and reduces engine maintenance [30]. Fuel ionization by using magnetic field caused complete combustion of air-fuel mixture. Improper mixing of hydrocarbon and oxygen led to incomplete combustion and lower efficiency. Fuel is ionized by magnetic fuel ionization 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 exhaust emissions of vehicle [31].

This work aims to study the effect of fuel magnetism on performance parameters, exhaust emissions and combustion characteristics of an industrial oil burner using diesel and waste cooking oils as fuels. The physical and chemical properties of waste cooking oil were measured and compared to diesel oil. Performance parameters such as fuel consumption exhaust gas temperature and combustion efficiency of industrial oil burner using diesel and waste cooking oils. Radial inflame temperatures distributions at different positions of the flame length for these fuels were investigated. Exhaust gas emissions concentrations such as CO, CO_2, NO_x, HC and unused oxygen were analyzed. Performance parameters, exhaust emissions and combustion characteristics comparison were made between diesel and waste cooking oils.

2. Chemical and Physical Properties of Waste Cooking Oil

In this study, 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 and filters and then preheated up to 90°C. Waste cooking oil was fed to the oil burner at a constant preheating temperature of 90°C which its viscosity near to diesel fuel. The chemical and physical properties of waste cooking oil were measured and analyzed in Petroleum Research Institute, Cairo, Egypt. Effects of temperature on dynamic viscosity and density for diesel and waste cooking oils were shown in Fig.1. Physical and chemical properties of waste cooking oil were compared to diesel oil as shown in Table I.

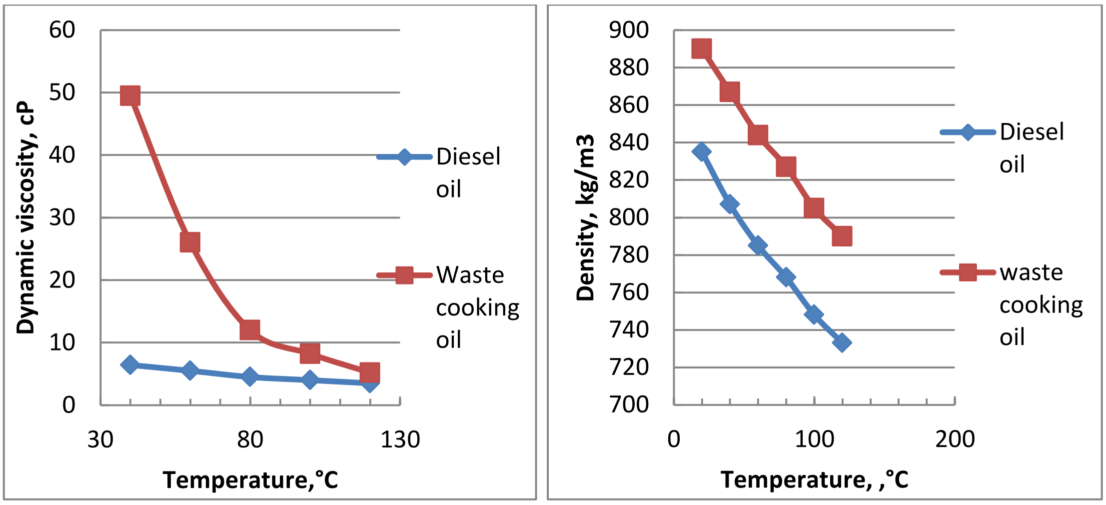


Fig. 1. Effect of temperature on dynamic viscosity and density for diesel and waste cooking oils.

Table I
Chemical and physical properties of waste cooking oil compared to diesel fuel.

Properties	**Light Diesel oil**	**Waste Cooking Oil**
Density at 15 °C , kg/m^3	834	887
Dynamic viscosity at 40°C, cP	4.5	52
Lower heating value, MJ/kg	42.49	36.59
Flash point , °C	160	70
Cetane number	55	52
% C (wt.)	86.13	76.95
% H (wt.)	13.87	12.14
% O (wt.)	0	10.91
% S (wt.)	0.045	0.03
Stoichiometric fuel/air ratio	1: 14.67	1: 12.55

3. Fatty Acid Composition of Waste Cooking Oil

Fatty acids may be saturated such as palmitic acid and stearic acid or unsaturated, with one double bond such as oleic acid in which case they are called polyunsaturated fatty acids such as linoleic and linolenic acids. Chain length and number of double bonds for fatty acids determine the physical properties of both fatty acids and triglycerides. Fatty acids in waste cooking oil were oleic, linoleic, palmitic, palmitoleic, pentadecanoic, myristic, linolenic, heptadecanoic and stearic fatty acids. Fatty acid composition of the oil is dominated by oleic acid (34.94%) and palmitic acid (28.78%). Free fatty acid composition had been carried out in the laboratories of National Research Centre, Giza, Egypt by using gas chromatograph. Free fatty acid composition for waste cooking oil was shown in Table 2. Gas chromatography analysis was performed by using Hewlett Packard model 5890 gas chromatography unit equipped with a flame ionization detector (FID). GC analysis was indicated in Fig.2 [32].

Table II
Fatty Acid composition for waste cooking oil.

Fatty Acid Methyl Ester	FFA Composition (wt. %)
Myristic acid (C14:0)	0.91
Pentadecanoic acid (C15:0)	0.12
Palmitic acid (C16:0)	28.78
Palmitoleic acid (C16:1)	2.32
Heptadecanoic acid (C17:0)	0.14
Linoleic acid (C18:2)	21.19
Ioleic acid (C18:1)	34.94
Linolenic acid(C18:3)	5.20
Stearic acid (C18:0)	6.41

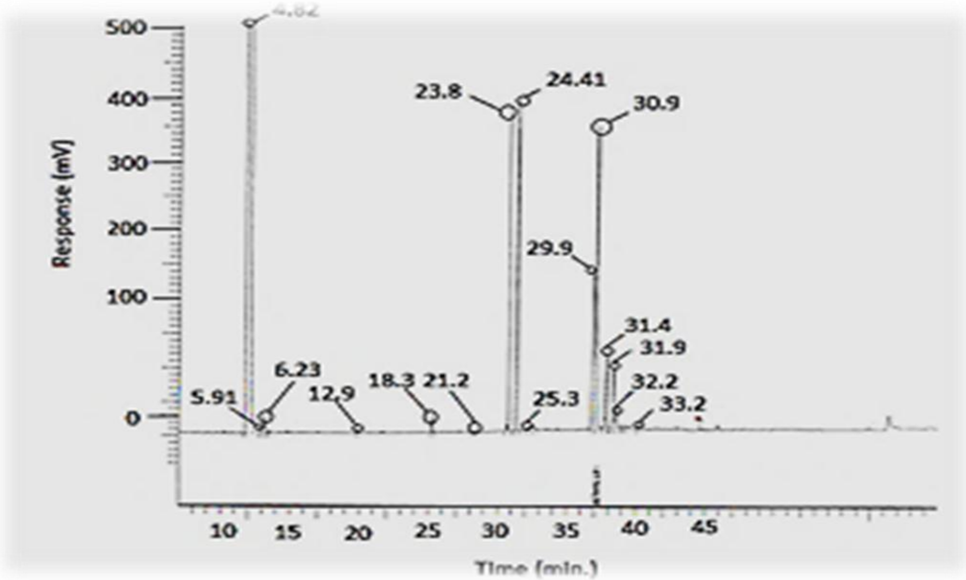


Fig. 2. Gas chromatography analysis for waste cooking oil.

4. Experimental Setup and Instrumentations

The experimental setup consists of a heavy oil burner with heating load of 102 kW as shown in Fig.3. The oil burner was provided with automatic ignition system for controlling air and fuel mass flow rates. A fuel tank equipped with electric heater to preheat waste cooking oil up to 90°C as maximum limit and thermostat to adjust the required preheating temperature. The burner was inserted horizontally inside the combustion chamber. The combustor was a cylindrical furnace with inner diameter of 40 cm and 200 cm length. The combustor was cooled longitudinally by nine divided separate water jackets. The combustion chamber had different glass holes to follow the flame structure. The chimney had certain holes for exhaust emissions measurements at a height of 110 cm and for smoke measurement at a height of 30 cm. Nine thermocouples of type K measured outlet cooling water temperature. The flow rate of cooling water was controlled by a valve and measured by a rotameter.

The primary air was used to draft the oil fuel from preheating tank to fuel nozzles. The primary air line consists of air compressor, pressure regulator, air rotameter, air safety valve and air pressure gauge. Air compressor produced air capacity of 12 m^3/min and a maximum air pressure of 5 bar. The air flow rate was adjusted and regulated by adjusting the valve of the compressor. The primary air flow rate was measured using an air rotameter. The secondary air was fed by air blower and its flow rate was adjusted. A vane type swirler was used and its position will control the length and shape of the flame. The secondary air was adjusted at a constant flow rate. The positions of air swirler and opening of secondary air were adjusted to make the flame stable. Swirl was imparted to the secondary air stream using vanes inclined at 20º. The igniter produced high voltage electrical discharge.

Two fuel nozzles were used to spray oil fuels. The fuel nozzle had a mixing chamber where the pressurized air impinged on the fuel jet to form a good quality and liquid gas mixture then sprayed. The drafted fuel volume coming out of the nozzle is directly proportional to the primary air pressure. The burner was controlled by a programmable electronic card (Arduino) connected to personal computer by LABVIEW software.

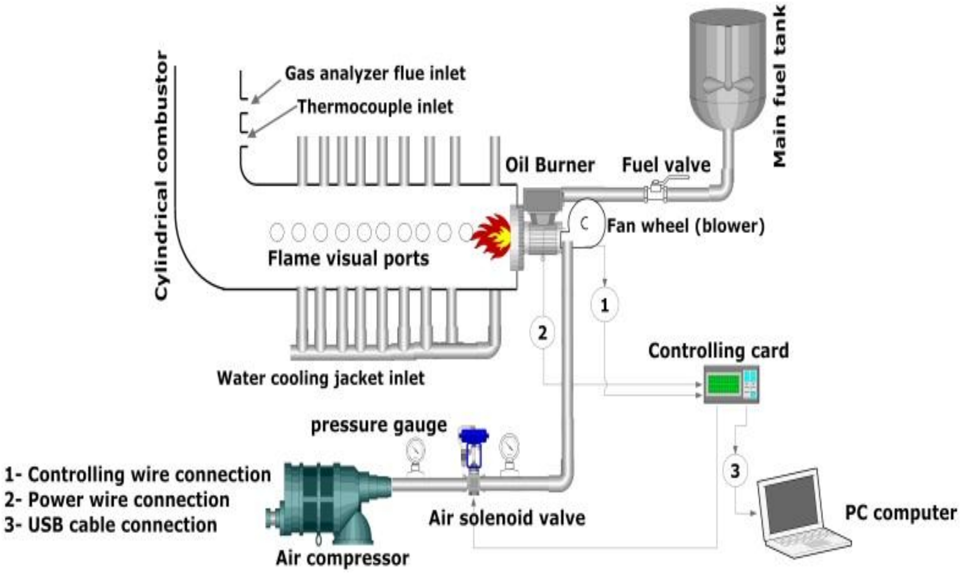


Fig. 3. Schematic diagram of experimental set up.

Exhaust gas, water cooling inlet and outlet temperatures were measured by thermocouple of S and K types, respectively. Exhaust emissions concentrations were measured by flue gas analyzer of type LANCOM series II. Inflame temperatures were measured axially and radially along the combustion chamber. The inflame temperature distribution were measured using R type thermocouple which was positioned at different axial and radial positions in the flame to obtain inflame temperature distribution.

Diesel and waste cooking oils were used as fuels. Waste cooking oil was filtered to get rid of impurities and deposits. Waste cooking oil was preheated to a temperature of 90°C to decrease its viscosity near to diesel fuel. Diesel and waste cooking oils were burned at a constant primary air pressure of 1 bar according to flow rate of fuel nozzles. Solenoid air valve was adjusted to draft fuel from preheating oil tank. Waste cooking and diesel oils were burned under the same operating conditions.

5. FUEL MAGNET INSTALLATION

A permanent magnetic was installed before the two fuel nozzles for achieving maximum alignment and maximum effect. The magnetic field was used to magnetize the fuel before discharging from the fuel nozzle. Fuel line was subjected to a permanent magnet mounted on the fuel inlet line of strength 4000 Gauss. South pole of the magnet was adjacent the fuel line and its north pole was spaced apart from the fuel line as shown in Fig.4.

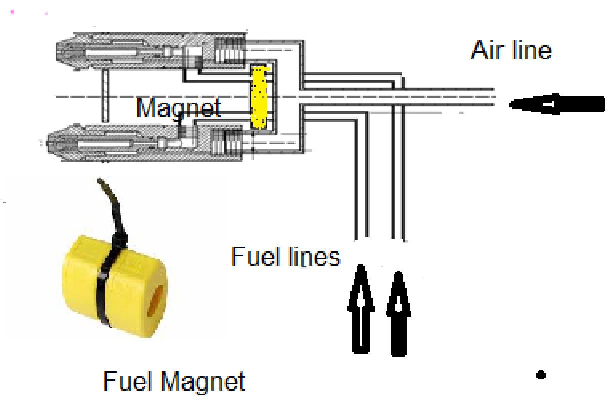
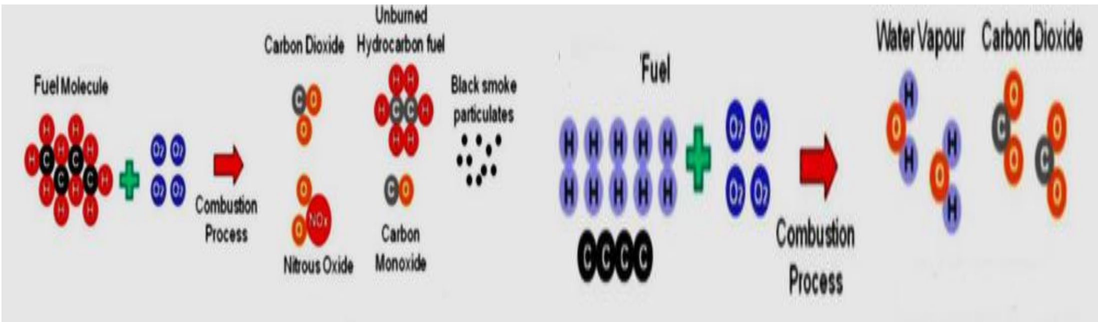


Fig. 4. Fuel magnet installation.

6. EFFECT OF MAGNETIC FIELD ON FUEL

Fuels of engines consist of hydrocarbons. 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. Fuel 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. Fuel molecules had been realigned and were interlocked with oxygen during combustion. Hydrocarbon fuel molecules are arranged in clusters. If Strong permanent magnetic breaks down the clusters, viscosity decreases, disperses molecules and acquires 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.5 [25].

Hydrogen occurs in two distinct isomeric forms para and ortho. Hydrogen is characterized by the different opposite nucleus spins. Ortho state of hydrogen is more effective than para state for maximum complete combustion. Ortho state can be achieved by adapting strong magnetic field along the fuel line. Strong permanent magnets changes the fuel orientation (para to ortho) and its change their configuration as shown in Fig.6. 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 allows hydrocarbons fuel to attract and bond with negatively charged oxygen and causes more complete carbon/oxygen bond and more complete efficient combustion [16]. This led to fuel better atomization and better fuel-air mixing. Fuel economy, better fuel consumption and reduction of exhaust emissions such as hydrocarbons, carbon monoxide and carbon dioxide under the effect of magnetic field [7].



(a) Without magnet (b) With magnet

Fig. 5. Effect of magnetic field on hydrocarbon fuel.

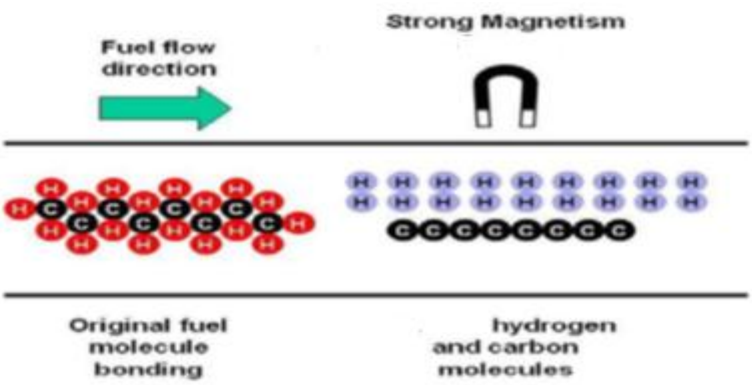


Fig. 6. Effect of strong magnet on hydrocarbon fuel.

7. Results and Discussions

7.1 Effect of fuel magnetism on fuel consumption

Figure 7 showed the effect of magnetic field on fuel consumption of industrial burner using diesel and waste cooking oils as fuels at a primary pressure of 1 bar. Fuel consumption of waste cooking oil was lower than that of diesel oil due to reduced viscosity and density by preheating of waste cooking oil. Reduction of fuel consumption for waste cooking oil about diesel oil was about 14%. Applying the magnetic field to diesel and waste cooking oil lines led to reductions in fuel consumptions by about 22, 21%, respectively [25].

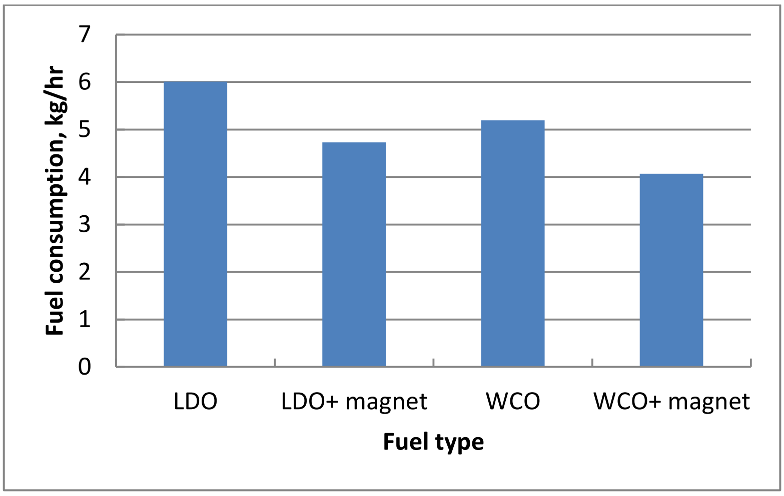


Fig. 7. Fuel consumption for diesel and waste cooking oils with and without magnet at a primary pressure of 1 bar.

7.2 Effect of fuel magnetism on exhaust gas temperature

Effect of magnetic field on exhaust gas temperature of industrial burner using diesel and waste cooking oils at a primary pressure of 1 bar was shown in Fig. 8. The primary air pressure has an effect on the flow rate of drafted fuel. At lower primary air pressure of 1 bar, fuel flow rate for waste cooking oil was near to diesel oil. Exhaust gas temperature for waste cooking oil was lower than that of diesel oil by about 4%. Exhaust temperature was decreased when exposing diesel and waste cooking oils to the magnetic field by 7%. Exhaust temperature was decreased when exposing waste cooking oil to the magnetic field by 7 and 17%, respectively. Decrease of exhaust gas temperature led to a decrease in heat loss in exhaust, increase of combustor efficiency and heat release.

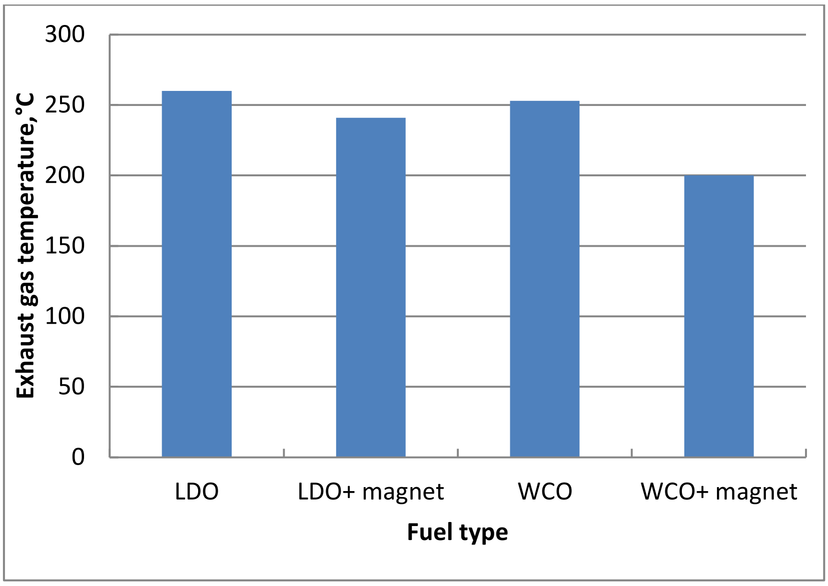


Fig. 8. Exhaust gas temperature for waste cooking oil and diesel fuels with and without magnet at a primary pressure of 1 bar.

7.3 Effect of fuel magnetism on thermal heat balance

The thermal heat balance of the combustor was calculated by total heat input, heat transfer to the combustor wall, exhaust gases heat loss and radiation losses. Applying thermal heat balance for waste cooking oil and diesel fuels, the percentage of heat transferred to the combustor to the total heat input was calculated. Figure 9 showed the effect of fuel magnetization on combustor efficiency for diesel and waste cooking oil. Applying magnetic field to fuel line led to decrease in the percentage of heat transferred to the combustor wall due decrease in fuel drafting, improvement in in fuel atomization, fuel- air mixing and decrease of heat loss in cooling water and exhaust gases. The heat transferred to the combustor wall increased for waste cooking oil about diesel oil due the increase in fuel consumption and heat loss in exhaust and cooling water. The maximum decrease in combustor efficiency for waste cooking oil was 11% about diesel oil. Applying magnetic field to fuel line achieved increase in combustor efficiency about 8 and 12%, respectively for diesel and waste cooking oils. Magnetization of waste cooking oil produced increase in combustor efficiency of 12%.

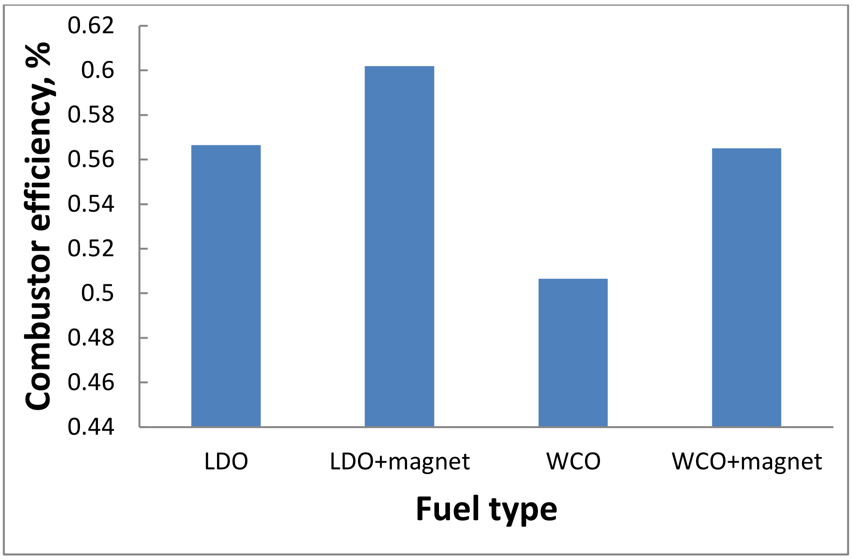


Fig. 9. Combustion efficiency for WCO and LDO fuels with and without magnet at a primary pressure of 1 bar.

7.4 Effect of fuel magnetism on Radial distribution of Inflame temperatures

Radial inflame temperatures were measured radially according to the length of the flame. The radial inflame temperature profiles were taken at different positions of the flame length for each fuel. The effect of relative axial distributions of flame temperature (X/L) of 0.0275, 0.075 and 0.125 on relative radial inflame temperature distribution (R/R_0) were displayed in the following Figs. 10, 11, 12 and 13. The radial inflame temperature decreased from the center of combustor towards the combustor walls for WCO, LDO, LDO+ magnet and WCO+ magnet at different axial positions from the exit of burner because of cooling water jacket that surrounding the combustor wall. In axial direction, the flame shape and its length varied in flame zones (preheating, reaction, recirculation and cooling). The decrease in inflame temperature in axial distribution appeared in transition from preheating to cooling zone. The preheating zone is near to the burner exit. A rapid temperature zone increased in reaction zone. Radial distribution of inflame temperature from the center of the flame to the outer of the combustor decreased due to the water cooling effect of combustor walls.

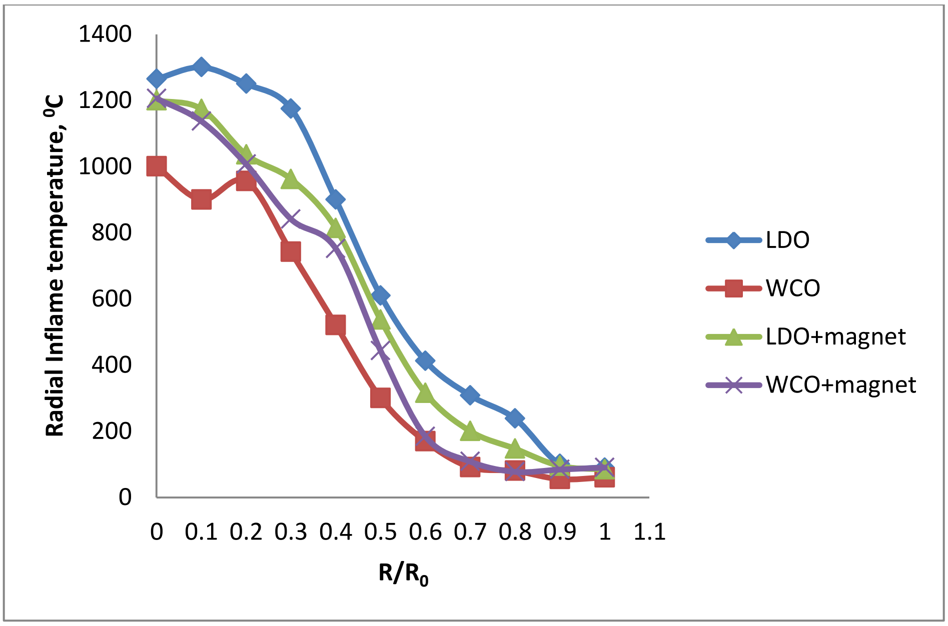


Fig. 10. Radial inflames temperatures for waste cooking oil and diesel fuels with and without magnet at X/L= 0.0275.

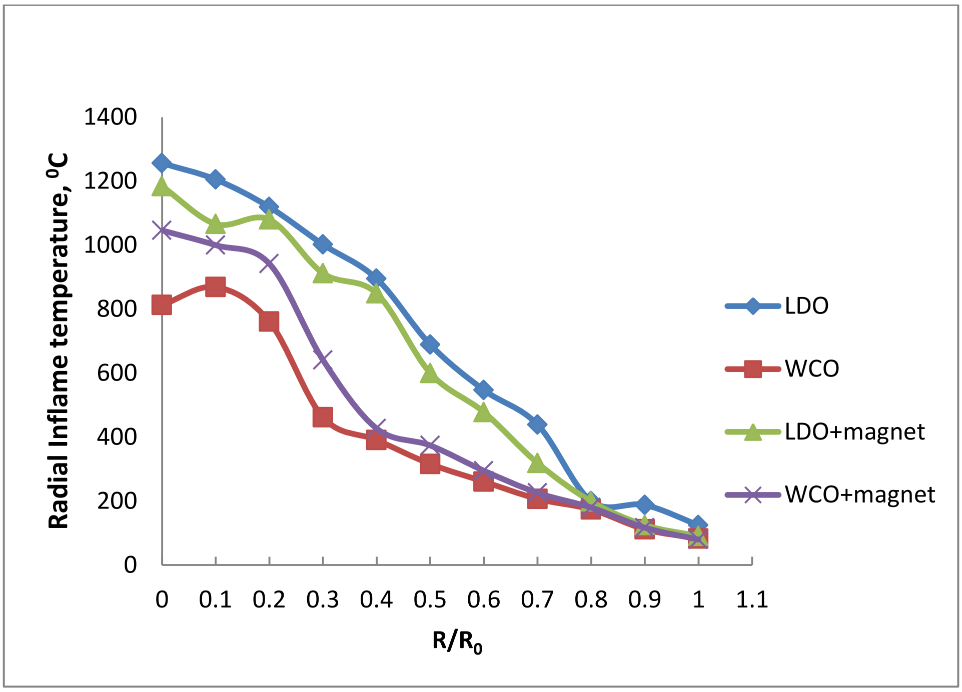


Fig. 11. Radial inflames temperature for WCO and LDO fuels with and without magnet at X/L= 0.0725.

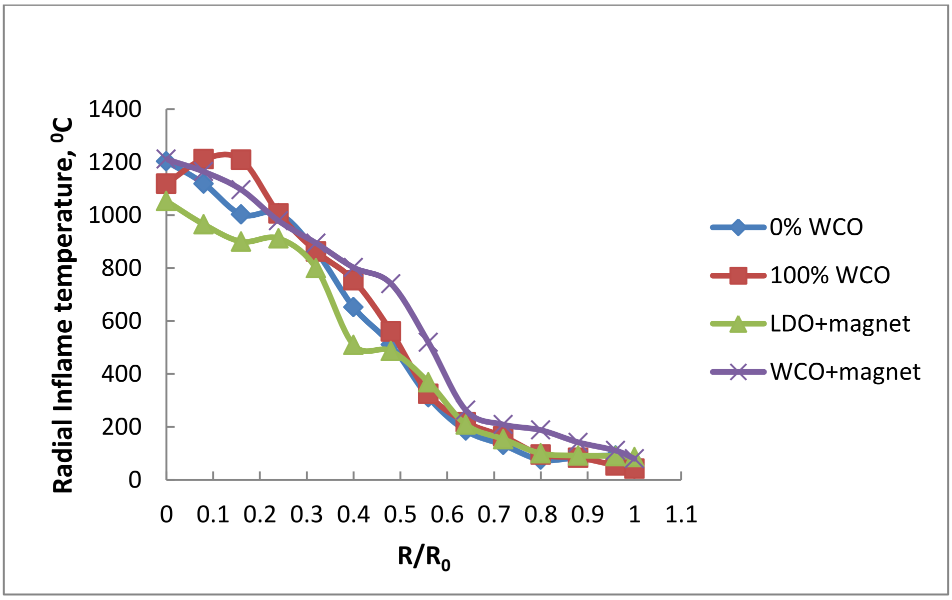


Fig. 12. Radial inflames temperature for WCO and LDO fuels with and without magnet at X/L=0.125.

There was increase of radial inflame temperature for diesel oil about waste cooking oil. This was due to the increase in fuel consumption and heat release for diesel oil about waste cooking oil. The radial inflame temperatures at center of flame increased for diesel oil about waste cooking oil. At the center of the flame for WCO and LDO, the radial inflame temperatures were nearly the same. Applying magnetic field achieved decrease in fuel consumption, heat release and radial inflame temperatures for waste cooking and diesel oils. The maximum radial inflame temperatures were 1300, 1180, 1170 and 1000°C for LDO, LDO+ magnet, WCO+ magnet and WCO, respectively at axial position of 0.0275. The maximum radial inflame temperatures were 1300, 1200, 1050 and 920°C for LDO, LDO+ magnet, WCO+ magnet and WCO, respectively at axial position of 0.0725. The maximum radial inflame temperatures were 1220, 1050, 1210 and 1230°C for LDO, LDO+ magnet, WCO+ magnet and WCO, respectively at axial position of 0.125.Lower amount of energy of waste cooking oil due to decrease of lower heating value of waste cooking oil compared to diesel oil.

7.5 Effect of fuel magnetism on CO_2 emissions

Figure 13 displayed the variation of CO_2 formation for the two fuels at a primary pressure of 1 bar. Increase of primary air pressure led to increase in fuel consumption and heat release. CO_2 emissions values for waste cooking oil were lower than that of diesel fuel. Waste cooking oil had higher carbon content compared to diesel oil and oxygen molecules in its structure. Reduction of CO_2 emission for waste cooking oil about diesel fuel was 11%. Applying fuel magnetism to waste cooking and diesel oils led to decrease in CO_2 emission about 28, 31%, respectively.

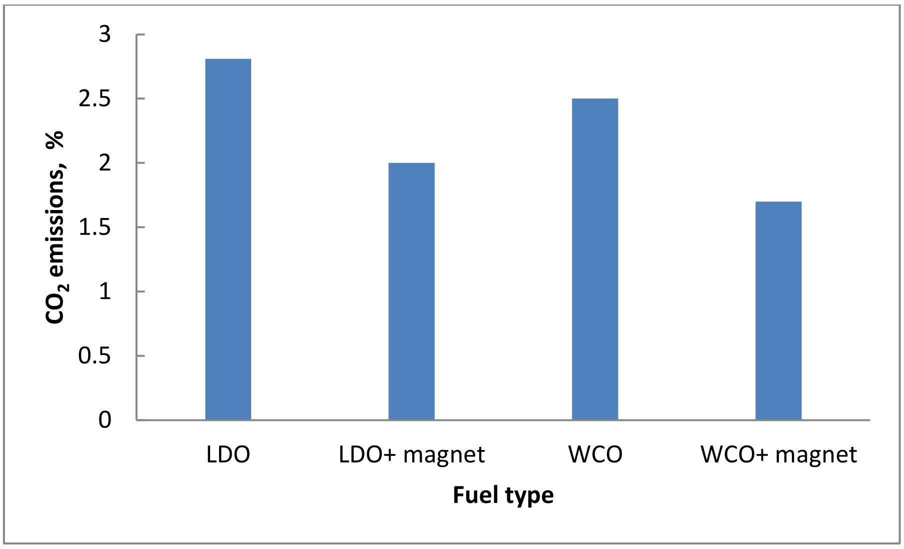


Fig. 13. CO_2 emissions for WCO and LDO fuels with and without magnetism at primary pressure of 1 bar.

7.6 Effect of fuel magnetism on HC emission

Variation of unburned hydrocarbons produced by waste cooking oil and diesel fuels at a primary air pressure of 1 bar was investigated in Fig.14. Hydrocarbons emissions for waste cooking oil were higher than diesel fuel. This was due higher viscosity, problems of fuel atomization and improper fuel- air mixing led to incomplete combustion and higher hydrocarbons emissions. The increase of hydrocarbons for waste cooking oil about diesel fuel was about 39%. Diesel oil magnetism led to reduction of HC emissions by about 29%. Applying magnetic field to waste cooking oil led to reduction of HC emissions by about 25%.

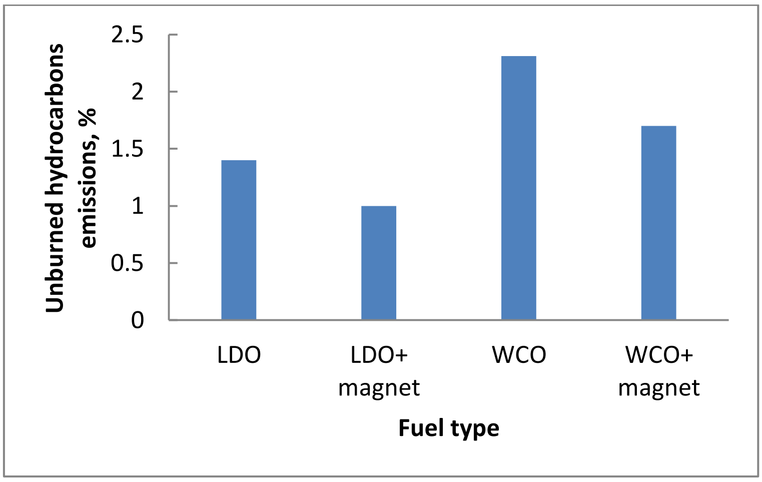


Fig. 14. Hydrocarbon emissions for WCO and LDO fuels with and without magnet.

7.7 Effect of fuel magnetism on NO_x emission

Figure 15 showed the variation of NO_x emissions for diesel and waste cooking oils at a primary air pressure of 1 bar. NO_x emission for waste cooking oil was lower than diesel oil due to decrease of inflame, exhaust gas temperatures and nitrogen content of waste cooking oil. NO_x emission for waste cooking oil was lower than diesel oil by about 70%. NO_x emission production is controlled by Zeldovich mechanism. Magnetic field made the fuel molecules realigned and were interlocked with oxygen during combustion. There will be an acquired maximum space available for oxygen molecules to combine with fuel molecules and this increased NO_x emissions. Diesel oil magnetism led to increase of NO_x emissions by about 40%. Applying magnetic field to waste cooking oil led to increase of NO_x emissions by about 48%.

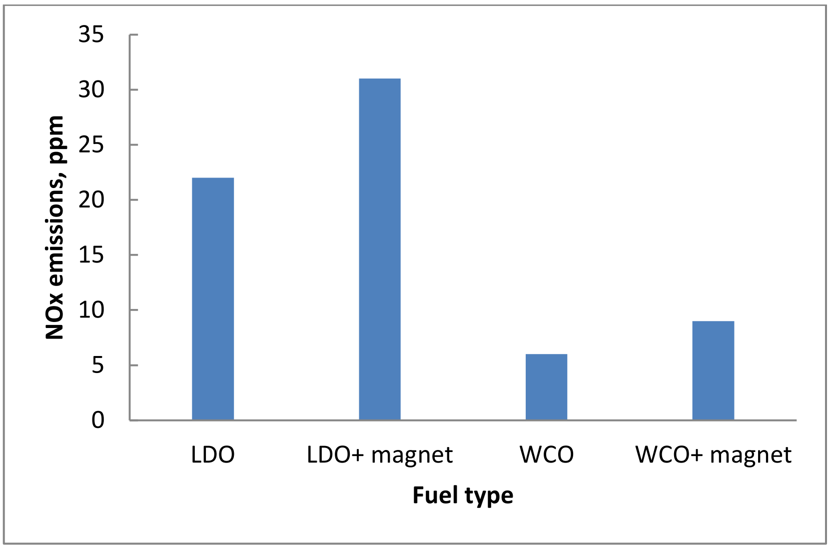


Fig. 15. NO_x emissions for WCO and LDO fuels with and without magnet.

7.8 Effect of fuel magnetism on CO emission

Figure 16 showed the variation of CO emissions for diesel and waste cooking oils at a primary air pressure of 1 bar. Waste cooking oil produced lower CO emissions compared to diesel oil. Oxygen content in waste cooking oil led to more complete combustion than diesel oil. The percentage of CO emission decrease of waste cooking oil about diesel oil was about 48%. Subjecting the fuel line 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 burn in the combustion chamber. Fuel magnetism led to reductions in CO emissions for diesel and waste cooking oils about 30, 37 %, respectively.

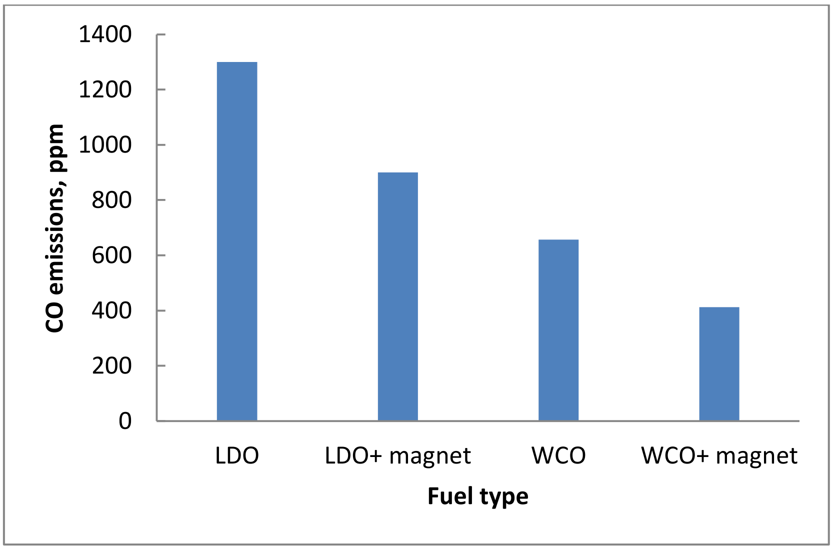


Fig. 16. CO emissions for WCO and LDO fuels with and without magnet.

7.9 Effect of fuel magnetism on used oxygen concentration

Figure 17 showed the variation of unused oxygen concentration for diesel and waste cooking oils at a primary air pressure of 1 bar. Oxygen content for waste cooking oil was higher than diesel fuel. This content of oxygen in fuel and air was consumed in converting CO to CO_2. The unused oxygen concentration measured for diesel fuel was lower due the consumption of oxygen to make complete combustion. Increase of unused oxygen for waste cooking about diesel fuel was about 31%. Applying magnetic fuel led to increase of unused oxygen concentration in diesel oil and waste cooking oils by 21 and 12%, respectively because of acquired maximum space available for oxygen molecules to combine with fuel molecules.

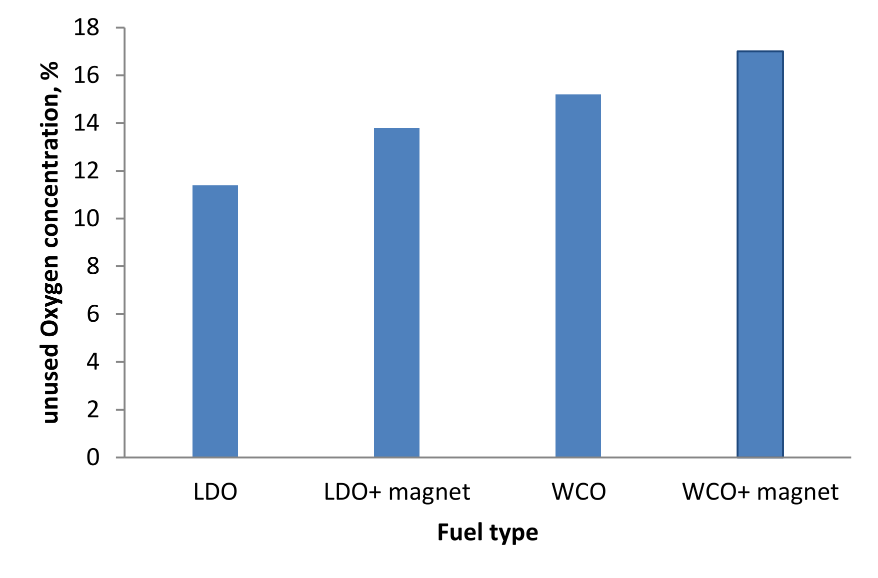


Fig. 17. Unused oxygen concentration for WCO and LDO fuels with and without magnet.

8. CONCLUSIONS

Waste cooking oil can be used as an alternative to diesel fuel in oil burners, boilers, and furnaces. Waste cooking oil is favorable due its lower cost and reducing dependence on diesel fuel. Waste cooking oil and diesel fuels were burned in a swirled oil burner at a primary air pressure of 1 bar. A magnetic field was applied to the fuel lines of these fuels. Effect of magnetic field on performance parameters and combustion characteristics such as fuel consumption, exhaust gas temperature, combustion efficiency and radial inflame temperatures were investigated. Effect of magnetic field on exhaust emissions such as CO, CO_2, HC, NO_x and unused oxygen were studied. Comparison of performance parameters, combustion characteristics and exhaust emissions were analyzed between waste cooking and diesel oils. The main conclusions between comparisons of performance, exhaust emissions and combustion characteristics for the two fuels are:

1- Waste cooking oil had higher density and viscosity than diesel oil. Preheating waste cooking oil to 90°C made its properties near to diesel oil.

2- Fuel consumption of waste cooking oil was lower than that of diesel oil due reduced viscosity and density of waste cooking oil under preheating effect. Applying the magnetic field to diesel and waste cooking oil lines led to reductions in fuel consumptions by about 22 and 21%, respectively.

3- Exhaust gas temperature of waste cooking oil was near to diesel oil. Exhaust gas temperatures decreased when exposing diesel and waste cooking oils to the magnetic field by 7 and 17%, respectively.

4- Applying magnetic field to fuel line achieved increase in combustor efficiency by about 8 and 12 % for diesel and waste cooking oils, respectively. The increase in combustor efficiency of fuel oils due to decrease of viscosity of fuels, better atomization of the fuel and better mixing of the fuel-air mixture.

5- There was increase of radial inflame temperature for diesel oil about waste cooking oil due to increase in fuel consumption and heat release of diesel oil compared to waste cooking oil.

6- CO_2 emissions values for waste cooking oil were lower than that of diesel fuel because of oxygen content in waste cooking oil. Subjecting fuel magnetism to diesel and waste cooking oils led to decrease in CO_2 emission by about 31 and 28%, respectively.

7- Hydrocarbons emissions for waste cooking oil were higher than diesel fuel. This was due higher viscosity, problems of fuel atomization and improper fuel- air mixing led to incomplete combustion and higher hydrocarbons emissions. Applying magnetic field to waste cooking and diesel oils led to reductions of HC emissions about 25 and 29%, respectively.

8- NO_x emission for waste cooking oil was lower than diesel oil due to decrease of inflame, exhaust gas temperatures and nitrogen content of waste cooking oil. There will be an acquired maximum space available for oxygen molecules to combine with fuel molecules and this increased NO_x emissions. Fuel magnetism led to increases in NO_x emissions for diesel and waste cooking oils about 40 and 48 %, respectively.

9- Waste cooking oil produced lower CO emissions compared to diesel oil. Oxygen content in waste cooking oil led to more complete combustion than diesel oil. Subjecting the fuel line 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 burn in the combustion chamber. Fuel magnetism led to reductions in CO emissions for diesel and waste cooking oils about 30 and 37 %, respectively.

10- The unused oxygen concentration measured for diesel fuel was lower compared to waste cooking oil due the consumption of oxygen to make complete combustion. Applying magnetic fuel led to increase of unused oxygen concentration in diesel oil and waste cooking oils by 21 and 12%, respectively because of acquired maximum space available for oxygen molecules to combine with fuel molecules.

REFERENCES

[1] Kulkarni M.G., Dalai A.K., "Waste Cooking Oils an Economical Source for Biodiesel: A Review", Ind. Eng. Chem. Res. 2006; 45: 2901-2913.

[2] Daho T., Vaitilingom G.,Sanogo O., Ouiminga S. K., Zongo A. S., Piriou B., Koulidiati J., "Combustion of vegetable oils under optimized conditions of atomization and granulometry in a modified fuel oil burner", Fuel 2014; 118:329–334.

[3] Chhetri A. B., Watts K. C., Islam R. M., "Waste Cooking Oil as an alternate Feedstock for Biodiesel Production", Energies 2008; 1: 3-18.

[4] Mohan B., Yang W., Tay K. L., Yu W., "Experimental study of spray characteristics of biodiesel derived from waste cooking oil", Energy Conversion and Management 2014;88: 622–632.

[5] Kafuku G, Mbarawa M., "Alkaline catalyzed biodiesel production from Moringa oleifera oil with optimized production parameters", Applied Energy 2010;87(8):2561–2565.

[6] Sequera D., Agrawal A. K., Spear S. K., Daly D. T., "Combustion Performance Liquid Biofuels in a swirl-stabilized Burner", Journal of Engineering for Gas Turbines and Power 2008; 130/032810-1.

[7] Arumugam K., Veeraraja S., Esakkimuthu P., "Combustion of Waste/Used oil by using Specialized Burner", International Journal of Applied Engineering Research 2013; 8:1839-1846.

[8] Aldana C., Gollahalli S. R., Parthasarathy R.N., "Combustion Characteristics of Spray Flames of Soy Methyl Ester and Diesel Blends", 49 th AIAA Aerospace Sciences Meeting including the new horizons forum and Aerospace Exposition, American Institute of Aeronautics and Astronautics 2011; AIAA 2011-618.

[9] Niguse Y.G., Agrawal A. K., Taylor R.P., "Combustion Performance of a scaled –up flow blurring injector", Spring Technical Meeting of the central states Section of the combustion Institute 2012; USA.

[10] Alonso J.F., Avila C. R., Hernandez L. M., Awaf A., "Characteristics biofuels and selecting the most appropriate burner for their combustion", Fuel Processing Technology 2013; 103:39-44.

[11] Morcos V. H., Abdel-Rahim Y. M., "Parametric Study of flame length characteristics in straight and swirl light-fuel oil burners", Fuel 1999; 78:979-8-985.

[12] P. M. Patel, G. P. Rathod, and T. M. Patel, "Effect of magnetic field on performance and emission of single cylinder four stroke diesel engine", IOSR Journal of Engineering, Vol.4, No. 5, 2014.

[13] P. M. Patel, G. P. Rathod, and T. M. Patel," Performance and Emission Analysis of Single Cylinder Diesel Engine under the influence of Magnetic Fuel Energizer ", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Vol.11, No.2, pp.34-39, 2014.

[14] V. Ugare, N. Bhave, S. Lutade,"Performance of spark ignition engine under the influence of magnetic field", International Journal of Research in Aeronautical and Mechanical Engineering, Vol.1, No.3, pp.36-43, July 2013.

[15] V. Ugare, A. Dhoble, S. Lutade," Performance of internal combustion (CI) engine under the influence of strong permanent magnetic field ", IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), Vol.9, No.10, pp.11-17, 2014.

[16] A. R. Attar, P. Tipole,V. Bhojwani, and S. Deshmukh," Effect of magnetic field strength on hydrocarbon fuel viscosity and engine performance", International Journal of Mechanical Engineering and Computer Applications, Vol.1, No.7, pp.94-98, December 2013.

[17] P. M. Patel, G. P.Rathod , and T. M.Patel, "Effect of magnetic fuel energizer on single cylinder C.I. engine performance and emissions", Mechanical and Automobile Engineering (ICCIET-2014), 2014.

[18] K. Chaware,"Review on Effect of Fuel Magnetism by Varying Intensity on Performance and Emission of Single Cylinder Four Stroke Diesel Engine", International Journal of Engineering Research and General Science, Vol.3, NO. 1, pp.1174-1178, January-February, 2015.

[19] K. Chaware, M. Basavaraj, " Effect of Fuel Magnetism by Varying Intensity on Performance and Emission of Single Cylinder Four Stroke Diesel Engine", International Research Journal of Engineering and Technology (IRJET), Vol.2, NO. 07, pp.1121-1126, October 2015.

[20] A. R. A. Habbo, R. A. Khalil, and H. S. Hammoodi," Effect of magnetizing the fuel on the performance of an S.I. engine", Al-Rafidain Engineering Journal, Vol.19, No.6, pp.84-90, December 2011.

[21] A.E. Farrag, M. S. Gad," Effect of Fuel Magnetism on Engine Performance and Emissions", Australian Journal of Basic and Applied Sciences, Vol.04, No.12, pp.6354-6358, 2010.

[22] A. S. Faris, S. K. Al-Naseri, N. Jamal, R. Isse, M. Abed, Z. Fouad, A. Kazim, N. Reheem, A. Chaloob, H. Mohammad, H. Jasim, J. Sadeq, A. Salim, and A. Abas," Effects of Magnetic Field on Fuel Consumption and Exhaust Emissions in Two-Stroke Engine", Energy Procedia, 327 – 338, Vol.18, pp.327-338, 2012.

[23] T.V. Rakesh, G.V. Rao, P. K. Sankar," Fuel Ionization by magnetic field in four stroke S.I. Engine", International Journal of Mechanical Engineering and Computer Applications, Vol.03, No.02, pp.38-42, March- April, 2015.

[24] N. N. Petkar, P. K. Khamkar," Performance and emission analysis of magnetic fuel energizer for motorcycles", International Journal of Advance Research in Science and Engineering, (IJARSE), Vol.5, No.02, February 2016.

[25] A. M. Salih, A. M. Ahmed, "The effect of magnetic field on the boiler performance fueled with diesel", International Journal of Scientific and Engineering Research, Vol.07, No.02, pp.406-410, February 2016.

[26] A. A. Abdel-Rehim, A. A. Attia, "Does magnetic fuel treatment affect engine performance?", SAE Technical Paper 2014-01-1398, 2014.

[27] H. P. Siregar, R. Nainggolan, "Electromagnetic fuel saver for enhancing the performance of the diesel engine", Global Journal of Researches in Engineering Mechanical and Mechanics Engineering, Vol.12, No.6, 2012.

[28] V. A. Jundale, D. A. Patil, " Analysis of Fuel and Exhaust Gases of SI Engine by Using Magnet", International Journal of Science and Technology, Vol.3, No.4, 2015.

[29] D. C. Uguru-Okorie, A. A. Dare, " Combustion Enhancers in Diesel Engines: Magnetic Field Option", IOSR Journal of Engineering (IOSRJEN), Vol.7, No.4, pp.21-24, 2012.

[30] S. Jain, S. Deshmukh, "Experimental Investigation of Magnetic Fuel Conditioner (M.F.C) in I.C. engine ", IOSR Journal of Engineering (IOSRJEN), Vol.2, No.7, pp.27-31, 2012.

[31] N. Karande, S. K. Kore, A. Momin, R. Akkiwate, Sharada P.K, S. K. Kumbhar, " experimental Study the Effect of Electromagnetic Field on Performance & Emission of IC Engine ", International Journal of Mechanical and Industrial Technology, Vol.3, No.1, pp.27-34, 2015.

[32] Christie, W.W., preparation of ester derivatives of fatty acids for chromatographic analysis, Advances in Lipid Methodology - Two, 1993; 69-111