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Effect of Waste Cooking - Diesel Oils Blends on Performance, Emissions and Combustion Characteristics of Industrial Oil Burner

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Abstract: Waste cooking oil as an alternative fuel in oil burners allow facing the challenges of rising diesel oil prices, reducing gradual depletion of fossil fuel, saving imported fuel from abroad with foreign currency and reduction of exhaust emissions that cause global warming. Waste cooking oil was preheated to 90 ℃. Properties of waste cooking oil were near to diesel fuel.This paper proposes to investigate the combustion characteristics of waste cooking-diesel oil blends at constant heat load. Waste cooking- diesel oils blends were prepared by volume percentages of 0, 20, 40, 60, 80 and 100%.Exhaust gas temperature, axial inflame, radial inflames temperatures, exhaust emissions and combustor were investigated for waste cooking- diesel oils blends in swirled oil burner.The experimental results showed that WCO- LDO blends emitted lower emission and values compared to diesel oil. Hydrocarbons emissions for waste cooking- diesel oils blends were higher than diesel oil. Increases of radial inflame temperature of waste cooking- diesel oils blends compared to diesel oil. NOx emissions of for LDO was higher than any waste cooking- diesel blend. The percentage of heat transferred to the combustor wall decreased for WCO- LDO blends compared to LDO.Waste cooking diesel oil blends can be used as an alternative fuel oilsin oil burner.

Keywords: Waste Cooking Oil, Swirler Burner, Combustor, Inflame Temperature, Exhaust Emissions, equivalence ratio.

Nomenclature

WCO	Waste Cooking Oil.
LDO	Light Diesel Oil.
λ	Excess air ratio.
R0	Radius of combustor cylindrical section, m.
R	Radial distance from the centerline axis of combustor, m.
R/R0	Relative distance, dimensionless.
X	Axial distance of measurement from the burner exit,
L	Axial distance between burner exit and the end of flame length, m
X/L	Relative distance, dimensionless
ɳ	Percentage of heat transferred to the combustor to the total heat input, dimensionless.
mw	Mass flow rate of water, kg/sec.
Cpw	Specific heat at constant pressure of water, kJ/kg. K.
Twi	Inlet temperature of cooling water, K.
Two	Outlet temperature of cooling water, K.
mf	Mass flow rate of fuel, kg/sec.
mair	Mass flow rate of air, kg/sec.
Cpexh	Specific heat at constant pressure of exhaust gases, kJ/kg. K.
Cpf	Specific heat at constant pressure of fuel, kJ/kg. K.
Ti	Initial temperature of fuel, K.
Tpreheat	Preheating temperature of fuel, K.

I. INTRODUCTION

Vegetable oils have received considerable attention as alternative fuels for combustion systems during last few years. Utilization of waste cooking oil as an alternative fuel in oil burners allows facing the challenges of rising diesel oil prices, reducing gradual depletion of fossil fuel, saving imported fuel from abroad with foreign currency and reduction of exhaust emissions that cause global warming to our planet. Fossil fuel has consumed in different section such as transport, agriculture, commercial, domestic, and industrial sectors for the generation of power mechanical energy [1-8].

Biodiesel is a mixture of mono alkyl esters of long chain fatty acids derived from edible and non-edible vegetable oils [9, 10].Vegetable oils have higher kinematic viscosity and surface tension compared to that of standard diesel oil due to their larger molecular size. These two physical properties are the major obstacles of adequate atomization, so, oil preheating is necessary for efficient combustion. Furthermore, during the startup and shut down process the usage of a more volatile fuel might solve all the practical problems [2, 4].

Tashtoush et al. investigated combustion characteristics of ethyl ester derived from waste vegetable oil in a boiler [5]. Combustion efficiency, exhaust temperature and levels of regular emissions were carried out across wide range of air to fuel ratios. Smoke, NO and CO emissions of B20 soy bean oil methyl ester in residential oil burning equipment were measured [6-10]. The tests were performed over a range of fuel flow rates and excess air [11]. Kiat Ng and Gan made experimental investigations on exhaust emissions and performance at constant fuel flow rate and at various flue gas oxygen contents.They also evaluated CO and NO_x emissions levels of palm oil methyl ester and its blend in a combustion chamber at different fuel pressures in the boiler [12, 13, 14].

Lee et al.[1-15] verified using of B20 soy bean oil methyl ester in a residential oil fired burner. They compared the levels of emissions such as CO and NO of B20 with oil preheating. Vanlaningham et al. [1-6] verified the performance of B20 soy bean oil methyl ester as preheated fuel and studied exhaust emissions levels of NO_x. Ghorbani et al.[16-17] accomplished a comparative study of combustion performance and exhaust emission of biodiesel blends of B5, B10, B20, B50, B80 and B100 and diesel fuels in an oil boiler. Bazooyar et al. [1-17] investigated combustion characteristics and exhaust emissions of diesel and vegetable oils in a semi industrial boiler. They studied the effect of fuel pressure and air-fuel ratios on exhaust emissions and combustion characteristics. The influence of flue gas oxygen concentration on performance, exhaust emissions of the boiler was studied in order to verify whether the use of biodiesel and its blends in the boiler is economically feasible [17, 18]. Use of waste cooking oil as an energy supply for heating purposes is becoming a possible and technically workable option to reduce the intensive dependence on fossil fuels [19, 20].

Diesel oil flames produced higher concentrations of CO emissions compared to vegetable oils. Both 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 [21, 22]. Biofuels have some characteristics such as higher percentage of oxygen, higher density and higher viscosity. All of this leads to that biofuels cannot use the same burners as those are used to burn diesel fuel. Burner flame stability depends on the density and viscosity of the fuels. Vegetable oils gave performance characteristics and exhaust emission concentrations near to diesel oil. Flame length in swirl oil burners increased with the increase in axial distance between combustor exit and the entrance of burner tube and fuel mass flow rate [23, 24].

The purpose of this work is to investigate performance,exhaust emissions and flame characteristics of diesel oil and waste cooking oil blends inside horizontal cylindrical combustor. Using waste cooking oil blended with light diesel oil as an alternative fuel can accomplish four goals such as enhancement of public food safety, increase in combustor efficiency produced from renewable energy, reduced fossil fuels consumption and reduction of exhaust emissions. Properties of waste cooking oil were near to diesel fuel. Waste cooking- diesel oils blends of 0, 20, 40, 60, 80 and 100% were prepared. Performance, flame characteristics and exhaust emissions of waste cooking- diesel oils blends were investigated at a constant heat load. Effects of waste cooking- diesel oils blends on exhaust gas temperature, combustor efficiency, radial inflame temperatures, axial inflame temperatures, thermal contour and exhaust emissions were investigated.

II. WASTE COOKING OIL PROPERTIES

LDO and WCO were used as fuels in industrial oil burner.Waste cooking oil was collected from different sources such as restaurants (KFC, and McDonalds), food factories (chips and cakes), hotels and domestic consumption. All waste cooking oil quantities were used and mixed with diesel oil have the same chemical composition all over the whole experiments. The fuel was fed to the burner from a tank of about 5 liters volume capacity at a constant preheating temperature of 90°C. Waste cooking oil was preheated and filtered to avoid clogging and depositing and get rid of all impurities on fuel nozzles.Chemical and physical properties of waste cooking oil compared to diesel fuel were previously measured in Petroleum Research Institute and National Research Centre, Egypt [25].

Table1: Properties of waste cooking and diesel oils.

Properties	LDO	WCO
Density at 15 °C, kg/m^3	834	887
Kinematic viscosity at 40°C, cSt	2.72	5.16
Lower heating value, MJ/kg	42.49	36.59
Flash point, ^{0}C	66.3	178
Sulfur, ppm	335	1.5
% C (wt.)	86.13	76.95
% H (wt.)	13.87	12.14
% O (wt.)	0	10.91
Stoichiometric fuel/air ratio	1: 14.67	1:12.55

III. EXPERIMENTAL TEST FACILITIES

The experimental results were done in continuous combustion lab., Power Mechanical Department, Faculty of Engineering, Mattaria, Helwan University, Cairo, Egypt. Figure 1 shows the schematic diagram of test rig. The system consists of a heavy oil burner (Giersch Enertech Group – Germany) with a heating load of 102 kW. The burner was provided with automatic ignition system for controlling the air and fuel mass flow rates. A separate fuel tank equipped with electric heater to warm up the fuel up to 90 °C as maximum limit and a thermostat to adjust the required preheating temperature. The burner is inserted horizontally inside the combustion chamber.

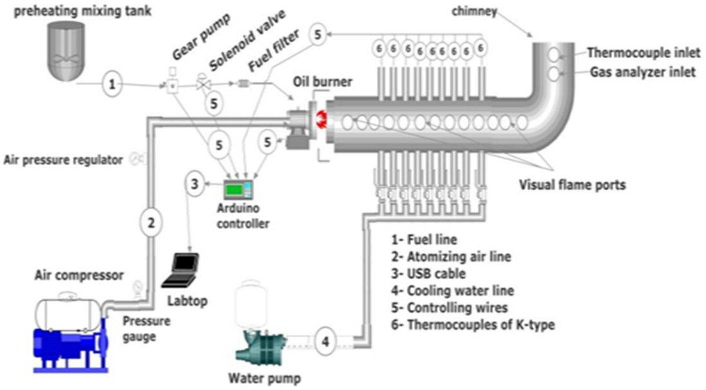

Fig.1: Schematic diagram of experimental set up.

The combustor was a cylindrical furnace with inner diameter of 0.4 m. The combustor was cooled longitudinally by nine divided separate water jackets. The chamber had different side holes. A chimney at the end of the combustion chamber had certain hole to provide point for exhaust emissions measurements. Nine thermocouples of type K were used for measurements of outlet cooling water temperature. The cooling water mass flow rate was controlled by valves.Two Delavan siphon nozzles of flow rates 0.8 GPH and 0.96 GPH were used to make a constant heat load. Waste cooking-diesel oils blends were burned using 0.96 GPH nozzle and diesel fuel was burned using 0.8 GPH nozzle to produce a constant heat load of 30 kW with consideration of lower heating values variation. The fuel nozzle had a mixing chamber where the pressurized air impinged on the liquid jet and formed a good quality liquid gas mixture which is then sprayed.

The primary airline consists of compressor, pressure regulator, air rotameter, air safety valve and air pressure gauge. The compressor was used to supply primary air to the fuel nozzles. The air flow rate was regulated by regulating the valve on the compressor. The flow rate of primary air supplied to the fuel nozzle was measured using an air rotameter. The primary airflow should be set using the pressure regulator according to the required burner output. The secondary air is supplied by a blower and its flow rate is adjusted by measuring the quantity of secondary air responsible for combustion. The volume of the fuel coming out of the fuel nozzle is directly proportional to the primary air pressure at which it is supplied to the nozzle.The burner was programmed and controlled by electronic card (Arduino) interfaced to personal computer with LABVIEW software. The swirler was a vane type swirler. Swirl was imparted to the secondary air stream using vanes inclined at 20º with a plane normal to the burner axis. The swirler position is adjusted to control the flame length. The ignition system was attained by a high voltage electrical discharge with nearly 3000 volt.

Different blends of waste cooking and diesel oils were prepared by volume at various percentages of 20, 40, 60 and 80 and 100% WCO. Burning of WCO and LDO blends was done under the same operating conditions. Exhaust gas and outlet water cooling jacket temperatures were measured by thermocouples of type S and K types, respectively to calculate the combustor efficiency. Exhaust emissions were measured by flue gas analyzer of type LANCOM series II. Exhaust emissions concentrations such as CO, O_2, CO_2, NO_x and C_xH_y were measured. Inflame temperatures were measured axially and radially along the combustion chamber. The inflame temperature distributions were measured using S Type thermocouple which was positioned along the length of the flame. The inflame temperature distributions were measured at different axial and radial positions in the flame in order to obtain a general overview of the temperatures in the flame environment. Comparisons of combustor efficiency, exhaust gas temperatures, radial inflame temperatures, axial inflame temperatures and exhaust emissions were made for diesel- waste cooking oils blends at a constant load of 30 kW.

IV. RESULTS AND DISCUSSIONS

A. Effect of Waste Cooking- Diesel Oils Blends On Exhaust Gas Temperature

Effect of waste cooking- diesel oils blends on exhaust gas temperature at air- fuel equivalence ratio of 1.35 was shown in Fig.2. Exhaust gas temperatures were directly proportional to combustor efficiency. Maximum exhaust gas temperatures were measured at 0, 20, 40, 60, 80 and 100%WCO as shown. Diesel fuel produced higher exhaust gas temperature due to higher calorific value compared to waste cooking oil. Blend of 40% WCO emitted higher exhaust temperature than diesel fuel due to its oxygen content.

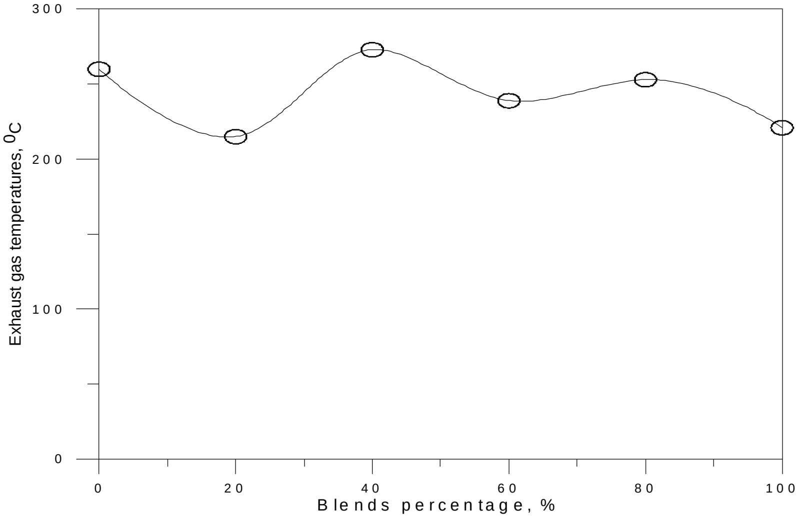

Fig.2: Exhaust gas temperatures of waste cooking- diesel oils blends at air- fuel equivalence ratio of 1.35.

B. Effect of Waste Cooking- Diesel Oils Blends on Thermal Heat Balance

The thermal heat balance of the combustor was calculated by means of total heat input, heat transfer to the combustor wall, exhaust gases heat loss and radiation losses. Applying thermal heat balance for 0, 20, 40, 60, 80 and 100% waste cooking- diesel oils blends at air- fuel equivalence ratio of 1.35. The percentage of heat transferred to the combustor to the total heat input was calculated. Figure 3 showed the effect of waste cooking- diesel oils blends on heat transferred to the combustor walls (combustor efficiency) at a constant heat load of 30 kW and air- fuel equivalence ratio of 1.35. The increase in the percentage of heat transferred to the combustor wall due to the increase in fuel drafting and closer to complete combustion. The percentage of heat transferred to the combustor wall to the total heat input (η) was calculated using the following equation:

$$\eta(\%) = \frac{M_w * C_{pw}(T_{wo} - T_{wi}) + M_{exh} * C_{exh}(T_{exh} - T_{amb})}{M_f * C.V_f + M_{f\,heating} * C_f(T_{heating} - T_{f0})}$$

Blend of 20%WCO had lower combustor efficiency about diesel fuel by 27%. Combustor efficiency of blend 40% increased over blend 20%WCO by 13% but lower than that of diesel fuel by 16.8%. Combustor efficiency for blend 60 and 80% WCO are nearly equal and had values of 26% reductions compared to diesel oil.

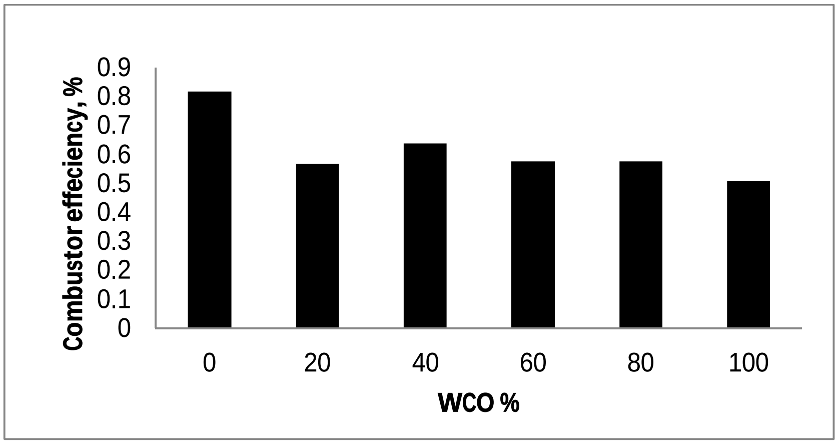

Fig.3: Percentage of heat transferred to the combustor walls for waste cooking- diesel oils blends at a constant heat load of 30kW.

C. *Effect of Waste Cooking- Diesel Oils Blends on Radial Inflame Temperatures*

Inflame temperatures were measured axially and radially according to the length of the flame and radius of combustor, respectively. The inflame temperatures in X\L (axial distribution) and R/R$_0$ (radial distribution) were measured. Effects of waste cooking-diesel oil blends of 0, 20, 40 and 60% WCO on the radial distribution of flame temperature at different axial positions of 0.0275, 0.075, 0.125 and 0.175 at a constant heat load and air- fuel equivalence ratio of 1.35 are shown in Figs.4, 5, 6, 7 and 8. The radial inflame temperature decreased from the center of combustor towards the combustor walls for WCO and LDO at different axial positions from the exit of burner because of cooling water jacket effect surrounding the combustor walls. Diesel fuel had heating value higher than that of waste cooking diesel blends. The inflame temperatures decreased gradually as going far in axial positions.The core of the flame for waste cooking- diesel oils blends had nearly equal inflame temperatures at R/R$_0$=0.1. At X/L= 0.125, radial inflame temperatures decreased because of fuel consumption decrease.

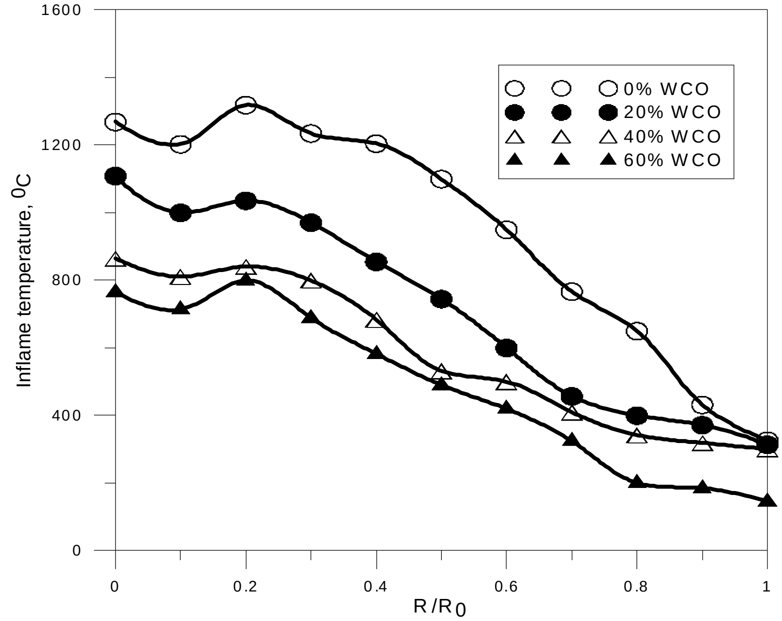

Fig.4: Radial inflames temperature of waste cooking- diesel oils blends at X/L=0.0275 and 30 kW heat load input.

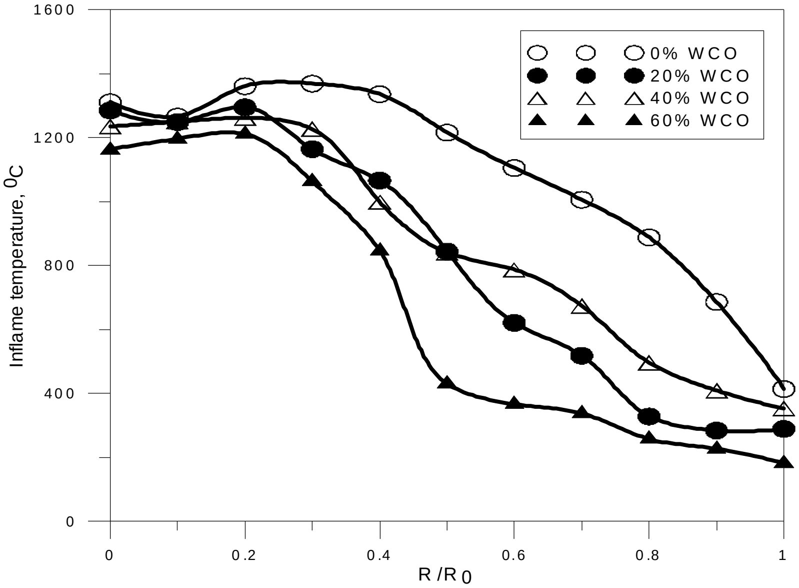

Fig.5: Radial inflames temperature of waste cooking- diesel oils blends at X/L=0.075and 30 kW heat load input.

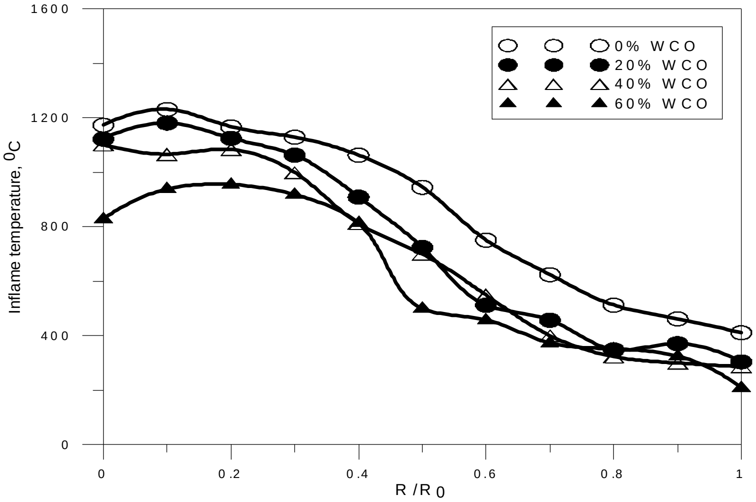

Fig.6: Radial inflames temperature of waste cooking- diesel oils blends at X/L=0.125 and 30 kW heat load input

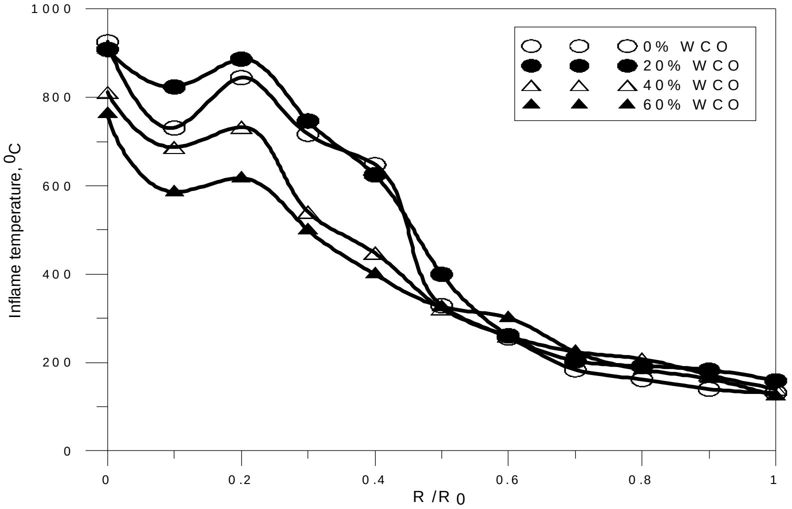

Fig.7: Radial inflames temperature of waste cooking oil- diesel oils blends at X/L=0.175 and 30 kW heat load input.

D. Effect of Waste Cooking- Diesel Oils Blends on Axial Inflame Temperatures

Effect of waste cooking- diesel oils blends on axial inflame temperatures at a constant heat load and air- fuel equivalence ratio of 1.35 was shown in Fig.8. The flame shape and its length changed in flame zones (unstable shear zone, turbulent zone and complete combustion zone). The decrease in inflame temperature appeared in transition from ignition zone to unstable shear. The preheating zone is found near the burner exit. This is followed by a rapid temperature increase in the reaction zone. A maximum temperature occurs and followed by temperature decay due to water jacket cooling of combustor. The increase of waste cooking oil percentage in each blend made the flame shorter and decrease the axial inflame temperature due to higher viscosity and chemical composition of fatty acids. The peak inflame temperature was farther away from the centerline. Firstly, light diesel oil was atomized and burned quickly because it had flash point lower than waste cooking oil. Finally, waste cooking oil entered the turbulent zone (reaction zone) to complete combustion.

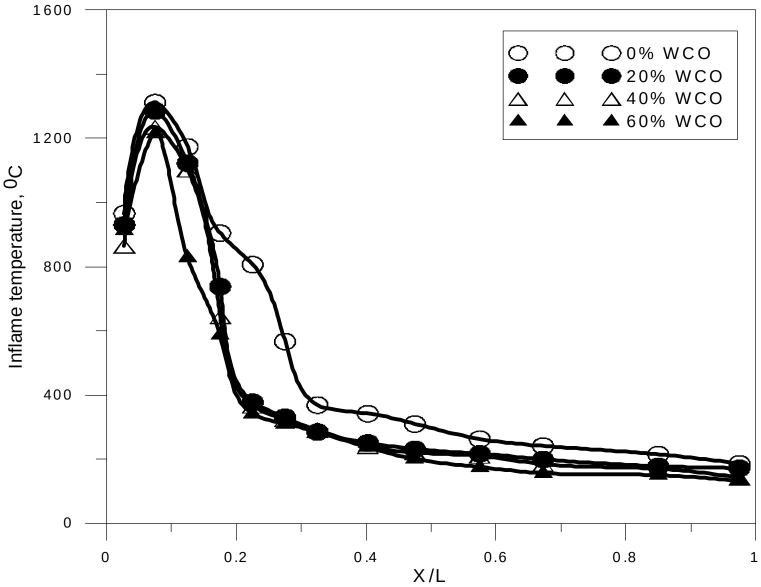

Fig.8: Axial inflames temperature of waste cooking- diesel oil blends at 30 kW heat load input.

E. Effect of Waste Cooking- Diesel Oils Blends on Thermal Contouring

Inflame thermal contouring were recorded for waste cooking- diesel oils blends of 0, 20, 40 and 60% WCO. Thermal temperature contouring of diesel oil flame at primary air pressure of 2 bar was shown in Fig.9. Thermal temperature contouring of 20, 40 and 60% WCO blend flame at a primary air pressure of 2.75 bar was shown in Figs.10, 11, and 12. Increasing of waste cooking oil percentage in diesel- waste cooking oils blends led to production of higher inflame core temperatures. Larger areas of high inflame temperatures were produced beside the flame had been become narrower than diesel oil thermal flame for 20% WCO. Waste cooking oil particles decreased the diameter of the flame due to its large particles. 40 and 60% WCO blends produced longer flames about 20% WCO blend but had smaller areas of higher temperatures due to the excess of oxygen molecules supplied. So, some molecules were not burnt and rise in exhaust emissions as seen from exhaust emissions analysis.

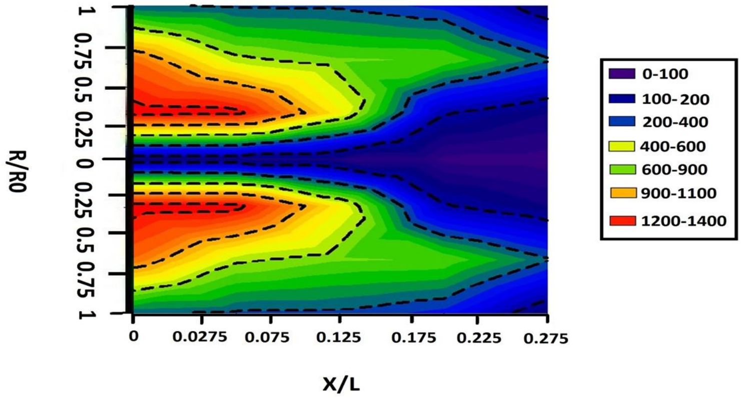

Fig.9: Thermal temperature contouring of diesel oil flame at a primary air pressure of 2 bar.

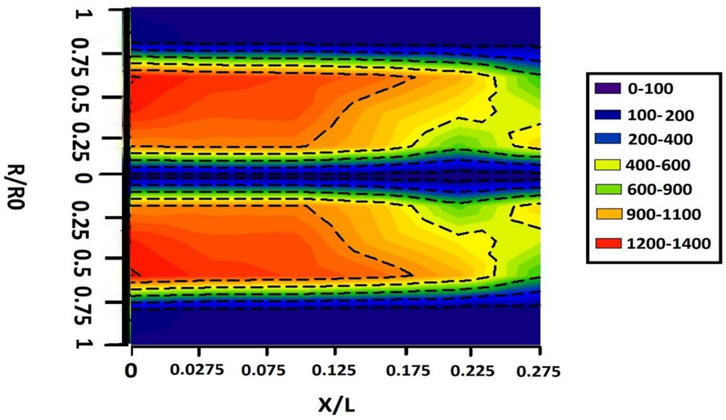

Fig.10: Thermal temperature contouring of 20% WCO blend flame at a primary air pressure of 2.75 bar..

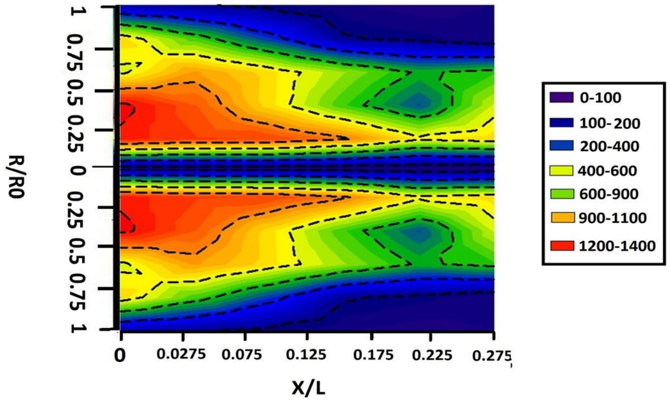

Fig.11: Thermal temperature contouring of 40% WCO blend flame at a primary air pressure of 2.75 bar.

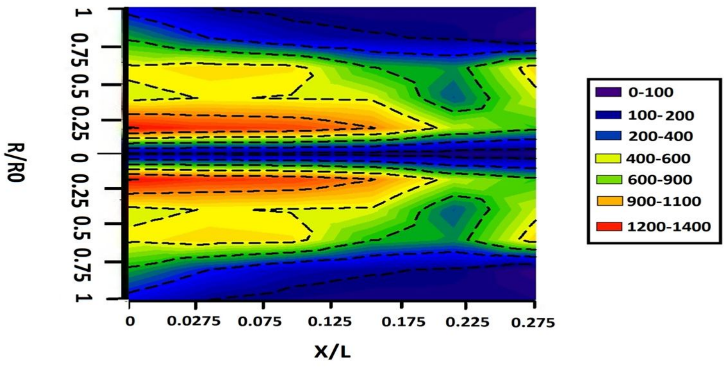

Fig.12: Thermal temperature contouring of 60% WCO blend flame at a primary air pressure of 2.75 bar.

F. Effect of Waste Cooking- Diesel Oils Blends on Exhaust Emissions

Emissions concentrations such as CO, SO_2, C_nH_m and NO_x, were measured using LDO, WCO and their blends as fuels in universal oil burner. The following figures showed the effect of waste cooking-diesel oil blends on exhaust emissions at a constant heat load of 30 kW and air- fuel equivalence ratio of 1.35. Figure 13 showed the variation of CO emissions for light diesel oil blended with waste cooking oil. CO emissions concentrations decreased with the increase of waste cooking oil percentage. The oxygen content in waste cooking oil resulted in more complete combustion than diesel oil. CO emission measurements showed that waste cooking oil and diesel- waste cooking oils blends produced very low CO emissions compared to light diesel oil.

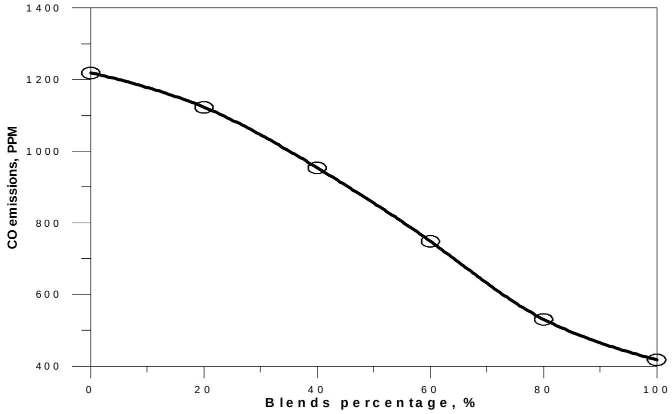

Fig.13: CO emissions for waste cooking- diesel oils blends at a constant heat load of 30 kW.

The variations of unburned hydrocarbons emissions of different percentages of waste cooking - diesel oils blends were investigated in Figure 14. Increase of waste cooking oil percentage in each blend increased the unburned hydrocarbons emissions due to higher viscosity and its chemical composition compared to diesel fuel. Waste cooking oil- diesel blends caused problems of fuel atomization and improper fuel- air mixture led to incomplete combustion and higher unburned hydrocarbons.

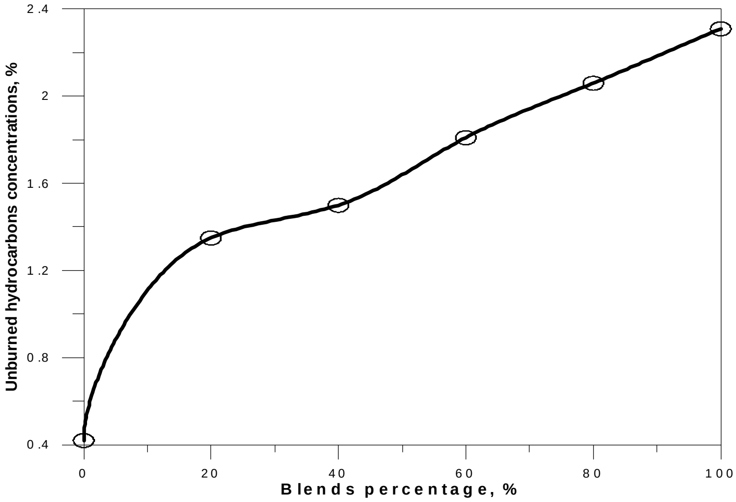

Fig.14: Unburned hydrocarbonsemissions for waste cooking oil- diesel oils blendsat constant heat load of 30 kW.

Effect of waste cooking- diesel oils blends on NO_x emissions are shown in Fig.15. Formation of NO_x emissions decayed at higher excess air ratios. NO_x emissions of waste cooking oil blends (60, 80 and 100% are nearly vanished. the highest values of NO_x emissionsare expected from high exhaust temperature due to thermal NO_x of Zeldovich mechanism.

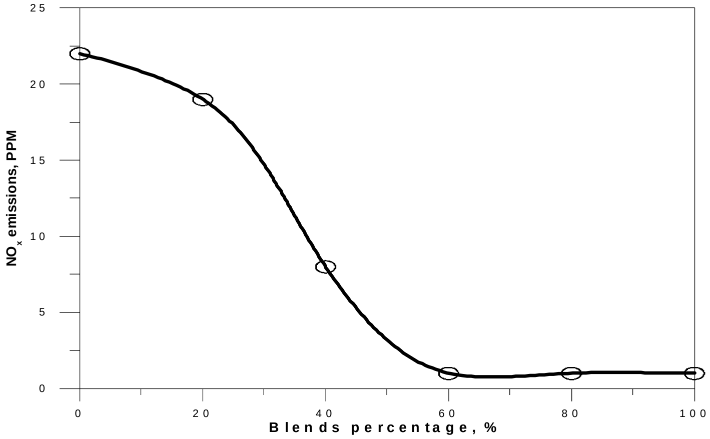

Fig.15: NO_x emissions for waste cooking-diesel oils blends at constant heat load of 30 kW.

Oxygen concentrations for waste cooking- diesel oils blends are shown in Fig.16.Oxygen concentrations for WCO were higher than LDO due to higher oxygen content in WCO compared to LDO. This content of oxygen was consumed in converting CO to CO_2. The oxygen concentration measured in the chimney of the combustor for LDO fuel was lower due to the consumption of unburned oxygen to make complete combustion.

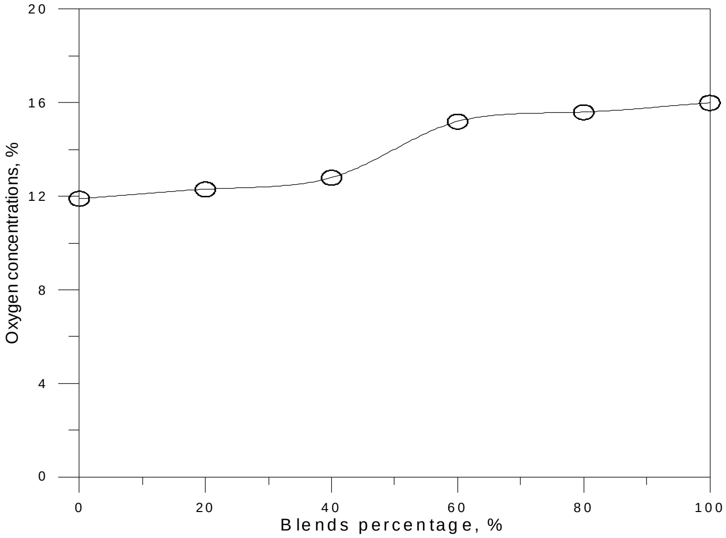

Fig.16: Oxygen concentrations of waste cooking oil - diesel oils blends atconstant heat load of 30 kW.

Figure 17 displayed the variation of SO_2 emissions for 0, 20, 40, 60, 80 and 100% waste cooking-diesel oil blends. Increase of primary air pressure led to increase of fuel consumption, increase of fuel-air equivalence ratio and heat release. SO_2 emission for diesel fuel was higher than any other blend due to its chemical composition. Waste cooking oil does not contain sulfur in its composition (very small percentage can be neglected). Waste cooking- diesel oils blends can be used to avoid corrosion of metals.

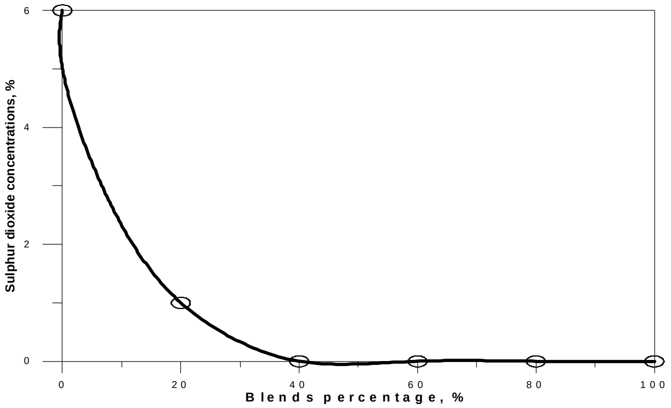

Fig.17: SO_2 emissions for waste cooking- diesel oils blends at a constant heat load of 30 kW.

V. CONCLUSIONS

Waste cooking –diesel oil blends can be used as alternative fuels in oil burners, boilers, power stations, warming domestic regions, brick and cement factories and furnaces. Using of WCO would be favorable due its lower cost and reducing dependence on conventional diesel fuel. Rapprochement between performance characteristics and exhaust emissions were done for different waste cooking- diesel oils blends. The main conclusions that rose from combustion processes are:

A. WCO was considered as oxygenated fuel oil despite of its higher viscosity and density.

B. Blends of 0, 20 and 60% had nearly the highest exhaust gas temperatures at constant heat load and air- fuel equivalence ratio of 1.35 due to increase of heat loss in exhaust.

C. Hydrocarbons emissions for WCO were higher than LDO due to higher viscosity and improper fuel- air mixing of waste cooking oil compared to diesel fuel. Hydrocarbons emissions were directly proportional to waste cooking oil percentage.

D. NO_x emissions of for LDO were higher than any waste cooking- diesel blend due to production of higher flame temperatures compared to waste cooking- diesel oils blends.

E. CO emission measurements showed that waste cooking oil and its blends with diesel oil produced very lower emissions compared to light diesel oil. By increasing waste cooking oil in blends, CO emissions in exhaust decreased.

F. The percentage of heat transferred to the combustor wall decreased for WCO and LDO blends compared to LDO due to the increase of fuel consumption, heat loss in exhaust and cooling water.

G. The peak inflame temperature was farther away from the centerline because of late combustion for waste cooking- diesel oils blends. Light diesel oil has higher inflame temperature and burnt easily. Increasing of waste cooking oil percentage in diesel-waste cooking oils blends led to production of higher inflame core temperatures.

REFERENCES

[1] Bazooyar B., Afshin G., Ahmad S.,"Combustion performance and emissions of petrodiesel and biodiesels based on various vegetable oils in a semi industrial boiler", Fuel 90, (2011), 3078–3092.
[2] Viktor J., Attila K. B., "Spectroscopic analysis of crude rapeseed oil flame", Fuel Processing Technology, 139, (2015), 61–66.
[3] Kulkarni M.G., Dalai A.K., "Waste Cooking Oils an Economical Source for Biodiesel: A Review", Ind. Eng. Chem. Res., 2006; 45: 2901-2913.
[4] 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.
[5] Tashtoush G., Al-Widyan M., Al-Shyoukh M., "Combustion performance and emissions of ethyl ester of a waste vegetable oil in a water-cooled furnace",Appl. Therm. Eng.,2003;23:285–93.
[6] Vanlaningham N., Gibson H., Kaufman B., "Evaluation of soybean heating oil blends for use in residential applications", No. 046082, ASAE paper, Annual meeting held on August 23–24; 2004.
[7] Bozbas K., "Biodiesel as an alternative motor fuel: production and policies in the European Union", Renew. Sust. Energy., Rev 2008; 12:542–52.
[8] Barnwal BK, Sharma MP. "Prospects of biodiesel production from vegetable oils in India", Renew. Sust. Energy, Rev 2005; 9:363–78.
[9] Qi DH, Chen H, Matthews RD, Bian YZH., "Combustion and emission characteristics of ethanol–biodiesel–water micro-emulsions used in a direct injection compression ignition engine", Fuel 2010; 89:958–64.
[10] Gui MM, Lee KT, Bhatia S., "Feasibility of edible oil vs. non-edible oil vs. waste edible oil as biodiesel feedstock", Energy, 2008; 43:1643–53.
[11] Batey M., "Combustion testing of a bio-diesel fuel oil blend in residential oil burning equipment", Massachusetts Oil heat Council & National Oil heat Research Alliance, Final Report; 2003.
[12] Krishna CR, Celebi Y, Wei G, Butcher T, McDonald R, "Lab tests of biodiesel blends in residential heating equipment", Proceedings of the 2001 national oil heat research alliance technology conference; 2001.
[13] Krishna CR., "Biodiesel blends in space heating equipment",National renewable energy laboratory report NREL/SR-510-33579; 2004.
[14] Kait Ng H, Gan S., "Combustion performance and exhaust emissions from the non- pressurised combustion of palm oil biodiesel blends", Appl. Therm. Eng., 2010; 30:2476–84.
[15] Win L. S., Herage T., Young B., "Emission reduction potential from the combustion of soy methyl ester fuel blended with petroleum distillate fuel", Fuel 2004;83:1607–13.
[16] Ghorbani A, Bazooyar B, Shariati A., Jokar SM, Ajami H., Naderi A, "A comparative study of combustion performance and emission of biodiesel blends and diesel in an experimental boiler", Appl. Energy 2011; 88:4725e32.
[17] Afshin G., Bahamin B., "Optimization of the combustion of SOME (soybean oil methyl ester), B5, B10, B20 and petrodiesel in a semi industrial boiler",Energy, Vol.44 No.1 pp.217-227, 2012.
[18] Barnes CD., Garwood DR., Price TJ.,"The use of biodiesel blends in domestic vaporizing oil burners", Energy 2010; 35:501e5.
[19] 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.
[20] Kafuku G., Mbarawa M., "Alkaline catalyzed biodiesel production from Moringa oleifera oil with optimized production parameters", Applied Energy 2010;87(8):2561–2565.
[21] 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.
[22] 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.
[23] 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.
[24] 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.
[25] Abdelgawad A., Emara A., Gad M.S., Elfatih A., "combustion characteristics of a swirled burner fueled with waste cooking oil", Proceedings of the ASME 2015 International Mechanical Engineering Congress and Exposition conference; 2015; volume 6A:Energy IMECE2015-53437, pp.V06AT07A007.