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Study the Effect of Biodiesel Blend and Exhaust Gas Recirculation on Flame Characteristics and its Emission

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Abstract: *Due to the decrease in fuel resources, intense research is being carried out on the combustion of biodiesel, one of the main alternative fuels available in the world market. The present experimental study aims to investigate the combustion and emission characteristics of diesel and blend biodiesel 10% (B-10) under conditions of different air to fuel ratios of twin fluid air assist atomizer. In order to analyze the flame structure, a small scale water cooled laboratory furnace is used. Comparative Biodiesel is prepared and mixed with diesel liquid as 10% biodiesel and 90 % diesel. The combustion characteristics of blend is compared with those of pure diesel at different values of air to fuel ratio. The results show that, diesel fuel enhances the flame temperature and the heat flux to the water jacket, but the pollutant emissions decrease. In order to reduce* NO_x *in combustion products EGR (Exhaust Gas Recirculation) technique was applied. Fraction of the exhaust gases are cooled through heat exchanger and compressed using a compressor to be used as an atomizing fluid. The combustion and emission characteristics of EGR are compared with those of using air as atomizing fluid. Exhaust gas recirculation (EGR) is an effective strategy to control NOx emissions from furnaces. It is found that the flame temperature decreases and the concentration of NOx decreases by 15 % when EGR is used.*

Keywords: *biodiesel, Spray combustion, Emissions, EGR, Inflame temperature.*

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I. Introduction

The limited fossil fuel resources and increasing demand for energy have become major issues for our modern world leading to the discovery and exploration of new ways to utilize alternative fuels to replace the conventionalfossil fuels. Biodiesel is one of the common alternative biofuels intended to satisfy some of the energy needs. Biodiesel is produced through the trans-esterification process of triglycerides from sources such as vegetable oils and/or animal fats. Pereira et al. [1] studied experimentally the combustion of biodiesel in a large-scale laboratory furnace. The tests were carried out to evaluate the feasibility of using biodiesel as a fuel in industrial furnaces. For comparison purposes, petroleum-based diesel was also used as a fuel. It was found that the spray cone angle changed as a function of the atomizing air/fuel ratio (A/F). Also, it was seen that the spray cone angle decreased as (A/F) increased regardless of the liquid mass flow rate. In addition, they found that the CO emissions from biodiesel and diesel combustion are rather similar and not affected by the atomization quality. Bazooyar et al. [2] and Daho et al. [3] showed that utilizing triglyceride based fuels in boiler results in satisfactory engineering results. Bazooyar et al. [4, 5] found that the NO level in the boiler can be reduced if biodiesel is sprayed into the chamber at a 60° patternand ignites with 45° swirl air. The NOx formation is of great importance in the evaluation of the environmental impact of different fuels. Ghorbani and Bazooyar [6], Ghorbani et al. [7], Lee et al. [8], Macor and Pavanello [9] and Tashtoush et al. [10] found that the NOx emissions of biodiesel fuels did not changed or slightly decreased when compared with petrodiesel fuels. On the other hand, others [11-16] reported that biodiesel fuels emit more NOx than perodiesel fuels. Abu-Qudais [17] studied experimentally the performance and emissions characteristics of a cylindrical water cooled furnace using non-petroleum (shale oil) fuel. The rate of heat transfers to the water jacket of the water cooled furnace was improved in the case of shale oil compared to diesel fuel when they were tested under the same conditions. Also, Hosseini et al. [18] has reported an experimental comparison of combustion characteristics and pollutant emissions of gas oil and biodiesel. Creating blends from othertypes of fuels may be leads to a good result in combustion characteristics. Akash [19] determined the combustion performance and gas emission of diesel fuel, kerosene and various mixtures of diesel fuel and kerosene in a horizontally positioned cylindrical furnace. It was found that the best results when a fuel blend of 75% kerosene and 25% diesel was prepared and burned in the unit. Lulin et al. [20] investigated the low-emission combustion of diesel, biodiesel and straight vegetable oil (VO) in a fuel-flexible combustor employing a flow blurring (FB) injector for fuel atomization. The results showed that the FB injector produced clean blue flames indicating mainly premixed combustion for all three fuels. Matching profiles of heat loss rate and product gas temperature showed that the combustion efficiency was fuel independent.

Exhaust gas recirculation (EGR) is an effective strategy to control NOx emissions from furnaces. The EGR reduced NOx through lowering the oxygen concentration in the combustion chamber, as well as through heat absorption that led to reduction of the combustion temperature. Khair et al. [21] reviewed the exhaust gas recirculation topic. Several configurations had been proposed, including high and low-pressure loop EGR, as well as hybrid systems. NOx emissions might be further reduced by cooled EGR, in which recirculated exhaust gas was cooled in an EGR cooler. Drawbacks of EGR included increased PM emissions and fuel consumption. Nitrogen, Argon, and CO were used as the atomizing gas in an air-assist fuel nozzle to determine the effect of these gases on droplet size, number density, and velocity distribution in kerosene spray [22].

There was little data available in the literature on effect of EGR and biodiesel fuel on combustion and emission characteristics upon to the knowledge of the authors. This is the main motivation behind the present study.In the current paper, an experimental study is carried out in a laboratory scale water cooled horizontal furnace. A detailed comparison between combustion characteristics and emissions of pure diesel and blend of biodiesel and diesel fuels were carried out. In addition, the effect of exhaust gas recirculation was also investigated.

II. Experimental setup

An experimental setup was designed and constructed to provide an experimental data of spray flame combustion. The test rig shown schematically in Fig. 1a consists of a horizontal small-scale cylindrical furnace (1) equipped with an external mixing air assist atomizer (2) which installed through the burner (3). The combustion air is supplied to the burner by a centrifugal Blower (4). The combustion air flow rate regulated through a globe valve (5) and measured using calibrated orifice meter (6). The atomizing air is supplied from a large tank (7) of volume 7 m^3 and charged with screw compressor (8). The atomizing air pressure is regulated through a pressure regulator (9) and its flow rate is measured using calibrated orifice meter (10). The liquid fuel is supplied from a fuel supply system as shown in detail in Fig. 1b consists of a tank (11) pressurized by a compressed air. The pressure of compressed air in the fuel tank is regulated using a pressure regulator (12). The fuel is filtered through a filter (13) to prevent the atomizer blockage, hence keep a constant fuel flow rate. A pressure relief valve (14) is used as a safety valve and helps in keeping constant air pressure above the liquid fuel surface. The combustor is an insulated horizontal cylindrical water cooled flame tube of 480 mm inner diameter and 1500 mm length manufactured of thick steel sheet of 5 mm thickness. The cylindrical flame tube is cooled by a water circular jacket of 600 mm external diameter and is segmented to a 10 unequal segments. At the middle of each segment a radially aligned tap of 15 mm diameter is provided to allow the insertion of the different temperature measuring probes. A 50 mm diameter main cooling water header is used for the distribution of the cooling water to each segment via an 18.5 mm diameter inlet pipe (15) at the bottom of each segment. Gate valves (16) are located at the entrance of each segment for the purpose of controlling the water flow rates. The volume flow rate of cooling water is measured using a calibrated orifice meter at the inlet of each segment. The hot water leaves each segment at the top side (17) and its temperature is measured using thermocouple (18) before drained to the sink. The exhaust temperature is measured at exhaust port (19). The emissions concentrations are measured using gas analyzer (20) at port (21). Figure 2a illustrates a schematic diagram of an external mixing air assist atomizer with a fuel nozzle of 1 mm diameter. The atomizer installed through a burner tube as shown in Fig. 2b. Figure 3 shows the exhaust gas recirculation system. Fraction of the exhaust gases at the exit of the furnace is drowned and cooled through a single pass shell and tube heat exchanger. The gases move through the pipe due to the suction pressure generated by a compressor. The gases leave the heat exchanger and are stored in the compressor tank. The discharge gases from compressor are used as an atomizing fluid in the air assist atomizer instead of air and the pressure of gases is regulated through a pressure regulator.

III. Measuring Instruments

This section describes the different measuring devices that are used to measure inflame temperature distribution, exhaust temperature, water temperature, air flow rate, emissions and fuel flow rate. The inflame temperature and exhaust gas temperature measurements system consists of thermocouple and position guide. The thermocouple employed in the present study is made of platinum/ (platinum 10% rhodium) wires of 190 µm diameter. The thermocouple wires are supported in a twin-bore ceramic tube having an external diameter of 4 mm. The ceramic tube is placed inside a stainless steel tube of 6 mm external diameter. The temperature of the hot water at the exit of each furnace segment is measured using calibrated T-type thermocouple located at the exit of each segment. The fuel flow rate, combustion air and atomizing air flow rate are measured using calibrated orifice meter for each. The exhaust gases concentrations are measured using calibrated E-instrument gas analyzer.

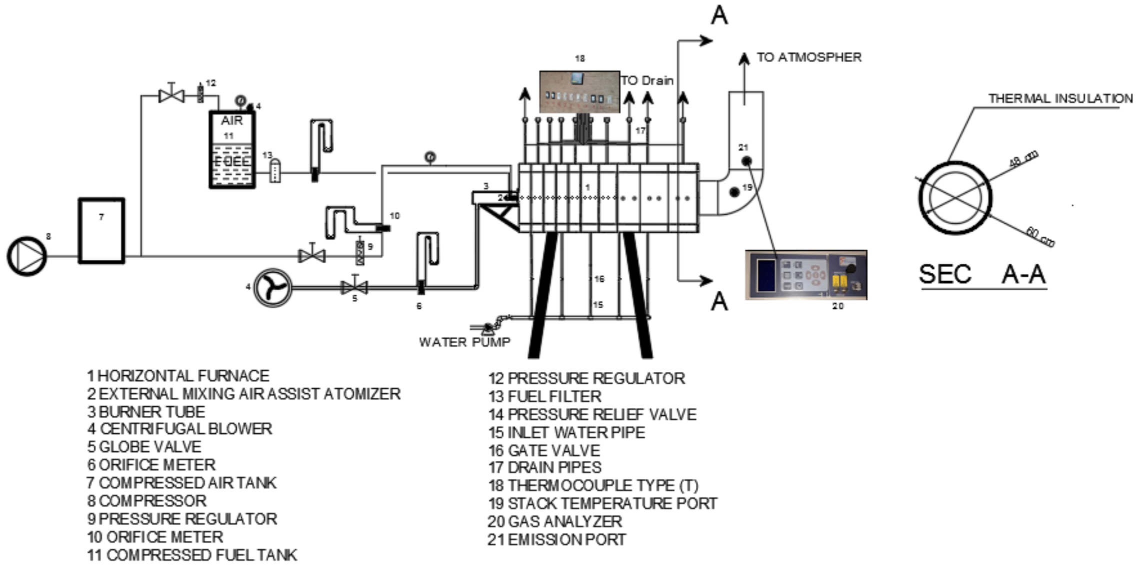

Fig. 1. Schematic diagram of an experimental test rig.

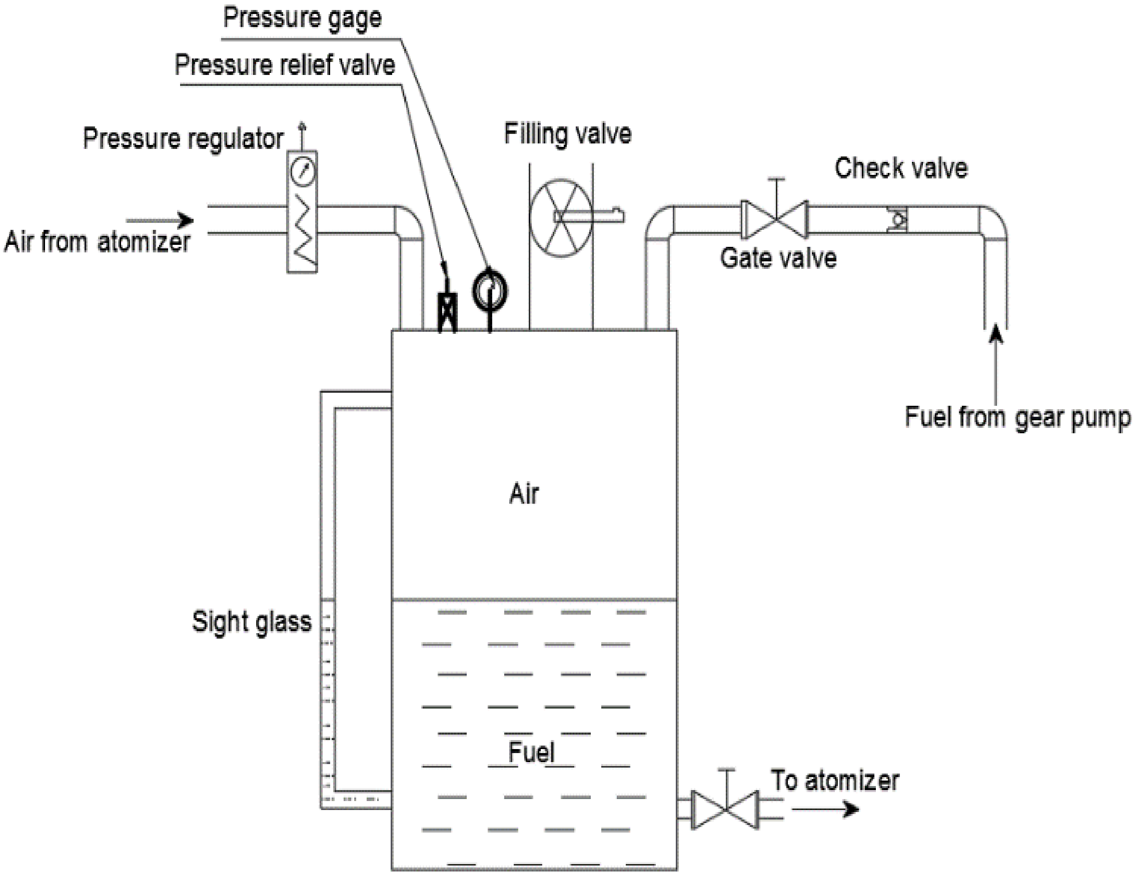

Fig. 1b. The air pressurized fuel tank.

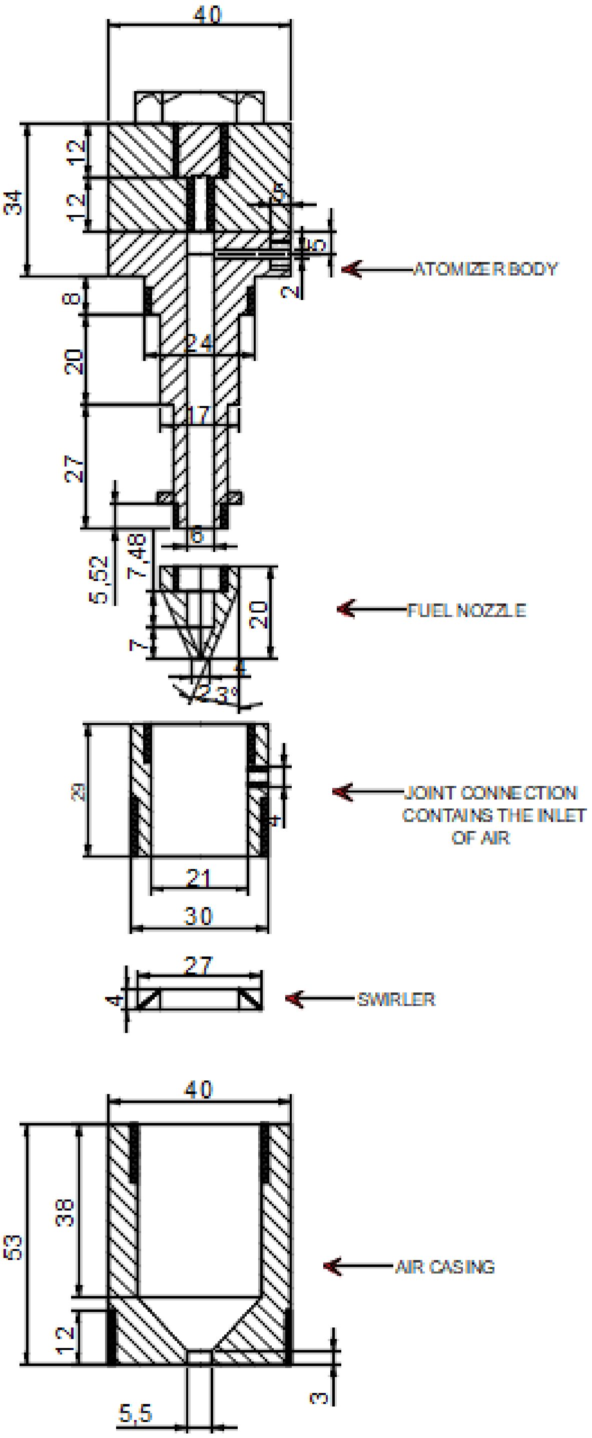

Fig. 2-a External mixing air assist atomizer Dimensions in (mm)

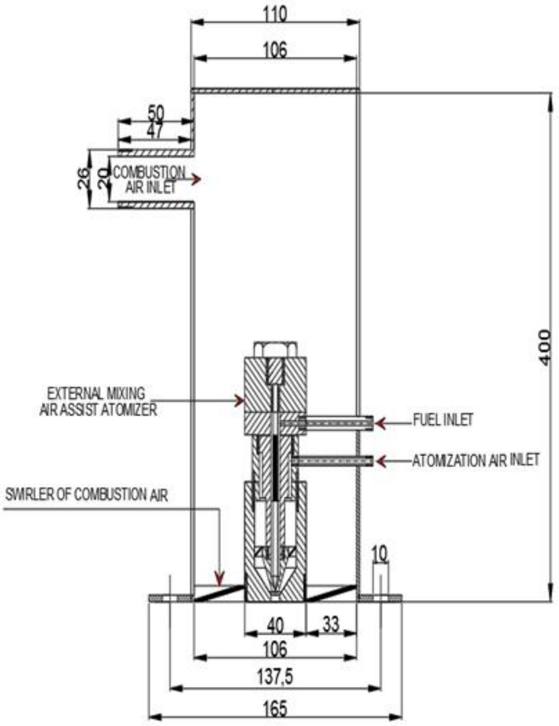

Fig. 2-b. Burner assembly.

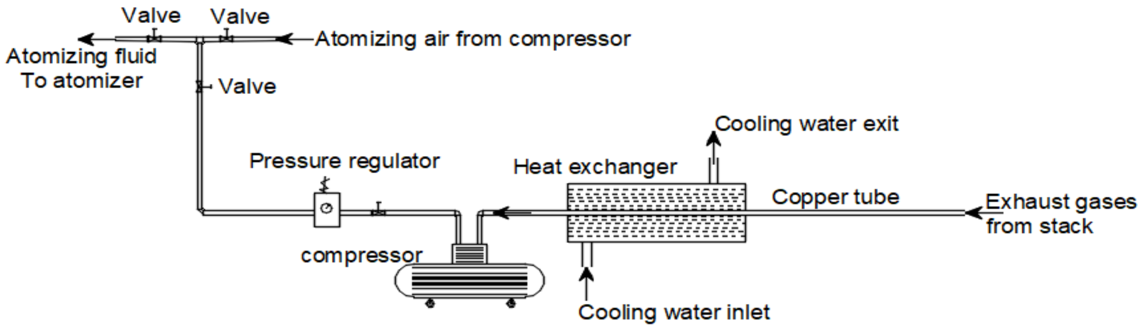

Fig. 3. Schematic diagram of Exhaust Gas Recirculation (EGR) system.

IV. Experimental Uncertainty

The most common sources of errors in the measured parameters are found in the pressure drop across orifice meter, inflame temperature, and cooling water temperature. These parameters have direct effect on the accuracy of temperature and mass flow rates. Uncertainty of each parameters is shown in Table 1.

Table 1 Uncertainty in the measured parameters

Parameter	Uncertainty	Range
Inflame temperature	± 6.9 ^{o}c	1:1800 ^{o}c
Cooling water temperature	± 0.5 ^{o}c	1:100 ^{o}c
Time	± 0.01 s	_
Flame length	± 0.5 mm	_
Combustion air mass flow rate	± 0.9 kg/hr	Up to 170 kg/hr
Fuel mass flow rate	± 0.06 kg/hr	Up to 10 kg/hr

V. Results and discussions

In the following subsections the effect of both biodiesel blend and exhaust gas recirculation on the combustion characteristics, heat flux, and exhaust emissions concentration will be presented and discussed

5.1 Axial inflame temperature

Figure (4) shows the inflame-temperature distribution along the axis of the furnace for B-10 fuel and pure diesel fuel respectively, at different overall air-to-fuel ratios. As shown, the temperature at the centre of the furnace increases downward up to the maximum value then decreases again. This trend is repeated at all the cases of different fuels. It is obvious also the values of temperatures of diesel fuel are higher compared with biodiesel blend, as well as the higher the air-to-fuel ratio the lower the level of temperature. As known, increasing air in the reactants increases the amount of nitrogen that is a parasitic gas which absorbs a quantity of heat released and reduces the temperature of gas products. The differences in temperature are small near burner region, while differences increases for far region from burner tip because of decreasing flame length with increasing air-to-fuel ratio due to an good mixing and sufficient oxidant, moreover the heating value of biodiesel blend is lower that of pure diesel.

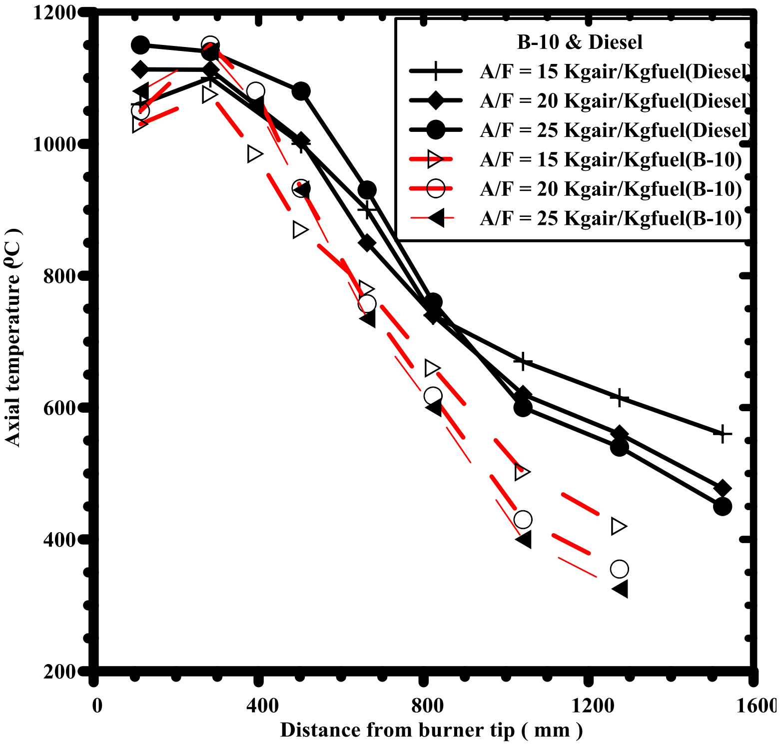

Fig. 4. The inflame temperature distribution along the axis of the flame for different overall air to fuel ratios for both fuels diesel and B-10at Pa=1 bar and θs= 45°.

5.2. Cooling water heat transfer per unit area (heat flux)

Figure (5) compares the heat transfer rate per unit area (heat flux) to the water jacket for both fuels at different values of air-to-fuel ratios. It can be seen that, the heat flux decreases with increasing the combustion air. Also, it is observed that the heat flux in the case of diesel is higher due to the more premixed nature of the flame for diesel, which is attributed to the lower density and viscosity of diesel compared to B-10 in addition to high calorific value of diesel fuel relative to biodiesel blend. This behavior agrees with the inflame temperature distributions.

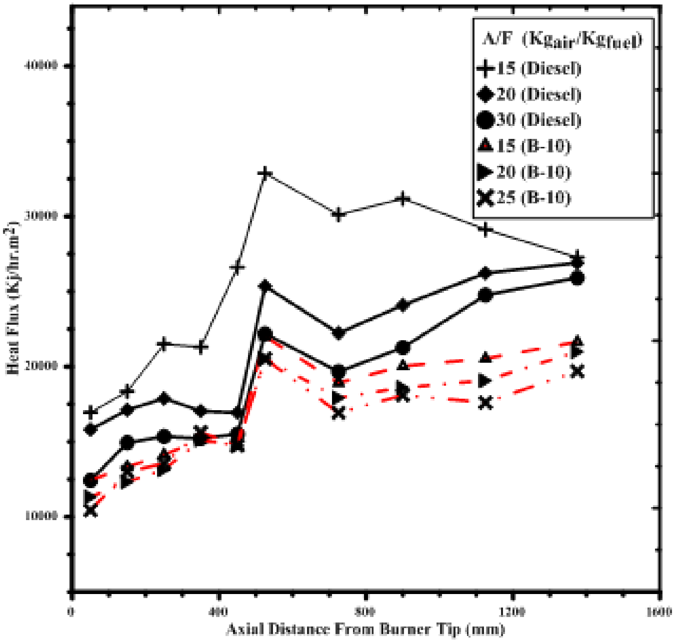

Fig. 5. Total heat flux to the water jacket for different values of air to fuel ratio for both fuels diesel and B-10 at Pa=1 bar and θs= 45°.

5.3. Emission concentrations

Figure (6) illustrates the variation of CO concentration at different values of air to fuel ratios. It is clear that the CO concentration decreases with increasing the combustion air flow rate in both cases of diesel and B-10 fuels. It can also be seen that the CO concentration of diesel fuel is higher than that of blend B-10 (by 15.8 %) due to the high temperature and probability of dissociation of carbon dioxide into carbon monoxide at higher level of temperatures.

Figure (7) presents the variation of NOx concentration at different values of air to fuel ratios. As noticed that the NOx concentration decreases with increasing the combustion air flow rate in both cases of diesel and blend B-10. The NOx concentration of diesel fuel is greater than that of blend B-10 (by 22.4 %) due to the high temperature. This means a gradual increase in the thermal NO formation as A/F increases in the range of high temperature.The main reason support this evidence is that the diesel firing leads to lower temperatures in the near burner region, as shown in Fig. 4, which reduces the formation of NO via the thermal mechanism.

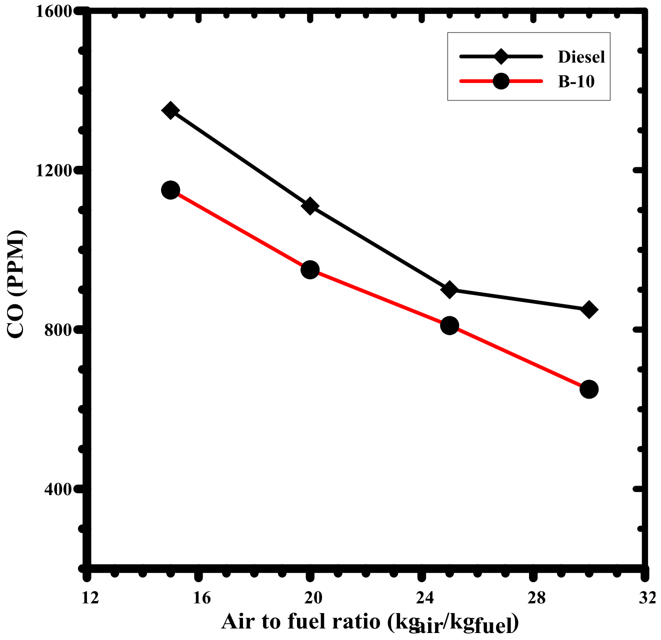

Fig. 6 Effect of air to fuel ratio on CO emissions at atomizing pressure 1 bar for both fuels diesel and B-10 at Pa=1 bar and θs= 45°.

5.4 Effect of Exhaust Gas Recirculation (EGR)

In this section the effect of exhaust gas recirculation (EGR) strategy on temperature distribution, heat flux to the cooling water and emission will be discussed. EGR in this work means that afraction of exhaust gases is used as atomizing gas instead of atomizing air. The results are compared with those of cases that depend on the air as atomizing fluid.

Figure 8 shows the axial inflame temperature distribution for different overall air to fuel ratios. It is observed that the axial temperature values are lower with highervalues of the combustion air in all cases. Also, it is found that the inflame temperature decreases with using the exhaust gases as atomizing fluid because of the energy absorbed by those gases, as well as the exhaust gases hinder the reactivity of the reactants that leads to reduction of heat release rate that decreases the temperature.

Figure 9 shows the heat transfer rate per unit area (heat flux) to the water jacket for different A/F ratios. It can be deduced that, the heat flux decreases with increasing the combustion air due to the lower level of combustion temperatures. Also, it is found that the heat flux for cases of using the atomizing air is higher than that using atomizing exhaust gases. It is believed that may be due the lower levels of temperature of the flame with exhaust gas recirculation.

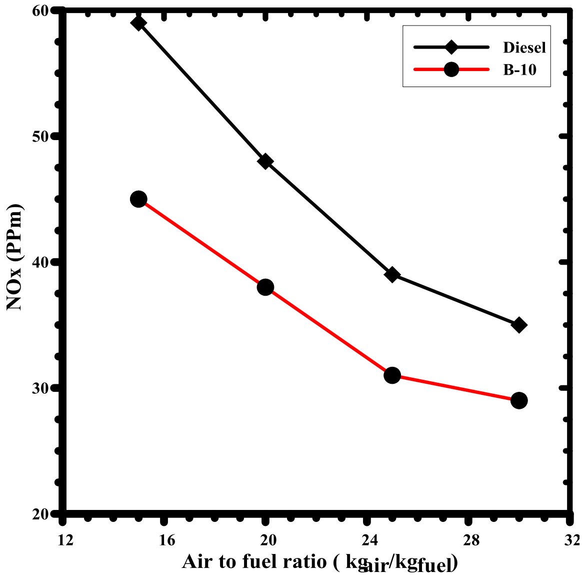

Fig. 7 Effect of air to fuel ratio on NOx emissions at atomizing pressure 1 bar for both fuels diesel and B-10 at Pa=1 bar and θs= 45°

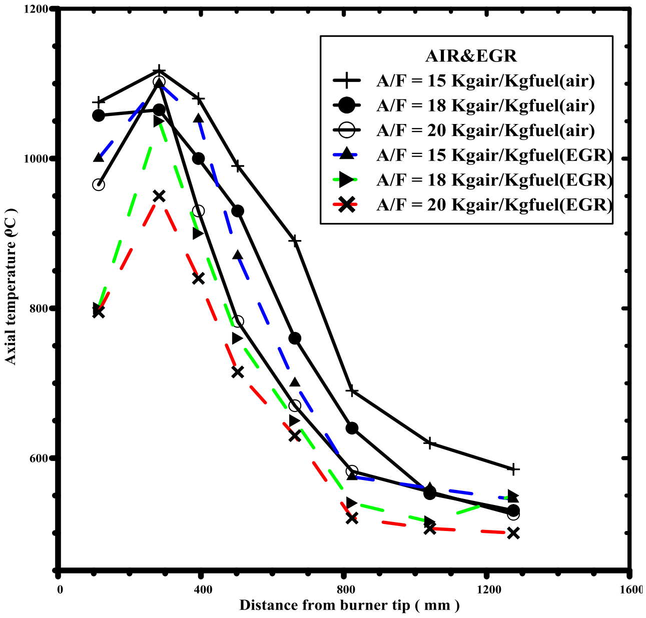

Fig. 8 The effects of EGR on inflame temperature distribution along the axis of the flame for different overall air to fuel ratios at Pa=1 bar and θs= 45°.

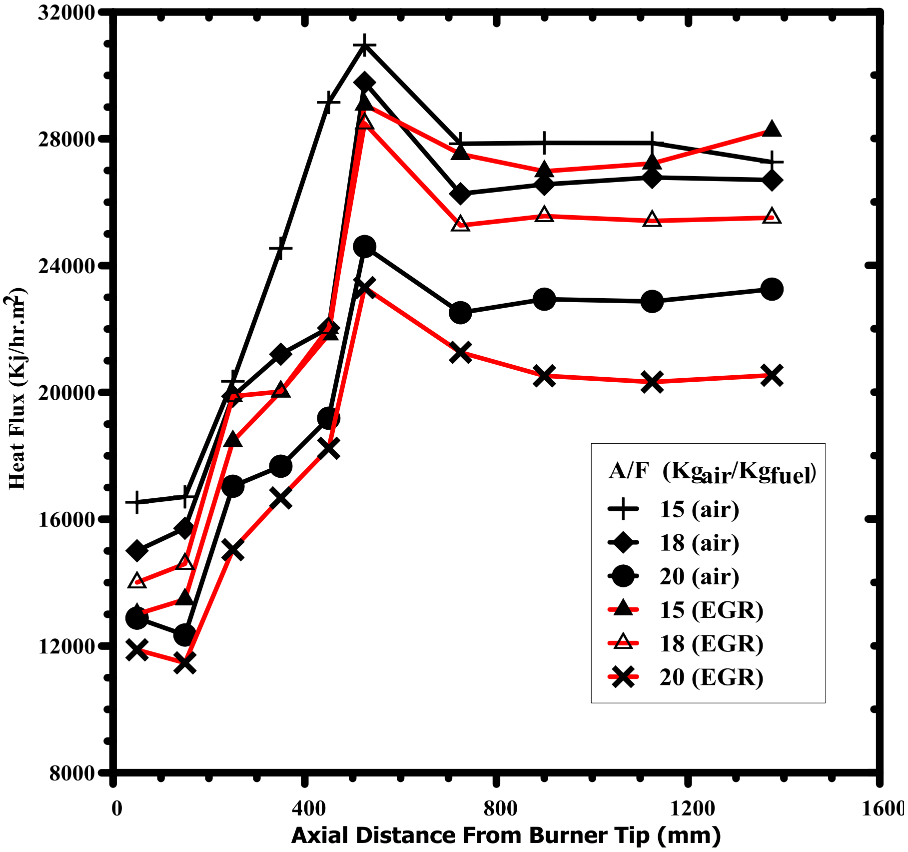

Fig. 9. The effects of EGR on total heat flux to the water jacket for different values of air-to-fuel ratio at Pa=1 bar and θs= 45°.

It is well known that the formation of NOx depends greatly on the temperature and sufficient of air. The worst case of NOx formation is near the slightly lean mixture of fuel and air. Figure 10 illustrates the variation of NOx concentration at different values of air to fuel ratios. It is seen that increasing air-to-fuel ratio from 15 to 25 effectively decreases the NOx. The figure clarifies also that the concentration of NOx decreases by 28.5 % at A/F =15 with using EGR and 15 % at A/F=25. This means that pronounced effect of this strategy for reducing NOx is more effective at slightly lean mixture. The EGR reduces NOx through lowering the oxygen concentration in the combustion zone, as well as through heat absorption that reduces the combustion temperature and cooled EGR in water cooler.

VI. Conclusions

In the present study, the combustion and emission characteristics of diesel and biodiesel blend 10% (B-10) under conditions of different air to fuel ratios of twin fluid air assist atomizer are investigated. Moreover, the combustion and emission characteristics of EGR are compared with those of using air as atomizing gas. The following conclusions are obtained:

1. Using blend (B-10) reduces the level of flame temperature compared with pure diesel fuel that leads to lower heat flux to the furnace water jacket.
2. CO and NOx emissions from B-10 combustion are lower than those from diesel combustion.
3. The EGR is an effective technique in reducing the inflame temperature, subsequently a decrease in the NOx emissions in the exhaust products resulting from combustionespecially at slightly lean mixture which is considered the worst case of NOx formation.

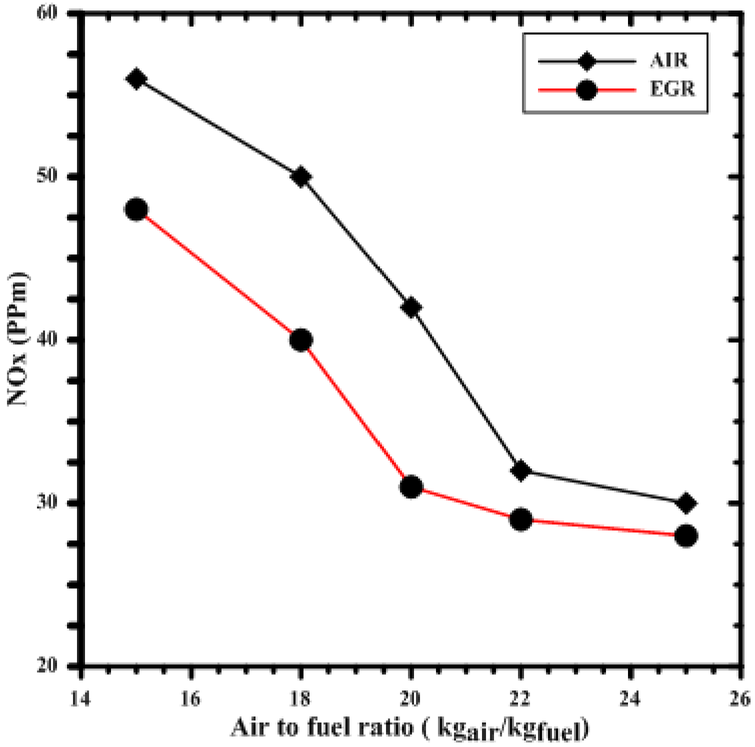

Fig. 10 The effects of EGR on NOx emissions at various air to fuel ratios at Pa=1 bar and θs= 45°.

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