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Experimental Investigations on Combustion Characteristics of *Jatropha* biodiesel (JME) and its Diesel Blends for Tubular Combustor Application

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Abstract

Scarcity of fossil fuels and their negative impact on environment drive the research in the field of alternative fuels. Biodiesel is one such promising alternative fuel that is used in automobile, gas turbine, boiler and other furnace applications. In the present study, combustion characteristics of biodiesel (*Jatropha* methyl ester) and its diesel blends in gas turbine like combustor have been studied experimentally. An airblast atomizer along with axial swirler (swirler no. 0.76) is employed to investigate the combustion characteristics. During the experiment, heat rate (24 kW), Air to liquid ratio (ALR=2) and air temperature (600K) was kept constant. For different equivalence ratio, spray and flame characterization, flame temperature, combustion efficiency and emission parameters such as carbon dioxide (CO_2), Carbon monoxide (CO), Nitrogen oxide (NO_x) and unburned hydrocarbon (UHC) were determined. It is found that the flame temperature increases with increase in JME percentage in diesel whereas and major pollutants such as CO, CO_2 and UHC emissions decrease but the NOx emissions increases. The obtained results indicate that the biodiesel can be promising fuel for gas turbine power plants instead of fossil fuels.

Keywords: Biodiesel; Combustion; Emission; Flame structure; *Jatropha* methylester

Introduction

At present, globe is facing a problem of global warming and climate change, due to high pollutants emitted by the conventional fossil fuels. Hence, there is need to use fuels which are renewable and produces lesser environment damage. The major alternative fuels [1] presently used are alcohol, bioethanol and biomass etc. Biofuels like JME derived from *Jatropha* plant (Ratanjot) is one of the most promising alternative fuels [2-4]. Many researchers [5-8] studied C.I. engine performance and emission of JME and its blends. They reported that it results in reduced brake power and increases specific fuel consumption (SFC) as percentage of biodiesel increased. Emission characteristic in term of CO, UHC, smoke decreases but NO_x is slightly higher. Hashimoto et al. carries out combustion characteristic of palm methyl ester for gas turbine combustor at atmospheric pressure and high temperature air (617 K) and found that adiabatic flame temperature, emission CO_2, CO, UHC and NO_x were lesser than conventional diesel [9]. Saroj et al. carried out flame temperature analysis for biodiesel blends and found encouraging results in term of increased flame temperature and reduced emissions [10]. Erazo et al. studied atomization and combustion characteristic using canola methyl using an airblast atomizer at atmospheric pressure and temperature 600 K. They found that NO_x emissions are lowered in biodiesel compared to the conventional diesel [11]. Rehman et al. carried out tests on single stage gas turbine engine using *Jatropha* oil-diesel blends, observed similar trends for efficiency, brake specific fuel consumption (sfc) and emission (CO and UHC) as compared to diesel fuel [12]. So far extensive research work in the area of biodiesel as fuel for intermittent combustion devices such I.C. engines has been carried out. But very little information is available on use of these fuels in continuous combustion like gas turbine and liquid fuel burners using JME derived from *Jatropha* oil found in India.

Therefore in present research, the fundamental combustion characteristic like spray behavior and open flame, temperature distribution along axial and radial direction, combustion efficiency and emission characteristic CO, CO_2, UHC, NO_x were carried out by using JME and its diesel blends.

Nomenclature

B25: 25% biodiesel + 75% Diesel by Volume

B50: 50% biodiesel + 50% Diesel by Volume

B100: 100% Biodiesel

Methodology

Fuel properties

The fuel properties (biodiesel, diesel and their blends) were measured in the chemistry laboratory of VNIT, Nagpur and the values are given in the Table 1. The temperature dependency of viscosity and density are shown in Figures 1 and 2.

Figures 1 and 2 show the plot of kinematic viscosities and density of the fuel as a function of fuel temperature. The results revealed that kinematic viscosity and density value decrease rapidly up to temperature 80°C with increase in temperature of biodiesel blends [13,14]. During the experiment, biodiesel blends were maintained at higher temperature than diesel for neglecting the effects of temperature on the spray behaviour for different injection pressure.

Experimental setup

Figure 3 shows a schematic of the experimental setup used for the combustion studies. It consists of a tubular combustion chamber

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Properties	Unit	Diesel	B25	B50	B100
Density@ 40°C	kg/cm3	832.4	843.2	854.8	882
Viscosity@40°C	cSt	2.67	3.324	4.78	7.28
Surface Tension	dyne/cm	26.43	27.42	28.68	29.4
Lower Calorific value	MJ/kg	42.32	40.23	39.72	37.62

Table 1: Fuel properties.

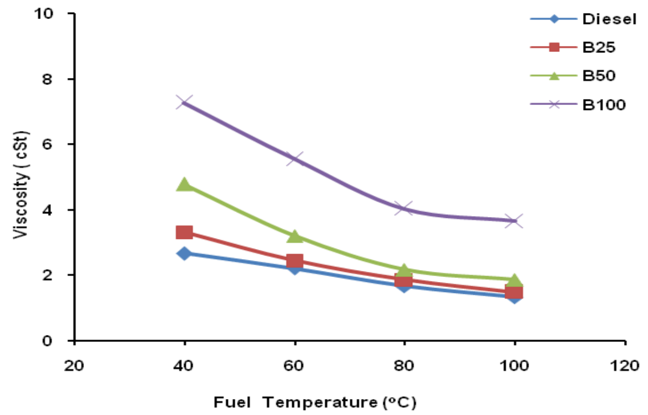


Figure 1: Variation of kinematics viscosity with temperature.

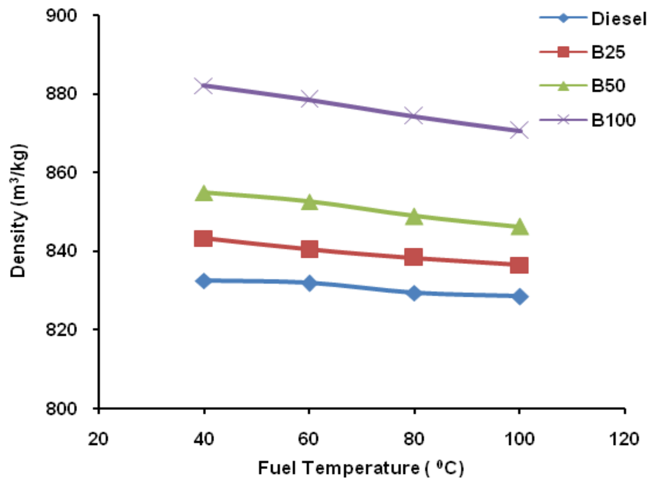


Figure 2: Variation of density with temperature.

made of mild steel, fuel supply tank, airblast atomizer, ignition system, a compressor, an air supply line, a fuel supply line, flow meter, control valves, K-type thermocouple, exhaust gas analyzer and a smoke meter. The air supplied by the compressor is bifurcated into primary air (co-flow air) and atomizing air. The atomizing air supply is connected to the air blast atomizer through calibrated rotameter and control valve. The primary air is supplied to the heating chamber. The heating chamber is provided with two heaters of capacity 3 kW each with temperature controller. The fuel supply is pressurized using nitrogen gas. The fuel temperature was varied with thermoelectric bath. The fuel supply is controlled by a control valve fitted to the fuel rotameter and supplied to an air blast atomizer. The air-fuel mixture is ignited by spark created by two electrodes and ignition transformer. The specification of the various components of setup is given in Table 2.

Experimentation

Experimentation was carried out as follows.

1. The air compressor was switched on and air pressure maintained at 4 bars by pressure regulating valve and supplied to an airblast atomizer.
2. The fuel supply pressure is maintained at 7 bars with nitrogen gas.
3. Air-fuel ratio maintained stoichiometric condition using air rotameter and fuel rotameter.
4. The air to liquid ratio (ALR) is maintained 2 throughout the experiment 4.

The spray structure was captured using digital camera (canon 5X, speed 3 frames/sec). After the spray study, air-fuel mixture was ignited by the spark plugs and open diffused flame obtained at different air fuel ratio and again captured by digital camera [15]. To study flame temperature and exhaust emission, injection unit was fitted to combustion chamber, the primary air was supplied through the swirler. Having after obtaining stable flame, an equivalence ratio was varied by varying air flow. Input and output parameters mention below were recorded at various equivalence ratios for parametric study. The input value measured were mass flow rate of fuel, mass flow rate of air, fuel pressure, air pressure and temperature. The output parameter measured were centre line temperature, exit temperature, and exhaust parameters like CO, CO_2, NO_x and UHC. The operating condition for fuel tested was shown in Table 3.

Results and Discussion

The combustion Characteristics of biodiesel and its diesel blends were investigated for different equivalence ratios. The details are as under.

Spray structure

Figure 4 shows spray characteristic for Biodiesel blends and diesel. The spray characteristics were measured in terms of cone angle and spray penetration. The spray cone angle is found to decrease with increase in the percentage of biodiesel in the bends at constant injection pressure [16]. This is due to higher viscosity affect atomization of biodiesel and also due higher surface tension liquid stick near orifice affect the cone angle. The penetration lengths were found to increase bring with by increasing biodiesel percentage in blend due to higher viscosity and density. The biodiesel blends had poor atomization characteristic compared to diesel fuels.

Flame appearance

Color photographs of the spray flames of the diesel and biodiesel blends were presented in Figure 5. These pictures were taken with digital camera (canon 5 D, Speed 3 frame/sec). The flame height was measured by reference line provided in the setup. The visual height of spray flames of JME blends were found to decrease with increase in JME content in the blend [17,18]. The luminosity of the flames was found to reduce with volumetric content of JME. The reduction in luminosity with bio fuel concentration indicates the reduction in soot content in the flames because inherent oxygen helped for complete combustion.

CO_2 emission

Figure 6 shows the mole fraction of CO_2 at different equivalence ratio. CO_2 emission had declined for biodiesel fuel as compared to

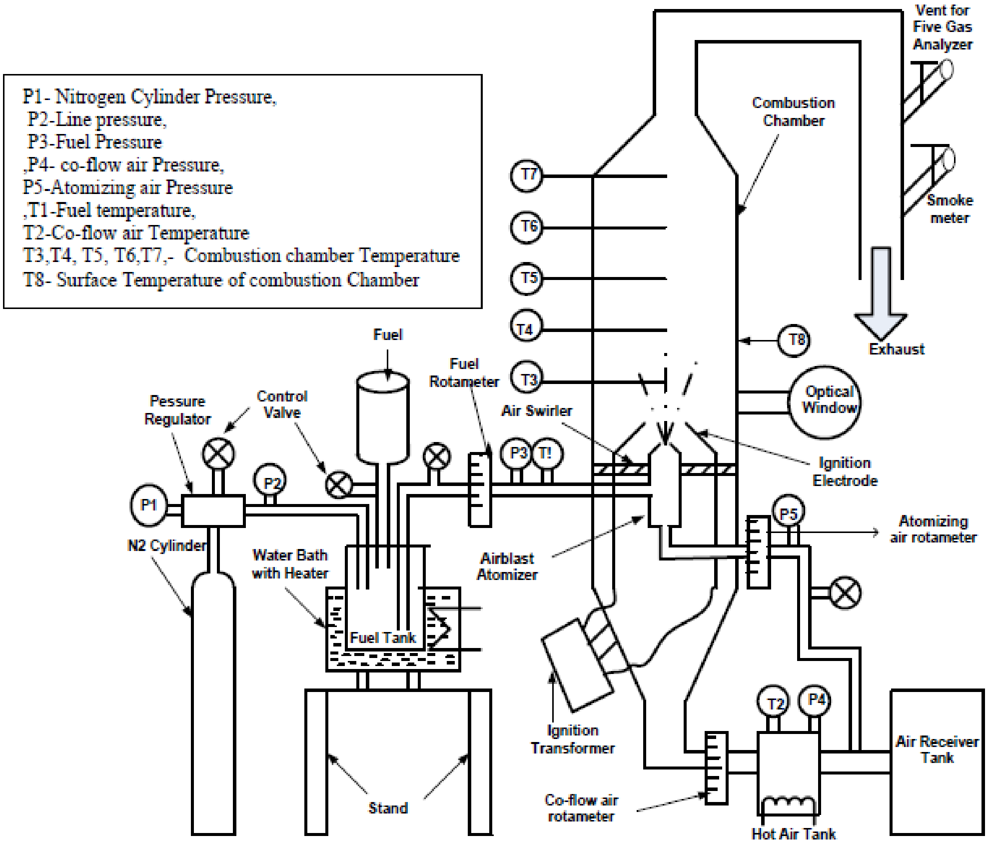


Figure 3: Schematic diagram of experimental setup.

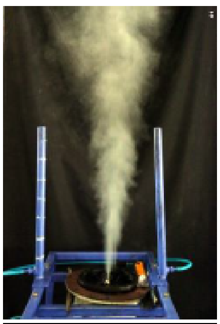
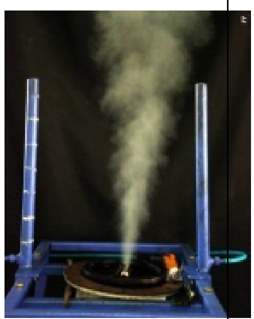
Fuels	Diesel	B25	B50	B100
Spray Structure				
Spray length	98 cm	99cm	99.8 cm	105 cm
Cone angle	23°	21.5°	19°	17.5°

Figure 4: Spray Structure of diesel and biodiesel blends.

diesel because of inherent oxygen in the fuel. The CO_2 % increases with the increase of equivalence ratio of 0.5 to 2.5 due to complete combustion because of less air velocity and more time spent in combustion chamber.

CO emission

Figure 7 shows the effect of equivalence ratio on CO emission. CO emission was lowered at slightly lean mixture due to complete combustion. It increases rapidly at richer mixture as compared to

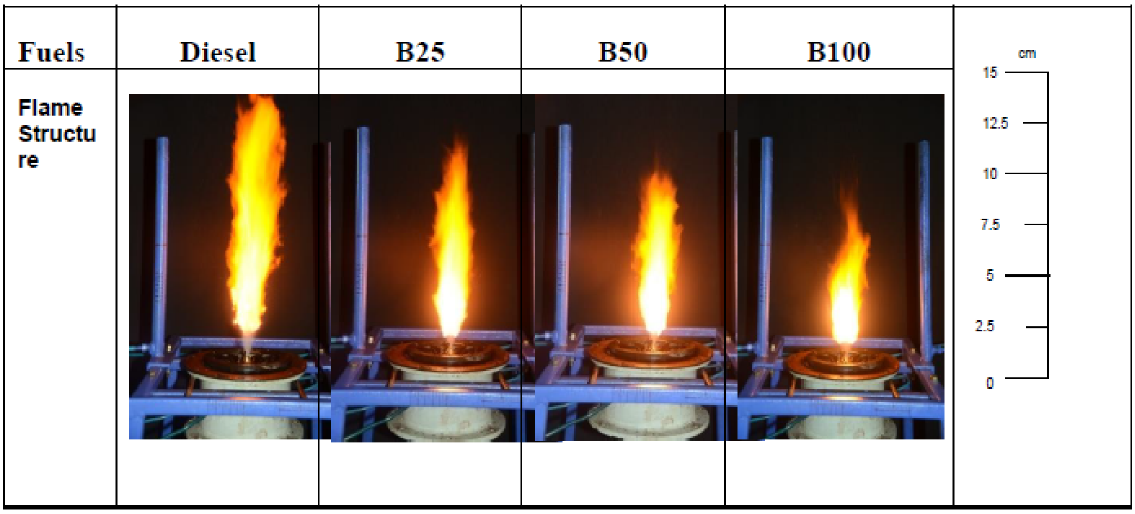


Figure 5: Flame structure of diesel and biodiesel blends.

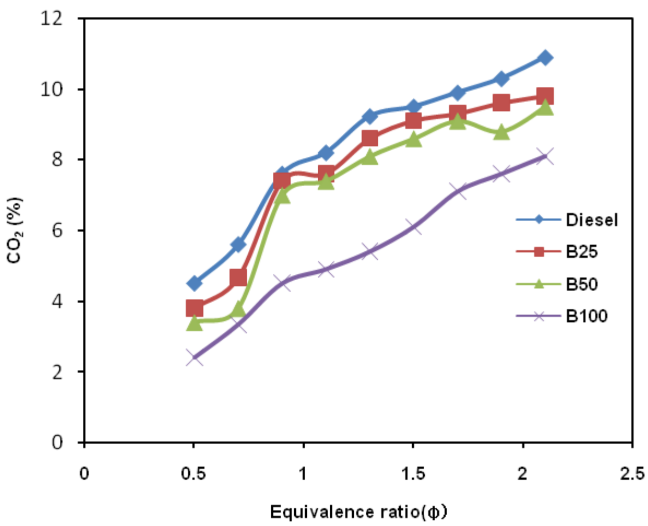


Figure 6: Variation of CO_2 with equivalence ratio.

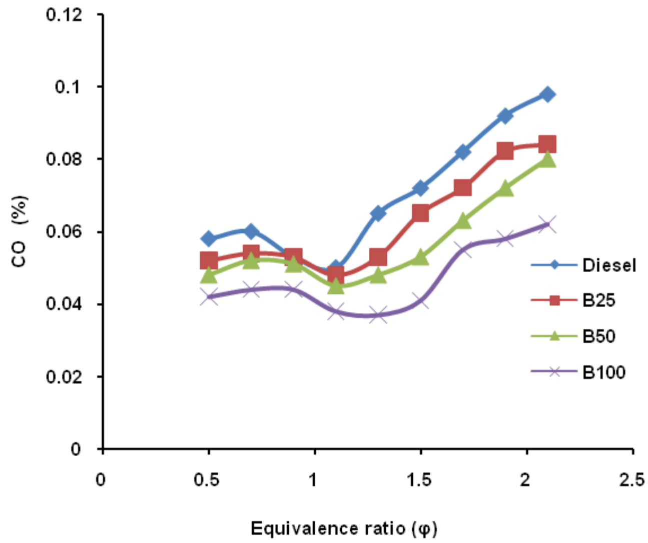


Figure 7: Variation of CO with equivalence ratio.

Reciprocating compressor	**Maximum pressure= 15 kgf/cm² capacity 200 litre**
Fuel tank	5 litre capacity
Tubular Combustion chamber	
Length	60 cm
Diameter	16 cm
Diffuser	
Length	14 cm
Inlet diameter	8 cm
Outlet diameter	4.2 cm
Axial Swirler	
Outer diameter	13 cm
Inner diameter	5 cm
Swirler angle	45°
Air blast atomizer	
Orifice diameter	0.4 mm

Table 2: The specification of the various components.

Properties	**Diesel**	**B25**	**B50**	**B100**
Heat rate (kW)	24	24	24	24
Fuel (ml/min)	40	41	41.5	42
Atomizer ALR	2	2	2	2
Main Air Temperature(K)	600	600	600	600
Fuel temperature (°C)	30	50	60	80
Primary air pressure (bar)	4	4	4	4

Table 3: The operating condition for fuel tested.

leaner mixture. CO emission was lower value as an increase in biodiesel percentage. Both side of stoichiometric condition CO emission was higher. This was increased rapidly in rich side due to insufficient air for combustion.

NO_x emissions

Figure 8 shows the effect of equivalence ratio on NO_x formation. NO_x formation was observed higher at slightly rich mixture due to higher temperature. In richer value of equivalence ratio, it decreased gradually as compared to steep rise in leaner value. In the case of biodiesel, NO_x is higher value as compared to diesel fuel.

UHC emission

Figure 9 shows the variation of unburned hydrocarbon at various equivalence ratios. Higher hydrocarbon is observed at lower equivalence as compared to a lower value at higher equivalence ratio. At a higher equivalence ratio, air velocity is lowered fuel has higher residual time to burn. Therefore, lower value of UHC at a higher equivalence ratio owing towards complete combustion.

Exhaust gas temperature

Figure 10 illustrates the effect of equivalence ratio on exhaust gas temperature. The figure shows that the temperature of the exhaust gas had increased slowly with equivalence ratio for diesel and biodiesel blends. The maximum temperature occurs at slightly rich mixture at an equivalence ratio (φ) = 1.1. It can be seen that the temperature increase with higher value of biodiesel percentage in blends because inherent oxygen help for complete combustion.

Axial temperature distribution

Figure 11 shows variation of temperature along the axial direction inside the combustion chamber. There is a slight variation of temperature along the axial direction. Diesel and biodiesel blend temperature are comparable.

Combustion efficiency

Figure 12 shows the variation of combustion efficiency at various equivalence ratios. Combustion Efficiency was determined from the ratio of mean heat release rate at the exit of combustor to the total calorific value. Combustion efficiency was found to increase steeply with an increase in the equivalence ratio till the equivalence ratio of about 1.1, there after the efficiency drops gradually with further increase in the equivalence ratio. The upward trends show good mixing due to increasing residence time and decreasing trend due to insufficient mixing and less air for complete combustion.

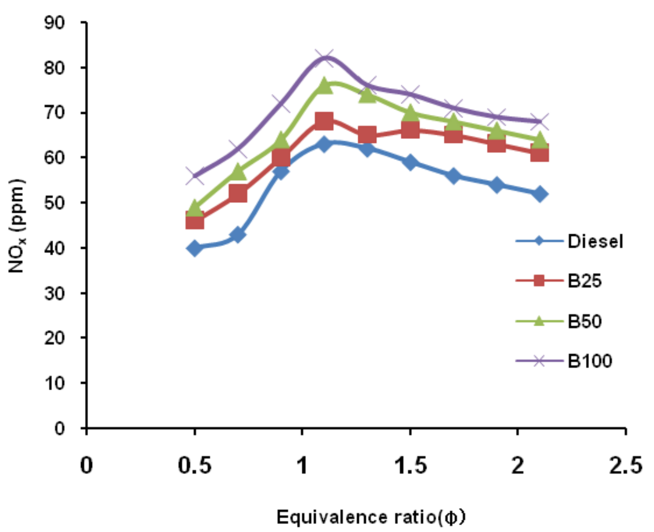


Figure 8: Variation of NO_x with equivalence ratio.

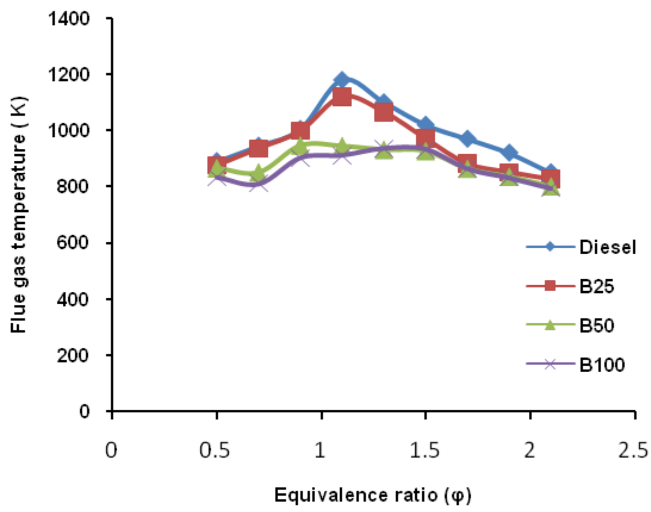


Figure 10: Variation of flue gas temperature with axial distance.

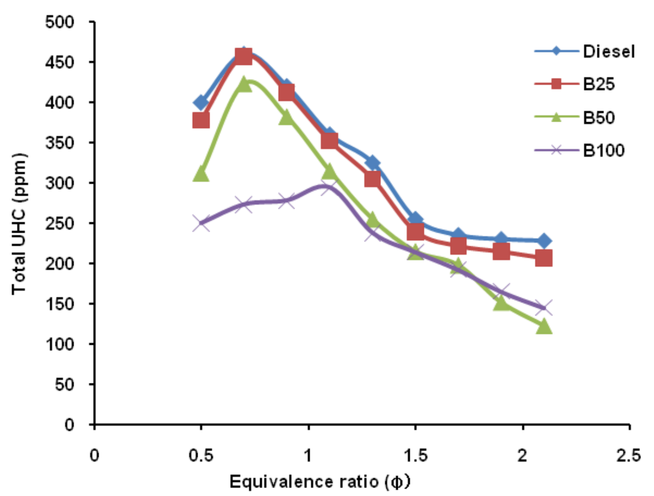


Figure 9: Variation of TUHC with equivalence ratio.

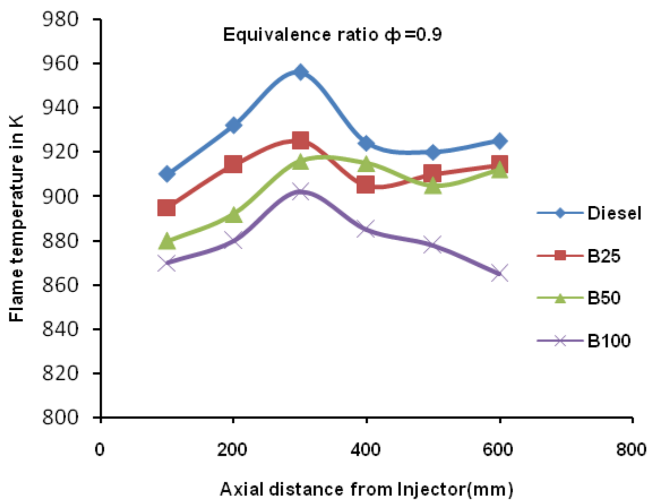


Figure 11: Variation of flame temperature with equivalence ratio.

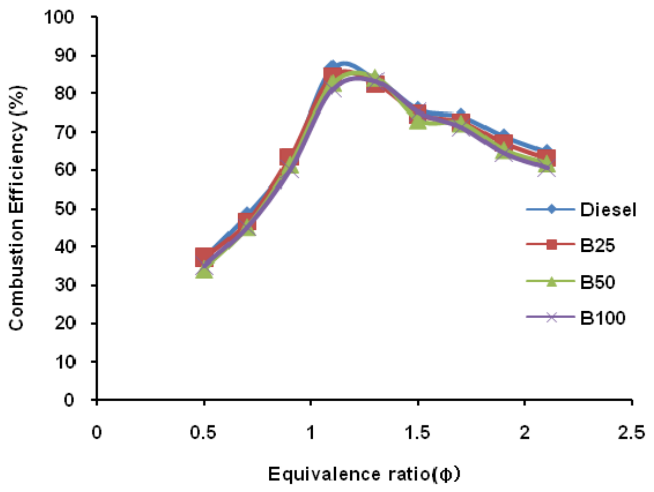


Figure 12: Variation of combustion efficiency with equivalence ratio.

Conclusions

Based on the results obtained from the measurements, the following conclusions were drawn.

- The flame luminosity decreased with increase JME content in blends, indicating the presence of less soot in the flames in biodiesel flame as compared to diesel.
- By using biodiesel, lower emission of CO_2, CO, UHC were obtained as compared to diesel fuel.
- NO_x emission is slightly higher for biodiesel blend. NO_x can be reduced by using lean mixture.
- Considerable enhancements were noticed in CO and CO_2 emission with increase in equivalence ratio (φ).
- Combustion efficiency was observed same for diesel and biodiesel blends.
- It is concluded that biodiesel blends can be successfully used for continuous combustion applications like gas turbine and oil furnace.

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