Experimental Investigations on Combustion Pollutant Emissions of Sunflower Biodiesel and Its Blends with Diesel and Kerosene for Furnace Application

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Abstract

Biodiesel is one of the promising substitution fuels that are used in cars, gas turbine and furnace. In this study, the experiments liquid fuels used during the tests are biodiesel and its blends (biodiesel-diesel (Bx) and biodiesel-kerosene (Bkx)) in a furnace have been studied experimentally. An airblast atomizer was used to investigate the combustion properties. During the experiments, the heat rate is (12.2kW), the atomization-air to liquid fuel ratio (ALR = 1) and the constant air temperature is (301K) were maintained. For the range of equivalence ratio from 0.6 to 1.4, the characteristics of emission factors such as carbon dioxide (CO_{2}), carbon monoxide (CO), nitrogen oxides (NOx) and unburned hydrocarbons (UbH) were measured experimentally. The results observed that the main pollutants such as CO_2, CO, UbH were decreased with an increase in SME, while NOx emissions also decreased .Biodiesel could be a promising fuel for furnaces instead of fossil fuels.

Key word: - Biodiesel, Pollutant, Atomizer, Airblast, Emissions.

1. Introduction

Now days, the concern about the most important reason cause of environmental legislation, so we must look for alternative energy sources where the use of bio-diesel is a promising alternative fuel in the world. It is not just a source of renewable energy, but it can also reduce the dependence on conventional oil and help the agricultural subsidies in some areas. It is defined of biodiesel is alkyl esters of fatty acids, obtained by the transesterification of vegetable oils or animals fats, with alcohols such as ethanol and methanol. It has a performance similar to that of the engine with conventional diesel and can be used pure or blended with diesel and kerosene. Biodiesel is non-toxic, non-flammable, biodegradable and non-explosive. Besides, it is used to alleviate many harmful exhaust gases. A near-total absence of sulfur oxide (SO) emissions, particulate matter and soot, and reduction of in polycyclic aromatic emissions can be achieved.

Alternative fuel should produce values of NOx, SOx, CO, CO_2 and particulate matter less than conventional fossil fuels. Biofuels provide the offer of possibility of reductions in emissions as alternative fuel. At present biofuels mainly used in vehicles. The wide use of ethanol and mixed with gasoline in spark ignition engines, and biodiesel is blended with conventional fuel (diesel) for use in compression engines and burners. There is great interest in the application of bio-diesel in the combustion systems such as industrial fuel turbines, turbines and small furnace [1]. The increasing of biodiesel is used in the types of ground transportation system. Take the majority on studies of emission biodiesel focus on internal burning reciprocity such as compression ignition engines (CI) engines [2]. However, reports of biodiesel emissions of NOx and CO from existing engines inconsistent. Some studies have shown that biodiesel reduces carbon CO emissions, UHC and PM but NOx increases [3], while others said the low nitrogen oxides [4], [5]. This disparity in the literature may be due to the variation of parameters such as engine models, and injection timing or on biodiesel quality. Although, these results appear the potential of bio-diesel and provide for the application of mitigation of emissions procedures ideas.

As mentioned above that the use of biodiesel is not restricted only to diesel engines. There is a growing interest in the use of bio-diesel engines in the type of gas turbine for power generation. However, information relating to the use of biodiesel in gas turbine engines is relatively rare still. The results of emission of biodiesel derived from the internal combustion engine is not inferable for gas turbine marked difference in the structure of flame, any engine works with reaction non-premixed intermittently under high intense pressure compression type, while the gas turbine combustion results in generally lean, partially premixed reaction with the longest period for process of droplet evaporation [6].

The fuel Cetane number is very necessary parameter for the internal combustion engine but not for gas turbines. Several field-tests using alternative fuels in gas turbine like bio-oil, biodiesel and blends [7], [8]. Experimental test utilized a 40 MW gas turbine class E, the NOx emission of using rapeseed methyl esters reported to be less than diesel fuel [8]. The lower NOx emission because the lower adiabatic flame temperature of biodiesel than diesel fuel adiabatic flame temperature, as explained by Glaude *et al.* [9] through the calculations of the enthalpy and free mixtures energy. The high adiabatic flame temperature of flame like the diesel fuel case, help the production of high level of NOx through the 'thermal NOx' mechanism. But, Ellis *et al.* [10] tested the emissions of soya and palm biodiesel also 20 % biodiesel blend with diesel (B20) in gas turbine. Almost the results of fuels tests are similar for NO and CO emission for all. The difference of the parameter air-liquid mass ratio (ALR) shows high influence on the performance of emissions.

The emissions of NOx for biodiesel were found to decrease with increasing of ALR. The test explained that optimized NO and CO emissions could be achieved with the modification of the conditions of atomizer. [2]. [11] study the emission and thermal performance of biodiesel of castor and the blends of biodiesel with diesel in a 30 kW diesel turbine engine. The performance of thermal showed that the use of biodiesel fuel resulted in a higher fuel specific consumption compared to diesel due to the heating value is lower. The result of emission showed a decrease of NO and an increase of CO emissions compared to the emission of diesel fuel. [12] Investigated the emission performance of biodiesel and jet-A1 fuel in a 30 kW gas turbine. The biodiesel for experiments derived from canola, soya, rapeseed, animal-fat and blends of biodiesel with Jet A fuel. The results showed that in spite of the gas exhaust temperature of turbine were not change with the type of fuel, the values of NO and CO emission decrease when used biodiesel, also pure biodiesel showed higher thermal efficiencies than Jet A and biodiesel blends. [13] Tested the palm biodiesel emissions relative to conventional fuel (diesel) in a burner gas turbine at ambient pressure. The pressure atomizer used in the burner is swirl type. The results showed that NO emissions for palm biodiesel were lower compared to diesel fuel as a function of, air pressure of atomizing, excess air ratio, SMD and viscosity. The values of CO and UbH were including the range of 2 ppm. R. senthiklkumar and S.siraprakasam [14] conducted their experimental study on the influence of kriya bio-additive with diesel fuel in internal combustion engine. They found that the bio additive enhances the two parameters, cetane umber & emissions when added to diesel fuel. [15] Studied emissions produced from a liquid fuel burner that operating on several biodiesel and diesel fuel percentage. Their results showed that the use of biodiesel reduce CO, CO2 and particulate matter emissions but increase of NOx, using of biodiesel has indicator of benefits in industrial burner. [16] Conducted their experimental study on the influence of Jatropha biodiesel and its diesel blends on emissions produced from air-blast burner. Their results showed that the use of biodiesel reduce the major emission such as CO, CO2, UHC and particulate matter emissions but increase of NOx. These results lead to the use of biodiesel has indicator of benefits in industrial burner of power plants instead of conventional fuels. [17] Studied the impact of kind of vegetable oil on emissions of biodiesel – gasoil mixture from furnace. They found that maximum of NOx, SO2 and temperature by using sunflower and corn biodiesel blends with gasoil.

The aim of this paper is to measure regulated emissions such as CO, CO2, NOx and UbH from cylindrical furnace, fueled with biodiesel (SME) and its diesel blends, for different values of equivalence ratio.

2. Experimental setup

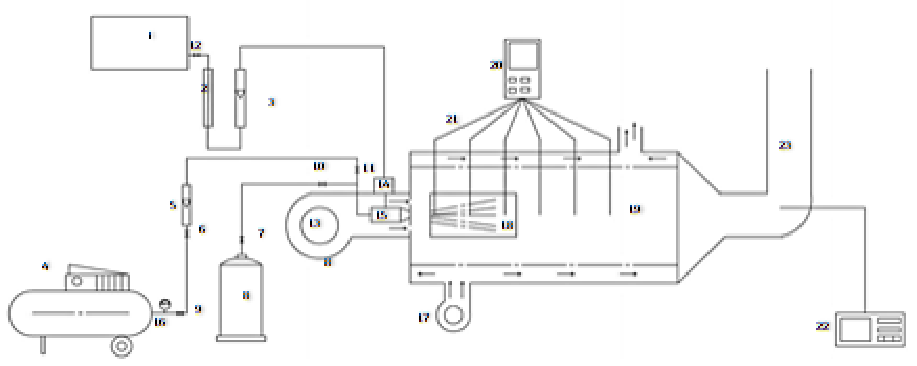
2.1 The apparatus units with auxiliaries

In this research, we fabricated a liquid fuel burner for experiments Fig.2-1. Which includes the units and systems below, the combustion apparatus schematic diagram is given in Fig.2-2:

2.1.1 Combustion chamber unit

In this rig, a cylindrical tube, which represents a combustion chamber, is used. The tube made from s-steel 316, 1.5mm thickness, has 350 mm inside diameter, and 1000 mm length. The selection of s-steel material to fabricate combustion tube is due to high thermal conductivity, high molten point and high resisters of corrosion and resting. Cylindrical galvanized steel shell is surrounding the combustion chamber with gap (75mm) between shell and combustion chamber represented air-cooling jacket, and equipped with air blower to supply the air for cooling the combustion chamber to maintain the combustion process in steady state during the experiments. On the rims of combustion chamber, six holes in uniform distance from the burner nozzle have been made for measuring temperature along the combustion chamber, measured with K-type thermocouple, using multi-channel digital thermometer. Combustion chamber equipped with 1500mm high chimney for exhaust gas exits and two holes after 90 elbow to locate gas analyzer probe. Two symmetrical rectangular opening equipped with thermal double-glazing, have been made in front of the side of atomizer and flame zone for monitoring the processes of spray atomization and flame propagation.

Fig. 2-1: The experimental apparatus



No.	Description	No.	Description	No.	Description
1	Fuel tank	13	Main air blower	20	Multi-channel thermometer
2	Calibrating scale	14	Electrical solenoid valve	21	Thermo-couple type K
3	Fuel flow meter	15	Air-blast atomizer	22	Gas analyzer
4	Air compressor	16	Pressure gauge	23	Chimney
5	Air flow meter	17	Cooling blower		
6,7,9, 10, 11, 12	Control valve	18	Opening		
8	LPG container	19	Combustion chamber		

Fig.2-2: The experimental schematic diagram of combustion apparatus.

2.1.2 Burning unit

- **Air blast atomizer**

A non-reacting and reacting atomization facility is utilized to investigate biodiesel and it's blending with kerosene and diesel. Sprays established via modified an external mix air blast atomizer. The air and fuel orifice diameter are (da 2.5mm) and (df 1.5mm) respectively, the details of the atomizer geometry shown in Fig.2-3.

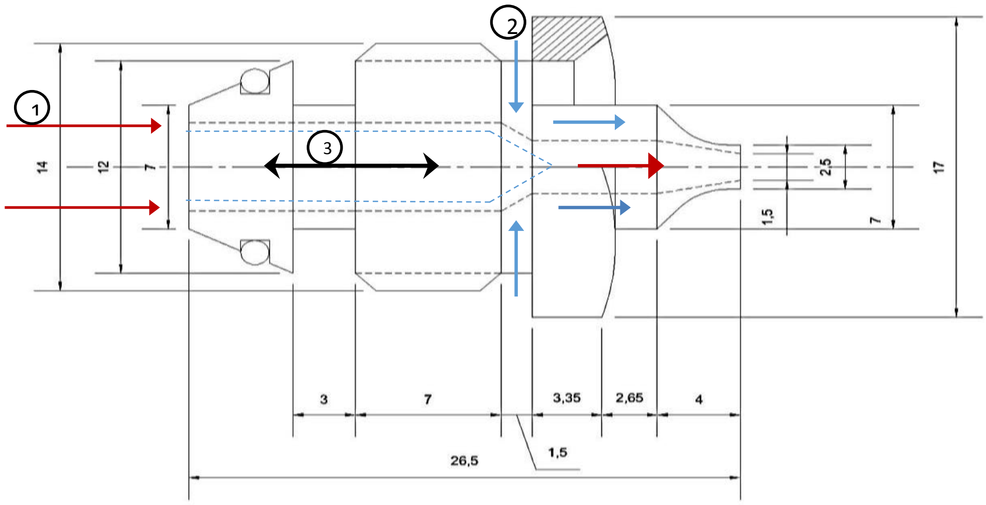


Fig.2-3: The atomizer geometry

- **Atomization air supply line**

The atomization air-line including compressor which used for supply compressed air to atomizer through regulator valve to determine the value of atomization air pressure, also equipped with controlled air flow meter after the regulator valve to determine the flow rate volume of atomization air through the atomizer

- **Fuel supply line**

The complete fuel line including fuel storage tank which is used for supply liquid fuel to atomizer by effect of air flow through the atomizer due to pressure reduction (sucking) in the nozzle tip, there are two manual control valves, first one after the storage tank just for open and close the fuel line, another one is accurate needle control valve equipped inside the atomizer which used for determine the amount of fuel. In the same line after the tank valve there is a fuel filter then a scale tube for calibrating the liquid flow meter exists after the calibrating tube.

- **main air supply line**

The main air enters the system through the blower inlet which is controlled by movable gate. Air passes to combustion chamber by the blower through a 0.15 m square and 0.3m long steel duct. The atomizing air , fuel and LPG starting lines passes through this duct which also include the control valves of fuel , air blast and LPG. The blower inlet equipped with digital anemometer to measure the velocity of air to calculate the mass flow rate of main air.

- **Ignition starting line**

Electrical spark and Liquefied petroleum gas (LPG) is stored in pressurized cylinder, fitted with shutoff valve. The LPG flow rate is regulated by the control valve which supplies the atomizer with LPG through the same line of atomization air, just during the starting; electrical high voltage igniter is placed in front of atomizer exit to supply the spark of the ignition.

2.2 Gas analyzer

The concentration of CO, CO_2, NOx and UH fuel in exhausted were measured and determined using HG-540/550 gas analyzer. For each reading we followed the operation guide of the analyzer, including power ON, ready state, insert prop to the exhaust outlet, measuring, pull out the prop and clean up after each reading.

2.3 Biodiesel Production and Preparation of experiments blending fuel

The biodiesel used in this research produced from sunflower oil and methanol by transesterification process, in combustion laboratory, mechanical engineering department, University of Technology by using the biodiesel reactor, made locally by the researcher. The tested Gasoil and Kerosene obtained from Al-Dura refinery. The blending of biodiesel were prepared and most fuels tests was down in the fuels laboratory, University of Technology and GC mass in laboratory of Chemical science department – Almustansirea University. The physicochemical properties of the diesel, kerosene, biodiesel and blends according to ASTM are shown in Table (2-1, 2-2 and 2-3).

Table (2-1): properties of biodiesel, diesel and kerosene.

Property (unit)	Test method	biodiesel	diesel	kerosene
Approx. formula	GC mass	$C_{19}H_{36}O_2$	$C_{16}H_{34}$	$C_{11}H_{21}$
H/C	-	1.89	1.9	1.98
Viscosity cSt at (40 ^{0}C)	ASTM D445	4.92	2.8	1.38
Cloud point (^{0}C)	ASTM D2500	4	-	-
Pour point (^{0}C)	ASTM D97	0	-7	-9
Flash point (^{0}C)	ASTM D93	176	67	45
Density at (15^{0}C)(kg/m^3)	ASTM D1298	875	833	807
Cetane index	ASTM D976	67.4	53	-
Molecular weights g/mol	-	296	226	153
LHV (kJ/kg)	-	36770	43090	43150

Table (2-2): The physicochemical properties of the biodiesel, diesel and its blends

Proper.	Blending range					limits
	0:100 B100	20:80 B20	35:65 B35	50:50 B50	100:0 D100	
Density kg/m^3	875	855	859	862	850	815-870
Viscosity cSt (40 ^{0}C)	4.92	3.22	3.54	3.86	2.8	2-5
Flash point ^{0}C	176	89	105	121	67	Min60 diesel Min100 biodiesel
cloud point ^{0}C	4	-1	0	2	-	Max 18
Pour point	2	-3	-2	-1	-7	Max 18
Cetane index	67.4	57.4	59	60.3	53	48-67

Table (2-3): The physicochemical properties of the biodiesel, kerosene and it's blends

Proper.	Blending range					limits
	0:100 Bk100	20:80 Bk20	35:65 Bk35	50:50 Bk50	100:0 K100	
Density kg/m^3	875	820	830	841	807	815-870
Viscosity cSt (40 ^{0}C)	4.92	2.1	2.6	3.15	1.38	2-5
Flash point ^{0}C	176	71.2	91	110.5	45	Min60 diesel Min100 biodiesel
cloud point ^{0}C	4	-2	0	2	-	Max 18
Pour point	2	-4	-3	-1	-7	Max 18
Cetane index	67.4	50.2	51.3	52.5	-	48-67

3. Experimental results discussion

3.1 Combustion emissions

In the present work, the effect of equivalence ratio on pollutant emissions from combustion of biodiesel, gasoil, kerosene and their blends is investigated. The concentration of CO, CO_2, NOx and UbH are recorded experimentally using the gas analyzer. All the experiments are conducted three times at consistent performance conditions in order to reduce uncertainties.

3.1.1 Effect of equivalence ratio upon emissions

CO is an intermediate combustion product and is formed mainly due to incomplete combustion of fuel. If combustion is complete CO is fully converted to CO2, but if the combustion is incomplete, due to shortage of air or low temperature in the furnace, CO will be formed.

Figures (3-1) and (3-2) demonstrates the trend of CO emissions of Bx and Bkx blends combustion at various equivalence ratio (Φ) at ALR=1. It can be observed that the minimum amount of CO is produced for the lower (Φ) and higher value of ALR=1 which help to produced finer droplet size that reduce the resident time of evaporation where the combustion is almost complete. For higher (Φ) values, insufficient O2 content of the combustion gives a rise to the level of CO emission. These figures also demonstrate the correlation between CO emission and biodiesel content in fuel blends at different percentage of (Φ). It can be seen that CO emission is decreased with increasing all kind of methyl esters fraction in the biodiesel blends, due to the inherent of oxygen in biodiesel chemical structure. As it can be seen lower CO emission is achieved for the combustion of B100, B50 and Bk50 are 0.012%, 0.018% and 0.018 respectively at same conditions (Φ=0.6).

NOx appears in the form of nitric oxide (NO) and nitrogen dioxide (NO2) but the (NO) former dominates during the combustion process. Several routes have been identified through which NO is produced, namely thermal NO, prompt NO, fuel NO.

Figures (3-3) and (3-4) shows the effect of various equivalence ratio at ALR=1.0 on NOx emission for Bx and Bkx combustion. It can be seen that generally, NOx production is dependent on three factors are fuel type, atomization quality and the other is the excess oxygen. As it can be seen maximum emission of NOx is reached for the combustion of (D100) about (85ppm), at Φ =1.0, and maximum level of NOx emission of blends from B20 blend about (81 ppm) that is record at same conditions. The level of NOx emission decreases with the decreases of (Φ) and it might be because of higher amount of air, which reduce the exhaust temperatures, and from another side the increasing of (Φ) also decreasing the NOx level, due to the reduction of temperature degrees. And the reduction of bio-additives increase the amount of the nitrogen in blend combines that help the NOx formation. Although the oxygen inherent of biodiesel help to produce high temperatures at first location of flame but after that the temperature degrees reduces along the combustion chamber which reduce the thermal formation of NOx. From results the NOx emission of Bk blends show lowest emission values compared to B blends about (43), especially at (Φ)=0.6.

UbH and Co2 are a function of equivalence ratio, due to the dependently on the oxygen amount in combustion. Figures (3-5) and (3-6) and figures (3-7) and (3-8) shows set of results from the experimental work, which summarizes the effect of equivalence ratios on UbH and CO_2 at ALR=1.0. It can be observed that for all fuels the UbH decreases with equivalence ratio increase but CO_2 increases. In addition, the results showed that the maximum UbH emission from blends are B20 and Bk20 blends, are (43.1) and (42) ppm respectively at (Φ) =0.6. In addition, minimum values at B50 and Bk50 blends are (11) and (10) ppm at (Φ) =1.4.

From the trends of results of CO2, emission has low value for biodiesel fuel as compared to diesel and kerosene because of inherent oxygen in the fuel. The CO_2 % increases with the increase of equivalence ratio of 0.6 to 1.4 due to complete combustion because of less air velocity and more time spent in combustion chamber, also the results trends show CO_2 values has little effect at lean side of equivalence ratio, due to the percentage of O_2 in exhaust which cover CO_2 with excess air increase.

Also for UBH, at a high equivalence ratio, air velocity lowered, the fuel has higher residual time to burn. Therefore, lower value of UBH at a higher equivalence ratio owing towards complete combustion.

The biodiesel blends show that the CO2 concentration decreases with the increase of biodiesel percentage in the mixture. The CO2 concentration decrease is not totally justified by the increase of the CO concentration. The presence of CO in the exhaust gas is a sign of incomplete combustion [18]. During an incomplete combustion process, in addition to CO, there are also unburned hydrocarbons, the presence of which also leads to the decrease of the CO2 concentration.

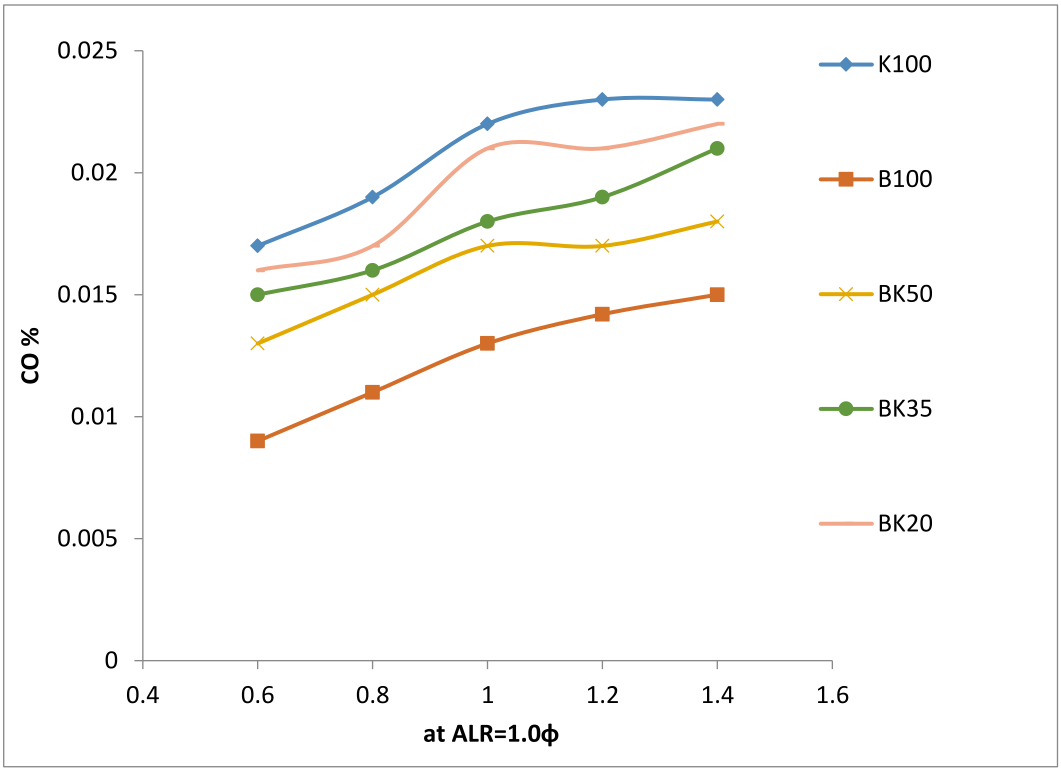


Fig. (3-1): Variation of Carbone monoxide (CO) with equivalence ratio (Φ) at atomization ratio ALR=1.0 of Bkx blend

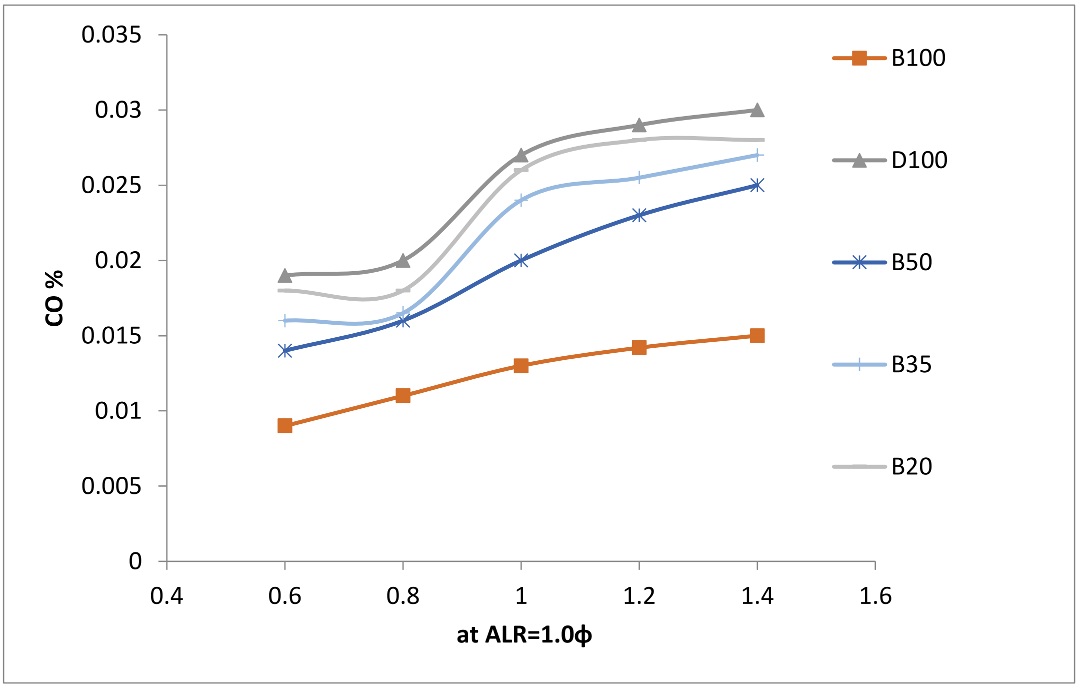


Fig.(3-2): Variation of Carbone monoxide (CO) with equivalence ratio (Φ) at atomization ratio ALR=1.0 of Bx blend

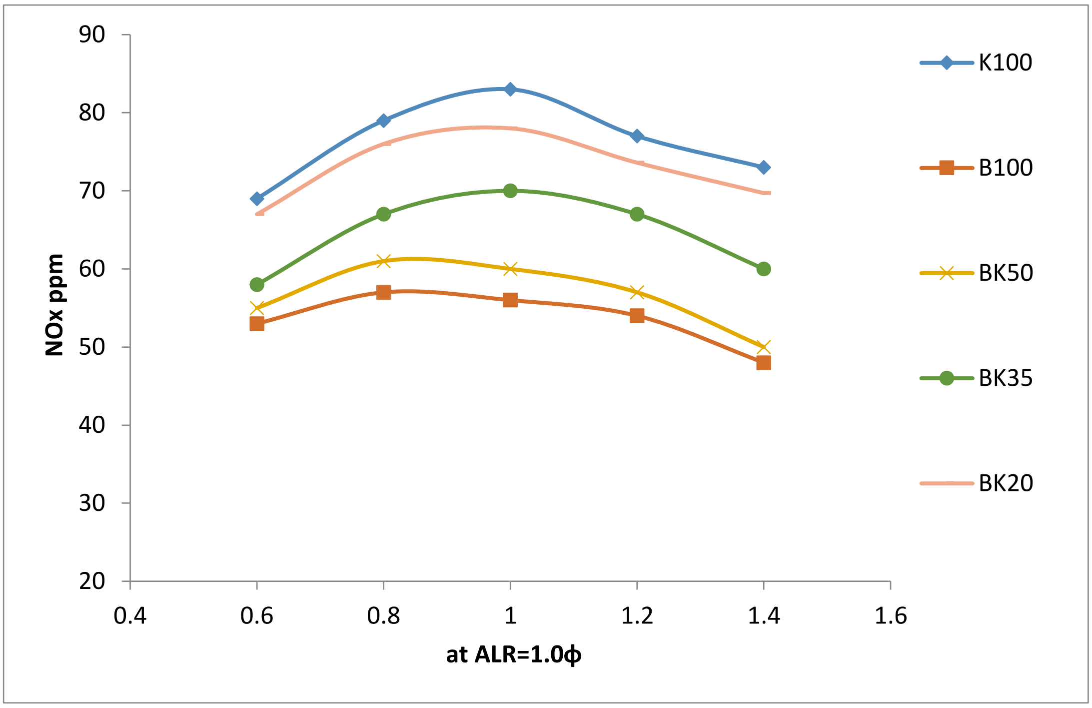


Fig. (3-3): Variation of Nitrogen oxide (NOx) with equivalence ratio (Φ) at atomization ratio ALR=1.0 of Bkx blend

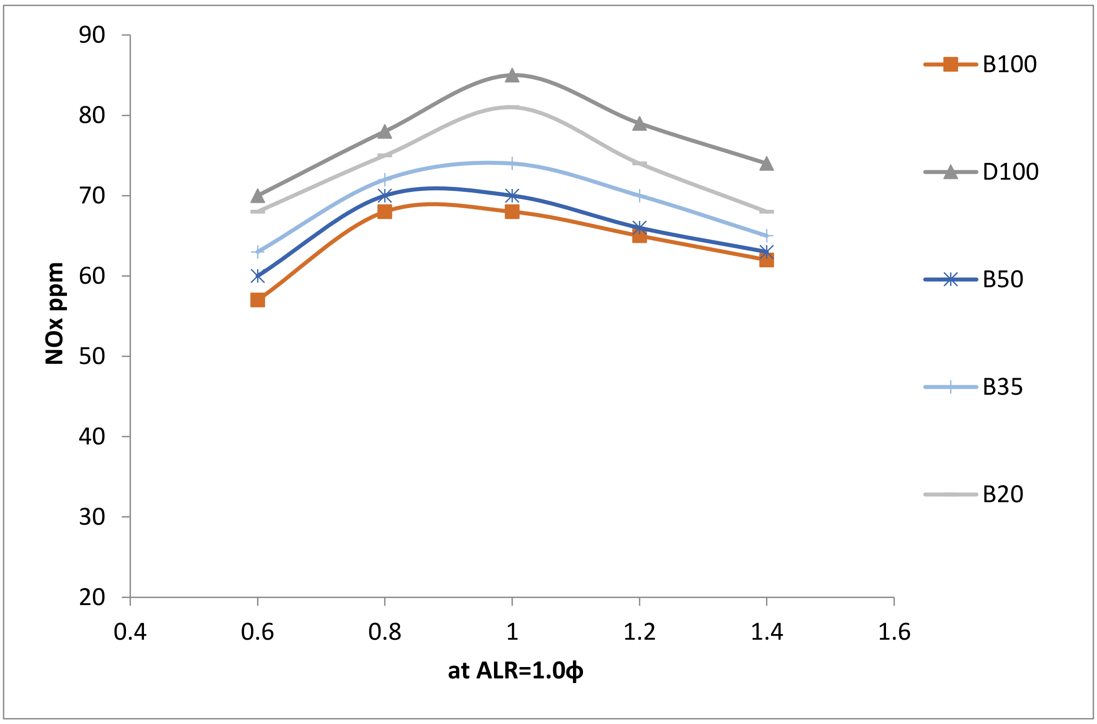


Fig. (3-4): Variation of Nitrogen oxide (NOx) with equivalence ratio (Φ) at atomization ratio ALR=1.0 of Bx blend

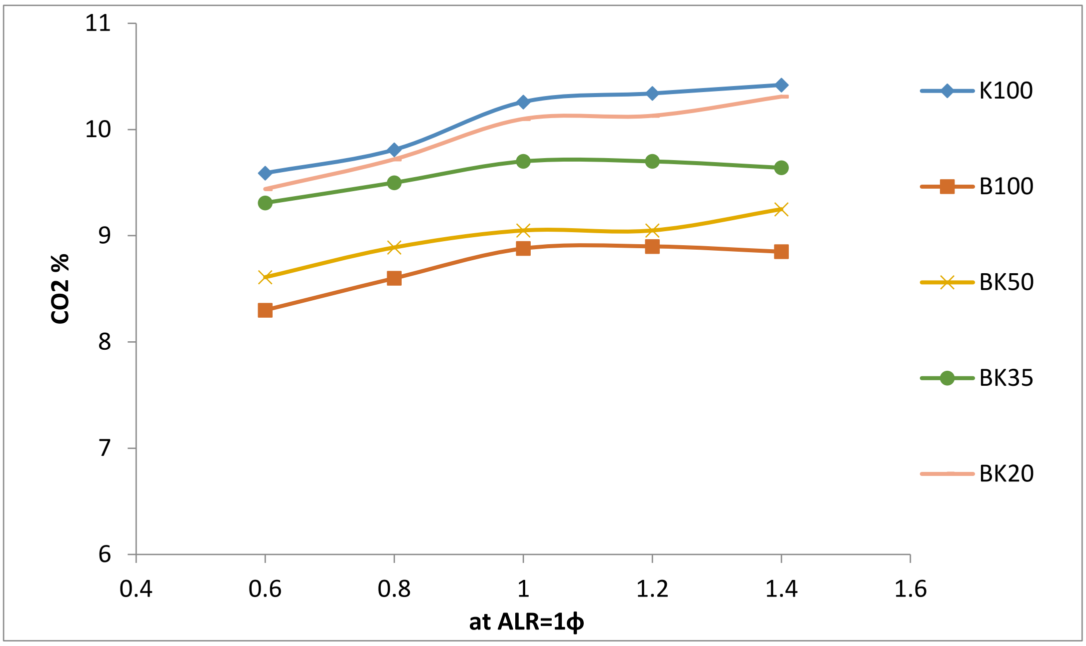


Fig. (3-5): Variation of Carbone dioxide (CO2) with equivalence ratio (Φ) at atomization ratio ALR=1.0 of Bkx blend

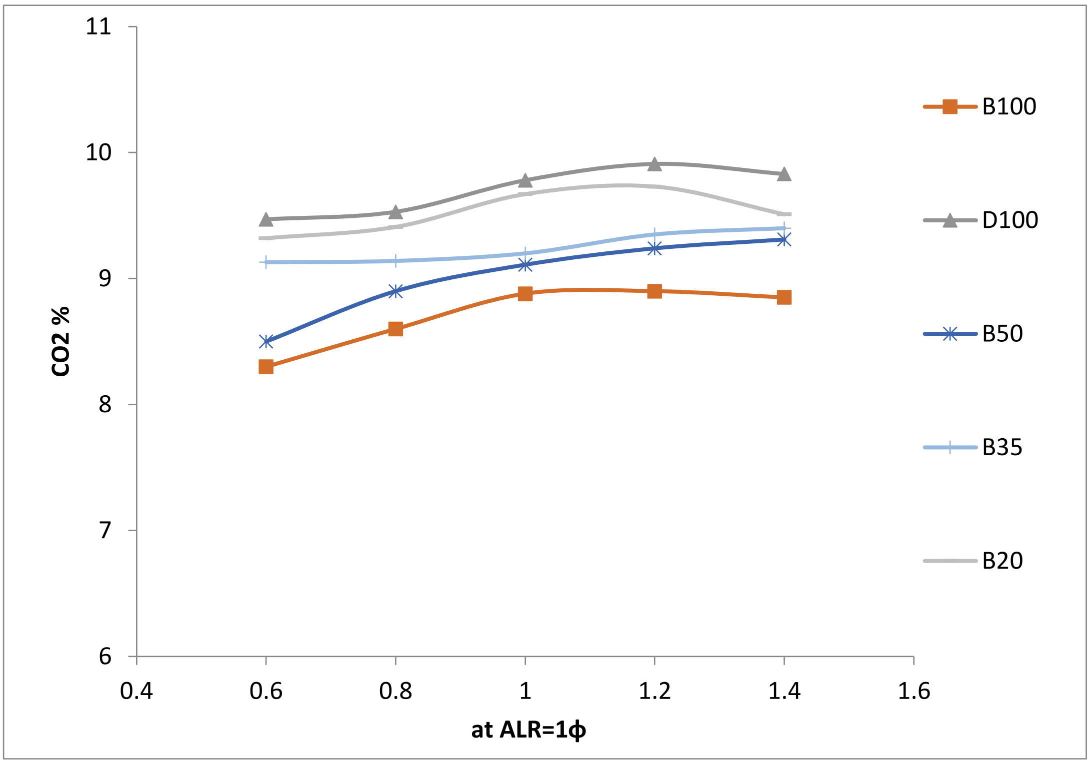


Fig. (3-6): Variation of Carbone dioxide (CO2) with equivalence ratio (Φ) at atomization ratio ALR=1.0 of Bx blend

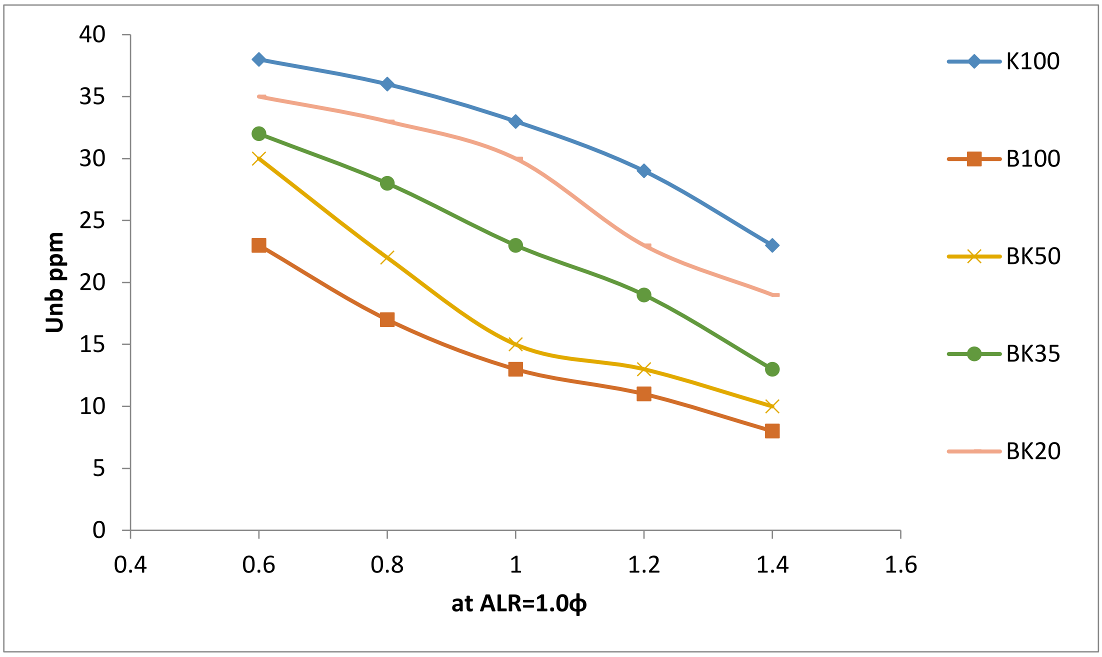


Fig. (3-7): Variation of Unburned Hydrocarbon (UbH) with equivalence ratio (Φ) at atomization ratio ALR=1.0 of Bkx blend

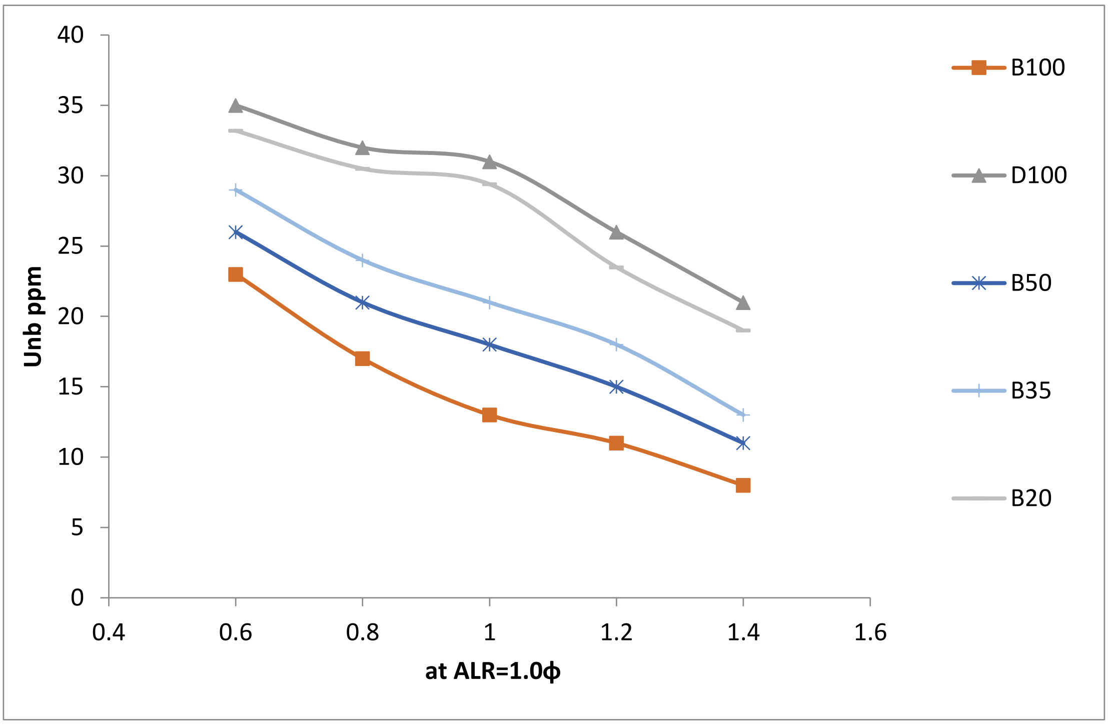


Fig. (3-8): Variation of Unburned Hydrocarbon (UbH) with equivalence ratio (Φ) at atomization ratio ALR=1.0 of Bx blend

4. Conclusion

From the results obtained from the experiments, the following conclusions can be drawn:

1. By using biodiesel SME, lower emission of CO2, CO, UHC were obtained as compared to diesel fuel.

2. NOx emission of biodiesel blend is slightly lower than diesel.

3. NOx can be reduced by using lean mixture values of equivalence ratio (φ).

4. Considerable enhancements were noticed in CO and CO2 emission with increase in equivalence ratio (φ).

5. The reduction in NOx emissions is due to the absence of nitrogen-bound components in biodiesel.

5. Combustion priorities were observed same for diesel and biodiesel (SME) blends.

6. The biodiesel (SME) blends could be successfully used for continuous combustion applications like oil furnace.

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الخلاصة

وقود الديزل الحيوي هو أحد أنواع الوقود البديلة الواعدة التي تستخدم في السيارات وتوربينات الغاز والأفران. في هذه الدراسة، تم تجريبيا اختبار وقود الديزل الحيوي وخلائطه (الديزل الحيوي–الديزل (Bx) ووقود الديزل الحيوي–كيروسين((Bkx) باستخدام منظومة الاحتراق (البيرنر) المصنع للبحث. حيث تمت التجارب باستخدام مرذذ وقود نوع (airblast atomizer) وذلك للتحقق من خواص عملية الاحتراق خلال التجارب. تم اجراء التجارب ولجميع انواع الوقود عند قدرة 12.2 كيلو واط عند نسبة ترذيذ ثابته ALR=1 ودرجة حرارة 301K ولقيم نسب تكافؤ (0.6 الى 1.4). تم قياس الانبعاثات الناتجة عن عملية الاحتراق مثل CO_2 و CO و NOx و UbH باستخدام محلل الانبعاثات Gas analyzer، حيث اظهرت النتائج ان الملوثات الرئيسية مثل CO_2 و CO و UbH تنخفض بزيادة نسبة الوقود الحيوي (biodiesel) لزهرة عباد الشمس (SME)، كما انخفضت اكاسيد النتروجين المنبعثة. لذلك وحسب النتائج والاستنتاجات فان وقود الديزل الحيوي يمكن ان يكون بديلا جيدا للوقود الاحفوري.

الكلمات الداله: وقود الديزل الحيوي، ملوثات، مرذذ، قاصف هوائي، انبعاثات.