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Experimental Analysis of Used Cooking Oil Blended with Diesel and Ethanol in A Mini Hot Water Generator

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ABSTRACT

Biofuel is a viable and eco-friendly substitute for traditional diesel, due to their high volatility, better combustion, and compatibility. Biofuel is easy to use while preserving engine performance, in contrast to many other alternative fuels, without any modifications in engine. It works similarly to petroleum diesel, but because it is biodegradable, made from renewable resources, and emits less emission, it is safer for the environment. One of the main advantages of biofuel is that it may be mixed with diesel in any ratio, from tiny additions to total replacement. The objective of this investigation is to assess the combustion and emission properties of various mixtures prepared by using diesel, used cooking oil and ethanol. And also, to ensure a steady supply of thermal energy, while maintaining continuous and stable combustion. However, there are few difficulties to use vegetable oils directly, such as their high viscosity and low volatility, which have an adverse effect on combustion efficiency. A dilution approach is used to solve these issues; fried cooking oil is used with diesel and ethanol in various proportions to improve fuel properties. The resulting mixes are then utilized in a burner system to heat water in a hot water generator with an extra air supply system, allowing for effective and extended combustion.

Keywords: Biofuel, Used Cooking Oil, Diesel Blends, Ethanol, Combustion, Emissions

1.Introduction

One-third of the world's petroleum oils are used for transportation, thus finding sustainable alternatives is very important. Biofuels, sustainable fuels made from plants and animals, are starting to pose a threat to fossil fuels. However, the majority of early biofuel production was from food crops, which sparked worries about deforestation, rising food prices, and land dispute. In order to solve these problems and provide more clean and sustainable energy sources, more kinds of biofuels are being created, especially those derived from algae and non-food crops. . Energy sources other than fossil fuels and nuclear fuels are referred to as alternative fuels, often called non-conventional fuels. These include biofuels like vegetable oils, biodiesel, bio-ethers, bio-alcohols like methanol and ethanol, biomass from municipal or agricultural waste, and fuels derived from algae. These choices are becoming more popular because they lessen reliance on finite natural resources and minimize pollution in the environment.

Biofuels are gradually becoming an important alternative in the world's energy utilization, due to the increasing energy crisis and supportive government policies. One of their key advantages is that they provide a stable energy security with reasonable price. Many countries mostly rely on imported traditional fossil fuel oils, which are liable to price variations and supply interruptions. This requirement might be reduced by producing the biofuels locally. The considerable economic growth, creating jobs and rural economies can be achieved through this biofuel production For example, countries like India are promoting the mixing of conventional diesel with biofuels to enhance their energy sector and reduce their crude oil imports.

The main benefits of utilizing biofuels are reducing acid rain and air pollution caused by sulfur concentration and more environmentally friendly than diesel fuel. Biofuels may include some nitrogen molecules, but their overall environmental effect may be better controlled throughout production. The CO_2 emission is neutralized by planting more biofuel derived plants and thus a carbon cycle is nearly balanced. Due to this greenhouse effects could also be reduced significantly.

Because biofuels come from resources that can be renewed on a regular basis, such crops grown once a year or algae grown more often, biofuels are regarded as renewable. Despite this, issues including rivalry with food production and land usage limit their availability. Due to the lower energy production of traditional food crops like corn and soybeans are less suited for large-scale fuel substitution. Algae and jatropha are being investigated due to their, high yield. Biofuels can be transported by existing fuel systems and infrastructure in CI engines with relatively slight modifications. More technological development is needed for the thermal systems, which are working with an alternatives like hydrogen or electric energy systems compared to the biofuel.

Biofuel is preferred as sustainable energy for future, due to their advantages like Increased energy security, renewable energy, less pollution, and economic expansion. But the problems like food security, production efficiency, and land use are to be resolved. The second-generation and algae-based biofuels are expected to play a significant role in meeting the world's energy demands in the future, due to their continued improvements.

2.Literature Review

Investigations of alternative fuel such as straight vegetable oil, used cooking oils and biodiesel blends for various thermal systems were examined by various researchers. Bari et al. (2002) Used cooking oil as alternative fuel in a diesel engine, and exposed that the performance of the engine was alike to diesel. Also due to poor atomization and rich fuel blends emissions like But CO, NO, and SO_2 were exhibited more.

Vaitilingom et al. (1998) and Alonso et al. (2006) investigated rapeseed oil, which has a high viscosity and slows down atomization and ignition and suggested that the burner modifications can be used in place of refined or degummed vegetable oil. Also found that the emissions such as SO_x and CO_2 decreased as oil concentration increased, higher oil percentages require fuel heating to maintain acceptable viscosity levels. Improved engine performance and lowered CO and smoke emissions is achieved by Pugazhvadivu's (2005), by using 135°C used cooking oil.

Daho et al. (2009) investigated mixtures of 25-30% cottonseed oil and diesel oil in a boiler and understand that blends to be preheated to retrieve the better performance of the system. Souza et al. (2009) produced the biodiesel from waste vegetable oil and fired in a furnace to analyze and the flame temperatures and heat transfer rates, which was greater than biodiesel. Macor et al. (2009), the PM and CO emission level are reduced considerably by using biodiesel blended with heating oil in a boiler; this is due the molecular structure of biodiesel which contains more oxygen. Nevertheless, the research also detected a little rise in emissions of sulfur dioxide (SO_2).The gasoline blend's sulfur compounds, which are produced after combustion, were blamed for this rise. Barroso et al. (2010) discovered that the burner design helps to decrease the NO_x and SO_2 emissions in a boiler while burning bio-ethanol compared to conventional diesel. Hazar et al. (2010) made experiments on preheated rapeseed oil-diesel mixtures and discovered that spray properties and air-fuel mixing, can enhanced by preheating and leading in lower CO and fuel consumption while increasing NOx emissions.

Rakopoulos et al. (2011) identified that soot emission was reduced, when the proportion of vegetable oils such as sunflower, cottonseed, corn, and olive oils increased in diesel blends in a bus engine testing. Franco et al. (2011) derived the relationship between viscosity and oil content and the rheological properties for diesel and vegetable oil blends. In CI engines vegetable oil-ethanol emulsions was investigated by Nandkishore et al. (2012) through that spray characteristics and brake thermal efficiency enhanced and fuel viscosity and CO emissions were decreased by ethanol addition, when compared to diesel. According to Panua et al. (2013), alternative fuels other than diesel can be used in direct injection diesel engines, and the mixture of 30% Jatropha oil shown the better performances like diesel fuel and could be used without modifications.

Arumugam et al. (2018) made experimental analysis in a mini boiler fueled with diesel and vegetable oil mixtures and found that by adding secondary air in system, enhances the thermal efficiency, and decreases the CO and HC emissions. Mixture of conventional diesel and vegetable oil, lowered the emissions like CO and HC and increased the efficiency of a boiler, according to the experiments made by Punnaivanam et al. (2020). Research indicates that since vegetable oils, biodiesel, and ethanol blends are renewable and may improve performance while reducing emissions such smoke, HC, and CO, they can be utilized as effective alternative fuels for thermal systems. Even though these fuels offer great potential as sustainable alternatives, issues with viscosity, atomization, and fuel preparation must be fixed for thermal systems to function properly.

3. Methodology

Alternative fuels are desperately needed since fossil fuels are always running out. Because of their eco-friendliness and rather easy manufacturing methods, biofuels offer a lot of potential in this regard. Vegetable oils, such as used cooking oil (UCO), have the potential to replace diesel among biofuels. The atomization, performance and emission characteristics of the system are affected by the direct utilization of used cooking vegetable oils as fuel in thermal systems due to their high viscosity, low volatility, and polyunsaturated composition.

The primary investigation of this study is to inspect the combustion ability of the used cooking oil burns and emission studies of the different proportion of used cooking oil, diesel and ethanol. In order to increase efficiency and replicate real-world combustion circumstances, this experiment is performed in a burner with primary and supplemental air supply units.

In this investigation two different fuel blends were produced, such as B25, which has lower UCO percentage i.e. 25% UCO and 75% diesel; and B50, which contained 50% UCO and 50% diesel, indicating a larger proportion of UCO. Additionally 10% ethanol by volume was added to both fuel mixtures, to enhance the improve fuel atomization and reduce viscosity, now the modified fuel blends are namely B25E (25% UCO + 65% diesel + 10% ethanol) and B50E (50% UCO + 40% diesel + 10% ethanol).

Addition of ethanol increases the volatility and promotes more thorough combustion, hence lowering smoke and unburned hydrocarbons. All fuel blends are to be tested in a mini boiler integrated with burner, equipped with main and secondary air supply systems, which provided the oxygen required for burning while also allowing for improved air-fuel mixing.The mini boiler performance and environmental impact of the various fuel mixtures with ethanol were evaluated by measuring temperature, flame stability and intensity, as well as emissions like CO, CO_2, NOx, and smoke.

3.1 Exhaust Gas Analyzer

Crypton Gas Analyzer is used to measure the emissions, such as hydrocarbons (HC), carbon dioxide (CO_2), oxygen (O_2), and carbon monoxide (CO), during the combustion of fuel. The exhaust is to be filtered before entering in to the gas analyzer, through which the sensitive parts like oxygen sensor can be protected. The analyzer is connected to a PC that has specialized software loaded, to record and show emission values in real time. The instrument setup and specifications of the gas analyzer are shown in table 3.1.

- Analyzer Model: Crypton 290-EN2- 4 Gas Analyzer
- O_2 Cell type = Electro - Chemical and
- Flow Rate = 5 Liters/ Min nominal

Table 3.1 Specification of Crypton 290-EN2 Gas Analyzer

Measuring gas	CO (% of air)	HC (ppm)	CO_2 (% of air)	NO_X (ppm)	O_2 (% of air)
Maximum range	0-10	0-20,000	0-20	0-1000	0-25

4.Experimental Setup

The combustion and emission characteristics of used cooking oil has been studied with an experimental setup for burning the fuel with and without additional (secondary) air supply unit. The experimental setup for the study of the performance of hot water generator fired with various vegetable oil blends or used cooking oil with diesel as fuel is explained below and the schematic diagram is shown in Figure 4.1. The experimental setup consists of a blower, burner, fuel tank, Hot Water Generator, combustion chamber and an exhaust gas analyzer.

The necessary air to the system is provided through blower. The outside air is sucked into the whole setup by means of a blower. This air enters the setup from the blower through a hose. A manometer is present in the middle of the path of air in order to measure the pressure of air flowing through the burner. By measuring the height difference between the pipes, pressure of the air is found out.

The fuel is supplied to the burner by means of the fuel system. The fuel system consists of a fuel tank and a hose. The fuel tank is cylindrical in shape and its diameter and height is 15cm and 30 cm respectively. The fuel tank has a capacity of 10 litres and made up of stainless steel. The fuel flows from the tank to the burner through the hose. Mass flow rate of fuel is controlled by using a needle valve and is connected in between the burner and the hose. Thermocouples are used to determine the temperature of combustion chamber and temperature of water in the Hot Water Generator. They have the capability to measure temperatures up to 400°C. Pressure gauge is used to measure the steam pressure in the Hot Water Generator. The measuring range of the pressure gauge is 0 bar-2 bar.

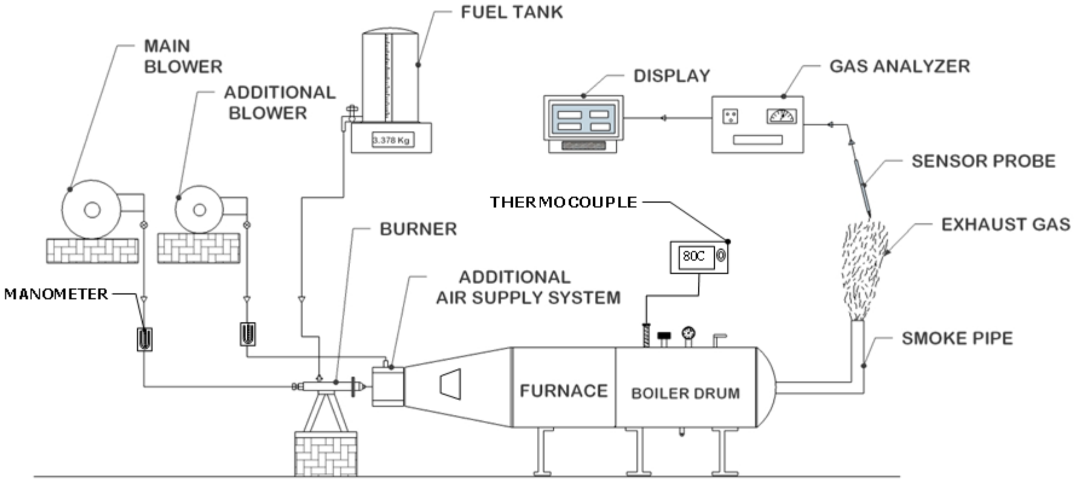

Fig. 4.1 Schematic diagram of experimental set up with primary and secondary air supply

The burette is connected across the Hot Water Generator to measure the capacity of water in the Hot Water Generator. 1cm in the burette scale corresponds to 0.5 litre in the Hot Water Generator. The additional air supply system is added to the existing setup in between the burner and the conical chamber. Air to the additional air supply system is given by means of another blower. The additional air unit enhances the flow of fuel into the conical chamber. Fig 4.4 shows the schematic diagram of the setup with additional air supply unit. Fig 4.5 shows the photograph of experimental setup with additional air supply unit.

5.Results and discussion

5.1 Calorific Value and Viscosity

The calorific values of the blends are found out using bomb calorimeter and the viscosity of the blends are found out using Redwood viscometer and shown in Table 5.1.

Table 5.1 Properties of various fuel blends

Fuel Blend	Calorific Value (kJ/kg)	Kinematic Viscosity (cSt)
Diesel	41263.94	3.97
25% used cooking oil + 75% diesel	40458.56	24.92
50% used cooking oil + 50% diesel	36861.35	28.84
25% used cooking oil + 65% diesel + 10% ethanol	34458.21	13.76
50% used cooking oil + 40% diesel + 10% ethanol	31295.15	18.74
100% used cooking oil	33570.04	50.19

The calorific value decreases when ethanol is added to the blend. It shows that on addition of ethanol to the blends, the viscosity reduces.

5.2 Thermal Efficiency with Primary and Secondary air Supply

Experiments were carried out on hot water generator with different used cooking oil blends. Four different blends were used and for each blend, thermal efficiency is calculated. It is found that thermal efficiency is maximum in the range of 40.05% for diesel fuel. This is because of high calorific value of the diesel. The addition of ethanol did not have much effect on the thermal efficiency of the blends. Even though the calorific value of the blended fuel with ethanol is low, the thermal efficiency does not fall. This may be due to the better viscosity of the blended fuel with ethanol.

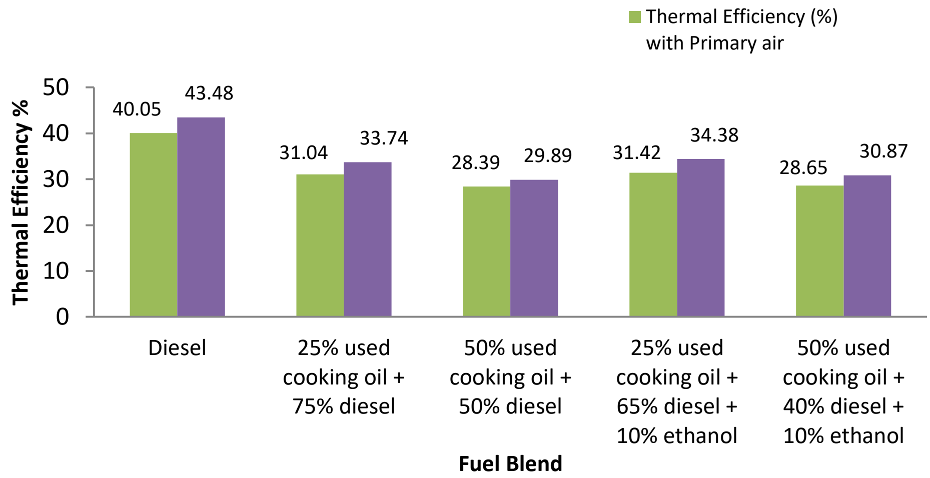

Fig. 5.1 Thermal Efficiency of various fuel blends with secondary Air supply

Thermal Efficiency of hot water generator with the primary air supply unit for various fuel blends are compared in Figure 5.1. It is found that thermal efficiency is maximum in the range of 43.48% for diesel fuel. The addition of ethanol increased the efficiency of B25 and B50 blends in the range of 5-9%.

5.3 Emissions Comparison Studies For Primary and Secondary Air Supply.

5.3.1 Emission of CO_2

The emission levels of CO_2 with primary air and additional air unit in all the five cases were compared in Figure 5.2. It is observed that B25 and diesel showed higher percentage of CO_2 emissions in the range of 12.2 % of air and in the case of B50 blend the emission level is 7.38 % of air, while blends with ethanol showed CO_2 in the levels of 5-6% of air.

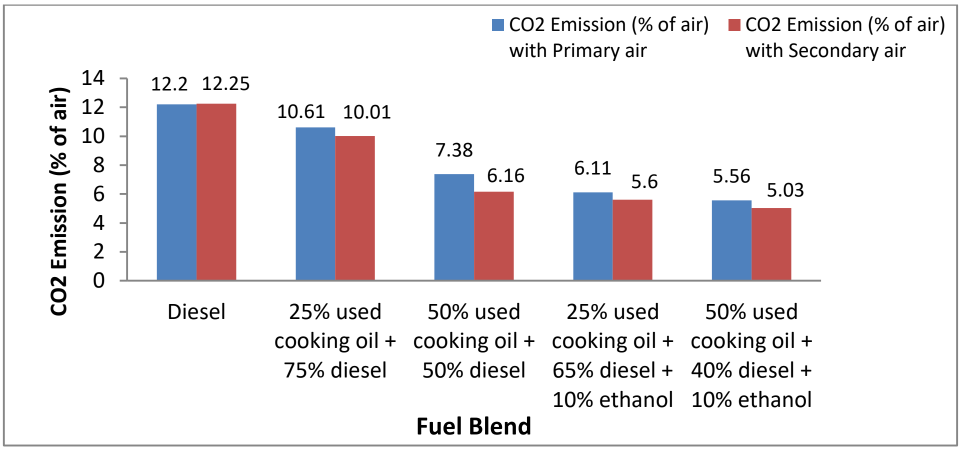

Fig 5.2 Emission results of CO_2 for the blends with primary and secondary air supply

It is also observed that B25 blend showed better combustion characteristics as optimal percentage of CO_2 is an indication of complete combustion. The CO_2emission levels decreased when the percentage of used cooking oil in the blend is increased and the level further dropped by 5% when small percentage of ethanol is added to the blend.

5.3.2 Emission of CO

The emission levels of CO in all the five cases with primary air and with additional air unit were compared in Figure 5.3. The emission level of CO was minimal in the range of 0.32-0.98 % of air when ethanol is added to the blends. The CO emission reduced when the amount of used cooking oil in the blends increased. This shows that when biofuel is blended with diesel fuel, the CO emission reductions are generally proportional to the amount of biofuel in the blend. The emission level of CO was minimal in the range of 0.37-0.26% of air when ethanol is added to the blends.

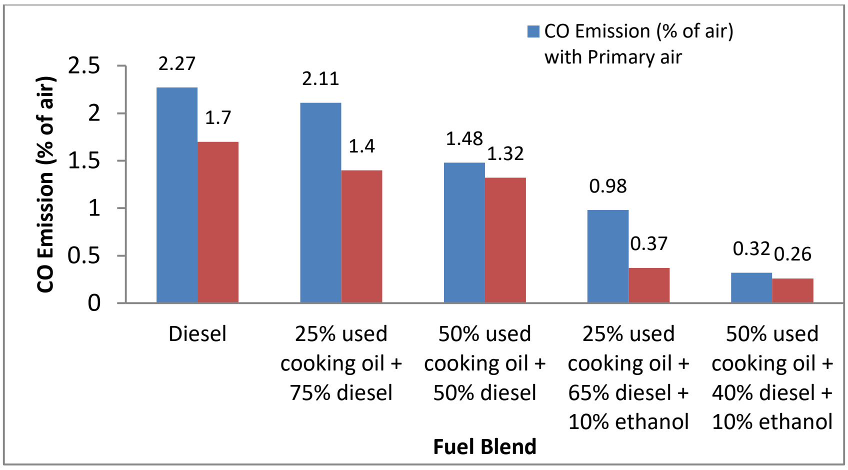

Fig 5.3 Emission results of CO for the blends with primary and secondary air supply

The CO emission reduced when the amount of used cooking oil in the blends increased. This shows that when biofuel is blended with diesel fuel, the CO emission reductions are generally proportional to the amount of biofuel in the blend.

5.3.3 Emission of HC

The emission levels of HC in all the five cases with primary air and additional air supply unit were compared in Figure 5.4. The emission level of HC indicates the amount of unburned or partially burnt fuel in the exhaust gas .The emission levels of HC were in the range of 645 ppm in the case of diesel fuel. The emission level of HC for B25 blend was lower in the range of 594 ppm. With the increase in the amount of cooking oil in the B50 blend, the HC emission reduced to lower level in the range of 330 ppm. The emission levels of HC were in the range of 554 ppm in the case of diesel fuel. The emission levels of HC comparatively reduced with increase in the percentage of cooking oil in the blend. With the addition of 10% ethanol in the B50 blend, the HC emission reduced to lowest level in the range of 236 ppm.

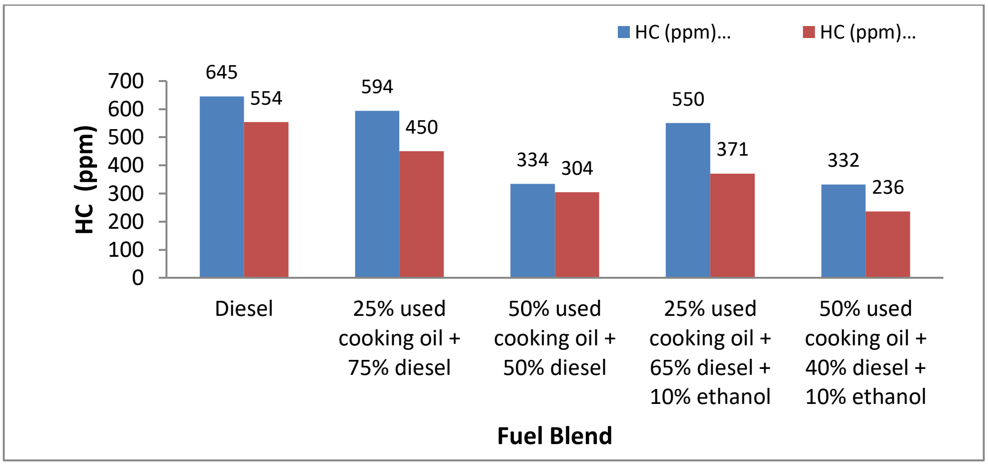

Fig 5.4 Emission results of HC for the blends with primary and secondary air supply

This is due to better atomization of the fuel that ensures complete combustion of the fuel. This ensures that no unburned particle escapes through the exhaust which produces lower HC emission.

5.3.4 Emission of NO_x

The emission levels of NO_x in five fuel blends with the supply of primary and additional air is compared in Figure 5.5. The NO_x emission values primarily depends on the flame temperature and the temperature of the combustion chamber. It is clear that a NOx emission is highest in diesel. This is due to high temperature prevailing in the combustion chamber during running condition. The lower level of NO_x shows that combustion has just been initiated in the burner. The NO_x emission value primarily depends on the flame temperature and the temperature of the combustion chamber. It is clear that a NO_x emission is highest in diesel. This is due to high temperature prevailing in the combustion chamber during running condition. The NO_x emission levels increased with increase in the temperature of furnace in the case of all the blends.

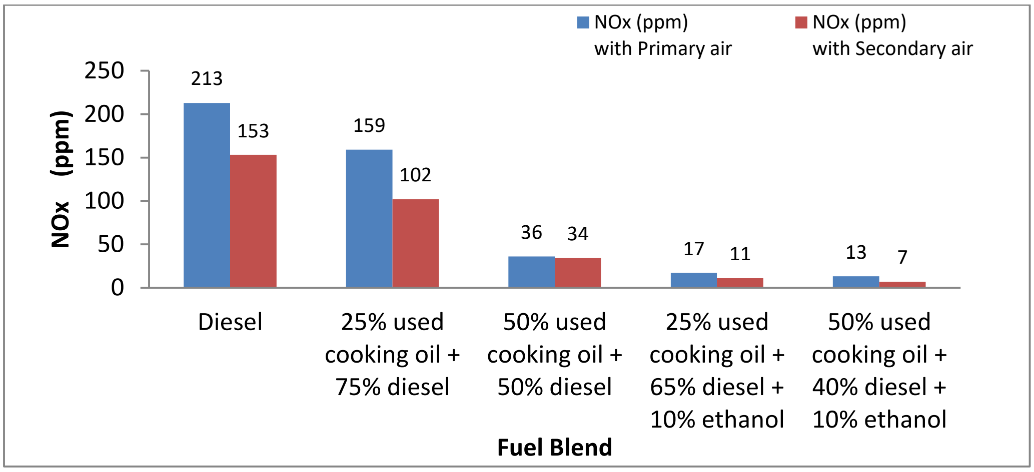

Fig 5.5 Emission results of NO_x for the blends with primary and secondary air supply

CONCLUSION

The performance and exhaust emissions for the blend of diesel, used cooking oil, and ethanol blend were investigated for both primary and secondary air supply conditions. The conclusion reveals that significant differences in emission characteristics based on the proportion of the blends. Emissions of CO_2 were found to be the highest, reaching approximately 12.2 –12.25% of the air for diesel. As compared to diesel, 50% used cooking oil, 40% diesel, and 10% ethanol fuel blend shows lower CO_2 emissions, with better combustion efficiency and less carbon emission. The carbon monoxide was recorded as 0.32% with primary and 0.26% with secondary air supply; this is significantly lower than the conventional diesel and also facilitates complete combustion due to the presence of a good oxygenated fuel blend.

Lower HC emissions were obtained for the blended fuels in comparison to conventional diesel. Diesel exhibited the more level of HC, i.e. 645 ppm with primary air. The lowest HC emissions (332 ppm with primary air and 236 ppm with secondary air), were recorded for 50% UCO, 40% diesel and 10% ethanol. This result indicates the complete combustion, due to the better oxidation of unburned hydrocarbons. As the amount of ethanol is increased in the mixture of UCO and diesel, the NO_x emissions decreased. The highest NO_x emissions were produced by diesel (213 ppm with primary air).

The lowest NO_x emission (13 ppm with primary air and 7 ppm with secondary air) was released while using 50% UCO, 40% diesel and 10% ethanol fuel blend.

In comparison to primary air operation, the installation of secondary air supply further decreased emission levels in all the emission criteria taken into consideration (CO_2, CO, HC, and NO_x). In comparison to conventional diesel fuel, blends incorporating 50% UCO, 40% diesel and 10% ethanol can successfully minimizes the hazardous pollutants. This blend showed the significant emission performance among the other blends used in the experimental investigation, also making it a suitable substitute fuel for lowering environmental impact and advancing waste-derived renewable fuels.

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