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Experimental Investigation on the Performance and Emission Characteristics of a Diesel Engine Fueled by Syngas and HHO gas

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Abstract:
The world's energy demand is growing remarkably due to the robust growth of population and economy. As fossil fuels are limited resources and affect the environment, they are not the perfect choice to satisfy the energy demand any more. Different methods were used to replace the fossil fuel such as biomass and the mixture of hydrogen and oxygen. The most widely recognized utilization of biomass for energy is direct combustion, trailed by gasification, carbonization, and pyrolysis. The synthesis gas "syngas" resulted from the biomass gasification process and HHO gas resulted from water electrolysis can be burnt and used as a fuel for an internal combustion engine instead of the conventional kinds of fuel. In this work syngas and HHO gas were used as secondary fuel for a single cylinder diesel engine. The engine performance and emissions were evaluated and recorded during each test. Different parameters were measured such as engine torque, gasifier temperature, engine RPM and the exhaust gas analysis. The results showed that the maximum recorded values of brake thermal efficiency achieved for diesel fuel was 29.5% while in dual fuel mode the maximum values were 26.1% and 35.1% for diesel + syngas and diesel + HHO gas respectively. Also, higher recorded values of carbon monoxide emission are observed by using syngas compared with pure diesel fuel and diesel + HHO gas. Finally using diesel + HHO gas gives the minimum-recorded values for NO emission and this an important advantage for using HHO gas as a secondary fuel for diesel engines.

Keywords: *Performance; Emission; Diesel engine; Biomass; Syngas and HHO.*

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I. INTRODUCTION

Energy is one of the most fundamental elements of our life. Energy can be obtained mainly from two sources namely conventional and renewable ones. The main sources of energy today are conventional like oil, natural gas, coal and nuclear fission. The consumption of these sources of energy increases with a critical rate. The estimates show that the total petroleum reserves in the world will be depleted in the next two or three decades if the consumption continues to increase above the present rate. Conventional sources of energy have also a very bad effect on environment due to the emission of harmful gases. Biomass is considered as the oldest energy source and currently accounts for about 10% of the total energy consumption. The biomass can be converted into power and heat by a certain adopting suitable method [1]. In the process of gasification, syngas can be produced from biomass by the use of heat in an oxygen-starved environment and heat is generated through partial combustion of the feed material [2].The producer gas in gasifiation process consists of mixture of hydrogen, methane, carbon monoxide, nitrogen, and carbon dioxide. In that mixture hydrogen, methane, and carbon monoxide are combustible gases, whereas carbon dioxide and nitrogen are non-combustible gases. The obtained gas can be used to produce heat or generate electricity [3]. The obtained gas also can be burnt directly in open air, much like Liquefied Petroleum Gas (LPG), and thus it can be used for boiling water, cooking, producing steam and drying food. Krishna and Kumar [4] studies the operational characteristics of a diesel engine running in dual-fuel mode using syngas obtained from the gasification process of coffee husks. The results showed that there are a value of 31% only was recorded as the higher rate value of diesel reinstatement. In addition, it is clear from the study that the syngas can be used as a fuel for CI engines. In addition, most of the experiments in different studies were performed to ascertain the emissions and performance of dual-fuel syngas-powered engines.

Wagemakers and Leermakers [5] reviewed the effect of using dual fuel of diesel and different types gaseous fuels on the emission and performance. They concluded that the main objectives of using dual-fuel mode are the reduction of nitrogen oxides (NO_x) emission and particulate matter with potential economic and efficiency advantages. Generally, dual-fuel mode for combustion of diesel and gaseous fuels decreases soot emissions. However, using of syngas or hydrogen in dual-fuel mode combustion leads to increase the emissions of nitrogen oxide and the emissions of carbon monoxides and the unburned hydrocarbons tend to increase due to incomplete combustion. The emissions characteristics of responding CI dual fuel engine operating with the producer gas as fuel was evaluated by Seridhar et al. [6]. The engine was operated firstly at high engine speed using diesel fuel with producer gas and the emitted NO_X was observed to be lower in dual fuel mode technique compared with using pure diesel fuel. The CO levels were higher because of ignition inefficiencies and lower CO and NO_X levels were observed when the producer gas was utilized as a flash ignition engine.

Shrivastava et al. [7] planned and built up a downdraft gasifier to utilize wood chips and mustard oil cakes in the proportion of 7:3 as a feed stock. Additionally they assessed the presentation and discharge parameters of a solitary chamber diesel engine controlled by double fuel mode. The outcomes indicated that a decrease in the utilization of diesel was watched contrasted and the double fuel mode. Nitrous oxide emanation was seen as very low in double fuel, which is an extraordinary favorable position of double fuel mode over diesel. Dascomb et al. [8] investigated an experimental study for the gasification of wood pellets to produce syngas by using a 100 kW fluidized bed gasifier with temperatures levels up to 850 °C. The produced syngas concentration and gas efficiency were found to increase with steam to biomass weight ratio and bed temperature to reach a maximum values of 124% and 51% respectively. Also, the maximum energy conversion to syngas was found to be 68% and the maximum conversion of all energy sources to hydrogen was found to be 25%.

The hydroxy gas (HHO) is a blend of hydrogen and oxygen and produced from the water electrolysis in a dry cell that made from the stainless steel plates. The HHO gas can be used in many and different applications. One of the most and important application is internal combustion engine. Wang et al. [9] studied the effect of using HHO gas on gasoline engine performance. The obtained results showed that the fuel consumption decreases by using the HHO gas and the emissions of CO decreased. Masjuki et al. [10] used the HHO gas in IC engine powered by biodiesel fuel. They concluded that the HHO gas improved the engine power by 2%, decreased the fuel consumption by 5% and HC and CO emissions reduced by 10% and 20% respectively. Sopena et al. [11] studied a comparison between the characteristics of emissions by using the hydrogen and gasoline engines. They concluded that the engine thermal efficiency by using hydrogen was higher than that of the gasoline engine and the torque output was lower than that of the gasoline engine. Baltacioglu et al. [12] performed an experimental study on the diesel engine performance and emission characteristics by using HHO gas and biodiesel. Their results showed that the engine performance was increased by using the HHO gas and the exhaust emission provided better results for using hydrogen. Ismail et al. [13] studied the effect of using HHO gas on engine performance and emissions by using dry cell and NaOH as the electrolyte. Their results concluded that the fuel consumption reduced by15%, the CO emission reduced by 17% and HC emission reduced by 27%.

The main objective of the current study is to design an updraft gasifier that uses wood chips as a feed stock to produce syngas. Use the obtained syngas as a secondary fuel to operate a four stroke single cylinder diesel engine. Use the HHO gas from water electrolyte as a secondary fuel for the same diesel engine. Compare between the methods of using diesel fuel, diesel + syngas and diesel + HHO gas as a secondary fuel. Evaluate the engine performance and emission by diesel fuel, diesel + syngas and diesel + HHO gas.

II. EXPERIMENTAL SETUP

The experimental setup was performed using a small gasification plant to produce syngas and HHO generator to produce the brown gas. The diesel engine was operated with pure diesel, diesel + syngas and diesel + HHO gas. The schematic diagram of the experimental setup is shown in Fig. (1). The gasification plant consists of the updraft gasifier, cyclone, cooling system and blower for feeding the syngas to the diesel engine through a flow meter. Air compressor is provided to feed the necessary air into the gasifier. Fig. (2) shows a schematic diagram of the gasification plant and the Fig. (3) shows a photograph of the main parts in the experimental setup.

2.1 The gasification plant

The wood biomass fuel is fed into the gasifier by batch of 10 kg, and air enters the ignition zone to produce syngas. The produced syngas from the gasifier was introduced in the inlet manifold of engine at flow rates of 4 liter per minute. The gasifier consists of the core which is the main part of the gasifier. It is the place where the gasification processes take place and it is mainly consists of internal and external cylinders. The gas flow passes between the external cylinder and the internal cylinder in the gasifier. It's also containing between it and the internal cylinder the space for air to air heat exchange between hot syngas and cold inlet air passage to increase air inlet temperature. The gasifier is made of steel with anti-rust prime to withstand high temperatures. The external cylinder contains the air nozzle, the gas outlet, thermocouples and the ignition hole. Ten kilograms of wood chips were fed into the gasifier and the weight was measured by digital balance. The cyclone separators is a centrifugal separator in this type the particles, due to their mass, are pushed to the outer edges as a result of the centrifugal force. While the particles which are present in the gas are forced to the outer edges to leave the separator via a collection device fitted to the bottom of the separator. The cyclone is made from steel and the gas enters from one side while the tar exits from the bottom of the cyclone as shown in Fig. (2). Water tank was used to condensate the mostly water steam in the syngas and also to make the syngas denser and flammable.

2.2 HHO Generator

The HHO generator of oxy-hydrogen represents an electrolyzer, which is placed in an aqueous solution of an electrolyte (like potassium hydroxide or sodium) and metal electrodes are immersed. Based on the application of a voltage on the electrodes through the electrolyte passes electrical current, which leads to a directed motion of the positive ions H+ and negative OH- ions, respectively, to the cathode and anode. On the electrodes flow redox reactions leads to release of hydrogen and oxygen respectively on the cathode and the anode. In this work Potassium Hydroxide (KOH) is the used as electrolyte and the installation of all components were made separately and installed in plastic jar. A 12V battery is used to feed the HHO generator for the gas generation. Fig. (3) shows the HHO generator that used in the experimental setup.

2.3 The Diesel Engine

The diesel engine is a single cylinder, four stroke engine with five horsepower was used in the experimental setup. This engine has a cylinder bore and stroke of 80×100 mm, nominal compression ratio of 16.5:1 and provided with air cooled system. The fuel consumption was measured by using calibrated burette and data acquisition was used to collect the data from the sensors. The emissions of the exhaust gases were measured by Kane 450 gas analyzer as shown in Fig. (1).Diesel fuel, syngas and HHO gas were fed in to the engine with a certain values to ensure good comparison between the obtained results.

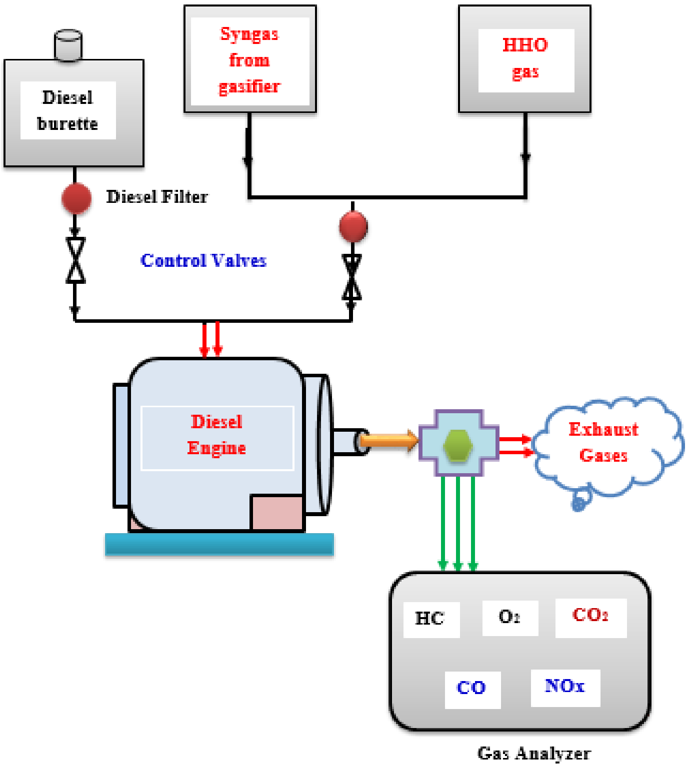

Fig. (1): Schematic diagram of the experimental setup.

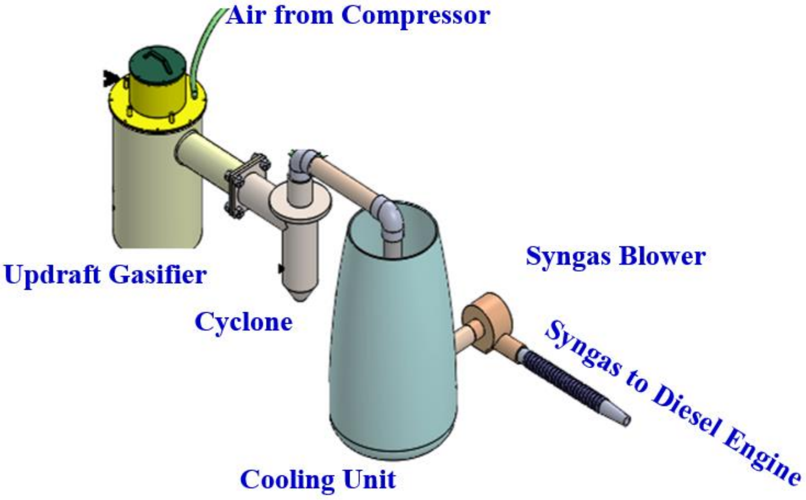

Fig. (2): Schematic diagram of the gasification plant.

Updraft gasifier Diesel engine HHO generator

Fig. (3): Photograph of the experimental setup.

2.4 Measurements and Instrumentations

The Kane 450 gas analyzer was used to measure the exhaust gases of hydrocarbon HC, nitrogen oxides NO_x and carbon monoxide CO in addition to carbon dioxide CO_2 and oxygen O_2, as shown in Fig. (4). The digital torque meter is used to measure the diesel engine torque to determine the engine power required. Fig. (4) presents the digital torque meter device that used in the experimental work. A tachometer laser type is used to measure the rotation speed of the engine shaft. The temperature was measured by a calibrated k-type thermocouples (Nickel-Chromium / Nickel- Alumel) with data acquisition during the experimental setup. The temperature measurements include the biomass temperature material in the gasifier core, the engine exhaust gas temperature. Fig. (4) shows the k-type thermocouple with digital display. Many experimental tests were done using pure diesel fuel, syngas from the gasification plant and HHO from the generator. The diesel engine was initially run at full load using pure diesel fuel to measure the maximum brake power and the specific fuel consumption. The engine torques different values were recorded during the experimental tests.

Kane 450 gas analyzer

digital torque meter

tachometer with digital display

K-type thermocouple with digital display.

Fig. (4): Measurements and instrumentations.

2.5 Error Analysis

In order to know the accuracy and the power of the experimental results, uncertainty analysis is necessary to prove the errors in the experimental work. Holman [14] method was used to estimate the uncertainty in experimental results. The minimum error value for any devise can be expressed as the ratio between its least count and minimum value of the output measured [13]. All measured values have small values compared with the obtained data and found to be within the allowable range of the measurements as shown in Table (1).

Table (1): The uncertainties values for the measured and calculated parameters.

Parameters	Uncertainty (%)
Temperature (ºC)	0.05
Engine power (kW)	0.10
Speed (rpm)	0.063
Fuel consumption (kg/s)	0.02

The wood biomass material are cut, prepared and feed into the gasifier as a batch. The gasifier is closed well and the interaction inside the gasifier lasts for 30 minutes and the syngas starts to pass from the gasifier to enter the diesel engine. The produced syngas was used as a secondary fuel for a single cylinder diesel engine. The producer syngas was introduced in the inlet manifold of engine at flow rates of 4LPM. The k-type thermocouples were used to measure the gasifier temperature at three different positions (bottom, middle and top). At the point when the reactor temperature reaches to 600ºC-1000ºC, a small quantity of syngas is checked to know its quality before entering the engine. After time of about thirty minutes the produced gas has a good quality and generates in a continuous method to feed the diesel engine. The produced syngas was examination and utilized as an alternative fuel for the diesel engines. For the HHO generator the devise was connected with an electric source and the gas starts to feed the diesel engine with the same value as syngas. The produced HHO gas was examination and utilized as an alternative fuel for the diesel engine also. The engine performance with pure diesel, syngas and HHO gas was evaluated, analyzed and the emissions from the engine were recorded continuously during the experimental tests. The thermal efficiency can be calculated as follows,

$$\eta_{th} = \frac{Break\ power}{Fuel\ flow \times calorific\ value} \times 100 \quad (1)$$

The engine break power can be obtained by the following,

$$Break\ power = T \times \omega \quad (2)$$

Where T is the diesel engine torque and it can be measured from the digital torque meter, ω is the number of revolution in RPM. The fuel flow is the sum of dual fuel and equal to the mass flow rate of diesel fuel, the syngas and the HHO gas. The calorific value of automotive diesel is generally taken as 42,500 kJ/kg. The fuel consumption can be measured using a graduated cylinder fixed into the experimental setup.

III. RESULTS AND DISCUSSIONS

In the current study, the performance and emission tests were conducted on diesel engine at dual fuel mode i.e. diesel as primary fuel, syngas and HHO gas at the same mass flow rate. The results of the performance and emission test are described below. In this context, diesel engine performance operating with pure diesel fuel syngas and HHO gas was evaluated and analyzed in different terms and at different loads started from 0 (no load) to 4.5 kW brake power at a rated speed of 1500 rpm. The engine power and the RPM were adjusted by using the adjustable nut of the diesel engine. The brake thermal efficiency, exhaust gas temperature, brake specific energy consumption and the emission characteristics will be presented and discussed at different loads.

3.1 The Engine Brake Thermal Efficiency

The variation of engine brake thermal efficiency with brake power using diesel fuel, syngas and HHO gas is shown in Fig. (5). From this figure it is clear that the brake thermal efficiency of the diesel engine using HHO gas is higher than that of pure diesel fuel and syngas at different values of brake power. The maximum recorded values of brake thermal efficiency achieved for diesel fuel was 29.5% while in dual fuel mode the maximum values were 26.1% and35.1% for diesel + syngas and diesel + HHO gas respectively. The main reason for brake thermal efficiency reduction is due to the lower calorific value of the producer syngas. In addition, the producer syngas evolved from the diesel engine is at high temperature and therefore its density is reduced. The syngas mass flow rate and the required air for combustion process are reduced also with low values of oxygen to cause incomplete combustion inside the engine combustion chamber. The same results are reported by [15].

3.2 The Engine Brake Specific Energy Consumption

In fact, the engine brake specific fuel consumption is not a recommended to compare between two fuels having different density and calorific values, thus the term brake specific energy consumption is preferred in ICEs. The engine brake specific energy consumption is calculated from the fuel (gas or diesel) calorific value and the fuel consumption. The variation of engine brake specific energy consumption with brake power using diesel fuel, diesel + syngas and diesel + HHO gas is shown in Fig. (6). From the analysis of this figure, it's clear that the brake specific energy consumption decreases as the engine brake power increase in diesel fuel, diesel + syngas and diesel + HHO gas. The brake specific energy consumption of the diesel at full load is found to be 16.1 MJ/kWh, while for diesel + syngas and diesel + HHO gas it is found to be 19.04 and 14.2 MJ/kWh respectively.

3.3 The Engine Exhaust Gas Temperature

Figure (7) shows the variation of engine exhaust gas temperature with brake power in different values of using diesel fuel, diesel + syngas and diesel + HHO gas. From the analysis of this figure it can be concluded that the exhaust gas temperature of pure diesel at maximum brake power is found to be 405 ^{o}C while the exhaust gas temperature at maximum brake power for diesel + syngas and diesel + HHO gas are found to be 430 and 380^{o}C respectively. At higher temperature greater than 1100^{o}C, the nitrogen will reacts with the oxygen to produce NO_x emission. This means that under the working conditions, there is no probably to find NO_x in the exhaust gas.

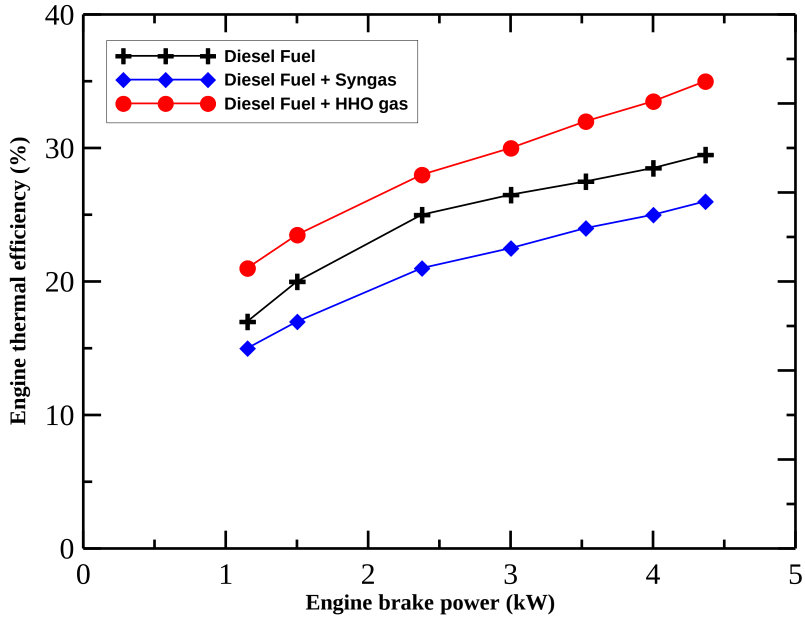

Fig. (5): The variation of engine thermal efficiency with brake power

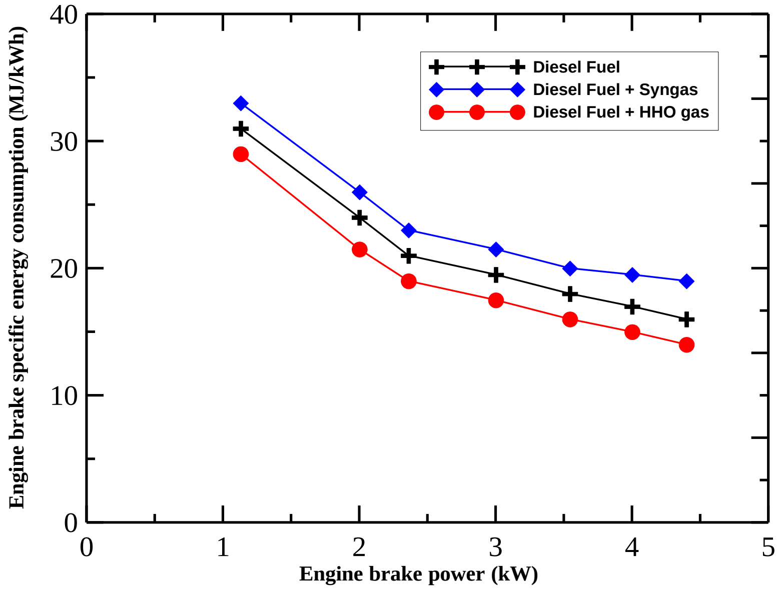

Fig. (6): The variation of engine brake specific energy consumption with brake power

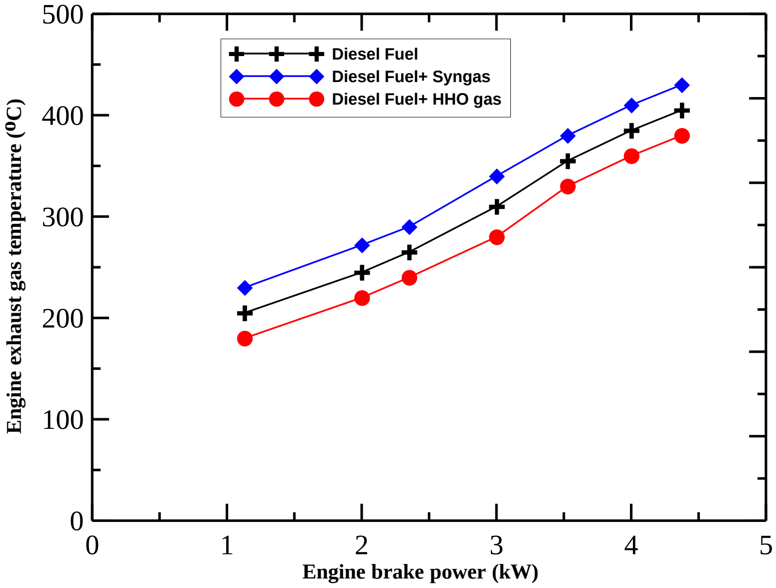

Fig. (7): The variation of engine exhaust gas temperature with brake power

It is very important to control and evaluate the engines emission, because it gives us all information about the combustion process quality inside this engine. So in this section the different and most engine emission will be discussed with the variation of engine brake power. These emissions include the emission of Carbon monoxide (CO), Hydrocarbon (HC) and Nitric oxide (NO) as follows.

3.4 The emission of Carbon monoxide

The emission of carbon monoxide can be formed due to the incomplete combustion process in the combustion chamber (insufficient quantity of oxygen entering the engine) or due to the insufficient time needed for fulfilment the combustion process in this engine. Fig. (8) shows the variation of carbon monoxide emission with engine brake power in dual fuel technique at different loads for diesel fuel, diesel + syngas and diesel + HHO gas. From the analysis of this figure, it can be concluded that the emission of carbon monoxide increases as the engine brake power increase. Also higher recorded values of carbon monoxide emission are observed by using syngas compared with pure diesel fuel and diesel + HHO gas. This occurs due to the incomplete combustion process in engine combustion chamber and this is generating high quantities of carbon monoxide emission. The maximum recorded values of carbon monoxide emission achieved by diesel fuel was 315 PPM, while in case of using diesel + syngas and diesel + HHO gas the recorded values were 317 PPM and 275 PPM respectively.

3.5 The emission of Hydrocarbon

The incomplete combustion process yields high-unburnt hydrocarbon emissions. The variation of hydrocarbon emission with engine brake power at different loads using diesel fuel, diesel + syngas and diesel + HHO gas is shown in Fig. (9). From this figure it is clear that the emission of hydrogen carbon slightly decreases as the engine load increases. The maximum recorded values of hydrocarbon emission achieved by diesel fuel was 27.0 ppm, while in case of using diesel + syngas and diesel + HHO gas, the recorded values were 28.0 and 22.0 ppm respectively. In addition, it can be seen that the using diesel + HHO gas gives the smallest recorded values of hydrocarbon emission compared with diesel fuel and syngas.

3.6 The emission of Nitric oxide

The Nitric oxide emissions strongly relies on the ignition chamber temperature which relies on the engine load. Figure (10) shows the variation of NO emission with engine brake power at different loads for diesel fuel, diesel + syngas and diesel + HHO gas. From the analysis of this figure it can be noticed that, the emanation of NO increases with increasing the engine load for pure diesel fuel, diesel + syngas and diesel + HHO gas. This occurs due to the high temperature gradient in the engine combustion chamber at high loads. In addition, it is clear that the diesel fuel gives the highest recorded values of NO emission compared with using diesel + syngas and diesel + HHO gas. Using diesel + HHO gas gives the minimum-recorded values for NO emission and this an important advantage for the using HHO gas. The maximum recorded values of NO emission achieved by diesel fuel was 390.0 ppm, while in case of using diesel + syngas and diesel + HHO gas, the recorded values were 370.0 and 300.0 ppm respectively.

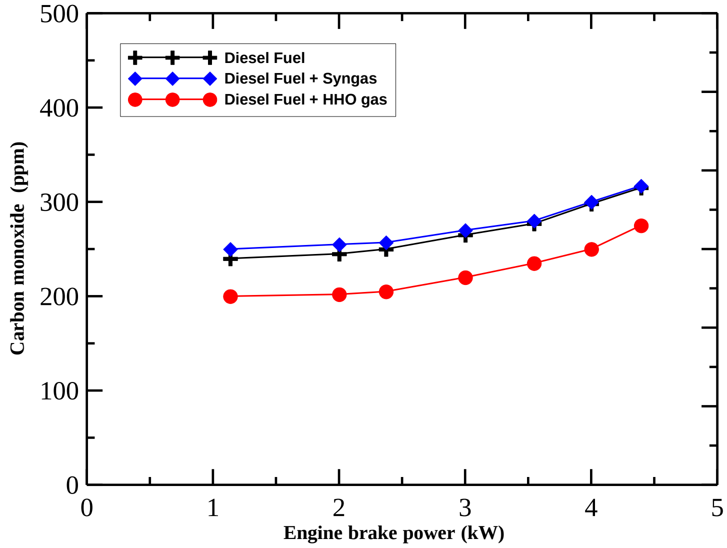

Fig. (8): The variation of CO emission with engine brake power.

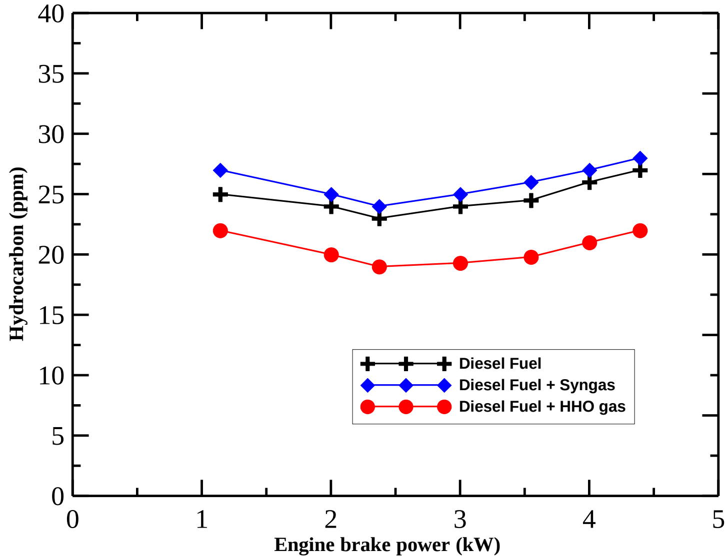

Fig. (9): The variation of HC emission with engine brake power

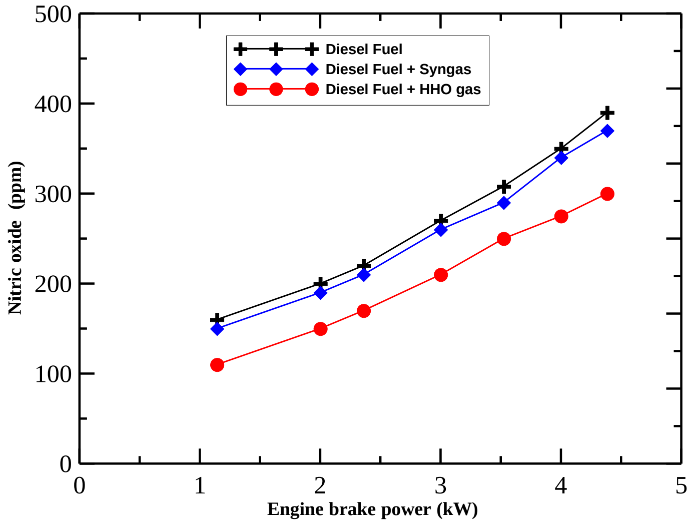

Fig. (10): The variation of NO emission with engine brake power

IV. CONCLUSIONS

Fossil fuels are limited resources and affect the environment and human life. The use of renewable energy would allow us to replace carbon-intensive energy sources and significantly reduce the global warming emissions. In this work an updraft gasifier was designed and wood biomass was used as a feedstock. The produced gas from the gasifier was used as a secondary fuel for single cylinder diesel engine. In addition the HHO gas from water electrolyte was used as a secondary fuel for the same diesel engine. The engine performance and emission were evaluated by using diesel fuel, diesel + syngas and diesel + HHO gas. The results concluded that The maximum recorded values of brake thermal efficiency achieved for diesel fuel was 29.5% while in dual fuel mode the maximum values were 26.1% and 35.1% for diesel + syngas and diesel + HHO gas respectively. The exhaust gas temperature of pure diesel at maximum brake power is found to be 405 ^{o}C while the exhaust gas temperature at maximum brake power for diesel + syngas and diesel + HHO gas are found to be 430 and 380^{o}C respectively. The maximum recorded values of carbon monoxide emission achieved by diesel fuel was 315 PPM, while in case of using diesel + syngas and diesel + HHO gas the recorded values were 317 PPM and 275 PPM respectively. Using diesel + HHO gas gives the minimum-recorded values for NO emission and this an important advantage for the using HHO gas as a secondary fuel in internal combustion engines.

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