American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN: 2320-0936
Volume-9, Issue-1, pp-295-306
www.ajer.org
Research Paper
Open Access

Syngas Production from Biomass Using Gasification Process: An Experimental Studyfor Diesel Engine

Hatem Elhuseen Nasr, S.I. Abdel-Mageed, Tamer M. Ismail*and Khaled Ramzy*

Department of Mechanical Engineering, Suez Canal University, Ismailia, Egypt

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 aren't the perfect choice to satisfy the energy demand any more. The biomass gasification process is considered one of the solution for the previous situation. It is basically depends on burning the raw biomass materials. The Synthesis gas "Syn. Gas" resulted from the biomass gasification process which can be burnt and used as a fuel for an internal combustion engine instead of the conventional kinds of fuel. A cleaning and filtration stages is used to get rid of the impurities and the ashes which is in this syngas to make it proper to be used as a fuel. In this work an up draft gasifier was designed and fabricated at faculty of Engineering Suez Canal University. The gasifier was tested using different plants that are available at Ismailia city- Egypt. The produced syngas was used as a secondary fuel for single cylinder diesel engine. The engine performance and emissions were evaluated and recorded during each test. The results showed that, with the increase in gasifier temperature (from 600^oC to 1000^oC), the hydrogen percentage increases continuously. The maximum recorded efficiency achieved by diesel fuel was 28.51%, while in dual fuel technique the recorded value was 27.1%, 26.02% and 25.51% for diesel + syngas 5%, diesel + syngas 10% and diesel + syngas 15% respectively.Also, it is observed that the emissions of CO and HC were very high in dual fuel techniquedue to the insufficient oxygen quantity in combustion chamber which leads to incomplete combustion.*

Keywords: *Syngas; Biomass; Gasification; Gasifier; diesel engine; performance; emissions*

I. INTRODUCTION

The conversion of biomass into charcoal was perhaps the first large-scale application of biomass conversion process. It has been used in India, China and in the preindustrial era of Europe for extraction of iron from iron ore. The economy of biofuel will grow rapidly during the 21st century and this economy development is based on the agricultural growth and production [1].All conventional and petroleum-based fuels can be replaced by renewable biomass fuels such as bioethanol, bio-diesel, and bio-hydrogen which can be converted into liquid and gaseous fuels. Biofuel is a locally available, less-polluting, sustainable, accessible and reliable fuel obtained from renewable energy sources. The most widely recognized utilization of biomass for energy is direct combustion, trailed by gasification, carbonization, and pyrolysis. The creation of transportation fuel from biomass through pyrolysis, trans-esterification, aging, and gasification-based combination is likewise increasing business significance. Gasification is a concoction procedure that changes over carbonaceous materials like biomass into valuable advantageous vaporous fills or substance feedstock [2]. Pyrolysis, halfway oxidation, and hydrogenation are connected procedures. Ignition likewise changes over carbonaceous materials into item gases yet with some critical contrasts. For instance, the item gas of ignition doesn't have any helpful warming worth, however the item gas from gasification does [3]. Gasification packs vitality into synthetic bonds in the item while burning discharges it. Gasification happens in decreasing (oxygen-lacking) conditions requiring heat, though burning happens in an oxidizing situation discharging heat. Syngas can be delivered from numerous sources, including gaseous petrol, coal, biomass, or essentially any hydrocarbon feedstock, by response with (steam changing), carbon dioxide (dry transforming) or oxygen (fractional oxidation). Syngas is a vital transitional asset for generation of hydrogen, smelling salts, methanol, and engineered hydrocarbon energizes [4]. Syngas is likewise utilized as a moderate in delivering manufactured oil for use as a fuel or ointment process. Generation strategies incorporate steam transforming of gaseous petrol or fluid hydrocarbons to deliver hydrogen, the gasification of coal, biomass, and in certain sorts of waste-to-vitality gasification facilities [5]. Gasification takes place at high temperature within the sight of an oxidizing specialist (called a gasifying agent also). Oxidizing specialists are commonly air, steam, nitrogen, carbon dioxide, oxygen or a blend of these. Within the sight of an oxidizing specialist at high temperature, the huge polymeric atoms of biomass disintegrate into lighter particles and in the long run to perpetual gases (CO, H_2, CH_4 and lighter hydrocarbons), debris, roast, tar and minor contaminants. Char and tar are the consequence of fragmented change of biomass. Syngas is utilized to deliver a wide scope of engineered items for example solvents, garments, and fuels [6]. It is utilized in the creation of methanol which is the starting point of many items including paste. The hydrogen got from acidic corrosive and formaldehyde is utilized as a fuel for shuttle rockets since hydrogen gives high vitality content per weight of unit. Manures likewise have their starting point in syngas. Hydrogen got from syngas is utilized in the generation of NH3 and hydrogen itself is utilized in the processing plant to remove gas and more diesel from unrefined petroleum. Hydrogen produced using syngas is advanced as the vitality bearer of things to come. Sharma [7] displayed a trial concentrate to create gas from wood squander in a downdraft gasifier. The gasifier execution was assessed dependent on theproduced gas, the gas calorific worth, zone temperatures, gas age rate and cold gas effectiveness. The outcomes indicated that the biomass utilization rate diminished with an expansion in dampness content and expanded with an expansion the wind current rate. Diverse upgrade techniques were utilized to improve the gasification procedure, for example, permitting air dispersion, recycling gas and increment the protection as revealed by Mukunda et al. [8]. Barrio et al. [9] infused air at the focal point of the reactor to acquire uniform conveyed air along the gasifier. Altafini et al. [10] expanded the reactor proficiency by recycling the maker gas to build the reactor temperature and along these lines diminishing tar development.

Guo et al. [11] examined the impact of working and plan parameters on the exhibition of the gasification procedure of biomass in a three air organize persistent fixed bed downdraft reactor. The outcomes showed that because of the three phase of air supply, a high and uniform temperature was accomplished in the oxidation and decrease zones for better tar breaking. The gas organization and tar yield were influenced by the parameters including identicalness proportion and biomass nourishing rate. At the point when biomass bolstering rate was 7.5 kg/h and ER was 0.25 - 0.27, the item gas of the gasifier achieved a decent condition with lower warming an incentive around 5400 kJ/m3 and cold gas proficiency about 65%. Devi et al. [12] assessed of the essential measures for tar disposal in biomass gasification forms. They presumed that the rich oxygen gasification, because of the low nitrogen, can successfully improve the syngas calorific worth, upgrade the gasification rate, increment the gasification temperature and limit the tar. Shrivastava et al. [13] 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. SohanLal and S.K.Mohapatra [14] considered the presentation and emanation qualities by utilizing downdraft gasifier and direct infusion to a diesel engine. The outcomes presumed that most extreme diesel sparing rate was 8.7%, 31.82%, 57.14% and 64.3% at a pressure proportion 12, 14, 16 and 18 separately. A normal decrease of 63.62% in HC discharge was accomplished by expanding the pressure proportion from 12 to 18 at 3.2 kW brake control. Das et al. [15] evaluated the biogas and maker gas based CI engine innovation for remote power age. They audited likewise the impact of different working parameters on the exhibition, burning and outflow qualities of diesel engines.Ismail and AbdEl-Salam [16] discussed an experimental and numerical simulation for biomass gasification on the performance of an updraft gasifier. The influence of equivalence ratio and gasification temperature on gas production and tar yield were studied. The results showed that there is an increase in the H_2 and CO contents. In addition there was a decrease in tar yields, CO_2 content, and the temperature of the gas products necessary to reduce the CH_4.

The mainobjective of the present study is to construct and build an up draft gasifier that utilization rice straw and mango wood as a feed stock to create syngas. The created syngas is utilized to satisfy warming necessity for heat treatment heaters. In addition the produced syngas is used to perform an experimental investigation on the performance and emissions of ICE powered by the pure diesel and syngas mixture with diesel. This study includes the engine performance such as engine efficiency and brake specific fuel consumption. The engine exhaust emission characteristics such as carbon monoxide, nitric oxide and hydrocarbon.

II. EXPERIMENTAL SETUP AND PROCEDURE

The experimental setup was performed using the gasification plant which is designed and fabricated at faculty of Engineering Suez Canal University. The design of the gasification plant with all parts is appeared in

Fig. 1. A photo of the gasification plant with diesel engine is appeared in Fig. 2. The biomass fuel is fed into the gasifier through the top opening, and air is provided to the gasifier utilizing a blower. Air enters the ignition zone and the producer gas generated goes near the base of the gasifier. When the unfaltering activity of the gasifier is accomplished, the hot produced gas is then permitted to go through the cyclone, heat exchanger and gas filter channel for the cleaning and cooling forms as appeared in Fig. 2. A different series of experimental tests were done in this study using pure diesel fuel and syngas mixture with diesel at different values after 30 min of the gasifier fired up. The diesel engine was initially run at full load using pure diesel fuel to measure the maximum brake power and the specific fuel consumption. Then, the engine torques different values were recorded during the experimental tests. The gasifier components, the materials, the function of each component and experiment accessories will be discussed briefly in this section. The gasification plant is composed of the following components.

2.1 The Gasifier

It's the reactor where the biomass thermos conversion takes place and produces Syn. Gas. The gasifier consists of the corewhich is the main component of the gasifier. It is the place where the gasification process (including combustion, pyrolysis, drying and reduction) take place and it is mainly consists of external and internal cylinders.Fig. 3-a shows a cross sectional view in the gasifier body. The gas flow pass between theexternal cylinder and the internal cylinder in the gasifieras shown in Fig. 3-b. 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 external cylinder is made of steel with anti-rust primer. The produced ash from gasification process is stored in the ash store as shown in Fig.3-c.

2.2The Cyclone

Cyclone separators are gas cleaning devices that using the centrifugal forcecreated by the spinning gas stream to separate particles from a gas as shown in Fig. 3-d.

2.3Cooling System for Produced Syngas

It is very important to cool the pipes where the gas passes in order to get more clean syngas. So, a great water tank was used to condensate the mostly water steam in the syngas and also to make the syngas denser and flammable.

2.4 The Diesel Engine

A single cylinder, fourstroke 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 as shown in Fig. 2.

2.5 Materials

In this work two materials types of biomass were used according to their availability in Ismailia city. Rice strawand mango wood chips biomass were used to feed the gasifier in the experimental setup. Fig. 4 show a photograph of the rice strawand mango wood chips biomass.

2.6Measurements and Instrumentation

There are different devices, instruments and tools were used to measure the different parameters and to complete the experimental setup such as air compressor, blower, air flow meters and thermocouples. Reciprocating compressor is used to improve the supplied air into the gasifier unit. The compressor specifications is 500-liter capacity, 1.5 HP and 8 bar as shown in Fig. 5-a. Centrifugal blower device is used for air suction, at the first of the operation of the gasifier, the air is needed to ignite the biomass material. So, the blower supplies the gasifier with the air needed. Air flow meters is used to control the quantity of supplied air to the gasification process and a hot wire sensor type is used to record the air flow rate quantity. The K-type thermocouples was used to measure the temperature inside the gasifier core as shown in Fig. 5-b. Uncertainty analysis was done for each device and all values were in accepted range. Computerized gas and smoke analyzer was used in the experimental tests to measure and record the emissions and gas analysis as shown in Fig. 5-c.

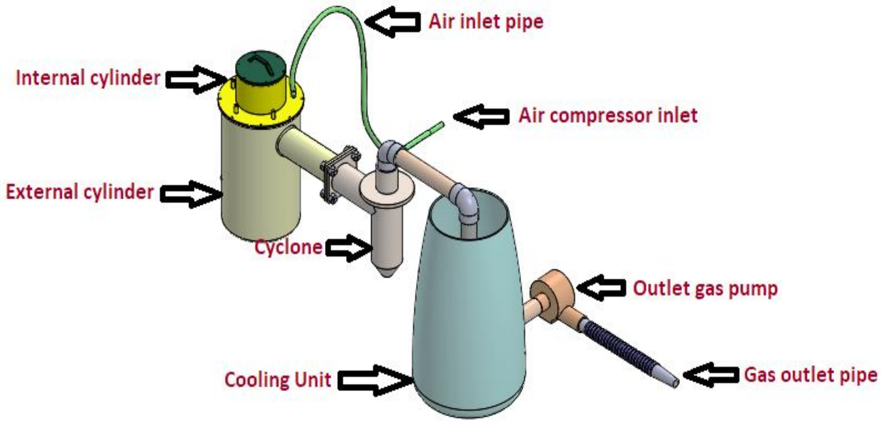
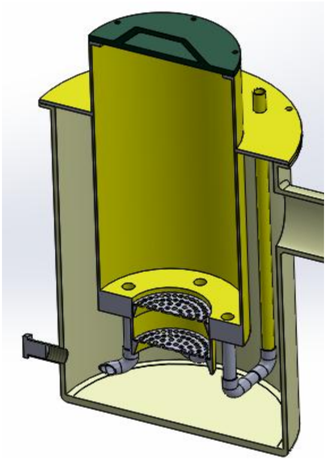
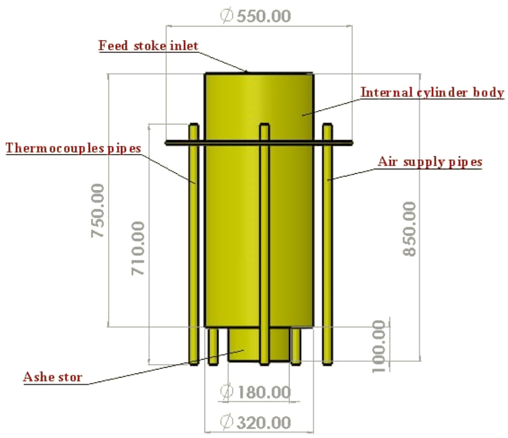


Fig. 1. *Schematic diagram of the gasification plant layout*

(a) The gasification plant *(b) The diesel engine*

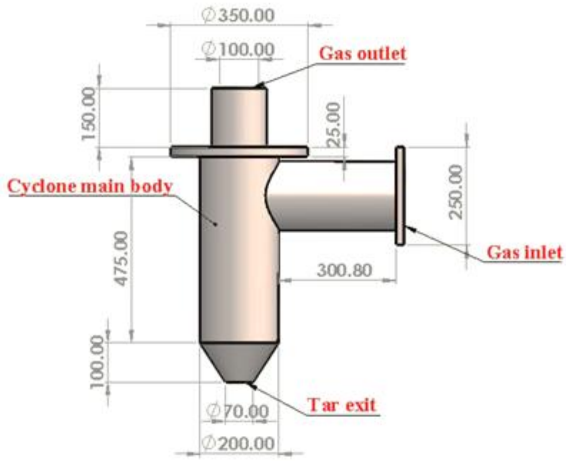
Fig. 1. *Photograph of the gasification plant layout with diesel engine*





(a) The gasifier *(b) Internal cylinder*

(c) Ash store



(d) The cyclone

Fig. 3. *Schematic diagrams of the gasifier, internal cylinder, ash store and the cyclone*

(a) Rice straw biomass

(b) Mango wood chips biomass

Fig. 4 *Photograph of the rice strawand mango wood chips biomass*

(a) Air compressor

(b) K-type thermocouple

(c)Computerized gas and smoke analyzer

***Fig.5**.Photograph of air compressor, k-type thermocouplesand computerized gas analyzer*

2.7 Experimental Procedure

The rice straw and mango wood chips biomass material are prepared and feedinto the gasifier. The K-type thermocouples was used to measure the gasifier temperature. At the beginning of gasification process, the produced syngas at first is low quality thus it is discharged into the environment atmosphere. 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. In 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 is examination and utilized as an alternative fuel for the diesel engines. The produced syngas was utilized in different three values of 5, 10 and 15% with the pure diesel for the engine. The engine performance with pure diesel and the produced syngas is evaluated, analyzed and the emissions from the engine were recorded continuously during the experimental tests.

III. RESULTS AND DISCUSSIONS

3.1 Syngas Production from the Gasifier

The gasifier was operated at different temperature ranges with rice straw and mango wood chips biomass material. The produced syngas compositions such as H_2, CO, CH_4 and CO_2 were evaluated and recorded at each test.

3.1.1 Rice Straw Biomass

Rice straw biomass was used as to feed to the gasifier with a rate of 10 kg per hr and the syngas composition was recorded at different temperatures as shown in Table 1.

***Table 1.**The producedsyngas composition (volume %) at different temperatures*

Temperature (°C)	H_2 (vol. %)	CO (vol. %)	CH_4 (vol. %)	CO_2 (vol. %)
600	33.31	23.11	7.52	36.80
700	36.31	23.41	8.61	31.62
800	43.61	23.42	7.67	26.71
900	48.23	24.12	7.51	21.21
1000	55.25	24.21	7.45	18.22

3.1.2 Mango Wood Chips Biomass

Another experimental test was done on mango wood chips with a feed rate of 10 kg per hr and the syngas composition was recorded at different temperatures as shown in Table 2.

Table 2.*The produced syngas composition (volume %) at different temperatures*

Temperature (^oC)	H_2 (vol. %)	CO (vol. %)	CH_4 (vol. %)	CO_2 (vol. %)
600	29.51	25.71	7.60	33.20
700	36.60	23.62	7.56	29.81
800	41.21	21.11	8.12	26.82
900	46.22	19.52	8.83	25.00
1000	50.23	17.81	9.32	23.52

3.2 Performance of Diesel Engine

The main factors which affect the operating of gasifier combustion engine is the economy of the used liquid fuel. In this context, diesel engine performance operating with pure diesel fuel and the producer syngas is evaluated and analyzed in different terms and at different loads started from 0 to 4.5 kW brake power. Thebrake thermal efficiency, exhaust gas temperature, brake specific fuel consumption and the emission characteristics will be presented and discussed at different loads.

3.2.1. The Engine Brake Thermal Efficiency

The variation of engine brake thermal efficiency (BTE) with brake power in dual fuel technique is shown in Fig. 6. From this figure it is clear that the brake thermal efficiency (BTE) of the diesel engine usingdual fuel technique is lower than that of pure diesel at different values of brake power. The maximum recorded values of brake thermal efficiency achieved for diesel fuel was 28.51% while in dual fuel mode the maximum valueswere 27.1%, 26.02% and 25.51% for diesel + syngas 5%, diesel + syngas 10% and diesel + syngas 15% respectively. The main reason for brake thermal efficiency reduction is 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 [17].

3.2.2 The Engine Brake Specific Energy Consumption

The variation of engine brake specific energy consumption (BSEC)with brake power in dual fuel technique is shown in Fig. 7. In fact the engine brake specific fuelconsumption (BSFC) is not a recommended parameter to compare between two fuels having different density and calorific values, therefore the term brake specific energy consumption (BSEC)is preferred in ICEs. The engine brake specific energy consumption is calculated from the fuel (gas or diesel) calorific value and the fuel consumption. From the analysis of this figure it’s clear that the BSEC decreases as the engine brake power increase in diesel fuel and dual fuel technique. Also from the analysis of Fig. 6 and 7 it can be seen that the BSEC is inversely proportional tothe engine brake thermal efficiency. The BSEC of the diesel at full load is found to be 12.7MJ/kWh, while for diesel + syngas 5%, diesel + syngas 10% and diesel + syngas 15% it is found to be 14.02, 16.04 and 16.5 MJ/kWh respectively

3.2.3 The Engine Exhaust Gas Temperature

Fig. 8. Shows the variation of engine exhaust gas temperature with brake power in different values of dual fuel technique. 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 340.5^{o}C while the exhaust gas temperature at maximum brake power for diesel + syngas 5%, diesel + syngas 10% and diesel + syngas 15% are found to be 370.8, 390.6 and 410.3^{o}C respectively. The excess energy supplied to the diesel engine is responsible for the high values of the exhaust gas temperature in case of using dual fuel technique and it can be reduced by increasing the fuel mixture density as reported by [18].At higher temperature greater than 1100 ^{o}C, the nitrogen will reacts with the oxygen to produce NOx emission.

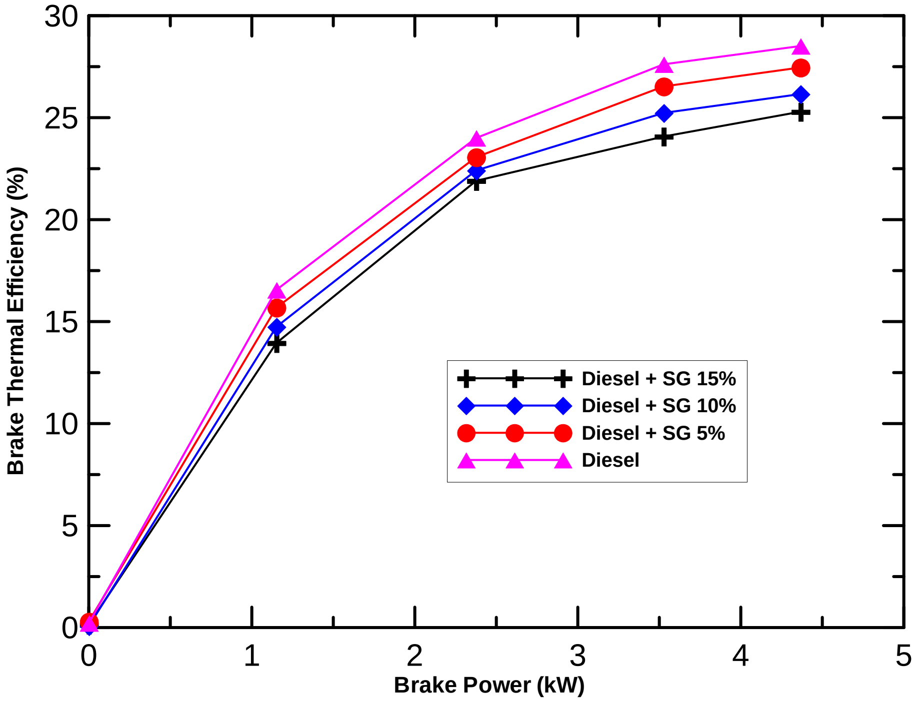


Fig. 6. *The variation of engine brake thermal efficiency with brake power in dual fuel technique*

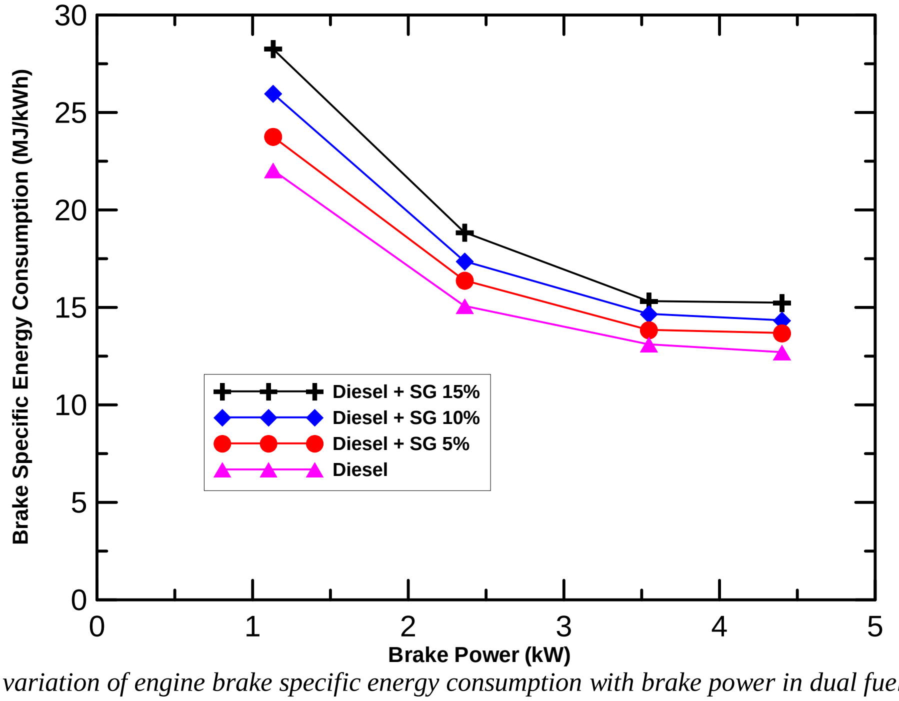


Fig. 7. *The variation of engine brake specific energy consumption with brake power in dual fuel technique*

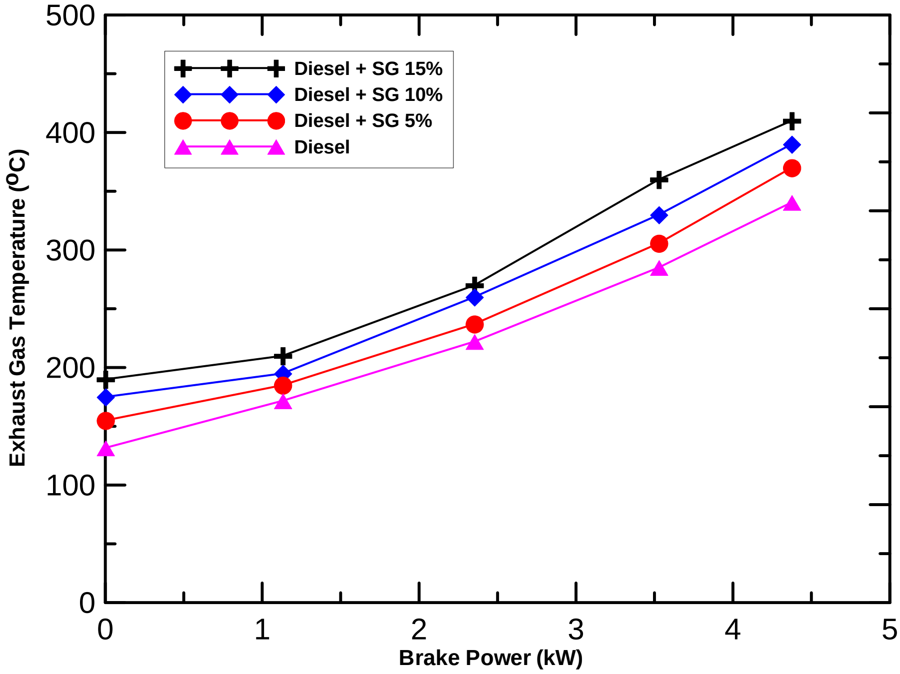


Fig. 8. *The variation of engine exhaust gas temperature with brake power in dual fuel technique*

3.3The Diesel Engine Emission Characteristics

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 context 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), Hydro carbon (HC) and Nitric oxide (NO) as follows.

3.3.1 The emission of Carbon monoxide (CO)

The emission of carbon monoxide can be formed by two major methods. The first method is due to the incomplete combustion process in the combustion chamber due to the insufficient quantity of oxygen entering the engine. While the second method is due to the insufficient time needed for fulfilment the combustion process in this engine.Fig. 9 shows the variation of CO emission with engine brake power in dual fuel technique at different loads. 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 CO emission are observed in dual fuel technique compared with pure diesel fuel. This occurs due to the incomplete combustion process in engine combustion chamber and this is generate high quantities of CO emission. The maximum recorded values of CO emission achieved by diesel fuel was 0.0201%, while in dual fuel technique the recorded value was 0.0233, 0.0251 and 0.0298% ppm for diesel + syngas 5%, diesel + syngas 10% and diesel + syngas 15% respectively.

3.3.2 The emission of Hydro carbon (HC)

The incomplete combustion process yields high unburnt hydrocarbon emissions. The variation of HC emission with engine brake power in dual fuel technique at different loads is shown in Fig. 10. From this figure it is clear that the emission of hydrogen carbon increases as the engine load increases. Thevaporized unburnt hydrocarbon is namely as VOCs (volatile organic compounds) and it reacts with nitrogen oxides to form oxidants and smog in the presence of sunlight [19]. The maximum recorded values of HC emission achieved by diesel fuel was 20.1 ppm, while in dual fuel technique the recorded value was 22.02, 24.1 and 26.04 ppm for diesel + syngas 5%, diesel + syngas 10% and diesel + syngas 15% respectively. Also it can be seen that the pure diesel fuel gives the smallest recorded values of HC emission compared with the dual fuel technique.

3.3.3 The emission of Nitric oxide (NO)

The high temperature gradient and oxygen accessibility are the two primary explanations behind the NOxformation. Nitrogen interact with oxygenat temperature higher than 1100 oC to form nitrogen oxides [20]. Therefore NO emissions strongly relies on the ignition chamber temperature which relies on the engine load.Fig. 11 shows the variation of NO emission with engine brake power in dual fuel technique at different loads. 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 and dual fuel technique. This occurs due to the high temperature gradient in the engine combustion chamber at high loads. Also it is clear that the diesel fuel gives the highest recorded values of NO emission compared with dual fuel technique. Using diesel + syngas 15% gives the minimum recorded values for NO emission and this an important advantages for the using of dual fuel technique [21]. The maximum recorded values of NO emission achieved by diesel fuel was 440.1 ppm, while in dual fuel technique the recorded value was 288.5, 260.2 and 214.1 ppm for diesel + syngas 5%, diesel + syngas 10% and diesel + syngas 15% respectively.

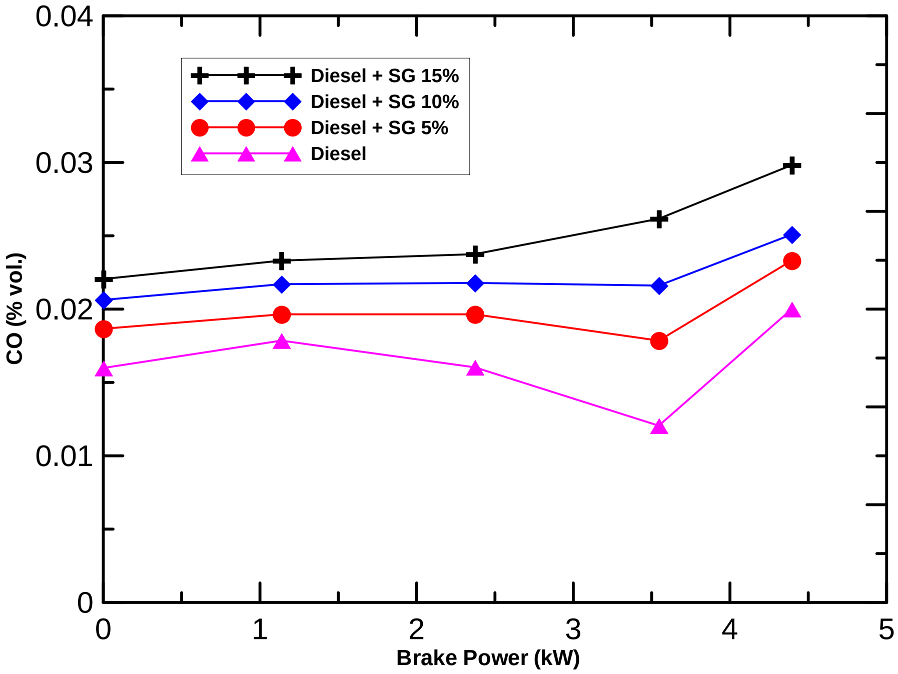


Fig. 9. *The variation of CO emission with engine brake power in dual fuel technique at different loads*

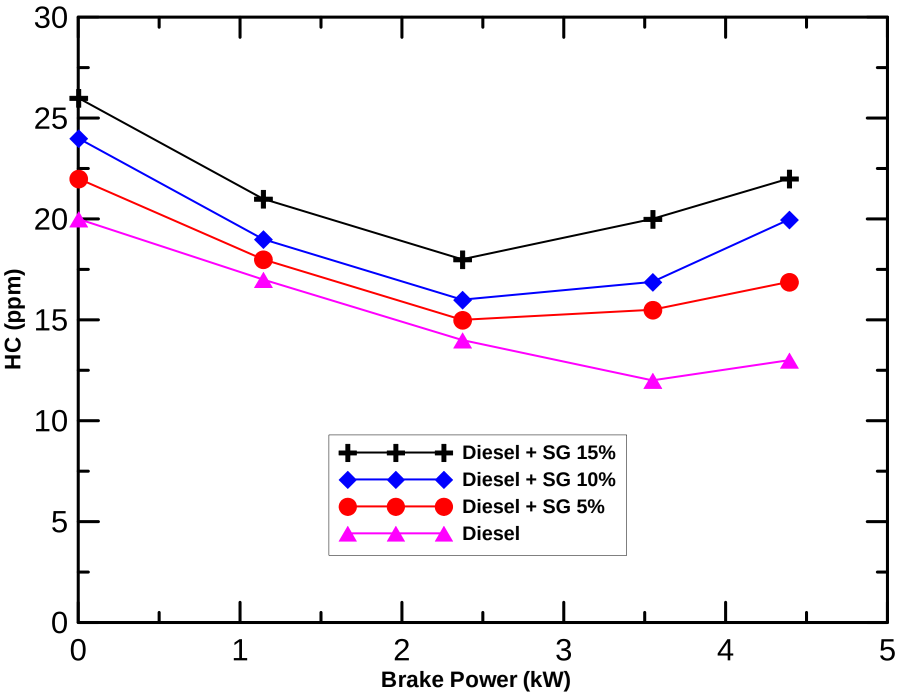


Fig. 10. *The variation of HC emission with engine brake power in dual fuel technique at different loads*

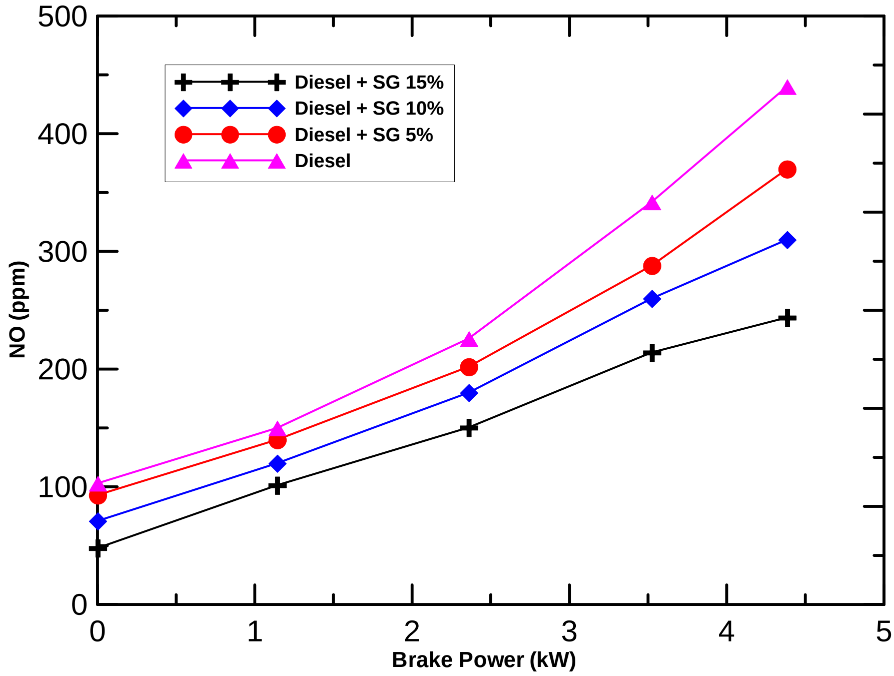


Fig. 11. *The variation of NO emission with engine brake power in dual fuel technique at different loads*

IV. CONCLUSION

The biomass gasification process is a promising future technology to replace the use of fossil fuels and reduce the emissions of CO_2. This work focuses on a two types of biomass (rice straw and mango wood chips) based on their availability in Egypt. In this work a gasification plant was designed and fabricated at faculty of Engineering Suez Canal University. The produced syngas was used as a secondary fuel for single cylinder diesel engine. The engine performance and emissions were evaluated and recorded during each test. The results showed that, with the increase in gasifier temperature (from 600^{o}C to 1000^{o}C), the hydrogen percentage increases continuously.The maximum recorded efficiency achieved by diesel fuel was 28.51%, while in dual fuel technique the recorded value was 27.1%, 26.02% and 25.51% for diesel + syngas 5%, diesel + syngas 10% and diesel + syngas 15% respectively. Higher measure of diesel fuel can be spared by supplanting diesel with syngas despite the fact that there would be a decrease in brake warm effectiveness which is because of lower warming estimation of syngas and deficient measure of oxygen supply. Additionally it is seen that the emissions of CO and HC were exceptionally high in dual fuel technique which gives a sign of lacking oxygen in burning chamber.

REFERENCES

[1]. Demirbas, A. Biofuels sources, biofuel policy, biofuel economy and global biofuel projections. Department of energy conversion and management, 2008; 49(8): 2106-2116.

[2]. Gasification Technologies, a Primer for Engineers and Scientists, John Rezaiyan, Nicholas P. Cheremisinoff.

[3]. Sarkar N, Ghosh SK, Bannerjee S, Aikat K. Bioethanol production from agricultural wastes: An overview. Renewable Energy, 2012; 37(1): 19-27.

[4]. Handbook of Biomass Downdraft Gasifier Engine Systems by Solar Energy Research Institute under US Department of Energy Solar Technical Information Program.

[5]. Vasudevan P, Sharma S, Kumar A. Liquid fuel from biomass: an overview. J Sci Ind Res. 2005. (64): 822–31.

[6]. Biomass Conversion Technologies, Renewable Energy World, page no. 46, 2006

[7]. Sharma K.A. Experimental study on 75 kWth downdraft (biomass) gasifier system, Renewable Energy, 34 (2009), pp. 1726-1733.

[8]. Mukunda H, Dasappa S, Paul P, Rajan N and Shrinivasa U 1994 J. Energy for Sustainable Development, p 27-38.

[9]. Barrio M, Hustad J, and Fossum M, 2001 Progress in thermochemical biomass conversion, p426-440.

[10]. Altafini C R, Wander P R and Barreto R M 2004, J.Biomass and Bioenergy27, p467–476.

[11]. Effect of design and operating parameters on the gasification process of biomass in a downdraft fixed bed: An experimental study, Feiqiang Guo, Yuping Dong, Lei Dong, Chenlong Guo, 2014. International Journal of Hydrogen Energy, Volume 39, Issue 11, 4 April 2014, Pages 5625-5633

[12]. Lopamudra Devi, Krzysztof J. Ptasinski, Frans J.J.G. Janssen, A review of the primary measures for tar elimination in biomass gasification processes, Biomass and Bioenergy 24 (2003) 125–140.

[13]. Vinay Shrivastava, Abhishekh Kumar Jha, Arun Kumar Wamankar and S. Murugan, 2013, Performance and Emission Studies of a CI Engine Coupled with Gasifier Running in Dual Fuel Mode, Procedia Engineering 51, pp. 600 – 608

[14]. SohanLal and S.K.Mohapatra, 2017, The effect of compression ratio on the performance and emission characteristics of a dual fuel diesel engine using biomass derived producer gas, Applied Thermal Engineering, Vol. 119, pp 63-72.

[15]. S. Das, D.Kashyap, P.Kalita, V.Kulkarni and Y.Itaya, 2020, Clean gaseous fuel application in diesel engine: A sustainable option for rural electrification in India, Renewable and Sustainable Energy Reviews, Volume 117, 109485.

[16]. Ismail, T. and AbdEl-SalamM., 2017, Parametric studies on biomass gasification process on updraft gasifier high temperature air gasification. Applied Thermal Engineering, vol. 112, pp. 1460-1473.
[17]. Samir J. Deshmukh, Lalit B. Bhuyar and Shashank B. Thakre, Investigation on Performance and Emission Characteristics of CI Engine Fuelled with Producer Gas and Esters of Hingan (Balanites) Oil in Dual Fuel Mode, 2008.
[18]. S. Hassan, F. Mohd Nor, Z.A.Zainal and M.A. Miskam, Performance and emission characteristics of supercharged Biomass producer gas-diesel dual fuel engine. 2011.
[19]. B.P.Pundir,"A textbook of Engine Emissions-pollutant formation and advances in control technology" Narosa publication, ISBN 978-81-7319-819-9, pp 2-40.
[20]. M.L. Mathur, R.P.Sharma, Internal combustion engine, Dhanpat rai publication, 2006, p738.
[21]. R.N. Singh, S.P. Singh, B.S. Pathak. "Investigations on operation of CI engine using producer gas and rice bran oil in mixed fuel mode." Renewable Energy. 32, pp1565-1580, 2007.

Hatem Elhuseen Nasr,etal. "Syngas Production from Biomass Using Gasification Process: An Experimental Studyfor Diesel Engine". *American Journal of Engineering Research (AJER)*, vol. 9(01), 2020, pp. 295-306.