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Biomass Utilization for Green Environment: Co-Combustion of Diesel Fuel and Producer Gas in Thermal Applications

Ahmad Hussain*, Farid Nasir Ani, Lim Xin Yi and Ahmad Fadzil Mohamed
Faculty of Mechanical Engineering, Universiti Teknologi Malaysia - 81310, Skudai, Johor, Malaysia

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Abstract. Study of co-combustion of diesel oil and producer gas from a gasifier, individually as well as combined, in an experimental combustion chamber revealed that the producer gas can be co-combusted with liquid fuel. The process produced more CO, NO_x, SO_2 and CO_2 as compared to the combustion of diesel oil alone; the exhaust temperature for the process was higher than the diesel combustion alone.

Keywords: biomass utilization, co-combustion, palm oil solid waste, producer gas, diesel oil, dual fuel engine

Introduction

World energy consumption is increasing every year due to the increased population, the rising quality of life and industrialization. With the increase in the current world population of 6.4 billion people, in the near future, the demand in energy will also increase (Wise, 1983).

In Malaysia, the principal energy resource is petroleum which contributes to about 68% of the total requirements and is mainly used for transportation and power generation in industry etc. However, these natural resources are decreasing every year due to high consumption.

Combustion of fossil fuels such as coal and petrol produces harmful gases like carbon monoxide (CO) and sulphur dioxide (SO_2). Even the cleanest fossil fuels produce carbon dioxide on burning. Carbon dioxide is a harmless gas but its build up in the atmosphere causes greenhouse effect (Cheremisinoff *et al.*, 1980).

Understandably, there is a need to find alternate sources of energy to curb the oil consumption to the minimum possible level, to increase the utilization efficiency and also to minimize the pollution from energy generation. An alternate source of energy that can be utilized in Malaysia is biomass. Some of common biomass resources available in Malaysia, are wood and agricultural residues.

Most of the biomass energy resources such as agricultural residue is abandoned without being used for other purposes. Palm oil solid waste is one of the most potential biomass resources which can be used for energy generation. The first commercial oil palm estate in Malaysia was set up in 1917. Since then the industry in Malaysia has grown by leaps and bounds and the country is now the largest producer and exporter of palm oil. Palm oil is expected to demonstrate an annual growth of 4.57% and production is expected to reach 26.2 million tonnes by the end of 2005, anticipated to account for around 20% of the global oil and fat supply.

Based on the past statistics, it is estimated that every one million tonne of palm oil produces 0.8 million tonne of palm oil shell. This large amount of solid waste could be used as a fuel for boilers in the palm oil mill (Razuki, 1988).

Biomass gasification, with less air to achieve complete combustion, converts biomass solid residue chemically into producer gas. Producer gas consists of mainly carbon monoxide (CO), hydrogen (H_2), methane (CH_4), water vapour and some other inert gases. Mixed with air, producer gas can be used in the internal combustion engine with a little modification (Donald and George, 1981). It can be used as a co-combustion fuel as well with other liquid fuels to minimize the fuel consumption. Producer gas from the gasification process thus can be utilized in many ways (Fig. 1).

In the present study, a downdraft gasifier was used to produce the producer gas. In the downdraft gasifier the tar has to pass through the hot combustion and reduction zones. If the gasifier is properly designed, it will lead to sufficient combustion and cracking of the tar to make the gas useful with minimal cleaning process. Initially, producer gas was burned without the liquid fuel and then with liquid fuel.

Co-combustion of biomass. Co-combustion of biomass is the process of burning of biomass with other types of fuel, such as fossil fuel, simultaneously. Recently, there has been several designs of plants that use producer gas as fuel for co-combustion. This concept has been applied to the internal combustion engine and burner. It is sometimes called dual fuel engine or dual fuel burner.

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*Author for correspondence; E-mail: ahmadutm@gmail.com

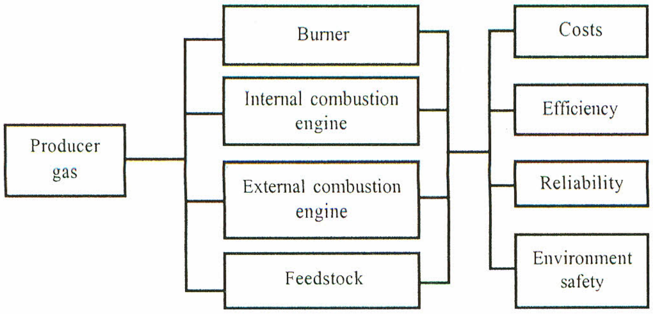

Fig. 1. Various ways of producer gas utilization.

Gasification process generally uses reactants such as oxygen or steam to increase gas yield while consuming charcoal. In systems, where solid fuels are gasified in the presence of sub stoichiometric air, several chemical reactions occur. Gasification reaction and temperature zone are shown in Table 1.

Table 1. Gasification zone temperature profile and reactions

Zone	Temperature and reaction
Drying	25 °C - 150 °C
Pyrolysis	150 °C - 900 °C coal + tar + $H_2O + CH_4$ + HC
Combustion	900 °C -1400 °C $2C + O_2 = 2CO$
Reduction	600 °C - 1100 °C $C + CO_2 = 2CO$ $C + H_2O = CO + H_2$ $CO + H_2O = CO_2 + H_2$

In this case, there is a surplus of solid fuel, carbon dioxide and water vapour from the combustible zone which can be passed through the glowing layer of charcoal and are reduced to carbon monoxide (CO) and hydrogen (H_2) in the region known as the reduction zone (Naksite, 1989).

The exothermic reactions occuring in the combustion zone are:

$$C + O_2 \rightarrow CO_2 \tag{1}$$

$$2H_2 + O_2 \rightarrow 2H_2O \tag{2}$$

The endothermic reactions, taking place in the reduction zone and decreasing the temperature during the reduction process, are as follows:

$$C + CO_2 \rightarrow 2CO \tag{3}$$

$$C + H_2O \rightarrow CO + H_2 \tag{4}$$

$$C + 2H_2 \rightarrow CH_4 \tag{5}$$

$$CO + 3H_2O \rightarrow CH_4 + H_2O \tag{6}$$

$$C + 2H_2O \rightarrow CO_2 + H_2 \tag{7}$$

$$CO + H_2O \rightarrow CO_2 + H_2 \tag{8}$$

$$C_nH_m + \text{Heat} \rightarrow CH_4 + C_2H_4 + C_2H_6 + C_3H_6 + C_3H_8 \tag{9}$$

Producer gas is therefore, a mixture of the gases such as hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), nitrogen (N_2), methane (CH_4), and small amounts of other hydrocarbons. The combustible components of the gas are CO, H_2, CH_4 and C_xH_x, the percentages of which should be made as high as possible. The quantity of CO in the gas depends on the temperature in the reduction zone. To achieve complete reduction, the temperature in the reduction zone must be at least 1100 °C (Bungay, 1981).

The reaction (4), if water vapours are present, plays an important role in enriching the gas with H_2 and thus enhancing its heating value. However, if too much water is present, CO may react with H_2O to form CO_2 and H_2, as indicated by reaction (8) and the quantity of CO may be reduced.

Materials and Methods

For this experiment, downdrift or gasifier was used for the gasification process. The setup consisted of downdraft gasifier, air ejector, inter connection duct, oil burner, gas analyzer and air blower (Fig. 2). A small quantity of air is needed for combustion process, and in the present set up, air was blown using a blower through the primary air duct. Gas, emitted during the gasification process, was ducted out through the producer gas outlet to the gas burner. Water vapour collector was used to collect water vapour from the gasification process.

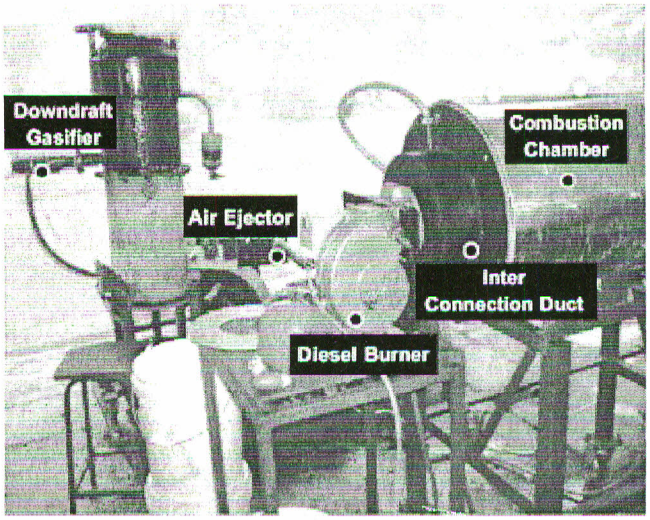

Fig. 2. The experimental setup.

Interconnection duct was used to combine the combustion process of liquid fuel and producer gas (Fig. 3). Producer gas from the gasifier passes through the interconnection duct and burns along with the liquid fuel. The water flow in the interconnection duct was for cooling the duct during the experiment so as to prevent any hazard during the experiment; without coolant it becomes very hot and could be really dangerous. It can also be used as an energy converter to burn the producer gas.

The dimension of palm oil shell loaded in the gasifier was about 10-20 mm with a solid density of 1.53 g/cm^3 and 1.47 g/cm^3, apparent density (Guo and Lua, 2000).

Table 2 shows the proximate and ultimate analysis of the palm shell waste, indicating that it contains high percentage of volatile matter and carbon but low percentage of ash (Ani, 1992).

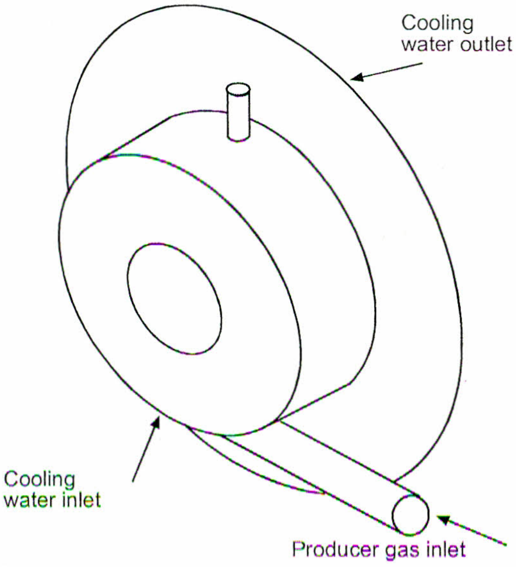

Fig. 3. Layout of the interconnection duct.

Table 2. Proximate and ultimate analysis of oil palm shell waste

Proximate analysis (wt. %)	
Ash	2.10
Volatile matter	67.0
Fixed carbon	20.3
Ultimate analysis (wt. %)	
Carbon	47.62
Hydrogen	6.20
Oxygen	43.38
Nitrogen	0.70
Moisture (wt. % dry air)	9.70
Low calorific value (MJ/kg)	19.10

The experimental work comprised of three distinct experiments conducted to compare and analyse the emission properties of combustion with different fuel conditions and properties:

- combustion of diesel oil,
- combustion of producer gas and
- co-combustion of diesel oil and producer gas.

The mass flow rate of the diesel oil used in the burner was 0.001195 kg/sec.

Combustion of diesel fuel. Diesel fuel burner was used in this experiment. Before starting the experiment, the valve for water circulation was opened to assist the cooling process in the combustion chamber and in the interconnection duct. The combustion chamber was preheated using the diesel burner for 15 min to prevent heat losses during the experiment. The diesel burner was set with different baffle air openings to get different equivalence ratio settings. Data was recorded for equivalence ratio (Φ) ranging from 0.9-1.2. The emission data was analyzed using the TELEGAN gas analyzer.

Combustion of producer gas. After completion of diesel fuel combustion, the diesel fuel burner was turned off to allow combustion of producer gas to proceed, which was prior generated using the downdraft gasifier. Gasifier was started by filling the bottom of the bed with charcoal to assist the reduction process for generation of the producer gas. The gasifier was then filled up with palm oil shell upto 1/2 of the gasifier bed. The load was ignited by adding a little petrol, left for 15 min then primary air supply valve was opened and the windowpane was left open (Lukeman, 2004).

The feeding process was continued by filling the gasifier to about three quarters with palm oil shell. Then the windowpane was closed and properly tightened and the primary and the secondary air valves were reduced to 1/4 valve opening, to generate the producer gas. After a few minutes, white thick smoke was seen drifting to the interconnection duct and then to the combustion chamber. The producer gas was then ignited using burning paper through the burner port in the interconnection duct. After a few minutes, when the burning process became stable, data was recorded for 1/4 and 1/2 secondary valve opening.

Co-combustion of diesel oil and producer gas. Next the experiment was continued for the co-combustion of diesel oil and producer gas. Since during the earlier experiment, the amount of palm oil shell in the gasifier had become reduced due to burning, the gasifier is re-filled with palm oil shell and the experiment is then started.

The windowpane was closed and the diesel burner was turned on. It was left for a few minute then the data was recorded for 1/4 and 1/2 secondary air valve opening and for equivalence ratio (Φ) equal to 0.9, 1.0 (stoichiometric), 1.1 and 1.2 and graphs for the values of gas emission, combustion temperature versus equivalence ratio were plotted.

Results and Discussion

Equivalence ratio (Φ) is used to indicate quantitatively whether a fuel oxidizer mixture is fuel rich, lean or stoichiometric. For Φ>1 the mixture is fuel rich, for Φ<1 the fuel is fuel lean, and for Φ=1 the fuel mixture is stoichiometric (Turns, 2000). The emissions were plotted as a function of equivalence ratio for diesel combustion only as shown in Fig. 4. O_2 and CO_2 graphs were also plotted as function of equivalence ratio (Fig. 5). It was found that by increasing the equivalence ratio, the NO_x, SO_2 and CO_2 formation increased during the diesel combustion process, whereas O_2 percentage decreased with the increase of equivalent ratio. Fig. 6, shows that with the increase in equivalence ratio, the exhaust temperature also increased. At stoichiometric condition the exhaust temperature was 680 °C.

For only producer gas combustion, the data was collected based on two secondary air valve openings, 1/4 and 1/2. The secondary air valve is used to control the amount of producer gas flow to the interconnection duct for burning in the combustion chamber and also as an air supply for the combustion of producer gas.

The formation of CO, NO_x and SO_2 increased with larger valve opening as shown in Fig. 7. Whereas, O_2 and CO_2 show very little reduction with the increase of valve opening (Fig. 8). Compared with CO and SO_2, NO_x shows the highest production with 1/4 valve opening but it shows the lowest with 1/2

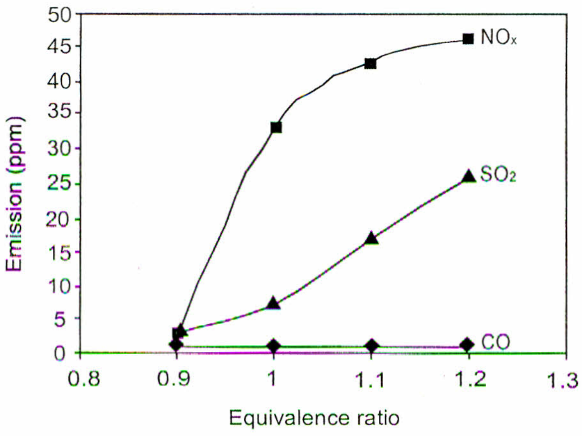

Fig. 4. Emissions profile for diesel combustion only.

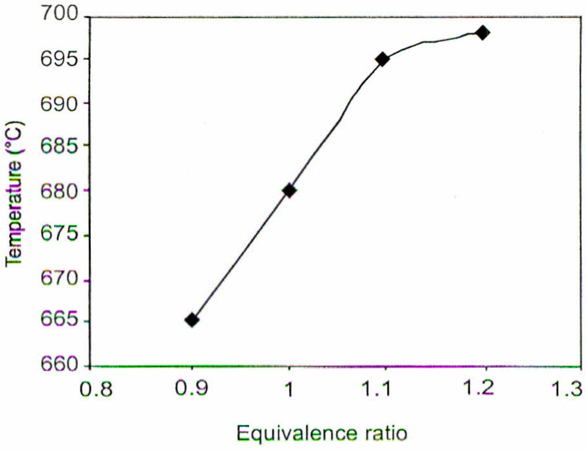

Fig. 6. Temperature profile for the diesel combustion.

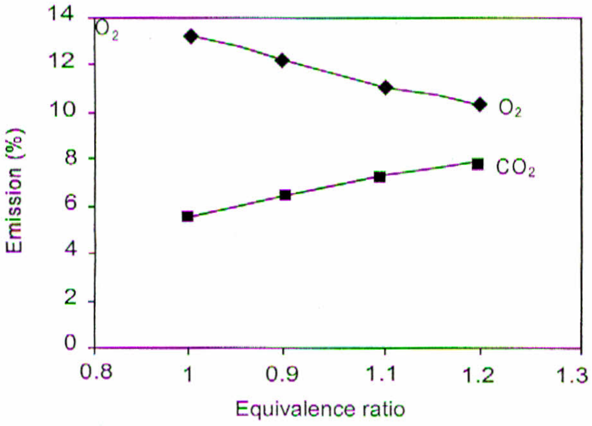

Fig. 5. Variation of O_2 and CO_2 during diesel combustion.

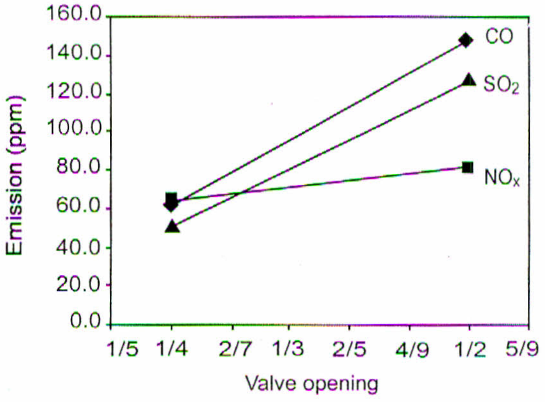

Fig. 7. Emissions profile for the combustion of producer gas from downdraft gasifier.

valve opening. The reason is that with larger valve opening, more air and producer gas is ducted to the combustion chamber and this means that more producer gas is burned and more CO, SO_2 and NO_x are produced.

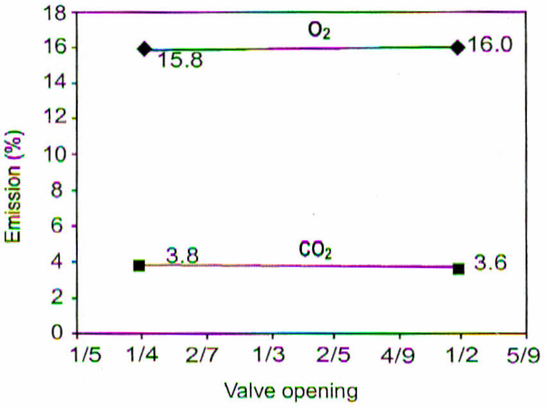

Fig. 8. Variation of O_2 and CO_2 for the producer gas combustion.

Fig. 9 signifies that with the increase of secondary valve opening, the combustion temperature increased. With larger valve opening, more air is ducted through and also more producer gas flows to the combustion chamber generating more heat.

Co-combustion of diesel and producer gas was performed for different secondary valve openings and equivalence ratios of diesel fuel burner. Emission data has been plotted and is compared with that of the combustion of diesel. Fig. 10 indicates that the value of CO decreased with the increase in equivalence ratio. However, for the combustion of only diesel, CO formation is constant at 1 ppm for any value of equivalence ratio. Co-combustion at 1/4 secondary valve opening shows higher value of CO gas emission.

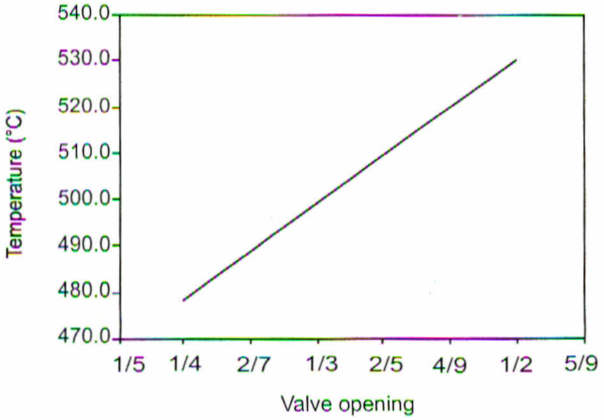

Fig. 9. Temperature profile for the combustion of producer gas.

The value of NO_x emitted from the co-combustion increased with the increase in the equivalence ratio (Fig. 11). However, there is a rapid increase in diesel combustion at the equivalence ratio of 0.9 to the stoichiometric condition. At $\Phi>1$, NO_x emission shows a little increase. Co-combustion with 1/4 secondary valve opening shows the highest NO_x emission and the lowest, with pure diesel combustion.

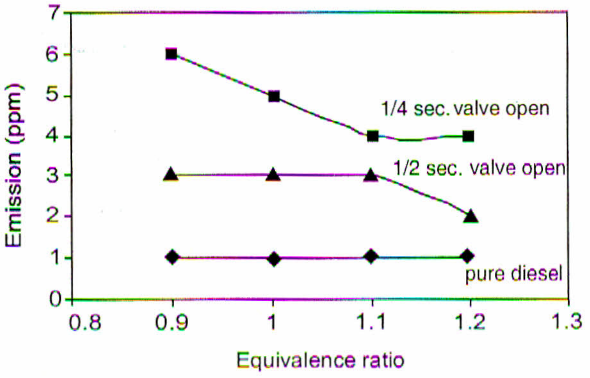

Fig. 10. Emission of CO in the co-combustion process.

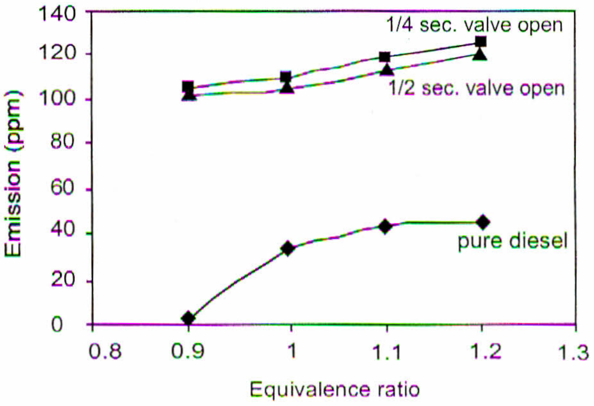

Fig. 11. Emission behavior of NO_x during co-combustion process.

From the graph of the emission value of SO_2 (ppm) versus the equivalent ratio of diesel burner (Fig. 12), it can be seen that the SO_2 formation for the co-combustion decreased with the increase in equivalence ratio but for the combustion of pure diesel, wherein it increased with the increase in equivalence ratio. The largest amount of SO_2 was formed at the co-combustion of diesel oil and producer gas with 1/4 secondary valve opening. Combustion of pure diesel produced the lowest SO_2 emission as compared to the combustion of the fuel combination.

The O_2 emission (%) decreased with the increase in the equivalence ratio (Fig. 13). The largest amount of O_2 was emitted emission during the combustion of pure diesel fuel and the smallest, at 1/4 secondary valve opening; the reason is that, during the co-combustion process, most of the O_2 is used and with small valve opening, less air with little O_2 flows into the combustion chamber.

It is evident from Fig. 14, that the amount of CO_2 emission increased with the increase in the equivalence ratio. Equivalence ratio Φ>1 means that the fuel burns with less air. Incomplete combustion produces more CO_2. The largest amount of CO_2 emission was given at 1/4 secondary valve opening and the smallest, during the combustion of pure diesel.

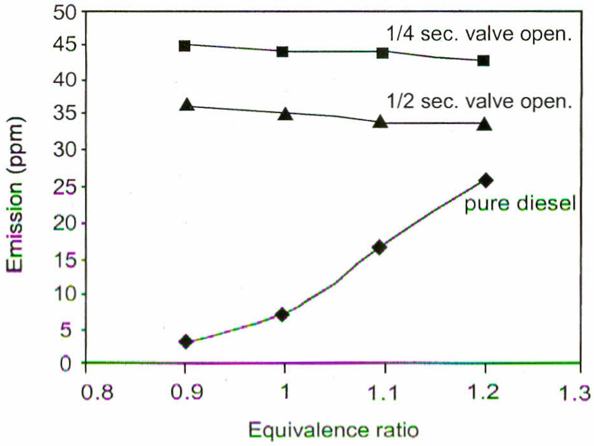

Fig. 12. Emission of SO_2 in the co-combustion process.

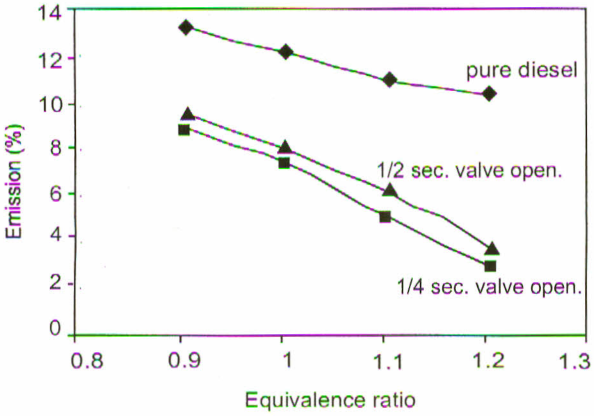

Fig. 13. Emission of O_2 in the co-combustion process.

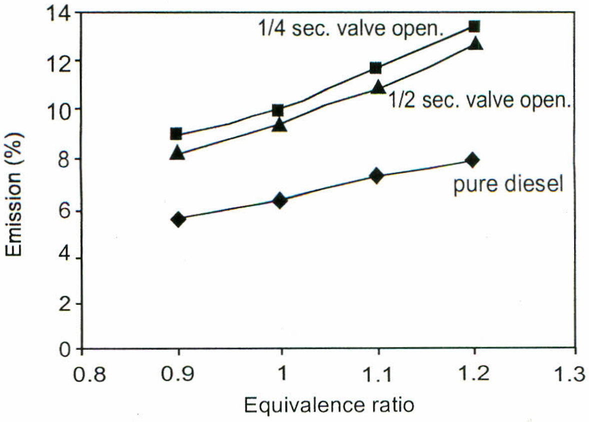

Fig. 14. CO_2 emission in the co-combustion process.

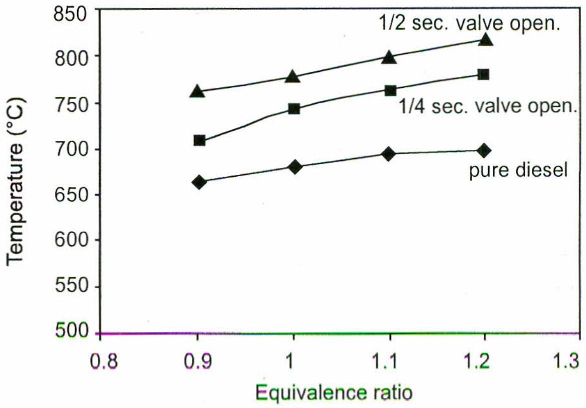

Fig. 15. Temperature profile for the co-combustion process.

The graph of combustion temperature for pure diesel combustion and the fuel combination versus the equivalence ratio (Fig. 15), indicates that the temperature increased with the increase in equivalence ratio. Temperature for the co-combustion with producer gas is higher as compared to the temperature for pure diesel fuel combustion. The highest temperature is achieved at 1/2 secondary valve opening; this is due to the flow of more producer gas and air with larger valve opening, producing more heat.

Conclusion

The producer gas generated from the downdraft gasifier can be used as an alternative fuel for combustion. It can be used for power generation such as in gas turbine, gas burner, heating process etc. Experimental results show that co-combustion of diesel oil and producer gas emitted more CO, NO_x, SO_2 and CO_2. The greatest amount of CO, NO_x, SO_2

and CO_2 are emitted with 1/4 secondary valve opening. Combustion of pure diesel oil has the highest level of O_2 gas as compared to the combustion of fuel combination. The least quantity of O_2 is emitted at co-combustion with 1/4 secondary valve opening. Higher temperature is attained during the co-combustion process than during the combustion of pure diesel oil because during the co-combustion, more fuel is burnt generating more heat.

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