Efficient Gasification using Combustion of Hydrocarbon with Oxygen to Yield Maximum Volatiles from Organic Waste

Muhammad owais shafi[1], Azhar Hussain[2]
[1]Department of Mechanical Engineering
University of Engineering and Technology Taxila
mkowaisshafi@gmail.com

[2]Department of Mechanical Engineering ,
University of Engineering and Technology Taxila
azharhussain@uettaxila.edu.pk

ABSTRACT

The focus on the use of sustainable energy sources, like waste, wind and solar is gaining importance. In this research work waste will be degenerated to useful energy contents using biomass gasification. The organic waste material is thermochemically transformed into valuable combustible gases known as syngas. This work is focuses on the gasification of organic waste with controlled amount of pure oxygen at high temperature to yield maximum volatiles from the hydrocarbons using oxyacetylene flame as a heating source. Experiments were conducted to understand how several important factors such as gasification temperature, oxygen to biomass ratio, residence time and equivalence ratio affect gasification process. The residence time was assumed to be 3s for complete gasification, the temperature was varying from 2200ºC to 2450ºC, equivalence ratio ranges from 0.2 to 0.6 and oxygen to biomass ratio from 0 to 1. The finding suggested that high temperature increase the volume fraction of CO and H_2 in the product gases. In this investigation, a 0.5 oxygen to biomass ratio, 0.2 equivalence ratio and 2350ºC were found optimum value to yield maximum volatiles from waste material. A high temperature gasification process is made possible with the help of technique designed in this research work.

Keywords: organic waste, syngas, gasification temperature, equivalence ratio, oxygen to biomass ratio.

1. INTRODUCTION:

Due to increase in population of the world, urban and industrial development a large amount of solid waste is generated. On other hand energy demand is also increasing so the effective management of renewable energy sources is becoming a great challenge as the primary fuels are depleting day by day. Looking at the present condition the waste treatment is seems to be a suitable option to obtain useful energy, so efficient thermal processing of waste material is becoming a great challenge. [1] The different method for the thermal treatment of waste materials to obtain useful energy products include incineration, pyrolysis, and gasification. Compared to the incineration and pyrolysis the gasification is capable of producing energy that is both more affordable and effective.[2] Moreover, it is clean and efficient way to yield maximum volatiles having high energy content. This type of technology uses different types of gasifiers including fixed bed, moveable bed, fluidized bed, and entrained bed gasifier.[3] Based on the properties of these reactor a new setup for the gasification is designed in this research to make the gasification process more efficient and to get more and better quality of volatiles. Using the oxyacetylene flame produce high temperature in the reactor, ranges from 2200°C to 2450°C and at the same time oxygen is also supplied through bypass which act as a gasification agent. At this high temperature the maximum organic waste is decomposed into volatiles and negligible amount of tar and ash is produced.[4]

2 EXPERIMENTAL WORK

2.1 Feed Material

The biomass materials used in this work were rice husk, wheat husk and sawdust. All these materials were collected locally. These wastes were dried in open sunlight and then they are cut into smaller pieces after that they were further grind to obtain a uniform particle size less than 10mm of waste material. Then they were dried in furnace at 110°C to remove all the moisture content, the remaining content of solid matter was used for the gasification process. The approximate and ultimate analysis of waste material is given in the table 1.1 and table 1.2. [5]

Table 1.1 Proximate Analysis of Organic Waste

Biomass type	Rice husk%	Wheat husk%	Saw dust%
Moisture	6.10	8.41	11.99
Volatile matter	63.40	62.39	62.35
Fixed carbon	15.95	23.31	13.36
Ash	14.55	5.59	12.30

Table 1.2 Ultimate Analysis of Organic Waste

Biomass type	Rice husk%	Wheat husk%	Saw dust%
Carbon	43.44	46.37	47.34
Hydrogen	5.35	5.26	5.40
Nitrogen	0.28	1.11	0.31
Oxygen	50.44	46.89	46.16
Sulphur	0.58	0.37	0.78

2.2 FACILITIES AND PROCEDURES

The test was performed in experimental setup shown in figure 1.1 it consists of feeding system through which grind and dry waste material having particle size less than 10mm is supplied continuously to gasification chamber. The alumina pipe having 500mm length and 75mm diameter was used as a reactor. The acetylene flame was used as heating source. Three S type thermocouple integrated with Arduino is used to monitor and control the temperature in the reaction chamber.[6] The extra oxygen is supplied through the bypass of flame torch which act as a gasification agent. At the top of a reaction chamber the dry waste fed into chamber which falls on the intermediate temperature zone of oxyacetylene flame. At the end of reaction chamber three filter plates are adjusted in the main pipe which permit the volatiles in gaseous forms to pass through them. The ash cannot pass through these filters and is collected in ash collector which is attached with the main pipe just below the filter plates. The volatiles generated in this process are collected in gas sample bag after colling it. The test was performed at different operating conditions and sample were collected separately for the analysis. The volatiles collected at different conditions was tested in biogas analyser.[7] which shows the volume fraction of CO, H_2, CH_4 and CO_2. The block diagram of the the whole process from the drying of waste material to the formation of product gas and ash is given figure 1.2.

Figure 1.1 Experimental Setup

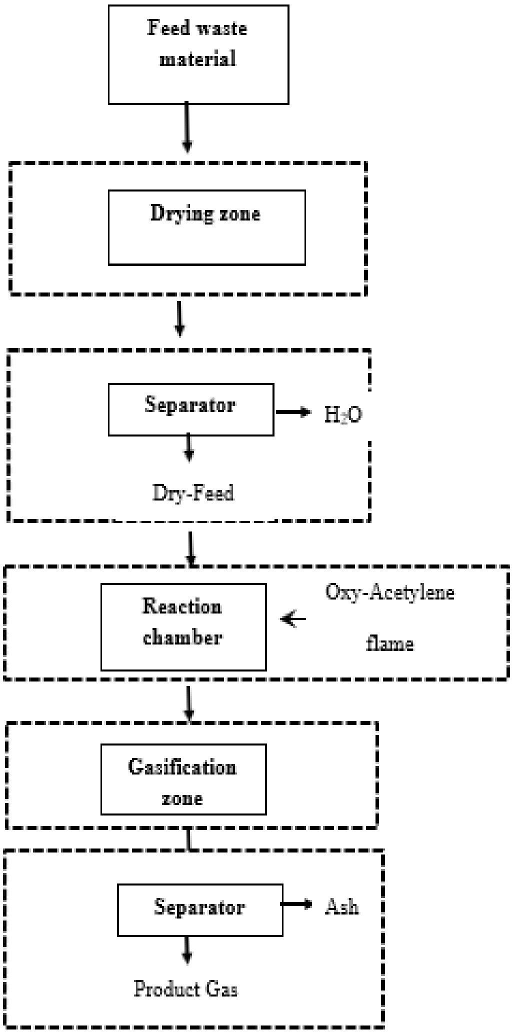

Figure 1.2 Block Diagram of gasification process

3 RESULT AND DISCUSSION

3.1 Effect of temperature on composition of syngas

Temperature is very important factor which play an important role in the gasification. By keeping the oxygen to biomass ratio 0.5 and equivalence ratio 0.2 the temperature was increased from 2200ºC to 2450ºC in 50ºC increments. it was found that by increasing temperature the content of CO and H_2 start increasing while the volume fraction of CO_2 and CH_4 decrease. This is due to the Le Chatelier's principle which state that high temperatures favor the products of endothermic reaction as the formation of CO and H_2 is endothermic so their contents in the volatiles will increase at high temperature and as the formation of CO_2 and CH_4 is exothermic so it will not be favored by increasing temperature hence their volume fraction in the volatiles start decreasing with rise in temperature. As CO and H_2 are the main components of syngas, hence the quality of syngas is improved at high temperature which improves the cold gas efficiency of syngas from 65% to 80% as temperature rises from 2200ºC to 2450ºC. The variation of the components of product gas with increase in temperature is show in figure 1.3

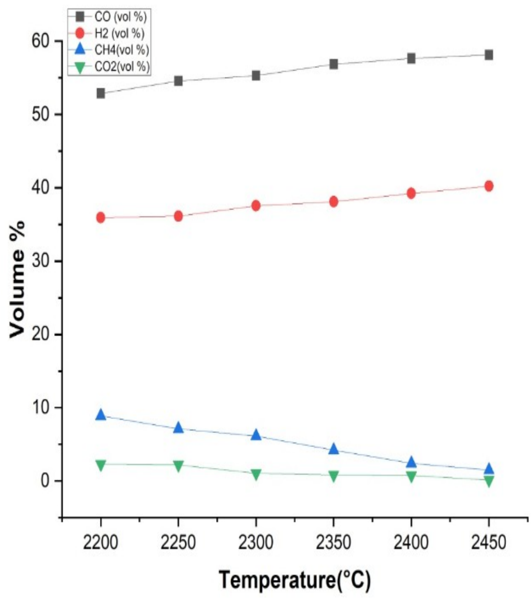

Figure 1.3 Experimental Product Gas Composition vs Temperature

3.2 Effect of Oxygen to biomass ratio on composition of syngas

The Oxygen to biomass ratio (g/g) has a significant impact on how well the gasification process works. It is described as the ratio of the amount of Oxygen added to the mass of biomass added in the gasifier. When oxygen is added to gasifier than the concentration of hydrogen decreases because H_2 react with O_2 to form H_2O and the contents of CH_4 become negligible as oxygen to biomass ratio increases. The volume of CO first increase but as more oxygen is added then it decreases rapidly because more oxygen reacts with carbon to form carbon dioxide, as a result the content of CO_2 increases sharply. It was found that 0.5 O/B was optimum value up to which carbon conversion efficiency is maximum and H_2/CO is also maximum. If more oxygen will add than both H_2/CO and carbon conversion efficiency will decreases. The results are plotted in the figure 1.4 given below.

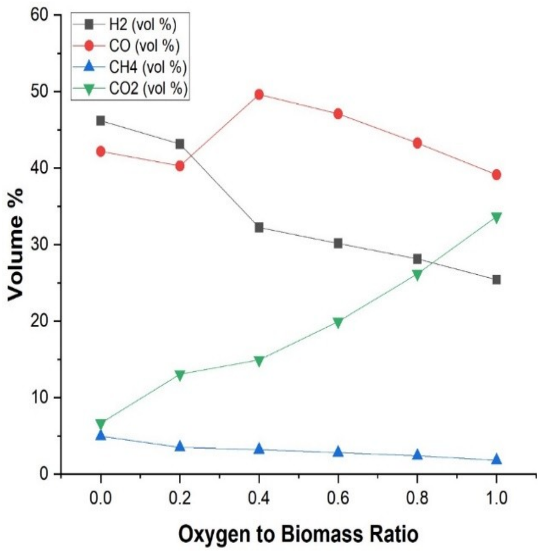

Figure 1.4 Experimental product gas composition vs oxygen to biomass ratio

3.3 Effect of Equivalence ratio on composition of syngas

The mass ratio of the gasification agent to the fuel or biomass in any combustion unit is known as the equivalence ratio (ER). The stoichiometric ratio is the smallest amount of gasification agent to fuel, or biomass required to thoroughly burn the fuel. The equivalence ratio in biomass gasification is a perimeter which play a very critical role in determining the composition of syngas. In performing the experiment its value was changed from 0.1 to 0.6 in six steps. The temperature of the gasifier and oxygen to biomass ratio was kept constant which was 2350ºC and 0.5.Moreover, the feed rate of biomass is also remained constant which is 10kg/hr. it was found that when the ER value was increased from 0.1 to 0.6 than the content of H_2, CO and CH_4 start decreasing but amount of CO_2 start increasing because of oxidation reaction in which more amount of oxygen combines to form CO_2. At the same time LHV of syngas decreases from 17.19MJ/Nm3 to 8.14 MJ/Nm3. This decrease in value of LHV of volatiles which is due to the large amount of CO_2 and small amount of CO, H_2, and CH_4 which are combustible gases. The variation of the components of product gas with increase in equivalence ratio is show in figure 1.3

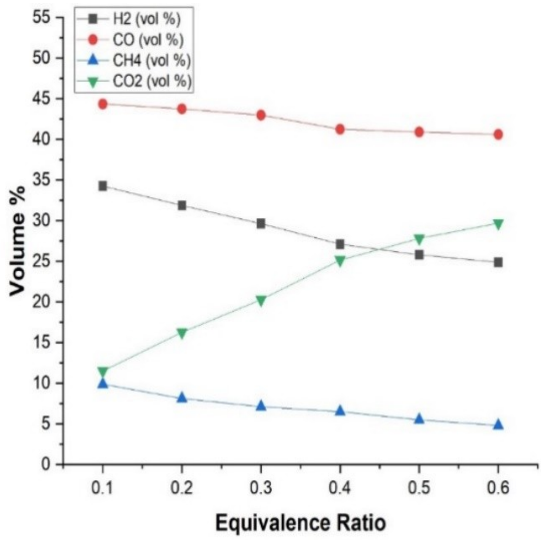

Figure 1.5 Experimental product gas composition vs equivalence ratio

3.4 Effect of Temperature and Equivalence ratio on Cold Gas Efficiency

Compared to the energy in the initial solid fuel, the resultant gas has more chemical energy. The ratio of this energy input to the total potential energy output is called the cold gas efficiency. The experiment was performed by keeping equivalence ratio constant and changes the temperature and it was observed that cold gas efficiency increases with increase in temperature while keeping the equivalence ratio constant shown in figure 1.6 whereas when equivalence ratio was increased at constant temperature than cold gas efficiency decrease. The results are plotted in the figure 1.7 given below.

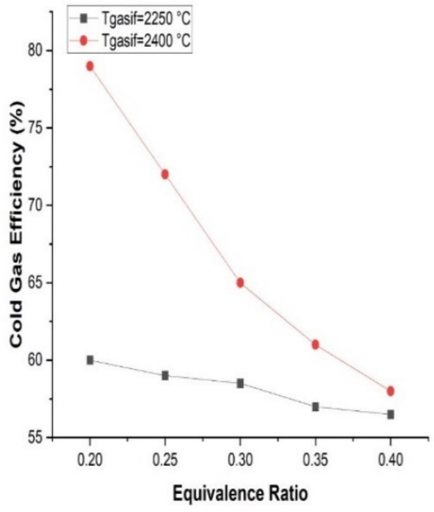

Figure 1.6 Cold gas efficiency vs equivalence ratio at constant temperature

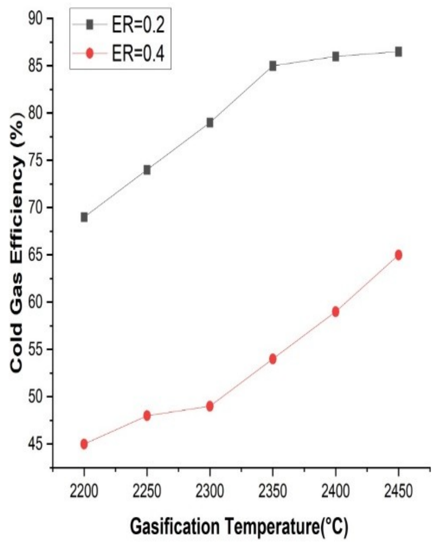

Figure 1.7 Cold gas efficiency vs temperature at constant equivalence ratio

4 CONCLUSIONS

The organic material including rice husk, wheat husk and sawdust was selected from literature review. They were first dried to remove the moisture content and feed to the gasification chamber where oxyacetylene flame is used for burning the waste in pure oxygen environment. The experiments were performed in different operating conditions by varying the gasifier temperature, equivalence ratio and oxygen to biomass ratio. The useful results for the efficient gasification process at optimum conditions were obtained. It was found that useful components of the product gas is maximum at the temperature of 2350°C, Equivalence ratio of 0.24 and oxygen to biomass ratio 0.5 . The analysis of syngas gas was done in biogas analyzer, which indicates the volume percentages of H, CO, CH4, and CO2 . The findings demonstrate that when the temperature rises, the hydrogen and carbon monoxide contents in the resultant gas rises quickly. Also, higher equivalency ratios are not recommended for gasification because it cause combustion instead of gasification. Whereas adding too much oxygen produce a large amount of CO2 which is which decreases the quality of product gases. Using oxyacetylene flame with pure oxygen increase the quality and quantity of volatiles generated from the organic waste. Hence maximum amount of organic waste was converted into syngas which can be used as a fuel to overcome energy problems. These volatiles have good energy contents. The result obtained can be used to make the gasification process more efficient and to improve the quality of syngas. In future it can be used for unsegregated waste at large scale.

5 REFERENCES

[1] T. H. Tsui and J. W. C. Wong, “A

critical review: emerging bioeconomy and waste-to-energy technologies for sustainable municipal solid waste management," Waste Dispos. Sustain. Energy, vol. 1, no. 3, pp. 151–167, 2019, doi: 10.1007/s42768-019-00013-z.

[2] A. Demetrious and E. Crossin, "Life cycle assessment of paper and plastic packaging waste in landfill, incineration, and gasification-pyrolysis," J. Mater. Cycles Waste Manag., vol. 21, no. 4, pp. 850–860, 2019, doi: 10.1007/s10163-019-00842-4.

[3] J. Dong, Y. Tang, A. Nzihou, Y. Chi, E. Weiss-Hortala, and M. Ni, "Life cycle assessment of pyrolysis, gasification and incineration waste-to-energy technologies: Theoretical analysis and case study of commercial plants," Sci. Total Environ., vol. 626, pp. 744–753, 2018, doi: 10.1016/j.scitotenv.2018.01.151.

[4] S. Ge, D. Chen, L. Yin, L. Hong, H. Zhou, and Z. Huang, "Municipal solid wastes pyro-gasification using high-temperature flue gas as heating resource and gasifying agent," Waste Manag., vol. 149, no. May, pp. 114–123, 2022, doi: 10.1016/j.wasman.2022.06.010.

[5] Y. S. Pradana, Daniyanto, M. Hartono, L. Prasakti, and A. Budiman, "Effect of calcium and magnesium catalyst on pyrolysis kinetic of Indonesian sugarcane bagasse for biofuel production," Energy Procedia, vol. 158, pp. 431–439, 2019, doi: 10.1016/j.egypro.2019.01.128.

[6] F. A. Rodrigues, K. F. A. Okada, J. R. Ferreira-Oliveira, and L. R. R. Da Silva, "Temperature Measurement of Polymers Under Intermittent Heating Through Use of Thermocouple and Arduino® Microcontroller," Rev. Eng. Térmica, vol. 20, no. 1, p. 87, 2021, doi: 10.5380/reterm.v20i1.80462.

[7] P. Seghman, L. Krátký, and T. Jirout, "EFFECT OF MEMBRANE SEPARATION PROCESS CONDITIONS ON THE RECOVERY OF SYNGAS COMPONENTS," vol. 62, no. 3, pp. 394–399, 2022.