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Experimental Study of CO_2 Gasification of Biomethanation Waste

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ABSTRACT
Gasification is one of prominent thermochemical processes generally used to convert organic feedstock to combustible syngas (CO and H_2). An experimental study of biomass gasification using carbon dioxide as an gasifying medium was carried out in a fixed bed gasifier. The main aim of this study was to determine the effect of temperature on the output syngas. The present study reported the results for producing syngas with CO_2 as gasification agent and biomass (rice husk and bio-methanation waste) as raw material. The gasification was performed at 700-900°C respectively and CO_2 flow rate was maintained at 0.5 lpm. Maximum syngas production found at high temperature (900°C). The syngas analysis showed higher hydrogen yield at higher temperatures.
Keywords: Rice husk, Bio-methanation waste, Gasification, Hydrogen.

I. INTRODUCTION

Biomass has a great potential as renewable energy resource due to huge availability and some prominent fuel properties like minimum sulfur content and low percentage of ash (Ahmad et al. (2016); Chan and Tanksale 2014). The Green energy policy has given tremendous importance to generation of energy from agro-waste (Alipour Moghadam et al. 2014). Generally organic feed stocks are converted to syngas (CO + H_2) via gasification route (Arafat and Jijakli 2013). Solid waste management via thermochemical processes (e.g. incineration, pyrolysis, or gasification) can resolve the waste management issues of impact on human beings and environment. Gasification is a efficient technology to produce syngas from solid wastes (Begum et al. 2014) and involves high temperature reactions to convert solid materials containing carbon, such as coal, solid waste or biomass, into a gas called syngas which contains hydrogen and carbon monoxide (Rajasekhar et al. 2015).

Many gasification studies have been reported in literature. Air gasification of rice husk at 750-850°C in a fluidized bed showed that carbon conversion rate decreased with respect to change in temperature and feed rate and equivalence ratio (Makwana et al. 2015). Gasification of various solid wastes (wood, textile, kitchen garbage, paper separately) in a fixed bed reactor with oxygen gave maximum syngas and lower CO_2 at higher temperatures (800-850°C) (Niu et al. 2014) Another research study reported that steam gasification of dried sewage sludge (in presence of activated carbon, dolomite, and CaO) yielded tar free syngas, with low amount of ammonia in a fixed bed reactor at 900°C (Li et al. 2015). CO_2 gasification of thin wood biomass at 850°C has reported that the rate limiting step was the global pyro-gasification reaction as this reaction required nearly 95% of the entire biomass conversion time (Guizani et al. 2015). Gasification of coal at 1400°C in presence of CO_2, O_2 and H_2O separately showed that, soot formation slightly decreased during O_2 and H_2O gasification, while the soot formation was low with increase in carbon conversion rate in CO_2 gasification (Umemoto et al. 2016). Zhai et al. have investigated the steam gasification of bio char (prepared from rice husk) at 700-950°C and reported that the gasification temperature is the key factor in whole process i.e. char conversion rate increased from 27.7% to 90.73% and 46.9% hydrogen was obtained at 950°C (Zhai et al. 2015)). The effect of plastic addition in steam gasification showed an increase in syngas yield with higher amount of hydrogen in absence of catalyst (Alvarez et al. 2014).

The gasification process is mainly affected by temperature, catalyst, residence time and oxygen to fuel ratio (Bronson et al. 2016); Parthasarathy and Narayanan 2014)). In another research study, it was reported that gasification of cotton stalk at 850°C, with oxygen fuel ratio (0.12-0.4) in presence of $Ca(OH)_2$ yielded 45 % H_2, and 33% CO (Hamad et al. 2016). Gasification of woody biomass in fluidized bed using air as gasifying agent & fluidizing gas (with control flow rate) gave low calorific value syngas (Kim et al. (2013). Also autothermal steam gasification of biomass in fluidized bed gave low nitrogen content syngas

(Mayerhofer et al. 2014). Catalytic gasification (using K_2CO_3 as catalyst) of low rank coal at 700°C in presence of steam and CO_2 as gasifying agents resulted in syngas formation with H_2/ CO ratio 1, 2, 3, which can be used in Fischer Tropsch synthesis (Sharma et al. 2015).

It was also reported that CO_2 gasification of rice husk at 800°C with ZnO/γ-Al_2O_3 as catalyst resulted in 22.1% CO, with only 22.4% CO_2 conversion, and 71.7% rice husk conversion (Chen and Zhang 2015). In another study on steam gasification of biochar using nickel based catalyst (Ni-dolomite, Ni–MgO and Ni–Al_2O_3) showed better hydrogen yield than in absence of the catalyst (Waheed et al. 2016). Another research study showed that gasification using radio frequency heating in presence of CO_2 helped to maximize the conversion of CO_2 to CO at 850°C (Lahijani et al. 2015).Generally, it is seen that solid waste generated after the biomethanation process is used as manure or as raw material for composting. This biomethanation waste contains significant amount of carbon, so this waste can be used as feed for thermal treatment like pyrolysis or gasification.

CO_2gasification of bio-methanation wastes have not yet been reported in literature. This study was undertaken along with CO_2 gasification of rice husk as base study in the same experimental setup. The experimental study of solid wastes using CO_2as gasifying agent was undertaken in a fixed bed reactor. The feed materials for the study were collected from various sources. The rice husk samples were obtained from a rice mill in Chhattisgarh, India; while the bio-methanation waste samples was taken from bio-methanation process plants in NEERI, Nagpur.

II. MATERIALS AND METHODS

2.1 Proximate analysis

The proximate analysis of all feed samples was done by standard procedure and the results are shown in table 1. The moisture content in rice husk was lower as compared to the other waste samples. It was observed that maximum combustible matter was found in rice husk as 81.90 %, and it was 45.02% and 41.15% respectively in biomethanation waste samples (MSW waste and Food waste). The presence of combustible matter shows efficiency of feed material to recover energy from waste.

Characteristics	Rice husk	Biomethanation waste (MSW sample)	Biomethanation waste (Food waste sample)
Moisture	6.47%	8.91%	9.45%
Combustible Matter	81.90%	45.02%	41.15%
Ash	11.71%	22.43%	24.51%

Table 1: Proximate analysis of solid waste samples

2.2 Ultimate analysis

The CHNS analysis of gasifier feed material was carried out in the CHNS analyzer (Thermo Finnegan, Flash EA112 Series) in Analytical instrument laboratory at CSIR-NEERI, Nagpur and the results are presented in Table 2**.** The carbon content was found to be highest in rice husk (48.69%), while it was 16.68 % and 14.85 % respectively in the biomethanation wastes (MSW waste and food waste).

Component	% by weight dry ash free basis		
	Rice husk	Biomethanation waste (MSW sample)	Biomethanation waste (Food waste sample)
C	48.69	14.85	16.78
H	6.97	2.232	2.481
N	0.37	0.996	1.332
S	0.009	0.963	1.390

Table 2: Ultimate analysis of solid waste samples

2.3 Calorific value

The calorific value of the gasifier feeds was determined by Bomb calorimeter. The calorific value of rice husk, Bio methanation waste (MSW sample and Food waste sample) were found to be 5.456 MJ/ Kg, 2.0041 MJ/ Kg, and 1.3839 MJ/ Kg respectively. The calorific value of feed material describes the energy content of feed material.

2.4 Gasifier operating conditions

The gasification of rice husk and biomethanation wastes was carried out at different set of experimental conditions in the temperature range 700 - 900 °C. The biomethanation waste samples - wet samples and dry samples were used as feed. The experimental conditions are shown in Table 3. 15 gm of each sample was used in experimentation.

2.5 Experimental Procedure

The gasification study was done in a fixed bed reactor system as shown in figure 1. The dimensions of the Inconel tube reactor were: 600 mm long and 3.25 mm in diameter, while 300 mm was the length of the heating zone. Experiments were performed in CO_2 atmosphere. The reactor tube had one gas inlet at top side for passing CO_2 gas in the reactor. The experimental set up had auto tuning PID controller and K-type thermocouples were used in the furnace section as well as at the reactor section to detect the furnace temperature. A water condenser and vapour liquid separator were attached to the fixed bed reactor for cooling the gaseous products and separating the liquid and gas respectively. The gasification of biomass sample (rice husk) and the bio-methanation wastes (15 gm) was performed at temperatures 700°C to 900°C and the syngas generated was analysed using an online gas analyser.

Run No.	Feed	Temperature (°C)	Initial weight (gm)
1	Rice husk	700 °C	15 gm
2	Rice husk	800 °C	15 gm
3	Rice husk	900 °C	15 gm
4	Bio-methanation waste	700 °C	15 gm
5	Bio-methanation waste	800 °C	15 gm
6	Bio-methanation waste	900 °C	15 gm
7	Bio-methanation waste	700 °C	15 gm
8	Bio-methanation waste	800 °C	15 gm
9	Bio-methanation waste	900 °C	15 gm
10	Bio-methanation waste	700 °C	15 gm
11	Bio-methanation waste	800 °C	15 gm
12	Bio-methanation waste	900 °C	15 gm
13	Bio-methanation waste	700 °C	15 gm
14	Bio-methanation waste	800 °C	15 gm
15	Bio-methanation waste	900 °C	15 gm

Table 3: Corresponding conditions of Gasification process.

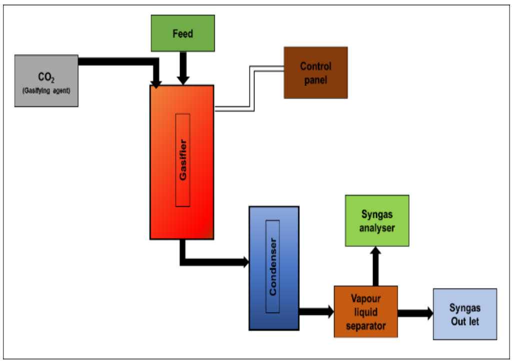


Figure 1: Schematic of Gasification process.

III. RESULTS AND DISCUSSION

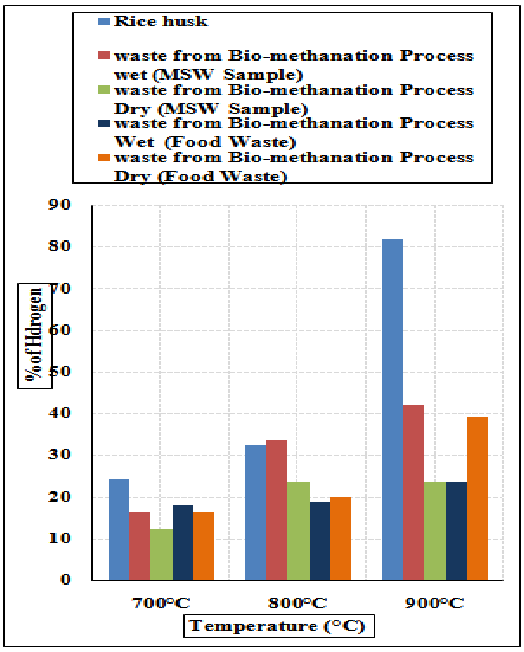
3.1 Product Distribution

In general, it was observed that gasification of solid wastes produces syngas and negligible amount of tar as shown in figure 2. In this study we have noted the hydrogen yield in CO_2 gasification at different temperatures. The hydrogen production with respect to change in temperature and feed condition is shown in figure 3. The char formed in the process remains as solid residue in the reactor. The solid char produced in gasification process was analysed by CHNS analyzer. It gave the elemental composition (carbon, hydrogen, nitrogen and sulfur) of solid char and the result is shown in table 4.

Figure 2: Product Distribution of Rice husk gasification

Component	% by weight dry ash free basis		
	Rice husk	Bio methanation waste (MSW sample)	Bio methanation waste (Food waste sample)
C	83.15	43.64	41.61
H	2.965	2.560	4.070
N	0.088	1.188	1.048
S	0.095	0.706	0.122

Table 4: CHNS analysis of solid char (at 900°C)



3.2 Effect of moisture on syngas generation

The biomethanation waste samples were initially wet. These wet samples were used in gasification study as it is. The dry samples were prepared by drying the biomethanation waste in oven. The gasification of both wet and dry samples was studied in similar environment. The gasification of the samples was carried out at different temperatures such as 700°C, 800°C, and 900°C separately. The results show that the hydrogen yield was higher in gasification of wet samples as compared to dry samples. Figure 3 shows the hydrogen yield (%) in case of biomethanation waste samples. It was seen that the wet sample gasification yielded 16.1 % of H_2 at 700°C, 33.5 % of H_2 at 800°C, and 41.9 % of H_2 at 900°C. The same trend was found during gasification of wet samples of food waste. Similarly, in gasification of dry samples at 700°C, 800°C and 900°C, the H_2 yield increased from 13.9% at 700°C to 23.5% at 800°C respectively.

3.3 Effect of Temperature

The effect of temperature on CO_2 gasification of rice husk samples was studied at different temperatures (700°C, 800°C and 900°C). The results showed (figure 3) that H_2 generation is favored at higher temperature, i.e. the hydrogen yield was 24.1% (at 700°C), 32.8% (at 800°C) and 81.1% (at 900°C) respectively. The gasification of bio-methanation waste samples also showed the same trend for both wet and dry samples i.e. the hydrogen yield in gasification of wet MSW samples of bio-methanation was 41.9%, while for dry sample, it was 23.5% (at 900°C). In case of gasification of food waste samples from bio-methanation the hydrogen yield was found to be 39.3%, while for dry sample, it was 17.8% (at 900°C).

3.4 Calorific value of solid char

The solid char obtained in the gasifier at the end of each experiment was studied and were analyzed by bomb calorimeter for determination of its calorific value. Table 5 shows calorific value of char. A comparison of calorific value of the gasifier feed and char obtained after gasification was done. It was observed that the calorific value of char was greater than calorific value of raw material.

Sr. No.	Solid Char obtained	Temperature (°C)	Calorific Value (MJ/ Kg)
1.	Rice husk	900 °C	17.4500
2.	Biomethanation waste (MSW sample)	900 °C	5.1271
3.	Biomethanation waste (Food waste sample)	900 °C	5.8550

IV. CONCLUSION

The gasification of biomass in presence of CO_2 performed on a variety of biomass feed stocks that included rice husk and bio methanation waste. The hydrogen generation potential in CO_2 gasification of these wastes with respect to temperature was studied. The result shows that higher gas yield was obtained at higher temperature. The moisture content in the feed also increased hydrogen generation. The rice husk and wet MSW bio-methanation waste sample gave maximum hydrogen yield at 900°C .i.e. 81% and 42 % respectively. The calorific value of solid char obtained after gasification was much higher that the feed.

REFERENCES

[1]. Ahmad, A. A., Zawawi, N. A., Kasim, F. H., Inayat, A., & Khasri, A. (2016). Assessing the gasification performance of biomass: A review on biomass gasification process conditions, optimization and economic evaluation. Renewable and Sustainable Energy Reviews, 53, 1333-1347.

[2]. Alipour Moghadam, R., Yusup, S., Azlina, W., Nehzati, S., & Tavasoli, A. (2014). Investigation on syngas production via biomass conversion through the integration of pyrolysis and air–steam gasification processes. Energy conversion and management, 87, 670-675.

[3]. Alvarez, J., Kumagai, S., Wu, C., Yoshioka, T., Bilbao, J., Olazar, M., & Williams, P. T. (2014). Hydrogen production from biomass and plastic mixtures by pyrolysis-gasification. International Journal of Hydrogen Energy, 39, 10883-10891.

[4]. Arafat, H. A., & Jijakli, K. (2013). Modeling and comparative assessment of municipal solid waste gasification for energy production. Waste Management, 33, 1704-1713.

[5]. Begum, S., Rasul, M. G., Cork, D., & Akbar, D. (2014). An Experimental Investigation of Solid Waste Gasification Using a Large Pilot Scale Waste to Energyplant. Procedia Engineering, 90, 718-724.

[6]. Bronson, B., Gogolek, P., Mehrani, P., & Preto, F. (2016). Experimental investigation of the effect of physical pre-treatment on air-blown fluidized bed biomass gasification. Biomass and Bioenergy, 88, 77-88.

[7]. Chan, F. L., & Tanksale, A. (2014). Review of recent developments in Ni-

based catalysts for biomass gasification. Renewable and Sustainable Energy Reviews, 38, 428-438.

[8]. Chen, Z.-M., & Zhang, L. (2015). Catalyst and process parameters for the gasification of rice husk with pure CO2 to produce CO. Fuel Processing Technology, 133, 227-231.

[9]. Guizani, C., Louisnard, O., Sanz, F. J. E., & Salvador, S. (2015). Gasification of woody biomass under high heating rate conditions in pure CO2: Experiments and modelling. Biomass and Bioenergy, 83, 169-182.

[10]. Hamad, M. A., Radwan, A. M., Heggo, D. A., & Moustafa, T. (2016). Hydrogen rich gas production from catalytic gasification of biomass. Renewable Energy, 85, 1290-1300.

[11]. Kim, Y. D., Yang, C. W., Kim, B. J., Kim, K. S., Lee, J. W., Moon, J. H., Yang, W., Yu, T. U., & Lee, U. D. (2013). Air-blown gasification of woody biomass in a bubbling fluidized bed gasifier. Applied Energy, 112, 414-420.

[12]. Lahijani, P., Mohammadi, M., Zainal, Z. A., & Mohamed, A. R. (2015). Advances in CO2 gasification reactivity of biomass char through utilization of radio frequency irradiation. Energy, 93, Part 1, 976-983.

[13]. Li, H., Chen, Z., Huo, C., Hu, M., Guo, D., & Xiao, B. (2015). Effect of bioleaching on hydrogen-rich gas production by steam gasification of sewage sludge. Energy Conversion and Management, 106, 1212-1218.

[14]. Makwana, J. P., Joshi, A. K., Athawale, G., Singh, D., & Mohanty, P. (2015). Air gasification of rice husk in bubbling fluidized bed reactor with bed heating by conventional charcoal. Bioresource Technology, 178, 45-52.

[15]. Mayerhofer, M., Fendt, S., Spliethoff, H., & Gaderer, M. (2014). Fluidized bed gasification of biomass – In bed investigation of gas and tar formation. Fuel, 117, Part B, 1248-1255.

[16]. Niu, M., Huang, Y., Jin, B., & Wang, X. (2014). Oxygen Gasification of Municipal Solid Waste in a Fixed-bed Gasifier. Chinese Journal of Chemical Engineering, 22, 1021-1026.

[17]. Parthasarathy, P., & Narayanan, K. S. (2014). Hydrogen production from steam gasification of biomass: Influence of process parameters on hydrogen yield – A review. Renewable Energy, 66, 570-579.

[18]. Rajasekhar, M., Rao, N. V., Rao, G. C., Priyadarshini, G., & Kumar, N. J. (2015). Energy Generation from Municipal Solid Waste by Innovative Technologies – Plasma Gasification. Procedia Materials Science, 10, 513-518.

[19]. Sharma, A., Matsumura, A., & Takanohashi, T. (2015). Effect of CO2 addition on gas composition of synthesis gas from catalytic gasification of low rank coals. Fuel, 152, 13-18.

[20]. Umemoto, S., Kajitani, S., Hara, S., & Kawase, M. (2016). Proposal of a new soot quantification method and investigation of soot formation behavior in coal gasification. Fuel, 167, 280-287.

[21]. Waheed, Q. M. K., Wu, C., & Williams, P. T. (2016). Hydrogen production from high temperature steam catalytic gasification of bio-char. Journal of the Energy Institute, 89, 222-230.

[22]. Zhai, M., Zhang, Y., Dong, P., & Liu, P. (2015). Characteristics of rice husk char gasification with steam. Fuel, 158, 42-49.