International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-12 Issue-6, May 2023

Gasification of MSW and Biomass using Aspen Plus®

Nguyen L. Hoang

Abstract*: Municipal Solid Waste (MSW) refers to solid waste generated by towns and cities from different types of household activities1. Over 2 billion tons of MSW are produced annually. Improper disposal can lead to adverse health outcomes through water, soil and air contamination. Hazardous waste or unsafe waste treatment such as open burning can directly harm waste workers or other people involved in waste burning and neighbouring communities. At the same time, in order to keep up with the need in development, the energy demand also increasing. Therefore, utilize MSW to produce energy is gaining more recognition from public interest. Gasification offers some advantages over traditional method of utilize MSW (incineration, compost). Gasification plants produce significantly lower quantities of air pollutants. The process reduces the environmental impact of waste disposal because it allows for the use of waste products as a feedstock. In this paper, Aspen Plus software was deployed to assess and predict the outcome of the gasification process of MSW. The model was calibrated and validated with various observed data. The condition of input MSW and biomass, as well as the gasification agent were considered. The results revealed that primary products of gasification process are similar to other previously conducted experiments.

Keywords: MSW, Gasification, Waste to Energy, Biomass, Aspen Plus.

I. INTRODUCTION

Municipal solid waste is becoming one of the biggest problems for humans for sustainable development. Every year, more and more waste products are left untreated, causing ecological and environmental disasters. Poor management of MSW not only has detrimental environmental consequences but also puts public health at risk and introduces several other socioeconomic problems [11]. However, despite the significant increase in recycling and recovery in those areas, only a small amount of MSW goes thought the process, leaving the majority of MSW to be disposed of in landfill or incineration. These traditional methods are becoming less viable. Landfills consume valuable lands, and in the process of decomposing, MSW generates greenhouse gas and other highly toxic gases, leaking from MSW can pollute the surrounding land and water sources. Incineration of MSW also produces many greenhouse gases and carcinogenic substances.

Manuscript received on 17 April 2023 | Revised Manuscript received on 24 April 2023 | Manuscript Accepted on 15 May 2023 | Manuscript published on 30 May 2023.

*Correspondence Author(s)
Nguyen L. Hoang*, Research Scholar, Innovative Technologies for High-Tech Industries, Moscow Power Engineering Institute, Moscow, Russia. Email: hoangnl3592@gmail.com, ORCID ID: https://orcid.org/0009-0004-9159-9174

Gasification is more cost-effective, cleaner and more efficient than conventional incineration and more useful in that it produces many byproducts that can be used in downstream production. It can be applied to change lower-priced feedstock like MSW into valuable products like fuels, fertilizers and electricity. Gasification is a heating process that transforms large molecules in solid form into gaseous, small molecules under oxygen-lean (or free) environments [12]. It is an attractive alternative fuel production process for the treatment of solid waste as it has several potential benefits over traditional methods [13].

In order to provide useful data for decision-maker to develop realistic strategies and to save resources, simulations are taken into consideration. Simulation provides precision and strategy for problem-solving and enable a systematic understanding of the system being modeled. It is an effective tool for improving, optimizing and visualizing process flow systems. It helps estimating and establishing relationship between input and output products. The aim of this study is to assess and predict composition of syngas products from MSW gasification with the help of simulation software Aspen Plus.

II. BASIC OF GASIFICATION

Gasification is thermochemical conversion of carbonaceous materials to gaseous products with the aid of gasification agents. The products obtained from this process are called syngas, mostly consisting of hydrogen (H_2), carbon monoxide (CO), with smaller amount of carbon dioxide (CO_2) and methane (CH_4) [1].

The equivalence ratio is the ratio between the oxygen content in the oxidant supply and that required for complete stoichiometric combustion [2]. This parameter is the most important operating parameter in the gasification process because it affects syngas composition, tar content, gas yield, and its chemical energy. ER values close to zero correspond to pyrolysis conditions, while values greater than one indicates combustion conditions [3].

In the gasifier, the carbonaceous materials undergo several different processes:

1. Dehydration: or drying. This process occurs at around 100°C. Typically, the resulting steam is mixed into the gas flow and involved with subsequent chemical reactions.
2. Pyrolysis process occurs at around 200 - 400°C. Volatile matters are released and char is produced. This process is dependent on the properties of carbonaceous materials.

3. Combustion process occurs as the volatile matter and some of the char react with oxygen to primarily form carbon dioxide and small amounts of carbon monoxide. These reactions provide heat for the subsequent gasification reactions. The basic reaction is

$$C + O_2 \rightarrow CO_2$$

4. The gasification process occurs as the char reacts with steam and carbon dioxide to produce carbon monoxide and hydrogen. Reactions are as follow

$$C + H_2O \rightarrow H_2 + CO$$

$$C + CO_2 \rightarrow 2CO$$

5. The water-gas shift reaction [7] also occurs and reaches equilibrium very fast at the temperature in the gasifier. This balances the concentration of carbon monoxide, carbon dioxide, hydrogen and stream. The mechanism is thought to occurs as follows [8] (where ✻ denote vacant site)

$$CO + O(a) \rightarrow CO_2 + ✻$$

$$H_2O + ✻ \rightarrow H_2 + O(a)$$

Combining the above two reactions gives

$$CO + H_2O \leftrightarrow CO_2 + H_2$$

The reaction is slightly exothermic, therefore inside the gasification reactor, the reaction tends toward reverse order to produce high amount of carbon monoxide.

III. METHODOLOGY

Aspen Plus (AP) is a powerful chemical process simulator. AP allows the user to build a process model and then simulate it using complex calculations (models, equations, math calculations, regressions, etc.). Given a process design and an appropriate selection of thermodynamic models, AP uses mathematical models to predict the performance of the process. Engineers will typically simulate this using the software in order to optimize the design and improve existing ones. This accurate modeling of thermodynamic properties is particularly important in the separation of non-ideal mixtures. One of the best advantages is that Aspen Plus has already an existing data base of species and their pure/binary regressed parameters. The author's simulation model was constructed using AP and its setting were calibrated based on experiments data [6, 9, 10]. The model requires component analysis of input biomass. Different types of biomass waste were used. Proximate and ultimate analysis components are shown in Table 1. Analyses show that the main compositions of biomasses are volatile contents and carbon and oxygen are the major chemical elements. The following settings were used in during simulation: base method: Soave-Redlich-Kwong equation of state [5]; the equivalence ratio is 0.25; input biomass temperature is 25°C; pressure is 1 atm; input air (gasification agent) consists of 90% O_2 and 10% N_2.

Fig 1 shows the flowsheet of the process in aspen plus software. Table 2 further explains more details in the flowsheet.

Table 1: Proximate and ultimate analysis of different types of biomass waste [4]

Components (% weight)		Biomass waste		
		MSW	Rice straw	Cotton stalk
Proximate analysis	Moisture	6.16	7.01	1.3
	Ash content (dry)	16.82	16.82	7.1
	Volatile matter (dry)	72.6	66.62	62.2
	Fixed carbon (dry)	10.58	16.56	30.7
Ultimate analysis	Carbon	49.23	39.75	80.27
	Hydrogen	8.15	4.93	7.43
	Oxygen	23.73	37.38	3.16
	Nitrogen	1.82	0.94	0.46
	Sulphur	0.25	0.19	1.58

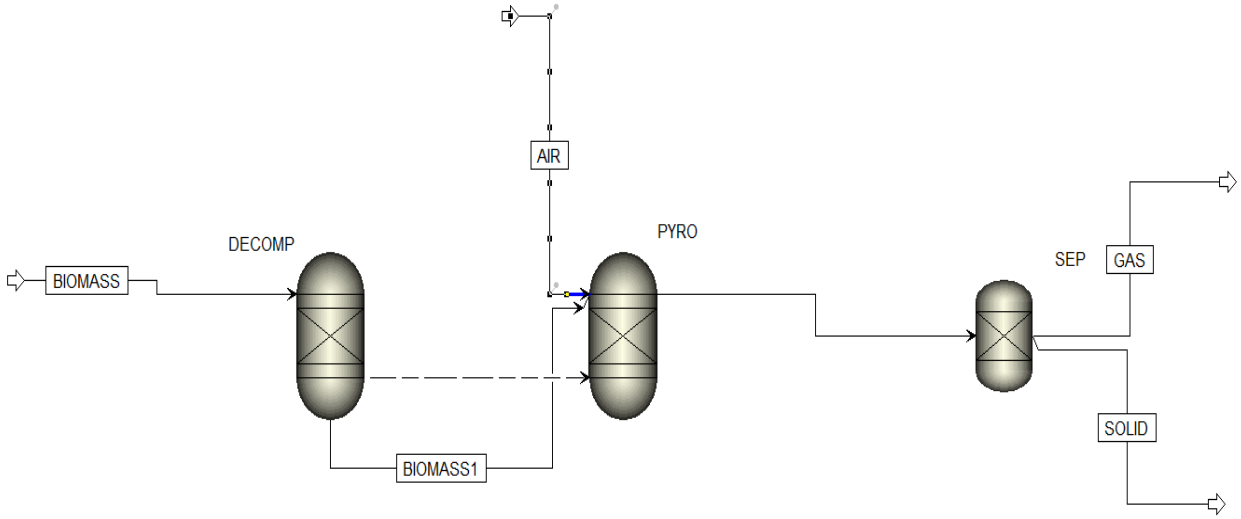

Figure 1: Aspen Plus flowsheet

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Table 2: Functions of each block

Block	Type	Function
Decomp	R Yield	Reactor for drying and decomposing biomass
Pyro	R Gibbs	Main reactor for gasification process
Sep	Sep	Separate gas and char products
BIOMASS	Data stream	Input biomass
BIOMASS1	Data stream	Biomass after drying and decomposing
AIR	Data stream	Input air for gasification
GAS	Data stream	Output syngas products
SOLID	Data stream	Output char product

The following assumption are made:

• Process is steady state

• No pressure drop and no lost heat are considered

• All considered components are in chemical equilibrium

• Sulfur, nitrogen in biomass are assumed to go to the gas phase.

Fortran statements for dry mass of biomass after DECOMP reactor are calculated as follow:

$$m_{decompC} = \frac{100 - m_{H_2O}}{100} \cdot \frac{m_C}{100}$$

$$m_{decompH_2} = \frac{100 - m_{H_2O}}{100} \cdot \frac{m_H}{100}$$

$$m_{decompN_2} = \frac{100 - m_{H_2O}}{100} \cdot \frac{m_N}{100}$$

$$m_{decompAsh} = \frac{100 - m_{H_2O}}{100} \cdot \frac{m_{ash}}{100}$$

$$m_{decompH_2O} = \frac{m_{H_2O}}{100}$$

Fortran statement for the input air (gasification agent) is calculated as follow:

$$m_{air} = \frac{0.25(m_C + m_{H_2} - m_{O_2})}{0.9}$$

where 0.25 is the equivalent ratio; 0.9 is the ratio of oxygen in the gasification agent, as stated above

IV. RESULTS AND DISCUSSION

Table 4 shows results from other experiments conducted by different authors in comparison to this author's simulated results. Simulation of municipal solid waste has a higher in hydrogen generation. This could be the results of MSW has much lower amount of fixed carbon and higher amount of hydrogen. The other two simulation results (rice straw and cotton stalk), both hydrogen and carbon monoxide are quite close to experiments data. The higher amount of CO_2 in both results from MSW and Rice Straw can be contributed to the higher moisture in their approximate analysis. The differences in nitrogen could be the results of nitrogen from gasification agents used in the assumption. The vary in composition of carbon dioxide, methane and hydrogen sulfide could be the results of RGibbs reactor during simulation tried calculating and balancing the reaction whilst under no specific restriction from the program settings.

Table 3: Comparison of simulation results (mol fraction)

Parameters	MSW	Rice straw	Cotton stalk
H_2	0.39	0.302	0.3917
CO	0.4132	0.3971	0.571
CO_2	0.0054	0.1253	5.42E-05
CH_4	3.05E-06	1.12E-05	9.32E-05
O_2	0	0	0
N_2	0.0308	0.0254	0.0319
H_2O	0.1113	0.1492	0.0001
SO_2	3.42E-08	1.24E-08	1.15E-11
H_2S	0.0009	0.0009	0.0052

Table 4: Comparison of Simulation Results and Experiments in Dry Mass (Mol Fraction, %)

Parameters	MSW	Rice straw	Cotton stalks	The Wabash River Coal Gasification Repowering Project [9]	Said MA Ibrahim and Mostafa EM Samy's experiment [10]	Wen and Chaung's experiment [6]
H_2	46.41	35.5	39.17	34.3	33.575	39.13
CO	49.17	46.68	57.103	45.3	48.683	57.57
CO_2	0.64	14.73	0.005	15.8	13.171	2.95
CH_4	3.62E-04	1.32E-03	9.32E-03	1.9	4.367	0.12
H_2S	0.11	0.11	0.52	--	0	0.06
N_2	0.0308	0.0254	0.0319	--	0.204	--

V. CONCLUSION

The Aspen Plus software was employed to simulate and study the pyrolysis behavior of different biomasses, including municipal solid waste, rice straw and cotton stalk. The following conclusions can be drawn.

- The simulation could predict the yields of pyrolysis products with reasonable accuracy
- The components of the input biomass have significant impact on the results of the output syngas

From the simulation model, the following information can also be obtained:

- Profile of temperature
- Flow rate of products
- Enthalpy and entropy of products

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

DECLARATION

Funding/ Grants/ Financial Support	No, I did not receive.
Conflicts of Interest/ Competing Interests	No conflicts of interest to the best of our knowledge.
Ethical Approval and Consent to Participate	The article does not require ethical approval and consent to participate with evidence.
Availability of Data and Material/ Data Access Statement	The data used and/or analyzed during the current study are avaible from the author upon reasonable request.
Authors Contributions	I am only the sole author of the article.

REFERENCES

1. National Non-Food Crops Centre. "Review of Technologies for Gasification of Biomass and Wastes, NNFCC project 09/008".
2. S.A. Salaudeen, P. Arku, Animesh Dutta, 10 - Gasification of Plastic Solid Waste and Competitive Technologies, Editor(s): S.M. Al-Salem, In Plastics Design Library, Plastics to Energy, William Andrew Publishing, 2019, Pages 269-293, ISBN 9780128131404, [CrossRef]
3. U. Arena, 17 - Fluidized bed gasification, Editor(s): Fabrizio Scala, In Woodhead Publishing Series in Energy, Fluidized Bed Technologies for Near-Zero Emission Combustion and Gasification, Woodhead Publishing, 2013, Pages 765-812, ISBN 9780857095411, [CrossRef]
4. ECN Phyllis classification. https://phyllis.nl/Browse/Standard/ECN-Phyllis.
5. Furkan Kartal, Uğur Özveren, A deep learning approach for prediction of syngas lower heating value from CFB gasifier in Aspen plus®, Energy, Volume 209, 2020, 118457, ISSN 0360-5442, [CrossRef]
6. C.-Y. Wen, T.-Z. Chaung, “Entrainment coal gasification modeling”, Ind. Eng. Chem. Process Des. Dev., 18: 684-695, 1979. [CrossRef]
7. H. Idriss, M. Scott, V. Subramani, 1 - Introduction to hydrogen and its properties, Editor(s): Velu Subramani, Angelo Basile, T. Nejat Veziroğlu, In Woodhead Publishing Series in Energy, Compendium of Hydrogen Energy, Woodhead Publishing, 2015, Pages 3-19, ISBN 9781782423614, [CrossRef]
8. Gokhale, Amit A, Dumesic, James A, and Mavrikakis, Manos. 2008. "On the Mechanism of Low-Temperature Water Gas Shift Reaction on Copper". United States. [CrossRef]
9. Phil Amick, 18 - Case study: Wabash River Coal Gasification Repowering Project, USA, Editor(s): Ting Wang, Gary Stiegel, Integrated Gasification Combined Cycle (IGCC) Technologies, Woodhead Publishing, 2017, Pages 699-714, ISBN 9780081001677, [CrossRef]
10. Said MA Ibrahim, Mostafa EM Samy. Syngas Compositions, Cold Gas and Carbon Conversion Efficiencies for Different Coal Gasification Processes and all Coal Ranks. J Mining & Mech Eng 1(2)- 2020. JOMME.MS.ID.000109. DOI: 10.32474/JOMME.2020.01.000109. [CrossRef]
11. Kundariya N, Mohanty SS, Varjani S, Hao Ngo H, W. C. Wong J, Taherzadeh MJ et al. A review on integrated approaches for municipal solid waste for environmental and economical relevance: Monitoring tools, technologies, and strategic innovations. Bioresource technology. 2021 Dec;342:125982. doi: 10.1016/j.biortech.2021.125982. [CrossRef]
12. Duu-Jong Lee, Gasification of municipal solid waste (MSW) as a cleaner final disposal route: A mini-review, Bioresource Technology, Volume 344, Part A, 2022, 126217, ISSN 0960-8524, [CrossRef]
13. Seo, Yong-Chil & Alam, Tanvir & Yang, Won Seok. (2018). Gasification of Municipal Solid Waste. 10.5772/intechopen.73685. [CrossRef]

AUTHORS PROFILE

Nguyen L. Hoang is a post graduate student at National Research University "Moscow Power Engineering Institute", Department of Innovative technologies for high-tech industries. His main area of research including utilizing municipal solid waste to produce energy sources, energy of high temperature technology, and the uses of simulation and modelling for chemical processes.