Chemical Engineering Research Bulletin 23 (2023)
Available online at http://banglajol.info/index.php/CERB
*DOI: https://doi.org/10.3329/cerb.v23i10.78503*

Special Issue on the 7th International Conference on Chemical Engineering (ICChE), 2023
ISSN: 2072-9510 (Open Access)

# SYNGAS PRODUCTION FROM SAWDUST VIA BIOMASS GASIFICATION: A SIMULATION USING ASPEN PLUS SOFTWARE

**Mohammad Nurur Rahman*, Md. Mehedi Hasan and Md. Jahidul Islam Faisal**
Rajshahi University of Engineering & Technology (RUET), Rajshahi-6204, Bangladesh

**Abstract**

Syngas or synthesis gas is very demanding gas mixture mainly containing Hydrogen ($H_2$) and Carbon monoxide (CO) gas which is used in producing of Hydrogen fuel, Methanol, Ammonia. Syngas can be produced from renewable resource like biomass. Sawdust is one of the common, less costly waste biomass found in sawmill. Generally, sawdust is used for burning to make heat for cooking but pyrolysis and Gasification process can turn it as biofuel which is more economic and have versatile usability. By simulating the gasification of sawdust through Aspen plus software, the amount of formation of syngas can be calculated. R-yield or yield reactor is used to calculate the production of syngas for 100% conversion of Biomass into Biofuel as R-yield as ideal reactor, need to specify the basic yield based on ultimate analysis of sawdust. R-Gibb reactor is used to calculate the total heat required completing the whole process found in combustion reaction and dryer is used to dry wet biomass using combustion heat. Produced syngas contains not only $H_2$, CO rather than the mixture of $H_2$, CO, $CO_2$, $CH_4$, $C_2H_4$, $N_2$, $NH_3$, $H_2S$, $H_2O$, solid Carbon and ash content. The simulation conducted on gasification clearly gives the information that's by entering about 1000 kg sawdust in a gasifier with 1358 kg air, temperature raised about 700° C, after thermal conversion about 2218.5 kg syngas, 111.2 kg $H_2O$ and 28.3 kg ash would have found. Primarily, simple flash separator is used to calculate the separated ash content and solid carbon. Cryogenic distillation can be used for individual gas separation.

*Keywords: Biomass, Sawdust, Gasification, Syngas, Optimization, Simulation, Economic evaluation*

## 1. Introduction

Fossil fuels currently account for the greatest portion of the world's energy supply and, if current trends continue, will make approximately 80% of it by 2040 [1]. This scenario will lead to disastrous consequences in terms of environmental damage because of greenhouse gas (GHG) emissions associated with fossil fuels. Inter governmental Panel on Climate Change (IPCC) 2014 report on climate change concluded that more than 75% of total GHG emissions contain $CO_2$. Coal is considered as one of the largest $CO_2$ emission sources in the energy sector that accounts for 40.58% of electricity generation in 2010. According to another report, the share of coal towards world energy output will increase by 33% in 2035 as compared to 2009 because of its abundant nature, affordability and an already existing infrastructure for power generation [2]. Biomass is considered as one of the most promising renewable energy sources and has the potential to replace fossil fuels. Biomass a carbon-neutral fuel also mitigates a very common problem in most other renewable energy sources; such as the intermittent nature of wind and solar energy. Bioenergy is estimated to contribute between a quarter and third of the global energy supply mix by 2050 [3] Conversion of biomass to bio-energy can be divided into two major categories; biochemical and thermochemical. Thermochemical conversion routes for bioenergy production can be divided into four main types; gasification, pyrolysis, liquefaction, and combustion. Gasification among these particularly has the highest conversion efficiency. Biomass gasification to produce syngas (a mixture of CO and $H_2$) is one of the major applications of gasification process. Sawdust has a convenient amount of chemical components, good availability in Bangladesh, and a low price for raw sawdust, so it would be preferable to use it as biomass in the gasification process to produce syngas. Aspen Plus has been used by researchers to simulate processes for biomass derived hydrogen production as well as syngas production [4].

Reduction of fossil fuel is one of the major problems now-a-days. Combustion of fossil fuel has many disadvantages. Fossil fuels pollute the environment. Fossil fuels contribute to greenhouse gases, which is one of their major disadvantages. So we need to reduce our dependency on using fossil fuels and have to introduce renewable energy like biofuel. Production of biofuel from biomass is now one of the most practicable topics. Syngas is very valuable intermediate produced from biomass gasification that can be used in different purpose like: Hydrogen fuel production, Methanol production, Ammonia production etc. This type of biofuel is eco-friendly, and produce less harmful chemical

*Corresponding Author: *nurur@che.ruet.ac.bd*

component during combustion reaction compare to fossil fuel combustion. Our objective is to determine the yield and composition of syngas produced via gasification of sawdust through simulation and to analyze the controlling factors.

Section 2 describes methodology used in this work. Section 3 is the results and discussions followed by conclusions in the Section 4.

## 2. Methodology

Aspen Plus is a process modeling tool used for process monitoring, optimization and conceptual design, especially by chemical process industries. This is a simple course on Aspen Plus Simulation engine that will teach one how to model the most common unit operations of a chemical plant. Basic unit operations such as Pump, Reactor, Valve, Heater, Distillation Column etc. will be demonstrated which would be helpful for students, teachers, engineers and researchers in the area of R&D and Plant Design/Operation. General steps of process modeling on Aspen plus: (1) Selection of Design basis, (2) Process assumption, (3) Components specifications, (4) Method specifications, (5) Property method, (6) Equipment selection and (7) Run process.

Biomass flow rate 1000 kg/hr. Chemical composition of biomass by proximate analysis, ultimate analysis and sulfur analysis are given below [5].

The determination, by prescribed methods, of moisture, volatile matter, fixed carbon (by difference), and ash. The term proximate analysis does not include determinations of chemical elements or determinations other than those named.

Table 1: Proximate component of sawdust

| Proximate Analysis | Wt % (As Received) | Wt % (Dry) |
|---|---|---|
| Moisture | 8.52 | |
| Fixed Carbon | 14.89 | 16.27 |
| Volatiles | 73.68 | 80.54 |
| Ash | 2.91 | 3.18 |
| Total | 100 | 100 |
| HHV (MJ/kg) | | 19.22 |
| LHV (MJ/kg) | | |

Table 2: Ultimate component of sawdust

| Ultimate | Wt% (Dry) |
|---|---|
| Moisture | |
| Ash | 3.18 |
| Carbon | 45.64 |
| Hydrogen | 5.41 |
| Nitrogen | 0.36 |
| Sulfur | 0.06 |
| Oxygen | 45.35 |

Ultimate analysis is defined as the determination of carbon, hydrogen, nitrogen and sulfur in a wide type of organic and inorganic samples, both solid and liquid.

Simulation steps for biomass gasification through Aspen plus is shown in Fig. 1.

Process Assumptions: (1) Process is steady state, (2) No pressure drop and no heat loss are considered, (3) All considered component are in chemical equilibrium (4) Sulfur, nitrogen and chlorine in biomass are assumed to go to the gas phase.

Components were specified based on the analysis of ultimate, proximate and sulfur compound in biomass. A new file was selected, then reactant and product component ID, component name and alias were inputted [6, 7].

PENG-ROB method was selected as base method to predict several pure component properties. PENG-ROB property method is used for nonpolar or mildly polar mixture. Examples hydrocarbon and light gas such as $CO_2$, $H_2$, $H_2S$. This property method particularly is suitable in the high temperature and high pressure regions, such as $H_2$ processing application.

Raw material stream line draw and input all basis data (ultimate, proximate, sulfur), Temperature 25° C and Pressure 1 bar [8].

Dryer (R-Stoic) and Separator:

R-Stoic models a reactor when: Reaction kinetics are unknown or unimportant, Stoichiometry is known, Need to specify the extent of reaction or conversion. Temperature 100°C and Pressure 1bar was specified for Reactor 1.

Reactor-2 (R-Yield) and Separator:

R-Yield models a reactor by specifying reaction yields of each component. This model is useful when: Reaction stoichiometry and kinetics are unknown or unimportant and Yield distribution data or correlations are available. Specifications: Temperature 700°C and Pressure 1 bar.

Reactor-3 (R-Gibbs):

This section describes how to specify, Phase equilibrium only, Phase and chemical equilibrium, restricted chemical equilibrium, Reactions, Electrolyte Systems and Solids.

R-Gibbs accepts restricted equilibria specifications: Fixed moles of any product, Percentage of a feed component that does not react, Temperature approach to equilibrium for the entire system, Temperature approaches for individual reactions and Fixed extents of reaction. Here air is used for combustion reaction to make heat which is used in yield reaction and in dryer to remove moisture from wet biomass [6-7]. The whole process is illustrated in Fig. 2.

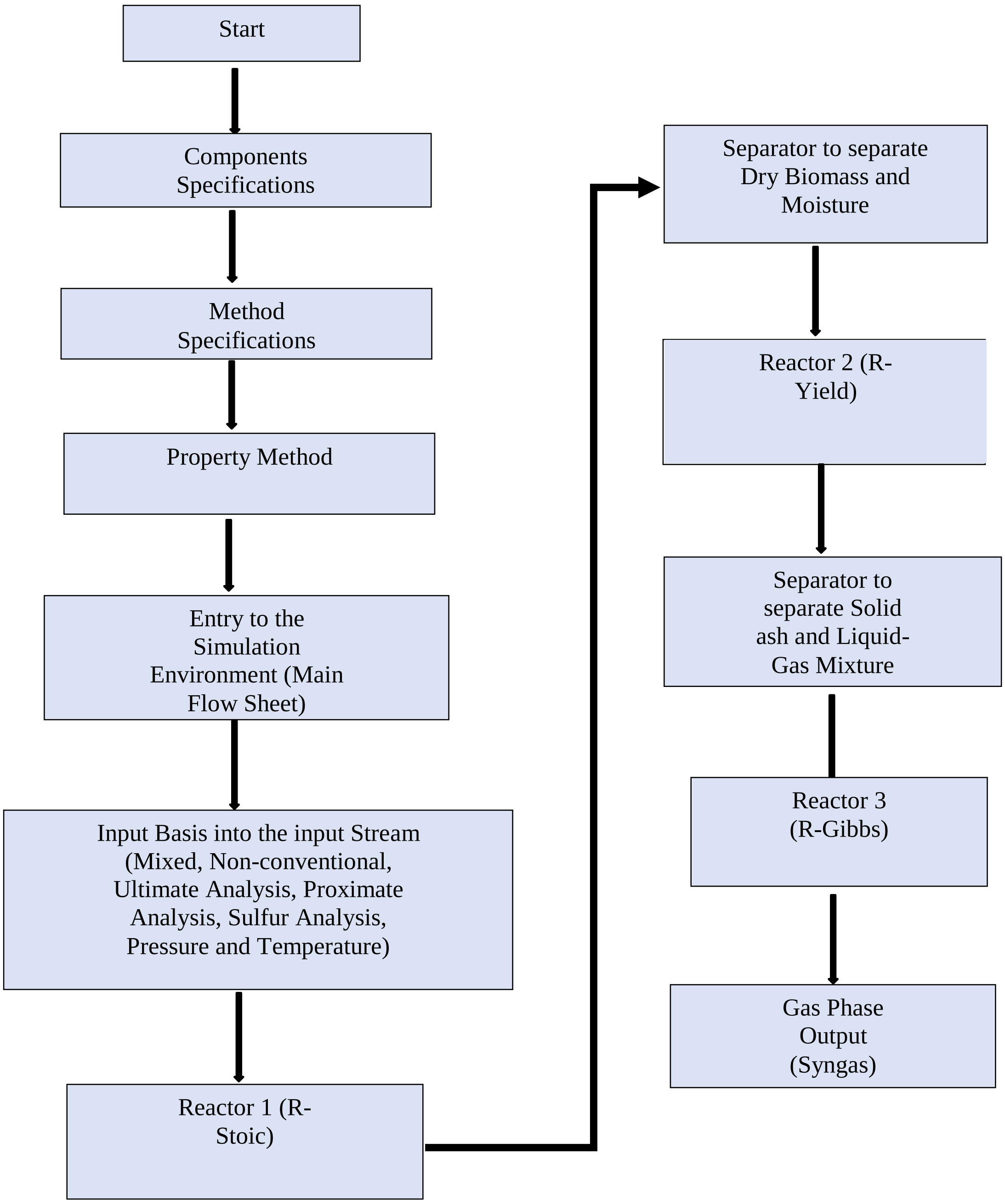


Fig. 1: Biomass gasification through Aspen plus simulation

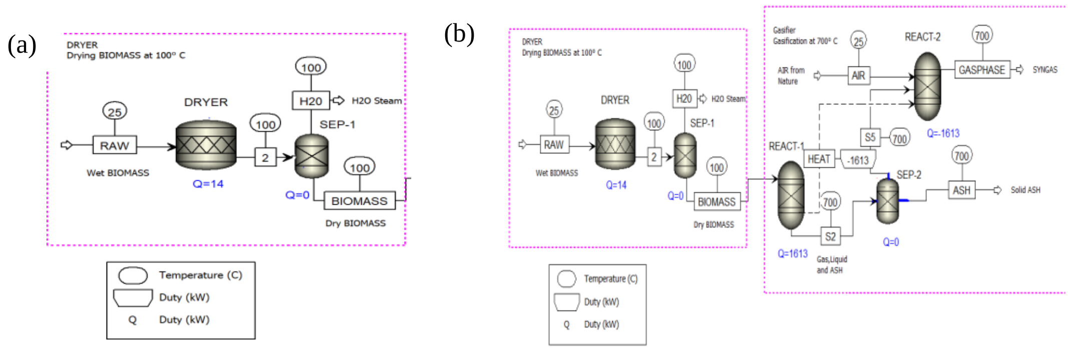




Fig. 2: (a) Dryer unit, (b) Process flow diagram for biomass gasification

## 3. Results and Discussion

This simulation of biomass shows the amount of syngas produced if 100% conversion of biomass is done. Here the data are tabulated with different unit, this are mass flow rate (kg/hr), Mole flow rate (kmol/hr) and mass fraction (unit less).

Table 3: Material balance for whole process

| | Units | Input biomass | Input AIR | ASH | Dry Biomass | GAS PHASE | H20 |
|---|---|---|---|---|---|---|---|
| Description | | | | | | | |
| From | | Dryer | | 2-Sep | 1-Separator | REACT-2 | 1-Separator |
| To | | separator 1 | REACTOR-2 | | REACT-1 | | |
| Temperature | C | 100 | 25 | 700 | 100 | 700.1704718 | 100 |
| Pressure | bar | 1 | 1 | 1 | 1 | 1 | 1 |
| Mass Flows | kg/hr | 1000.001 | 1358 | 28.263 | 888.8 | 2218.546 | 111.201 |

The simulation conducted on gasification clearly gives the information that's by entering about 1000 kg sawdust in a gasifier with 1358 kg air, temperature raised about 700° C, after thermal conversion about 2218.5 kg syngas, 111.2 kg $H_2O$ and 28.3 kg ash would have found.

Table 4: Amount of syngas

| Components | Units | Mole Flows | Mole Fractions *10-3 |
|---|---|---|---|
| Syngas | kmol/hr | 94.05 | 1000 |
| $H_2$ | kmol/hr | 19.27 | 204.87 |
| $CH_4$ | kmol/hr | 0.44 | 4.63 |
| $C_2H_4$ | kmol/hr | 1.58E-1 | 1.68E-06 |
| CO | kmol/hr | 25.40 | 270.10 |
| $CO_2$ | kmol/hr | 7.93 | 84.36 |
| $O_2$ | kmol/hr | 5.19E-2 | 5.52E-23 |
| $N_2$ | kmol/hr | 37.30 | 396.57 |
| $NH_3$ | kmol/hr | 0.01 | 4.10E-03 |
| $H_2S$ | kmol/hr | 0.02 | 0.17 |
| $H_2O$ | kmol/hr | 3.69 | 39.23 |
| S | kmol/hr | 0 | 0 |
| C | kmol/hr | 0 | 0 |

By using of sensitivity tool as model tool analysis, effect of temperature on production of syngas are clearly shown. Table 5 of production rate of different gas at different temperature with 100% conversion of biomass are given below.

The key components are $H_2$, CO, $CO_2$, $N_2$, $NH_3$. The table does not indicate the direct conversion of biomass rather than conversion of some conventional gas into other conventional gas. Here some are decreased and some are increased for the reason of further chemical reaction. $H_2$ and $N_2$ reacts and form $NH_3$, as well as CO decrease and $CO_2$ increase reason of perfect combustion reaction on organic hydrocarbon

Conversion of reactant into product depends on reaction kinetics and pressure can effect on reaction kinetics if the reactant is in gas form.

Table 5: Temperature effect on syngas production

| Temp °C | $H_2$ Kmol/hr *10-3 | CO Kmol/hr *10-3 | $CO_2$ Kmol/hr *10-3 | $N_2$ Kmol/hr *10-3 | $NH_3$ Kmol/hr *10-3 |
|---|---|---|---|---|---|
| 650 | 19273.05 | 25411.28 | 7929.81 | 37297.92 | 3.846 |
| 700 | 19268.79 | 25403.65 | 7934.46 | 37297.92 | 3.852 |
| 710 | 19267.94 | 25402.13 | 7935.40 | 37297.92 | 3.853 |
| 730 | 19266.22 | 25399.05 | 7937.27 | 37297.91 | 3.855 |
| 750 | 19264.47 | 25395.94 | 7939.17 | 37297.91 | 3.858 |
| 810 | 19259.1 | 25386.41 | 7944.98 | 37297.91 | 3.865 |
| 830 | 19257.28 | 25383.18 | 7946.95 | 37297.91 | 3.867 |

Table 6: Effect of Pressure

| Pressure BAR | $H_2$ Kmol/hr *10-3 |
|---|---|
| 1 | 19268.79 |
| 51 | 19268.79 |
| 151 | 19268.79 |
| 201 | 19268.79 |
| 301 | 19268.79 |
| 351 | 19268.79 |
| 451 | 19268.79 |
| 500 | 19268.79 |

Table 6 and shows that theoretically, there is no effect of pressure on that chemical conversion reaction because the reactant was in solid phase and product is formed as gas mixture. This table shows that theoretically there is no effect of pressure on this process.

Effect of combustion air on reactor Temperature: In combustion reaction, heat of reaction depends on the amount of Oxygen enter to the reactor and being completely combusted.

Table 7: Effect of combustion air on reactor Temperature

| Air Kg/hr | Reactor1 °C |
|---|---|
| 1315.00 | 685.95 |
| 1321.11 | 686.31 |
| 1333.33 | 689.97 |
| 1351.67 | 697.38 |
| 1357.78 | 700.07 |
| 1363.89 | 702.87 |
| 1370.00 | 705.79 |

Since Aspen plus simulation is a theoretical process modeling tool used for process monitoring, optimization so the total amount of $O_2$ present in air was entered to the reactor would have combusted completely and produced maximum amount of heat. From table 7 it is clearly seen that to reach 700°C temperature in two reactor 1358 kg/hr air was needed to enter to the reactor for combustion reactor.

## 4. Conclusions

By simulating the gasification of sawdust through Aspen plus software, the amount of formation of syngas can be calculated. R-yield or yield reactor is used to calculate the production of syngas for 100% conversion of Biomass into Biofuel as R-yield as ideal reactor, need to specify the basic yield based on ultimate analysis of sawdust. R-Gibb reactor is used to calculate the total heat required completing the whole process found in combustion reaction and dryer is used to dry wet biomass using combustion heat. Produced syngas contains not only $H_2$, CO rather than the mixture of $H_2$, CO, $CO_2$, $CH_4$, $C_2H_4$, $N_2$, $NH_3$, $H_2S$, $H_2O$, solid Carbon and ash content. The simulation conducted on gasification clearly gives the information that's by entering about 1000 kg sawdust in a gasifier with 1358 kg air, temperature raised about 700° C, after thermal conversion about 2218.5 kg syngas, 111.2 kg $H_2O$ and 28.3 kg ash would have found. Primarily, simple flash separator is used to calculate the separated ash content and solid carbon. Cryogenic distillation can be used for individual gas separation.


## Acknowledgement

The authors acknowledge greatly the support provided from RUET.


## 5. References


[1] Tauqir, W., Zubair, M. and Nazir, H. Parametric analysis of a steady state equilibrium-based biomass gasification model for syngas and biochar production and heat generation, *Energy Conversion and Management*, **2019**, vol. 199, p. 111954.

[2] Han, C. et al. IGCC Process Alternatives for Simultaneous Power Generation and $CO_2$ Capture. *PhD thesis*, **2015**.

[3] Basu, P. Biomass gasification and pyrolysis: practical design and theory. *Academic press*, **2010**.

[4] Abdelouahed, L., Authier, O., Mauviel, G., Corriou, J. P., Verdier, G. and Dufour, A. Detailed modeling of biomass gasification in dual fluidized bed reactors under aspen plus, *Energy & fuels*, **2012**, vol. 26, no. 6, pp. 3840–3855.

[5] Wang, B., Zhao, S., Huang, Y., and Zhang, J. Effect of some natural minerals on transformation behavior of sulfur during pyrolysis of coal and biomass, *Journal of analytical and applied pyrolysis*, **2014**, vol. 105, pp. 284–294.

[6] Segovia-Hern´andez, J. G. and G´omez-Castro, F. I. Stochastic process optimization using Aspen Plus®. CRC Press, **2017**.

[7] Hantoko, D., Yan, M., Prabowo, B., Susanto, H., Li, X. and Chen, C. Aspen plus modeling approach in solid waste gasification in *Current developments in biotechnology and bioengineering*, **2019**. pp. 259–281.

[8] Han, J., Liang, Y., Hu, J., Qin, L., Street, J., Lu, Y. and Yu, F. Modeling downdraft biomass gasification process by restricting chemical reaction equilibrium with aspen plus, *Energy conversion and management*, **2017**, vol. 153, pp. 641–648.