Available online at www.sciencedirect.com

ScienceDirect

Procedia Engineering 90 (2014) 710 – 717

Procedia Engineering

www.elsevier.com/locate/procedia

10th International Conference on Mechanical Engineering, ICME 2013

A Numerical investigation of municipal solid waste gasification using aspen plus

SharminaBegum[a*], M. G. Rasul[a]and DelwarAkbar[b]

[a]*School of Engineering and Technology, Central Queensland University, QLD 4702, Australia*
[b]*School of Business and Law, Central Queensland University, QLD 4702, Australia*

Abstract

The purpose of this paper is to present a numerical simulation model of a fixed bed gasifier for municipal solid waste (MSW) using ASPEN Plus (Advanced System for Process Engineering Plus) software. The model wasdeveloped based onGibbs' free energy minimisation approach and was validated with experimental data of MSW gasification available in literature. Proximate and ultimate analysis of MSW and operation conditions used in the model development are presented and discussed. The study found that simulated and predicted composition of syngas wasin good agreement with experimentally measured data (within 4%). The model can be used to analyse performance of gasification process for varying operating parameters, such as air-fuel ratio, gasifier temperature and moisture content of MSW. This model can be used for other biomass feedstocks, such as wood waste, green waste, food waste etc. to predict the syngas composition at optimised operating condition.

Selection and peer-review under responsibility of the Department of Mechanical Engineering, Bangladesh University of Engineering and Technology (BUET)

Keywords: Gasification; Municipal solid waste; Fixed bed; Aspen Plus; Syn-gas

1. Introduction

The demand for energy in our daily life is increasing day by day. Now it is a major issue to explore and exploit new sources of energy that are renewableandeco-friendly.Renewable energy sourceshave a minimum environmental impact than conventional energy sources. The renewable energy sources such as solar, wind, hydro wave, geothermal and biomass offer attractive prospects because they are unlimited and cheap [1]. Biomass, which is made

* Corresponding author. Tel.: +61-7-49309283
E-mail address: s.begum@cqu.edu.au

Selection and peer-review under responsibility of the Department of Mechanical Engineering, Bangladesh University of Engineering and Technology (BUET)
doi:10.1016/j.proeng.2014.11.800

up of a wide variety of municipal solid waste (MSW), green waste and agricultural residues, are found in large quantity and it is amajor contributor to renewable energy [2]. Biomass is also considered as a valuable energy alternativeto fossil fuels. It may be converted to a variety ofusable forms of energy such as syngas, biogas and liquid transportationbiofuels [3].

Municipal solid waste (MSW) gasification is likely to play a significant role in energy production and conversion. The application of MSW gasification has enormous prospects in the energy security, mitigation of climate change and sustainable settlement development. A number of thermo chemical processes can convert the carbonaceous materials of biomass to a combustible syngas where Gasification plays lead role [4]. Gasification takes place when oxygen (O_2) or air is reacted at high temperatures with available carbon in biomass or other carbonaceous material within a gasifier. The gasification process is comprised of three linked processes; pyrolysis (decomposition), gasification, and partial combustion. Partial combustion is necessary because it supplies the heat required by the endothermic gasification reactions [5]. The end product, syngas, is comprised mainly of carbon monoxide (CO) and hydrogen (H_2) which have a large number of industrial and household applications. Nowadays, gasifiers are not only utilised for the chemical and petrochemical industries, but also has its application in many other fields.

The research on process simulation for gasification is limited, though there has been substantial research involving gasification of MSW, sugarcane bagasse, green waste and other different types of wastes. Recently, Mavukwana*et al.* [6] performed simulation of sugarcane bagasse gasification using Aspen Plus and they compared the model data with experimental results published in the literature, and the overall data were found to be in good agreement. Ramzan*et al.* [7] developed a steady state model using Aspen Plus to study the gasification of MSW, food waste and poultry waste. They validated the model with experimental data obtained through a hybrid biomass gasifier. They also investigated the effect of equivalent ratio (ER), gasification temperature and moisture content on gasification performance. Another study has been done by Chen *et al.* [8] on two different types of fixed bed reactor for MSW simulation. They discussed the effect of flue gas from the combustion section on the composition and lower heating value (LHV) of syngas, heat conversion efficiency, and carbon conversion at different gasification temperatures and air equivalence ratios.

The aim of this study is to develop a fixed bed gasifier model for MSW to predicting the steady-state performance of the model. The developed simulation model is validated with data for MSW measured by Naveed*et al.* [9]. This paper presents details of the modelling approaches taken to obtain a process simulation model and its validation. The model can be used for a number offeedstocks, such as, wood waste, green waste, food waste and parametric studies to predict the effect of air-fuel ratio, gasifier temperature and moisture content.

2. Model Development

Aspen Plus, an extensive process modelling computer software packageswas used in this study due to its huge capacity and precise outcomes in process modelling. A fixed bed gasifier model was developed for MSW gasification using Aspen Plus software. The simulations of the biomass gasification process were based on mass-energy balance and chemical equilibrium among all processes. Aspen Plus is based on 'blocks' consequent to unit operations as well as chemical reactors, through which most industrial operations can be simulated. It comprises several databases containing physical, chemical and thermodynamic data for a wide variety of chemical compounds, as well as a selection of thermodynamic models required for accurate simulation of any given chemical system [10]. In this study, the developed Aspen Plus model involves the following sequential steps: (1) stream class specification, (2) property method selection, (3) system component specification (from databank) and identifying conventional and non-conventional components, (4) defining the process flowsheet (using unit operation blocks and connecting material and energy streams), (5) specifying feed streams (flow rate, composition, and thermodynamic condition) and (6) Specifying unit operation blocks (thermodynamic condition, chemical reactions, etc.). To simulate fixed bed unit operation in Aspen Plus, a number of FORTRAN codes and reactions are nested within the Aspen plus input file.

2.1 Simulation Assumptions

The assumptions were considered in simulation are:(a)The model is at steady state, kinetic free and isothermal, (b) Chemical reactions take place at an equilibrium state in the gasifier, and there is no pressure loss, (c)All elements except sulphur content take part in the chemical reaction, (d)All gases are ideal gases, including hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), steam (H_2O), nitrogen (N_2) and methane (CH_4) and (e)Char contains only carbon and ash in solid phase.

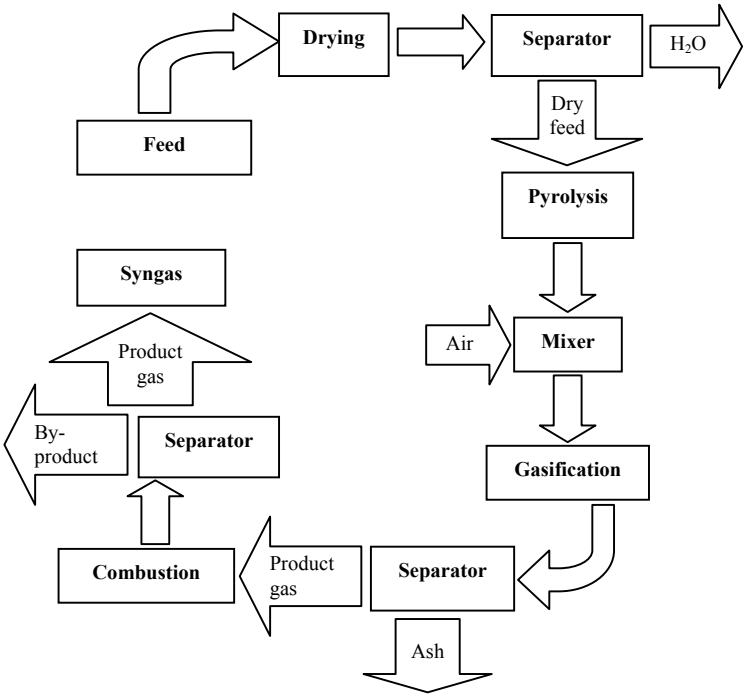

Fig. 1. Process flowchart of fixed bed gasification

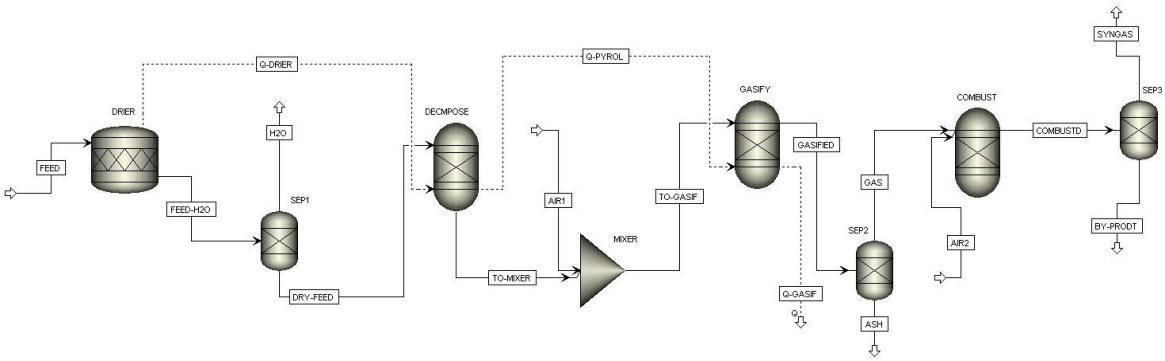

Fig. 2. Aspen Plus simulation flowchart

2.2 Gasification Model

A number of steps consist of the overall gasification process: (a) drying; (b) decomposition; (c) gasification; and (d) combustion. A process flowchart and an Aspen Plus simulation flowchart of biomass gasification are shown in Figures 1 and 2 respectively. Feed is specified as a non-conventional component in Aspen Plus and defined in the simulation model by using the ultimate and proximate analysis. The model is based on minimisation of the Gibbs free energy at equilibrium. This simulation is developed under the assumption that the residence time is long enough to allow the chemical reactions to reach an equilibrium state. The characteristic of MSW and input parameters of gasifieroperating conditions are given in Table 1 and Table 2 respectively.

Table 1: Characteristics of MSW [9]

Proximate Analysis (%)	
Moisture content (MC)	12
Fixed carbon (FC)	15.47
Volatile matter (VM)	38.29
Ash	46.24
Ultimate Analysis	
C	36.4
H	4.97
O	10.15
N	1.44
S	0.802

Table 2: Gasifier operating parameters for MSW

Feed (kg/hr)	Flow rate (kg/hr)	10
	Pressure (bar)	1
	Temperature (°C)	25
Air	Flow rate (kg/hr)	1-10
	Pressure (bar)	1
	Temperature (°C)	25
Gasifier	Pressure (bar)	1
	Temperature (°C)	500-1000

2.3 Property Method

The Redlich-Kwong-Soave (RKS) cubic equation of state with Boston-Mathias alpha function (RKS-BM) has been used to estimate all physical properties of the conventional components in the gasification process. This property method is comparable to the Peng Robinson cubic equation of state with the Boston-Mathias alpha function (PR-BM) property method. RKS-BM is recommended for gas-processing, refinery and petrochemical applications such as gas plants, crude towers and ethylene plants. Using RKS-BM, reasonable results can be expected at all temperatures and pressures. The RKS-BM property method is consistent in the critical region. The enthalpy and density model selected for both feed and ash are non-conventional components, HCOALGEN and DCOALIGT. In this study, feed was defined as non-conventional components from the perspectives of ultimate and proximate analysis (Table 1). Ashes were also defined as a non-conventional component with an ash content set to 100%.

2.4 Model Sequence

A number of Aspen Plus reactors were used to develop the model. The main processes were simulated by three reactors in Aspen plus: RStoic, RYield and RGibbs. The gasification process begins with the decomposition (pyrolysis) region and continues with the combustion region. The relevant reactions (1) – (7) considered in these processes were [11& 12]:

$C + O_2 = CO_2$(carbon combustion) (1)

$C + 0.5O_2 = CO$ (carbon combustion) (2)

$C + CO_2 = 2CO$ (Boudouard) (3)

$C + H_2O = CO + H_2$ (water -gas) (4)

$CO + H_2O = CO_2 + H_2$ (CO shift) (5)

$C + 2H_2 = CH_4$ (methanation) (6)

$H_2 + 0.5O_2 = H_2O$ (hydrogen combustion) (7)

2.4.1 Drying

The purpose of this region is to reduce the moisture content of the feedstock. The Aspen Plus stoichiometric reactor, RStoic (model id: DRIER), was used to simulate the evaporation of moisture. The drying operation was controlled by writing a FORTRAN statement in the calculator block. RStoic converts a part of feed to form water which requires the extent of reaction known as:

$$Feed \rightarrow 0.0555084 H_2O \quad (8)$$

In this step, the moisture of each feedstock is partially evaporated and then separated using a separator model, Sep2 (model id: SEP1) through split fractionation of the components. The dried feedstock is placed into the next region for decomposition after being separated from the evaporated moisture. The evaporated moisture was drained out from the process. The produced heat of reaction associated with the drier (model id: Q-DRIER) was passed by a heat stream into the RYield reactor where decomposition occurs.

2.4.2 Decomposition

Decomposition is one of the main steps of the gasification process where each feedstock is decomposed into its elements. The Aspen Plus yield reactor, RYield (model id: DECMPOSE), was used to simulate the decomposition of the feed. The yield reactor converts non-conventional feed into conventional components by using a FORTRAN statement. In this step, feed is converted into its components including carbon, oxygen, nitrogen, hydrogen, sulphur and ash by specifying the yield distribution according to the feedstock's ultimate analysis. The yield distribution of feed into its components was specified by a FORTRAN statement in the calculator block. The decomposed elements mixed with air at an Aspen MIXER block are ready for gasification.

2.4.3 Gasification

The RGibbs reactor is a rigorous reactor for multiphase chemical equilibrium based on Gibbs free energy minimisation. RGibbs was used to simulate gasification of biomass. The Gibbs free energy of the biomass cannot be calculated because it is a non-conventional component. Therefore, before feeding the biomass into the RGibbs block it was decomposed into its elements (C, H, O, N, S, etc.) using the RYield reactor. The reactor calculates the syngas composition by minimising the Gibbs free energy and assumes complete chemical equilibrium. The heat of reaction associated with the decomposition (Q-PYROL) of feed was passed by a heat stream into the RGibbs reactor where gasification occurs. The decomposed feed and air enter into the RGibbs reactor where partial oxidation and gasification reactions occur. Carbon partly constitutes the gas phase, which takes part in devolatisation, and the remaining carbon comprises part of the solid phase. A very minimum heat (model id: Q-GASIF) produced at gasification escapes from the process through a heat stream. A separator model, Sep2 (model id: SEP2) was used to separate ash from the gas mixture using split fractionation of the components.

2.4.4 Combustion

To complete the gasification process, another RGibbs reactor was used in the combustion section with minimum air mixing. This combustion process is also based on the principle of minimisation of Gibbs free energy. To identify the syngas components from by-products, a separator model, Sep2 (model id: SEP3), was used.

3. Results and Discussion

The developed simulation model was validated using measured experimental data of MSW gasification for a lab-scale hybrid gasifier published by Naveed*et al.* [10]. The experimental and simulation results are shown in Figure 3. It is observed from Figure3 that the simulation results are in good agreement with experimental results. Experimental results are compared and presented with error bars which indicate that the simulation data are within 96% confidence level. The effect of air-fuel ratio and gasification temperature on gasifier performance was studied using the validated model. The concentration of syngas composition (H_2, CO, CO_2 and CH_4) for varying air-fuel ratios and gasification temperatures are shown in Figure 4 and 5 respectively.

The air-fuel ratio is the ratio of the amount of air required for a unit amount of fuel to complete combustion. This ratio has a strong effect on syngas production. In this study, the air-fuel ratio was varied from 0.1 to 1.0 while the gasifier temperature was 700°C. It can be seen from Figure 3 that the concentration of CO_2 increases (10% to 40%) with increasing air-fuel ratio and that of CO decreases (75% to 40%) after the air-fuel ratio increases from 0.3 to 1.0; and concentration of H_2 decreases (10% to 2%), whileCH_4 does not vary with air-fuel ratio. The effects of gasification temperature on syngas production at an air-fuel ratio of 0.2 are shown in Figure 5. The gasifier temperature was varied from 500°C to 1000°C. It is clearly seen from Figure 5 that the Concentration of CO increases (75% to 90%) with increasing gasifier temperature, particularly after 650°C; conversely, CO_2 decreases as shown in Figure 7. H_2 and CH_4 both vary slightly with highertemperature.

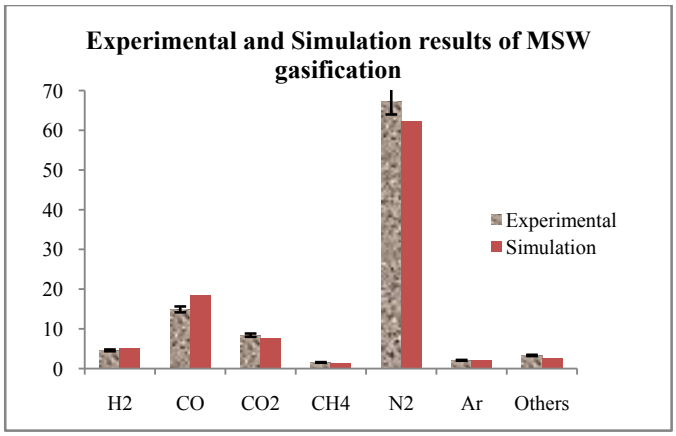

Fig.3.Experimental and simulation results of syngas composition.

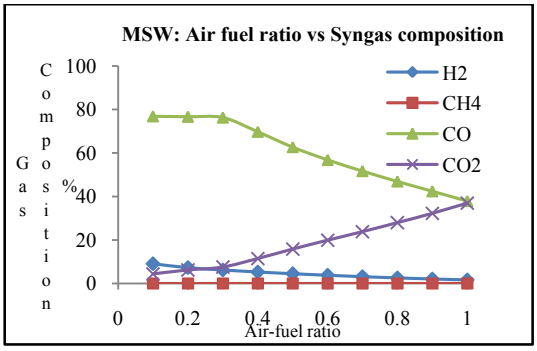

Fig. 4. Effect of air-fuel ratio (Gasifier temperature: 700°C).

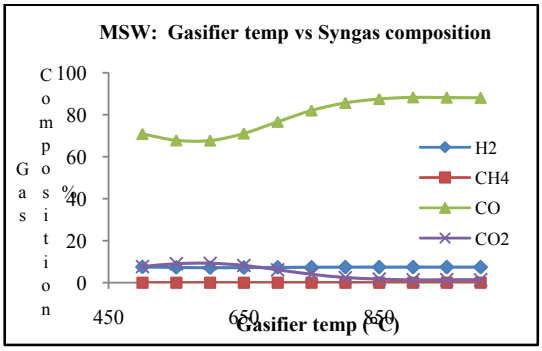

Fig. 5. Effect of gasifier temperature (air-fuel ratio: 0.2).

4. Conclusion

This research developed a fixed bed gasifier model by using Aspen Plus simulation software for MSW gasification, along with detail information regarding model development and simulation flow sheet for MSW gasification. The model was validated and compared with the experimental data measured by Naveed*et al*. The key results generated fromthis model were good agreement (within 4% range) with the experimental data. This model is also suitable for simulation of MSW and other feedstock such aswood, green waste, sugarcane baggage etc.). The model is capable ofpredicting gasifier performanceover a wide range of operating conditions.Using the model, the impact of parameters, e.g. air-fuel ratio, gasifier temperature, moisture content on the entire operation can be estimated.Further study is being under taken for modelling performance by optimising operating condition using different biomass feedstocks such as, wood, green waste, sugarcane baggage, coffee bean husk etc.

References

[1] J.-F. Akinbami,,M.Ilori, T. Oyebisi, Akinwumi, I., &O. Adeoti, Biogas energy use in Nigeria: current status, future prospects and policy implications. *Renewable and Sustainable Energy Reviews, 5*(1) (2001), 97-112.

[2] B.Antizar-Ladislao, &J. L.Turrion-Gomez, Second-generation biofuels and local bioenergy systems. *Biofuels, Bioproducts and Biorefining, 2*(5) (2008), 455-469.

[3] Converti, A., Oliveira, R., Torres, B., Lodi, A., &Zilli, M. Biogas production and valorization by means of a two-step biological process. *Bioresource technology, 100*(23) (2009), 5771-5776.

[4] J.Rezaiyan,&N. P. Cheremisinoff, *Gasification technologies: a primer for engineers and scientists*: CRC press.2005

[5] W. Doherty, A.Reynolds, &D.Kennedy, *Simulation of a circulating fluidised bed biomass gasifier using Aspen Plus: A performance analysis.* Proceedings of 21st International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems, June 24-27, 2008, Crakow-Gliwice, Poland, 1241-1248.

[6] A.Mavukwana,K.Jalama, F.Ntuli, &K.Harding, *Simulation of sugarcane bagasse gasification using Aspen Plus*. Proceedings of International Conference on Chemical and Environmental Engineering (ICCEE'2013), April, 2013, Johannesburg, South Africa, 70-74.

[7] N.Ramzan, A.Ashraf, S.Naveed, &A.Malik, Simulation of hybrid biomass gasification using Aspen plus: A comparative performance analysis for food, municipal solid and poultry waste. *Biomass and Bioenergy, 35*(9) (2011), 3962-3969.

[8] C.Chen, Y.Jin, J.Yan, &Y. Chi, Simulation of municipal solid waste gasification in two different types of fixed bed reactors. *Fuel,* 11(8)(2011).

[9] S.Naveed, A.Malik, N.Ramzan, &M.Akram, A comparative study of gasification of food waste (FW), poultry waste (PW), municipal solid waste (MSW) and used tires (UT). *Nucleus, 46*(3) (2009), 77-81.

[10] L.Zheng, &E.Furimsky, Aspen simulation of cogeneration plants. *Energy Conversion and Management, 44*(11) (2003), 1845-1851.

[11] N.Ramzan, A.Ashraf, S.Naveed, &A.Malik, Simulation of hybrid biomass gasification using Aspen plus: A comparative performance analysis for food, municipal solid and poultry waste. *Biomass and Bioenergy, 35*(9) (2011), 3962-3969.

[12] V.Skoulou, A.Zabaniotou, G. Stavropoulos&G.Sakelaropoulos, Syngas production from olive tree cuttings and olive kernels in a downdraft fixed-bed gasifier. *International Journal of Hydrogen Energy, 33*(4) (2008), 1185-1194.