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Research paper



Study of Kinetic Modelling of Syngas Production Over Plasma Gasification

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Abstract

Plasma gasification is able to produce syngas from several feedstock e.g. sawdust, pellet, plastic and oil but there is lack of knowledge in this process through kinetic modelling. To have better understanding this study determines parameters kinetic modelling due to changes of temperature and conversion. The method uses the stoichiometry chemical reaction, material balance, energy balance, and numerical solution to calculate parameters of kinetic modelling. The result of simulation gets pre-exponential factor 9.78 to 13.1 for sawdust, pellet, and plastic with temperature 1200-1500^{o}C and conversion 99%. Meanwhile oil need a higher temperature 1600^{o}C to achieve similar conversion and it indicate a higher pre-exponential factor 67.6 than other feedstock.

Keywords: *Kinetic Modelling; Pre-exponential Factor; Plasma Gasification; Syngas*

1. Introduction

Gasification of biomass is one of thermal treatment to produce energy [1] and it is green and renewable technology to produce bioenergy and biofuel from biomass. [2,3]. In addition it decreased possibility to disposal waste to landfill [4]. The one of energy generated by gasification is syngas which come from high density polyethylene (HDPE) [5], biomass [6,7].

Plasma gasification has been developed causes conventional gasification has limitations due to a lower temperature and dilution oxidation media with the chemical product [8]. Experiment plasma gasification has been applied for Municipal Solid Waste (MSW) [9–11], Medical Waste (MW), [3,12], and biomass [8]. To make better understanding during process modeling of plasma gasification also has been conducted such as Gibbs energy minimization [13], Euler-Euler multiphase model [14], Numerical modeling [15], an equilibrium plasma gasification model [16].

There are study of kinetic model in coal gasification and biomass gasification but it is not for syngas production of plasma gasification of biomass and waste [1,17]. There is lack of knowledge related kinetic modelling over plasma gasification for biomass and waste. The study has two problem statements. Firstly, how pre-exponential factors in kinetic modeling of plasma gasification for biomass and waste are. Secondly, how pre-exponential factors from biomass and waste have effect in temperature and conversion are.

This paper conducted research to determine parameters of kinetic modelling and to know influence feedstock in temperature and conversion during process. The result is useful to design Plasma Gasification Reactor (PGR) of biomass and waste.

2. Materials and Methods

Method of research is to develop proposed chemical reaction through molar equilibrium in reactant and product over plasma gasification and to understand chemical reaction through kinetic modelling. From previous experiment the four feedstock (sawdust, pellet, plastic, and oil) was used [8].

2.1 Proposed Chemical Reaction

(1) use %volume of syngas production, (2) convert flowrate of syngas production from slm (standard liter per minute) to m3/min, (3) use density and Molecular Weight (Mr) [19] to calculate product coefficient in kmol/hr (a,b,c,d, and e). (4) use rule of stoichiometry to calculate reactant coefficient in (x,y,z,p, and q) as showed in table 2 and 3. (5) calculate Mr CxHyOz which sum atom relative C, H, and O multiply x, y, and s, respectively.

2.2 Kinetic Modelling

Determination of model assumption, (2) Generation of mass balance and energy balance to have Ordinary Differential Equation (ODE), (3) Solving of simultaneously ODE with Runge Kutta in Program of MATLAB 2016b.

Table 1: Nomenclature

Notation	Description
A	Pre Exponential Factor,1/min
C	Concentration, kg/min
C_{in}	Concentration of Input, kg/min
C_{out}	Concentration of Output, kg/min
Cp	Specific Heat Capacity, kJ/kg.K
Cp_h	Oxidation of Specific Heat capacity. kJ/kg.K

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E	Activation Energy, kJ/kmol
LHV	Low Heat Value, kJ/kg
m_h	Oxidation of Flow rate, kg/min
Mr	Molecular Weight, kg/kmol
R	Gas Constant, 8.314 kJ/kmol.K
T	Temperature of process, K
T_h	Oxidation of Temperature
X	Conversion
P	Density, kg/m^3
a	Coefficient of CO product, kmol/h
b	Coefficient of CO_2 product, kmol/h
c	Coefficient of H_2 product, kmol/h
d	Coefficient of CH_4 product, kmol/h
e	Coefficient of O_2 product, kmol/h
x	Coefficient of Carbon reactant, kmol/h
y	Coefficient of Hydrogen reactant, kmol/h
z	Coefficient of Oxygen reactant, kmol/h
p	Coefficient of CO_2 reactant, kmol/h
q	Coefficient of H_2O reactant, kmol/h

Model Assumptions

(1). Reactor uses batch process, so there is no input and output during process.

(2). Chemical Reaction follows First Order Chemical Reaction, equation 1.

$$r = k.C \quad \ldots(1)$$

(3). Chemical Reaction Constant follows Arrhenius Equation, equation 2.

$$k = A.\exp\left(\frac{-E}{RT}\right) \quad \ldots(2)$$

(4). Homogen Reaction happen in this process, equation 3.

$$Cout = C \quad \ldots(3)$$

(5). Unsteady state applies in this chemical reaction so there is changes of concentration, conversion or temperature toward time.

Mass Balance

$$\text{Rate of Accumulation} = \text{Rate of Input} - \text{Rate of output} \pm \text{Rate of Reaction} \quad \ldots(4)$$

for feedstock reaction,

$$(-V.Cin)\frac{dX}{dt} = 0 - 0 - (r.V) \quad \ldots(5)$$

Where,

$$Cout = Cin(1 - X) \quad \ldots(6)$$

then,

$$\frac{dX}{dt} = A.\exp\left(\frac{-E}{RT}\right).(1 - X) \quad \ldots(7)$$

Energy Balance

$$\text{Rate of Accumulation} = \text{Rate of Input} - \text{Rate of output} \pm \text{Rate of Reaction} \quad \ldots(8)$$

for exothermic reaction,

$$(m.Cp)\frac{dT}{dt} = m_h.\text{Cp}.(T - T_h) - 0 + LHV.r.V \quad \ldots(9)$$

where,

$$m = \rho.V \quad \ldots(10)$$

and,

Cph for CO2 and H2O = f(Th) [19]

then,

$$\frac{dT}{dt} = \left[LHV.A.\exp\left(\frac{-E}{RT}\right).C_{in}.(1 - X) + m_h.Cp_h.(T - T_h)\right].\frac{1}{(Cp.\rho)} \quad \ldots(11)$$

Numerical Solution

Fourth Order Runge-Kutta could solve simultaneously ODE [18]. It applied for equation 6 and 9 with initial condition t = 0 to 10 minute with step size 0.1 min, Tin = 1200 oC or 1200 (+273) K, X in = 0.

3. Results and Discussion

Conversion of syngas production increases significant at first 5 minutes for all materials. Meanwhile temperature is range between 1200-1500oC for sawdust, pellet and plastic and it is up to 1600 oC for oil. Table 2 shows the proposed chemical reaction over plasma gasification. Solving of equation (6) and (9) results table parameters of kinetic modelling represented table 3.

All materials use single value of energy activation but they use different values of pre-exponential factor.

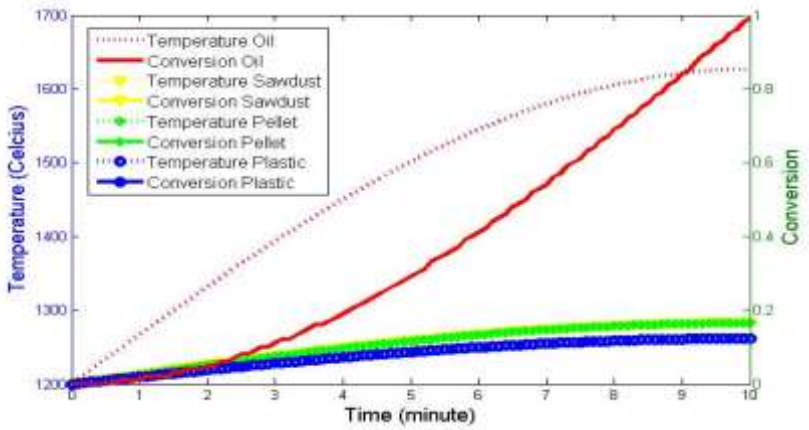


Figure 1: Simulation of Kinetic Modelling

Table 2: Proposed Chemical Reaction

Material	Chemical Reaction
Sawdust	$C_{5.51}H_{1.82} + 0.46\ CO_2 \rightarrow 0.85\ CO + 0.06\ CO_2 + 0.84\ H_2 + 0.03\ CH_4$
Pellet	$C_{4.53}H_{1.54} + 0.38\ CO_2 \rightarrow 0.73\ CO + 0.03\ CO_2 + 0.75\ H_2 + 0.01\ CH_4$
Plastic	$C_{4.14}H_{1.49}O_{0.38} + 0.35\ CO_2 \rightarrow 0.74\ CO + 0.09\ CO_2 + 0.75\ H_2 + 0.02\ O_2$
Oil	$C_{2.55}H_{0.48}O_{0.01} + 0.21\ H_2O \rightarrow 0.17\ CO + 0.02\ CO_2 + 0.40\ H_2 + 0.02\ CH_4 + 7.0\times10^{-4}\ O_2$

Table 3: Parameters of kinetic modeling

Notation	Sawdust	Pellet	Plastic	Oil
A	13.1	13.1	9.78	67.6
E	150.31	150.31	150.31	150.31
LHV	1.914×10^{-2}	2.312×10^{-2}	2.331×10^{-2}	6.408×10^{-2}
Mr	7.32	6.06	6.01	3.03
ρ	448.56	448.56	1762.6	913.14
Cp	2.310	2.310	1.5254	1.428
C_{in}	0.5	0.5	0.19	0.152
m_h	1.433	1.433	5	0.18
T_h	1473	1473	1473	1473

LHV, C_{in}, T_h, m_h Source:[8]
ρ, Cp, R Source: [19]
E Source: [20]

Figure 1 presents simulation of kinetic modelling over plasma gasification. It shows that sawdust, pellet and plastic have similar range of pre-exponential factor 9.78 to 13.1 to achieve similar temperature range 1200-1500oC and conversion 99%. Therefore, these results have agreement with previous experimental study [8]. Other results for oil as feedstock indicate a higher pre-exponential factor 67.6 to have similar conversion with other materials. There is possibility that the liquid state such as oil needs higher temperature to achieve high conversion.

4. Conclusion

This research is study of kinetic modelling over plasma gasification. The result get pre exponential factor 9.78 to13.1 to achieve similar temperature 1200-1500oC and conversion. Meanwhile to achieve similar conversion oil used a higher pre-exponential factor 67.6 causing a higher temperature up to 1600oC.

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