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Preliminary Study of Slow Pyrolysis for Banana Peel Biomass in Tube Chamber based on Computational Fluid Dynamics

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Abstract. Dry banana peel as a biomass can be converted towards bio-char using slow pyrolysis methods. The tube chamber that used where slow pyrolysis occur must be in relatively uniform temperature at to ensure the condition are fulfilled in the process. Computational Fluid Dynamics (CFD) method applied to estimate the temperature distribution inside the tube chamber and time needed for the uniformity of temperature is achieved. The tube chamber dimension is 36.5 cm of height with 7.7 cm diameters. The grid generation process performed for the chamber using full hexahedral cell with average orthogonal quality close to 1 that indicated excellent mesh. The observation plane placed right in the middle of tube chamber axially where 6 observation points was placed to observe the change of temperature over time. The simulation process take place in transient regime where the temperature change overtime. The heating sources with heat flux entering uniform in whole outer surface as the wall temperature will peak at 923 K. The heat balance and P1 radiation method was used to obtain the temperature distribution. The simulation results showed a good agreement compared to the experiments. The distribution temperature showed that minimum temperature for pyrolysis process (650°C) already achieved in all of the region. The uniformity of temperature itself achieved after the surfaces of tube chamber reached 650°C for more than 200 seconds.

1. Introduction

Indonesia is a country that has huge amount of biomass resources. Biomass can be obtained from household and industrial waste [1]. One of the popular process to convert biomass is the utilization of pyrolysis technology. Pyrolysis is a process that requires heat that used to decompose biomass into a simple molecule from long chain of hydrocarbon. By using pyrolysis, biomass can be converted towards liquid, solid, and gas phase. Liquid and gas phase product can be used as bio-oil while the solid phase are called char [2]. Pyrolysis operation condition usually lies between 500 – 600°C and considered as high temperature process with lots of energy necessary [3]. Pyrolysis divided into two main categories which are slow and fast pyrolysis.

Fast pyrolysis has widely used as a process where the desired product is bio-oil or liquid hydrocarbon. Slow pyrolysis instead used when production of char is the main product. Bio-char can be converted to activated carbon which predominantly on the size of micro and mesoporous that potentially used as adsorbent for hazardous material in the air [4]. However, the slow pyrolysis process can be modified and resulted in significant amount of bio-oil and gas. Fast pyrolysis system usually has short residence time (10-20 seconds) with high heating rate whereas slow pyrolysis system has long residence time (5 – 30 minutes) with low heating rate [5]. Temperature and heating rate are two of the most variables with major influence concerning yield of slow pyrolysis products. It is most importance to control the temperature uniformity and constant heating rate [6]. While it is difficult to ensure the temperature distribute equally through experiment because of cost barrier, another method such as computational fluid dynamics (CFD) has widen the possibility. However, CFD approach should only utilize with proper validation. Nevertheless, the usage of CFD has flexibility advantageous compared to experiment [7].

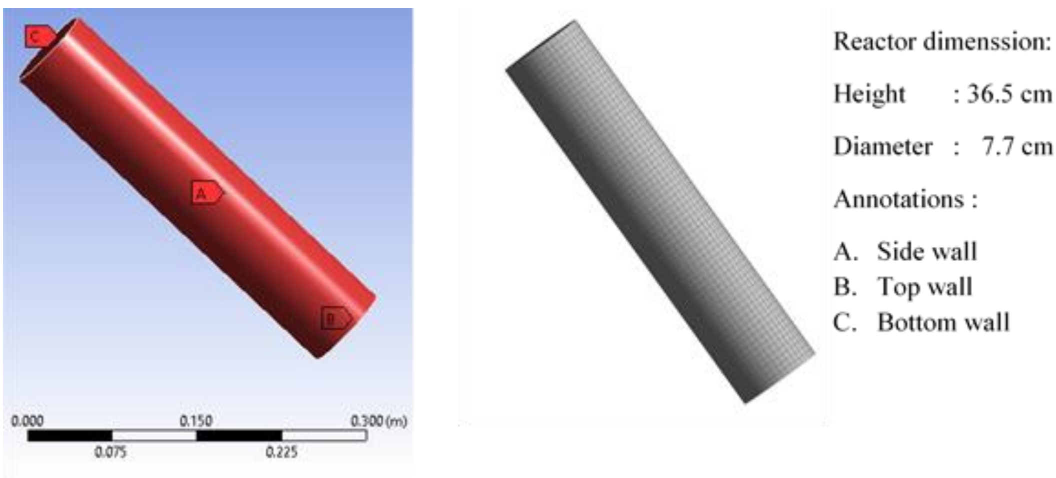
Lots of scientist used CFD as a tools to predict pyrolysis characteristic. Papakidis (2009) conducted investigation of fast pyrolysis using CFD in entrained flow reactor resulted in good agreement between experiment and simulation using Langrangian (discrete model) approaches. Boateng (2012) and Gentile (2015) enquire continued fast pyrolysis investigation with CFD to assisted and showed that simulation is able to reproducing satifactory results compared with the experiments. Aside from Langrangian approaches, many scientist also using Euler-Euler approach with practically similar result and demonstrated tha capability of CFD to predict the key variables of fast pyrolysis [11], [12]. Yu (2015) and Zhong (2019) amplified the utilization of CFD to characterizes fast pyrolysis using user defined function (UDF) and novel gas-solid separation mechanism also stated its great potential to aid the optimization of biomass fast pyrolysis process. However, only few researchers using CFD to assist slow pyrolysis process due to high computational cost. Hartulistiyoso (2015) can be considered using CFD to predict the temperature distribution of slow pyrolysis process of polyethylene terephtalate (PET) degradation. The result of inside temperature prediction with CFD only has small difference value compared to experiment data.

Banana peel is one of indonesian potential sources of biomass. The characteristic of its high cellulose motivate many researcher to fabricate it become bio-char. Slow pyrolysis process with temperature around 650°C across the chamber are the proposed optimum operating condition. It is important to ensure the uniformity of temperature inside pyrolysis chamber and time needed to achieve the optimum temperature. The aim of this paper is preliminary study of slow pyrolysis simulation based on CFD to investigate the temperature distribution and time to reach optimum temperature for banana peel biomass pyrolysis chamber after the surface of pyrolysis temperature reached 923 K.

2. Methods

2.1. Pre-Processing

Geometry of pyrolysis chamber is cylindrical tube where the main process take places. The experiment will commence heat to reactor by electrical jacket. Geometry of pyrolysis chamber will be set as one whole cellzone with wall as a surface where the heat enter in to the chamber.



(a) (b)

Figure 1. Definition of grid generation on pyrolysis chamber (a) and mesh full hexahedral (d)

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For grid generation (mesh), multizone methods is conducted to achieve full hexahedral mesh.

Table 1. Mesh specification for pyrolysis chamber

No	Component	Parameter
1	Number of nodes	20097
2	Number of elements	18538
3	Skewness average	0.13
4	Orthogonal quality average	0.981

Mesh quality shown by skewness and orthogonal quality. Average skewness resulted in 0.13 (< 0.25) indicated excellent mesh and supported by average orthogonal quality close to 1. The almost identical number of nodes and elements signify each control volume uniformity and orderliness.

2.2. Solver

Solver is a step in CFD where correct model considered to get temperature distribution. Slow pyrolysis simulation steps are :

1. Activate heat balance model
   Heat balance model equation :
   $$\frac{\partial(\rho E)}{\partial t}+\frac{\partial}{\partial x_i}\left(U_i(\rho E+p)\right)=\frac{\partial}{\partial x_i}\left(k_{eff}\frac{\partial T}{\partial x_i}-\sum_{j'}h_{j'}J_{j'i}+U_j(\tau_{ij})_{eff}\right)+S_h$$
   Where k_{eff} is effective conductivity and $J_{j'I}$ is species flux diffusion. The first three variables on the right side represent heat transport through conduction, species diffusion, and viscous dissipation respectively. S_h is heat from chemical reaction with T_{ref} 300 K.
2. Radiation Model
   Radiation model used for this simulation is P1 as the most simple model. This model based on radiation intensity expansion on the geometry.
   P1 radiation model equation :
   $q_r=-\frac{1}{3[a+\sigma_s]-C\sigma_s}\nabla G$; where
   a = Absorption coefficient
   σ_s = Scattering coefficient
3. Numerical methods used for calculation is finite volume with second order upwind as discretization scheme dan SIMPLE as algebraic algorithm
4. Wall boundary condition set as a heating sources with heat flux entering uniform in whole surface as the wall temperature will peak at 923 K.

2.3. Post-Processing

Post-processing design start by made an observation plane right in the middle of pyrolysis chamber. The main idea of observation plane is to get general temperature contour inside the pyrolysis chamber. Across the observation plane there are 6 observation points attached along the axis that has distance 0.0025, 0.0625, 0.1225, 0.1825, 0.2425, and 0.3025 meter also named observation point 6 to 1 respectively from the bottom of pyrolysis chamber.

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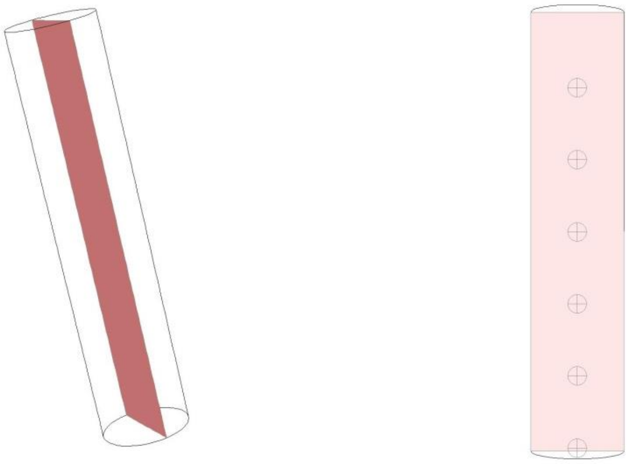


(a) (b)

Figure 2. Design for observation plane (a) and observation points (b) inside the pyrolysis chamber

3. Result and Discussion

From experiment design, the themocouple was placed in the wall surface of the pyrolysis chamber. It shows that the temperature at 923 K was achieved at 72 minutes heating process. However, the thermocouple should only observe the temperature of the middle surface of the chamber, while uniformity indeed needed to achieve better yield for slow pyrolysis.

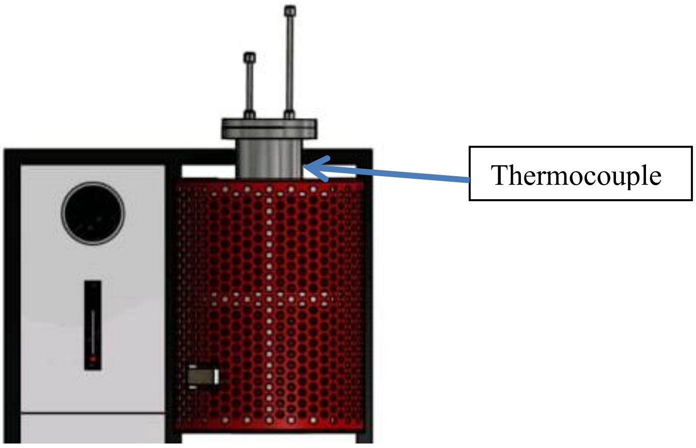
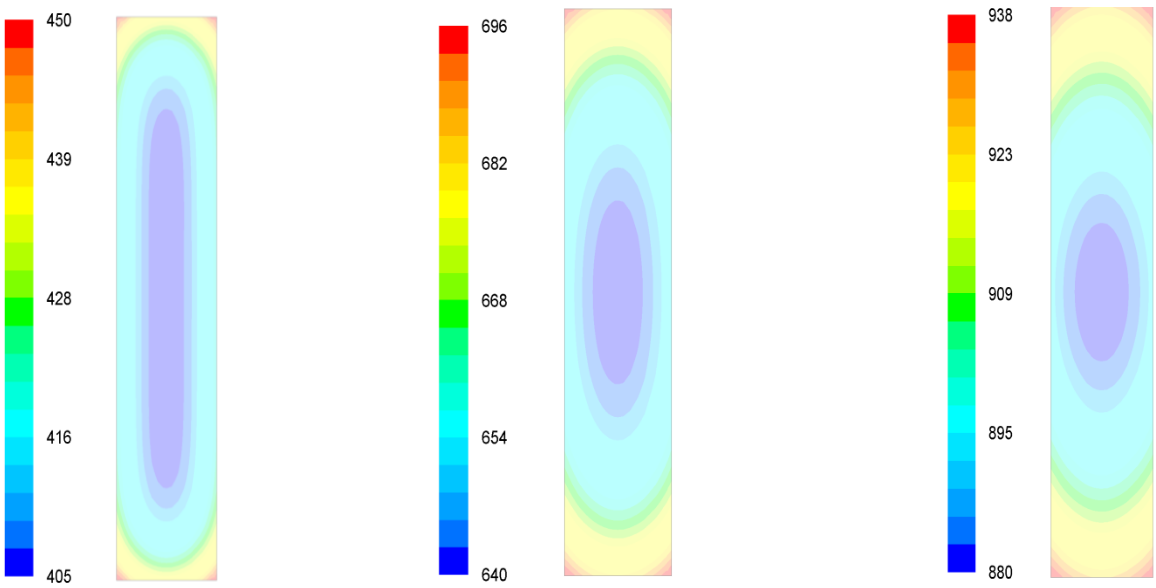


Figure 3. Thermocouple placement in the pyrolysis chamber

The heat source setting is only coming from wall heat flux and the heat loss was neglected. The simulation commencing in transient / unsteady state regime with 1 second time step to reduce the computational cost. The results shown that even after the surface of the chamber reach 923 K, it will take times to distributed uniformly.



(a) (b)

Figure 4. Contour of temperature (in Kelvin) distribution when the surface of pyrolysis chamber after (a) t = 2000 s ; (b) t = 3000 s ; (c) t = 4000 s

It can be seen as figure 4 (a) shown, after heating time reach 2000 s the dark blue zone still dominantly occur in the chamber. The dark blue zone means relatively low temperature (880 K) and still not optimum for slow pyrolysis operating condition. The dark blue zone relatively decreased along the continuation of heating as figure 4 (b) shown. After the heating continued for almost 4000 s, the contour of temperature starting to distributed relatively uniform as can be concluded from the figure 4 (c). The dark blue zone starting to decrease significantly and the temperature uniformity starting to achieved. The simulation shows it will take 66.7 minutes duration of heating to reach 923 K surface temperatures and has approximately 7.36% error compared to experimental data (72 minutes). The difference can be occurred due to noice of thermocouple that not included in the calculation for CFD simulation.

Figure 5 shown that the phenomenon varies for each observation points. The observation point 6 is the first to reach 923 K as its placed closest to wall as the heating source. The last point that reached the optimum temperature were observations point 3 that has to be expected since it placed relatively in the middle of pyrolysis chamber. It can be stated from figure 5 that as the beginning after the surface temperature reached 923 K, the temperature inside the pyrolysis chamber still varies across the axis. The uniformity starting to occur when the heating process prolonged for more than 200 seconds. It suggest that even after the temperature indicator in the experiment design shown 923 K, it needs more times to reach temperature uniformity so the heating source should not be turn off.

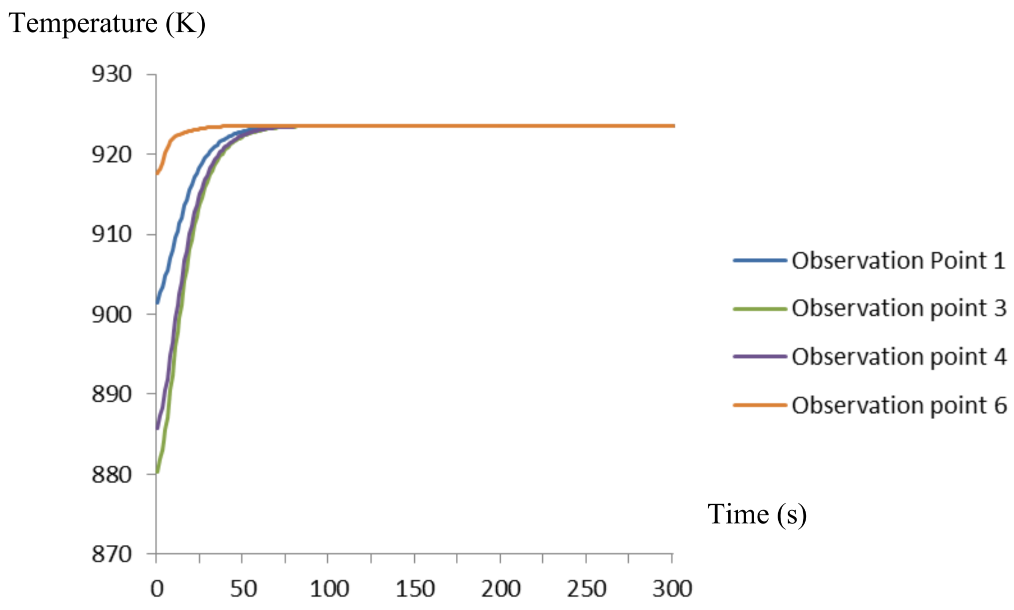


Figure 5. Temperature distribution over time across the pyrolysis chamber based on observation points after t = 4000 s

4. Conclusions

Unsteady state simulation based on CFD has conducted for the simulation of slow pyrolysis process of banana peel with 1 second time step size. There is still 7.36 % error compared with experimental data due to the absence of thermocouple noice calculation in CFD simulation. The simulation results suggest that the uniformity will take more times to achieved after the surface temperature reached 923 K, so the prolonged heating will need to be commenced. There is an opportunity for further study for the CFD approach to estimate the yields of slow pyrolysis by the incorporation of reaction parameters and experimental validation.

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