TEMPERATURE DISTRIBUTION OF EMPTY FRUIT BUNCH IN A VERTICAL REACTOR 3D MODEL SIMULATED BY COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT

Oil palm empty fruit bunch (EFB) has a moderate calorific value, comparable to palm mesocarp fiber and wood chips. An important energy source based on the huge amount of EFB, approximately 500,000 tonnes, generated each year from oil palm milling activities, with a large fraction of the fiber and much of the shell are used as fuel to generate process steam and electricity in the palm processing mill. EFB conversion into liquid product know as 'pyro-oil' by fluidized bed fast pyrolysis method is considered to be one of the most promising thermochemical conversion processes. Pyrolysis has been proven to be a mature technology in many other biomasses, such as wood waste and agriculture stalks. Hence, pyrolysis is a viable solution for managing the palm oil EFB waste, especially in Malaysia, one of the most important alternative technology energy sectors. The liquid oil may be used as a fuel in dedicated diesel engines and in industrial gas turbines. Besides, there are scopes to upgrade this oil to obtain high grade fuel and valuable chemicals. Basically, inside the pyrolyzing of EFB, heat is transmitted by the conduction inside the solid particle, convection inside the solid pores; and convection and radiation from the surface of the pellet. A better understanding on heating process is needed before implement pyrolysis method. The simplicity, it is assumed that heat is transmitted inside the solid by conduction where heat transfer coefficient represents the overall effect of the above mechanisms. A 3D EFB in a vertical reactor model was developed using an advanced computational fluid dynamics (CFD) technique. CFD is a computer-based tool for simulating the behavior of process systems involving mass and heat transfer, and other related physical heating processes. The used of CFD tools is to predict the temperature distribution during heating process, which also involve control volume based on finite element method for solving mathematical heat model. Two shapes of EFB models were used to investigate the temperature distribution at 300°C. Thus, the established heating method used to implement into pyrolysis method in order to validate the experimental work where to produce highly quality of renewable source of energy.

Keywords: *Oil palm, EFB, CFD, heating, pyrolysis, temperature, validate*.

INTRODUCTION

Computer speed has been widely used over the last few years. It becomes interesting, tempting and within acceptable time and cost constraints to simulate packed beds with three-dimensional computational fluid dynamics (CFD), in order to provide insight in flow patterns (Jafari et al, 2008). Computational fluid dynamics (CFD) has evolved in the past decades into a formidable field, reaching from numerical methods through the turbulence theory to chemical kinetics and drawing upon many other areas such as multiphase flows or radiative heat transfer (Hájek, 2008). It is a fast growing technology that can be useful to obtain shorter product process development cycles, to optimize energy requirements, to optimize existing processes and to efficiently design new products and processes (Jafari et al, 2008). CFD has allowed promising applications of numerical simulations to the modeling of multiphase flow in packed bed reactors.

Therefore it is not surprising that CFD finds applications in a field so varied as thermal waste treatment. However, the frequency of applying CFD to simulate parts of thermal waste treatment (TWT) technologies is small compared to other processes employing combustion as glass or metal production, furnaces in chemical and petrochemical industry (Hájek, 2008). So far, most of the studies in literature on pyrolysis more into the models for biomass particles, slabs or cylinders and some handfuls of reports investigate the behavior of wood biomass particles during pyrolysis and gasification (Vijeu et al, 2008). Rostami et al (2004) has integrated the Distributed Activation Energy Model (DAEM) with the CFD application to predict the evolution rate and yield of some volatiles from pyrolysis of cellulose, charcoal and tobacco sample. Papadikis et al (2008) has used the Eulerian approach to model the bubbling behavior of the sand inside fluidized bed reactors during fast pyrolysis by using the CFD modeling. This simulation has been done for 2-D and 3-D model and it was compared each others.

The main purpose of CFD development is to offer a capability comparable to other computer-aided engineering tools. Some of the advantages of CFD are (Versteeg and Malalasekera, 2005):

i. It is a package that reduces the lead times and the cost of new designs.

ii. It is able to study the system where controlled experiments are difficult or impossible to perform which
iii. usually used for large system.

iv. It is also able to study the system under hazardous conditions at and beyond their normal performance limit which have been used in safety studies and accident scenarios.

v. CFD also producing practically unlimited level of details results.

The objective of this paper is to investigate the effects of the Empty Fruit Bunch (EFB) shape to the temperature distribution during the pyrolysis process. According to the literature, most of researcher was interested to investigate the effect of the parameters to the yield of the product during pyrolysis process compared to the parameters that effect the temperature distribution on the pyrolyzed materials.

THEORETICAL OF RESEARCH

Empty Fruit Bunch (EFB) is an example of the solid waste that has a potential in producing a renewable energy. It is one of the type biomass resources and can be classified as agricultural crops (Goyal et al, 2008). Now a day, waste management become a big issue due to the rapid out-growth and urbanization. The thermo-chemical conservation process is one of the ways to overcome this problem. Thermo-chemical conversion process which including pyrolysis, gasification and liquefaction is a promising non-nuclear form of future sources of energy. Due to the waste management problem, biomass still become the most traditional fuel in the rural sector where it is utilized in a highly inefficient manner with a low overall efficiency, contributed significantly to environmental pollution and health hazard.

Pyrolysis process is one of the process that consist of the thermal degradation by application heat in absence of oxygen or air where the relatively low temperature is between 500°C-900°C is employed compared to gasification is between 800°C-1500°C (Sadhukan et al, 2008). This process is an independent process for the production of useful energy and chemical which occurs as the first step in the gasification or combustion process (Babu and Chaurasia, 2003). Using the pyrolysis route, low chemical energy density biomass fuels can be converted to high energy density gaseous fuels and residual char.

Tsai et al (2007) was investigated about the effects process parameter such as pyrolysis temperature, heating rate, holding time, nitrogen gas flow rate, condensation temperature and particle size on the pyrolysis product yields and chemical compositions. Abdullah and Gerhauser (2008) was derived bio-oil from empty fruit bunches through fast pyrolysis process and analyzed the oil product composition and compared it with the bio-oil that derived from wood and petroleum fuels. Chaurasia and Babu have developed a model and run a simulation on pyrolysis of biomass to predict the effect of thermal conductivity, the effect of the reactor temperature and particle size on the product concentrations. These effects have been analyzed by different types of geometries such as slab, cylinder and sphere.

When a solid particle of biomass is heated in an inert atmosphere the following phenomena occur (Babu and Chaurasia, 2003):

- Heat is transferred to the particle surface by radiation or convection and then to the inside of the particle.

- The temperature inside the particle increases and causing:
  - Removal of moisture that is present in the biomass particle
  - The pre-pyrolysis and main pyrolysis reaction takes place

- The heat changes due to the chemical reactions and phase contribute to a temperature gradient as function of time.

- Volatile and gaseous products flow through the pores of the particle and participate in the heat transfer process. The pyrolysis reactions proceed with a rate depending upon the local temperature.

- During pyrolysis process, the pores of the solid are enlarged and solid particle merely becomes more porous because biomass converts into gases.

- The enlarged pores of the pyrolyzing solid offer many reaction sites to the volatile and gaseous products of pyrolysis and favour their interaction with the hot solid.

- Inside the pyrolyzing particle, heat transmitted by the following mechanism:
  - Conduction inside the solid particle
  - Convection inside the particle pores
  - Convection and radiation from the surface of the material

- For simplicity, It is assumed that heat transmitted inside the solid by conduction only.

IMPORTANT ASSUMPTIONS

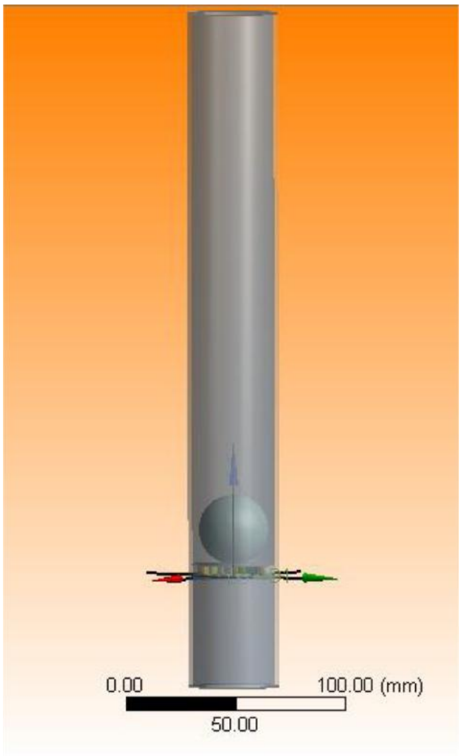
The pyrolysis model is constructed using four interacting submodels for the main phenomenon occurring in the reactor which are heat transfer, drying and thermo-chemical decomposition of Empty Fruit Bunch (EFB). So some important assumptions are needed and listed below:

1. The properties of the helium gas and empty fruit bunch are assumed to be constant throughout the simulation;
2. Helium gas at 1000˚C is used instead of microwave to heat the palm oil empty fruit bunch as the substitution of pyrolysis process.
3. The pyrolysis reactor fluidized bed is an adiabatic process.
4. Heat is introduced through reactor walls and the heat transfer model calculates the temperatures for all nodes, for the solid part as well as for the fluid part.

MODEL DESCRIPTION

Designing a model

The helium gas flow through a filter plate at 50.71 mm from the bottom of the reactor (glass plate material with inner diameter = 38 mm, outer diameter = 42 mm and the length of reactor = 307.71 mm) at a mass flow rate of helium is 5.9607x 10-7kg/s. The EFB was located at the center of the reactor and the shape of the EFB was designing into two shapes which are irregular shape and regular shape (sphere shape where the diameter is 32 mm) where both models have the porosity values equal to 0.25. This reactor then was heated to the 300˚C and the helium gas flow was considered as a laminar flow. The scope of this simulation is to determine the temperature profile inside the reactor and the EFB. Figure 1.1 show the model of the EFB and flow of the gas inside the reactor.



(a)

(b)

Figure 1.1: The position of EFB inside the vertical reactor (a) Regular shape of EFB (b) Irregular shape of EFB

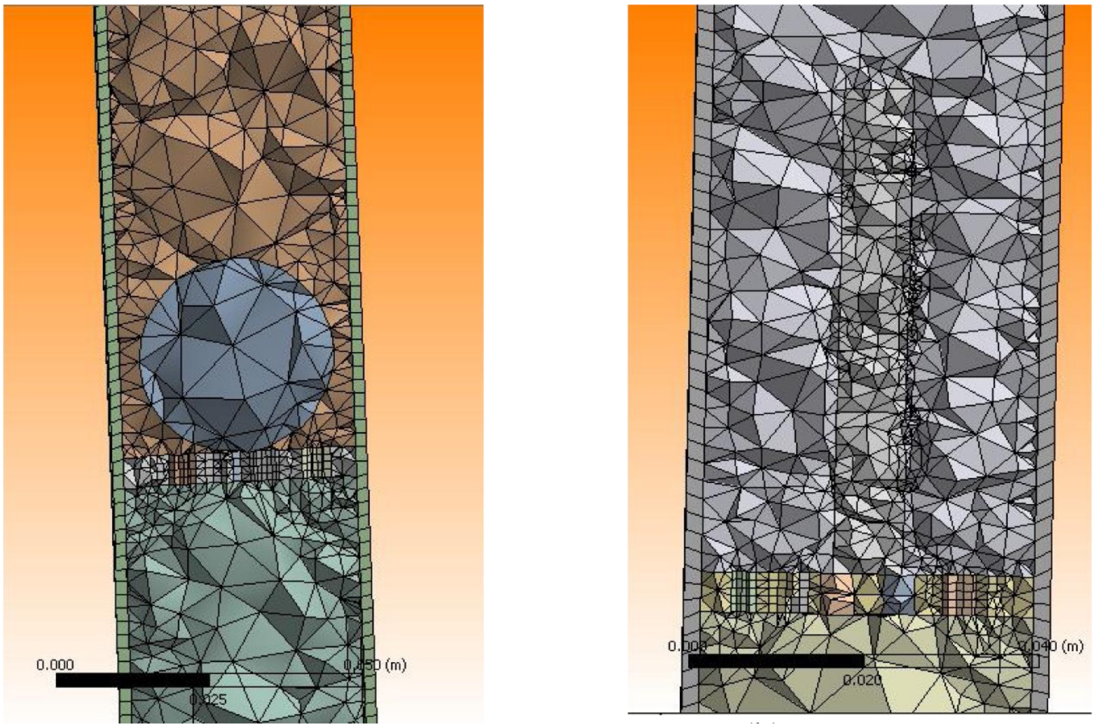
Meshing the model

Meshing is process where the cell on the domain of the model was generated. In this part, the automatic method was selected for this model where there exist various editable variables to be adjust to be define the mesh in the domain. Both models were meshing and all the meshing properties are stated in table 1.1.

Table 1.1: The mesh statistic for regular and irregular models of EFB

Parameters	Regular shape (sphere)	Irregular shape
Total no of nodes	28319	35222
Total no of elements	75867	105473

Figure 1.2 (a) and (b) was showed the meshing part inside the reactor and it was showed that the mesh are topology each other. The smaller the mesh sizes the more tetrahedrons the domain can carry and hence the more precise the result would be.



(a) (b)

Figure 1.2: The meshing part inside the reactor (a) Regular shape of EFB (b) Irregular shape of EFB

Physic definition

All the properties of the materials that involved in this simulation are assumed to be constant throughout the simulation and were shown in the table below:

Table 1.2: The properties of helium gas

Properties	Helium gas	Source
Density, ρ (kg/m3)	0.179	Ansys CFX software
Specific Heat, CP*(J/kg.˚K)	5240	
Thermal Conductivity, *k* (W/m.˚K)	0.1415	
Dynamic Viscosity, μ (kg/m.s)	1.86 x 10-5	
Molar Mass (kg/kmol)	4.0	

Table 1.3: The properties of empty fruit bunch

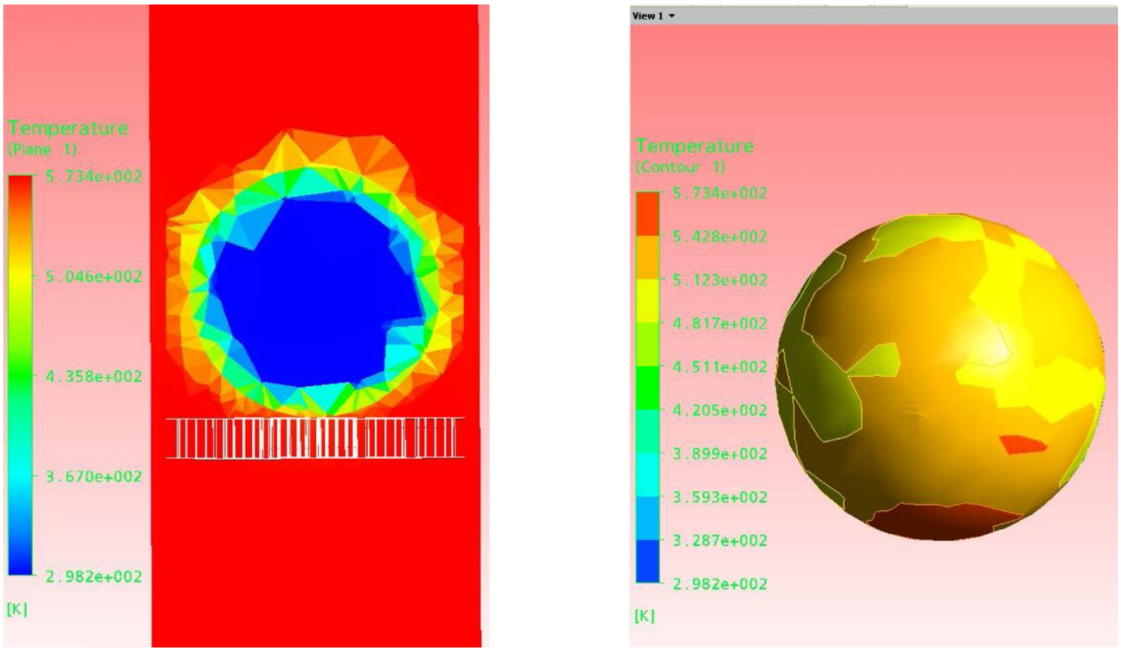
Properties	Palm Oil Empty Fruit Bunch	Source
Density, ρ (kg/m3)	1420	Rozita Omar et al., 2007
Specific Heat, CP (J/kg.˚C)	2817	MPOB Bangi
Thermal Conductivity, *k* (W/m.˚C)	0.195	MPOB Bangi
Molar Mass (kg/kmol)	1.5×106 -	-

Table 1.4: The properties of glass plate (material for reactor)

Properties	Glass Plate	Source
Density, ρ (kg/m3)	2500	Ansys CFX software
Specific Heat, CP (J/kg.˚K)	750.00	
Thermal Conductivity, *k* (W/m.˚K)	1.4	
Molar Mass (kg/kmol)	1.0	

RESULTS AND DISCUSSIONS

According to the figure 1.3 (b), it's shown that the temperature distribution on the surface of EFB, where the bottom part of the sphere is heated more and the temperature is at the greatest compared to the top part which shows the lowest temperature. The hot helium flow over from the bottom to the top which cause the bottom part of the EFB heated the most and with highest temperature distribution on the EFB (Cengel, 2004).



(a) (b)

Figure 1.3 (a) Temperature distributions on regular shape of EFB at 300°C. (b) Temperature distributions at plane YZ of regular shape of EFB at 300°C.

While figure 1.3 (a) was shown the temperature distribution inside the reactor and the EFB where the temperature inside the sphere EFB is lower compared to the nearest the surface. The red colors represent the hottest part while the blue colors represent the coolest part.

For the irregular shape, the temperature profile has been shown in figure 1.4 (b). It is observed that the temperature distribution on bottom of the irregular shape of EFB is higher compared to others part. While, inside the reactor and EFB (refer figure 1.4 (a)), it was observed that, only in the middle part of that shape showed the lowest temperature compared to the left and the right side of this shape. This is because the flow pattern of the helium gas over the irregular shape of EFB is different from the spherical shape.

CONCLUSIONS

A model was developed to simulate the temperature distribution inside the reactor (including the EFB) during the pyrolysis process. This simulation was run for two shapes of empty fruit bunch (EFB) to see the effects of the shapes to the temperature distributions during the pyrolysis process. A CFD code, Ansys-CFX 11.0 was used as the computational tool for the numerical computation where with the helium gas of 300°C is used instead of microwave to heat the EFB as the substitution of pyrolysis process.

From the temperature distribution of both shapes, it is obviously showing that the irregular shape EFB contains more portions in higher temperature and is distributed uniformly compared to the regular shape of EFB. As a result, irregular shape of EFB will be more efficiently pyrolyzed compared to the regular shape if the pyrolysis process is carried out. As a conclusion, irregular shape EFB carried out under laminar flow of 300°C nitrogen gas of heating will give better result compared to regular shape EFB.

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