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COMPUTATIONAL FLUID DYNAMICS SIMULATION OF LABORATORY SCALE REACTOR OF FAST PYROLYSIS FLUIDIZED BED

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DECLARATION

I, the undersigned, hereby declare that this report is my own independent work except as specified in the references and acknowledgements. I have not committed plagiarism in the accomplishment of this work, nor have I falsified and/or invented the data in my work. I am aware of the University regulations on Plagiarism. I accept the academic penalties that may be imposed for any violation.

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ABSTRACT

The application of fluidized bed has emerged since the past decade as one of the most potential and promising solution to a relatively wide spectrum of engineering field, particularly on the biochemical processing industry. Fast pyrolysis has gained its huge popularity in the biofuel and bio-oil industry due to its high production rate using the technology of fluidized bed. Even though an enormous number of academic studies have been performed experimentally to improve and understand more on the fluidization process; however, the complex hydrodynamics and interaction of the fluidized particles are still not largely understood. Therefore, computational fluid dynamics (CFD) has turned out to be a useful tool to predict and solve for the particles interaction and flow behaviour in the fluidized bed. Among the CFD techniques and module available on the market, Euler-Eulerian Two-Fluid Model (EE-TFM) have been chosen as to study and obtain the operational parameters required for the fluidization of different materials and different particle diameters. In the present work, the effect of the material, namely stainless steel and sand and the respective diameters of 0.5 and 1 millimetre have been investigated with the aid of Ansys FLUENT 15. From the simulation, it has found that the minimum fluidization velocities of steel beads are 0.7 m/s and 1.4 m/s respectively for diameter of 0.5 millimetres and 1.0 millimetre. On the other hand, the minimum required velocities to fluidize the less dense sand beads are 0.3 m/s and 0.7 m/s for particle diameter of 0.5 millimetres and 1.0 millimetre respectively. It has also discovered that the minimum fluidization velocity will increase as the density of the particle material increases; while it will also increase when the particle diameter increases. Therefore, it can be concluded that the drag force required to fluidize the specific solid bed material is proportional to both the density and the diameter of the particle chosen.

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DEDICATION

This thesis is dedicated to my dearly beloved family.

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LIST OF ABBREVIATIONS

2D	Two-Dimensional
3D	Three-Dimensional
AISI	American Iron and Steel Institute
CFD	Computational Fluid Dynamics
CPFD	Computational Particle Fluid Dynamics
DEM	Discrete Element Method
DIA	Digital Image Analysis
DNS	Direct Numerical Simulation
DPM	Discrete Particle Method
ECT	Electrical Capacitance Tomorgraphy
EE	Eulerian-Eulerian
IB	Immersed Boundary
KTGF	Kinetic Theory for Granular Flow
KTRS	Kinetic Theory for Rough Sphere
LBM	Lattice Boltzmann Method
LES	Large Eddy Simulation
MP-PIC	Multi-Phase Particle-In-Cell
NN-MOIRT	Neural Network Multi-Criteria Optimization Image
PIV	Particle Image Velocimetry
TFM	Two Fluid Model
TLBM	Thermal Lattice Boltzmann Method
UDF	User Defined Function

CHAPTER 1

INTRODUCTION

1.1. Background

In 2010, the global production of biofuel has exceeded over 100 billion liters, comparing to the previous year, it has rose by approximately 17%. The trend has shown that many nations are driven to invest more on the renewable energy, namely biofuel. Glancing through the public concern regarding the human strong dependency on fossil fuels and its insecure supply, biofuel has turned out to be an alternative to reduce the consumption of fossil fuels for transportation need. However, it is crucial to ensure that the demand for biomass does not compete with the regional food supplies, such as corn and sugarcane. Therefore, the biofuels has to be derived from the lignocellulose portion of biomass – or in other words, the byproduct or waste of agricultural activities to prevent the conflict of food source. According to the research conducted by Stephan et al. (2011), second-generation biofuels extracted from cellulosic source could be commercially competitive to replace the first-generation ethanol that are generally made from corn by 2020 if second-generation biofuel industry is supported. Currently, there are several techniques available in the industry for the conversion of unwanted biomass to combustible, energy-packed fuel; nevertheless, pyrolysis appears to be a relatively promising technique in terms of its simplicity, production yield and economical value.

In recent years, fluidized beds have been extensively used as reactors for pyrolysis as they overcome some of the disadvantages of the conventional pyrolysis reactors such as fixed bed (Trambouze and Euzen, 2005). Fluidized beds have a comparably higher rate of reaction per unit volume due to the highly turbulent flow of the dense solid bed. The turbulence has promoted a better mixing environment for the biomass to have a higher heat transfer rate with the inert particles. Mellin et al. (2013) have reported that their designed reactor was able to reach an astounding rate of 1000 ^{o}C/s. The turbulent environment has also give rise to the even temperature distribution of the bed, which prevents the formation of local hot spots.

Fluidization is a phenomenon where granular solids behave like fluid state through contact with either gas or liquid or even both. It can be achieved by imposing fluid drag on the solid particles. As the drag force increases, the gravitational pull on the particles will be slowly offset by the drag, which causes the solids to remain in a semi-suspension condition. When the drag force exerted by the fluid velocity passing through the solids is exactly equal to the gravitational pull, the solids bed is said to be fluidized. This stage is named as incipient fluidization and the fluid velocity is known as the minimum or critical fluidization velocity. At this stage, the particles will exhibit the fluid behavior and suspend within the fluid flow. Once the particle velocity surpassed the critical velocity threshold, the fluidized solids bed will start to expand and swirl turbulently like boiling water where bubbles are forming constantly.

1.2. Problem Statement

Bubbling fluidized beds have gained its rising popularity in the biochemical industry nowadays due to its even mixing capability and thermal distribution. Large quantities of experimental studies and numerical research have been conducted for different process parameters on pyrolysis; however, the hydrodynamics of the fluidized bed reactors are still not well understood yet due to the complexity of the particle interactions. Therefore, simulations using computational fluid dynamics (CFD) stands out as a useful tool to study the fluidization process and ultimately obtain the required parameters for specific operation.

1.3. Objectives of the Research

The primary aim of this thesis is to develop a CFD simulation model on the complex fluidization process of particles in a fast pyrolysis fluidized bed reactor. The overall objectives of the research are pointed out as follows:

- To model a laboratory-scale bubbling fluidized bed for pyrolysis of biomass
- To obtain the parameters required for the fluidization of particles
- To compare the effect of different particle materials and sizes on the fluidization process

1.4. Scope of the Research

Fluidization is the stage where the drag force acting on the granular, dense particles completely offset the gravitational pull. The biomass will always have a lower density than the inert particles; if the drag exerted is sufficient to fluidize the inert particles, the biomass will definitely be flowing upwards through the afloat particles. Hence, the research will be focused on the hydrodynamics of the inert particles only without taking account of the biomass dynamics. Since the biomass will only be introduced into the fluidized bed after the particles have been fluidized, the particle-biomass interaction and chemical reaction will not be considered in the simulation.

1.5. Report Organization

The next chapter of the paper covers a detailed literature review of several experimental and computational approaches on fluidization and the survey on the hydrodynamics model of dense bed particles. In the third chapter, the methodology and research parameters of the study were described in details. The simulation result and the corresponding discussion were presented in the fourth chapter. Lastly, the conclusion on the present research paper and the potential future works recommendation have been drawn in the fifth chapter.

CHAPTER 2

LITERATURE REVIEW

2.1. Experimental Survey

Laverman et al. (2008) have performed an experiment to study the fluid dynamics of a bubbling fluidized bed. The author used two different kind of technique and equipment to observe the effect of bed height to reactor diameter ratio. The implication of changing the superficial speed of the nitrogen gas was also observed. In the experiment, the author combined the usage of Particle Image Velocimetry (PIV) and Digital Image Analysis (DIA) in the experiment. Both of the equipment is considered as a more advanced approach as it does not destruct the specimen while measurement was taken place. Hence, it allowed the authors to study the bubble formation and fusion. Besides that, it also allows correction or modification on the model to eliminate the effect of the interaction between the nitrogen bubble and the solid phase on the velocity profile of the solid.

Similar to Laverman et al. (2008), Yuu, Umekage and Johno (2000) have conducted a study on the kinetics and hydrodynamics of the solid and gas phase in a bubbling fluidized bed. In their experiment, approximately 100,000 particles with nominal diameter of 310 μm, which are categorized as Geldart Scale B particles. The solid phase was used to observe the particle reaction and interaction with the gas bubble. The corresponding simulation was also carried out to verify with the experimental outcomes. A three-dimensional Lagrangian distinct element method (DEM) was deployed to calculate the particle–particle interactions. Apart from the Eulerian approaches, the DEM technique solve the Navier–Stokes equation and the flow characteristic equation of the particles simultaneously. The numerical or simulation results were found to be conforming to the experimental results.

Instead of using PIV or DEM, Warsito and Fan (2001) used a different approach to monitor their results on fluidized bed. An electrical and sensor circuit was used to measure the cross-sectional volume fraction contour of the solid phase. The contour was then used to show the location of gas holdups in the system. The experiment was