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# HEAT TRANSFER ANALYSIS OF LABORATORY SCALE REACTOR OF FAST PYROLYSIS FLUIDISED BED

By

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FINAL PROJECT REPORT

Submitted to
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## APPROVAL

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Approved:

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September 2014

# 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

This report presents the results of heat transfer analysis of a fluidised bed by using different type of fluidised bed sands. Academic version of FLUENT 15.0 was used in performing the simulations. Eulerian-Eulerian two-fluid granular model is used as the multiphase flow model to solve this simulation. 2-D axisymmetric fluidised bed (2.5cm × 50cm), glass beads and stainless steel beads of 1mm and 0.5mm in diameter are used in the simulations. Thermal conductivity of the material is calculated using the standard approach used by Kuipers et. al. (1992). Gidaspow model is used for the drag equation and Gunn's model (1978) is used in the calculation for interphase heat transfer coefficient.

In order to analyse the heat transfer of different material and different sizes, heat transfer is evaluated by comparing the HTC measured in the simulation. It is found out that stainless steel beads is better in heat transfer compared to glass beads as it has higher heat transfer coefficient, interphase HTC and wall to bed HTC. Nevertheless, the temperature rise of the glass beads is higher than stainless steel beads after 30 seconds. It is also found out that temperature rise for small diameter granular solids is much higher than that of the larger diameter granular solids.

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I would like to thank Tan Zhong Jian for his help in providing the data for minimum fluidisation velocity of the materials which is one of the crucial components required in order to conduct successful simulations.

I would also like to thank INTI International University in providing the software required to set up and solve this simulation, which is FLUENT 15.0. I would like to express my gratitude to Mr. Panir, the lab assistant for CAE lab, in providing access in using FLUENT 15.0 in the CAE lab for this project. I would like to also express my gratitude to all those who have directly or indirectly provided much needed help and guidance in completing this project.

# DEDICATION

*This thesis is dedicated to my family.*

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# LIST OF ABBREVIATIONS

| | |
|---|---|
| BFB | Bubbling Fluidised Bed |
| CFD | Computational Fluid Dynamics |
| CWBFB | Corrugated Wall Bubbling Fluidised Bed |
| DEM | Discrete Element Method |
| DPM | Discrete Phase Model |
| DPS | Discrete Particle Simulation |
| DWS | Diffusing Wave Spectroscopy |
| FBR | Fluidised Bed Reactor |
| FFT | Fast Fourier Transform |
| HTC | Heat transfer coefficient |
| ISAT | In-Situ Adaptive Tabulation |
| MFIX | Multiphase Flow with Interphase eXchanges |
| KTGF | Kinetic Theory Granular Flows |
| TGA | Thermogravimetry Analysis |
| RPT | Radioactive Particle Tracking |
| 1-D | 1 Dimensional |
| 2-D | 2 Dimensional |
| 3-D | 3 Dimensional |

# CHAPTER 1

# INTRODUCTION

## 1.1 Background

Current era has seems to walk into a dilemma where crude oil, the primary source of energy and common plastic products, is reaching depletion within decades but yet, an alternative option is yet far from being found. Renewable energy source like solar and hydropower has much lower efficiency and unsatisfying economic value that results it from being less advocated within the industry. In this project the prospect of combining fast pyrolysis using fluidised bed is being scrutinized whereby the process is being analysed with thermochemical conversion method. Reactor plays an important role in this process especially in fluidised bed's reactor.

### *1.1.1. Pyrolysis*

Biomass products can be categorized into 3 different types' namely liquid fuels, gaseous fuels and solid fuels (Prabir Basu, 2013). They are produced through processes such as plain combustion, pyrolysis, gasification or torrefaction. Pyrolysis is formally defined as the usage of heat in chemical decomposition of organic materials without or with minimal amount of oxygen (FRTR, n.d). As referring to the work of Prabir Basu (2013, p.13), pyrolysis is able to decompose organic matters into respective states at above 300 °C, and the pyrolysis process for biomass aimed to produce liquid bio-fuels which has high energy density. Currently there are three types of pyrolysis namely flash pyrolysis, fast pyrolysis and slow pyrolysis. They are differentiated by process time as varying process time affect the yield output of the biomass. He shows that purpose of different speed is because slow pyrolysis produces gas and solid products like charcoal while fast pyrolysis is able to produce mainly liquid fuel.

### *1.1.2. Fluidised Bed*

Fluidised bed can is still a new technology as the fundamental understanding of the system is yet to be established for it to be used in general industry. This technology emphasizes on fluidising solids inside the reactor in certain conditions to utilise the behaviour of the fluidised solid for certain purpose, e.g. higher combustion efficiency or higher heat transfer rate. The advantage of fluidised bed against normal heating process is the extremely high surface contact between the liquid and solid grains, and complete intermixing of different particles which promotes efficiency in heat conduction in fluidised bed. There are various categories of fluidisation available, as shown in Figure 1.1 below.

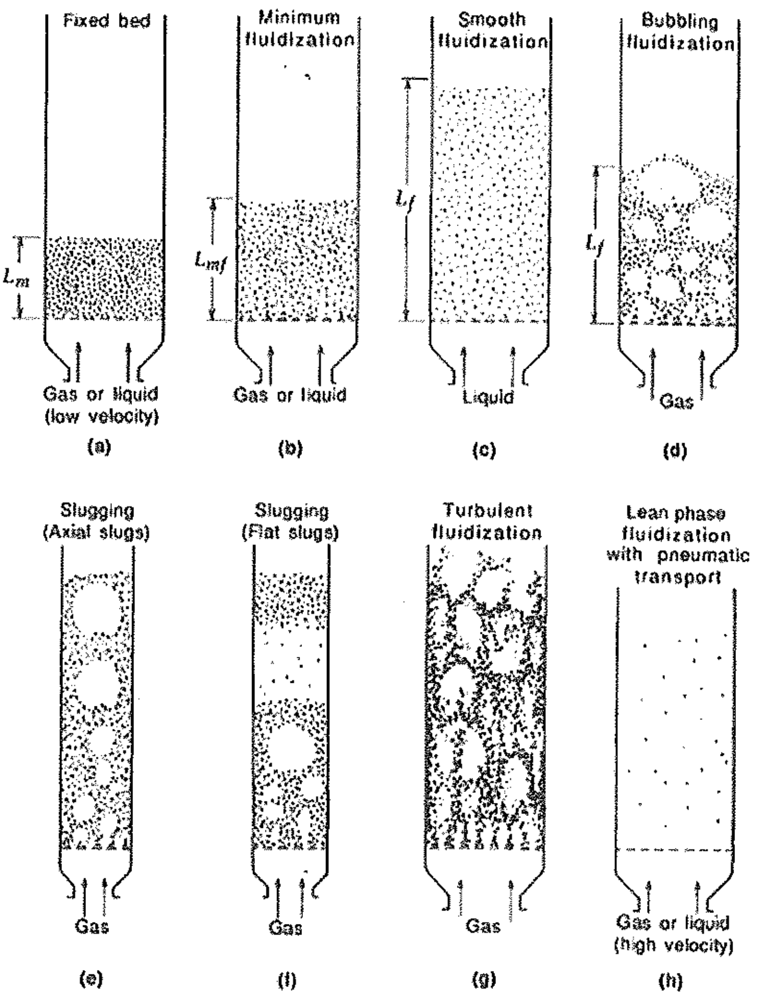


Figure 1.1: Types of granular solid fluidisation

As referred from Figure 1.1 above, the fluidisation type normally used in fluidised bed is in the form of bubbling fluidisation. For pyrolysis of biomass using fluidised bed, the fluidisation behaviour of granular solids aid the heat transfer to biomass particles through heat conduction due to continuous collision and intermixing of granular solids and through convection with the fluidising gas. There are several advantages and disadvantages of utilising fluidised beds in industrial operations. The characteristics of fluidised bed, which is the fluidised solid allows continuous automated controlled operations with easy handling and it has high heat and mass transfer rate which makes it suitable for many large-scale operations. Nevertheless, the condition whereby the granular solids is constantly heated and mixed with the fluidising gas will cause the erosion of pipes and bed wall and also varies the residence times of biomass particles in BFB (Kunii, Levenspiel and Brenner, 1991).

### *1.1.3. Computational Fluid Dynamics (CFD)*

As accurately explained and shown in the work of Versteeg and Malalsekera (2007), CFD is the usage of compùter simulation in conducting analysis for fluid dynamics systems such as heat transfer and fluid flow. The core tenets of CFD are solving fluid flow problems using numerical methods and algorithms with computer. By using CFD, one will be able to find the pattern or a distribution of a system, reduce the lead time, new designs start-up cost, study systems under hazardous condition as many controlled experiments are yet impossible to perform or unable to obtained highly detailed results. A CFD code mainly consists of 3 components: pre-processor, solver and post-processor. The definition and the category of the processes in each element for CFD coding are shown in Table 1.1 below.

Table 1.1: Element definition and their processes

| **Pre-processor** | **Solver** | **Post-processor** |
|---|---|---|
| User input and conversion into form for the solver | Solving the equation | Output result showing with versatile visualisation tools |
| • Computational domain<br>• Mesh generation<br>• Fluid properties<br>• Boundary Conditions | • Integration of governing equation<br>• Discretization<br>• Iterative Method | • Domain geometry & grid display<br>• View manipulation<br>• 2D and 3D surface plot<br>• Particle tracking<br>• Contour plots |

Although the 3 elements of the CFD code can be clearly defined as shown in Table 1.1 above, their relationship are interlinked with one another depending on the pre-processor input provided by the user. For instance, finer mesh will produce a more accurate solution but with the cost of longer solving time. The optimal solution is to have an uneven mesh whereby areas of high variations will have very fine mesh while areas of minute change will have coarse mesh for obtaining accurate results in least amount of time.

## 1.2 Problem Statement

The contemporary dilemma of industries will be choosing in between environmentally friendly or towards increasing the profit margin. Recent research focused their efforts toward increasing the biomass energy efficiency in order to provide a solution for the dilemma. Currently the focal point of interest is by utilising fluidised bed for pyrolysis of biomass. Fluidised bed, which is not yet a mature technology, requires more efforts and interests in order to set up a fundamental establishment of the knowledge towards this new area of knowledge. This thesis concentrates on solving the heat transfer model of the bubbling fluidised bed for fast pyrolysis and forming a simulation model.

## 1.3 Objectives of the Research

The overall objectives of the research can be as follows:

- To compare the heat transfer coefficient of fluidised bed using sand beads and stainless steel beads
- To model a laboratory scale cylindrical fluidised reactor
- To visualise the on-going heat transfer processes inside the reactor with computational modelling and simulation
- To compare the heat transfer coefficient using fluidised bed sands of different sizes.

## 1.4 Scope of the Research

This project only model and simulates the heat transfer of a bubbling fluidised bed. The project does not include experimental set up for a lab-scale fluidised bed. The designed fluidised bed type is only the bubbling fluidised bed without including evaluation and comparison of efficiency against other types of fluidised bed. Stainless steel beads and glass beads of 0.5 mm and 1 mm diameter in size are used as fluidised bed sands to determine the effects of heat transfer with different types of particles used in the fluidised bed.

## 1.5 Report Organization

In Chapter 1, the scope and objective of project is accurately defined with an introduction. Problem statement for this final year project is accurate defined as shown. The outline of the topics and the knowledge involved in this final year project is shown and briefly explained.

Chapter 2 of the final year project report contains the literature review regarding aspects of biomass fast pyrolysis, simulation of fluidised bed model, experimental work done on fluidised bed reactor for biomass and especially towards bubbling fluidised bed for pyrolysis. It includes the important settings needed for the simulations, general correlations between the variables involved in the fluidised bed fast pyrolysis process and also effects and impacts of various boundary conditions in a simulation setup.

The methodology of conducting the project is introduced in Chapter 3. It shows the whole setup of the simulations, from the equations used in solving the simulations to the settings of the boundary conditions. Dimensions of the fluidised bed and the methods used are also included in this chapter.

## 1.6 Summary

An introduction is done on showing different types of fluidised bed and also structures of CFD are shown. The correlation and benefits of using fluidised bed in pyrolysis process are also discussed. The problem statements that this project aimed to tackle are stated and the objectives required to achieve are listed. Scope of research is defined and the structure of the report is presented as shown in the report organisation.