Hydrodynamic Characterization of an 8" Fluidized Bed Reactor Using a Cold Air Flow Model

Richard D. Wynn

Chun Ling Huang

Samuel Ibekwe

Department of Mechanical Engineering
Southern University and A&M College
Baton Rouge, LA 70813

Abstract

Fluidized bed reactors (FBR) are commonly used to convert biomass to pyrolysis by heating the raw biomass in the absence of an oxidizer (air). The 8" FBR is a cylindrical stainless steal vessel partially filled with sand, which serves as a heat reservoir to keep a constant mean temperature in the bed. Superheated (600°C) steam or nitrogen is injected into the FBR and cause the sand/gas to fluidize. Once fluidization occurs, the raw biomass is fed into the reactor, which will pyrolyze as it interacts with the sand and gas. A problem associated with the FBR's thermo-chemical process is that its hydrodynamics cannot be observed or, in turn, characterized. Thus, a clear plastic 8" cold airflow (room temperature) fluidized bed model was constructed to observe the simulated hydrodynamics of the 8" FBR.

For the cold airflow model to effectively and accurately characterize the original FBR Reynolds number was used in the comparison and characterization. Prior to this experiment, the only fluid velocity was applied to the hydrodynamic estimations. Reynolds number is not only dependent on fluid velocity, but also viscosity, density, and sand diameter. The cold airflow model, which uses 20°C air as the injection gas and two different sand sizes, enables the hydrodynamics to be closely observed and also provide researchers with a better understanding of what is going on within the FBR. The two major objectives of this experiment are to use the cold airflow model to estimate the minimum fluidization's airflow rate and the sand blow out rate in the FBR. The minimum fluidization in the cold airflow model occurred when the airs mass flow rate was at 1.5 kg/h and 5kg/h, for the 90-micron and 190-micron sand diameters respectively. The FBR estimated minimum fluidization gas flow rate was determined to be 1.45kg/h when superheated nitrogen is the injection gas and 1.2kg/h with superheated steam. The following was determined for the sand blow out rate; 300kg/h for the cold airflow model,

29kg/h with superheated nitrogen in the FBR, and 24kg/h with superheated steam in the FBR.

In conclusion, this experiment provides engineering students, engineers, and scientists with an opportunity to learn more about fluid mechanics by using a “hands on” experiment that reinforces theories learned in text. It confers a better general understanding about sand/gas fluidization. This experiment also provides much more accurate estimates for the minimum fluidization and material blowout rate. The information obtained in the experiment will be implemented to design better, more efficient fluidized bed reactors and biomass to pyrolysis processes.

Introduction

In 2000, North America imported more than half its oil at a cost of $109 billion, according to the Energy Information Administration (EIA)[1]. New energy technologies based on indigenous, self renewing resources will help keep these dollars at home to strengthen the economy and create new job opportunities. With an increasing demand for energy and a decreasing amount of fossil fuels, alternative methods of producing energy are being researched heavily. One of the forerunners in the research and development of alternative fuels is the National Renewable Energy Laboratories (NREL)[2]. Converting solid feedstock into a gaseous fuel increases the opportunity to use biomass as an energy source. One conversion process NREL uses is the Thermo-Chemical Process Development Unit (TCPDU)[3], shown below in Figure 1.

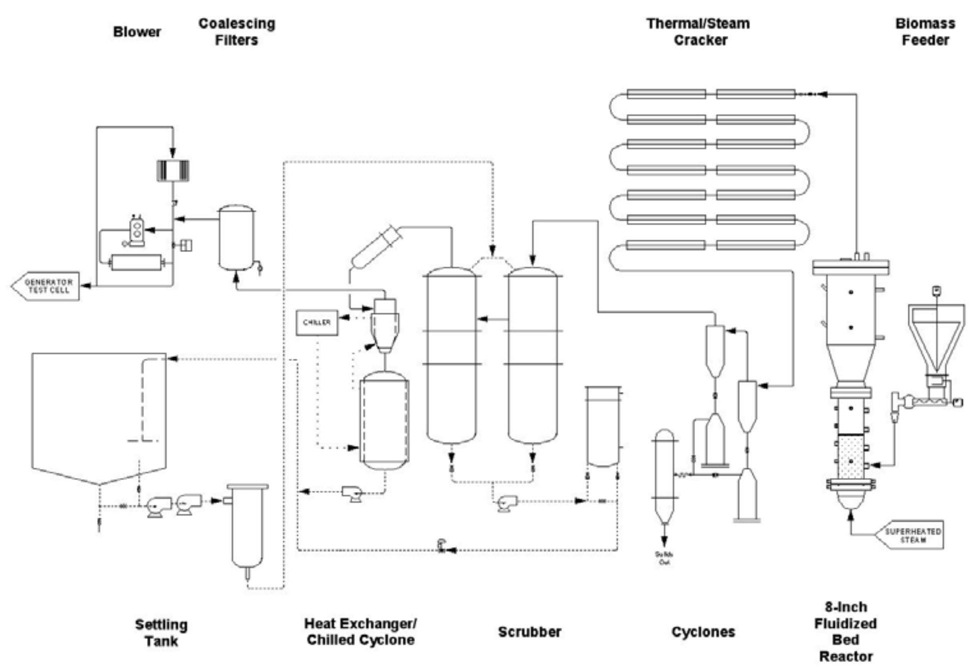

Figure 1 TCPDU

Although the TCPDU has many elements within it, its conversion process is not difficult at all. First of all, biomass (which can range from peanut shells to sawdust) is fed into the Fluidized Bed Reactor (FBR). Here the biomass is heated without the presence of an oxidizer (air). The heat gasifies the biomass into pyrolysis leaving char and tar as a byproduct. From the FBR the gaseous contents along with some small charred/tar particles continue through the rest of the system, which consists of several filtration elements. The first of these elements that the pyrolysis will encounter is the thermo cracker, then cyclones and a scrubber. After the pyrolysis exits the scrubber most of the char and tar particles have been removed and then the gas can be condensed into oil (which can be used for adhesives, plastics, and insulation). The product can also and is often kept as a gas to be burned for electrical generation.

Fluidized Bed Reactor (FBR)

The 8" FBR is the component of the TCPDU that converts biomass to pyrolysis by heating the raw biomass in the absence of an oxidizer (air). The 8" FBR is a cylindrical stainless steel vessel partially filled with sand which serves as heat reservoir that promotes the thermo-chemical reaction (Figure 2). While the biomass is being fed into the reactor superheated steam or nitrogen at 600°C is also being injected, which causes solid/gas fluidization with the sand and biomass. Fluidization[4] is when solid particles take on characteristics of a fluid, which promotes uniform heat transfer and distribution. The extreme heat causes the feedstock to pyrolyze, leaving tar and ash as byproducts.

Figure 2 FBR

Cold Air Flow Model

A problem associated with the 8" FBR is not able to allow its content's hydrodynamics to be observed or characterized due to its stainless steel construction. Thus, a 1:1 scale plexi-glass model was built as shown in Figure 3. The clear model was constructed to simulate the hydrodynamics of the FBR. Besides material composition, the only other significant difference between the FBR and the model is the operation temperature; the FBR uses superheated steam or nitrogen as the fluidizing gas, the model (referred to as the cold air flow model) uses air at room temperature to fluidize.

The cold air flow model is to permit the characterization of the minimum fluidization velocity and carryover/blowout rate of solid particles. Reynolds Number[5], a dimensionless property, was prescribed to effectively and accurately characterize these hydrodynamics of the FBR. Prior to the construction of the cold air flow model the injected gas' fluid velocity was the only variable considered for the FBR hydrodynamic estimates. Reynolds number includes not only fluid velocity, but also density, viscosity, and sand diameter. Therefore, the cold air flow model in tandem with Reynolds number can provide more accurate estimates of the FBR's hydrodynamics.

Figure 3 Cold Air Flow Model

Experimental Results

The are three objectives for this experiment: to determine the minimum gas flow rate that causes fluidization (minimum fluidization rate), approximate rate that material is blown out of the FBR, and to determine the discrepancy between the Reynolds number and fluid velocity hydrodynamic estimates. Each of the objectives was met and was expressed quantitatively.

Minimum Fluidization

Once the cold air flow model was completely assembled, the minimum fluidization rate was to be determined. Two minimum fluidization rates were determined using sand diameters of 90 micron and 190 micron. Testing was conducted with 20 kg of sand inside the cold air flow model. The air mass flow rate was increased in 0.25 kg/h increments until fluidization was observed. The minimum fluidization rate in the cold air flow model occurred when the air mass flow rate reached 1.5 kg/h and 5 kg/h, for 90 micron and 190 micron sand respectively. According to the dimensionless property Reynolds number (Re), between the two sand sizes, the 90 micron sand in the cold air flow model would simulate the conditions in the FBR (which uses 190 micron sand). The Re[6] is defined as

$$Re = (\rho\ V\ D)/\mu \qquad (1)$$

where ρ is the fluid density, V is the average fluid velocity, D is the diameter of the sand, and μ is fluid viscosity. Thus, with the 90 micron sand in the cold air flow model and 190 micron in the FBR, Reynolds number was then used to estimate the minimum fluidization rate of the FBR. The minimum fluidization gas flow rate in the FBR was determined to be 1.45 kg/h with superheated nitrogen, and 1.2 kg/h with superheated steam.

Material Blow Out

Another experimental objective was to determine the rate that material would be blown out of the FBR operating with 20 kg of sand within the vessel. This quantity is detrimental when designing the entire TCPDU. In order for the process to work accordingly proper filters, cyclones, and scrubbers must be implemented to remove the material (sand, ash, and char) that has been blown out of the FBR and into the rest of the system. By determining the rate sand is blown out of the vessel at a given air flow rate in the cold air flow model, the rate material is blow out of the FBR using both gases can be estimated.

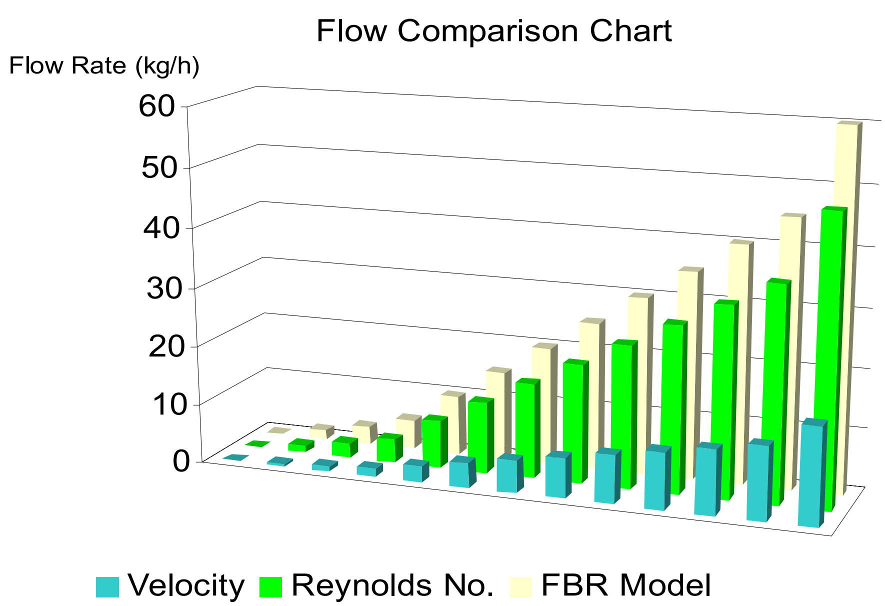

Figure 4 Fluid Velocity/Reynolds Number Comparison

When assuming operating conditions with an injection gas flow rate of 50 kg/h, the rate that sand is blown out of the cold air flow model is 30 grams/hour. According to Reynolds number, the equivalent material blow out rate in the FBR would be 29g/h using superheated nitrogen, and 24g/h with superheated steam.

Fluid Velocity/Reynolds Number Comparison

The estimated results determined using Reynolds number are believed to be far more accurate than those previously made using only fluid velocity. For example, operating the cold air flow model with a 60 kg/h air mass flow rate, its fluid velocity adjusted equivalent in the FBR with superheated steam would have to flow at 16.5 kg/h (Figure 4). Remember, this is without considering the steam's viscosity, density or the sand diameter. When these factors are included in the calculations using Reynolds number, the FBR's superheated steam's mass flow rate would be 48.2 kg/h, which is 52.83% closer to the air flow rate in the model.

Educational Application

Including the Cold Air Flow Model into a Fluid Mechanics course can provide students with a greater learning opportunity. The Southern University College of Engineering offers Introduction to Fluid Mechanics, which is a lecture and lab course of three credit hours. One required course for civil and mechanical majors, Intro to Fluid Mechanics has nearly 250 students enrolled per academic year. Implementing the Cold Air Flow Model into the laboratory will provide students with a better understanding of the following: pipe/duct flow, fluid velocity, valves, head pressure, viscosity, and Reynolds number. Currently being considered for acquisition by faculty within Southern's College of Engineering, the Cold Air Flow Model can be a useful tool in aiding student understanding in the sometimes confusing fluid mechanics. However, the success of this project depends on the university support and research funding from agents such as NSF, and DOE, and NREL.

Conclusion

The experiment conducted using the 1:1 scale cold air flow model provides engineers and engineering students with a better understanding of fluid dynamics and the 8" Fluidized Bed Reactor. For one, the cold air flow model enables engineers to observe its hydrodynamics, due to its plexi-glass construction. Also, the cold air flow model also can provide more accurate FBR minimum fluidization and material blow out estimates when used with Reynolds number. The cold air flow model can not only be used to increase engineering student understanding of fluid mechanics, but can provide vital information for future designs of fluidized bed reactors and biomass to pyrolysis processes.

References

1. Energy Information Administration
   http://www.eia.doe.gov/oil_gas/petroleum/info_glance/importexport.html
2. NREL, National Renewable Energy Laboratory in Golden Colorado
   1617 Cole Boulevard, Golden, Colorado 80401-3393
   URL: http://www.nrel.gov/.
3. Robert S. Wegeng, 2000, "Chemical And Thermal Systems (CATS) Beyond 2000," Proceedings of 4th International Conference on Reaction Technology, Pacific Northwest National Laboratory, Richland, Washington, March 5-9, 2000
4. Octave Levenspiel, Diazo Kunii, 1991, Fluidizing Engineering 2nd Edition, Butterworth-Heinemann
5. The Columbia Encyclopedia, Sixth Edition, 2001, Columbia University Press
6. Frank M. White, 2003, Fluid Mechanics, 5th Edition, McGraw-Hill Book Company,

Acknowledgement

The author would like to thank to NREL for providing experimental equipments and site during Summer 2002.

RICHARD D. WYNN JR.
Mr. Wynn is currently a senior majoring in Mechanical Engineering at Southern University and A&M College at Baton Rouge (SUBR), Louisiana. His Research interests include fluid mechanics and non-destructive mechanical testing.

CHUN LING HUANG
Dr. Chun Ling Huang earned B.S. and M.S. Degrees in mechanical engineering from Chung Yuan Christian University (CYCU) in Taiwan, and a Ph.D. degree in mechanical engineering from the University of Alabama (UA) at Tuscaloosa. Currently, he is an associate professor of mechanical engineering in SUBR. He is a member of ASME and ASEE.

SAMUEL IBEKWE
Dr. Samuel Ibekwe is an Associate Professor & Interim Chairman of mechanical engineering department. His interests are in Design, Manufacturing, and Engineering mechanics area. A past recipient of the department's faculty of the year award, Dr. Ibekwe is a Louisiana State registered professional engineer who holds one design U.S. patent. His funded research projects from Louisiana Board of Regents, NSF, DOD, and LaSPACE.