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Challenge problem: 1. Model validation of circulating fluidized beds

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ABSTRACT

The National Energy Technology Laboratory (NETL) worked with Particulate Solids Research Inc. (PSRI) to conduct the third CFD Challenge Problem in granular fluid flow to evaluate the progress and state of the art in simulating gas solids flow in a circulating fluidized bed. Both Group A and B particles were tested at several gas velocities and solids circulation rates. For both particle groups pressures and particle velocities were measured within the riser. For the Group B cases local radial solids fluxes and high speed pressure fluctuations were measured. Model predictions were compared against these experimental results and vetted in the workshop at the Circulating Fluid Bed X. The modelers were given detailed descriptions of the experimental facilities as well as physical property and small scale fluidization data on the different bed materials tested. Two general types of modeling simulations were submitted: Eulerian–Eulerian and Eulerian–Lagrangian. Both types of model had successes and failures indicating that good results are strongly influenced by resources such as available time, computational facilities, and experience level of the modeler. By comparing the predicted behavior the strengths and weaknesses associated with the different modeling approaches were identified and shortcomings could be targeted for future development and improvements.

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1. Introduction

Scale-up of a fluidized bed reactor from a bench scale unit or pilot scale plant is required to optimize the performance of a full size commercial unit found in combustion, gasification, pyrolysis, Fluidized Catalytic Cracking (FCC), and polycrystalline silicon industries. As the diameter of the fluidized bed is increased, its hydrodynamic behavior may not remain similar. Computational Fluid Dynamics (CFD) model involves understanding of these hydrodynamic changes and their influence on chemical reaction rates, conversion efficiency, and thermal conditions through variations in gas distribution, gas–solid contact, residence time, solids circulation and mixing.

The goal of the Challenge Problem project was to benchmark state of the art in CFD models. NETL, in collaboration with PSRI, generated third Challenge Problem from data generated in NETL's circulating fluidized bed and PSRI's bubbling fluid bed. The package was presented to the international, commercial and academic modeling community at the NETL MFIX website [1]. The challenge being presented was to model the behavior of selected bed materials in the NETL circulating fluidized bed and PSRI bubbling fluid bed. Model predictions were compared against actual experimental results and the results of those comparisons were presented at the Workshop of Circulating Fluid Bed X held in Sun River Valley, Oregon on May 2011.

Several unique operating conditions were tested and simulated using Geldart Groups A and B particles. Measurements compared to simulations included: axial pressure profiles and bubble hydrodynamics in the fluidized bed; and axial pressure profiles, radial velocity and flux profiles in the circulating fluidized bed. Bubble hydrodynamics were quantified with a fiber optic probe. The local solids fluxes were experimentally measured using a piezo-electric probe, fiber optic, and solids extraction techniques. The piezo-electric method best met the qualifying standard of integrating over the cross section to the solids circulation rate measured by a NETL spiral and verified by tracer techniques. The particle velocities measured by the dual fiber optic were qualified by comparing with HSPIV at one location. Experimental error was reported at 95% confidence limits from replicates and by assuming continuity across radius from an analysis of variance (ANOVA). The metrics included determining the number of bi-variant relationships that agreed within the confidence limits across the length or diameter of the riser. Effective means

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of defining these test cases and the resulting performance data were established and improved through this project. All flux and velocity measurements recorded great variability in the measured values related to temporal variations in the process. Specific probe intrusions led to bias and many precautions were taken to obtain the best qualified data.

Challenge problems have been conducted in gas solids fluidization and granular flow systems since 1995 [2]. Simulations of the 0.2-meter ID by 22-meter riser were conducted using CFD and empirical hydrodynamic models [3]. Six years later, PSRI issued another CFB riser challenge problem based upon data collected from the same unit with the entrance region reconfigured for an angled standpipe [4]. In both these studies FCC catalyst powder and sand were used as the bed materials. The modeling results were unable to fully capture the axial and radial profiles. The third Challenge Problem was implemented in a multistep process: modelers were provided computer assisted drawings of the test facility, particle property data, and minimum fluidization data to set up their simulations. Eight modelers simulated 35 different responses including changes in operating conditions and sampling locations producing over 100 bi-variant relationships. After experimental test data were released [5] modelers were given the opportunity to revise their simulations. This study presents the results from the initial and refined models as well as a critical analysis of the differences between observations and models.

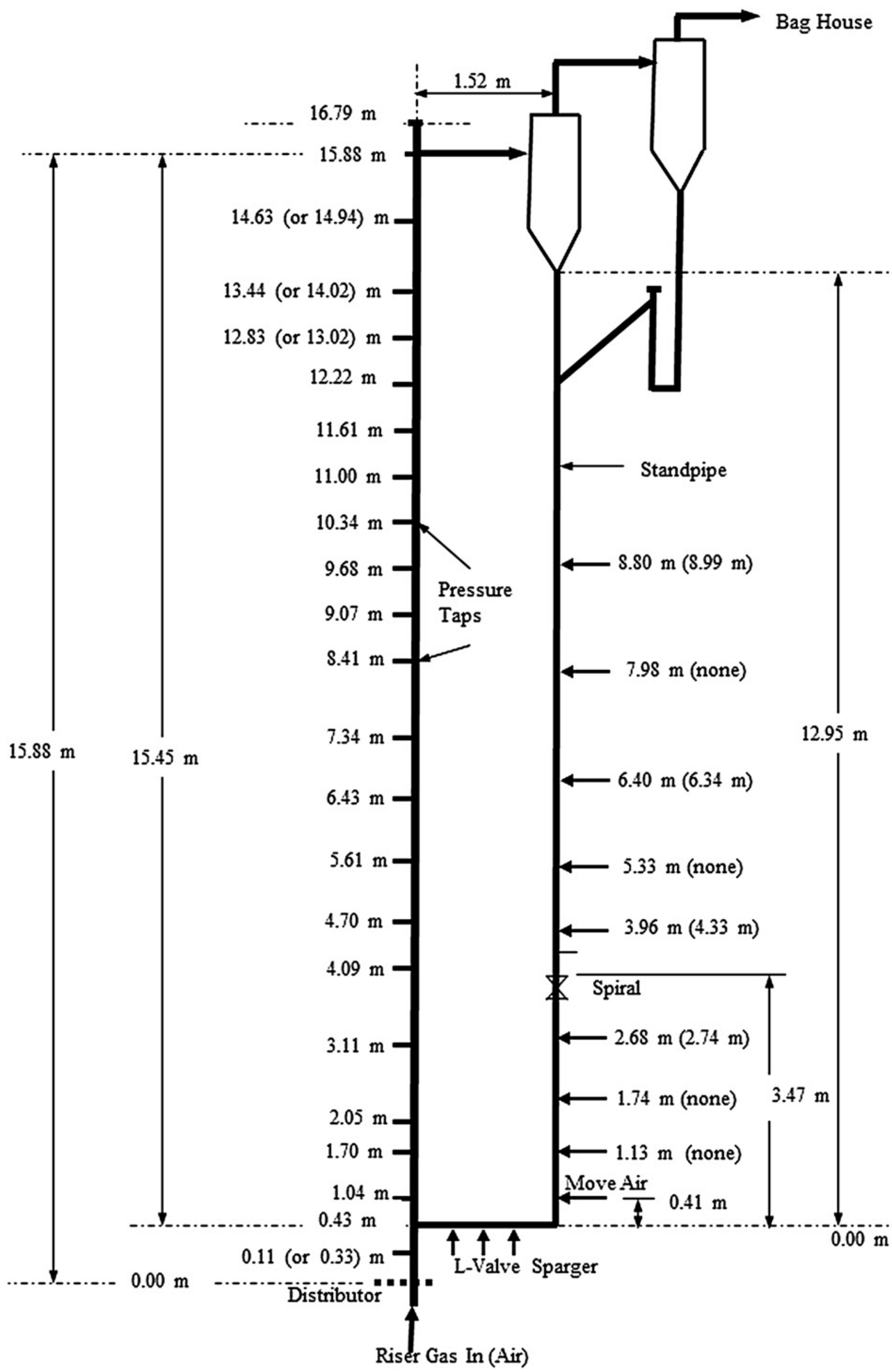

Fig. 1. Schematic of 30.48 cm ID NETL CFB facility. Values in the parentheses represent different locations for Group A tests.