A Bench Scale Two Dimensional Fluid Bed Experiment using High Speed PIV for CFD-DEM Model Improvement

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Scientific and Technical Merit Narrative

Knowledge of State-of-the-Art

The chances of full scale commercial fossil fuel conversion and carbon capture systems to be successful in the next few decades will be greatly enhanced if accurate CFD models of these systems are available [1]. A prime example is the development of full scale IGCC systems with carbon capture capabilities, a top priority for the Department of Energy[2]. However for a CFD simulation the reacting gas and particle flow fields of an IGCC system are of the most difficult to flow fields to model. One of the main reasons for this difficulty are that gasfier flow fields have high particle concentrations, and such flow fields are not well understood. The need to accurately model IGCC and other systems has led to the development of CFD software's like NETL's MFIX and Computational Particle Fluid Dynamics (CPFD's) Barracuda, where the approach is using representative computational "particles" that simulate the behavior of large numbers of actual particles. Recently, a new modeling approach called Discrete Element Method (DEM) that simulates individual particles is gaining in popularity because realistic results have been obtained for small systems using large particles that represent large numbers of small particles. The DEM approach of simulating large representative particles may provide insight into a large system like IGCC. However, it is more likely that DEM will facilitate the development of accurate constitutive models and correlations that could be used to improve software's like MFIX and CPFD.

To verify and improve the DEM approach, a small 2D fluidized bed using large particles will be constructed and NETL's high speed Particle Image Velocimetry (high speed PIV) system will be used to visualize and measure particle flow. to validate the DEM technique and to increase its accuracy.

NETL's Computational Science Division has recently developed a breakthrough technology called high speed PIV. NETL's high speed PIV system couples high speed imaging with a borescope that can probe into flow fields of high particle concentration. NETL has developed the first software that can analyze high speed PIV data for flow fields of high particle concentration. NETL's high speed PIV system is capable of recognizing and tracking the motion of thousands of particles simultaneously under conditions of high particle concentrations. For the past two years, NETL's high speed PIV system has been revealing individual particle flow behavior inside high concentration particle flow fields for the first time on a number of important experiments at NETL and the labs of PSRI in Chicago. In April of 2010 NETL filed a patent application for this technology.

High speed PIV is ideal for evaluating DEM simulations because high speed PIV measures exactly the same parameters that are simulated by DEM.

In this project, a relatively small two-dimensional fluidized bed will be constructed to visualize and measure particle flow fields with high speed PIV and other advanced flow diagnostic technologies (e.g. Electrical Capacitance Volume Tomography (ECVT) and Laser Doppler Velocimetry). The 2D fluidized bed will use relatively large particles (diameters in the range of 1 – 6 mm) to keep the total number of particles low enough (less than several hundred thousand particles) that they can be modeled with DEM. High speed PIV measures exactly the same

particle parameters that a DEM simulates; thus high speed PIV is the ideal tool for validation and improvement of DEM .

Proposed Research

The first phase of this project will be to construct and obtain ESH permitting for a small two-dimensional (2D) fluidized bed experiment. To ensure that experimental uncertainty is low enough for verification of CFD models, the 2D fluid bed will be carefully controlled and instrumented with accurate measurements. The 2D fluid bed experiment will be located on the 3rd floor of Building 22 inside the existing Class IV laser safety area. This laser safety area is already permitted for use of Laser Doppler Velocimetry (LDV) systems. This will allow LDV measurements on the 2D fluid bed without creating an additional Class IV laser safety area.

The face of the 2D fluid bed will be transparent to allow for high speed PIV visualization of particle flow over the entire area of the 2D fluid bed. The 2D fluid bed will also have access ports for a high speed PIV borescope to scan across the 2D fluid bed. These high speed PIV measurements will generate the exact same data (tracking of individual particle motion over long periods) as simulated by DEM CFD models. This will be the first time such data has been available.

Expected Project Impacts and Benefits

This project will provide the first experimental verification of DEM in which the experimental data measures exactly the same particle parameters as predicted by DEM. The experimental measurement uncertainty will be very low, allowing direct comparison with CFD model predictions. The experimental data produced will also be invaluable for evaluation of other CFD models, such as MP-PIC (Under development at NETL) and CPFD's Barracuda model.

This experimental verification of DEM and other CFD models is the first step in development of CFD models that can be used as practical tools in the design and operation of real, full scale fossil fuel conversion systems, such as IGCC systems with carbon capture. The benefits of a successful full scale IGCC system with carbon capture are profound. This technology could be one of the keys to reducing global climate change.

Project Details

Facility Requirements:

Existing Resources Allocated to this FWP:

Design and construction plans and ESH permitting is already under for the 2D fluid bed.

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New Laboratory Resources (Equipment and Services):

Most of the experimental equipment is already available for this project. Some minor upgrades of the experimental equipment will be necessary. These include:

- Software and hardware for synchronization of the high speed PIV and ECTV system
- Custom borescopes optimized for the large particles to be used in this project
- A seed particle feeding system for the LDV
- Support for optimization and parallelization of the high speed PIV analysis code.

New Engineering Upgrade Work Needed (e.g., SARS support):

This experiment has a low safety hazard level because no high pressures, high temperatures, or hazardous chemicals will be used. Only a modification to the existing ESH permit for B22 will be required. Because a Class IV laser safety area is already available, only a modification to the existing ESH permit for the LDV system in B22 will be required.

Prior Publications:

Journal Papers

"A_Decomposition_Method_for_High_Speed_Particle_Image_Velocimetry_Data," B. Gopalan and F. Shaffer, Submitted to Powder Technology, 2011 (Accepted).

"*The Effect of Cohesive Forces on Catalyst Entrainment in Fluidized Bed Regenerators*" R. Cocco, Frank Shaffer, R. Hays, S.B.R. Karri, T.M. Knowlton, J. Powder Tech, V. 203, Issue 1, October 2010

"A New View of Riser Flow Fields using HSPIV," F.Shaffer, B. Gopalan, R. Breault, R. Cocco, R. Hays, S.B.R. Kerri, T.M. Knowlton, submitted to Journal Powder Technology

Book Chapter:

"Clustering Behavior in Fluidized Beds," Chapter in Book by ACS, Ray Cocco, F. Shaffer, et al. in progress

Conference Papers and Presentations

B. Gopalan and F. Shaffer, "A New Data Decomposition Method for High Speed Particle Image Velocimetry Data" AIChE's Fall National Meeting (2010), 198790, Salt Lake City, Utah.

"Particle Clustering in and above a Fluidized Bed," R. Cocco, Frank Shaffer, R. Hays, S.B.R. Karri, T.M. Knowlton, Fluidization VIII, 2010

"Particle Clusters and Fluidized Beds," R. Cocco, R. Cocco, Frank Shaffer, R. Hays, S.B.R. Karri, T.M. Knowlton, Fundamentals of Fluidization, AIChE 2009

"High Speed Particle Imaging: Visualization and Measurement of High Concentration Particle Flow Fields," NETL Multiphase Flow Workshop, 2009

"Particle Imaging of Riser Flow Fields at NETL and PSRI: A New View of Riser Flow Behavior," F. Shaffer, B. Gopalan, R. Breault, L. Shadle, R. Cocco, R. Kerri, R. Hays, T. Knowlton, NETL Multiphase Flow Workshop, April 2010

"A New Approach to Decomposition of Particle Velocity and Calculation of Granular Temperature Using High Speed PIV Data," B. Gopalan and F. Shaffer, NETL Multiphase Flow Workshop, 2010

"A New View of Riser Flow Fields Using High Speed Particle Imaging Velocimetry (PIV)," F. Shaffer, B. Gopalan, R.Breault, R. Cocco, R. Kerri, R. Hays, T. Knowlton,

AIChE Annual Meeting, Nov. 2010

"High Speed PIV of Flow Fields in An Impeller Driven Respiratory Assist Catheter," F.Shaffer, B. Gopalan, G. Burgreen, N. Moore, W. Federspiel, AIChE Annual Meeting, Nov. 2010

"A New Approach to Decomposition of Particle Velocity and Calculation of Granular Temperature Using High Speed PIV Data," B. Gopalan and F. Shaffer, AIChE Annual Meeting, Nov. 2010

Purpose: (see above Knowledge of State-of-Art)

Background: (see above Knowledge of State-of-Art)

Approach: (see above Proposed Research and SOPO)

Technical Progress: N/A. This is a new Project.

Future Accomplishments: (see above Expected Project Impacts and Benefits)

Relationships to Other Projects: (This is for Initiative Level FWP only. Not for Project FWP's.)

NEPA Requirements:

Milestones: (see attached spreadsheet table)

Deliverables: (see Deliverables in SOPO)

Performance Measures and Expectations: ESH permitting and construction of 2D Fluid Bed experiment

1. Successful high speed PIV measurements
2. Successful ECTV measurements
3. Successful synchronization and comparison of high speed PIV and ECTV measurements
4. Successful LDV measurements
5. Successful synchronized LDV and high speed PIV measurements

ES&H Considerations: This project will conform to NETL SARS requirements. Only minor modifications to existing ESH permits for B22 are expected.

Human/Animal Subjects: N/A

Other (Specify):

References

[1] Holt, N.A.H. “Coal gasification research, development and demonstration—needs and opportunities. In: Gasification Technologies,” San Francisco, CA, USA, 7-10 Oct 2001. Arlington, VA, USA, Gasification Technologies Council, CD-ROM, session 10.1.

[2] Minchener, A.J. “Coal gasification for advanced power generation,” 2005, The 5th European Conference on Coal Research and its Applications, 8(17), Dec 2005.