HETEROGENEOUS REACTOR DEVELOPMENT

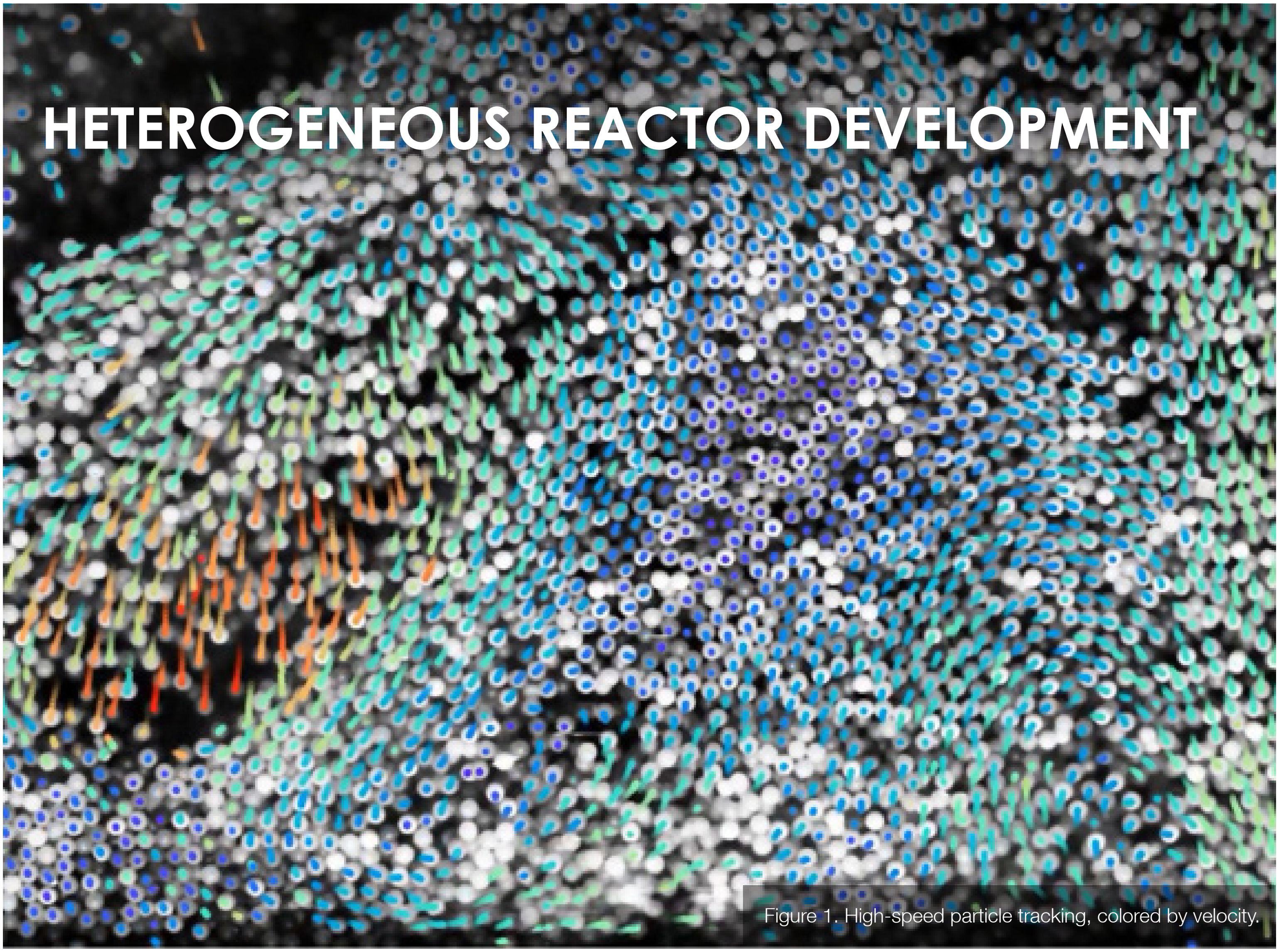
Figure 1. High-speed particle tracking, colored by velocity.

NETL

NATIONAL ENERGY TECHNOLOGY LABORATORY

OVERVIEW

Multiphase flow reactors consist of a mixture of gases, liquids and/or solids and are a ubiquitous staple of modern industry. These reactors are used to produce an array of products, ranging from the electricity powering modern gadgets to the gasoline fueling automobiles and even the food that feeds the nation. Multiphase flow reactors are a critical component of the next generation of clean fossil fuel combustion and gasification technologies.

These reactors come in many forms, such as moving beds, fluidized beds, spouted beds, and circulating fluidized beds, and are tailored to a specific process or technology to maximize performance, minimize cost and minimize environmental impact. While these reaction systems have been around for more than a century, challenges remain for process development, such as scale up, reactor and material performance, material degradation (mechanical and chemical) and solids handling. The U.S. DOE NETL is well-equipped to tackle many of these challenges, as it has a rich history in the development of gasification and fluidized bed combustion.

REACTOR DEVELOPMENT AT NETL

NETL's multiphase flow reactor engineering team focuses on the development of reactors and processes to support the next generation of fossil energy. This includes solid fuel (coal and/or biomass) combustion and gasification, as well as chemical looping combustion (CLC) and carbon capture.

Technical goals for heterogeneous reactor development include:

- Understand, measure, and predict oxygen carrier degradation mechanisms, including attrition.
- Achieve an oxygen carrier makeup cost of $5/MWth-hr in a continuously circulating chemical looping reactor.
- Increase the energy density of a typical transport gasification reactor by a factor of 10 by using innovative reactor designs.
- Release a high-performance, open source particle tracking application.
- Support model development and validation efforts, from correlations to computational fluid dynamics (CFD).

CAPABILITIES

NETL has unique capabilities to study reactions in fluidized beds for a variety of fields. This includes several reacting experimental units, as well as cold-flow (room temperature, not-reacting) units. In addition, NETL retains significant staff expertise in fluidized bed combustion, gasification, chemical looping and emissions reduction.

CHEMICAL LOOPING REACTOR

The chemical looping reactor facility is a 50-kWth natural gas-fed prototype unit for studying the performance of CLC materials. It is one of only a few circulating chemical looping test units in the U.S. The unit is carbon-steel refractory lined, and heat is added indirectly, separate from the solids path. The reactor system consists of an 8-inch bubbling fluidized bed fuel reactor and a 6-inch turbulent bed air reactor. The chemical looping reactor facility can operate up to 1,000 °C, with a global operating pressure between 8 and 20 pounds per square inch gauge (psig). The unit is also able to capture most of the fine materials, allowing for observation of the properties of the material over time and estimation of the rate of solids breakdown to assess the material lifetime.

Figure 2. Researchers inspecting instrumentation measuring the outlet gas composition of the single fluid bed reactor.

Figure 3. Researcher collecting high-speed video for particle tracking.

Figure 4. 50-kWth chemical looping reactor.

SINGLE FLUIDIZED BED REACTOR AND JET CUP

The single fluidized bed facility provides a high-temperature, geometrically flexible, well-instrumented reactor to study small batches (0.5 liter) of solids. The system consists of an interchangeable liner, which can be replaced with three options: a 2-inch bubbling fluid bed reactor, a conical jet cup attrition unit, and a small spouted bed. The system can be run with either methane (up to 13 kWth) diluted with nitrogen or air (up to 1,000 °C and 30 psig). The jet cup liner can provide a jet of nitrogen at 270 meters per second at 800 °C. The resulting product gases can be analyzed using mass spectrometry and non-disperse infrared to assess the reactivity of the solids over time. Additionally, the solids exiting with the product gases are filtered out using a filter bank, capturing fines at an efficiency of 93 percent of particles greater than 0.01 micron. This important feature facilitates attrition testing to measure the rate of material degradation.

SOLID FUEL FLUIDIZED BED REACTOR

The solid fuel fluidized bed reactor (under construction, to be ready in May 2018) is a 4-inch fluidized bed reactor with the ability to test larger quantities of solids mixed with pulverized solid fuel. The unit has the capability to react solids continuously at a maximum feed rate of 1 cubic foot per hour at 1,000 °C and 5 psig, instead of in batch mode as in the single fluid bed reactor. The bed is fluidized with nitrogen, while methane, carbon dioxide, steam, or air can be added to the fluidizing gas. The gas analysis capabilities are equivalent to that of the single fluidized bed reactor.

Figure 5. 4-inch diameter cold-flow bubbling fluidized bed.

2DIMENTIONAL SPOUTED BED REACTOR

The 2dimensional (D) spouted bed reactor unit consists of a 2-inch by 8-inch by 35-inch modified spouted bed with up to 100 liters per minute of nitrogen and methane that can be operated up to 530 °C and 5 psig.

COLD-FLOW CIRCULATING FLUIDIZED BEDS

NETL has three cold-flow circulating fluidized beds with different riser cross-sectional areas: a 12-inch diameter, 4-inch diameter and a 3-inch by 12-inch rectangular riser. All three units are constructed out of steel and acrylic and operate at room temperature. The 12-inch diameter circulating fluidized bed consists of a 12-inch diameter, 50-foot-tall riser and a 10-inch diameter stand pipe. The 4-inch diameter circulating fluid bed has been designed to be a one-third scale of the 12-inch diameter circulating fluid bed, allowing for scaling studies. The 3-inch by 12-inch rectangular circulating fluid bed has been designed specifically to allow high-speed imaging of the riser flow so that particle tracking techniques can be used to measure particle velocities and flow patterns. Solids can also be feed into the riser at various locations, allowing for jet penetration studies.

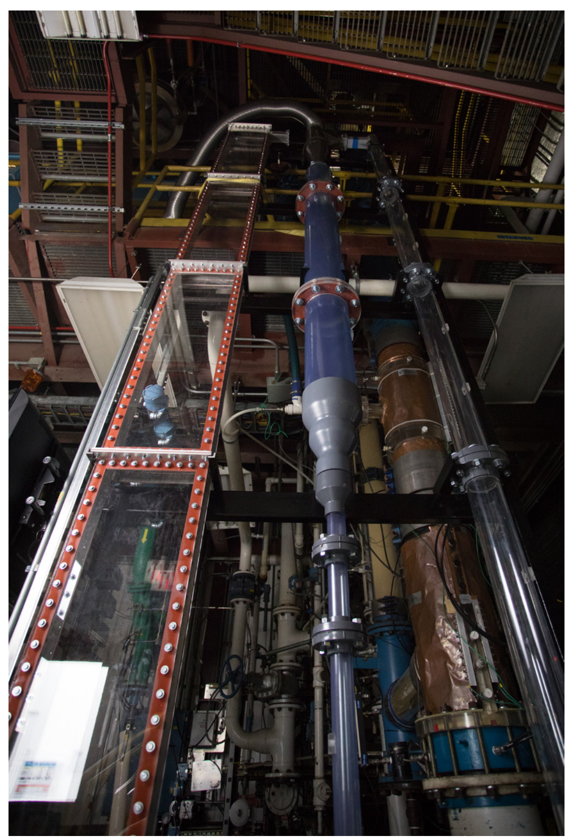

Figure 6. Cold flow 3-inch by 12-inch rectangular riser (left), 4-inch diameter riser (right), and 12-inch diameter riser (background).

COLD-FLOW HIGH-G REACTORS

NETL has two different “high-g” reactors that utilize a vortexing flow pattern established by a tangential gas inlet to provide high slip velocities as compared to conventional fluid beds and risers. The vortex circulating fluid bed reactor is an 8-inch diameter and 36-inch-tall unit, utilizing a single tangential gas inlet. This unit has an external recirculating loop, allowing for gas and solids re-circulating, established by the pressure difference between the center of the vortex (low pressure) and circumference of the vortex (high pressure). The rotating fluid bed reactor is 17 inches in diameter and 1 inch thick. This unit has a 3D-printed vortex chamber with 38 tangential gas inlets. Solids can be continuously fed into and extracted from both units.

COLD-FLOW SPOUTED BEDS

NETL has two cold-flow spouted beds with different cross-sectional areas: 1-inch by 4-inch and 3-inch by 12-inch. The units are constructed out of steel and acrylic, allowing for optical access of the spout. The 1-inch by 4-inch spouted bed is extremely flexible, allowing for various cone angles and spout injector geometries. The 3-inch by 12-inch spouted bed can be continuously fed as well as drained.

COLD-FLOW CARBON STRIPPER

The carbon stripper is a 4-inch diameter cold-flow spouted bed combined with a riser. This system is specifically designed to separate two solids based on particle density and/or particle diameter differences, such as separating coal ash from an oxygen carrier in a solid-fuel chemical looping process. A mixture of material can be continuously fed into the unit, with the two outlet streams continuously being measured with scales.

Figure 7. Researchers assembling the cold-flow carbon stripper.

ADVANCED INSTRUMENTATION

The units are outfitted with significant instrumentation, including numerous pressure differential transmitters, spirals for measuring solids circulation rate, electrical capacitance volume tomography sensors for measuring solid fraction and fiber-optic probes for measuring particle velocities. With units that have optical access, high-speed video can be collected, both external to the units and with various borescopes. These videos can then be analyzed with various techniques, including in-house-developed particle tracking software, extracting high-fidelity particle velocities.

IMPACT AND BENEFITS

The Heterogeneous Reactor Development team is charged with developing innovative multiphase flow reactors and processes that maximize performance, minimize cost and minimize environmental impact. The technologies developed directly impact the continued use of fossil energy for power production. These innovative ideas, technologies and results are disseminated to the public through peer-reviewed journals and presentations.

The team works with research organizations and industrial partners, exchanging ideas and insights to help advance technologies to market.

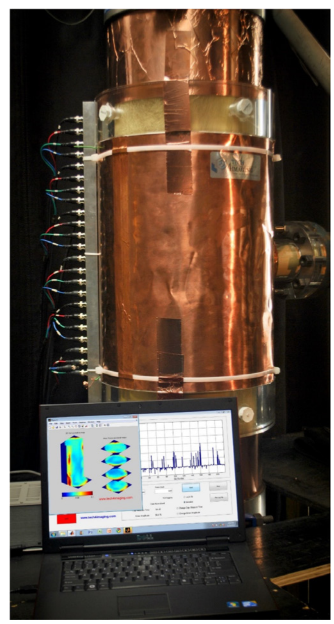

Figure 8. Electrical capacitance volume tomography (ECVT) sensor installed on the 12-inch diameter cold flow riser.

Research Partners

ALSTOM

Babcock & Wilcox [B&W]

National Renewable Energy Laboratory’s [NREL]

Particulate Solid Research, Inc. [PSRI]

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