# SANDIA SUPPORT FOR PETC FISCHER-TROPSCH RESEARCH: EXPERIMENTAL CHARACTERIZATION OF SLURRY-PHASE BUBBLE-COLUMN REACTOR HYDRODYNAMICS

NANCY B. JACKSON[1], JOHN R. TORCZYNSKI[2], KIM A. SHOLLENBERGER[2],
TIMOTHY J. O'HERN[2], AND DOUGLAS R. ADKINS[2]

[1]ADVANCED ENERGY TECHNOLOGY CENTER
[2]ENGINEERING SCIENCES CENTER
SANDIA NATIONAL LABORATORIES
ALBUQUERQUE, NEW MEXICO 87185-5800

## ABSTRACT

Sandia's program to develop, implement, and apply diagnostics for hydrodynamic characterization of slurry bubble-column reactors (SBCRs) at industrially relevant conditions is discussed. Gas-liquid flow experiments are performed in an industrial-scale 48 cm ID stainless steel vessel. Gamma-densitometry tomography (GDT) is applied to make spatially resolved gas holdup measurements. Both water and Drakeol 10 with air sparging are examined at ambient and elevated pressures. Gas holdup increases with gas superficial velocity and pressure, and the GDT values are in good agreement with values from differential pressure measurements. Other diagnostic techniques are also discussed.

## INTRODUCTION

In the Fischer-Tropsch approach to indirect liquefaction, industrial-scale slurry bubble-column reactors (SBCRs) are used to convert coal syngas into the desired product. However, gas distribution nonuniformity can cause buoyancy-driven flow, which in turn reduces the gas residence time and the process efficiency. Thus, it is essential to characterize the gas distribution nonuniformity, particularly as affected by the gas flow rate, the slurry material's thermophysical properties, the sparger geometry, and, most important for scaling considerations, the reactor diameter.

To this end, Sandia is developing, implementing, and applying diagnostics for hydrodynamic characterization of slurry bubble-column reactors at industrially relevant conditions [1-5]. An industrial-scale slurry bubble-column reactor experiment has been constructed as a testbed for diagnostics development and acquisition of data under relevant conditions. A gamma-densitometry tomography (GDT) system for measuring the gas holdup (gas volume fraction) distribution during gas-liquid (two-phase) flow has been implemented and validated for operation with the SBCR testbed. Gas holdup distributions in the SBCR vessel have been measured using the GDT system for both water and Drakeol 10 with air sparging at ambient and elevated pressures. Additional techniques such as electrical-impedance tomography (EIT) and electrical-conductivity bubble probes are also being examined.

## INDUSTRIAL-SCALE SBCR TESTBED

The SBCR experiment is shown in Figure 1 [3]. The vessel is made out of stainless steel and has an ID of 48 cm, a height of roughly 3 m, and a wall thickness of 1.27 cm. It is capable of operating at elevated pressures (up to 100 psig) and elevated temperatures (up to 200_C), where the latter are achieved via external heaters controlled at four vertical locations and an in-line heater for the gas. Two instrumentation ports and two view ports are placed at each of six vertical locations 45.7 cm apart. Differential pressure (DP) transducers are mounted at each of these vertical positions to measure the vertical pressure gradient, from which the average gas holdup between adjacent transducers can be inferred [6]. Prior to operation, the vessel is filled with liquid to a height of four diameters. Gas is subsequently injected into the liquid-filled vessel through one of several interchangeable spargers located near the bottom of the vessel. The current sparger is a 15-cm-diameter ring formed from 1.1-cm-ID stainless steel tubing with twelve 3.18-mm diameter holes in the top surface and is positioned adjacent to the bottom of the vessel. To date, gas superficial velocities up to 0.40 m/s, gas holdups up to 0.4, and pressures up to 50 psig have been examined in the SBCR vessel for water and Drakeol 10 with air sparging.

## GAMMA-DENSITOMETRY TOMOGRAPHY SYSTEM

GDT measures the spatial variation of the attenuation coefficient of gamma photons, which is linearly related to the gas holdup distribution. In brief, a beam of gamma photons is passed through the unknown distribution along several different but coplanar paths, and an axisymmetric tomographic algorithm is employed to reconstruct the gas holdup distribution that gave rise to the measured attenuation values [7]. A GDT system, including a gamma source and detector and axisymmetric tomographic reconstruction software, has been implemented [1-3]. A 5-Curie Cs-137 isotope source (0.6616 MeV photons) in a cylindrical lead vault is used, with a small-diameter aperture (0.25 in.) for collimation. The individual gamma photons are observed with a sodium iodide (NaI) scintillation detector, the temperature of which is controlled to minimize thermally induced drift. To avoid spurious acquisition of gamma photons that have been scattered through small angles, a small-diameter aperture (0.125 in.) is placed in front of the detector. A multichannel analyzer (MCA) is used to measure the energy spectrum of the gamma photons. A least-squares fit employing a function describing a spectral peak is applied to the spectral data around 0.6616 MeV to determine the number of photons corresponding to the peak. The source and the detector are mounted on two opposing arms of a heavy-duty computer-controlled two-axis traverse, which has 60 cm of travel in both the horizontal and the vertical directions and 66 cm of clearance between arms. When applied to the SBCR vessel, the GDT system typically scans a horizontal plane two diameters above the vessel bottom and counts for 30-60 s at each position within the scan plane. In the SBCR vessel, the gas holdup distribution in the scan plane is approximately axisymmetric, so an axisymmetric reconstruction algorithm is used.

## EXPERIMENTAL RESULTS

Experiments have been performed in the SBCR vessel using water and Drakeol 10 as the liquids with air sparging. As indicated earlier, the vessel is filled to four diameters above the bottom prior to sparging, and GDT scans are taken two diameters above the bottom. Additionally, the differential pressure (DP) transducers are used to measure the vertical pressure gradient, from which average gas holdup values can be inferred for the volume between transducers. Figure 2 shows the DP gas holdup results for water and Drakeol 10 at gas superficial velocities up to 0.25 m/s and pressures up to 50 psig, along with the Zuber-Findlay correlation [8]:

$$\varepsilon_G = \frac{j_G}{C_0\ j_G + C_1 \left[ \frac{\sigma\, g \left( \rho_L - \rho_G \right)}{\rho_L^2} \right]^{1/4}}$$

where $\varepsilon_G$ is the average gas holdup, $j_G$ is the gas superficial velocity, $\rho_L$ and $\rho_G$ are the liquid and gas densities, $\sigma$ is the surface tension, g is the gravitational acceleration, and both $C_0$ and $C_1$ are empirical coefficients (best-fit correlations for these constants to the present data are shown in the figure caption). Figure 3 shows the results of one GDT scan (both the raw data and the reconstructed profile of gas holdup), and Figure 4 shows plots of gas holdup radial profiles for both water and Drakeol 10 as functions of gas superficial velocity and pressure. It is seen that varying the pressure increases the overall gas holdup without changing the shape of the profile much whereas varying the velocity changes the shape of the profile somewhat. Average gas holdup values are in reasonable agreement with the values determined by DP measurements (Figure 2).

## ADDITIONAL TECHNIQUES

When considering three-phase systems such as slurry Fischer-Tropsch gas-liquid-solid flows, additional information is needed beyond that from GDT to determine the spatial variation of all three phases. Electrical-impedance tomography (EIT) is one technique that can potentially provide this additional information. In EIT, electrodes are mounted around the perimeter of the interior of a vessel. Current is passed from one electrode to another, and the resulting voltages are measured at the remaining electrodes. All distinct pairs of electrodes are employed in this fashion, and a reconstruction algorithm uses the measured voltages to determine the spatial variation of the electrical conductivity, which is related to the distribution of the phases. EIT electronics, hardware, and associated reconstruction software have been implemented and validated [4-5]. The EIT hardware consists of a lucite cylinder with 16 strip electrodes mounted on its inner surface. Validation tests were performed by placing a PVC cylinder within the lucite cylinder and filling the remaining annular region with water. Experimental data sets were acquired for several locations of the PVC cylinder. A two-dimensional finite element method electrical impedance tomography code called FEMEIT [4-5] was subsequently used to analyze these data sets and was able to successfully predict both the size and the location of the PVC cylinder, as shown in Figure 5.

In addition to determining gas holdup distribution, knowledge of bubble-size distribution is also important for reactor hydrodynamics characterization. To this end, a small electrical bubble probe has been fabricated. This probe consists of two needlelike electrodes with a 0.050 in. separation, similar to the expected bubble size. The interception of bubbles is recorded as an interruption of electrical current that would otherwise be conducted by the liquid from one electrode to the other. This probe has been placed in a calibration cell and coupled to a video recorder to assist in data interpretation. Figure 6 shows a plot of the history of the voltage difference between the electrodes. Large saturated peaks result when both electrodes intercept the bubble simultaneously, whereas smaller peaks correspond to interception by only one electrode or to near misses. Correlation of RMS bubble-probe voltage data with pressure-gradient data is also shown in Figure 6. Since the pressure gradient has previously been shown to correlate strongly with gas holdup, the bubble probe can also be used to measure gas holdup locally (after calibration).

## CONCLUSIONS

Gamma-densitometry tomography (GDT) has been applied to make spatially resolved measurements of the gas holdup in both water and Drakeol 10 at elevated pressures in a 48-cm-diameter SBCR vessel. Future efforts will focus on applying GDT to gain a better understanding of SBCR hydrodynamic behavior and on developing additional diagnostic techniques to better characterize bubble size and to enable three-phase flow measurements.

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## FIGURE CAPTIONS

Figure 1. Sandia’s slurry bubble-column reactor (SBCR) experiment. Vessel is 48 cm in diameter.

Figure 2. Average gas holdup dependence on gas superficial velocity and pressure in the SBCR vessel from differential pressure measurements for (a) air-water ($C_0 = 8.37 \exp(-0.050P)$ and $C_1 = 1.53$) and for (b) air-Drakeol 10 ($C_0 = 3.82 \exp(-0.015P)$ and $C_1 = 2.13$), where the pressure $P$ is in psia.

Figure 3. GDT scan two diameters above the SBCR vessel bottom for air-water (left, 30 s counting time per point) and for air-Drakeol 10 (60 s counting time per point): solid circles are experimental chordal averaged values; dashed curve is a fit (quadratic radial polynomial) to chordal averaged values; solid curve is the radial reconstruction of gas holdup profile. The slight asymmetry is probably related to the sparger.

Figure 4. Gas holdup profiles for air-water (top) and air-Drakeol 10 (bottom) as functions of gas superficial velocity at fixed pressure (left) and pressure at fixed gas superficial velocity (right).

Figure 5. Reconstruction of the size and position of a PVC pipe within a lucite cylinder: dashed line indicates PVC position and size; contours show reconstruction. Left, eccentric placement; right, concentric

placement. Roughness of the eccentric reconstruction is an artifact of the FEMEIT finite-element mesh.

Figure 6. Electrical-conductivity bubble probe results. Left, voltage history showing times during which the probe intercepts bubbles. Right, correlation of the bubble probe mean voltage with the differential pressure signal. Since differential pressure is strongly correlated to gas holdup, bubble probes can be used to measure local values of gas holdup after calibration.