Instrumentation for Real Time Monitoring of the 3-Dimensional Particulate Distribution in the Hanford Double Shell Tank Small Scale Mixing Demonstration Platform - 11242

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ABSTRACT

The ability to effectively mix, sample, certify, and deliver consistent batches of High Level Waste (HLW) feed from the Hanford Double Shell Tanks (DST) to the Waste Treatment Plant (WTP) presents a significant mission risk with potential to impact mission length and the quantity of HLW glass produced. At the end of 2009 DOE's Tank Operations Contractor, Washington River Protection Solutions (WRPS), awarded a contract to Energy*Solutions* to design, fabricate and operate a mixing demonstration platform to generate tank mixing performance data at two different scales.

The test platform [1] was constructed in early 2010 and testing commenced in July of the same year. The test platform consists of a flush vessel (11,000 liters), small transparent (acrylic) mixing test vessel (110 cm dia., 420 liters), and large transparent mixing test vessel (305 cm. dia, 8877 liters). A number of pumps provide the means to transfer batch material around the platform. The flush water vessel provides a bulk amount of flush water to all other vessels and pump suctions such that any blockages can be cleared. A simple connection to city water in the facility would not provide adequate flow or pressure for this duty. All tank internals, pumps and associated systems were scaled prototypically where possible. A suction wand feeding a recirculating sample loop provides the means to withdraw a small sample flow from the test vessels at any location, and return back to the vessel again.

A key objective of the test platform was the ability to develop a correlation of mixing conditions of two scaled DST models through the 3-dimensional (3-D) measuring of the distribution of solid particles during mixing. There was also a requirement to capture 3-D flow velocity vectors within the two scaled vessels for calibration and validation of a computational fluid dynamics (CFD) model. Testing was conducted using water, single component particulates, and also more complex simulants containing particles of different sizes and densities. Due to the cyclic nature of the mixing in this system as a result of the rotating jet mixer pumps, a continuous measurement technique was required rather than a spot measurement. A review of the initial test results is presented in a separate paper [2].

INTRODUCTION

While there are technologies which can look at small areas, and even volumes, of a tank contents, measuring 3-D solids distribution information over the complete volume of a large (305 cm diameter in this case) fluidically mixed tank in real time has not been achieved before. There is no single off the shelf technique which will give a quantitative real time solids concentration profile, so after an exhaustive review [3] of technologies available, the following combination of instrumentation was selected:

Overall mixing performance was evaluated through the use of custom designed Electrical-Resistance Tomography (ERT) systems. The ERT system works on the principle of taking conductivity measurements and comparing these to a known reference measurement. The ERT systems provided real-time viewing of mixing performance within the test vessels. This application on a 305 cm diameter liquid filled vessel is the first time such a system has been used at this scale, and it required close collaboration with the vendor, Industrial Tomography Systems (ITS), during the design and build phase of the system. The ERT system measurement technique measures the distribution of electrical resistance (or conductivity) in the vessel. Measurements can be taken rapidly allowing real-time viewing of data, both in terms of slices through the vessel, and real time 3-D images. The purpose of the ERT is to provide a qualitative picture of the mixing such that areas of “good” and “less good” mixing can be identified. The test systems comprise of a set of radial electrodes around the vessel walls, and also separate linear probes which can be placed in the vessel at any point to provide a high resolution image of conductivity at that location. An important feature of the linear system is the potential to be applied in the full scale DSTs at Hanford.

Coriolis meters were mounted in sample flow lines and used to measure solids concentration vs. time. Density data vs. time at a dynamic steady state in the jet mixer agitated test vessels has proved invaluable to quantifying mixing behavior. This is another technique that can be applied to the full scale DSTs.

Using a Focused Beam Reflectance Measurement (FBRM®) probe, the chord length distribution (CLD) of particles in a vessel was measured in real time without sampling or extracting product. Thus when mixing a tank containing a range of particle sizes, it was possible to measure, in real time, the amount of each particle size range at any location in the mixed volume. The probe could also be inserted in-line to measure the CLD as batch transfers were made out of the vessel. Again, this technique has the potential to be used when mixing and transferring the full scale DSTs.

Acoustic Doppler Velocity (ADV) Meters were used to measure the 3-D velocities at various locations within the test vessels. The ADVs were used to measure water velocity vectors only, and for this testing were intended to provide data to help calibrate and validate a CFD model. This paper will discuss the significant operational problems encountered, and solutions developed for this novel application of these instruments.

INSTRUMENTS

Coriolis Meter

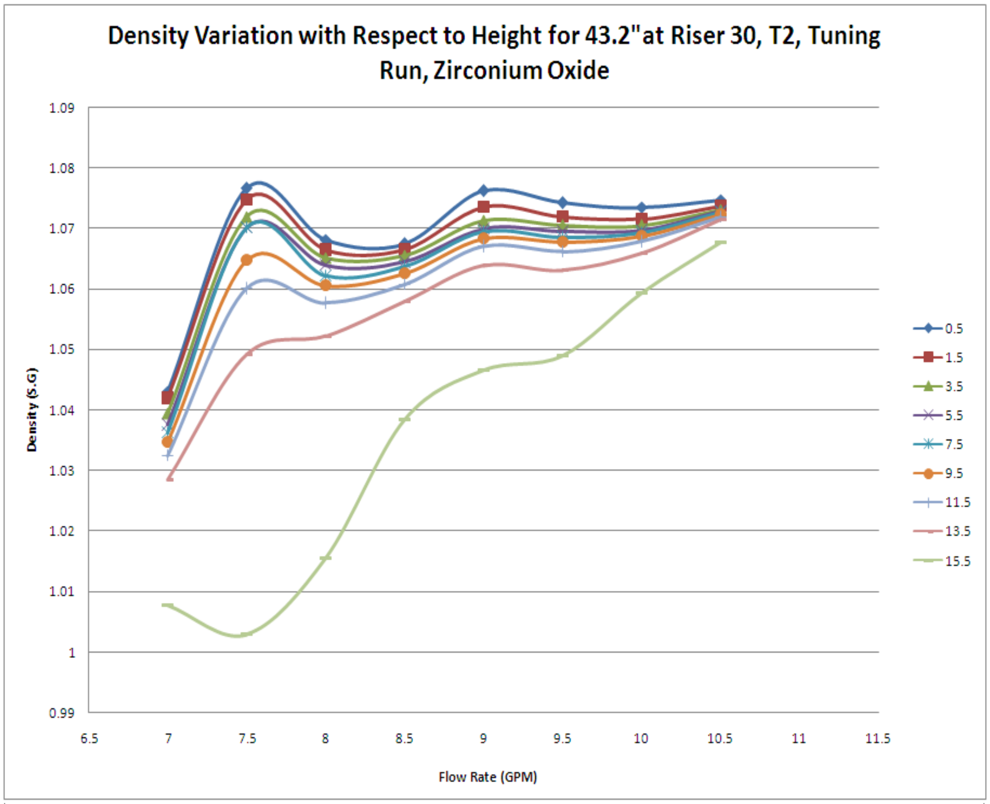
A Coriolis meter, see Figure 1, was mounted in the recirculating sample loop and was used during testing to determine the density at a specific location in the testing tank. The sample was taken continuously by drawing it out over at least 3 jet mixer rotations for a particular elevation and location in the tank. For the purposes of this testing, Micromotion F-series Coriolis meters were used.

Fig. 1. Coriolis Meter

The Coriolis meter measures mass of the fluid as it flows through two parallel tubes. An actuator induces a vibration of the tubes. There are two parallel tubes which are counter-vibrating, which makes the measuring device less sensitive to outside vibrations. The actual frequency of the vibration depends on the size of the mass flow meter, and ranges from 80 to 1000 vibrations per second. The amplitude of the vibration is too small to be seen, but it can be detected by touch. When no fluid is flowing, the vibration of the two tubes is symmetrical. When there is mass flow, there is some twisting of the tubes. This causes a shift in the phase of vibration, and it is this degree of phase-shift that is used as a measure for the amount of mass that is flowing through the tubes.

It should be noted that the Coriolis meter cannot differentiate between different simulant components since it only measures the overall density of the slurry stream flowing through it. No requirements were imposed on the simulant selection process by the Coriolis meter.

These data were presented in two standard formats for the purposes of reporting [4], see Fig. 2. The first is a plot of slurry density vs. mixer jet flowrate at different measurement elevations from the tank base. This shows the variation in density at a point as mixing energy is increased. The second is a plot of measurement location above the tank base vs. density measured at different mixer jet flow rates. This effectively shows a vertical density profile through the tank. On the second graph, the homogeneous density of the slurry assuming perfect mixing is drawn as a reference.



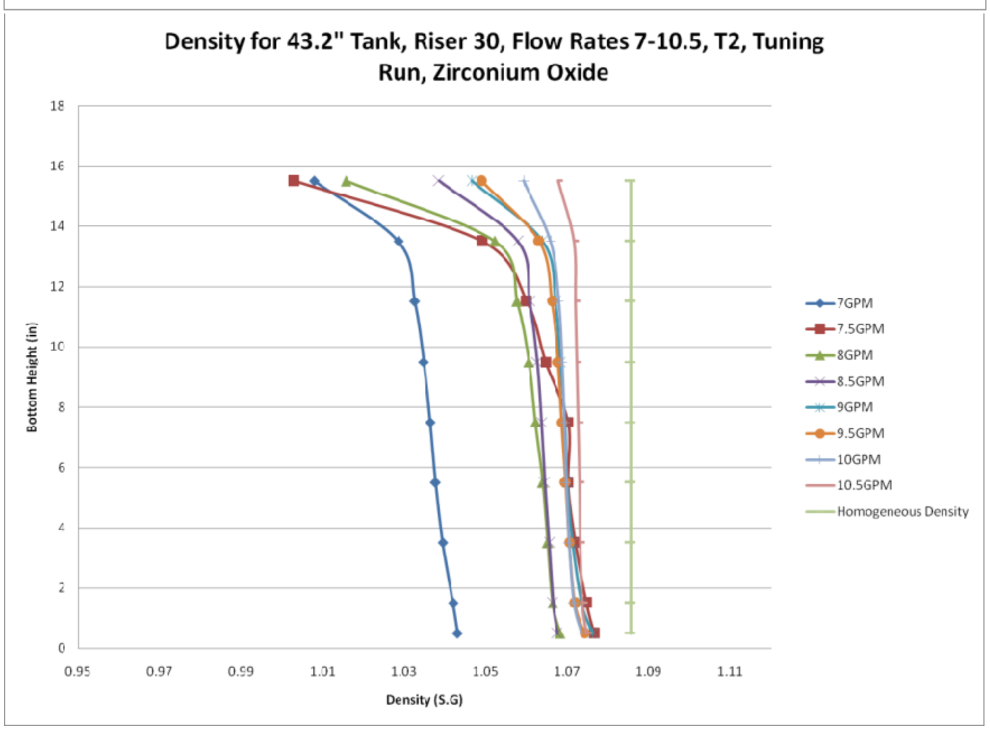


Fig. 2. Density vs. Location Plots in 110 cm Dia. Mixing Test Vessel

Mettler Toledo FBRM®[1]

Using Focused Beam Reflectance Measurement (FBRM®), the chord length distribution (CLD) of particles in the test tanks can be precisely measured in real time without sampling or extracting product. The CLD measurement is a function of particle size, particle shape, and particle population. It is important when interpreting the data to understand that this instrument does not measure particle size, but chord length. Hence a mono-dispersed particle (i.e. at a single discrete particle size) will have a chord length distribution when measured by the FBRM®, see Figure 3. It is hence an extremely valuable tool for real time measurement and data comparison in particulate systems, but does not generate absolute particle size data.

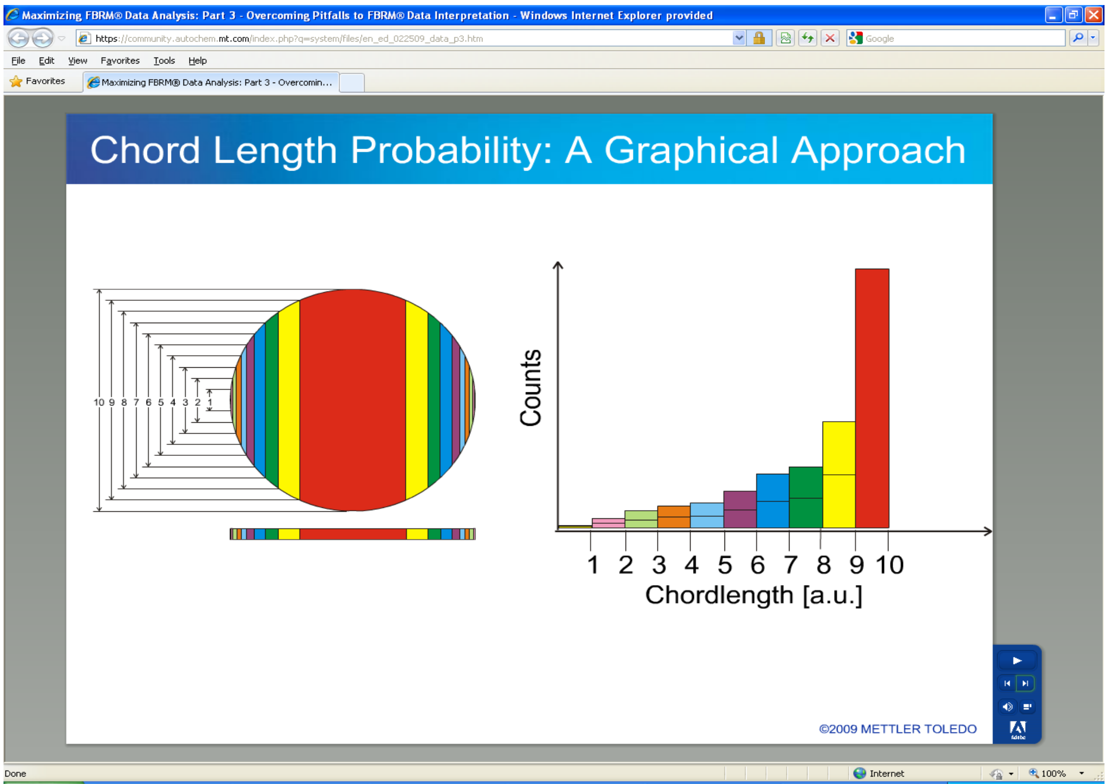


Fig. 3. FBRM® Chord Length Distribution for a Single Particle

Figure 4 shows a photograph of the instrument, and the cutaway schematic in Fig. 5 illustrates the key internal components of the FBRM® probe. A solid-state laser light source provides a continuous beam of monochromatic light that is launched down the FBRM® probe. An intricate set of lenses focuses the laser light to a small spot. This focal spot is carefully calibrated to be positioned at the interface between the probe window and the actual process. A precision air drive motor is used to rotate the precision optics at a constant speed of 6 m/s. The speed is carefully monitored and controlled throughout the measurement to ensure maximum precision in the data. As viewed from the probe window, the focused beam scans a circular path at the interface between the probe window and the particle system. As the scanning focused beam sweeps across the face of the probe window, individual particles or particle structures backscatter

[1] FBRM® is a registered trademark of Mettler-Toledo Inc., 1900 Polaris Parkway, Columbus, OH 43240

Fig. 4. Photograph of Mettler Toledo FBRM® Probe

the laser light back to the probe. Particles and droplets closest to the probe window will be located in the scanning focused spot and will backscatter distinct pulses of reflected light. These pulses of backscattered light are detected by the probe and translated into chord lengths (Fig. 6) based on the simple calculation of the scan speed (velocity) multiplied by the pulse width (time); a chord length is simply defined as the straight-line distance from one edge of a particle or particle structure to another edge. Thousands of individual chord lengths are typically measured each second to produce the Chord Length Distribution which is the fundamental measurement provided by FBRM®.

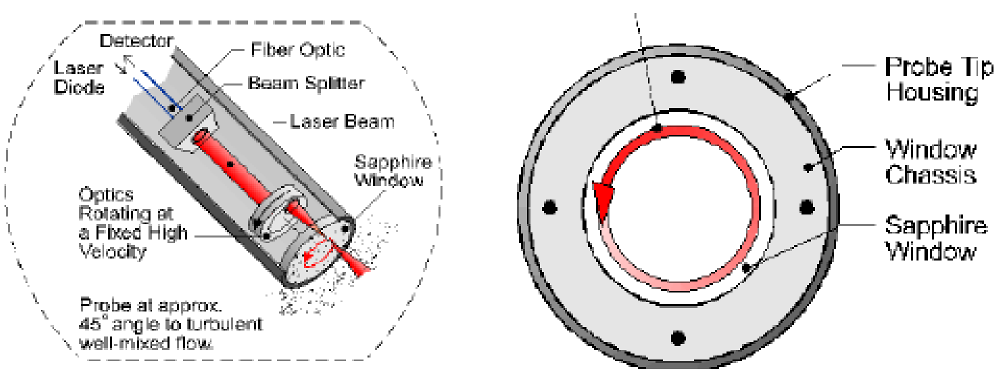


Fig. 5. Schematic of Mettler Toledo FBRM® Probe

The Chord Length Distribution, as a “fingerprint” of the particle system, provides the ability to detect and monitor changes in particle dimension and particle count in real time. Note that unlike other particle size analysis techniques, with FBRM® measurement there is no assumption of particle shape. This allows the fundamental measurement to be used to directly track changes in the particle system without unnecessary complex mathematical assumptions that could introduce significant errors to the measurement.

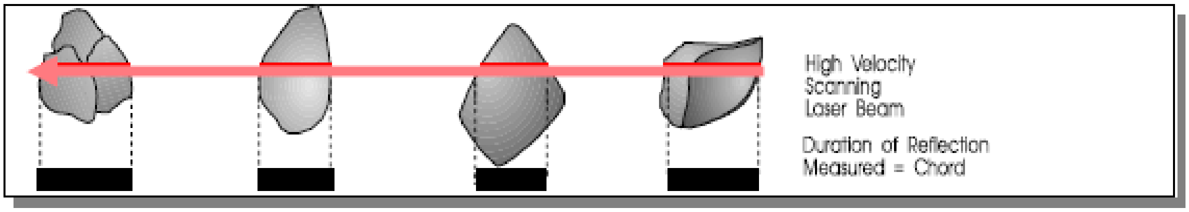


Fig. 6. Duration of Reflected Measurement Equate to Chord Length

Care had to be taken in selecting simulants such that the simulant materials allowed for light reflection to ensure light was reflected back to the probe. Smooth surfaced spherical and/or translucent simulant particles, e.g. glass beads, were avoided due to problems in clearly detecting chord lengths.

Electrical Resistance Tomography

Overall mixing performance was evaluated through the use of Electrical Resistance Tomography (ERT). The ERT system provides a real-time viewing of mixing performance and off-line analysis for determination of qualitative concentration profiles (with respect to the mixing zone changes) within the tank. The ERT system measurement technique measures the distribution of electrical resistance (or conductivity) in a cross-sectional plane of a pipe or tank. For the purposes of visualization, both tanks are broken up (i.e. dealt with as a grid) into 4 planes equally spaced off the bottom, and in each plane there is a ring of 16 electrodes around the internal walls of the test vessels. Each plane produces measurements of resistivity in real-time. The software displays the data for each plane by using a tomogram where the values are scaled from lower conductivity (blue) to higher conductivity (red) for each plane and also in a 3D rendering of the measurement volume. Conductivity measurements are useful as the different phases of a multi-phase process have very different values. This makes ERT a powerful technique for observing processes such as mixing, by using the changing electrical properties within a test tank to provide a global indication of the mixing dynamics. The circular array breaks the cross sectional area into a 20 X 20 grid, and generates a planar image (slices) accordingly. The purpose of the ERT is to thus provide a qualitative picture of the mixing such that areas of “good” and “less good” mixing can be identified. Previous studies using this technology in small to large vessels can be found in the references [5,6].

A linear array (probe), one per test tank, can also be used to provide localized analysis of the mixing by measuring resistivity from the top to bottom of the tank. The linear ERT has a sensing profile that is typically a solid quadrant of length equal to the active length of the probe and radius equal to half the active length. The direction of sensitivity is normal to the electrodes on the probe. The active length of the probe is dependent on the liquid level, with the control system switching planes off if an electrode in that plane is above the liquid level.

For the purposes of this initial phase of test work, the linear probe was not used due to better than expected performance of the circular ERT system in the large 305 cm test tank (this is the first time a circular array has been used on a tank of this diameter). Circular arrays however, while they do provide an overall image of the tank mix, are impractical in large tanks (i.e. they cannot be implemented in the DSTs). The linear probe can be placed at multiple points throughout the tank with its readings being validated by the previous scaled demonstrations using the circular array, and this will be demonstrated during the next phase of testing.

ERT measures the bulk system conductivity, hence cannot differentiate between different species within a mixed tank.

The ERT system works on the principle of taking conductivity measurements and comparing these to a known reference measurement. In the case of the SSMD project the reference measurement is taken independently for each of the four electrode planes and that reference is used to compare against the measurement values taken in real time during testing activities. The setup up of the reference files were taken with the majority of the simulant settled out and only the fines still suspended in solution (water).

Setting up the reference file in this way leads to an inherent limitation which is best described as a gradient effect across all four planes. This effect is caused from the simulant being added before the reference frame was taken. The result is reference measurements that differ in conductivity between each of the four planes with the bottom plane P4 being slightly more conductive (or less conductive depending on simulant used) then the plane above it P3 which continues up through P2 and into the top plane P1. It should be noted that pure water is not a viable reference frame because it results in very large differences between the reference and measured values that was seen to mask the relatively small changes created by the mixing environment.

Given the above limitation, the ERT output can only be absolutely compared in a single plane within the same tank or between the two scaled tanks. It should be noted that the color regime of blue is less conductive and red being more conductive still holds, but as stated is limited to single plane comparisons. However in general terms the overall mixing environment, material suspension though planes, can be inferred using the tomogram and 3D rendering output from the ERT software even though the above limitation inhibits specific plane comparisons. The use of the ERT required the simulant to posses differing conductivities to that of water, thus allowing for the instrumentation to differentiate between the baseline case water and the simulant.

The ERT data presented in Fig. 7 was collected using an ITS p2+ instrument, and shows an example of the typical output from the instrument when mixing gibbsite and silicon carbide [4]. The figure consists of 3 planes numbered from top to bottom in the “y” axis and flow rate (and hence mixing intensity) increasing left to right in the “x” axis for the 110 cm diameter tank. Also included is a 3D rendering based off the upper 3 planes above it. The bottom plane is separated from the upper planes due to large differences in reference frames (as explained earlier). Plane 4 begins with a premix frame that shows a constant green color throughout the planes which indicates zero mixing. At low mixing intensity, the red patches indicate the buildup of silicon carbide (more conductive than the reference) on the E/W datum (relative to the reference frame) and the blue patch is representative of the gibbsite (less conductive than the reference) relative to the reference frame. For both simulants, the red and blue observations are also seen when the ERT measurement was conducted on the test vessel with each of those components in separately. As the flow rate is further increased the red patches appear to be significantly reduced, which indicates an increase in mixing performance along the E/W datum for the bottom plane. As the flow rate increases further the large red patches are replaced by smaller mobile red patches that appear to swirl around the outer edge of the plane. The blue patch appears to be constant throughout the upper ranges of flow. In summary, the figure shows a map of conductivity throughout the measurement volume as mixing intensity is increased, and hence the location of solids within that volume.

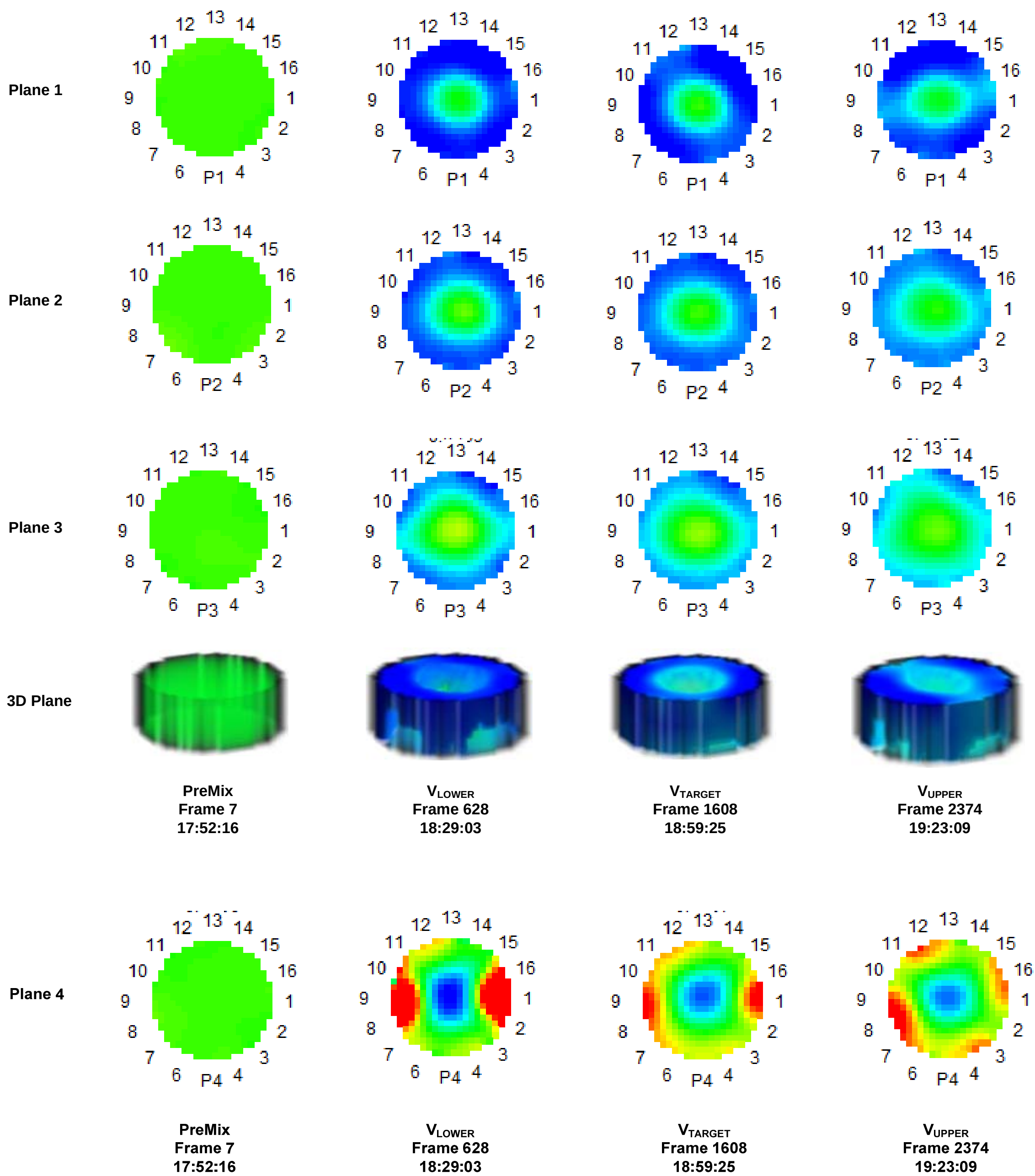


Fig. 7. ERT – Bi-Modal Al(OH)3 and SiC Planes (110 cm Tank)

Using this instrument on both test vessels allowed each vessel to be set up so that the mixing in each was equivalent, and this information, combined with later testing, will be used to derive scaling correlations for this type of fluidically mixed system. Testing has, in fact, demonstrated that the two scales of test vessel can be set up to show almost identical mixing patterns as observed via the ERT system. This will allow mixing and sampling of the full size Hanford DSTs to be predicted. It is also possible that a linear probe based ERT system will be deployed on the full scale DSTs to monitor mixing during full scale mixing demonstrations scheduled for approximately 2015.

ADVs

The Acoustic Doppler Velocity (ADV®[2]) Meters were sourced from Nortek USA, and used to measure the 3-D velocities of fluid at various locations within the test tanks. The ADV® is a high-resolution acoustic velocimeter used to measure 3-D water velocity. The basic measurement technology is an array of ultrasonics with coherent Doppler processing, which is characterized by accurate data with no appreciable zero offset that provides localized 3-D fluid velocity measurement in the vicinity of the probe. The Nortek Vectrino+ ADV® selected for this work is a bistatic sonar, in that it uses separate transmit and receive beams. It transmits through a central beam and receives through four beams displaced off to the side. The beams intersect each other 50 mm from the transmitter and the measurement volume is defined by this intersection and by range gating in time. The transmit transducer sends a short pulse that covers 3 – 15 mm vertically (user adjustable), and the receivers listen to an echo that corresponds from this volume. The diameter of the volume is 6 mm. The Vectrino uses four receivers, all focused on the same volume, to obtain three velocity components from that volume. It should be noted that the ADV® is used to measure water velocity vectors <u>only</u>. It cannot be used to measure particle velocities and hence slip velocity.

The ADV® measurements provided data to calibrate and validate the computational fluid dynamics modeling work (by others). Fig.8 shows the two configurations of ADV® used in this test work. For most measurements, the regular downward looking probe was used. For measurements close to the tank side wall a sideways probe was used.

Prior to using these probes in the test vessels their calibration was verified by using a precision tow track mounted above a tank filled with water. The probes were moved through the water at different velocities and the output compared against the known velocity. This was repeated for several different velocities, and with the probes mounted in different orientations to provide a read out of the x, y and z velocity components. The initial set of calibration verification runs was unsuccessful due to an unexpected noisy read out from the instrument. There are many user selectable parameters which are part of the instrument configuration and set up, and it was deduced (and later confirmed) that the transmit power had been set too high. In the confines of the tow tank this resulted in excessive reflected noise back to the sensors and hence an unusable and unstable reading. The second attempt to verify calibration was done with revised configuration parameters and was successful in demonstrating the high accuracy of this device.

Once calibration was confirmed, the plan was to run the mixers in the two scaled mixing test vessels and measure the velocity vectors. A considerable amount of time was spent attempting to obtain repeatable readings while locating the probes to within ±6 mm (0.25”) in all three planes.

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[2] ADV® is a registered trademark of Nortek USA, 222 Severn Avenue, Annapolis, MD 21403.

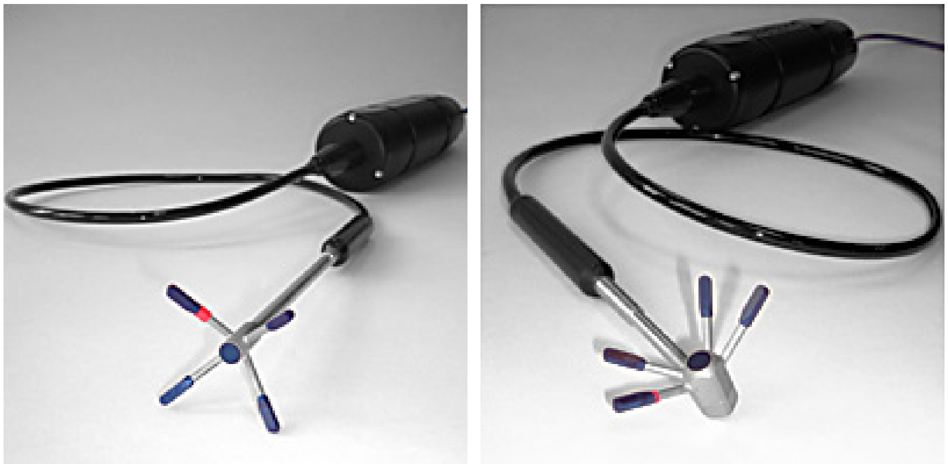

Fig.8. Downward Looking and Sideways Looking ADV® Probes

Probe location was achieved by using lasers to pin point where they needed to be, but repeatability could not be achieved. The problem in the end was thought to be due to the fact that the probes were too sensitive, and the mixing inside the tanks was too chaotic and micro scale in nature. Thus even if the probe was located to within 2 mm (0.1") of the target location, the flow velocity vector would be significantly different to the vector at the target.

Use of these instruments was therefore discontinued, ironically because they were too sensitive in the mixing environment that was under examination.

CONCLUSIONS

This paper has very briefly presented an overview of the instrumentation selected and developed for measuring three dimensional solids distribution and flow velocity vectors within two scaled mixing vessels. As a measure of success the ERT, FBRM®, and Coriolis meter were successfully used to map out a complex multi-component mixing system for two scaled tanks. This success is compounded with the added ability to match the mixing performance between the tanks in a system that is highly dynamic because of the chaotic nature of the jet mixer pumps.

Looking towards the future these instruments have the ability to measure mixing performance inside tanks in a minimally disruptive manner, which is very useful in situations where disturbing the contents of a tank is undesired.

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