AN INVESTIGATION OF SPARGED MIXING TANKS USING ELECTRICAL IMPEDANCE TOMOGRAPHY AND COMPUTATIONAL FLUID DYNAMICS

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ABSTRACT
A one metre diameter sparged mixing tank was fitted with an electrical imaging system and operated at six different operating conditions. Sparged mixing tanks are widely used in industry and it is relatively difficult to obtain measurements of gas dispersion during operation. This study investigates the performance of a Lightnin A310 in a gas sparged tank.

The results obtained using EIT were processed to provide time and spatial averages of electrical conductivity. Spatial averaging has been carried out in two stages: firstly radially at each measurement plane to produce five annular regions and also axially at six planes along the impeller shaft.

The corresponding CFD models provided steady-state values for volume fraction of air in the whole tank, and these results were processed to produce spatial averages for comparison.

This work has shown that it is possible to use electrical imaging techniques to investigate the gas dispersion in a sparged mixing tank and compare the results with those obtained from CFD models. Both sets of results compare well and can identify important trends in gas dispersion at the various operating conditions investigated.

INTRODUCTION
Commercial CFD codes available today can enable the rapid development of models of complex physical systems. The challenge for the engineer is to develop CFD models that represent the physical system with enough detail to provide some new insight to assist in the design process. Validation of the CFD models is therefore very important to give the engineer confidence in the model during the design process and also during plant optimisation activities.

This paper discusses some aspects of the on-going validation of a CFD model of a sparged mixing tank. Detailed measurements were made in a mixing tank using an electrical imaging system to obtain validation data at five different axial planes over a range of operating conditions. A three dimensional CFD model of the corresponding system was constructed and run at the corresponding operating conditions.

Electrical Impedance Tomography (EIT) has been used to obtain conductivity contours of a saline solution entering the surface of a mixing tank, Stanley et al, (2001). EIT data has successfully been used for the validation of CFD models in other conducting systems, such as a pipe reactor, White et al, (1999), and radial flow fixed bed reactor, Bolton et al., (2003). In the mixing tank and pipe reactor studies, the liquid tracer was a saline dye with relatively high conductivity, EIT could readily detect tracer-rich regions because of the difference in conductivity between the tracer and bulk fluid regions. The packing in the fixed bed reactor was non-conducting and EIT was well suited to track the locations of the conducting liquid.

Electrical tomographic techniques are not particularly well suited to identifying the presence of small features in large diameter vessels, even when there is a significant difference in electrical properties. Salem et al, (2001), report that the resolution of a 15 cm diameter copper sphere is acceptable near the wall but “grossly inferior” towards the centre of a 1.5 m diameter stirred tank filled with tap water. The copper sphere used in this study was hollow and weighted appropriately for neutral buoyancy.

EIT has often been used to track the movement of a tracer in the bulk fluid, and there is usually a significant difference in electrical conductivity between tracer and the bulk fluid. Researchers often use saline solutions as tracers, and the conductivity of the “tap water”, “sea water” and “salty tap water” was found to be 87.7, 49000 and 53600 µS/cm, respectively, at 25°C, Chanson et al, (2002). (Where the salty tap water was made up of tap water and 3.45 wt% sodium chloride of 99.5% purity.)

Alternative measurement techniques are available to investigate sparged mixing tanks and the results have been used to validate CFD models. Power consumption of the motor driving the impeller and visual observations of gas hold up can be used as performance indicators, Otomo et al, (2003). Photographic techniques can be used to measure the drop sizes present during the mixing of immiscible liquids, Ok et al, (2003). Photographic techniques where the camera is mounted outside a transparent-walled vessel would be difficult to apply to a sparged mixing tank because of the high bubble concentration through the whole of the vessel. Laser based techniques, such as LDV and PIV, are better suited to optically transparent systems, but particle tracking techniques, such as those reported by Fishwick et al, (2003), have been used to monitor internal circulation rates and can provide similar velocity data that can be used for validation purposes.

MIXING TANK AND ELECTRICAL IMPEDANCE TOMOGRAPHY SYSTEM
The mixing vessel used in this study was one metre in diameter and was fitted with a 25 mm diameter air entry point at the centre of the base. Air flow was controlled using a linear rotameter and experiments were carried out at air flowrates of 50 and 100 % Full Scale, equivalent to...
The gas dispersion at 120 rpm and 50% air in the central region is nearly as extensive as the gas dispersion at 0 rpm and 100% air and there is some recirculation of gas at the surface, see Figure 1 C and B, respectively.

At 120 rpm, the gas dispersion at 100% air is more extensive in the region mid-way along the shaft than at 50% air and there is no gas recirculation, see Figure 1 D and C, respectively.

At 210 rpm, gas dispersion is greater at the bottom of the tank than at the top of the tank at 25% air flow, see Figure 1 E.
• The gas dispersion at 210 rpm and 100% air is most extensive in the central region and there is significant recirculation of gas from the surface, see Figure 1 F.

The qualitative “feel” that can be developed for the internal flow pattern by this type of comparison has been useful in interpreting the quantitative results obtained from the EIT investigation of corresponding operating conditions. Figure 2 shows the overall average conductivities measured in each radial region across the lowest six measurement planes in the axial direction.

It is possible to rank the performance of the sparged mixing tank at each operating condition by analysing the trends presented in Figure 2. The assumption made in the ranking process is that the average conductivity in a particular region decreases with volume fraction of air, but as yet a relationship between the volume fraction of air and average conductivity is not fully understood. It is also important to understand that the results shown in the figure relate to an overall average conductivity determined in each radial region at six planes in the axis of the tank generally above the impeller and beneath the free surface. The trend lines presented in Figure 2 indicate that:

• At 0 rpm, the average conductivity plot indicates that the rising gas plume at 50% air flow is bell shaped in the radial direction. Gas holdup appears to be significantly greater in region A than in region E, and the plot for 0 rpm and 0% air flow is included as a baseline.

• At 0 rpm and 100% air flow, the rising gas plume appears to be significantly broader in region A than at 50% air flow, which is consistent with the qualitative analysis of the CFD results, compare Figure 1 A and B.

• The rising gas plume at 210 rpm and 100% air flow appears to be the most extensive, as indicated by the bell shaped, average conductivity plot. Conductivities in all regions are significantly lower than at 0 rpm, 100% air flow - a reduction in average conductivity of 0.5 µS/cm at region E and 1.25 µS/cm at region A, compared to 0 rpm and 100% air flow.

• The rising gas plume at 120 rpm and 100% air flow is not as extensive as that in the 210 rpm, 100% case, but follows a very similar form. Conductivities in all regions are roughly midway between the 0 rpm, 100% air flow case and the 210 rpm, 100% air flow case.

• At 210 rpm and 25% air flow, the average conductivity plot appears significantly “flatter”, indicating that more gas is present in the outer regions than at 50% and 100% air flow.

The comparison of trend lines for average volume fraction of air and for average conductivity, Figure 3 and Figure 2, respectively, has identified some quite striking similarities in behaviour. The trend lines identified in Figure 3 show that:

• At 0 rpm, gas dispersion is greater at 100 % air flow than at 50 % air flow, as expected.

• At 100% air flow, the rising gas plume at 210 rpm provides more extensive gas dispersion than at 120 rpm.

• It is very interesting that the trend lines for 0 rpm, 50% and 100% airflow, and 100% air flow, 120 rpm and 210 rpm, are generally the same form, as noted in the analysis of the average conductivity plots.

• The trend line at 210 rpm and 25% air flow plot appears significantly “flatter” than the other cases reported here, indicating a higher proportion of gas in regions adjacent to the centre of the vessel. This indication is consistent with the qualitative analysis of the EIT results.

• The trend line at 120 rpm and 50% air flow indicates that more gas is present in the outer regions than expected, as noted earlier in the analysis of the average conductivity plots.

The qualitative results showing average conductivity in each region obtained using the EIT have been compared with results from the CFD models. Figure 3 shows the average volume fraction of air that has been calculated for corresponding regions using results from the CFD runs.

The results of CFD models can readily be represented as contour plots showing the volume fraction of air and vector plots showing the velocity of water at an axial-radial plane through the centre line of the vessel, see Figure 4 and Figure 5, respectively. Plots of this type can assist in characterising internal flow:

• At 0 rpm and 100% air flow, the high volume fraction of air in the centre of the vessel is clearly visible, see Figure 4 A, and confirms the trend line shown in Figure 3. The velocity vectors, see Figure 5 A, confirm that the rising gas plume establishes a flow pattern in the water with downward flow at the walls and upward flow in the centre regions.

• At 210 rpm and 25% air flow, gas hold up can be seen to occur low in the tank and to extend beyond the centre of the tank, see Figure 4 B, and is consistent with earlier interpretations. The velocity vectors, see Figure 5 B, confirm the downward pumping action of the impeller.

• At 210 rpm and 100% air flow, an extensive plume of rising gas is clearly visible, see Figure 4 C, which is consistent with earlier interpretations. The velocity vectors, see Figure 5 C, indicate that impeller is not operating effectively and the circulation pattern more closely resembles that of the gas driven system, see Figure 5 A.

CONCLUSION

This work has shown that it is possible to use electrical imaging techniques to investigate the gas dispersion in a sparged mixing tank and compare the results with those obtained from CFD models.
The results obtained using EIT were processed to provide time and spatial averages of electrical conductivity. The spatial averaging was carried out in two stages: firstly radially at each measurement plane to produce five annular regions and also axially at six planes along the impeller shaft.

The corresponding CFD models provided steady-state values for volume fraction of air in the whole tank, and these results were processed to produce spatial averages for comparison.

Both sets of results compare well and can identify important trends in gas dispersion at the various operating conditions investigated. A more detailed investigation to compare performance at each plane is currently being undertaken.

Analysis of contour plots showing volume fraction of air and vector plots showing water velocity, obtained by analysing the results of the CFD models, provide useful insight into the performance of the sparged mixing tank.

It should be pointed out that of the operating conditions investigated, the impeller could only be considered to be operating effectively at one condition, namely 210 rpm and 25% air flow. This condition would also have been identified if an analysis of power consumption had been undertaken.

Possible future work includes a similar type of analysis to be carried out comparing EIT and CFD results at each of the six axial planes, and also investigating the performance of a six-bladed Rushton impeller in similar operating conditions.

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REFERENCES


Figure 1: Plots showing isosurfaces at 2.5% volume fraction of air for each test condition.

Figure 2: Plots showing overall average conductivity measured in each region at each test condition.

Figure 3: Plots showing overall average volume fraction of air in each region at each test condition.
Figure 4: Contour plots showing volume fraction of air at 100% at 0 rpm, and 25% and 100% airflow at 210 rpm.

Figure 5: Contour plots showing velocity vectors for water at 100% at 0 rpm, and 25% and 100% airflow at 210 rpm.