USING RADIOFREQUENCY TAGS TO ASSESS MIXING IN FLUIDS

J.A. Bamberger, D.S Daly, R.S. Brown, J.A. Vucelick, D.K. Tano, K.K. Anderson, and A.A. Diaz
Battelle Pacific Northwest Division, Richland, Washington, United States

Abstract: Radio frequency (RF) tags were used to track motion of slurry during mixing in a vertical cylindrical tank and to assess the degree of homogeneity obtained during the mixing process. Initially, the RF tags, each with a unique identity, were uniformly seeded across the top surface of the slurry. Repeated observations of the RF tags within range of a sparse grid of externally mounted antennas were used to estimate tag movement during mixing. After mixing, the final locations of the RF tags were estimated by manually sweeping the outer sidewall of the tank with an antenna. The technique has been applied to both clear and opaque slurries and provided a novel method for evaluating mixing in real time and after mixing has terminated.

Introduction: Individually numbered radio frequency tags, interrogated by antennas, provide a novel way to track mixing by tracking the travel of the tags. During this test, radio frequency PIT (passive integrated transponder) tags from Biomark, Inc. (http://www.biomark.com/) operating at 134.2 kHz were interrogated via antennas attached to the perimeter of the tank to track tag motion during mixing. Antenna placement and tank configuration are shown in Figure 1 and tank dimensions are summarized in Table 1. The antenna grid was mounted over ~180 degrees around the tank. The coverage in this grid was not 100% but provided information at three elevations around the tank sidewall surface, except for one low location. Antennas 1, 2, 3, 7, 8, and 9 were located along the wall at a gap between mixer tubes. The remaining antennas were located in line with the mixer tubes. The antenna dimensions are 25 cm (9.75 in.) outer diameter and 18 cm (7 in.) inner diameter. The antenna scanned volume was measured to be 4850 cm^3, half of an ellipsoid of dimensions 23 cm x 23 cm x 18 cm. To evaluate mixing, the tank was filled with 870 l (230 gal) of opaque 27 wt% slurry composed of 80 wt% kaolin clay and 20 wt% bentonite clay.

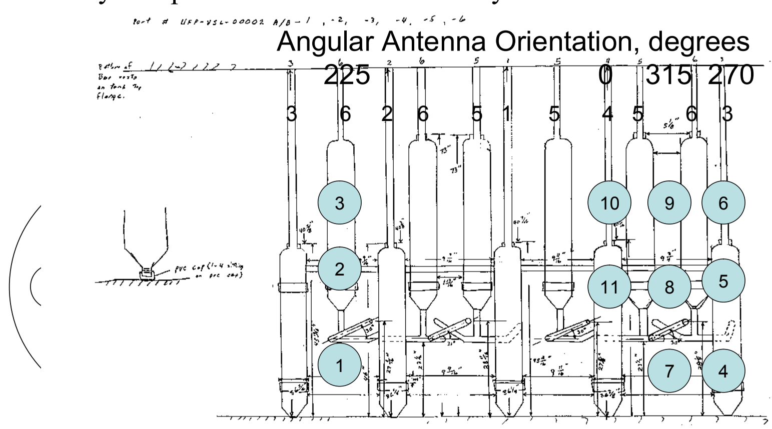


Figure 1. a) Antennas located around the tank perimeter, b) Top view of tank showing mixing tube locations (1 through 6) and c) Expanded side view showing numbered mixing tubes and antenna (1 through 11) locations

Table 1. Vertical tank dimensions

Parameter	Dimension
Tank diameter (D)	86 cm (34 in.)
Tank height	229 cm (90 in.)
Fluid height (H)	1.845 D = 159 cm (63 in.)
Pulse tube inner diameter	15 cm (6 in.)
Pulse tube 1 through 4 nozzle inner diameter	3 cm (1.2 in.)
2 upper PJM	15 cm (6 in.)
Pulse tube 5 and 6 nozzle inner diameter	2 each at 2.1 cm (0.82 in.)

Results: At the start of the test 60 tags were seeded on the top of the tank. At the end of the test 56 tags were retrieved from the slurry. During mixing the antennas recorded 1628 tags during the transient test. Post test scans around the tank perimeter identified 55 tags during the horizontal scan and 77 tags during the vertical scan. 57 unique tags were identified during the transient test, and horizontal and vertical scans. 51 unique tags were identified during the transient test. 26 unique tags (of the approximately 43 expected) were identified during the vertical scans. The expected value is based on an estimate of the range of the antenna when it is attached to the outside of the tank. The 43 excludes the out of view volume in the central core of the tank. 22 unique tags were identified during the horizontal scans. 20 unique tags were identified in both the horizontal and vertical scans. 21 unique tags were identified in both the transient and vertical sets. 17 unique tags were identified in both the transient and horizontal sets. Based on Chi-Squared analysis of the horizontal scan information, the assumption of homogeneity cannot be rejected (inferring that homogeneity can be accepted).[1] The statistical power of this particular test to detect non-homogeneity, however, is limited due to the few number of tags (22) observed.

Discussion: A series of RF tag measurements were made to characterize the tag performance. To ensure buoyancy and shield the tags from damage during mixing, the tags were coated with a layer of silicon. Prior to the start of mixing the tags were placed in a 60 square grid on the top surface of the slurry; each square was 14.8 cm (5.83 in.) on a side with a tag density of 1 per square. The slurry was able to support the tags on the top without the tags sinking into the slurry. Based on the fluid volume, the tag density was 1 tag /14.5 l (3.83 gal).

Tag Transient Measurements: The objective of the tag transient measurements was to track the tags as a function of time, using a set of stationary antennas, as the tags were entrained into the slurry and moved about the tank. After the mixer operation commenced, the tag locations were tracked for ~ 80 minutes. During this time the 11 readers recorded 1628 tag sightings. Each antenna continually tracks tags as they pass through its range; however, the data record only updates to record the presence of a newly observed tag. Of the 60 tags inserted into the tank, 51 were identified. The transient data was analyzed in two ways: to identify activity in the range of each antenna and to identify the travel history of each tag.

Antenna Activity: The plot in Figure 2 shows the time history of tags in the range of antennas 1, 2, and 3. The lines are color coded by antenna height: red = high, blue = mid, black = low. The plot in Figure 3 is a compilation of data for all of the eleven antennas.

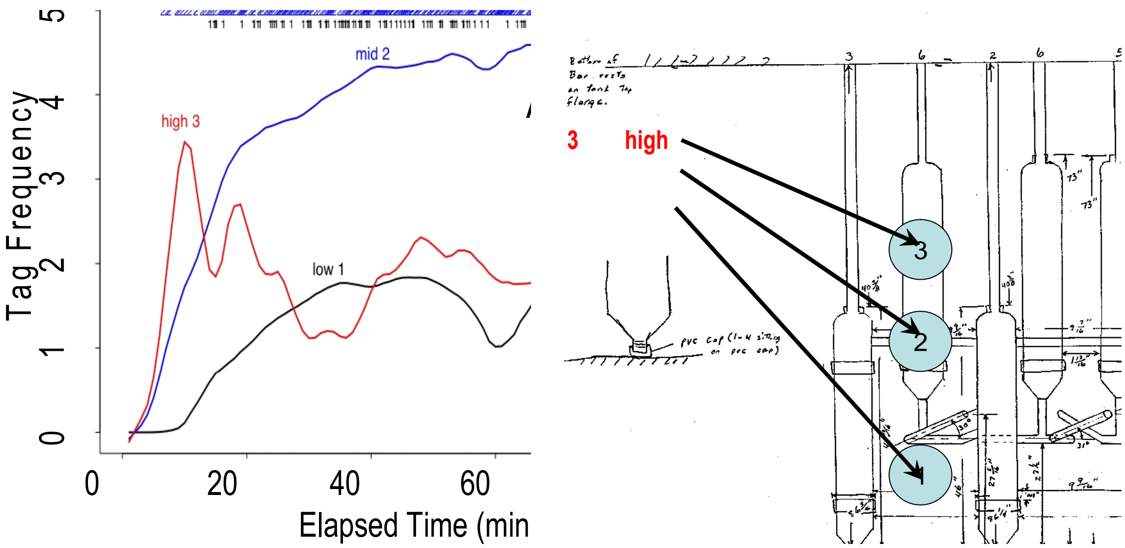
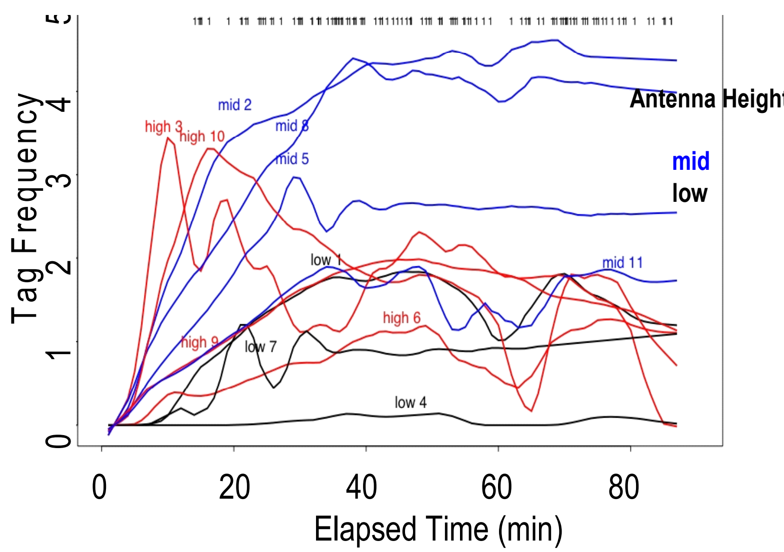


Figure 2. Transient tag detection by antennas 1, 2, and 3

Antenna locations 3 and 10 show quite a high frequency of tags in their range early in the test. This appears to be due to the reader oscillating between two, or possibly more, tags initially trapped in the vicinity of that reader. In Figure 3, which shows data from all antennas, the observed sightings per location per minute at the low and mid levels reach a steady state after ~ 40 minutes of mixing. More variability is observed at the high antenna location.



Most tag activity observed at mid levels

Figure 3. Transient Tag Detection as a function of Antenna

Tag Activity: In Figures 4 and 5 the transient data is plotted as a function of tag sighting. The elapsed time during the test is plotted along the x axis. The tag number (sorted from the first-identified tag to last) is plotted along the y-axis. The numbers on the plot identify the antenna that observed the tag at the given time. The numbers are coded by color with darker hues denoting antennae at lower elevations and ligher hues denoting antennae at higher elevations. In Figure 4 the first tag identified in time is shown at position 1 and the last tag to be identified is shown at position 51. The tag shown in position 51 was first observed by an antenna 58 minutes into the mixing process. In Figure 5 the last tag identified in time at minute 81 is shown in position 1 and the tag shown in position 51 was only observed once at ~ 55 minutes into the mixing process. These figures show some interesting details.

- **Two tags moving back and forth in the same antenna range**. In Figure 4 observe tags 10 and 16 at the start of the test; denoted by the dark red tags shown in the dark red circle. These tags both moved back and forth in the range of antenna 3. This phenomenon is also observed in Figure 4 with tags 9 and 19 (the pink tags to the right of the dark red circle) moving back and forth in the range of antenna 10. In Figure 5 areas of significant tag activity at antenna 10 are shown in pink ovals. Both of these antennas are located at the top of the tank.
- **One stationary tag and many others moving in and out of view.** In Figure 4, observe tag 1 at the end of the test, shown within the green oval. This tag is parked in the range of antenna 6 (also near the top). This tag alternates with quite a few different tags that move in and out of the antenna range from a variety of locations.
- **Timing.** The majority of tags (36 of 51 observed) came into view within the first 20 minutes of mixing. However the last tag identified, number 51, was observed after 55 minutes of mixing.

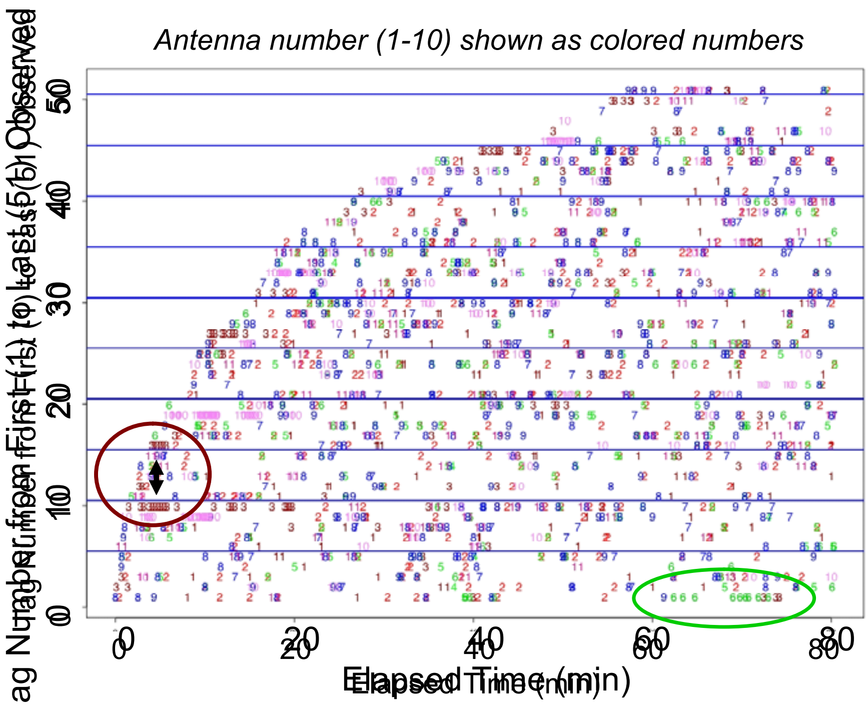


Figure 4. Transient tag frequency and location of observation ordered by time of first observation.

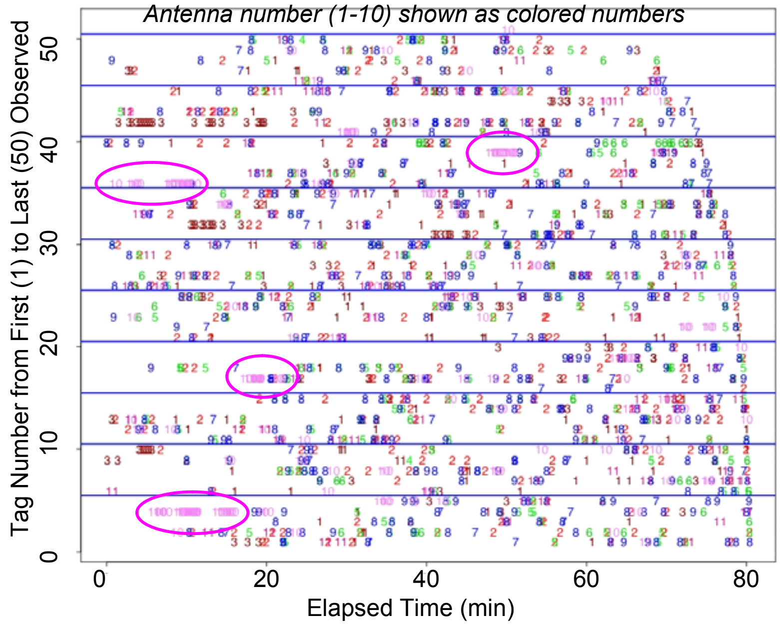


Figure 5. Transient tag frequency and location of observation ordered by time of last observation.

Post Test Tag Location Characterization: After mixing was stopped, the antennas were removed from the sides of the tank. A single antenna was used to scan the tank exterior horizontally and vertically.

Horizontal Characterization: To characterize the tank horizontally, measurements were made at the 7 elevations. The measurement location was tracked every 45 degrees using a previously identified externally-mounted reference tag. Therefore, the tank wall surface area was divided into 56 cells, 7 high by 8 in circumference. The data from this mapping is shown in Figure 6. The dark blue horizontal line at ~ 52 in. elevation represents the slurry surface. Note that some tags are observed above this level. This is because some tags stuck to the side of the tank at some point during the transient mixing test. These tags can be correlated with the data shown in Figure 4 to determine at what time they were removed from the mixing process. The antenna range is ~ 8 in. in depth and in width. The grid pattern scanned provided some overlap. This is shown by the multiple readings of certain tags. The large red numbers show the approximate location of the tag, based on visual triangulation of the points shown.

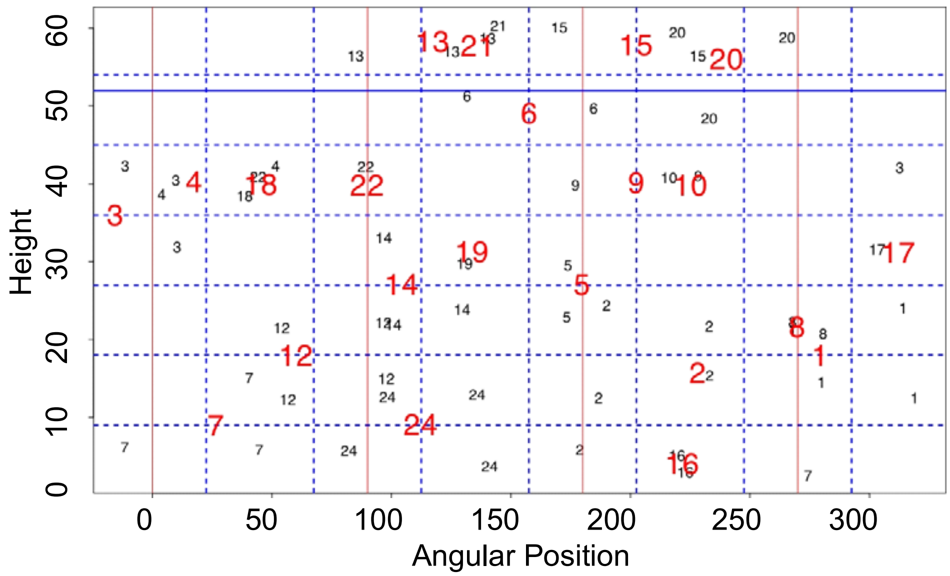


Figure 5. Tags detected during horizontal scanning of the static mixture

Vertical Characterization: Three unique vertical locations were characterized: those with the pulse tube near the wall (pulse tube gap), those with no pulse tube nearby (space) and those locations that are in between. The vertical tag data is summarized by location in Table 2 and plotted in Figure 6. At first observation this data shows that on average, 12 unique tags were observed in the spaces and 13 unique tags (26/2) were observed in the in between locations. Only 8 unique tags were observed in the pulse tube gap. One possible explanation for this difference is the width of the gap between the tube and the wall. The gap may limit the number of tags. Another way to address this is keeping in mind that the antenna range is greater than the gap width and the tube inhibits comparison of equal volumes. This orientation reduces the penetration of the antenna.

Table 2. Unique tags observed based on generic location

Location	**Pulse Tube Gap**	**In Between**	**Space**
Unique Tags	8	26/2=13	12
Angle	0, 90, 180, 270	22.5, 67.5, 112.5, etc	45, 135, 225, 315

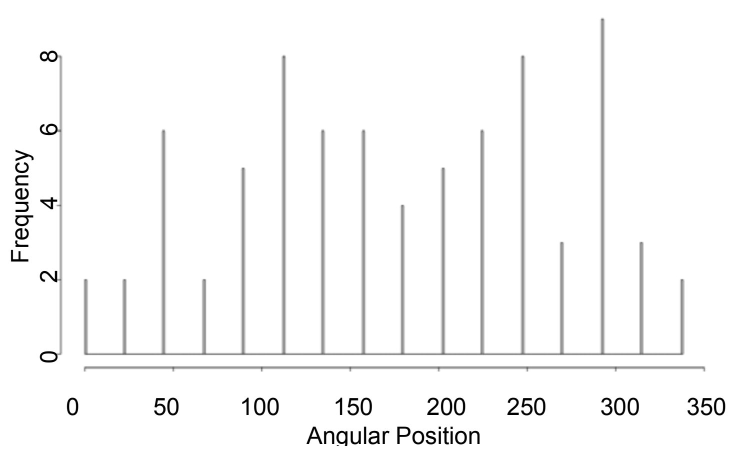


Figure 6. Unique tags detected during the vertical traverse

Conclusions: Tracking the motion of radio frequency tags provided a novel method to characterize tag and therefore fluid motion during mixing in a vertical tank. The tags were not damaged by the mixing process and the antenna range was sufficient to interrogate the tags while mounted on the wall of the tank. Both the transient and steady state data were analyzed to assess mixing. The tags were seeded in a grid on the top surface of the slurry. Mixing was monitored for 80 min. After 40 min the tag motion at each antenna reached steady state. Evaluation of the tag static location at the end of the test showed that the assumption of homogeneity could not be rejected.

References:
1. Lindgren, B.W., (1976). "Statistical Theory," Third Edition, Macmillan, New York.