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ENGINEERING DEVLOPMENT LABORATORY

PULSE JET TESTING CAPABILITIES

The Engineering Development Laboratory recently performed pulse jet mixer development studies related to Hanford's Waste Treatment Plant (WTP) Concentrate Receipt Vessel. These were performed on a wide variety of pulse jet arrangements, pulse jet sizes, nozzle diameters, nozzle configurations, nozzle velocities, pulse jet firing orders, and waste simulant rheologies. This paper describes the EDL Pulse Jet Mixing Test Stand capabilities, experimental methods and data acquisition.

Test Stand Description:

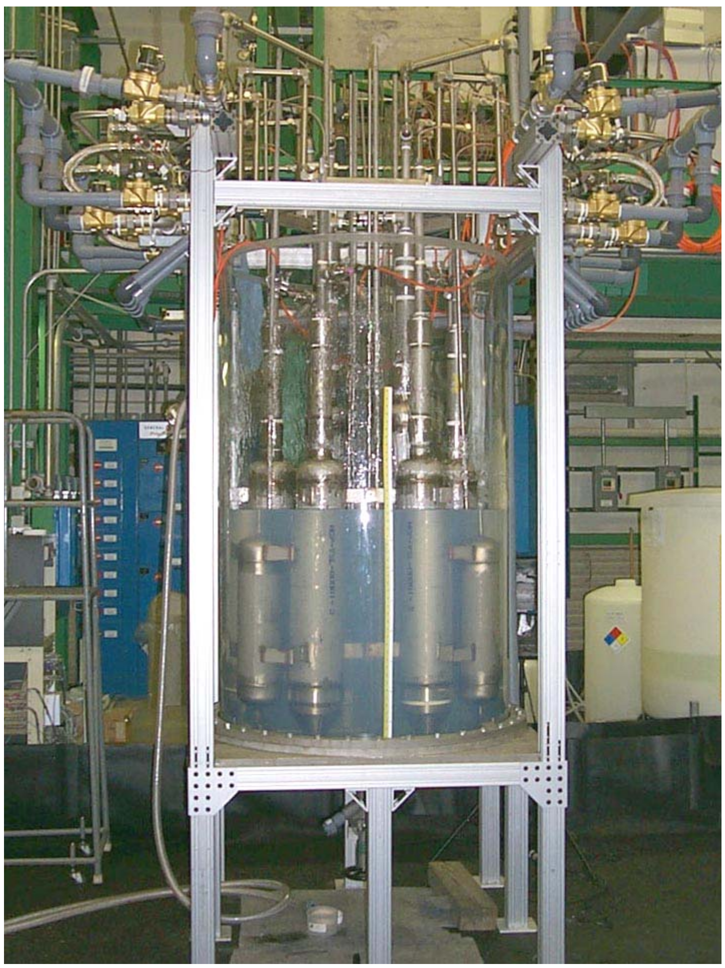


Figure 1 EDL Pulse Jet Mixer Test Stand

Figure 1 shows the EDL PJM Test Stand. The test tank is a 40.125 -inch-ID, 1-inch thick clear acrylic vessel, 76 ±1 inches tall with a ~2:1 elliptical dish head made out of stainless steel.

An overall view of the PJM Test Facility is shown in Figure 2**,** showing the test vessel, mixing tanks and control/data acquisition console.

Figure 2 Overall View of Concentrate Receipt Vessel Test Facility showing Subsystems

CRV PJM Assembly Configurations Tested

The following are some examples, but not all inclusive, of PJM assembly configurations tested. The hardware allowed for flexibility in re-arranging PJMs and utilizing various nozzle designs.

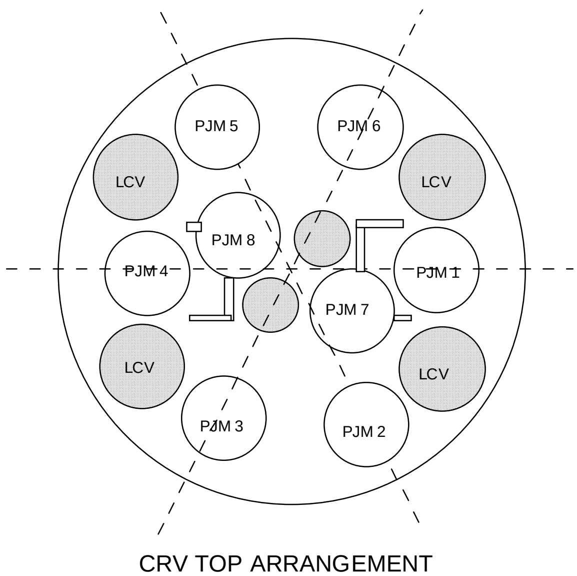
Baseline PJM Configuration

The baseline design is shown in Figure 3. Six 6-inch-diameter scaled PJMs and two additional Ram's Head PJMs can be inserted or taken out. Four large charge vessels (for operating the RFD transfer pump system) and two small charge vessels (for operating the RFD sampling system) are also simulated in the mockup. The arrangement of the components in this design is shown in Figures 3. An elevation view of the PJMs is also shown in Figures 3 4.

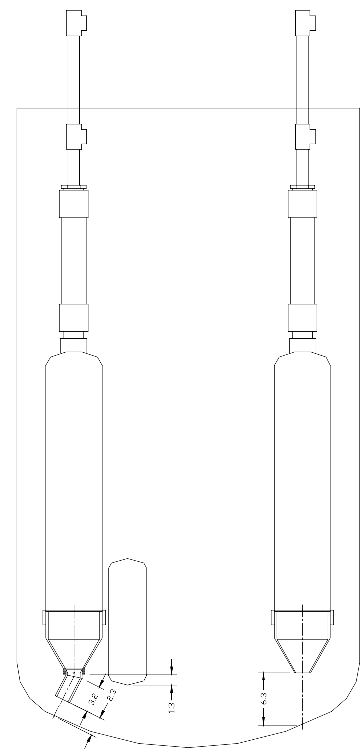
The PJMs for the Baseline design were constructed from 6-inch-diameter (6.625-inch ID) schedule 40 stainless steel pipes with the end connected to an approximately 60° angle cone terminating in two types of nozzles as shown in Figures 3. One type is a downward facing nozzle and the other, a nozzle perpendicular to the bottom head. The cylindrical section of the

PJMs was 37 ±1 inches tall, which is slightly over-scale in order to achieve the proper scaled expelled volume.

The Ram's Head PJMs, which direct flow to the outer wall region, are shown in Figure 5.



Plan View



Elevation View

Figures 3 Baseline PJM - Plan View **Figure 4 Baseline PJM - Elevation View**

Figure 5 Ram's Head Nozzles

Spider Arrangement

A variation of the Baseline design, the Spider arrangement uses four large (8-in. diameter) PJMs and two 6-in. diameter PJMs. The two inner PJMs have four pipe nozzles each where the flow from each nozzle is directed at a gap between the PJMs and charge vessels. See Figure 6.

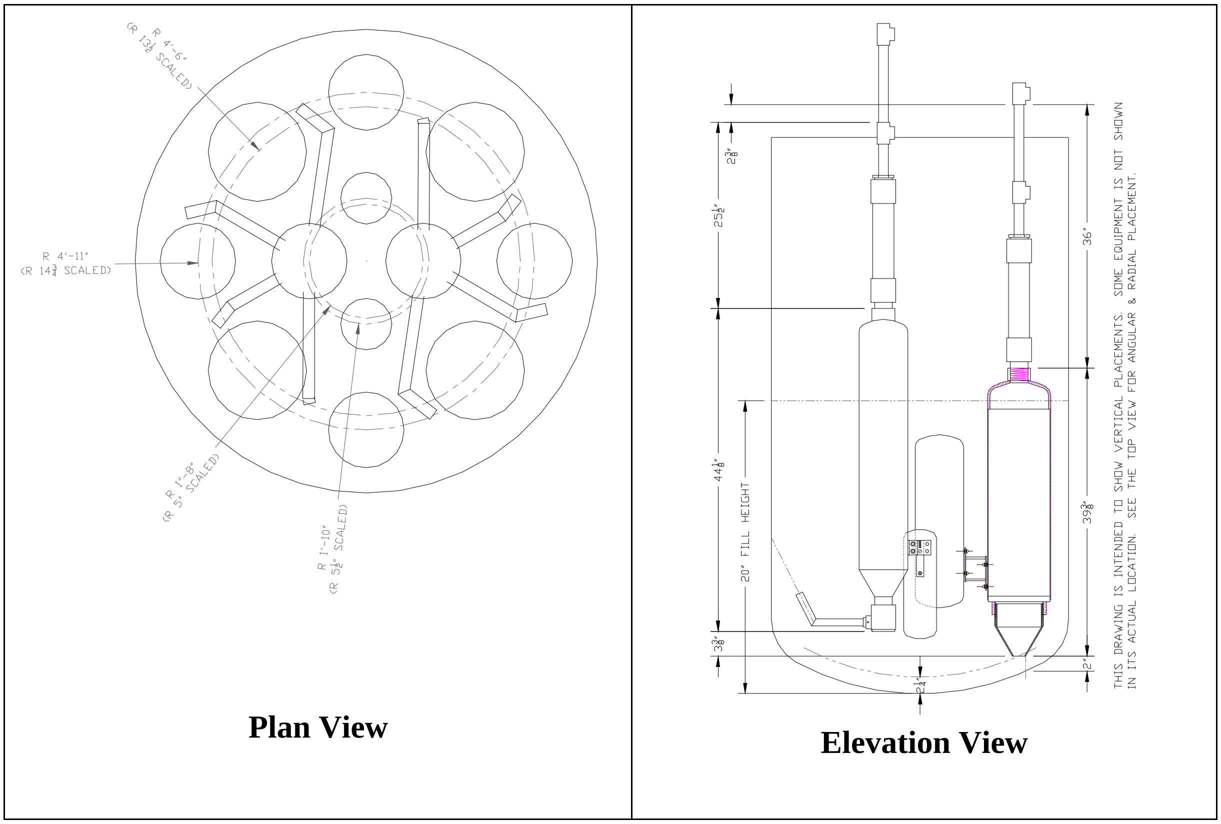


Figure 6 Spider PJM Configuration - Plan View and Elevation View

Chandelier PJM Arrangement

The final, selected PJM arrangement is the so called Chandelier arrangement, Figure 7. Here, the PJMs are clustered at the center of the vessel and the charge vessels are positioned along the vessel wall along radial centerlines between PJMs. This is to provide an annular flow distribution as close to symmetrical as possible.

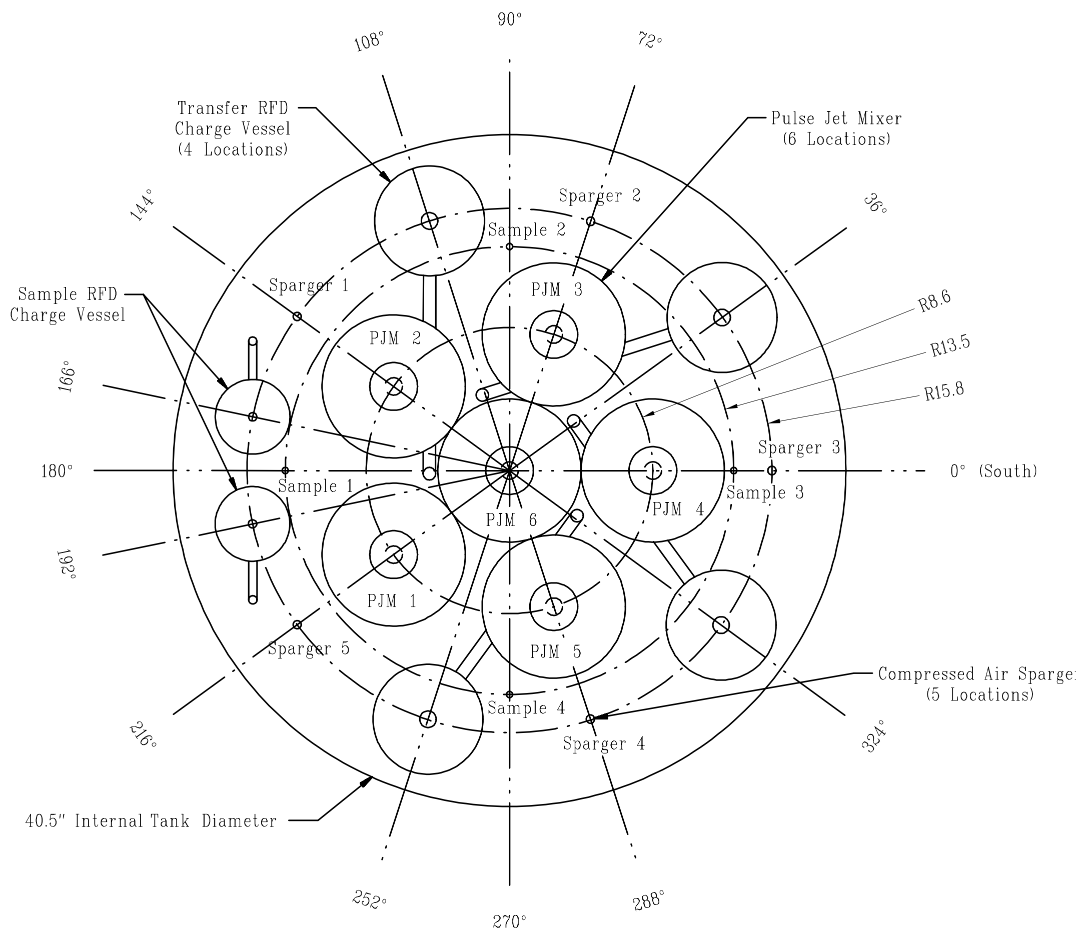


Figure 7 Top View of the CRV Prototypic Test Stand Showing Nominal Dimensions

All PJMs for the final, selected CRV prototype of the Chandelier arrangement were constructed from 8-inch-diameter (8.329-inch ID) schedule 10 stainless steel pipes with the end connected to an approximately 60° angle cone truncated to a 1.5-inch-diameter collar to which the nozzles were fitted. Figure 8 is a drawing of the PJM assembly; Figure 9 is a photograph of the entire assembly inside the CRV tank. The cylindrical section of the PJMs was 37 ±1 inches tall; this corresponds to a PJM height scale factor of ~ 4.32. However, the volume expelled from the PJMs is consistent with the CRV vessel scale factor of ~ 4.0.

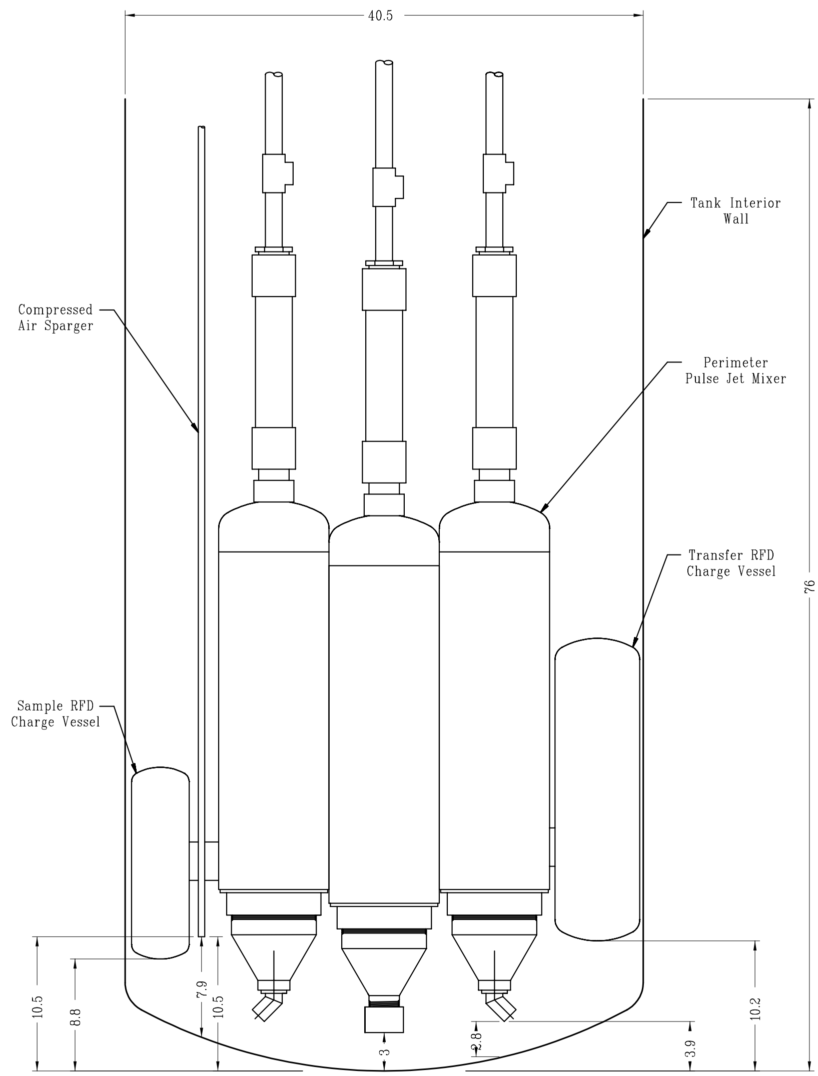


Figure 8 Plan View of the CRV Test Stand Showing Nominal Dimensions

The center PJM nozzle (Figure 10) was constructed from a drilled stainless steel pipe cap attached to a 60° cone and was pointed straight down toward the center of the tank bottom and raised approximately 2 inches off the bottom. Two types of perimeter PJM nozzles were used. One, (Figure 11 – 1.05-inch ID shown) was angled 45° (using welded pipe sections) from the vertical; and the other (Figure 12) was angled 135° from the vertical. Both were directed radially outward from the tank center and raised approximately 2 inches off the tank floor. Only two combinations of nozzles were used. The first, called the Down Nozzle Configuration, consisted of (5) 45° downward facing nozzles and (1) center down nozzle. The second, called the Up/Down Nozzle Configuration, consisted of (3) 135° Nozzles at PJMs 1, 2, and 4, (2) 45° down nozzles and (1) center down nozzle.

Figure 9 Final 8-inch diameter Chandelier PJM and charge vessel assembly (1.5-in. diameter Nozzles installed)

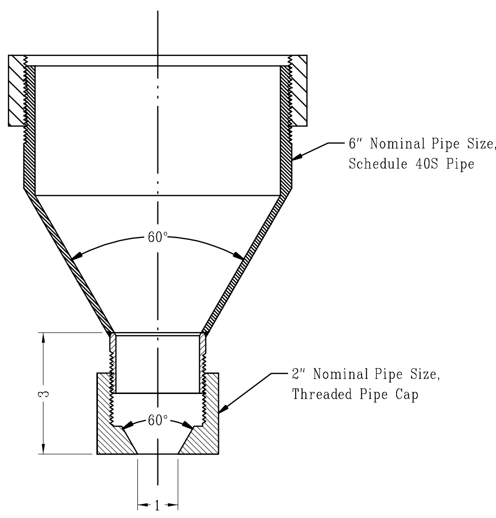


Figure 10 Center Nozzle Showing Nominal Dimensions for 1-inch Nozzle

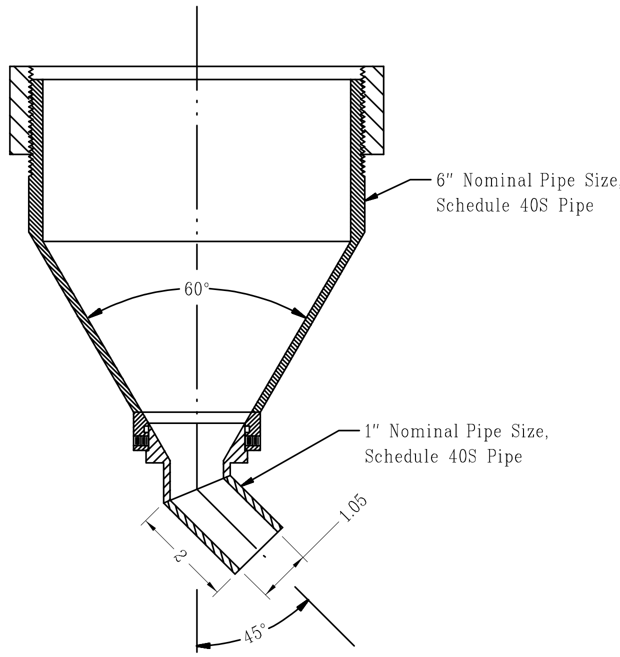


Figure 11 45° Nozzle; Showing Nominal Dimensions for 1-inch Nozzle

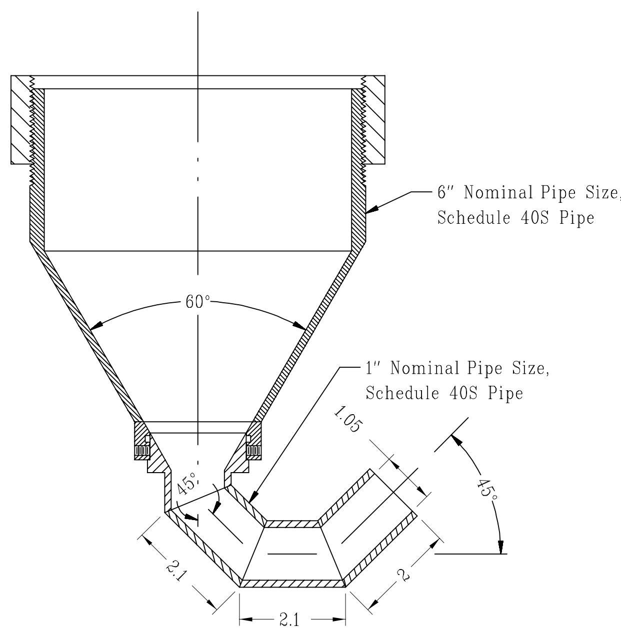


Figure 12 135° Nozzle Showing Nominal Dimensions for 1-inch Nozzle

Sparger Configuration

Tests using spargers have been performed using an array of 5 spargers at a pitch circle of 31.6 in. The spargers were located approximately at the center of the open regions between the charge vessels, as shown in Figure 13. The sparger tubes were made from 0.5-inch-OD (0.37-inch ID) stainless steel tubing, and the lower ends of the sparger tubes were approximately 10.5 inches above the bottom of the tank as measured from the tank bottom. The sparger flow rates are individually controlled with throttle valves and measured with rotameters for equal flows. The total air flow is measured with a Kurz mass air flowmeter and recorded on the data acquisition system.

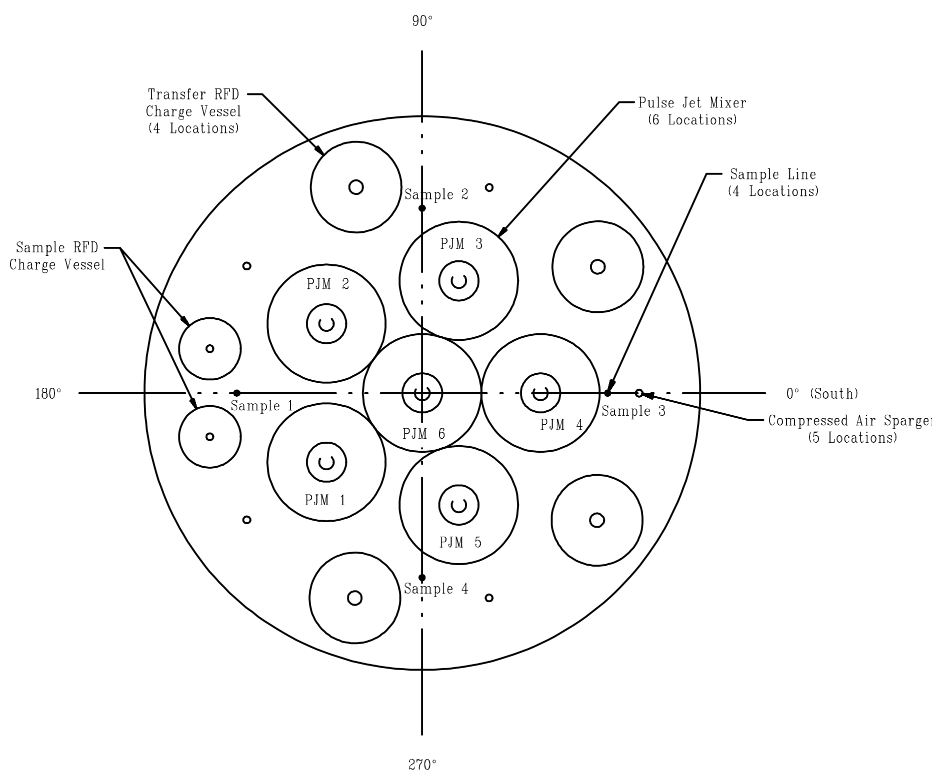


Figure -13 Sparger and Sample Line Locations in Final Chandelier Arrangement

System Operation and Data Acquisition

Unlike the plant PJMs, whose operation is regulated by Jet Pump Pairs (JPPs) driven by compressed air, the prototype test system used a series of solenoid valves and a combination of a direct air compressor source and a vacuum pump to simulate the drive and suction phases of PJM operation. The building air supply provides up to 50 scfm (may be potentially higher) of 90 psig air to the test facility. Other air sources can be supplied, e.g., air compressor charged air receivers. The PJM operations are controlled through a control logic program using Labview software that turns the appropriate solenoid valves on and off at specified time intervals. The duration of each phase, the applied pressure, and the vacuum are all variables that can be independently varied to simulate the operation of the PJMs. The PJMs can also be controlled separately in up to three groups for testing the effect of firing sequence.

Figure 14 gives a schematic of the PJM and level probe installation (6-inch PJM shown). A one-inch tee at the top provides an air inlet and vent. The compressed air and vacuum manifold systems are shown in the 3-D isometric drawing of the PJM test stand, Figure 15. Pressurized air source, vacuum, and venting are controlled by individual solenoid valves for each PJM. The liquid/slurry level inside each of the PJMs is measured using Drexelbook capacitance level probes and transmitters.

The drive distance is based on volume scaling to the plant, given the linearly scaled PJM diameter. The maximum drive distance was approximately 27-inches to avoid over-blowing air into the simulant. When the 8-inch PJM was used to simulate the 6-inch PJM, the drive distance is reduced to 16-inches. During the drive portion of the cycle, the drive time is set so that the nominal velocity is achieved, knowing the initial and final simulant levels inside the PJM. The cycle time is controlled to be one over the scale factor of the plant cycle time and includes times for venting and quiescent periods.

The PJMs are usually operated at a specific average nozzle velocity ($\bar{u}_{disch}$), which is defined as

$$\bar{u}_{disch} = \frac{\Delta H}{\Delta t} * AR$$

where ΔH is the length of the PJM stroke, Δt is the time for achieving the stroke, and AR is the area ratio of the PJM to the nozzle.

During each mixing test, several variables such as PJM liquid levels and pressures, tank temperatures, air supply pressure, and total sparger air flow rate are monitored continuously and recorded digitally on a computer. Compressor and vacuum supply pressures and the pressure inside each PJM are monitored using flush-diaphragm Endress+Hauser ceramic pressure transducers, installed at a pipe Tee fitting near the top of the PJM. Data from all the sensors are recorded on a laboratory computer, running Labview software at sampling times of approximately 0.1 seconds. The instantaneous nozzle velocity can therefore be related to the level change inside the PJM. For fast transients however, a delay in draining of the simulant coating on the level probe introduces an error in this instantaneous velocity. The nozzle velocity calculated from the level probe readings was benchmarked against vessel level changes as measured with a laser probe.

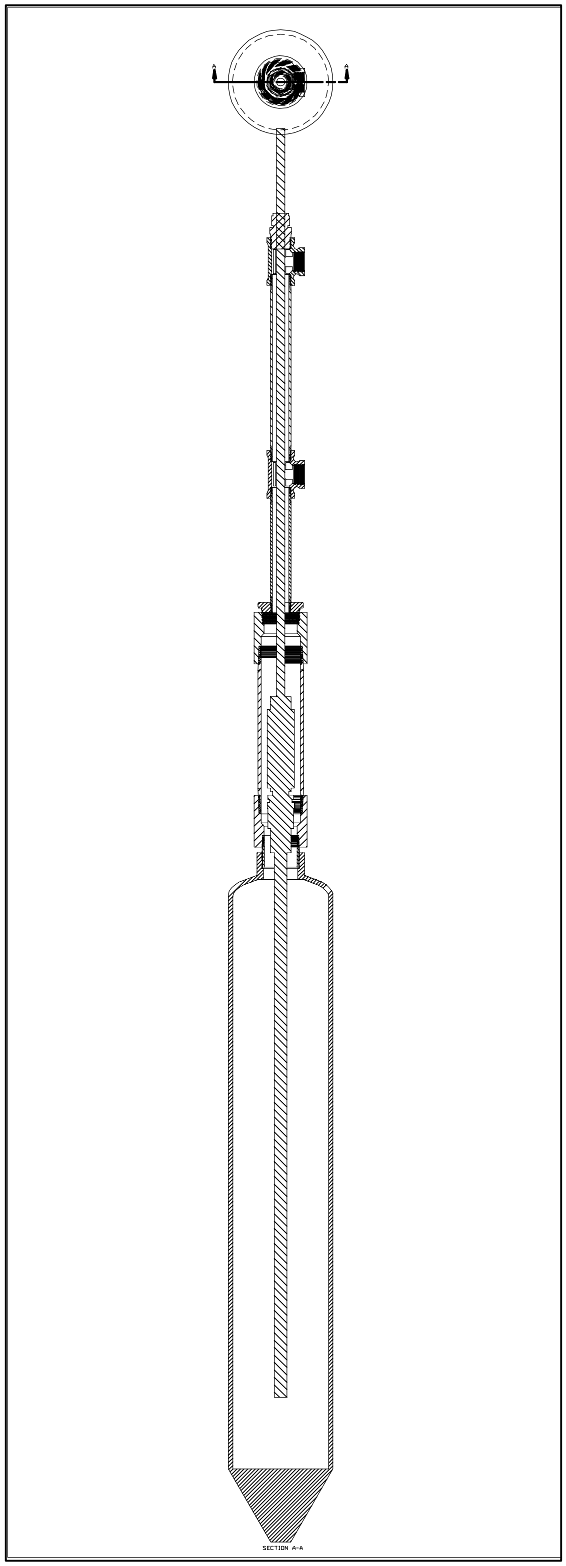


Figure 14 Level Probe Installation inside a PJM

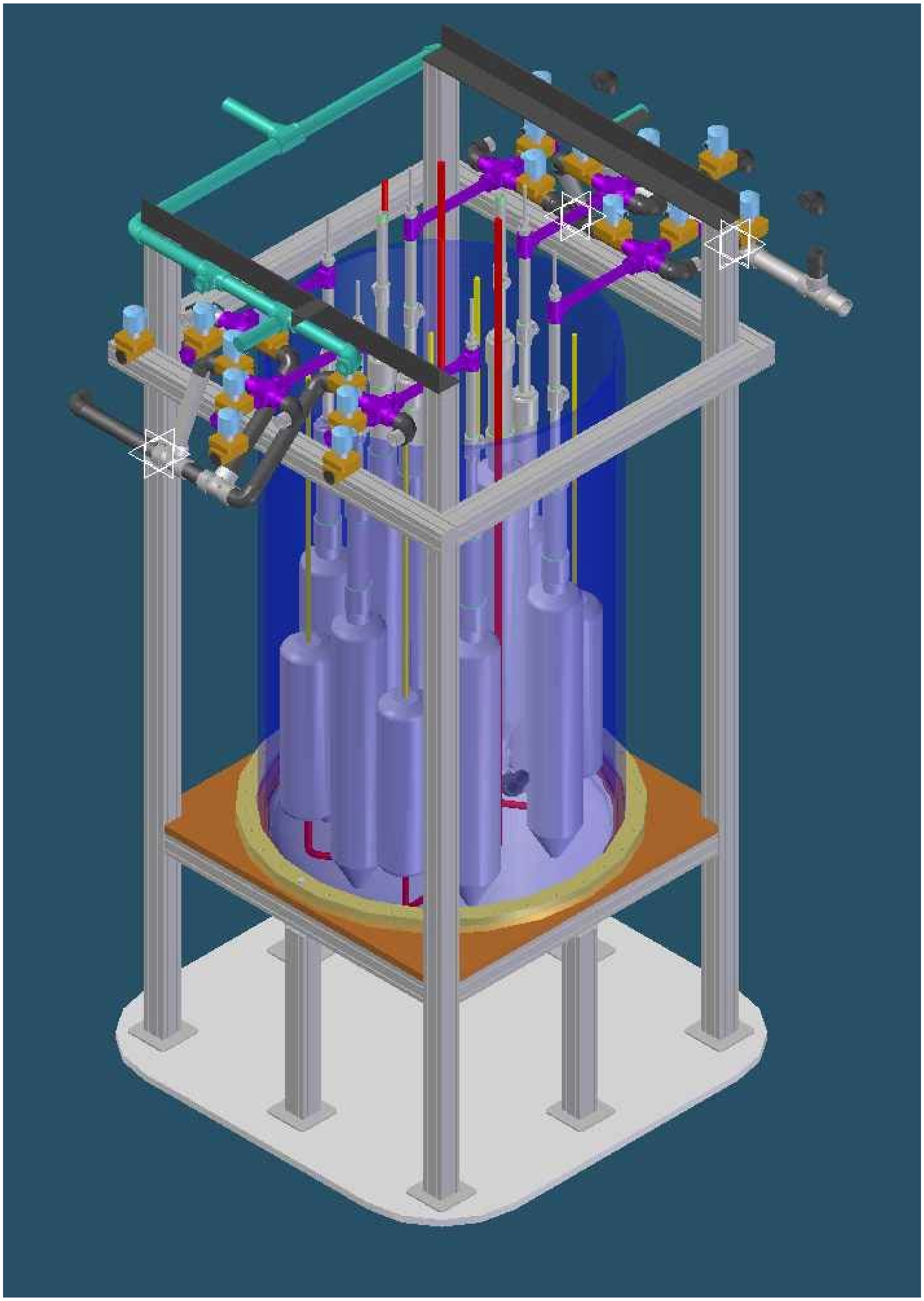


Figure 15 3-D Isometric Drawing of PJM Test Stand and Components

TESTING METHODS FOR DETERMINING MIXING EFFECTIVENESS

Measurement of PJM mixing effectiveness is achieved by one or a combination of four methods:

1) visual means during runs with Laponite;
2) a chemical (dye) tracer method,
3) an ultrasonic velocity probe (UVP) and,
4) glass bead tracers.

Visual Means

The transparency of Laponite enables one to determine the boundaries between moving fluid (entrained bubbles are clearly visible) and stagnant or jelled material. This allows a somewhat quantitative assessment of how much of the simulant is mixed.

Dye Method

A summary of the dye technique is as follows: First the baseline dye concentration in the simulant is obtained by taking an initial sample. The dye tracer is injected during the initial stages of the PJM test. Samples of the simulant are taken from several locations during each mixing test to determine the changes in dye concentration as a function of time and operating parameters. At the end of a test cycle, the test vessel is homogenized and a final sample collected. Determination of the fraction of tank volume mixed is based on the assumption that a contiguous volume of well sheared material or cavern is formed throughout which the dye is uniformly mixed. It is also assumed that a steady state dye concentration has been reached at the time a sample is taken.

The concentration of dye is measured with a UV-VIS spectrometer. This instrument requires a transparent sample. To overcome this limitation, the opaque kaolin:bentonite simulant was centrifuged, and the analysis is performed on the centrifuged liquid portion of the sample. The spectrometer measures the optical absorbance of the sample at multiple wavelengths of light. When the dye is present in the system a peak absorbance is observed at approximately 630 nm. According to Beer's law, the magnitude of this absorbance peak is directly proportional to the concentration of dye in the system.

The equation used to calculate the fraction mixed is as follows:

$$X_j = \frac{A_f - A_0}{A_j - A_0}$$

where

- X_j is the fraction mixed of the j-th tank sample
- A_f is the optical absorbance of the final homogenized simulant
- A_0 is the optical absorbance of the initial baseline simulant
- A_j is the optical absorbance of the j-th tank sample

Ultrasonic Velocity Probe

The Ultrasonic Velocity Probe (UVP) is used in this experiment to determine the interface between the flowing (sheared) region and the stagnant (unsheared) region. It is essentially an ultrasonic sensor that propagates a pulse of ultrasound of 1-2 MHz frequency through a narrow beam in the fluid. The clay particles in the simulant reflect part of this beam back to the sensor. The reflected beam frequency is Doppler-shifted by an amount proportional to the speed of the clay particles. This method relies on first principles, but requires knowledge of the speed of sound in the simulant. For the kaolin:bentonite solution used, the speed of sound is basically that of water.

For the UVP method, the question is: what is the minimum velocity that should be considered necessary for effective mixing. The required minimum velocity was set at a value that seemed to correspond to the value at which the velocity of the pulse jet decays at the boundary of the cavern. Detailed flow mapping was performed in the middle of the annular region between the PJM and the tank wall opposite a downward (45^{o} angled) PJM nozzle for the case of a 1-inch nozzle and using both upwards and downwards directed nozzles. Results are illustrated in Figure 16.

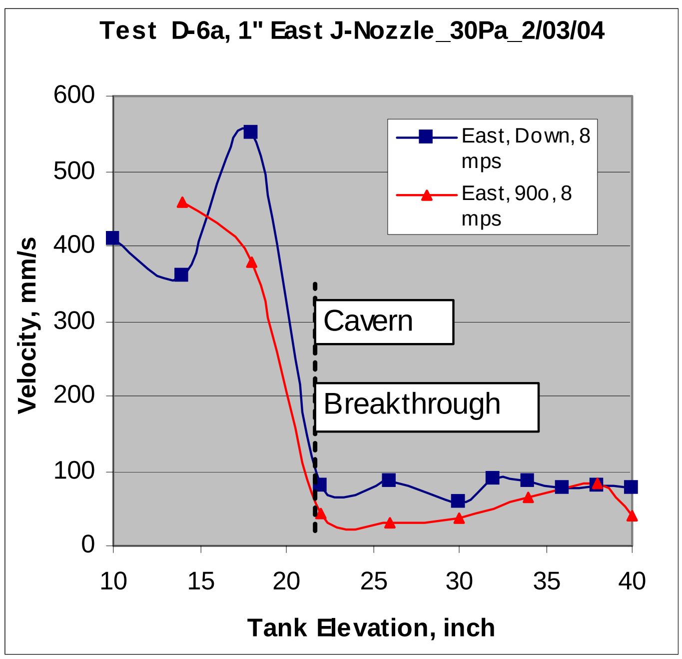


Figure 16 Typical Ultrasonic Velocity Probe Velocity Measurements

The velocity plotted is the peak value of the velocity pulse during the drive phase of the cycle. This indicates that the vertical velocity (measured with a downward looking probe) starts at a high initial value near the bottom of the tank, decays, and flattens out near the top surface of the simulant. A second probe, directed 90 degrees from the first probe towards the center of the tank, shows the horizontal velocity following the behavior of the horizontal velocity, decreasing from the lower regions towards the top and also flattening out at close to the same tank elevation of 21-inches. This breakpoint elevation correlates closely with the observation of the breakthrough of the pulse jet when the tank level is lowered with the PJMs operating.

Solids Mixing Method

The mixing capability of PJMs for the liquid phase can be validated satisfactorily through dye tracer studies and ultrasonic velocity probes. However, validation of an acceptable degree of mixing of the solids phase may also be required. The solids phase in the UFP, LS, and CRV vessels could contain a certain amount of high density particles such as rutile (ρ = 4.25 g/ml) from the glass former solids that may be carried over to the filter solids in the recycle streams. Based on the available data, these large particles may be on the order of 175 microns in size.

The solids mixing tests performed for the CRV test utilized tracer glass beads in the size range of 210 - 300 microns (50X70 mesh) in 2 simulants with 30 Pa and 6 Pa yield stress, respectively. The concentration of the tracer beads did not exceed 0.3 % by volume of the inventory of simulant in the CRV tank in order not to affect the simulant rheology significantly. The CRV tank was first filled with simulant to a level corresponding to the top of the heel (elliptical bottom) and 11.5 lbs of glass beads were distributed over the simulant surface. Then the tank was filled to the 40-inch level. The PJMs were then operated for a total of 66 cycles, equal to the same number of cycles for 1.5-hour plant operation.

At the end of the mixing period with the simulant in a static condition, the upper and the lower halves of the CRV were sampled at 10 random locations each. A grab sampler was used for this purpose, consisting of a 2-inch-diameter rotating cylinder attached to two upper and lower fixed cylinders by rubber sleeves. By rotating the movable cylinder, a 250 ml sample was trapped between the twisted rubber sleeves. In addition to this, the CRV heel was sampled multiple times (10 samples) at a single location near the bottom of one of the RFDs, using a peristaltic pump.

The solids concentration in each sample was determined by sieving, washing and drying the tracer solids from a known weight of the sample. This concentration is expressed as mass percent dry tracer solids in wet sample. In addition to this, the grab sampler was calibrated to determine any bias in collecting the tracer solids. Also, the initial clay solid concentration in the same size range as the glass bead tracers was determined as a correction to the measured sample solids concentration.