

SOLIDS SETTLING REMOTE SENSOR

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ABSTRACT

Buried tanks at various U.S. Department of Energy and Department of Defense facilities contain wastes with gamma radiation fields up to 1000 rad per hour, solution temperatures from 20-95 °C, and concentrations of caustic equivalent to 3 molar sodium hydroxide. Solids settling within these tanks is of interest, as decanting of liquids in a timely fashion creates additional solids storing space within the tanks. Remote sensing of solids characteristics is imperative to reduce or eliminate worker exposure. A robust, real-time monitor was developed to determine the density profile of the tank, which allows determination of liquid phase concentration, sludge-liquid interface, settling rate of solids, and point of diminishing returns for settling. A vertical array of pressure transducers was selected as the best alternative to achieve the project goals in an accurate and cost-effective manner. The array of transducers will be installed inside a waterproof column and lowered into the tank. Transducer readings are converted into density measurements with computer software developed for the equipment. Equipment, installation, operation, decontamination, and disposal costs for a single tank are \$769,000 for five years of operation. The design uses inexpensive, commercially available equipment and technology, and provides a safe, cost-effective, and robust system for the tank environment.

INTRODUCTION

One educational component of the Waste-management Education and Research Consortium (WERC's) is its prestigious Environmental Design Contest. The contest challenges college students with thorny real-world environmental problems developed by major sponsors ranging from Department of Energy facilities to mining companies. The responding student teams must research the problem, experimentally test possible solutions, and propose a solution. The teams construct a bench scale working model, and demonstrate their technologies at the contest. For the April 1998 contest, one of the assigned tasks (Task 4) was the design of a robust, in-tank, real time monitoring device for measuring density inside process tanks which contain radioactive slurries. This report contains the research and final solution of the Montana Tech team.

PROBLEM SUMMARY

Tens of thousands of nuclear warheads were produced during the Cold War era. In the United States, many nuclear complexes were built to research, manufacture, assemble and test nuclear bombs. The sites now include sixteen major facilities. The facilities cover large areas in Washington, Nevada, Utah, Idaho, South Carolina, Tennessee, and New Mexico. It is estimated

that 100 million gallons of defense nuclear processing waste is stored in underground tanks (1).

Tank waste is composed of complex radioactive and non-radioactive compounds. These compounds will need to be removed from the tanks for treatment and disposal. The thickness, physical characteristics, and chemical composition of these layers differ from tank to tank, but generalizations can be made as to the tank contents. The following layers may be present in the tanks from top to bottom: vapor, supernatant liquid, interstitial liquid, sludge, and saltcake. Radionuclides in the wastes include cesium, technetium, strontium, and transuranics. Other constituents include nitrates, nitrites, phosphates, aluminates, carbonates, sulfates, hydroxides, oxides, silicon, iron, uranium, and zirconium (1).

Due to the radioactive nature of the waste, worker exposure to radiation is an important safety consideration when sampling the waste. Density samples are used to determine the location and depths of the various waste layers; currently workers manually take cores of the waste for lab analysis. A remote automated in-tank density monitoring system will eliminate the need for physically handling the waste and significantly reduce worker exposure to radiation and hazardous waste.

WERC specified that the remote density-monitoring device be able to withstand a highly caustic environment, gamma radiation fields up to 1000 rad/hour, and temperatures from 20-95⁰C. The device must also be able to provide incremental solid concentrations for every six inches of vertical tank depth. The monitoring device must be adaptable for waste immersion depths of up to 40 feet.

PROCESS DESIGN

Summary of Alternatives Considered

Seven alternative methods were evaluated: laser interferometer, acoustic characterization, floats, conductivity, radiation measurement, acoustic tomography using acoustic transducers, and vertical pressure variations. Each method was evaluated for its cost-effectiveness, worker exposure, and accuracy in the surrogate and scale-up media.

Alternative #1: Laser Interferometer

A laser interferometer was considered as a means to measure particle concentrations and size. This device uses a circular array of sensors to measure scattering intensity at multiple angles from the source. A multi-parameter set of data is taken, which eliminates the need for continuous calibration as in some other single parameter techniques. A diode laser is used as the source.

The limitations that precluded use of this device include its limited area of scan, cost, and opaqueness of the fluid. This technique gives good size resolution for low particle concentration environments, but would not

produce reliable density data for higher concentration environments as found in Task 4 (2,3).

Alternative #2: Acoustic Characterization

A sonic echo device similar to a commercially available fish finder was considered as a method to locate and track the solid-liquid interface as well as any other submerged objects. The two main advantages to this method are its non-invasiveness and considerable commercially developed technology.

The disadvantages concern the redesign of the electronics to detect layers and objects other than fish (4); the fish finder is designed to locate fish and the lake or stream bottom and would have to be reprogrammed to find different object. Another concern is providing adequate transponder shielding from the slurry. Finally, similar work performed at Ames Laboratory indicate that while the device works for bench scale, it could not produce accurate results for the full size tanks due to the poor profile resolution in large tanks (5).

Alternative #3: Floats

A system of plastic floats of various specific gravities was considered as a way to track density changes. These floats would hover at different slurry densities and would be able to accurately determine settling rates and interfaces.

There are many disadvantages to this technique. Any particulate matter that settles onto the float would change its specific gravity and give inaccurate results (6). Tracking the floats remotely would be difficult, especially in an underground tank with limited access. Finally, recovery of the floats for cleaning and replacement would risk worker exposure and would be costly in terms of maintenance.

Alternative #4: Conductivity

A vertical conductivity profile was considered as a way to determine the density of the waste based on the slurry's electrical properties. Unfortunately, the high H and large amounts of clay and metal particulates make the slurry very conductive. The high conductivity found through out the waste would produce too small conductivity contrasts, precluding the use of this electrical method. While the technique could be used quite effectively for detecting leaks from the tank in the soil or water table (since the soil and water are naturally resistive in nature), it would not be effective inside the tank.

Alternate #5: Radiation Measurement

The presence of radioactive materials within the slurry led to the consideration of using a vertical array of radiation detectors in an attempt to measure the amount of material at the level of a particular detector. This would determine the amount of suspended radioactive material inside the tank.

Several difficulties precluded pursuance of this technology. First, it would not work for the bench scale model, since the surrogate material is not

radioactive. Also, the suspended radioactive material might not settle at the same rate as the other slurry components, thus not giving a clear indication of the overall composition of the tank. Finally, shielding the detectors from particles not emitted at the level of the detector would be difficult because of the highly penetrating nature of gamma radiation. Inadequate shielding would produce false counts and inaccurate results.

Alternate #6: Acoustic Topography Using Acoustic Transducers

A system incorporating a pair of acoustic transducers, one to emit and one to receive was designed. P-wave travel times through the media will vary with density; differences in wave travel time will correlate to density variation.

For bench scale experimentation, the expense of the array prohibited pursuing this technology. While a movable single pair would be affordable for experimentation, it was thought that effects of moving the transducer would disturb the settling patterns of the solids in the vicinity of the sensor.

Alternate #7: Vertical Pressure Variations

The amount of material at a given time in the slurry tank can be detected by looking at the pressure at a particular height and calculating how much of the pressure is from water; the excess pressure is from the solids in the slurry. Comparing pressure collected at the same time but at different heights in the tank gives an overall picture of how the solids are dispersed, and linear pressure regions in the tank are indicators of uniform consistency. By comparing where these linear regions intersect, interface depths are located, and changes in the pressure over time will give settling rates.

Disadvantages to this method include:

- it requires physical contact with the slurry at various heights in the tank
- several dozen detectors may be needed to give a good profile
- some hazard may be presented when installing and removing the mechanism in the hostile environment found in the full scale problem.

Chosen Alternative: Vertical Pressure Variations

After research and/or experimentation on each of the above alternatives, the pressure variation method was determined to be the best choice based on the following criteria:

- There are many commercially available pressure sensors that can be used for this application.
- The pressure transmitters can be connected to a computer with the help of an interface board, and all calculations can be performed via computer.
- The system is automated, which reduces man-hours and worker exposure.
- The accuracy of the apparatus is solely dependent on the accuracy and number of transmitters. Very sensitive devices are currently available.

Design Description

The design of choice is a vertical array of flush diaphragm pressure transducers that will read differential pressures in the column of fluid. The proposed system will be able to accurately determine the tank density profile, interfaces between layers, the point of diminishing returns, and settling rates. It will be able to fit inside a 12-inch diameter tank riser and will be adaptable to monitor a vertical column of up to 40 feet.

The transducers will be installed a vertical foot apart in a waterproof vessel made of stainless steel, which is resistant to heat and high pH. The radiation resistant wires from the transducers will run up the inside of the waterproof vessel, out of the tank, and into a computer for data processing. The pressure data will be processed to calculate a density profile of the fluid from the pressure readings. Solid-liquid interface levels will be determined by comparing regions of linear pressure. The elevation where the slurry density exceeds 5 WT% will be determined by calculating the density from the pressure reading. Settling rates will be calculated by the change in the slope of the pressure over time. The point of diminishing returns will be reached when the pressure reading for each sensor changes very little over time.

EXPERIMENTAL PROCEDURE

Calibration Experiment

The chosen sensor for the bench scale performance test was a flush diaphragm pressure transducer. The transducer was installed flush with the outside of the sensor vessel and was in direct contact with the fluid. This provided accurate, real-time pressure readings that were correlated to density. The sensor of choice required minimal calibration. Calibration entailed checking the linearity, hysteresis and repeatability of the sensor. The sensor demonstrated little hysteresis, excellent linearity, and high repeatability.

Pressure Calculations

Pressure calculations were performed using water column experiments. Pressure readings were taken at various heights in the column. The resulting millivolt readings were converted into pressure, based on the depth of the reading. Each sensor was modeled to find a pressure performance curve. For example, one particular sensor's performance curve produced the following relationship:

$$\text{Pressure (psi)} = (0.0589 * \text{MV Reading}) + 0.1219 \quad R^2 = 0.999$$

Eq. 1

Density at any specific time can be calculated using the formula:

$$\rho = P/(g * h) \quad \text{where}$$

Eq. 2

ρ = density (lbs/in³)

g = gravitational constant

h = height of measurement (inches)

P = pressure (psi)

Pressure measurements were taken in the surrogate waste using an array of sensors at varying depths over time. The tank density profile was determined by plotting density versus sensor height. The resulting plot produced a density profile of the tank. Monitoring pressure variations of the initial homogeneous waste mixture provided a means of calculating the settling rate of the particles, formation and position of the interfaces, density homogeneity within a layer, and the point of diminishing returns. A linear plot indicates a homogeneous mixture with constant density.

RESULTS OF TECHNICAL ASSESSMENT

The pressure sensors were used to determine the density of a column of water at varying heights. The percent error of the water data is 0.06% with a correlation coefficient (R^2) of 0.9992, which is statistically significant for the correlation of density to liquid height.⁹

The transducers also measured the density in a column of surrogate waste. Measurements were taken approximately every foot and were compared with waste sample at the same elevation. The maximum percent difference from the experiment was 2.59%

ECONOMIC ASSESSMENT

The Montana Tech team performed an economic assessment. A single installation of the sensor array was found to have a net present value (1998) of \$545,623 and an annual payment of \$143,935 when evaluated with a 10% interest rate, which includes fabrication, installation, maintenance, removal, decontamination, and disposal. Annually, the cost for maintenance is approximately \$52,000. Each additional unit will add approximately \$85,000 to the yearly cost. The unit may be used for a variety of tank styles. Specifics of equipment and installation cost can be found in Gill (7).

PERFORMANCE

A prototype was built and evaluated at the WERC Environmental Design Contest 1998. The prototype, interface board, and computer algorithms performed impressively, and the team was able to accurately determine settling rates, interface formation and location, and point of diminishing returns for settling. On the basis of this performance, the Montana Tech team was awarded First Place for Task 4 and Overall Best School.

CONCLUSION

The Montana Tech team developed an accurate, cost-effective monitoring system to meet the design challenge posed by WERC. Different designs were evaluated for their accuracy, cost, upscale feasibility, safety, and environmental impacts. The pressure transducer array was superior based on the selection criteria and experimentation.

The selected design consists of an array of pressure transducers mounted in a vertical column and lowered into the waste tank. This system gives pressure readings at various heights within the tank. These pressure readings are used to calculate density. Stratigraphic interfaces are represented by abrupt changes in density. Monitoring density over a period of time yields data on the settling rate of particulates, interface formation, and the point of diminishing returns for settling.

The pressure transducer system is an effective method of providing a density profile at any given time within a waste slurry tank. Commercially available equipment greatly reduces cost and construction time of the array. The simplicity of this process is very attractive from operation and maintenance standpoints, and the straightforward calculations indicate a widely applicable process. It is felt that this design concept can be applied to any process needing similar information with minimal system design modification.

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