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Literature Survey of Available Liquid Level and Density Measurement Technologies

by

G. E. Weeks

Westinghouse Savannah River Company
Savannah River Site
Aiken, South Carolina 29808

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cc: W. I. Lewis, 723-A
J. C. Whitehouse, 723-A
W. A. Henderson, 723-A
E. W. Holtzscheiter, 773-A
C. T. Randall, 704-T
L. F. Landon, 704-1T
J. I. Mickalonis, 773-A
B. J. Hardy, 704-1T
PCC Files, 704-T

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AUTHOR:

G. E. Weeks / SRTC

TECHNICAL REVIEWER:

W. E. Daniel / SRTC

APPROVAL:

L. F. Landon /SRTC

AUTHORIZED DERIVATIVE CLASSIFIER:

E. W. Holtzscheiter / SRTC

Background

In the early 1980's it was discovered that the plant standard liquid level instrument, the standard bubbler, plugged in several of the Defense Waste Processing Facility (DWPF) canyon vessels, where sludge-slurry solids are processed. Further, this plugging occurred in as little as 4 – 8 hours. The plugs were the consistency of concrete and could not be dislodged using techniques available at that time. Using the bubbler in this application was therefore abandoned.

A search for an acceptable alternate culminated in the selection of a one-to-one pneumatic pressure repeater manufactured by Holledge (instruments) Ltd., in the United Kingdom. However, DWPF operational experience has shown that Holledge sensor life was shorter than expected in some DWPF vessels. The most notable example of this is the Slurry Mix Evaporator (SME) where Holledge sensor life has been about six months. Based on Holledge level probe fabrication and calibration costs, DWPF requested assistance from the Tanks Focus Area (TFA) to develop a new liquid level probe.

The Savannah River Technology Center (SRTC) also began development of a new bubbler technology that would perform reliably in the SME environment. The large mouth bubbler was installed in January of 1997 and accepted for permanent installation on July 22, 1997. With the success of the large mouth bubbler, DWPF identified two additional liquid level measurement problems and requested TFA redirect their liquid level research to these problems:

1. Location of the organic/aqueous interface in the Organic Evaporator (OE) and the Organic Evaporator Condensate Tank (OECT).
2. Location of the frit/water interface in the new Cyclonic Frit Separator (CFS).

The Extended Sludge Processing (ESP) facility had also submitted a need statement to locate a sensor that could be used to measure the rate of settling in ESP tanks. These three needs were combined into a single TFA project that was appended to TTP #SR18WT21.

Statement of the Problem

OE/OECT

The OE and OECT are part of the DWPF Salt Cell, in which Cesium/Potassium tetraphenylborate slurry is hydrolyzed in the Precipitate Reactor (PR) to produce an aqueous stream containing the Cesium for subsequent blending in the Sludge Receipt and Adjustment Tank (SRAT). The phenyl fraction of the feed slurry is recovered primarily as benzene in the OE, where it is mixed with water and distilled to ensure the radionuclide concentration is less than 1000 d/m/ml (the limit for transfer outside the canyon building). The organic overheads from the OE are accumulated in the OECT.

The OE contains a mixture of water, benzene, and insoluble organic high boilers. These heavy organics accumulate in the OE and tend to coat interior surfaces and all exposed equipment, and can interfere with instrument operation. Although the radionuclide content of the OE should be low, the accumulated organics and all associated equipment will receive a very high radiation dose because of the Cs-137 inventory in the PR and Precipitate Reactor Bottoms Tank (PRBT). Other than problems associated with the high radiation fields (e.g. materials of construction), the OECT should not be a difficult level application. However, the accumulation of heavy organics makes the OE a more difficult problem.

Cyclone Frit Separator

The DWPF uses a 6 wt % glass frit/water slurry delivered through spray nozzles to decontaminate the exterior of full waste canisters. The spent frit slurry is then recycled back into the SME as part of the frit addition requirement. The problem with this strategy is the amount of water that is introduced into the SME with the spent frit slurry. This excess water must be boiled off, significantly increasing the SME cycle time. As the SME cycle time is a limiting factor in DWPF glass production, eliminating this water addition will improve DWPF attainment. The Cyclone Frit Separator (CFS) has been proposed to separate water from the spent frit slurry and send it directly to the tank farm for treatment and disposal. The frit slurry concentrate would be accumulated in a hold tank for subsequent addition to the SME. This application is to measure the level of frit in the frit slurry concentrate hold tank. Other than high radiation fields there are no complicating factors in the CFS.

Extended Sludge Processing

The Extended Sludge Processing (ESP) facility is used to wash high level waste sludge. Sludge solids are suspended in water and then allowed to settle for a period of weeks. The supernate is then decanted and the process is repeated until the soluble salts have been reduced to the target concentration. The process requires several multiple-week-settling cycles. Measuring settling rates and identifying when the decanting process can begin will optimize the total batch cycle time.

Previous Related Federally Funded Research

SEAlevel™

The Federal Energy Technology Center (FETC) funded the development of two liquid level measurement technologies conceived by engineers at Science and Engineering Associates, Inc. (SEA) in Albuquerque, NM. These liquid level probes were developed for use in Hanford waste storage tanks to locate the liquid level. Hanford's storage tanks contain supernate, saltcake, interstitial fluid, and sludge. SEA proposed an array of capacitance sensors that would be lowered into the tank via a fiberglass Liquid Observation Well (LOW). SEA also proposed an array of ultrasonic sensors that would be used in tanks with stainless steel LOWs[1]. Late in the phase one development cycle, SRS level measurement needs were presented to SEA and an abbreviated test schedule was implemented.

Time Domain Reflectometry

DOE Office of Technology Development funded the development of the TDR liquid level probe through the Savannah River Technology Center in 1990. This technology was installed and tested in the Precipitate Hydrolysis Experimental Facility (PHEF) and Integrated DWPF Melter System (IDMS) pilot plants. The PHEF is a 1/5 scale pilot plant of the DWPF Salt Cell and the IDMS is a 1/5 scale pilot plant for the DWPF Chemical Process Cell and a 1/10 scale pilot plant for the DWPF Melt Cell. TDR was successfully used in the PHEF[2]; however, in the IDMS heavy accumulation of sludge on the probe severely affected its accuracy.

Torsionally Excited Low Frequency Acoustic Waveguide

Development of the torsion wave sensor by Panametrics was partially funded by the DOE through an SBIR grant (DE-FG02-90ER80958)[3]. DOE funded this technology for the measurement of liquid level and density of high level nuclear waste stored in single walled waste tanks at Hanford. The technology clearly showed the ability to measure liquid level and density. However, problems with the accumulation of salts on the probe were not solved in phase 1.

Results

27 liquid level measurement technologies were reviewed for this Report. Of these technologies, four show the most promise for application at SRS. These technologies are listed below:

1. SEAlevel™ Capacitance Probe – an array of capacitance sensors.
2. SEAlevel™ Ultrasonic Probe – an array of ultrasonic sensors.
3. Time Domain Reflectometry.
4. Torsionally excited low frequency acoustic waveguide (Torsion Wave Sensor)

These sensors are listed below in order of recommendation with the application that looks like a good fit:

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[1] C. D. Cremer, A-RP-97-028, "The SEAlevel™ Approach for Monitoring Liquid Levels in DOE Waste Storage and Processing Tanks", Science and Engineering Associates, Inc., August 15,1997.
[2] H. R. Tilley, M. Hapstack, WSRC-MS-94-283, "Nuclear Waste Liquid Level Monitorint Using Time Domain Reflectometry", WSRC, 1994.
[3] L. C. Lynnworth, Y. Liu, DOE/SBIR 90-1, "Final Technical Report Phase 1, Torsional Sensor for Monitoring Liquid Level and Density", Panametrics, Inc., February 14, 1991.

OE/OECT

1. SEAlevel™ Capacitance Probe – an array of capacitance sensors
2. Time Domain Reflectometry
3. Torsion Wave Sensor

Cyclonic Frit Separator

1. Torsion Wave Sensor
2. SEAlevel™ Ultrasonic Probe

Extended Sludge Processing

1. Torsion Wave Sensor
2. SEAlevel™ Ultrasonic Probe

Principles of Operation

SEAlevel™ Capacitance Probe

A capacitor is essentially two plates separated by some dielectric and has the ability to store an electric charge. Plate area and dielectric constant determine capacitance. The SEAlevel™ capacitance probe is an array of capacitance sensors. Each sensor is essentially a capacitor with both plates in the same plane instead of parallel to each other. In this configuration the electric field lines are normal to and extend from plate to plate. Since the plate area is constant, variations in the dielectric that surrounds the sensor will cause its capacitance to vary[4]. The dielectric constant for water, organic compounds, and air are all significantly different. Therefore, it is possible to determine if the sensor is covered but also identify the type of fluid that is covering it. With this array of sensors it possible to determine the height of each phase by knowing the position of each sensor and then identifying which sensors are covered by which fluid.

SEAlevel™ Ultrasonic Probe

The SEAlevel™ Ultrasonic Probe is a pulse echo device. However instead of measuring the time of flight like most ultrasonic probes, it measures the amplitude of the echo. If an ultrasonic wave is passing through a series of tightly coupled materials, a portion of the acoustic energy is reflected at each interface. The amount of energy reflected is a function of the velocity of sound in each material and the density of each material. In this case the sensor is attached to a stainless steel pipe that is positioned in a tank. It is possible to determine that a sensor is submerged in water by the amplitude of the echo

[4] C. D. Cremer, A-RP-97-028, "The SEAlevel™ Approach for Monitoring Liquid Levels in DOE Waste Storage and Processing Tanks", Science and Engineering Associates, Inc., August 15,1997, pp 6-14.

from the fluid/steel interface[5]. Like the SEAlevel™ capacitance probe, this probe utilizes an array of sensors. Liquid level is determined by knowing the position of each sensor and its response. By positioning the ultrasonic sensors at a downward angle, it is also possible to use time of flight to locate the liquid level. Using both of these techniques together minimizes the number of sensors required in the level probe.

Time Domain Reflectometry

Time Domain Reflectometry (TDR) was originally developed to locate impedance anomalies in RF transmission lines. An impedance variation along a transmission line will reflect a portion of the signal back to the transmitter. TDR works by measuring the time of flight and magnitude of these reflections. Time of flight locates the position of the impedance anomaly and the magnitude of the return allows the actual impedance to be calculated.

In 1990 SRTC developed a liquid level probe using TDR. This probe is essentially a transmission line that is terminated at the bottom of the tank. Liquid in the tank will cause a change in impedance at the point of contact. TDR locates this impedance change. As long as the fluid does not short the probe (i.e. organic or other non-polar liquid), the probe can measure the depth of multiple phases of fluids. However, the probe can only sense to the point of the first direct short. This is not a problem if the aqueous fraction is in the bottom of the tank. In 1992 a TDR probe was installed in the Precipitate Hydrolysis Experimental Facility (PHEF) Reactor Condenser/Decanter (RCD) and was used successfully until the facility was shut down (eleven runs). The PHEF is a 1/5 scale pilot plant of the DWPF Salt Cell.

Torsionally Excited Low Frequency Acoustic Waveguide (Torsion Wave Sensor)

Any solid metal rod can be used as an ultrasonic waveguide. The torsion wave sensor uses magnetostriction to introduce torsional stress waves in an acoustic waveguide with a non-circular cross-section. The speed at which the stress wave moves through the waveguide is dependent upon the density of the waveguide as well as the density, level, and temperature of the fluid surrounding the waveguide. Reflections of the stress wave also occur at fluid interfaces. Measuring the transit time to the interface yields a measurement of liquid level independent of density. With this technique it is possible to locate phase boundaries in a tank and then determine the average density of each phase[6]. By partitioning the waveguide with notches is possible to look at specific regions in a tank and determine density, liquid level, and temperature in a single probe[7]. The density profile of a fluid in a vessel can also be determined using this technique.

[5] C. D. Cremer, A-RP-97-028, "The SEAlevel™ Approach for Monitoring Liquid Levels in DOE Waste Storage and Processing Tanks", Science and Engineering Associates, Inc., August 15,1997, pp 15-29
[6] L. C. Lynnworth, Y. Liu, DOE/SBIR 90-1, "Final Technical Report Phase 1, Torsional Sensor for Monitoring Liquid Level and Density", Panametrics, Inc., February 14, 1991, p573.
[7] Ibid.

Discussion

OE/OECT

Based on experience in the PHEF a layer of heavy organics is expected to accumulate at the aqueous/organic interface in the OE[8]. This accumulation is expected be slow in forming, but will present a challenge to any liquid level technology used in this application. In the literature reviewed, the technologies that met the need of locating the organic/aqueous interface were all insitu probes and would be susceptible to organic buildup. The accuracy of all of the three probes recommended for this application will suffer in the presence of this buildup. The organic product of the OECT is free from heavy organics. Any of the three probes recommended for this application should work well in the OECT. However, some economy of scale could be achieved by using the same technology in both applications.

In this application the best chance for success seems to be the SEAlevel™ capacitance probe. The large difference in dielectric constant between benzene and water indicate that a probe measuring electrical properties like the SEAlevel™ capacitance probe or the TDR probe would be a better match than probes measuring density. The torsion wave sensor should also be able to see the interface, but would be very susceptible any accumulation on the probe. Table 1 below contrasts the advantages and disadvantages of the top three sensor choices.

Cyclonic Frit Separator

Of the three applications studied in this report this is the simplest. There are just two components in the tank, glass frit and water. The largest measurable difference between water and frit is the density. The torsion wave sensor is the best choice in this case. Since the density of water and frit are both known, the torsion wave sensor can not only determine the respective levels of frit and water in the tank, but also the concentration of frit in the water[9]. The SEAlevel™ ultrasonic probe would also work admirably in this application. Table 2 below details some advantages and disadvantages of these two probes.

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[8] D. P. Lambert, WSRC-RP-96-0405, "Precipitate Hydrolysis Experimental Facility (PHEF) Final Inspection (U)", WSRC, September 10, 1996.

[9] J. O. Kim et al, "Torsional Sensor Applications in Two-Phase Fluids", *IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control,* Vol. 40, No. 5, September 1993, p573.

Technology	Advantages	Disadvantages
SEAlevel™ capacitance probe	• Measures electrical property (dielectric constant) • Feasibility testing completed • Less susceptible to buildup	• The most susceptible to radiation of the three best probes. • Sensor design is complex.
Time Domain Reflectometry	• Measures electrical property (dielectric constant) • Used successfully in the PHEF RCD • Sensor design is very simple. • Radiation hard	• Can loose calibration. • The TDR analyzer is very expensive.
Torsion Wave Sensor.	• Sensor design is very simple • Radiation hard • Able to measure several physical properties with a single probe.	• Measures density • No testing has been done for this application to date • Very susceptible to buildup

Table 1.

Technology	Advantages	Disadvantages
Torsion Wave Sensor	• Probe design is simple • Radiation hard • Very fine density resolution • Able to measure multiple physical properties with a single probe	• Requires development and demonstration prior to installation
SEAlevel™ Ultrasonic Probe	• Measures density change	• Probe design is complex • Less radiation hard • Requires development and demonstration prior to installation

Table 2.

Extended Sludge Processing

The ESP tanks require very fine resolution of density to be able to determine the level of settling that has occurred in the tank. With adequate timing resolution and temperature compensation, in some cases the torsion wave sensor has the ability to resolve density to 1 mg/cm^3 [10]. As stated above, if adequate information about the densities of the slurry particles and aqueous fraction are known, concentrations of slurry particles in the aqueous fraction can be measured insitu with the torsion wave sensor. In this application significant development and demonstration would be required with either of the two-selected sensor technologies. Table 3 details some advantages and disadvantages of these two sensors.

Technology	Advantages	Disadvantages
Torsion Wave Sensor	• Probe design is simple • Radiation hard • Very fine density resolution • Able to measure concentration of sludge particles in the aqueous fraction.	• Requires development and demonstration prior to installation
SEAlevel™ Ultrasonic Probe	• Measures density change	• Probe design is complex • Less radiation hard • Requires development and demonstration prior to installation

Table 3.

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