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LIQUID LEVEL MEASUREMENT IN HIGH LEVEL NUCLEAR WASTE SLURRIES (U)

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Liquid Level Measurement in High Level Nuclear Waste Slurries

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ABSTRACT

Accurate liquid level measurement has been a difficult problem to solve for the Defense Waste Processing Facility (DWPF). The nuclear waste sludge tends to plug or degrade most commercially available liquid-level measurement sensors. A liquid-level measurement system that meets demanding accuracy requirements for the DWPF has been developed. The system uses a pneumatic 1:1 pressure repeater as a sensor and a computerized error correction system.

INTRODUCTION

The Department of Energy has built and will operate a facility to vitrify High-Level Nuclear Waste (HLW) at the Savannah River Site (SRS). Much of the HLW at SRS is in the form of a sludge slurry. The DWPF will solidify nuclear wastes by immobilizing the wastes in durable borosilicate glass. Early in the development of the DWPF, dip tub bubblers were used to measure liquid level in the sludge processing vessels; however, these bubblers plugged in service.

The HLW slurry at SRS is caustic and contains halides and mercuric salts that are highly corrosive to stainless steel. The high level of radioactivity also precludes the use of polymers and elastomers in sensors that are in physical contact with the slurry. After the glass frit has been added, the slurry is very erosive as well. Hastelloy (C-276) was selected as the material of construction for items that come into intimate contact with the slurry.

Liquid level is one of the more important measurements in DWPF processing vessels. It is the basis for determining the mass of the process fluid in each vessel. Together with analytical analysis, mass measurement is used to formulate melter feed according to the specific compositional requirements of the batch DWPF feed preparation process. In short, the DWPF cannot process HLW without accurate liquid-level measurement.

An extensive search was conducted to locate a measurement technology that would meet the demanding accuracy requirements and survive the harsh operating environment. Most instrument manufacturers use polymers extensively in the manufacture of pressure and level sensors, thus, most of these sensors are not suitable for use in this application. The search yielded a pneumatic pressure sensor manufactured by Holledge Instruments, Ltd., of Crawley Down, Sussex, England, as the best choice.

In this application three pressure sensors are fabricated into a probe that is inserted through a nozzle in the top of the vessel. The sensors measure the hydrostatic head pressure of the process fluid at three places in the vessel. Using the hydrostatic equation and two of the three pressure measurements, the fluid density, liquid level, and mass of fluid are calculated. The third pressure measurement is used to detect the accumulation of elemental mercury in the bottom of the vessel.

INSTRUMENT CHARACTERISTICS

The selected instrument is a classical force balance, pneumatic 1:1 pressure repeater. Figure 1 is a cut away view of the sensor, which requires a constant air flow of 1.5 Standard Cubic Feet per Hour (SCFH). The output pressure of the sensor varies directly with changes in the inlet air flow rate. Any air flow changes effectively cause a zero shift in the calibration of the instrument.

The physical mounting of the level probe in the vessel introduces an interesting problem. The pressure sensor is a pneumatic device and requires a constant air flow at its inlet. This air is metered outside of the canyon at ambient conditions.

However, the air must travel to the sensor through impulse lines submerged in the heated process fluid. Thermal effects on the air and the sensor cause an increase in the measured pressure.

Another problem encountered was that the smallest Hastelloy sensor that could be purchased from Holledge has a range from 0 to 100 psig. These sensors will be used to measure pressures on the order of 9 psig (250 inches of water) or roughly the bottom 9 percent of the useful range of the instrument.

The sensors are also non-linear below 30 inches of water. Left uncorrected these problems cause an error of up to 40 percent in the calculated liquid level and density. Figure 2 represents the pressure and temperature response of a typical sensor.

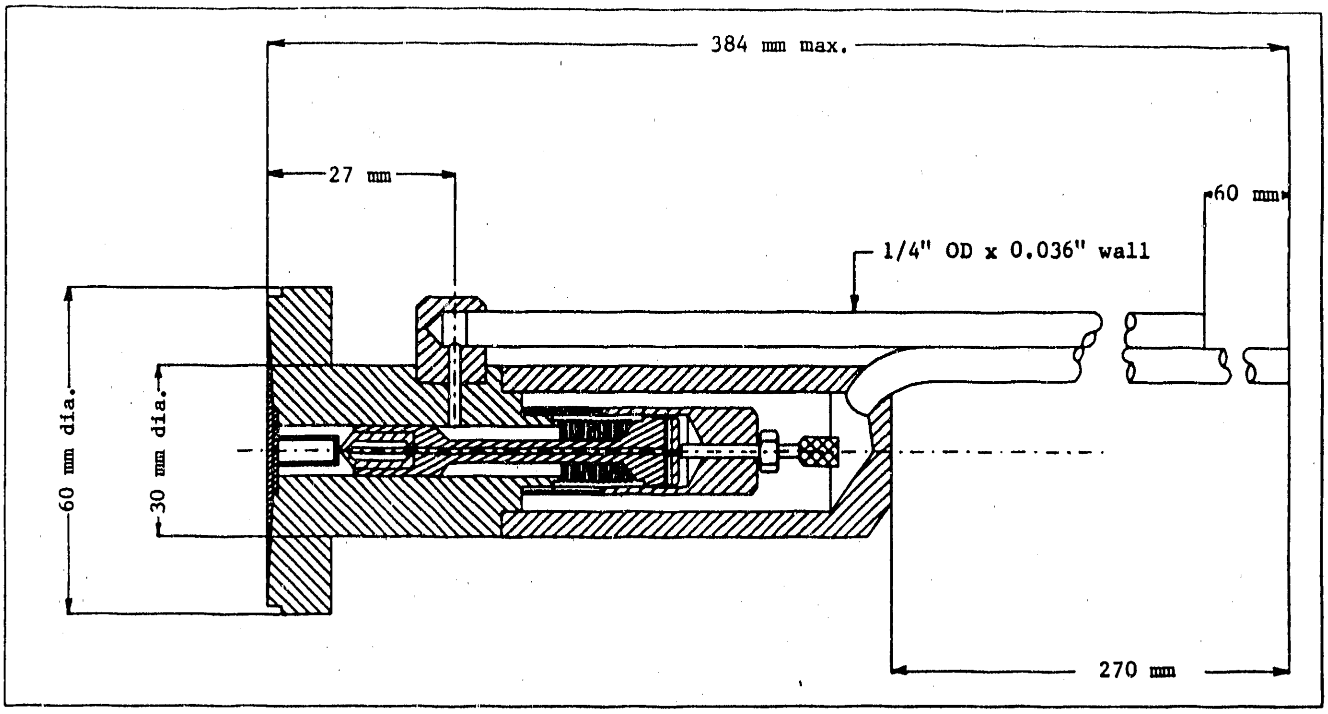

FIGURE 1. Sensor Detail

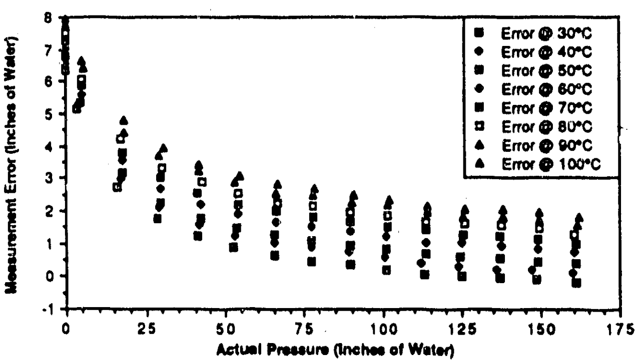

FIGURE 2. Sensor Pressure and Temperature Response

The following tests were done to determine the characteristics of the sensor.

- Repeatability
- Hysteresis
- Pressure response
- Temperature response
- Drift
- Radiation susceptibility

The results of these tests showed that the sensor repeats to within ±0.01 percent of the manufacturer's specified range. There was no detectable hysteresis.

The sensors do not drift significantly over long periods of time. No perceptible change could be seen in the calibration of a sensor after more than 690,000 pressure cycles between 0 and 200 inches of water. Radiation exposures of 1.0 x 10^8 Rads caused a small shift in calibration but always less than 0.25 inch of water. After one year of simulated use in a 1/10 scale pilot plant, there was a small but insignificant shift in the calibration on the order of 0.3 inches of water.

ERROR CORRECTION

With the stability and repeatability of these instruments, the error can easily be corrected using digital calibration techniques. The pressure and temperature response of each instrument is recorded and this data is used to create a computer model, which uses tank temperature and measured head pressure to calculate the actual head pressure for each sensor.

An automated calibration facility was built to characterize the pressure and temperature response of the sensors. A Programmable Logic Controller (PLC) was used to control temperature and liquid level during the calibration process. A separate computerized data acquisition system recorded the calibration vessel conditions as well as the response of each of the sensors. As many as 15 samples (data points) are collected at each discrete temperature and level setting. After the calibration run, the data were analyzed statistically to ensure the validity of the calibration. The data were than used to create a series of tables that define the measured pressure versus the reference pressure for each of eight temperatures (30°C to 100°C in 10° steps).

The corrected head is calculated using these calibration tables in a spline fit algorithm. The liquid level calculation program then uses the hydrostatic equation to calculate the fluid density and liquid level. from the hydrostatic equation:

$$P = \rho(g/g_c)h + P_0 \qquad (1)$$

Where:

ρ = fluid density,

(g/g_c) = conversion from pounds mass to pounds force,

h = height of fluid above the sensor, and

P_0 = Pressure above the fluid.

With two pressure sensors in a vessel, liquid level and density can be calculated using equation 1.

Statistical analysis has shown the error of the liquid level measurement system after correction to be within ± 0.3 percent of full scale in water. In simulated sludge, the statistics show the error to be slightly less than ± 2 percent. These statistics are based on measurements taken in a calm tank with the agitator off. Under these conditions the solid particles in the sludge settled out very quickly. Some of the difference between the water test and the sludge test is the result of the settling of the simulated sludge. Actual sludge is expected to settle less rapidly.

CONCLUSION

Extensive research has proven the stability and repeatability of this sensor. It has also been shown that sensor non-linearity and temperature response can be adequately corrected using digital calibration techniques to provide viable liquid level measurement for the DWPF canyon vessel.

ACKNOWLEDGEMENT

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