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WSRC-TR-94-0509
ACTIVITY NO.: SRT-ETF-TT-94003-0
SCOPING TEST

UNCLASSIFIED

DOES NOT CONTAIN
UNCLASSIFIED CONTROLLED
NUCLEAR INFORMATION

ADC &
Reviewing
Official:

Date:

John Itimke
(Name and Title)
11/8/94

KEYWORDS:
LEVEL SENSING INSTRUMENTS
HIGH-LEVEL WASTES
BUBBLER SYSTEM
AIR PRESSURE
FEEDTANKS
SLURRIES
SLUDGE
SRAT
AIR

RETENTION:
PERMANENT

**FINAL REPORT: DEVELOPMENT OF LIQUID LEVEL
AND DENSITY BUBBLER FOR DWPF
CANYON VESSELS (U)**

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ISSUED: October, 1994

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Westinghouse Savannah River Company
Prepared for the U.S. Department of Energy under
Contract DE-AC09-89SR18035

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Document: WSRC-TR-94-0509
Title: FINAL REPORT: DEVELOPMENT OF LIQUID
LEVEL AND DENSITY BUBBLER FOR DWPF
CANYON VESSELS (U)
Activity: SRT-ETF-TT-94003-0
Task title: ALTERNATE LIQUID LEVEL MEASUREMENT
FOR DWPF CANYON VESSELS (U)
TAR No: 93-DWPT-PMC-A0002
TTR Date: 02/02/94

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Report revision number 0

Report number WSRC-TR-94-0509

Description of major revisions			
Rev.	Page	Date	Revision
No.	No.		
0		10/94	Initial Release

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Executive Summary

Under Activity No.: SRT-ETF-TT-94003-0 (approved, 03/31/94), which is the result of Technical Assistance Request: 93-DWPT-PMC-A0002 (issued 02/02/94), an experiment was performed to test several alternate liquid-level and density measuring bubbler tubes to replace the standard "straight tube" bubbler sensor used in DWPF canyon vessels and Holledge-type sensors which are currently in use.

The instrument originally used to measure liquid level and density in DWPF mixing tanks [e.g., Slurry Receipt and Adjustment Tank (SRAT), Slurry Mixture Evaporator (SME) Tank, Melter Feed Tank (MFT)] was the fundamentally simple but rugged bubbler. In a typical "straight tube" bubbler, the slurry enters the tube because of the tank agitation and after some time sludge builds up and plugs, confounding measurement.

To overcome the plugging problem the bubbler-type level sensors were replaced with a similar, but more complicated pressure sensing device, a Holledge Diaphragm Probe. This device works like a bubbler tube in that air flows through a tube and the medium to be measured provides a back pressure, but instead of the air entering the medium it presses against a diaphragm which then presses against the medium. Unfortunately, there are many other problems, i.e., cost, linearity, temperature sensitivity, diaphragm failure, frequent recalibration, measurement threshold.

This report describes an experiment which elicited positive results from two alternate bubbler tubes that incorporate all of the advantages of the fundamentally simple "straight tube" bubbler while trying to minimize plugging. In this experiment, which modeled the hot slurry environment of the SME tank that has been found to plug the bubbler tubes the fastest, seven alternate bubbler designs were proposed. From the proposed alternates four were tested, resulting in two promising concepts. The first concept is a straight bubbler tube that is porous and covered with a concentric-tube jacket to slowly feed water through the tube wall which prevents plugging. The second concept is a large diameter straight tube that allows surface waves within the tube to assist in maintaining the sensor plug free. It is recommended that those two concepts receive further full-scale testing.

Acknowledgments

I would like to thank all of the TNX personnel who assisted me to understand the plugging problems of the bubbler-tube liquid-level sensors, especially, George Weeks, Chris Randall, and Gwen Gill, who was instrumental in obtaining and transporting simulant slurry from TNX to the Experimental Thermal Fluids Laboratory. Special thanks goes to the Summer Intern Student and my co-author, Allan Barnes. Allan performed most of the experimental tasks which required dedication. Also, thanks goes to the Co-op Student, Douglas Strege, who did a superb job of covering for Allan, during his short absence. Appreciation is extended to Tim Steeper who was the initial Activity Leader on this experiment and designed a considerable portion of the test apparatus. Finally, the work could not be done without the support and guidance of my manager, Dave Muhlbaier and customer, Chris Randall.

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Nomenclature

DWPF	- Defense Waste Process Facility
DWPT	- Defense Waste Process Technology
ETF	- Experimental Thermal Fluids (group or laboratory)
MFT	- Melter Feed Tank
PHA	- Precipitate Hydrolysis Aqueous
SME	- Slurry Melter Evaporator
SRAT	- Sludge Receipt and Adjustment Tank
SRTC	- Savannah River Technology Center
SRS	- Savannah River Site
TNX	- Full-scale Demonstration Facility
WSRC	- Westinghouse Savannah River Company
ρ	- Density
σ	- Surface Tension

1.0. Introduction

1.1. *The need*

The instrument originally used to measure liquid level and density in DWPF mixing tanks [e.g., Slurry Receipt and Adjustment Tank (SRAT), Slurry Mixture Evaporator (SME) Tank, Melter Feed Tank (MFT)] was the fundamentally simple but rugged bubbler. The advantage of a bubbler is in its construction, i.e., it is simply a straight tube with the open end located where a measurement is needed. Being just a tube it is easily replaced and calibrated, inexpensive to manufacture, has no moving parts to wear out, and contains no elastomers which will break down in a radioactive environment. Unfortunately, since one end of the tube is exposed to the medium, that it is measuring, one problem was encountered. In tanks that contain glass frit, Precipitate Hydrolysis Aqueous (PHA), and sludge (i.e., SME and the MFT) the tube becomes readily plugged, and the higher the temperature the faster it plugs. In the SME plugging can occur within hours! In a typical bubbler tube, which has a 0.5-inch to 1.0-inch inside-diameter tube, the liquid enters the tube because of the tank agitation and a typical plug is approximately two inches recessed inside the tube and is approximately two inches thick. Because of the drying effect of the heat and air the plug becomes a hard solid that can only be removed by mechanical means (e.g., metal lance).

In 1983 (1), the bubbler-type level sensors were replaced with a similar, but more complicated pressure sensing device, a Holledge Diaphragm Probe. This device works like a bubbler tube in that air flows through a tube and the medium to be measured provides a back pressure, but instead of the air entering the medium it presses against a diaphragm which then presses against the medium. After the air leaves the tube end and flows past the diaphragm it returns through a concentric tube that surrounds the downflowing air tube. That is, the air does not enter the liquid being measured but returns via an outside jacket on the tube through which it originally came. The end of this probe is sealed and no liquid can enter. Unfortunately, besides the fact that each probe is relatively expensive (\$50,000) (2) the operational experience with Holledge Probes has not been satisfactory. Several problems occurred since their introduction. Some of those problems are: 1) in the low pressure range of interest there are linearity problems, 2) highly sensitive to temperature, 3) diaphragms fail readily from stress, 4) need of

frequent recalibration which is not a simple process, 5) a diaphragm's limited movement creates a measurement threshold. In 1989 (3) a check of fifteen probes in five different tanks showed only one Holledge probe functioning properly.

In 1993 (2) a proposal was made to search the literature and vendors for liquid level indicators as a replacement for the Holledge Probe. That proposal generated a Technical Task (1) which gave two main recommendations: 1.) To study a radar liquid-level indicator, because it can operate in a radioactive environment and is medium independent. 2.) To develop a modified bubble tube to utilize all the advantages a bubbler type indicator while minimizing its plugging problem. The subject of this report is to address the second recommendation.

1.2. *The plan*

To pursue on the second recommendation, given above, some modifications on bubbler tubes were suggested (4). The basic idea was to keep the inside of the tube from drying out and therefore the slurry may not be able to stick and build up. One idea was to have concentric tubes to allow cooling water to flow and prevent the slurry from evaporating inside the tube. Another was to have the concentric tubing, but the inside wall of the tube would be porous to allow water to seep through and maintain the surface wet. In this case, a small flow of water would enter the slurry. These and other ideas are discussed below.

A Technical Assistance Request was issued (5) and a Technical Task (6) allowed the development of a test rig, Fig. 1, to test several different types of modified bubbler tubes. The task was to construct an experimental setup that could test several different bubble tube concepts in an environment similar to that of the SME tank (since the SME has the highest temperature, $\approx 100^{\circ}\text{C}$, and the fastest plugging, giving the worst case conditions). After finding modified bubblers that showed promise they would be tested in the full-scale TNX mixing tank.

The standard bubblers and proposed modifications to be tested were:

Standard bubbler

1.) Standard bubbler, Fig. 2, which is simply a metal tube with a 3/4 inch outside diameter and a wall thickness of 0.035 inch, giving an inside diameter of 0.680 inch.

Modified bubblers

- 2.) Standard bubbler, Fig. 2 but with the lower half of the tube made of 10-micron porous stainless steel.
- 3.) Double jacketed bubbler with water cooling, Fig 3, but with a solid tube inserted in the center instead of the porous-wall tube shown.
- 4.) Single jacketed bubbler with a porous lower inside-tube wall so that water could flow into the slurry. This is the same as the preceding tube except the lower half of the tube insert is a 0.5-micron porous tube and the jacket exit port closed off, Fig. 3.
- 5.) Single jacketed bubbler with a porous lower inside-tube wall so that air could flow into the slurry. This is same as the preceding tube, Fig. 3, except that air replaces water.
- 6.) Standard bubbler except for the lower section of the tube which was to be coated with a diamond film as a non-stick surface. There is no figure because the customer decided that this tube could not be readily made and therefore was not tested.
- 7.) Standard bubbler except for the lower section of the tube which was to be made of a highly polished shock resistant zirconia ceramic (or similar) material. There is no figure because the customer decided that this tube could not be readily made and therefore was not tested.

After testing began another option was added:

8.) Standard bubbler except instead of a 0.680 inside diameter, the diameter would be the largest that could be incorporated into the mixing tanks, Fig. 4. The modified stainless-steel beaker used had an inside diameter of 3.375 inches.

All of the above bubbler tubes had a notch at the tube exit to facilitate the air release. That notch was generally a 0.25-inch equilateral triangle

1.3. The expectations

Since the existing problem was the plugging of a liquid-level measuring device which was otherwise very effective, the intention

was to develop a similar concept device that would not plug when subjected to glass-frit and slurry mixture under conditions which exist in the mixing tanks. Of the seven modified bubblers listed in subsection 1.2 the first six were proposed as possible tube that would maintain its surface sludge free by covering it with a non-stick substance, e.g., air, water, etc. The last tube-type accepted the fact that some build-up would occur but that the air-liquid surface would be large enough so that surface waves would continually remove the sludge as it built up, as what happens along the air-liquid interface in a mixing tank. The following are some thoughts on how each tube was expected to function in the heated slurry environment.

Tube type 1: (Standard bubbler) This tube was expected to plug within an eight-hour period. Without this test there would be no way to know if plugging conditions exist.

Tube type 2: (standard bubbler except with the lower section made of porous metal) A porous tube wall has the potential to allow capillary action to draw liquid through the pores. This capillary action may be sufficient to maintain the surface wet and thereby prevent the onset of sludge build-up.

Tube type 3: (Double jacketed bubbler with water cooling) Water would circulate through a channel made from concentric solid-wall tubes. That is, water would circulate through a channel in the bubbler tube wall, but the water would not pass through the tube wall, into the slurry mixture. The idea was to maintain the end of the bubbler tube cool to prevent the evaporation of water from the slurry mixture. If the mixture was not given the chance to lose water it might not begin to stick to the tube wall.

Tube type 4: (Single jacketed bubbler with a porous lower inside-tube wall (7), so that water could flow into the slurry mixture). Water would be directed down a concentric tube channel and then exit through the inner tube wall, which was porous. As the water exited the tube wall it was to maintain a water jacket on the wall to prevent the sludge from adhering. The water would merge with the downcoming air in the bubbler tube and then exit together at the bottom of the tube into the slurry mixture.

Tube type 5: (Single jacketed bubbler with a porous lower inside-tube wall (7), so that air could flow into the slurry mixture) This has

the same mechanism as tube type 4 except for the substitution of water for air. The concern with air was that it might not uniformly prevent slurry from coming in contact with the wall which would allow some sludge to establish a foothold, eventually leading to plugging. Steam would also be tried if time allowed and the facilities made available.

Tube type 6: (Standard bubbler except with the lower section coated with a diamond film) A non-stick surface would prevent sludge build-up.

Tube type 7: (Standard bubbler except with the lower section made of a highly polished shock resistant zirconia ceramic (or similar) material) A non-stick surface would prevent sludge build-up.

Tube type 8: (Standard bubbler except the tube inside diameter would be 3.375 inches instead of 0.680 inch) At the air-liquid interface in a mixing tank, which has a twelve-foot inside diameter, the slurry has been noticed to cake onto the tank wall, but then the sloshing motion of the interface periodically washes off the build-up. A larger diameter tube was desired so that the free surface within could allow surface waves, which may prevent sludge plugging. The problem was to choose a tube with a large enough diameter. That is, what is the smallest diameter in which surface waves would be present. It is known that when a low density substance is accelerated into a high density substance (e.g., air and water) surface waves grow the fastest when their length is approximately the length of a Taylor wave (8). The Taylor-wave length is a function of the interface surface tension, gravity and the density difference $(2\pi(3\sigma/(\rho_{\text{liquid}} - \rho_{\text{gas}}))^{1/2})$. For the slurry, the air-liquid surface tension is not well characterized but for an air-water mixture near the boiling point the wave length is approximately, 1.1 inches. This dimension indicates that for an inside diameter of less than 1.1 inches the water would move up and down in a tube like a plug. However, even if a diameter was slightly larger than 1.1 inches a solitary standing wave in the tube would also act like a plug. It is assumed that several wave lengths would be needed to establish enough surface motion to promote sloshing. Therefore, it was decided to use a modified stainless steel beaker with an inside diameter of 3.375 inches. While this would only give approximately three wave lengths it is the largest that could be installed through the existing hole in the mixing tanks. Even though the inside diameter would allow three wave lengths (for air and water) there

would be some sludge build-up on the tube wall which would reduce the inside diameter, thus reducing the surface sloshing. In any case, this modified tube was thought to have as much chance as some of the other candidates and was therefore included.

2.0. Experimental Setup

2.1. General Operation

Figure 1 shows the schematic of the overall setup. The actual test procedure can be found in the Test Procedure (10), but they are outlined here for convenience.

Step 1: Have the insulated mixing beaker filled with the slurry to approximately 1.5 inches from the top.

Step 2: Install the proper bubbler tubes to be tested in the beaker lid and begin the 0.5 ft³/hr air flow.

Step 3: Secure the lid onto the beaker, submerging the tubes.

Step 4: Turn on the heater and the liquid agitator.

Step 5: When the liquid reached a constant 90°C (approximate) the test could commence and the pressure pulsing started.

Step 6: Pressure pulsing was stabilized with the computer controlled air valve while causing an approximately 2-inch plug to rise in the bubbler tubes.

Step 7: The following measurements were taken during testing: liquid temperature, meter air temperature, gauge pressure of the air above the liquid, differential pressure between the beaker air and the tube air.

2.2. Main Parameters

The experiment had to replicate two main features of the mixing tanks: 1.) The slurry and glass-frit mixture, and 2.) the pumping agitation of the mixing tanks' impellers.

Liquid Mixture - Two gallons of simulated SME/MFT waste were obtained from TNX to model the liquid for the bubbler. According to

the Environmental Evaluation Checklist (9) the properties of the mixture of sludge, glass frit, simulated PHA, and water were: specific gravity = 1.24, total mass = 9.39 kg, wt% of solids = 45%, and a pH = 6.

Liquid Agitation - The prototypic movement of the slurry within the end of a bubble tube is not known because of: 1) the fluid agitation is dampened by the heat transfer coils which enshroud the impellers, 2) the distance away from the impellers (about 3 feet from the tip of the lower impeller and only 6 inches away for the tank wall), 3) the lowest bubbler tube opening is only 1 inch off the bottom of the tank, where good mixing is questionable, and 4) on the air side of the tube the air line has pressure dampened which mask the agitation. The experimental agitation was to be such that a tube could become plugged. A pressurized air source which could apply pulses at a controlled frequency, was used for the simulation of the action of the tank impellers. An arbitrary pulse rate would be set up and if a "standard" bubbler did not plug, another rate would be used. Because of experience of tube plugging in the field, the actual rate was believed to be unimportant. Only that a pulsing slurry should be necessary. A pulse frequency of 2 pulses/second was used and the air valve was held open for 0.25 sec. Since control-bubbler tubes did plug at this frequency another was not employed. The air reservoir which fed the pulses was maintained at 8 psig.

2.3. Test Setup

2.3.1. Pre-test Rig

The test setup was pneumatically sealed except for an air-escape control valve, to regulate the rate of air escaping from the apparatus. Since a metallic container was necessary because of the slurry's effect on glass, the vessel was opaque. However, to obtain confidence on how the actual experimental setup would operate, a transparent one was put together with water as the working fluid. From this setup certain parameters were determined for the proper conditions in order to obtain an approximately 2-inch high liquid plug in the bubbler tubes. Those parameters were: the driving pressure to create a pulse (8 psig), the amount of time to open the air escape valve that relieved the pressure (0.25 sec.), and how often an air pulse was given (2 pulses/sec.). Moreover, use of this test rig gave the test engineer confidence on its operation during actual test operation.

2.3.2. Test Rig

As is shown in Fig. 1 the beaker contained two test bubblers: one as a control and one for test. One exception to this setup was when only control-tube testing was done, then only one tube was used. With only one control tube several tests were done to determine if a tube-plugging environment could be replicated and how long the plugging took to occur. Also, it was important to have a control tube present when testing the modified tubes because, it was necessary to know that plugging conditions existed. As opposed to the full-scale tank, with thousands of gallons of slurry, the test beaker only had approximately one gallon. As the many surfaces within the beaker began to accumulate sludge build-up the solids contents would be proportionately reduced. It was hoped that the plugging phenomenon would tolerate a certain amount of solids reduction in the slurry. As an indication of the pressure level during an air pulse, a U-tube was connected to the beaker lid. This U-tube served as both a way to see the pressure pulses, as they were applied, and a safety feature. If there were an accidental air surge, the water in the U-tube would be blown out and prevent any pressure build-up.

2.3.2.1. Slurry Level

As shown in Fig. 1, there was a sight gauge on the side of the steel beaker to measure the slurry level within. Unfortunately, the dampening effect of that tube caused a sludge build-up and tube plugged. Fortunately, until a bubbler tube plugged the measured pressure differential between the air on top of the liquid to the air in a tube indicated the liquid height.

2.3.2.2. Slurry Mixing

The initial slurry mixer was a magnetic stirrer that rotated on the bottom of the steel beaker. After one day of use there was enough settled frit that approximately one third of the stirrer was abraded away. The increased friction eventually caused the stirrer to stop spinning. This stirrer was replaced with a mixing impeller which entered the beaker through the lid and was suspended approximately one inch off the bottom. With the new mixer the slurry appeared to be more homogeneous, but on start-up each day the settled frit still had to be scraped off the bottom of the beaker and resuspended to maintain a good mixture.

2.3.2.3. Slurry Temperature

When the apparatus was tested with water the in-beaker thermocouple worked fine, but the substitution with slurry caused erratic readings. The increased level of ions caused the magnetic field to affect the grounded thermocouple. The thermocouple was changed for one isolated from the system and then it behaved properly. This new thermocouple was placed through the beaker lid instead of replacing the one in the bottom. The change of location was not considered significant because the liquid would be maintained in a well mixed state and the beaker was insulated. Important was that the liquid temperature be maintained high ($\geq 85^{\circ}\text{C}$) because of the faster plugging that had been observed in the SME tank at elevated temperatures.

2.3.2.4. Slurry Pressure

For most of the time the pressure above the slurry was at atmospheric pressure but periodic pulses of air were applied to the beaker such that an approximate two-inch liquid plug moved up in the bubbler tubes. This pressure was qualitatively observed in the overpressure U-tube and from a pressure transducer connected to the top of the beaker lid.

2.3.2.5. Bubbler-tube Air Pressure

For most of the time the pressure within the bubbler tubes was only several inches of water, just enough to overcome the liquid height above the bottom of the tube and to bubble out the end of the tube. However, upstream of the air flow meters the line gauge pressure was 20 psig, which gave a prototypic flow rate out of the bubbler tubes. Also, metering at this relatively high pressure provided a stable flow through the meters, despite the pressure pulses.

2.3.3.6. Air-flow Meters

To reproduce a prototypic air flow through the bubblers the same type flow meter used in the field was used. The type was a 3-inch Wallace & Tiernan Glass-tube Purge Meter with a capacity of 0 to 2.5 standard ft^3/hr of air together with a series 5800 purge flow controller. All tests were done such that the meters were at room temperature ($\approx 20^{\circ}\text{C}$) and metered at 20 psig and the air-flow rate was set at 0.5 standard ft^3/hr . That means at 20 psig the actual air-

flow rate through the meter was approximately $0.77 \text{ ft}^3/\text{hr}$. At the end of the control bubbler, where the temperature was approximately 90°C and the pressure was near standard ($\approx 14.7 \text{ psia} + 0.2 \text{ psi}$) the actual air-flow rate was approximately $2.2 \text{ ft}^3/\text{hr}$ or $1043 \text{ cm}^3/\text{min}$. In the field, the air meters are metered at 25 psig which give an actual flow rate of $0.82 \text{ ft}^3/\text{hr}$ through a meter, when set at 0.5 standard ft^3/hr , but this higher rate is countered by the higher back pressure of the 10 feet of slurry that sit over the end of the bubbler tube. Assuming 10 feet is the height of slurry (and $\rho = 1.24 \text{ g/cm}^3 = 77.4 \text{ lb}_m/\text{ft}^3$) then the air-flow rate out the end of the prototypic bubbler tube would be approximately $2.0 \text{ ft}^3/\text{hr}$, i.e., slightly less than the experimental air-flow rate. The actual flow rate given to use for the experiment was a range from 0.5 to 1.5 standard ft^3/hr . Therefore experimental flow rate was within that range. The intention was to use the lowest flow possible to be more conservative in that it may have a better chance of plugging.

3.0. Experimental Results

While testing, the results were recorded on a periodic basis (≈ 15 to 30 minutes) in the test notebook (11), along with during- and after-test observations. Further, results were recorded and stored every minute by a computer. As it turned out, the more frequent data were not needed because of the relatively long test time.

3.1. General Observations

The test showed that the control bubbler plugged. This meant that the experiment replicated the mixing tanks' environment correctly, or that plugging will always occur with the presence of moving hot slurry. In either case, all control tubes plugged anywhere from four (4) hours to eight (8) hours. The reason for the difference in times was not investigated because that was not the goal, but many variables may affect the time to plug, i.e., temperature of slurry, weight percentage of solids, surface of the metal tubes, level of liquid agitation, dryness of the air in bubbler, temperature of air in bubbler. All of these factors changed slightly from test to test. Knowing that plugging occurred in a prototypic time period then the goal was simply to test a modified tubes that remained plug free for a longer period of operation. Once a tube was discovered it would be tested in a full-scale tank for much longer time periods (weeks, months).

Before this experiment was terminated four types of tubes were tested. Of the four, two failed and two warrant further investigation. The two that plugged were types 2 and 5. That is, the single-walled tube with the lower half made from porous steel, and jacketed tube with an inner porous wall and air was forced through that wall into the slurry, respectively. The two that did not plug were types 4 and 8. That is, the jacketed tube with an inner porous wall and water was forced through the wall into the slurry, and the large-diameter bubbler tube, respectively.

3.2. Tube-specific Observations

There are only 7 tests reported here which highlight the results for each type tube. In reality, several tests may have been done or repeated which can be found in the test notebook (11). The results of those extra tests are combined to give an average experience for each. Table 1 lists the results but the specifics of each test are given in the following subsections:

3.2.1. Test 1: Type Tube 1

In the beginning of testing only a control-bubbler tube, Fig. 2, was tested to determine if plugging were possible and approximately how long it took. Then, with each modified bubbler tube, another control tube would be tested to insure that plugging conditions existed. This was especially important because there was only a finite amount of simulant slurry and as surfaces became coated with sludge the solids contents of the slurry would proportionately decrease.

Figure 5 shows a schematic of a control-bubbler tube with a typical sludge plug. The figure is a reproduction of the sketch made by the tester on page 70 of the task notebook (11) for the test that was done on 7/26/94. The full pluggage occurred after approximately four (4) hours in pulsating slurry at an average temperature of 88°C. Even though the plug profile shown in Fig. 5 was for only one test it is representative of all control tube pluggings.

For every plug the exact shape was slightly different but those differences are insignificant. The basic shape remained the same, i.e., the plug is recessed approximately two inches into the end of the tube and the plug has a height of approximately two inches. Below the plug the sludge tapers off to the tube end but the entire tube wall, below the plug, has a coating of sludge and the sludge is a deep

dark chocolate color and rather pliant. Above the plug the tube wall is relatively clean and the top of the plug is fairly flat and very dry, also the sludge is hard and lighter in color (sandy) than the rest of the plug. Presumably, the lighter color indicates drier sludge material.

Notice, in Fig. 5, that there is a slight opening in the center of the plug. This plug had a sort of Y-shaped crack. Generally, when a control tube first plugs the pressure would build up to the maximum system pressure (20 psig), but after a short time (different for each plug) the plug would fracture and then a steady-state cycling of unplugging and plugging would take over. Each plug would have a slightly different fission, but there would always be a very small crack through the plug. This crack was large enough to relieve the tube air pressure but small enough to prevent the tube from being used as a liquid level measure.

3.2.2. Test 2: Tube Type 2

The first of the modified bubbler tubes to be test was a type 2, (Fig. 2 with lower 3" of porous tube), i.e., a control-bubbler type tube but with the lower half of the solid stainless steel tube replaced with a 10-micron porous-tube section. This test can be found on pages 42 to 44 and was done on 7/14/94 (11). The test was only run for four (4) hours but when the tube was taken out and inspected there was already a significant build-up of sludge along the inside wall of the porous section, Fig. 6. The flow diameter was cut in half meaning the flow area was cut by 75%. The sludge build-up was significantly different than in the control-bubbler tube. Instead of a smooth coating of sludge on the inside tube wall the build-up was rough and in many little globs. This seemed to indicate that the porous surface provided a better surface on which to adhere. Also, the entire surface was coated, instead of just to the top of the plug, which may indicate that the slurry was able to rise higher and splash more than in the smooth tube. It was clear that further testing would lead to plugging and the plug would be thicker than in the smooth tube. The test was deemed a failure for blockage prevention.

3.2.3. Test 3: Tube Type 4

The second modified tube tested was a type 4 tube, (Fig. 3, i.e., a single jacketed bubbler with a porous lower inside-tube wall (0.5 micron), so that water could flow through the tube wall). This test

can be found on pages 49 to 59, 61, and 65 and it was done on 7/19-21/94 (11). Over the three days of this test a total of 19 hours of in-slurry test was accomplished. Because of safety and personnel needs the testing could not be continuous but it stopped at the end of each work day and started again on the following day. Attempts were made to minimize the accumulated slurry on the modified bubbler tube from drying out between test days. After a day's testing, the bubbler tube would be removed, then it was replaced into the beaker of slurry to commence testing on the following day.

Since water was to be injected into the jacket of the porous tube the rate of water flow needed to be determined. From previous tests the amount of water that evaporated from the slurry was approximately $100 \text{ cm}^3/\text{hr}$ ($\approx 0.6 \text{ gal/day}$). It was convenient to choose this rate of water injection to the tube so that the liquid level in the beaker would be kept nearly constant. That is, the water evaporating from the slurry would just be balanced with the water entering the slurry through the porous wall of the modified bubbler. It was hoped that this rate would be sufficient to prevent sludge build-up in the bubbler. A higher water input rate would be used if build-up did occur. Fortunately, the test showed that the water rate chosen was sufficient and the sludge build-up was insignificant.

Figure 7 shows the test notebook drawing (p. 65: Ref. 11) of sludge build-up after the three days of testing. The build-up was measured to be approximately $1/16$ th of an inch. This was considered insignificant for two reasons. This is the same thickness of build-up noticed on the previous two days of testing which means that it was not accumulating. This thickness was also approximately the same amount of slurry that would stick to the wall of the tube by simply dipping the tube in slurry (this was determined by dipping several tubes in the slurry). This tube type seemed to be a good candidate for further testing in the large scale test.

3.2.4. Test 4: Tube Type 5

The third modified tube tested was a type 5, (Fig. 3, i.e., a single jacketed bubbler with a porous lower inside-tube wall (0.5 micron), so that air could flow through the tube wall). This test can be found on pages 72 to 75, and it was done on 7/28/94 (11). An arbitrary air-flow rate was chosen to be $100 \text{ standard cm}^3/\text{min}$ (units are those of the meter used) and the actual flow rate through the meter, which was metered at 20 psig, was $154 \text{ cm}^3/\text{min}$. When converting

that metered air-flow rate to the lower pressure (near atmospheric) and higher temperature (90°C) conditions of the beaker, the air-flow rate was approximately 441 cm³/min. This is 42% of the tube downcoming flow rate of 1043 cm³/min (see 2.3.3.6.) . However, a more meaningful comparison would be based on flow area. The superficial velocity is defined as the volumetric flow rate divided by the flow area. For the tube flow that flow area is $\pi(0.680")^2/4 = 0.363 \text{ in}^2 = 2.343 \text{ cm}^2$, giving a superficial velocity of 445 cm/min. For the six-inch tall porous wall the inside-tube flow area is $\pi(0.680") \times 6" = 12.818 \text{ in}^2 = 82.7 \text{ cm}^2$, giving a superficial velocity of 5.3 cm/min, which is only approximately 1.2% of the downflowing air superficial velocity. What this means is that as the air exits the end of the tube 30%, $[441/(1043+441)]$, of the volume came through the porous-tube wall, but that the air flowing down the tube is moving almost two orders in magnitude faster than the air flowing from the porous-tube wall.

After a full day of testing (6 hours) the modified tube was removed when the pressure indication from that tube seemed to show that plugging was beginning. Upon removing the tube, a substantial sludge build-up was observed, see Fig. 8, which reduced the open flow area to approximately 20%. It was concluded that a few more hours would have produced a solid plug, or at least a plug sufficient to incapacitate the tubes proper operation. The test was classified a failure to maintain the tube plug free. After the tube was cleaned out and made ready again, another test was planned but with the air-flow rate, as indicated on the flow meter, doubled.

3.2.5. Test 5: Tube Type 5

This test is the same as test 4 except the air-flow rate to the porous tube jacket was increased. This test can be found on pages 76 to 79, and 81, and it was done on 8/1/94, (11). The air-flow rate was doubled to 200 standard cm³/min (once again, the units are those of the meter) and the actual flow rate through the meter, which was metered at 20 psig, was 307 cm³/min. When converting that metered air-flow rate to the lower pressure (near atmospheric) and higher temperature (90°C) conditions of the beaker, the air-flow rate was approximately 883 cm³/min. This is 85% of the tube downcoming flow rate of 1043 cm³/min (see 2.3.3.6.). Once again, a more meaningful comparison would be based flow area. The superficial velocity is defined as the volumetric flow rate divided by the flow area. For the tube flow that flow area is $\pi(0.680")^2/4 =$

$0.363 \text{ in}^2 = 2.343 \text{ cm}^2$, giving a superficial velocity of 445 cm/min. For the six-inch tall porous wall the flow area is $\pi(0.680") \times 6" = 12.818 \text{ in}^2 = 82.7 \text{ cm}^2$, giving a superficial velocity of 10.7 cm/min, which is only approximately 2.3% of the downflowing air superficial velocity. Analogous to the previous test, as the air exits the end of the tube the 46%, $[883/(1043+883)]$, of the volume came through the porous-tube wall but that the air flowing down the tube is moving almost forty times faster than the air flowing from the porous-tube wall.

After a full day of testing (7 hours) the modified tube was removed when the pressure indication from that tube seemed to show that plugging was beginning. Upon removing the tube, a substantial sludge build-up was observed, see Fig. 9, which reduced the open flow area to approximately 7%. The conclusion is that doubling the air-flow rate through the porous-tube wall had little effect, and the extra hour of this testing, over the previous test, allowed the plug to build up even more. A hour or two more would produce a solid plug and therefore the test was classified a failure to maintain the tube plug free.

3.2.6. Test 6: Tube Type 8

The fourth modified tube tested was a type 8 tube, (Fig. 4, i.e., a standard bubbler except the tube inside diameter would be 3.375 inches instead of 0.680 inch). This test can be found on pages 80, and 82 to 92, of Ref. 11, and it was done on 8/2-5/94 (also, a one-day ten-hour test was done on 7/25/95, pp. 63, 64, 66 to 70, but the results can be explained by the longer duration test). After four (4) consecutive days and approximately eighteen (18) hours of subjecting the tube to the heated agitated slurry a significant build-up of sludge had occurred. Even so, the tube did not plug and was still properly functioning.

Figure 10 depicts the sludge build-up as it was observed after the last day of testing. Since it was necessary to test other type tubes, because of priorities, further testing on this type was not carried out. Because the tube did not plug during the four days of testing it was considered a possible solution. However, there still is a question as to whether the sludge would continue to build up, to eventually plug the tube, or reach a steady state build-up, like that which occurs on the inside of actual slurry mixing tanks, and thus continue to

function properly for an indefinite time. This tube should be tested in the full-scale slurry tank over a long time period.

3.2.7. Test 7: Tube Type 5

The fifth modified tube tested was the same as the third modified tube tested, i.e., type 5, (Fig. 3, except that steam was used. To reiterate, this tube is a single jacketed bubbler with the lower inside porous-tube wall (0.5 micron), so that steam could flow through the tube wall). This test can be found on pages 93 to 95, and it was done on 7/16,19/94 (11). Unfortunately, after approximately a one-week time period, which was necessary to set up the lines necessary to supply steam, the first trial runs produced some difficulties. Some problems caused by steam had to be overcome and this caused some delays. While preparing to get the system running the experiment was stopped and continuation was put off indefinitely. While this may be an acceptable candidate for a bubbler tube, testing will be necessary to show that fact. However, the main disadvantage to this type tube arrangement is that a separate system is necessary to supply the steam. This added source of high energy fluid may prove too costly to maintain.

Table 1: Summary of Test Results

Test No.	Tube ^b Type	Duration (hours)	Slurry Temp.(°C)	Test ^c		Estimated Time to Pluggage ^f (hours)
				Notebook Page	Comment ^d	
1 ^a	1	4	88	70	Plugged (3.2.1.) ^e	4
2	2	4	90	42	Failed (3.2.2.)	6
3	4	19	91	49	Passed (3.2.3.)	0
4	5	6	88	72	Failed (3.2.4.)	8
5	5	7	90	76	Failed (3.2.5.)	8
6	8	18	88	80	Passed (3.2.6.)	0
7	5	<1	95	93	Not Completed (3.2.7.)	-

^a Test No. 1, Control Bubbler was actually done many times alone and along with the modified bubbler tubes. Only one instant was chosen for illustration. Results on all the control tubes test were similar.

^b Tube type is described in subsection 1.3 of this document.

^c Beginning page number of notes for specific test in Ref. 11.

^d Failed means that it did not meet expectations. Passed means that it did meet expectations and warrants full-scale testing. For a more detailed explanation see this document's subsection (listed in parentheses).

^e Tube Type 1 is an exception since it is the control tube and it was "expected" to fail, i.e., plug.

^f Pluggage times for tests 2, 4, and 5 are estimated since complete pluggage did not occur within the test period. For more information see the appropriate subsection.

4.0. Conclusions and Recommendations

The changing priorities of DWPF include the minimizing of the number of those projects considered enhancements to the current system. This test falls in the category of an enhancement so it was terminated prematurely. Despite not concluding all planned tests, some very useful information was obtained.

The conclusions are:

- 1.) Tube type 1 (Fig. 2, a standard bubbler, i.e., the straight tube-type bubbler) does readily plug when the mixture is a combination of slurry, PHA, and glass frit. This plugging prevents the proper operation of this instrument. For a 0.75-inch tube with a 0.035-inch wall the plug is generally located 2 inches from the bottom of the tube and 2 inches thick. The top of the plug is flat and the bottom is conical in shape. The plug solidifies to the consistency that requires mechanical means for removal, like a metal lance. For this type tube the plug forms between 4 to 8 hours when the slurry mixture is hot, i.e., greater than 85°C.
- 2.) Tube type 4 (Fig. 3, a single jacketed bubbler with a porous lower inside-tube wall (0.5 micron), so that water could flow into the slurry mixture) can be maintained plug free for at least 19 hours when the water flowing through the porous jacket is 100 cm³/hr ($\approx$ 0.6 gal/day). Three days of operation showed no signs of sludge accumulation, indicating that this tube may operate for a much longer time, or maybe indefinitely, in a plug-free state.
- 3.) Tube type 8 (Fig. 4, a standard bubbler except the tube inside diameter would be 3.38 inches instead of 0.68 inch) can be maintained plug free for at least 18 hours. After four days of operation there was significant sludge build-up on the inside tube wall, but not enough to effect the proper operation as a level and density sensing device. Further testing would be needed to definitively state the length of time this tube would operate without plugging.
- 4.) Tube type 2 (Fig. 2, with lower 3 inches of porous tube (10 micron)) and tube type 5 (Fig. 3, i.e., a single jacketed bubbler with a porous lower inside-tube wall (0.5 micron), so that air could flow through the tube wall) failed to remain plug free, therefore should not be further considered as candidates for tube replacements.

However, time did not allow for testing these tubes under different conditions which may have determined them to be acceptable substitutes. For example less plugging tendencies may have been found if, differing porosities for both tubes were used, using steam instead of air in the type 5 tube, or using different volumetric rates of gas flow through the type 5 porous tube.

As a minimum, the two modified tubes that did remain plug free should be tested in the full-scale SME/SRAT tank in TNX. This testing (and continual use) will be inexpensive relative to the \$50K to replace one of the currently used Holledge probes (2), since the estimated cost of manufacture and installation for each probe type to be \$5K. Tube type 8 should be considered first because of its simplicity. That is, like a standard bubbler it is only a tube with no external water or air flow systems needed. The key to this tube type is its size. The tube inside diameter should be the largest possible that can fit through the existing tank aperture. It should be at least 1 foot tall because the 3-inch deep steel beaker, used in this test, had significant sludge built up on the inside top surface, see Fig. 10, and because some of the straight tube tests showed that sludge splattered up to approximately 1 foot on the inside of the tube.

The water-injected type 5 tube should be tested but the porous section of the tube should also be made to about 1 foot in height. For this test the 6-inch porous tube was kept basically sludge free but where the porous tube met the non-porous section there was some sludge build-up. If the porous wall were made taller the water flow rate should be increased to maintain the same superficial water-flow velocity. That is by doubling the porous tube height then: $(2 \times \text{water-flow rate}) / (2 \times \text{porous inside-tube area}) = \text{the same superficial water-flow velocity}$. The new water-flow rate would be $2 \times 0.634 \text{ gal/day} = 1.3 \text{ gal/day}$.

If priorities change further testing may show that the other tubes not tested to be other possible substitutes, like the coated surface tubes (types 6 and 7) or those that were tested but with only a limited number of parameter, i.e., different gases, different gas rates, and different porosities.

5.0. References

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Figure 1: Overall experimental test apparatus

Figure 2: Control-tube bubbler

SCALE: FULL SIZE

MATERIAL: STAINLESS STEEL

Figure 3: Jacketed inner porous-tube bubbler

SCALE: ONE HALF SIZE
MATERIAL: STAINLESS STEEL

Figure 4: Large-diameter tube bubbler

Figure 5: Plugged - Control-tube bubbler

Figure 6: Plugged - Porous-tube bubbler

Figure 7: Plug free - Water-jacketed inner porous-tube bubbler

Figure 8: Plugged - Air-jacketed inner porous-tube bubbler
(volumetric air flow through tube wall 441 cm³/min)

Figure 9: Plugged - Air-jacketed inner porous- tube bubble
(volumetric air flow through tube wall 883 cm³/min)

LARGE MOUTH BUBBLER $\Rightarrow$ ≈ 18 HOURS OF USE

END
VIEW

Allan P. Banner

SIDE VIEW

Figure 10: Plug free - Large-diameter tube bubbler