**Final Report Full-Scale Test of DWPF Advanced Liquid-Level and
Density Measurement Bubbler s**

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by

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FINAL REPORT: FULL-SCALE TEST OF DWPF ADVANCED
LIQUID-LEVEL AND DENSITY MEASUREMENT
BUBBLERS (U)

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Executive Summary

As requested by the Technical Task Request (1), a full-scale test was carried out on several different liquid-level measurement bubblers as recommended from previous testing (2). This final report incorporates photographic evidence (Appendix B) of the bubblers at different stages of testing, along with the preliminary results (Appendix C) which were previously reported (3), and instrument calibration data (Appendix D); while this report contains more detailed information than previously reported (3) the conclusions remain the same. The test was performed under highly prototypic conditions from November 26, 1996 to January 23, 1997 using the full-scale SRAT/SME tank test facilities located in the 672-T building at TNX. Two different types of advanced bubblers were subjected to approximately 58 days of slurry operation; 14 days of which the slurry was brought to boiling temperatures.

The test showed that the large diameter tube bubbler (2.64 inches inside diameter) operated successfully throughout the 2-month test by not plugging with the glass-frit laden slurry which was maintained at a minimum temperature of 50°C and several days of boiling temperatures. However, a weekly blow-down with air or water is recommended to minimize the slurry which builds up.

The small diameter porous tube bubbler (0.62 inch inside diameter; water flow > 4 milliliters/hour = 1.5 gallons/day) operated successfully on a daily basis in the glass-frit laden slurry which was maintained at a minimum temperature of 50°C and several days of boiling temperatures. However, a daily blow-down with air, or air and water, is necessary to maintain accurate readings.

For the small diameter porous tube bubbler (0.62 inch inside diameter; water flow < 4 milliliters/hour = 1.5 gallons/day) there were varying levels of success with the lower water-flow tubes and these tubes would have to be cleaned by blowing with air, or air and water, several times a day to maintain them plug free. This may be too labor intensive for practical use.

All of the large diameter bubbler tubes tested could be readily cleaned in place by either blowing them down with just high pressure air or water (≈ 90 psig). While the use of both air and water produced the cleanest bubbler, using just air removed most of the slurry build-up, and the use of

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water resulted in basically a slurry free surface. For the small diameter bubbler tubes it was necessary to use high pressure air and water (≈ 90 psig) to effectively clean them. The water was only sent through the porous jacket and not introduced down the air line. However, even under these conditions there was one case where a plug was not removed when both air and water were used.

Primary recommendation: The large diameter probe is the best choice since none of the three tested plugged during the 2-month test period to the point which compromised liquid-level measure. However, after a week's operation at boiling temperatures several inches of a soft sludge builds up within the tubes. This sludge can be easily removed in place with either high pressure air or water (≈ 90 psig). A full-scale verification test should be carried out in S-area to confirm the conclusion.

Secondary recommendation: The small-diameter porous tube bubbler is recommended when an access port cannot accommodate the larger diameter probe. Bubbler #1 operated accurately during most of the test period. This probe had the highest water flow rate (≈ 1.6 gallons/day) and had the least distance from the slurry upper surface (37 inches). This probe can be made to accurately operate at lower depths if the 8-inch-long porous tube is made longer and the water flow rate made higher.

Substituting the current level and density probes (Holledge) with bubbler probes will result in a significant cost savings (inexpensive materials, less labor to manufacture, less labor to maintain, less down time due to less frequent instrument replacement).

(Table 1 is reproduced from page 8 of report.)

Table 1: Summary of Test Results (see Appendix C for Specific Results)				
Bubbler No.	Bubbler Type	Air Flow Rate CFH *1*	Water Flow Rate ml/min *2*	Time to Plug Days *3*
1	porous tube	1.5	4.4	7
2	porous tube	1.7	2	3
3	porous tube	1.6	1.2	5
4	porous tube	1.5	0.3	1
5	porous tube	1.5	0.5	3
6	porous tube	1.6	0.3	2
7	porous tube	1.5	4.2	7
8	porous tube	1.5	2	3
9	porous tube	1.8	1.3	2
10	large diameter tube	1.4	*4*	No Pluggage
11	large diameter tube	1.5	*4*	No Pluggage
12	large diameter tube	1.5	*4*	No Pluggage

Notes:
 1 This is the meter-indicated flow at 20 psig actual flow is higher
 2 These are average values over all of the test periods
 3 Rough estimate for a clean tube from one or more of the 6 test periods
 4 does not apply - only air is necessary

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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

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1.0. Introduction

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 and rugged bubbler. The advantage of a bubbler is in its construction and maintenance, 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 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 (4), 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) (5) 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) cannot be recalibrated once put in use, 5) a diaphragm's limited movement creates a measurement threshold. In 1989 (6) a check of fifteen probes in five different tanks showed only one Holledge probe functioning properly.

In 1993 (5) a proposal was made to search the literature and vendors for liquid level indicators as a replacement for the Holledge Probe. From the results of the search (4) two main recommendations were given: 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.

Path Forward

To pursue the second recommendation, given above, some modifications on bubbler tubes were suggested (7). 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 keep the surface wet. In this case, a small flow of water would enter the slurry.

In 1994, a bench-top experiment was carried out to test several different bubbler tube alternatives, to include a large diameter tube bubbler. It was thought that the large diameter would provide a larger free surface within the bubbler to allow internal wave action to keep the bubbler tube plug free. Of the five alternative bubbler tube tested the results (2) indicated that two types may operate successfully in DWPF slurries without pluggage: a small diameter (0.6 inch i.d.) porous tube with water flowing through the porous wall and a large diameter (3.4 inch i.d.) tube. Those suggestions were the basis for issuing a Technical Task Request (1) to carry out a full-scale test in the SRAT/SME tank at TNX so that the alternate technologies could be tested under prototypic conditions. This resulted in a Task Technical and QA Plan (8) to construct and do testing of the two types of bubblers. The testing began at TNX in November 1996 and ended in January 1997.

2.0. Experimental Setup

To satisfy the TTR (1) a set of twelve probes were constructed, Appendix A. The "probe tree" on the lower left hand side in Fig. A1 [WSRC Photograph No. 96-1569-1] shows the orientation of nine porous tube probes. Figure A2 [WSRC Photograph No. 96-1569-4] is a close-up of three of the pre-installed porous-tube bubblers, with Fig. A7 showing a profile drawing of this probe construction. All nine probes were exactly

the same, only the water flow rate would vary*. Figure A3 [WSRC Photograph No. 96-1569-6] is a close-up of the pre-installed large diameter bubblers, with Fig. A4 showing a profile of this probe construction**.

[*The bench-top test (2) showed that a water flow of 1.67 ml/min (0.6 gallons/day) maintained the tube plug free for 19 hours in slurry at 90°C, but this full-scale test was to determine if lower flow rates would also work so as to minimize the amount of water additions to waste tanks. For this test an equivalent water flow rate would be $1.67 \text{ ml/min} \times 8/6 = 2.2 \text{ ml/min}$ (0.8 gal/day), since the porous-tube length was increased to 8 inches, from 6 inches; the length was increased because the slurry was found to splash up to approximately 6 inches in the bench-top test (2). Therefore, the water flow rates were chosen to be multiples of the bench-top value, i.e., 2x, 1x, 0.5x, 0.25x, and 0.125x 2.2 ml/min, (see Figs. C1 to C9 for the actual flow rates used).]

[**The large tube has an inside diameter of 2.64 inches (2.5 sch 10 pipe) instead of the 3.4 inches used previously (2). It would have been better to use the larger diameter, but the access port on the S-area tanks for level probes only have 3-inch diameter openings. Combining this limitation with the fact that the tube must have significant structural strength to withstand the highly agitated slurry, led to this smaller dimension, i.e., 2.5 sch 10 pipe (2.88 o.d., 2.64 i.d.). The reduced diameter was expected to build up slurry much faster and have a higher potential to plug, but it was hoped that there was still sufficient flow area to maintain the bubbler operational over significantly longer time periods than the 4-8 hours that standard bubblers are known to plug.]

Figure A4 gives the relative distances of the probes along the probe trees. These distances are also valid for the small diameter probes since the vertical probe-to-probe distances were the same for either the small or large diameter probes. Using Section A-A from Fig. A9 and the Front Elevation View from Fig. A4 the distances from the bottom of the flange plate to each probe opening are shown to be 185.125 inches, 161.125 inches, and 130.125 inches (which takes into account that a probe's opening is at the apex of the "V" notch to allow air bubbles to easily escape into the tank; it is 1/8 inch high). The entire probe assembly rig shown in Fig. A1 was placed in a large tank opening (19.50 inches) shown in Fig. A11 (Ref. 9) on the right side of the tank, i.e., opposite the side that has the mercury sump. The distance from the top of that opening to the bottom of the tank, at the center of that opening, is approximately 186.5 inches (9, 10). Therefore, the distances between the probe openings and the bottom of the tank were 1.4 inch, 25.4 inches, and 56.4 inches, respectively. During the second week of testing, the probe assembly was raised 42 inches higher in the tank (see A10), which increased the distance from the tank bottom to the probe opening to 43.4 inches, 67.4 inches, and 98.4 inches, respectively. This was done to keep the top-most probes out of the slurry for a fixed period to simulate empty tank conditions. The goal was to see if probes, with some sludge accumulation but still operational, would continue to function after their reintroduction into the slurry.

3.0 Instrumentation

Each of the twelve bubbler tubes had a pressure gauge and an air flow meter. Each of the nine porous bubbler tubes also had a water flow meter. Specifics and calibrations for each of the devices are given in Appendix D.

4.0. General Operation

Details of the actual operating procedure can be found in the test procedures (11). The general procedure was:

- pre-calibrate the instruments
- install the twelve probes in the full-scale SRAT/SME tank
- monitor the twelve probes on an hourly basis
- when scheduled, raise the slurry to boiling temperature
- on a weekly basis remove the probes to document conditions
- after the first period with some days of boiling temperatures: raise the probes out of the slurry sufficiently to maintain the top set out of the slurry
- after the next period with some days of boiling temperatures: lower the probes to the original height
- after the next period with some days of boiling temperatures: document the condition in the morning, replace the probes in the slurry, blow down the probes, remove the probes for documentation
- after the last period with some days of boiling temperatures: remove and document
- post-calibrate the instruments

5.0. Discussion of Results

Definition of Pluggage

Pluggage of a tube simply means that a bubbler is sufficiently clogged with a combination of dried sludge, slurry, and glass frit that a level measurement is no longer practical, for example see Fig. B9. In fact, the inner tube of a bubbler could have a significant build-up of sludge and still function properly, Figs. B2 to B6. Only when the level measurement is affected, is it considered plugged. Moreover, during the tests once a tube became plugged it always re-

opened to temporarily indicated level again, however, it would begin to successively replug and unplug to the point that made the instrument useless.

General Observations of the Probes During Testing

Because of the labor necessary to install and remove the test probes from the full-scale tank, these activities were kept to a minimum with at least one week between removals. Therefore, daily sludge accumulations in the probes were not recorded. However, whether the probes were clean of slurry, or not, a week's time was sufficient to allow the slurry to build up in all the probes to the point that some appeared to be plugged (see Figs. B2 and B6), even though the data still did not indicate a pluggage (see Fig. C12, which corresponds to Figs. B2 to B5, and Figs. C7, C8, and C9 for test period 1, which correspond to Fig. B6).

Another feature common to all probes was that the location of the highest concentration of slurry build-up, in each probe, was a function of a probe's depth in the slurry. Probe 12, which was located 92 inches under the surface of the slurry, had a slurry plug recessed approximately 10 inches into the tube. Probe 11, which was located 68 inches under the surface of the slurry, had a slurry plug recessed approximately 6 inches into the tube. Probe 10, which was located 37 inches under the surface of the slurry, had slurry plugs recessed approximately 3 inches into the tube. This effect can be seen by comparing Figs. B2 with B3. These figures are of the same probe, 12, but after the first period of testing the probe was raised 42 inches (or to $92 - 42 = 50$ inches under the surface of the slurry) and held there for one week. The 10-inch plug depth was reduced to between 4 to 5 inches.

The smaller diameter porous-tube probes: 7, 8, and 9 at the same level as probe 12; 4, 5, and 6 at the same level as probe 11; and 1, 2, and 3 at the same level as probe 10, had differences in the plug depths into the tubes similar to the large diameter probes. However, the actual plug depths were about one-half that of the large diameter probes. For example, the plug depth for probes 7, 8, and 9 was about 5" (Fig. B6) compared to the 10" of probe 12 (Fig. B2). This is possible because, for equal pressure (tensile stress) and liquid wall shear stress, only geometry is important. A ratio of the forces, that result from these stresses, indicates that as the tube diameter decreases the force due to wall shear stress become more important which acts against the upward movement of a liquid plug, thus reducing its height.

These different plug locations exist because of the submerged wave heights within the liquid depend upon pressure. The importance here is if liquid level in a tank changes significantly over time, then the change in submerged wave heights will cause slurry plugs to occur at different locations. [As an illustration on the effect of pressure on these wave heights see Fig C13. A careful examination of the data between periods 1 and 2 shows that as pressure increases (increasing depth) there appears to be more variation in the data (Quantitatively, one standard deviation of those data increases from 1.2 inches H₂O, for lower pressure, to 2.9 inches H₂O, for the higher pressure. By comparing all the graphs, this same height effect is always present.]

Specific Features of the Data

Bubble Probes #1, #2, and #3 Porous Tubes [Figs. C1, C2, and C3]

Height from Tank Bottom: 56.4 inches

Out of all the small diameter tube bubblers, these three, as a group, showed the most success in operation without pluggage. This occurred for two reasons which must be taken together. They had the highest water flow rates and were the least submerged in the slurry (37 inches from the upper surface). This means that inner tubes had the most water lubricating the tube wall while having a slurry plug pulsating less than 3 inches into the bottom of the tubes. In fact, bubbler probe 1 which had at least twice the water flow rate as the other two probes remained fairly stable and accurate until the last period. The increase in the last period is thought to have occurred because of an unsuccessful attempt to dislodge significant slurry build-up on 1/16/97.

Bubble Probes #4 #5, and #6 Porous Tubes [Figs. C4, C5, and C6]

Height from Tank Bottom: 25.4 inches

With significantly lower water flow rates, and being twice as deep in the slurry (68 inches), than bubblers 1, 2, and 3, these three bubblers only needed a day or two to begin to plug once boiling temperatures were reached. At the beginning of period 6 they were shown to operate accurately after being blown down, but began to plug once several days past. A daily blow down would probably keep them operating successfully.

Bubble Probes #7, #8, and #9 Porous Tubes [Figs. C7, C8, and C9]

Height from Tank Bottom: 1.4 inches

Once again, the bubbler with the highest water flow rate (4.2 mL/min = 1.6 gallons/day) operated the longest without plugging, bubbler 7. On Fig. C7 it appears that between periods 1 and 2 and between periods 5 and 6 bubbler 7 operated several days accurately but with the onset of boiling temperatures, the pressure would increase. A daily blown down with air or air and water would probably keep the probes operating accurately indefinitely. However bubblers 8 and 9 showed a higher tendency to plug and would therefore be a less desirable choice.

The photographic evidence indicates that waiting more than couple of days to blow down a porous tube may allow enough sludge to build up to prevent a complete plug removal. Figure B6 shows a one-week build up of sludge. The probes were still functional (see test period 1 on Figs. C7, C8, and C9) but there was only a small hole in the center of the plug to allow operation. On 1/16/97 these probes were blown down with water, see Fig. B13. Initially these probes were operational but the data in Figs. C7, C8, and C9 indicate that pluggage began almost immediately after one more week of operation. Figure B9 shows the plugs near the end of the tubes. This indicates that the original plugs were not totally removed and therefore the sludge accumulation simply continued where it left off. These probes should be blown down often enough to prevent accumulation to occur.

Bubble Probes #10, #11, #12 Large Diameter Tubes [Figs. C10, C11, C12, and 13]

Height from Tank Bottom: 56.4 inches, 25.4 inches, 1.4 inches, respectively

Outside of the increased variance in the data as a probe is located deeper in the slurry, these three probes never indicated an onset of pluggage. After one week of operation there was enough slurry build-up in the probes to almost completely block the opening, however, there was always a channel to let it communicate hydraulically with the tank liquid, as can be seen in the center of the accumulated sludge in Figs. B2, B4, and B5. After two weeks of operation the probe appeared to be completely plugged when visually observed, e.g., see Fig. B3, but as the data show, see Fig C13, they all continued to measure accurately. This is verified by the independent measurement indicated on the graphs and by the fact that the relative distance between the probes are accurately shown in the data. That is, the physical distance between the two top-most probes was 31 inches [Fig. A4] and when accounting for the SpG, then $31 \times 1.3 = 40$ inches

H₂O. On Fig. C13 the data show approximately $78 - 37 = 41$ inches. The physical distance between the two bottom-most probes was 24 inches [Fig. A4] and when accounting for the SpG, then $24 \times 1.3 = 31$ inches H₂O. On Fig. C13 the data show approximately $110 - 78 = 32$ inches. Since the measurement uncertainty is considerably larger than $32 - 31 = 1$ inch, this difference is insignificant, see Fig. D24, D25, D26.

While sludge accumulations never affected the level measurement during any of the test periods for the large diameter probes, Figs. B2, B3, B4, and B5 indicate significant accumulations that may eventually build to the point where readings could be affected. Therefore, two of the test periods (5 and 6) began with a blowdown with water. Fig. B10 shows an almost totally clean probe and Fig. B11 shows similar results. Fig. B4 shows what the tube looked like before being blown down and Fig. B11 shows it after cleaning on the same day, 1/16/97. This was done by removing the probe after a week's worth of operation to document in the morning; replacing it in the full-scale tank, blowing it down with water in the afternoon, and then immediately removing it again for documentation.

Table 1: Summary of Test Results (see Appendix C for Specific Results)

Bubbler No.	Bubbler Type	Air Flow Rate CFH *1*	Water Flow Rate ml/min *2*	Time to Plug Days *3*
1	porous tube	1.5	4.4	7
2	porous tube	1.7	2	3
3	porous tube	1.6	1.2	5
4	porous tube	1.5	0.3	1
5	porous tube	1.5	0.5	2
6	porous tube	1.6	0.3	2
7	porous tube	1.5	4.2	7
8	porous tube	1.5	2	3
9	porous tube	1.8	1.3	2
10	large diameter tube	1.4	* 4 *	No Pluggage
11	large diameter tube	1.5	* 4 *	No Pluggage
12	large diameter tube	1.5	* 4 *	No Pluggage

Notes:

1 This is the meter-indicated flow at 20 psig actual flow is higher

2 These are average values over all of the test periods

3 Rough estimate for a clean tube from one or more of the 6 test periods

4 Does not apply - only air is necessary

6.0 Conclusions and Recommendations

1. Large Diameter Tube Bubbler (2.64 inches inside diameter)

Operated successfully throughout the 2-month test by not plugging with the glass-frit laden slurry which was maintained at a minimum temperature of 50°C and several days of boiling temperatures. However, a weekly blow-down with air or water is recommended to minimize the slurry which builds up. [Figs. C10, C11, C12 and B2, B3, B4, B5 vs. B10, B11] [Limitation: Because of the physical size of this bubbler it is probably not practical to place measurement locations closer than 24 inches, when they are located on top of each other. For example, see Figs. A1, A3, and A4]

2. Small Diameter Porous Tube Bubbler (0.62 inch inside diameter) (water flow > 4 milliliters/hour = 1.5 gallons/day)

Operated successfully on a daily basis in the glass-frit laden slurry which was maintained at a minimum temperature of 50°C and several days of boiling temperatures. However, a daily blow-down with air, or air and water, is necessary to maintain accurate readings. [Figs. C1, C7 and B6, B7 vs. B12, B13 (the tube closest to the bottom of the photographs)]

3. Small Diameter Porous Tube Bubbler (0.62 inch inside diameter) (water flow < 4 milliliters/hour = 1.5 gallons/day)

There were varying levels of success with the lower water-flow tubes but these tubes would have to be cleaned by blowing with air, or air and water, several times a day to maintain them plug free. This may be too labor intensive for practical use. [Figs. C2, C3, C4, C5, C6, C8, C9 and B6, B7 vs. B12, B13 (the two tube closest to the top of the photographs)]

4. Clean with Air or Air and Water

All of the large diameter bubbler tubes tested could be readily cleaned in place by either blowing them down with just high pressure air or water (≈ 90 psig). While using just air removed most of the slurry build-up, the use of water resulted in basically a slurry free surface, see Figs. B10 and B11. For the small diameter bubbler tubes it was necessary to use high pressure air and water (≈ 90 psig) to effectively clean them. The water was only sent through the porous jacket and not introduced down the air line. However, even under these conditions there were some tubes where plugs were not removed when both air and water were used, see Figs. B12

and B13 (on Fig. B12 only the two of the three tubes shown were blown down).

Recommendations

1. Replace all standard bubbler that plug and all Holledge probes with large diameter probes were the larger size probe can be tolerated.

The large diameter probe is the best choice since none of the three tested plugged during the 2-month test period to the point which compromised liquid-level measure. However, after a week's operation at boiling temperatures several inches of a soft sludge builds up within the tubes. This sludge can be easily removed in place with either high pressure air or water (≈ 90 psig). A full-scale verification test should be carried out in S-area to confirm the conclusion. [Note: When testing, it should be remembered that the TNX tank agitator runs at 100 RPM and the S-area SME tank runs at 130 RPM. Since level (and density) are measured by pressure differences these reading may be affected by the increase velocity of the tank liquid by a factor of $(130/100)^2 = 1.7$. However, within the measurement uncertainty of this test such dynamic pressure affects were not significant.]

2. Replace all standard bubbler that plug and all Holledge probes with small-diameter porous tube probes were the larger size probe cannot be tolerated.

The small-diameter porous tube bubbler is recommended when an access port cannot accommodate the larger diameter probe. Testing showed that bubbler #1 (Fig. C1) operated accurately during most of the test period. This probe had the highest water flow rate (≈ 1.6 gallons/day) and had the least distance from the slurry upper surface (37 inches). Therefore, this probe can be made to accurately operate at lower depths if the 8-inch-long porous tube is made longer and the water flow rate made higher.

7.0. References

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10. Drawing, "Test Tank Vessel Arrangement and Data," SRS Engineering Drawing No. PV182698, Rev. 35, 9/22/83.
11. WSRC Field Procedures to operate test: SP-672T-96-10-1, SP-672T-96-10-2, SP-672T-96-10-3, SP-672T-96-10-4.
12. Weeks, G. E., Task Notebook No. WSRC-NB-94-1440, issued 4/20/94.

APPENDIX A

Photographs and Drawings of the Experimental Apparatus

[Figures A1, A2, and A3]

Figure A1 (No. 96-1569-1, taken 11/96): This photograph shows the entire probe assembly before installation for the first time. The bottom left tree contained the nine porous-tube probes, the bottom right tree contained the three large diameter probes, the top tree was a support pipe to make the entire structure rigid.

Figure A2 (No. 96-1569-4, taken 11/96): This photograph shows the bottom 3 porous-tube bubblers before installation for the first time. The small tube connected at the side was one of the tubes which carried water to the concentric water tube channel. The tubes on top carried air to the center tube.

Figure A3 (No. 96-1569-6, taken 11/96): This photograph depicts the bottom large diameter tube before installation for the first time.

[Figures A4 to A10]

These figures are reductions of the developmental drawings used to construct the experimental apparatus that was installed in the full-scale SRAT/SME tank at TNX.

[Figure A11]

This figure shows the full-scale SRAT/SME tank at TNX (taken from Ref. 9).

WSRC Photograph No. 96-1569-1

Figure A1 (No. 96-1569-1, taken 11/96): Overall Test Apparatus

WSRC Photograph No. 96-1569-4

Figure A2 (No. 96-1569-4, taken 11/96): Porous-tube Bubbler Probes

WSRC Photograph No. 96-1569-6

Figure A3 (No. 96-1569-6, taken 11/96): Large-diameter Bubbler Probe

Figure A5: Development Drawing Number SRT-ETF-DD-96002, Rev. 0

Figure A6: Development Drawing Number SRT-ETF-DD-96003, Rev. 0

Figure A8: Development Drawing Number SRT-ETF-DD-96005, Rev. 0

Figure A9: Development Drawing Number SRT-ETF-DD-96006, Rev. 0

FigureA10: Development Drawing Number SRT-ETF-DD-96007, Rev. 0

APPENDIX B

Photographic Evidence

In pursuit to better understand the characteristics of the bubbler probes during operation more than 75 photographs were taken and are available through SRS Publications. The document numbers are listed below:

WSRC Photographs

<u>Date</u>	<u>WSRC Photograph Number</u>	<u>Comment</u>
11/96	96-1569-1 to -17	Probes before installation
12/05/96	96-1687-1 to -7	After 1st week of testing
12/12/96	96-1705-1 to -16	After 2nd week of testing
12/19/96	96-1717-1 to -10	After 3rd week of testing
01/07/97	97-1002-1 to -6	After 2 weeks hiatus
01/16/97	97-1022-1 to -7	After 6th week of testing(before blowdown)
01/16/97	97-1023-1 to -6	After 7th week of testing(after blowdown)
01/23/97	97-1039-1 to -7	After 8th week of testing(end of test)

To better describe the test apparatus and what was observed during the test some photographic highlights were chosen for inclusion in this report. The fourteen photographs included here are referred to in the body of the report but brief explanation are given below to facilitate understanding.

Test Apparatus

Figure B1 (No. 96-1705-14, taken 12/12/96): This photograph shows the entire probe apparatus after being subjected to two weeks of hot slurry operation. It was removed for one of the weekly inspections of the individual bubbler probes.

Sludge Build Up

- Large-diameter Bubbler Tube

[Figures B2, B3, B4, and B5]

Figure B2 (No. 96-1687-2, taken on 12/5/96): Starting from the new probe, this photograph shows the extent of the sludge accumulation that occurred during one week of operation in bubbler probe No. 12. Notice that

several air holes are present with the largest at the center. The build-up was located approximately 10 inches up into the tube. This particular probe was located 1.4 inches from the bottom of the tank that was filled with approximately 93 inches of slurry. For the probes located higher in the slurry the accumulated sludge was found to be located closer to the probe opening. For mid-height probe, located 25.4 inches from the bottom, the build-up was located approximately 6 inches within the tube and for the probe located 56.4 inches from the tank bottom the sludge build-up was only recessed in the probe by 3 inches.

Figure B3 (No. 96-1705-2, taken on 12/12/96): Comparing this figure with Fig. B2, this is a result from a second week of operation. Notice that the accumulation appears closer to the end of the tube, between 4 and 6 inches. This occurred because the entire probe assembly was maintained 42 inches higher in the slurry. Despite the considerable build-up the probe was still functioning well.

Figure B4 (No. 96-1022-2, taken on 1/16/97): This is the accumulation that occurred after one week of operation after it was blown down with air and water. On several of the days the slurry temperature was increased to create boiling. The probe was still operational.

Figure B5 (No. 96-1039-1, taken on 1/23/97): Only again, this is similar to Fig. B4. The figure shows the sludge build-up after one week of operation from being blown down with water. The texture seems a little drier than seen in Fig. B4 possibly because during the last week of operation the largest number of days at boiling temperatures occurred.

- Porous-tube Bubbler Tube

[Figures B6, B7, B8, and B9]

Figure B6 (No. 96-1687-3, taken on 12/5/96): Starting from the new probe, this photograph shows the extent of the sludge accumulation that occurred during one week of operation in bubbler probes Nos. 7, 8, and 9. They were all still functioning properly at the end of the week despite the appearance of sludge plugs. An air passage is visible in the center in two of the probes, the third was similar.

Figure B7 (No. 96-1705-5, taken on 12/12/96): After two weeks of operation these probes seemed to be totally plugged. However, while the level measurements being made by these probes was beginning to be

affected by the sludge they were still giving fairly accurate results one day before this photograph was taken.

Figure B8 (No. 97-1022-1, taken on 1/16/97): These probes became plugged after approximately 3 days of operation and after the slurry temperature was raised from 50°C to 101°C.

Figure B9 (No. 97-1039-2, taken on 1/23/97): These probes became plugged after being blown down with air and water and were subjected to boiling conditions for most of the preceding week.

Sludge Removal

- Large-diameter Bubbler Tube

[Figures B10 and B11]

Figure B10 (No. 97-1002-2, taken 1/7/97) [this photograph shows the probe after being cleaned with a blowdown of air at 90 psig for several minutes, and then cleaned with a blowdown of water at 90 psig for several minutes] and Figure B11 (No. 97-1023-2, taken on 1/16/97) [this photograph shows the probe after being cleaned with only a blowdown of air at 90 psig for five minutes]: After operating the bubbler probes for several weeks, and being held at different levels in the slurry, they were blown down with air and water to determine the effectiveness. Before being blown down the accumulation in this probe looked similar to Figs. B2 to B5. This probe appeared to be mostly clean of sludge after only an air blowdown but appeared to be almost sludge free after cleaning with air and then water.

- Porous-tube Bubbler Tube

[Figures B12 and B13]

Figure B12 (No. 97-1002-2, taken 1/7/97) [this photograph shows probes 7, 8, and 9 after probes 7 and 9 (the two lower tubes) were blown down with air at 90 psig (through their central channel) and water at 90 psig (through the porous tube)] and Figure B13 (No. 97-1023-1, taken 1/16/97) [this photograph shows probes 7, 8, and 9 after all the probes were blown down with air at 90 psig (through the central channel) and water at 90 psig (through the porous tube)]: After operating the bubbler probes for several weeks, and being held at different levels in the slurry, they were blown down with water to determine the effectiveness. Before being blown down

the accumulation in these probes looked similar to Fig. B6 to B9. For these smaller diameter tubes the success of cleaning was varied. On 1/7/97 a few of the probes were selected for cleaning. The two, of the three bottom tubes, that were selected for cleaning successfully dislodged the sludge, as shown in Fig. B12. A combination of air (through the central port) and water (through the porous jacket) was used. On 1/16/97 all of the probes were cleaned, but not all of the porous-tube probes cleaned successfully. Fig. B13 shows that two of the three bottom probes (8 and 9) still had significant sludge deposits after cleaning occurred. More frequent cleaning would be necessary if these smaller diameter probes are to be employed.

Typical Sludge Accumulation

Figure B14 (No. 96-1705-15, taken on 12/12/96): Close to the center of this photograph, sitting on one of the supporting member, part of a typical sludge accumulation. It fell out of the central large-diameter probe (No 11) as the probe assembly was being removed from the mixing tank for documentation, after two weeks of operation. Notice that it is several inches thick* and the side which faced the liquid is an oval with the lowest part of the oval close to where there was an exit hole which permitted the probe to continue to operate accurately. [*For scale, the plug was sitting on a bracing plate which was 4 inches wide, as described in the notes on Fig. A9.]

WSRC Photograph No. 96-1705-14

Figure B1: Test Apparatus During an Inspection on 12/12/96

WSRC Photograph No. 96-1687-2

Figure B2: Probe 12 After One Week of Operation, 12/5/96

WSRC Photograph No. 96-1705-2

Figure B3: Probe 12 After Two Weeks of Operation, 12/12/96

WSRC Photograph No. 97-1039-2

Figure B5: Probe 12 One Week of Operation From a Blowdown 1/23/97

WSRC Photograph No. 97-1022-2

Figure B4: Probe 12 One Week of Operation From a Blowdown 1/16/97

WSRC Photograph No. 97-1687-3

Figure B6: Probes 7,8,9 One Week of Operation From New Probes 12/5/96

WSRC Photograph No. 96-1705-5

Figure B7: Probes 7, 8, 9 Two Weeks of Operation From New Probes 12/12/96

WSRC Photograph No. 97-102

Figure B8: Probes 7,8, 9 One Week of Operation From a Blowdown 1/16/97
(Only Two Probes Were Blown Down)

WSRC Photograph No. 97-1039-2

Figure B9: Probes 7,8, 9 One Week of Operation From a Blowdown 1/23/97

WSRC Photograph No. 97-1002-2

Figure B10: Probe 12 After Blowdown Done on 1/7/97

WSRC Photograph No. 97-1023-2

Figure B11: Probe 12 After Blowdown Done on 1/16/97

WSRC Photograph No. 1002-1

Figure B12: Probes 7, 8, and 9 After Blowdown Done on 1/7/97
(Only Two Probes Were Blown Down)

WSRC Photograph No. 97-1023-1

Figure B13: Probes 7, 8, and 9 After Blowdown Done on 1/16/97

WSRC Photograph No. 97-1705-15

Figure B14: Typical Large-diameter Tube Plug, 12/12/96

APPENDIX C

Explanation of Experimental Measurement Data

While the data are discussed within the body of this report, there are several general features of the graphical presentation that are highlighted here for convenience.

1. Hourly data have been reduced to a datum point every four hours because the extra volume of data do not give any more information, but only serve to make the graphs harder to read.
2. Each time the probe tree was taken out of the tank for documentation a test period ended. Those periods are indicated at the top of each graph.
3. The test tank was "rodded" on 12/5/96 to obtain an absolute measurement of the slurry height. That information is depicted on the figures with a circle and error bars. The rod indicated 93 inches of slurry. That slurry height was then converted to the height (in inches of H₂O) that corresponded to a specific probe location so a comparison could be made to the reading given by each probe. For example, for bubbler probe #1, located 56.4 inches from the bottom of the tank, the reading should be:

$$(93" \text{ Slurry} - 56.4 \text{ inches}) * 1.3 \text{ inches H}_2\text{O/inches Slurry} - 7 \text{ inches H}_2\text{O} = 41 \text{ inches H}_2\text{O}$$

Note: The 1.3 is the approximate SpG of the slurry, the 7 inches H₂O is the approximate vacuum over the slurry pool, and the uncertainty bars shown in the figures are determined from the uncertainty in the SpG (± 0.05) and in the applied vacuum (± 2 inches H₂O).

4. Near the end of the testing periods, on 1/21/97, 500 gallons of water were added the tank to make up for the evaporative losses that occurred. The water addition amounts to approximately a 7-inch increase in slurry height which translates to slightly over a 9-inch increase in water pressure. This fact is indicated by a vertical line near the bottom of the graphs at the appropriate time.
5. On about 14 days, of the 2-month test, boiling temperatures were obtained. The specific boiling temperature times are indicated by horizontal lines near the bottom of the graphs. For days which show no indication, the slurry was maintained at 50°C.

6. All twelve probes had air flow measurements. Those measurements are located to the right of each graph along with the appropriate measurement uncertainty.

7. The nine porous tube probes also had water flow measurements. Those measurements are located to the right of each graph, below the air flow measurements, along with the appropriate measurement uncertainty.

8. For all the probes which were maintained out of the slurry between periods 2 and 4, i.e., probes 1, 2, 3, and 10 [Figs. C1, C2, C3, and C10], their data between the next periods, 4 and 5, cannot be used on an absolute basis, because the pressure gauges were not rezeroed. However, the data between periods 4 and 5 are useful in a relative sense because indication of pluggage would still be present if it had occurred. At the beginning of period 5 the gauges were reset and the data show that the probes were reading accurately once again.

Figure C1: Experimental Data - Bubbler Probe #1 (56.4" from tank bottom)
[see pages 42 and 43 for an explanation of graph and data]

Figure C2: Experimental Data - Bubbler Probe #2 (56.4" from tank bottom)
[see pages 42 and 43 for an explanation of graph and data]

Figure C3: Experimental Data - Bubbler Probe #3 (56.4" from tank bottom)
[see pages 42 and 43 for an explanation of graph and data]

Figure C4: Experimental Data - Bubbler Probe #4 (25.4" from tank bottom)
[see pages 42 and 43 for an explanation of graph and data]

Figure C5: Experimental Data - Bubbler Probe #5 (25.4" from tank bottom)
[see pages 42 and 43 for an explanation of graph and data]

Figure C6: Experimental Data - Bubbler Probe #6 (25.4" from tank bottom)
[see pages 42 and 43 for an explanation of graph and data]

Figure C7: Experimental Data - Bubbler Probe #7 (1.4" from tank bottom)
[see pages 42 and 43 for an explanation of graph and data]

Figure C8: Experimental Data - Bubbler Probe #8 (1.4" from tank bottom)
[see pages 42 and 43 for an explanation of graph and data]

Figure C9: Experimental Data - Bubbler Probe #9 (1.4" from tank bottom)
[see pages 42 and 43 for an explanation of graph and data]

Figure C10: Experimental Data - Bubbler Probe #10 (56.4" from tank
bottom)

[see pages 42 and 43 for an explanation of graph and data]

Figure C11: Experimental Data - Bubbler Probe #11 (25.4" from tank
bottom)

[see pages 42 and 43 for an explanation of graph and data]

Figure C12: Experimental Data - Bubbler Probe #12 (1.4" from tank
bottom)

[see pages 42 and 43 for an explanation of graph and data]

Figure C13: Experimental Data - Bubbler Probes #10, #11, and #12
[see pages 42 and 43 for an explanation of graph and data]

APPENDIX D

Instrument Uncertainty Analysis

High accuracy for the instruments used in this test was not needed since the main purpose of this test was to determine if a type of an advanced bubbler probe would plug or not under prototypic mixing tank conditions. A total pluggage would prevent air flow to continue in a probe and the air pressure to build up to line pressure; basically a go no-go situation. Even the exact water flow rate was not crucial, it only had to be in increments of the value used in the benchtop test, 2.2 cm³/min, for an 8-inch tall porous tube (2); A 10% uncertainty would suffice for the test. As such, instruments were chosen either for their prototypicality (same air flow meters used in the plant) or for being inexpensive (air pressure and water flow rate).

Each of the twelve bubbler tubes had a pressure gauge and an air flow meter. Each of the nine porous bubbler tubes had a water flow meter. All of the instruments were mounted on a single panel, Fig. D1 [WSRC Photograph No. 96-1569-16], and the make and range are given below:

<u>Measurement</u>	<u>Quantity</u>	<u>I.D. Numbers</u>	<u>Instrument Make</u>	<u>Range</u>
Water Flow	9	WF-1 to - 9	Gilmont	0-5 ml/min
Air Flow	12	AF-1 to -12	Wallace & Tieman	0-2.5 scfh
Air Pressure	12	AP-1 to -12	Noshok	0-200 inches H2O

The individual instrument measurement uncertainty can be found on the appropriate analysis sheet in this Appendix.

Highlights of the Uncertainty Analyses:

Water Flow Meters [Figure D2]- There is only a single calibration sheet which contains all the uncertainty analyses for the 9 meters. A rough pre-test and post-test check was done to determine the level of accuracy. All nine probes were calibrated together. This was done to save time and because high accuracy was not required. A tolerance of 10% was thought to be acceptable. As shown in the calibration sheet the meters performed as expected. One note of caution: the meter readings were confounded from time-to-time by the presence of air bubbles. Either trapped air or air coming out of solution would raise the float and affect the reading. However, the actual flow rate would not be affected. In this case, a reading could only be made after the bubble left the meter, returning the

ball to its original setting. This was done during calibration, but there may be field data affected by air movement in a meter.

Air Flow Meters [Figures D3-D14] - These instrument are not built for accuracy but for their robustness; they can withstand considerable overpressurization and high temperatures. However, two of the instruments (AF-1 and AF-7) had unusually high uncertainties $\approx 35\%$. These large variances were believed to the result of manufacture defects. Excluding these two devices the average uncertainty was approximately 0.5 scfh or 14% of the pressurized (20 psig) maximum flow rate of 4 scfh. This uncertainty is still high, but is acceptable for in-plant use, because the meter is more to indicate that a flow exists, as opposed measuring the actual flow rate. Setting the flow rate anywhere between 0.5 and 1.5 scfh is common practice.

Air Pressure Gauges [Figures D15-D26] - During the pre-test calibration these inexpensive gauges were found to be exceptionally accurate (2 in. H₂O) and repetitive. However, during the testing they were overpressurized which not only changed their calibration, but also affected their precision. The post-test calibration indicates a precision uncertainly of 15 inches H₂O. The overpressurization had the strongest impact on the accuracies. At the highest meter reading (200 in. H₂O) the instrument readings deviated from the true pressure by as little as 6 in. H₂O (AP-12) to as much as 70 in. H₂O (AP-2). The instruments which have uncertainties close to the latter value can only be used to determine a plugging situation and not for making liquid-level measurements. Fortunately, for two of the three large-diameter probes (AP-11 and AP-12) the pressure gauges still showed sufficient accuracy to make statements about liquid level measurement.

WSRC Photograph No. 1569-16

Figure D1 (No. 96-1569-16, taken 11/96): Instrument Panel

Gilmont Water Rotameters, WF1 to WF9

Pre-test Calibration: 10-14-96

Post-test Calibration: 03-11-97

Evaluation Date: 03-24-97

Standard used to measure flow rate was a calibrated flask and a
stop watch with a combined uncertainty of less than $\pm 2\%$ of Rdg.

Avg. Amb. Temp. was between 20 and 25 °C

Pre-test Calibration Results						
Time Minutes	Volume ml	Flowrate ml/min	Flowrate/Meter ml/min	Meter Setting ml/min	Difference ml/min	Difference %
Odd-numbered Flow Meters: WF-1, 3, 5, 7, 9*						
2.009	48.0	23.9	4.78	5.0	0.22	4.4%
2.006	47.5	23.7	4.74	5.0	0.26	5.3%
2.009	47.5	23.6	4.73	5.0	0.27	5.4%
Even-numbered Flow Meters: WF-2, 4, 6, 8*						
2.005	37.5	18.7	4.68	5.0	0.32	6.5%
2.009	37.5	18.7	4.67	5.0	0.33	6.7%
2.009	37.5	18.7	4.67	5.0	0.33	6.7%
All Flowmeters: WF-1, 2, 3, 4, 5, 6, 7, 8, 9*						
1.005	43.0	42.8	4.75	5.0	0.25	4.9%
1.007	43.0	42.7	4.75	5.0	0.25	5.1%
1.006	43.0	42.8	4.75	5.0	0.25	5.0%

Pre-test Overall Percent Deviation From Maximum Meter Setting 5.6%

Post-test Calibration Results						
Time Minutes	Volume ml	Flowrate ml/min	Flowrate/Meter ml/min	Meter Setting ml/min	Difference ml/min	Difference %
Odd-numbered Flow Meters: WF-1, 3, 5, 7, 9*						
2.006	47.0	23.4	4.69	5.0	0.31	6.3%
2.007	48.0	23.9	4.78	5.0	0.22	4.3%
2.005	48.0	23.9	4.79	5.0	0.21	4.3%
Even-numbered Flow Meters: WF-2, 4, 6, 8*						
2.012	38.0	18.9	4.72	5.0	0.28	5.5%
2.009	37.0	18.4	4.60	5.0	0.40	7.9%
2.010	37.0	18.4	4.60	5.0	0.40	8.0%
All Flowmeters: WF-1, 2, 3, 4, 5, 6, 7, 8, 9*						
1.013	43.0	42.5	4.72	5.0	0.28	5.6%
1.005	42.0	41.8	4.65	5.0	0.35	7.1%
1.006	43.0	42.7	4.75	5.0	0.25	5.0%

Post-test Overall Percent Deviation From Maximum Meter Setting 6.0%

With the Standard Uncertainty, the Overall Uncertainty based on the Post-Calibration is: 6.3% FS

The Overall Standard Deviation of the Uncertainty is: 1.2%

(*These meters were measured together to obtain a higher accuracy in the standard source - more volume per time - because of the small quantities of liquid. However, the listed meter uncertainty is an average therefore an actual meter uncertainty may be higher or lower. The overall standard deviation indicates the level of variance from the mean.)

Figure D2: Uncertainty Analysis, Water-flow Meters WF1-WF9

Wallace & Tiernan Air Flow Meter, AF1				Pre-test Calibration: 10-01-96			
Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180				Post-test Calibration: 03-10-97			
Measurement Uncertainty: $\pm 0.75\%$ of Reading				Evaluation Date: 03-13-97			
Conversion: 29,038.4 counts/liter = 822,276.02 counts/lit							
Pre-test Calibration Results				Post-test Calibration Results			
Califlow		W&T		Califlow		W&T	
counts	time, sec	scfh	scfh	counts	time, sec	scfh	scfh
8969	60.3342	0.65	0.70	9278	60.3420	0.67	0.70
12668	18.6919	2.97	1.50	12777	18.3650	3.05	1.50
12899	15.4505	3.66	2.50	12732	14.5945	3.82	2.50
12656	15.2839	3.63	2.50	12652	14.4874	3.82	2.50
12685	18.4068	3.02	1.50	12595	18.6561	2.96	1.50
9157	60.3321	0.66	0.70	8997	60.6160	0.65	0.70
Average Ambient Temperature = 21°C				Average Ambient Temperature = 23°C			
Average Ambient Pressure = 762 mmHg				Average Ambient Pressure = 757 mmHg			

Pre+Post	Pre+Post		
Califlow, scfh	WT, scfh	Best Fit	(Best Fit)-(WT)
0.65	0.70	0.61	-0.09
2.97	1.50	1.83	0.33
3.66	2.50	2.19	-0.31
3.63	2.50	2.18	-0.32
3.02	1.50	1.86	0.36
0.66	0.70	0.62	-0.08
0.67	0.70	0.63	-0.07
3.05	1.50	1.87	0.37
3.82	2.50	2.28	-0.22
3.82	2.50	2.28	-0.22
2.96	1.50	1.83	0.33
0.65	0.70	0.61	-0.09
rms deviation 0.26 scfh			

fit: Actual,scfh = $b_0 + b_1 \times (\text{W\&T,scfh})$
for DAS

b0	-0.150399...
b1	1.6683401...
corr.coef.	0.9359010...

fit: W&T, scfh = $a_0 + a_1 \times (\text{Actual, scfh})$
for statistics

a0	0.2733692...
a1	0.5250192...
corr.coef.	0.9359010...

STATISTICAL DATA

a	0.2733692...
b	0.5250192...
SEE	0.8074075...
MSE	0.0807407...
Sxx	20.676066...
sum(Xi^2)	93.4922
avg(X)	2.4633333...
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	8.402
W&T: Uncert.,Wy low	0.706 scfh
W&T: Uncert.,Wy high	0.685 scfh
Curve Fit: Uncert.,We	1.306 scfh
Cal. Equip. Uncert.,Wc	0.019 scfh
Total Uncertainty, Wt	1.31 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal. Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 1.4 scfh

Figure D3: Uncertainty Analysis, Air-flow Meters AF1

Wallace & Tiernan Air Flow Meter, AF2

Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180

Measurement Uncertainty: $\pm 0.75\%$ of Reading

Conversion: 29,038.4 counts/liter = 822,276.02 counts/ft³

Pre-test Calibration Results

Califlow			W&T
counts	time, sec	scfh	scfh
10289	60.4115	0.75	0.50
10831	20.4927	2.31	1.50
11757	12.4943	4.12	2.50
11338	12.3009	4.04	2.50
11242	20.4282	2.41	1.50
9949	60.6341	0.72	0.50

Average Ambient Temperature = 21°C

Average Ambient Pressure = 762 mmHg

Pre-test Calibration: 10-01-96

Post-test Calibration: 03-10-97

Evaluation Date: 03-13-97

Post-test Calibration Results

Califlow			W&T
counts	time, sec	scfh	scfh
11908	60.2427	0.87	0.50
12480	20.7783	2.63	1.50
12353	12.1148	4.46	2.50
12565	12.3033	4.47	2.50
12015	20.1790	2.61	1.50
12001	60.4459	0.87	0.50

Average Ambient Temperature = 23°C

Average Ambient Pressure = 756 mmHg

Pre+Post Califlow, scfh	Pre+Post WT, scfh	Best Fit	(Best Fit)-(WT)
0.75	0.50	0.49	-0.01
2.31	1.50	1.38	-0.12
4.12	2.50	2.41	-0.09
4.04	2.50	2.37	-0.13
2.41	1.50	1.44	-0.06
0.72	0.50	0.47	-0.03
0.87	0.50	0.56	0.06
2.63	1.50	1.56	0.06
4.46	2.50	2.61	0.11
4.47	2.50	2.61	0.11
2.61	1.50	1.55	0.05
0.87	0.50	0.56	0.06
		rms deviation	0.08 scfh

fit: Actual, scfh = $b_0 + b_1 \times (W\&T, \text{scfh})$

for DAS

b0	-0.080833...
b1	1.735
corr.coef.	0.9948705...

fit: W&T, scfh = $a_0 + a_1 \times (\text{Actual, scfh})$

for statistics

a0	0.0614619...
a1	0.5704711...
corr.coef.	0.9948705...

STATISTICAL DATA

a	0.0614619...
b	0.5704711...
SEE	0.0818606...
MSE	0.0081860...
Sxx	24.330766...
sum(Xi^2)	100.6364
avg(X)	2.5216666...
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	31.101
W&T: Uncert., Wy low	0.222 scfh
W&T: Uncert., Wy high	0.224 scfh
Curve Fit: Uncert., We	0.393 scfh
Cal. Equip. Uncert., Wc	0.019 scfh
Total Uncertainty, Wt	0.39 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal. Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.4 scfh

Figure D4: Uncertainty Analysis, Air-flow Meters AF2

Wallace & Tiernan Air Flow Meter, AF3
Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180
Measurement Uncertainty: $\pm 0.75\%$ of Reading
Conversion: 29,038.4 counts/liter = 822,276.02 counts/ft³

Pre-test Calibration: 10-01-96
Post-test Calibration: 03-10-97
Evaluation Date: 03-13-97

Pre-test Calibration Results

Califlow			W&T
counts	time, sec	scfh	scfh
12985	38.3316	1.48	0.50
12702	19.1057	2.91	1.50
12529	13.2216	4.15	2.50
12768	13.4554	4.15	2.50
13022	18.7595	3.04	1.50
13120	37.1204	1.55	0.50

Average Ambient Temperature = 21°C
Average Ambient Pressure = 762 mmHg

Post-test Calibration Results

Califlow			W&T
counts	time, sec	scfh	scfh
13020	38.9077	1.47	0.50
12828	18.2766	3.07	1.50
12798	12.9731	4.32	2.50
12587	12.3416	4.47	2.50
12782	18.3580	3.05	1.50
12953	38.3547	1.48	0.50

Average Ambient Temperature = 23°C
Average Ambient Pressure = 756 mmHg

Pre+Post	Pre+Post	Best Fit		(Best Fit)-(WT)
Califlow, scfh	WT, scfh			
1.48	0.50	0.47		-0.03
2.91	1.50	1.49		-0.01
4.15	2.50	2.37		-0.13
4.15	2.50	2.37		-0.13
3.04	1.50	1.58		0.08
1.55	0.50	0.52		0.02
1.47	0.50	0.46		-0.04
3.07	1.50	1.60		0.10
4.32	2.50	2.49		-0.01
4.47	2.50	2.60		0.10
3.05	1.50	1.59		0.09
1.48	0.50	0.47		-0.03
		rms deviation	0.08 scfh	

fit: Actual,scfh = b0 + b1x(W&T,scfh)

for DAS

b0	0.8452083...
b1	1.38875
corr.coef.	0.9955271...

fit: W&T, scfh = a0 + a1x(Actual, scfh)

for statistics

a0	-0.589790...
a1	0.7136448...
corr.coef.	0.9955271...

STATISTICAL DATA

a	-0.589790...
b	0.7136448...
SEE	0.0714051...
MSE	0.0071405...
Sxx	15.567966...
sum(Xi^2)	118.4696
avg(X)	2.9283333...
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	33.322
W&T: Uncert.,Wy_low	0.208 scfh
W&T: Uncert.,Wy_high	0.209 scfh
Curve Fit: Uncert.,We	0.293 scfh
Cal. Equip. Uncert.,Wc	0.019 scfh
Total Uncertainty, Wt	0.29 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal. Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.3 scfh

Figure D5: Uncertainty Analysis, Air-flow Meters AF3

Wallace & Tiernan Air Flow Meter, AF4

Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180

Measurement Uncertainty: $\pm 0.75\%$ of Reading

Conversion: 29,038.4 counts/liter = 822,276.02 counts/ft³

Pre-test Calibration Results

Califlow		W&T	
counts	time, sec	scfh	scfh
12934	50.5512	1.12	0.50
12669	20.3354	2.73	1.50
12498	12.3633	4.43	2.50
12364	12.2472	4.42	2.50
13216	20.1563	2.87	1.50
13322	50.0851	1.16	0.50

Average Ambient Temperature = 21°C

Average Ambient Pressure = 762 mmHg

Pre-test Calibration: 10-01-96

Post-test Calibration: 03-10-97

Evaluation Date: 03-13-97

Post-test Calibration Results

Califlow		W&T	
counts	time, sec	scfh	scfh
12699	50.5493	1.10	0.50
12911	19.3548	2.92	1.50
12629	12.3286	4.48	2.50
12539	12.2266	4.49	2.50
12517	19.3039	2.84	1.50
12323	50.4281	1.07	0.50

Average Ambient Temperature = 23°C

Average Ambient Pressure = 756 mmHg

Pre+Post Califlow, scfh	Pre+Post WT, scfh	Best Fit	(Best Fit)-(WT)
1.12	0.50	0.49	-0.01
2.73	1.50	1.46	-0.04
4.43	2.50	2.47	-0.03
4.42	2.50	2.47	-0.03
2.87	1.50	1.54	0.04
1.16	0.50	0.52	0.02
1.10	0.50	0.48	-0.02
2.92	1.50	1.57	0.07
4.48	2.50	2.50	0.00
4.49	2.50	2.51	0.01
2.84	1.50	1.52	0.02
1.07	0.50	0.47	-0.03
		rms deviation	0.03 scfh

fit: Actual, scfh = $b_0 + b_1 \times (\text{W\&T, scfh})$

for DAS

b0	0.2956249...
b1	1.67125
corr.coef.	0.9991995...

fit: W&T, scfh = $a_0 + a_1 \times (\text{Actual, scfh})$

for statistics

a0	-0.174205...
a1	0.5973970...
corr.coef.	0.9991995...

STATISTICAL DATA

a	-0.174205...
b	0.5973970...
SEE	0.0128013...
MSE	0.0012801...
Sxx	22.380425
sum(Xi^2)	116.6285
avg(X)	2.8025
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	78.989
W&T: Uncert., Wy low	0.088 scfh
W&T: Uncert., Wy high	0.088 scfh
Curve Fit: Uncert., We	0.147 scfh
Cal. Equip. Uncert., Wc	0.019 scfh
Total Uncertainty, Wt	0.15 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal. Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.2 scfh

Figure D6: Uncertainty Analysis, Air-flow Meters AF4

Wallace & Tiernan Air Flow Meter, AF5				Pre-test Calibration: 10-01-96			
Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180				Post-test Calibration: 03-10-97			
Measurement Uncertainty: $\pm 0.75\%$ of Reading				Evaluation Date: 03-13-97			
Conversion: 29,038.4 counts/liter = 822,276.02 counts/ft ³							
Pre-test Calibration Results				Post-test Calibration Results			
Califlow		W&T		Califlow		W&T	
counts	time, sec	scfh	scfh	counts	time, sec	scfh	scfh
11589	50.5030	1.00	0.50	13080	50.3641	1.14	0.50
12599	20.4315	2.70	1.50	12929	19.1157	2.96	1.50
12665	13.3201	4.16	2.50	12536	12.2101	4.49	2.50
12832	13.2143	4.25	2.50	12707	12.3657	4.50	2.50
12938	19.4799	2.91	1.50	12789	19.3551	2.89	1.50
11652	50.3214	1.01	0.50	12804	50.2879	1.11	0.50
Average Ambient Temperature = 22°C				Average Ambient Temperature = 23°C			
Average Ambient Pressure = 762 mmHg				Average Ambient Pressure = 756 mmHg			

Pre+Post	Pre+Post	Best Fit		(Best Fit)-(WT)
Califlow, scfh	WT, scfh			
1.00	0.50	0.44		-0.06
2.70	1.50	1.46		-0.04
4.16	2.50	2.34		-0.16
4.25	2.50	2.40		-0.10
2.91	1.50	1.59		0.09
1.01	0.50	0.44		-0.06
1.14	0.50	0.52		0.02
2.96	1.50	1.62		0.12
4.49	2.50	2.54		0.04
4.50	2.50	2.55		0.05
2.89	1.50	1.58		0.08
1.11	0.50	0.51		0.01
		rms deviation		0.08 scfh

fit: Actual,scfh = b0 + b1x(W&T,scfh)

for DAS

b0	0.2962500...
b1	1.6425
corr.coef.	0.9952123...

fit: W&T, scfh = a0 + a1x(Actual, scfh)

for statistics

a0	-0.164313...
a1	0.6030123...
corr.coef.	0.9952123...

STATISTICAL DATA

a	-0.164313...
b	0.6030123...
SEE	0.0764182...
MSE	0.0076418...
Sxx	21.7906
sum(Xi^2)	113.2018
avg(X)	2.76
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	32.200
W&T: Uncert.,Wy low	0.216 scfh
W&T: Uncert.,Wy high	0.215 scfh
Curve Fit: Uncert.,We	0.357 scfh
Cal. Equip. Uncert.,Wc	0.019 scfh
Total Uncertainty, Wt	0.36 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal. Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.4 scfh

Figure D7: Uncertainty Analysis, Air-flow Meters AF5

Wallace & Tiernan Air Flow Meter, AF6

Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180

Measurement Uncertainty: $\pm 0.75\%$ of Reading

Conversion: 29,038.4 counts/liter = 822,276.02 counts/ft³

Pre-test Calibration Results

Califlow			W&T
counts	time, sec	scfh	scfh
13094	38.1865	1.50	0.50
12761	17.8885	3.12	1.50
12620	12.7900	4.32	2.50
12129	12.6716	4.19	2.50
12876	16.8446	3.35	1.50
13188	37.7557	1.53	0.50

Average Ambient Temperature = 22°C

Average Ambient Pressure = 762 mmHg

Pre-test Calibration: 10-01-96

Post-test Calibration: 03-11-97

Evaluation Date: 03-13-97

Post-test Calibration Results

Califlow			W&T
counts	time, sec	scfh	scfh
13056	37.0390	1.54	0.50
12678	15.6969	3.54	1.50
12837	12.1017	4.64	2.50
12950	12.0015	4.72	2.50
12339	15.3837	3.51	1.50
13121	37.1163	1.55	0.50

Average Ambient Temperature = 23°C

Average Ambient Pressure = 756 mmHg

Pre+Post	Pre+Post			
Califlow, scfh	WT, scfh	Best Fit	(Best Fit)-(WT)	
1.50	0.50	0.44	-0.06	
3.12	1.50	1.50	-0.00	
4.32	2.50	2.28	-0.22	
4.19	2.50	2.20	-0.30	
3.35	1.50	1.65	0.15	
1.53	0.50	0.46	-0.04	
1.54	0.50	0.46	-0.04	
3.54	1.50	1.77	0.27	
4.64	2.50	2.49	-0.01	
4.72	2.50	2.54	0.04	
3.51	1.50	1.75	0.25	
1.55	0.50	0.47	-0.03	
		rms deviation	0.16 scfh	

fit: Actual, scfh = $b_0 + b_1 \times (\text{W\&T, scfh})$

for DAS

b0	0.9227083...
b1	1.46875
corr.coef.	0.9805269...

fit: W&T, scfh = $a_0 + a_1 \times (\text{Actual, scfh})$

for statistics

a0	-0.546147...
a1	0.6545927...
corr.coef.	0.9805269...

STATISTICAL DATA

a	-0.546147...
b	0.6545927...
SEE	0.3085351...
MSE	0.0308535...
Sxx	17.950091...
sum(Xi^2)	135.2001
avg(X)	3.1258333...
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	15.789
W&T: Uncert., Wy low	0.434 scfh
W&T: Uncert., Wy high	0.433 scfh
Curve Fit: Uncert., We	0.662 scfh
Cal. Equip. Uncert., Wc	0.019 scfh
Total Uncertainty, Wt	0.66 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal Data ◇ Post-test Cal Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.7 scfh

Figure D8: Uncertainty Analysis, Air-flow Meters AF6

Wallace & Tiernan Air Flow Meter, AF7

Pre-test Calibration: 10-01-96

Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180

Post-test Calibration: 03-10-97

Measurement Uncertainty: $\pm 0.75\%$ of Reading

Evaluation Date: 03-13-97

Conversion: 29,038.4 counts/liter = 822,276.02 counts/ft³

Pre-test Calibration Results

Califlow			W&T
counts	time, sec.	scfh	scfh
7603	60.5089	0.55	0.70
12832	20.5082	2.74	1.50
12625	14.7488	3.75	2.50
12378	14.6323	3.70	2.50
13085	19.2774	2.97	1.50
8235	60.3617	0.60	0.70

Average Ambient Temperature = 22°C

Average Ambient Pressure = 762 mmHg

Post-test Calibration Results

Califlow			W&T
counts	time, sec.	scfh	scfh
9394	60.3569	0.68	0.70
12866	18.4241	3.06	1.50
12713	14.3878	3.87	2.50
12729	14.4005	3.87	2.50
12860	18.4143	3.06	1.50
9385	60.3093	0.68	0.70

Average Ambient Temperature = 23°C

Average Ambient Pressure = 755 mmHg

Pre+Post	Pre+Post		
Califlow, scfh	WT, scfh	Best Fit	(Best Fit)-(WT)
0.55	0.70	0.58	-0.12
2.74	1.50	1.71	0.21
3.75	2.50	2.23	-0.27
3.70	2.50	2.21	-0.29
2.97	1.50	1.83	0.33
0.60	0.70	0.60	-0.10
0.68	0.70	0.65	-0.05
3.06	1.50	1.88	0.38
3.87	2.50	2.30	-0.20
3.87	2.50	2.30	-0.20
3.06	1.50	1.88	0.38
0.68	0.70	0.65	-0.05
		rms deviation	0.24 scfh

fit: Actual, scfh = $b_0 + b_1 \times (\text{W\&T, scfh})$
for DAS

b0	-0.239098...
b1	1.7233606...
corr.coef.	0.9440975...

fit: W&T, scfh = $a_0 + a_1 \times (\text{Actual, scfh})$
for statistics

a0	0.2939263...
a1	0.5171989...
corr.coef.	0.9440975...

STATISTICAL DATA

a	0.2939263...
b	0.5171989...
SEE	0.7071429...
MSE	0.0707142...
Sxx	21.680891...
sum(Xi^2)	94.3493
avg(X)	2.4608333...
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	9.056
W&T: Uncert., Wy low	0.663 scfh
W&T: Uncert., Wy high	0.642 scfh
Curve Fit: Uncert., We	1.242 scfh
Cal. Equip. Uncert., Wc	0.019 scfh
Total Uncertainty, Wt	1.24 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal. Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 1.3 scfh

Figure D9: Uncertainty Analysis, Air-flow Meters AF7

Wallace & Tiernan Air Flow Meter, AF8				Pre-test Calibration: 10-01-96			
Secondary Standard Used For Calibration Was: MKS "Calflow" TR-2180				Post-test Calibration: 03-11-97			
Measurement Uncertainty: $\pm 0.75\%$ of Reading				Evaluation Date: 03-13-97			
Conversion: 29,038.4 counts/liter $\square$ 822,276.02 counts/ft ³							
Pre-test Calibration Results				Post-test Calibration Results			
Calflow		W&T		Calflow		W&T	
counts	time, sec.	scfh	scfh	counts	time, sec.	scfh	scfh
12579	45.4081	1.21	0.50	12414	45.4327	1.20	0.50
12799	18.4794	3.03	1.50	12656	16.7916	3.30	1.50
12560	12.3208	4.46	2.50	12488	11.5838	4.72	2.50
12753	12.2243	4.57	2.50	12181	11.3050	4.72	2.50
13006	18.3741	3.10	1.50	12255	16.4569	3.26	1.50
13247	45.2702	1.28	0.50	12504	45.2438	1.21	0.50
Average Ambient Temperature = 22°C				Average Ambient Temperature = 22°C			
Average Ambient Pressure = 762 mmHg				Average Ambient Pressure = 755 mmHg			

Pre+Post	Pre+Post		
Calflow, scfh	WT, scfh	Best Fit	(Best Fit)-(WT)
1.21	0.50	0.45	-0.05
3.03	1.50	1.51	0.01
4.46	2.50	2.35	-0.15
4.57	2.50	2.41	-0.09
3.10	1.50	1.56	0.06
1.28	0.50	0.49	-0.01
1.20	0.50	0.45	-0.05
3.30	1.50	1.67	0.17
4.72	2.50	2.50	-0.00
4.72	2.50	2.50	-0.00
3.26	1.50	1.65	0.15
1.21	0.50	0.45	-0.05
		rms deviation 0.09 scfh	

fit: Actual,scfh = b0 + b1x(W&T,scfh)
for DAS

b0	0.4606249...
b1	1.69625
corr.coef.	0.9941864...

fit: W&T, scfh = a0 + a1x(Actual, scfh)
for statistics

a0	-0.251016...
a1	0.5827010...
corr.coef.	0.9941864...

STATISTICAL DATA

a	-0.251016...
b	0.5827010...
SEE	0.0927469...
MSE	0.0092746...
Sxx	23.2881
sum(Xi^2)	131.6484
avg(X)	3.005
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	29.199
W&T: Uncert.,Wy low	0.237 scfh
W&T: Uncert.,Wy high	0.236 scfh
Curve Fit: Uncert.,We	0.405 scfh
Cal. Equip. Uncert.,Wc	0.019 scfh
Total Uncertainty, Wt	0.41 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.5 scfh

Figure D10: Uncertainty Analysis, Air-flow Meters AF8

Wallace & Tiernan Air Flow Meter, AF9				Pre-test Calibration: 10-01-96			
Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180				Post-test Calibration: 03-11-97			
Measurement Uncertainty: $\pm 0.75\%$ of Reading				Evaluation Date: 03-13-97			
Conversion: 29,038.4 counts/liter = 822,276.02 counts/ft ³							
Pre-test Calibration Results				Post-test Calibration Results			
Califlow			W&T	Califlow			W&T
counts	time, sec	scfh	scfh	counts	time, sec	scfh	scfh
12009	45.3466	1.16	0.50	12086	45.6488	1.16	0.50
12876	18.3769	3.07	1.50	12937	16.7904	3.37	1.50
12596	11.9688	4.61	2.50	12397	10.3187	5.26	2.50
12691	12.7125	4.37	2.50	12275	10.2316	5.25	2.50
12745	18.3192	3.05	1.50	12482	16.3781	3.34	1.50
12002	45.2355	1.16	0.50	11819	45.5378	1.14	0.50
Average Ambient Temperature = 22°C				Average Ambient Temperature = 22°C			
Average Ambient Pressure = 761 mmHg				Average Ambient Pressure = 755 mmHg			

Pre+Post	Pre+Post		
Califlow, scfh	WT, scfh	Best Fit	(Best Fit)-(WT)
1.16	0.50	0.50	-0.00
3.07	1.50	1.50	-0.00
4.61	2.50	2.30	-0.20
4.37	2.50	2.18	-0.32
3.05	1.50	1.49	-0.01
1.16	0.50	0.50	-0.00
1.16	0.50	0.50	-0.00
3.37	1.50	1.65	0.15
5.26	2.50	2.64	0.14
5.25	2.50	2.64	0.14
3.34	1.50	1.64	0.14
1.14	0.50	0.49	-0.01
		rms deviation	0.14 scfh

fit: Actual,scfh = $b_0 + b_1 \times (\text{W\&T,scfh})$
for DAS

b0	0.2902083...
b1	1.85875
corr.coef.	0.9857974...

fit: W&T, scfh = $a_0 + a_1 \times (\text{Actual, scfh})$
for statistics

a0	-0.109422...
a1	0.5228226...
corr.coef.	0.9857974...

STATISTICAL DATA

a	-0.109422...
b	0.5228226...
SEE	0.2256271...
MSE	0.0225627...
Sxx	28.441766...
sum(XI^2)	142.1554
avg(X)	3.0783333...
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	18.563
W&T: Uncert.,Wy low	0.369 scfh
W&T: Uncert.,Wy high	0.374 scfh
Curve Fit: Uncert.,We	0.716 scfh
Cal. Equip. Uncert.,Wc	0.019 scfh
Total Uncertainty, Wt	0.72 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal. Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.8 scfh

Figure D11: Uncertainty Analysis, Air-flow Meters AF9

Wallace & Tiernan Air Flow Meter, AF10
Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180
Measurement Uncertainty: $\pm 0.75\%$ of Reading
Conversion: 29,038.4 counts/liter = 822,276.02 counts/ft³

Pre-test Calibration: 10-01-96
Post-test Calibration: 03-11-97
Evaluation Date: 03-13-97

Pre-test Calibration Results

Califlow		W&T	
counts	time_sec	scfh	scfh
12452	50.3993	1.08	0.50
12655	20.6028	2.69	1.50
12876	13.5903	4.15	2.50
12985	13.4824	4.22	2.50
12232	20.0512	2.67	1.50
12981	50.3941	1.13	0.50

Average Ambient Temperature = 21°C
Average Ambient Pressure = 761 mmHg

Post-test Calibration Results

Califlow		W&T	
counts	time, sec	scfh	scfh
12618	50.2877	1.10	0.50
12872	19.2116	2.93	1.50
12663	11.9051	4.66	2.50
12285	11.5433	4.66	2.50
12951	19.2090	2.95	1.50
12505	50.1777	1.09	0.50

Average Ambient Temperature = 22°C
Average Ambient Pressure = 755 mmHg

Pre+Post	Pre+Post	Best Fit	(Best Fit)-(WT)
Califlow, scfh	WT, scfh		
1.08	0.50	0.49	-0.01
2.69	1.50	1.45	-0.05
4.15	2.50	2.31	-0.19
4.22	2.50	2.36	-0.14
2.67	1.50	1.44	-0.06
1.13	0.50	0.52	0.02
1.10	0.50	0.50	0.00
2.93	1.50	1.59	0.09
4.66	2.50	2.62	0.12
4.66	2.50	2.62	0.12
2.95	1.50	1.60	0.10
1.09	0.50	0.50	-0.00
rms deviation 0.10 scfh			

fit: Actual,scfh = $b_0 + b_1(\text{W\&T,scfh})$
for DAS

b0	0.2856249...
b1	1.66125
corr.coef.	0.9931897...

fit: W&T, scfh = $a_0 + a_1(\text{Actual, scfh})$
for statistics

a0	-0.149238...
a1	0.5937853...
corr.coef.	0.9931897...

STATISTICAL DATA

a	-0.149238...
b	0.5937853...
SEE	0.1085925...
MSE	0.0108592...
Sxx	22.381825
sum(Xi^2)	114.9559
avg(X)	2.7775
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	26.957
W&T: Uncert.,Wy low	0.256 scfh
W&T: Uncert.,Wy high	0.259 scfh
Curve Fit: Uncert.,We	0.436 scfh
Cal. Equip. Uncert.,Wc	0.019 scfh
Total Uncertainty, Wt	0.44 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal. Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.5 scfh

Figure D12: Uncertainty Analysis, Air-flow Meters AF10

Wallace & Tiernan Air Flow Meter, AF11
Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180
Measurement Uncertainty: $\pm 0.75\%$ of Reading
Conversion: 29,038.4 counts/liter = 822,276.02 counts/lit

Pre-test Calibration: 10-01-96
Post-test Calibration: 03-11-97
Evaluation Date: 03-13-97

Pre-test Calibration Results

Califlow	W&T
counts	time, sec
scfh	scfh
11841	45.4076
12987	18.6225
12873	13.3611
12895	13.1815
13109	17.6427
12721	45.3108
1.14	0.50
3.05	1.50
4.22	2.50
4.28	2.50
3.25	1.50
1.23	0.50

Average Ambient Temperature = 22°C
Average Ambient Pressure = 760 mmHg

Post-test Calibration Results

Califlow	W&T
counts	time, sec
scfh	scfh
12486	45.3623
12858	16.3037
12652	11.5659
12286	11.2144
12816	16.2635
12401	45.2797
1.21	0.50
3.45	1.50
4.79	2.50
4.80	2.50
3.45	1.50
1.20	0.50

Average Ambient Temperature = 22°C
Average Ambient Pressure = 755 mmHg

Pre+Post	Pre+Post	Best Fit	(Best Fit)-(WT)
Califlow, scfh	WT, scfh		
1.14	0.50	0.42	-0.08
3.05	1.50	1.53	0.03
4.22	2.50	2.20	-0.30
4.28	2.50	2.23	-0.27
3.25	1.50	1.64	0.14
1.23	0.50	0.48	-0.02
1.21	0.50	0.46	-0.04
3.45	1.50	1.76	0.26
4.79	2.50	2.53	0.03
4.80	2.50	2.53	0.03
3.45	1.50	1.76	0.26
1.20	0.50	0.46	-0.04
rms deviation 0.16 scfh			

fit: Actual,scfh = b0 + b1x(W&T,scfh)
for DAS

b0	0.5102083...
b1	1.66375
corr.coef.	0.9795858...

fit: W&T, scfh = a0 + a1x(Actual, scfh)
for statistics

a0	-0.233651...
a1	0.5767624...
corr.coef.	0.9795858...

STATISTICAL DATA

a	-0.233651...
b	0.5767624...
SEE	0.3232917...
MSE	0.0323291...
Sxx	23.077091...
sum(Xi^2)	131.4975
avg(X)	3.0058333...
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	15.410
W&T: Uncert.,Wy low	0.445 scfh
W&T: Uncert.,Wy high	0.443 scfh
Curve Fit: Uncert.,We	0.768 scfh
Cal. Equip. Uncert.,Wc	0.019 scfh
Total Uncertainty, Wt	0.77 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.8 scfh

Figure D13: Uncertainty Analysis, Air-flow Meters AF11

Wallace & Tiernan Air Flow Meter, AF12

Secondary Standard Used For Calibration Was: MKS "Califlow" TR-2180

Measurement Uncertainty: $\pm 0.75\%$ of Reading

Conversion: 29,038.4 counts/liter = 822,276.02 counts/ft³

Pre-test Calibration Results

Califlow			W&T
counts	time, sec.	scfh	scfh
12462	45.4199	1.20	0.50
12848	17.7464	3.17	1.50
12759	13.0753	4.27	2.50
12765	12.9997	4.30	2.50
12970	16.8114	3.38	1.50
12960	45.3142	1.25	0.50

Average Ambient Temperature = 22°C

Average Ambient Pressure = 759 mmHg

Pre-test Calibration: 10-01-96

Post-test Calibration: 03-11-97

Evaluation Date: 03-13-97

Post-test Calibration Results

Califlow			W&T
counts	time, sec.	scfh	scfh
12457	45.3848	1.20	0.50
12853	16.5595	3.40	1.50
12719	11.5436	4.82	2.50
12368	11.2238	4.82	2.50
12426	16.2658	3.34	1.50
12511	45.7692	1.20	0.50

Average Ambient Temperature = 22°C

Average Ambient Pressure = 756 mmHg

Pre+Post Califlow, scfh	Pre+Post WT, scfh	Best Fit	(Best Fit)-(WT)
1.20	0.50	0.44	-0.06
3.17	1.50	1.58	0.08
4.27	2.50	2.22	-0.28
4.30	2.50	2.23	-0.27
3.38	1.50	1.70	0.20
1.25	0.50	0.47	-0.03
1.20	0.50	0.44	-0.06
3.40	1.50	1.71	0.21
4.82	2.50	2.53	0.03
4.82	2.50	2.53	0.03
3.34	1.50	1.68	0.18
1.20	0.50	0.44	-0.06
		rms deviation	0.16 scfh

fit: Actual, scfh = $b_0 + b_1(\text{W\&T, scfh})$

for DAS

b0	0.5241666...
b1	1.67
corr.coef.	0.9817397...

fit: W&T, scfh = $a_0 + a_1(\text{Actual, scfh})$

for statistics

a0	-0.248233...
a1	0.5771334...
corr.coef.	0.9817397...

STATISTICAL DATA

a	-0.248233...
b	0.5771334...
SEE	0.2894969...
MSE	0.0289496...
Sxx	23.148891...
sum(Xi^2)	133.2591
avg(X)	3.0291666...
Degrees Freedom	10
t(95% confidence)	2.228
Test Statistic, T	16.320
W&T: Uncert., Wy, low	0.420 scfh
W&T: Uncert., Wy, high	0.419 scfh
Curve Fit: Uncert., We	0.726 scfh
Cal. Equip. Uncert., Wc	0.019 scfh
Total Uncertainty, Wt	0.73 scfh

RESPONSE (Wallace & Tiernan, scfh)

○ Pre-test Cal. Data ◇ Post-test Cal. Data — Best Curve Fit

i.e., Uncertainty When Using Curve Fit: 0.8 scfh

Figure D14: Uncertainty Analysis, Air-flow Meters AF12

Noshok Air Pressure Gauge, AP1

Secondary Standard Used For Calibration Was: SENSOTEC TR-1503
Measurement Uncertainty: $\pm 2\%$ of Reading

Post-test Calibration Results

Average Ambient Pressure =
(29.80+29.78+29.79)/3 = 29.79 In.Hga

Standard		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.1	0	3	3
33.5	50.5	41	39	- 2
37.2	100.8	82	75	- 7
40.8	149.8	118	110	- 8
44.5	200.2	154	146	- 8
44.5	200.2	155	146	- 9
40.8	149.8	121	110	- 11
37.2	100.8	88	75	- 13
33.5	50.5	47	39	- 8
29.8	-0.1	0	3	3
29.8	-0.1	0	3	3
33.5	50.5	35	39	4
37.2	100.8	70	75	5
40.8	149.8	101	110	9
44.5	200.2	132	146	14
44.5	200.2	132	146	14
40.8	149.8	103	110	7
37.2	100.8	73	75	2
33.5	50.5	39	39	0
29.8	0.0	0	3	3
		rms deviation	8	In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal. Data — Best Curve Fit ---- Pre-Cal. Line

Pre-test Calibration: 10-15-96

Post-test Calibration: 03-12-97

Evaluation Date: 03-21-97

Pre-test Calibration Results

A cursory check before testing showed that all
gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

Noshok = 1 X (Standard), ± 2 In.H2O

fit: Standard, In.H2Og = $b_0 + b_1 \times (\text{Noshok, In.H2Og})$
for DAS

b0	-1.723377
b1	1.368044
corr.coef.	0.988266

fit: Noshok, In.H2Og = $a_0 + a_1 \times (\text{Standard, In.H2Og})$
for statistics

a0	2.9695672
a1	0.7139174
corr.coef.	0.9882664

POST CALIBRATION STATISTICAL DATA

a	2.96956717
b	0.71391739
SEE	1216.47177
MSE	67.5817648
Sxx	99918.9177
sum(Xi^2)	300977.545
avg(X)	100.2643075
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	27.451
W&T: Uncert., Wy low	18.529 In.H2O
W&T: Uncert., Wy high	18.522 In.H2O
Curve Fit: Uncert., We	25.943 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	26.25 In.H2O

i.e., Uncertainty in Post Cal. Curve Fit: 27 In.H2O

Figure D15: Uncertainty Analysis, Air Pressure Gauge AP1

Noshok Air Pressure Gauge, AP2

Secondary Standard Used For Calibration Was: SENSOTEC TR-1503

Measurement Uncertainty: $\pm 2\%$ of Reading

Pre-test Calibration: 10-15-96

Post-test Calibration: 03-12-97

Evaluation Date: 03-21-97

Post-test Calibration Results

Average Ambient Pressure =

$$(29.79 + 29.78 + 29.77) / 3 = 29.78 \text{ In.Hg}$$

Standard	Noshok
In.Hg	In.H2Og
In.H2Og	Best Fit (Best Fit)-(Noshok)
29.8	0.1
33.5	50.6
37.2	101.0
40.8	150.0
44.5	200.3
44.5	200.3
40.8	150.0
37.2	101.0
33.5	50.6
29.8	0.0
29.8	0.0
33.5	50.6
37.2	101.0
40.8	150.0
44.5	200.3
44.5	200.3
40.8	150.0
37.2	101.0
33.5	50.6
29.8	-0.1

rms deviation 4 In.H2O

Pre-test Calibration Results

A cursory check before testing showed that all gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

$$\text{Noshok} = 1 \times (\text{Standard}), \pm 2 \text{ In.H2O}$$

fit: Standard, In.H2Og = $b_0 + b_1 \times (\text{Noshok, In.H2Og})$
for DAS

b0	-5.601736
b1	1.517276
corr.coef.	0.996265

fit: Noshok, In.H2Og = $a_0 + a_1 \times (\text{Standard, In.H2Og})$
for statistics

a0	4.1853086
a1	0.6541612
corr.coef.	0.9962645

POST CALIBRATION STATISTICAL DATA

a	4.18530862
b	0.65416121
SEE	321.50449
MSE	17.8613604
Sxx	100000.8347
sum(Xi^2)	301523.658
avg(X)	100.379984
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	48.947
W&T: Uncert., Wy low	9.526 In.H2O
W&T: Uncert., Wy high	9.522 In.H2O
Curve Fit: Uncert., We	14.555 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	15.10 In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal Data — Best Curve Fit ---- Pre-Cal. Line

i.e., Uncertainty in Post Cal. Curve Fit: 16 In.H2O

Figure D16: Uncertainty Analysis, Air Pressure Gauge AP2

Noshok Air Pressure Gauge, AP3

Secondary Standard Used For Calibration Was: SENSOTEC TR-1503

Measurement Uncertainty: $\pm 2\%$ of Reading

Pre-test Calibration: 10-15-96

Post-test Calibration: 03-12-97

Evaluation Date: 03-21-97

Post-test Calibration Results

Average Ambient Pressure =
(29.80+29.78+29.79)/3 = 29.79 In.Hga

Standard		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.1	0	3	3
33.5	50.5	38	37	- 0
37.2	100.8	77	72	- 5
40.8	149.8	112	106	- 6
44.5	200.2	147	141	- 6
44.5	200.2	147	141	- 6
40.8	149.8	115	106	- 9
37.2	100.8	82	72	-10
33.5	50.5	44	37	- 7
29.8	-0.1	0	2	2
29.8	-0.1	0	2	2
33.5	50.5	35	37	2
37.2	100.8	68	72	4
40.8	149.8	100	106	6
44.5	200.2	130	141	11
44.5	200.2	130	141	11
40.8	149.8	101	106	5
37.2	100.8	73	72	- 0
33.5	50.5	37	37	0
29.8	0.0	0	2	2
		rms deviation	6 In.H2O	

Pre-test Calibration Results

A cursory check before testing showed that all
gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

Noshok = 1 X (Standard), ± 2 In.H2O

fit: Standard, In.H2Og = b0 + b1x(Noshok, In.H2Og)

for DAS

b0	-2.083811
b1	1.425461
corr.coef.	0.992745

fit: Noshok, In.H2Og = a0 + a1x(Standard, In.H2Og)

for statistics

a0	2.4787887
a1	0.6913847
corr.coef.	0.9927448

POST CALIBRATION STATISTICAL DATA

a	2.47878866
b	0.69138473
SEE	700.67369
MSE	38.9263158
Sxx	99918.9177
sum(Xi^2)	300977.545
avg(X)	100.2643075
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	35.029
W&T: Uncert., Wy low	14.063 In.H2O
W&T: Uncert., Wy high	14.057 In.H2O
Curve Fit: Uncert., We	20.331 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	20.72 In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal. Data — Best Curve Fit ---- Pre-Cal. Line

i.e., Uncertainty in Post Cal. Curve Fit: 21 In.H2O

Figure D17: Uncertainty Analysis, Air Pressure Gauge AP3

Noshok Air Pressure Gauge, AP4

Secondary Standard Used For Calibration Was: SENSOTEC TR-1503
Measurement Uncertainty: $\pm 2\%$ of Reading

Pre-test Calibration: 10-15-96

Post-test Calibration: 03-12-97

Evaluation Date: 03-21-97

Post-test Calibration Results

Average Ambient Pressure =
 $(29.79 + 29.78 + 29.77)/3 = 29.78$ In.Hga

Standard		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.3	0	3	3
33.5	50.6	49	49	0
37.2	101.0	100	96	- 4
40.8	150.0	146	141	- 5
44.5	200.3	187	187	0
44.5	200.3	186	187	1
40.8	150.0	142	141	- 1
37.2	101.0	98	96	- 2
33.5	50.6	51	49	- 2
29.8	0.3	0	3	3
29.8	0.3	0	3	3
33.5	50.6	50	49	- 0
37.2	101.0	99	96	- 3
40.8	150.0	143	141	- 2
44.5	200.3	182	187	5
44.5	200.3	182	187	5
40.8	150.0	140	141	0
37.2	101.0	97	96	- 1
33.5	50.6	50	49	- 0
29.8	0.3	0	3	3
		rms deviation 3 In.H2O		

Pre-test Calibration Results

A cursory check before testing showed that all
gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

Noshok = 1 X (Standard), ± 2 In.H2O

fit: Standard, In.H2Og = $b_0 + b_1 \times (\text{Noshok, In.H2Og})$

for DAS

b0	-2.337290
b1	1.080670
corr.coef.	0.999042

fit: Noshok, In.H2Og = $a_0 + a_1 \times (\text{Standard, In.H2Og})$

for statistics

a0	2.3407114
a1	0.9235807
corr.coef.	0.9990425

POST CALIBRATION STATISTICAL DATA

a	2.34071140
b	0.92358067
SEE	163.23423
MSE	9.0685686
Sxx	99782.4633
sum(Xi^2)	301523.918
avg(X)	100.43442
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	96.880
W&T: Uncert., Wy low	6.787 In.H2O
W&T: Uncert., Wy high	6.785 In.H2O
Curve Fit: Uncert., We	7.346 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	8.36 In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal. Data — Best Curve Fit ---- Pre-Cal. Line

i.e., Uncertainty in Post Cal. Curve Fit: 9 In.H2O

Figure D18: Uncertainty Analysis, Air Pressure Gauge AP4

Noshok Air Pressure Gauge, AP5

Secondary Standard Used For Calibration Was: SENSOTEC TR-1503

Measurement Uncertainty: $\pm 2\%$ of Reading

Pre-test Calibration: 10-15-96

Post-test Calibration: 03-12-97

Evaluation Date: 03-21-97

Post-test Calibration Results

Average Ambient Pressure =

$$(29.80 + 29.78 + 29.79) / 3 = 29.79 \text{ In.Hga}$$

Standard		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.1	0	1	1
33.5	50.5	51	48	- 3
37.2	100.8	103	96	- 7
40.8	149.8	152	142	- 10
44.5	200.2	198	189	- 9
44.5	200.2	199	189	- 10
40.8	149.8	152	142	- 10
37.2	100.8	104	96	- 8
33.5	50.5	53	48	- 5
29.8	0.1	0	1	1
29.8	0.1	0	1	1
33.5	50.5	45	48	3
37.2	100.8	90	96	6
40.8	149.8	134	142	8
44.5	200.2	176	189	13
44.5	200.2	176	189	13
40.8	149.8	134	142	8
37.2	100.8	91	96	5
33.5	50.5	46	48	2
29.8	0.1	0	1	1
			rms deviation	7 In.H2O

Pre-test Calibration Results

A cursory check before testing showed that all
gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

$$\text{Noshok} = 1 \times (\text{Standard}), \pm 2 \text{ In.H2O}$$

$$\text{fit: Standard, In.H2Og} = b_0 + b_1 \times (\text{Noshok, In.H2Og})$$

for DAS

b0	0.092993
b1	1.052577
corr.coef.	0.993931

$$\text{fit: Noshok, In.H2Og} = a_0 + a_1 \times (\text{Standard, In.H2Og})$$

for statistics

a0	1.0646816
a1	0.9385532
corr.coef.	0.9939314

POST CALIBRATION STATISTICAL DATA

a	1.06468164
b	0.93855320
SEE	1076.61365
MSE	59.8118695
Sxx	99782.4633
sum(Xi^2)	300977.563
avg(X)	100.29833
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	38.335
W&T: Uncert., Wy low	17.429 In.H2O
W&T: Uncert., Wy high	17.425 In.H2O
Curve Fit: Uncert., We	18.566 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	18.99 In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal. Data — Best Curve Fit ---- Pre-Cal. Line

i.e., Uncertainty in Post Cal. Curve Fit: 19 In.H2O

Figure D19: Uncertainty Analysis, Air Pressure Gauge AP5

Noshok Air Pressure Gauge, AP6

Secondary Standard Used For Calibration Was: SENSOTEC TR-1503
Measurement Uncertainty: $\pm 2\%$ of Reading

Post-test Calibration Results

Average Ambient Pressure =
(29.79+29.78+29.77)/3 = 29.78 In.Hga

Standard *		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.3	0	3	3
33.5	50.6	43	41	- 2
37.2	101.0	84	80	- 4
40.8	150.0	122	117	- 5
44.5	200.3	156	156	0
44.5	200.3	155	156	1
40.8	150.0	120	117	- 3
37.2	101.0	84	80	- 4
33.5	50.6	44	41	- 3
29.8	0.3	0	3	3
29.8	0.3	0	3	3
33.5	50.6	42	41	- 0
37.2	101.0	82	80	- 2
40.8	150.0	118	117	- 0
44.5	200.3	150	156	6
44.5	200.3	151	156	5
40.8	150.0	117	117	0
37.2	101.0	81	80	- 1
33.5	50.6	42	41	- 0
29.8	0.3	0	3	3
			rms deviation	3 In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal. Data — Best Curve Fit ---- Pre-Cal. Line

Pre-test Calibration: 10-15-96

Post-test Calibration: 03-12-97

Evaluation Date: 03-21-97

Pre-test Calibration Results

A cursory check before testing showed that all
gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

Noshok = 1 X (Standard), ± 2 In.H2O

fit: Standard, In.H2Og = $b_0 + b_1 \times (\text{Noshok, In.H2Og})$
for DAS

b0	-3.127160
b1	1.301843
corr.coef.	0.998548

fit: Noshok, In.H2Og = $a_0 + a_1 \times (\text{Standard, In.H2Og})$
for statistics

a0	2.6260528
a1	0.7659122
corr.coef.	0.9985475

POST CALIBRATION STATISTICAL DATA

a	2.62605277
b	0.76591220
SEE	170.41241
MSE	9.4673562
Sxx	99782.4633
sum(Xi^2)	301523.918
avg(X)	100.43442
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	78.631
W&T: Uncert., Wy low	6.934 In.H2O
W&T: Uncert., Wy high	6.932 In.H2O
Curve Fit: Uncert., We	9.051 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	9.90 In.H2O

i.e., Uncertainty in Post Cal. Curve Fit: 10 In.H2O

Figure D20: Uncertainty Analysis, Air Pressure Gauge AP6

Noshok Air Pressure Gauge, AP7
 Secondary Standard Used For Calibration Was: SENSOTEC TR-1503
 Measurement Uncertainty: $\pm 2\%$ of Reading

Post-test Calibration Results

Average Ambient Pressure =
 $(29.80+29.78+29.79)/3 = 29.79 \text{ In.Hg}$

Standard		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.1	0	2	2
33.5	50.5	42	41	- 1
37.2	100.8	84	79	- 5
40.8	149.8	122	116	- 6
44.5	200.2	161	155	- 6
44.5	200.2	161	155	- 6
40.8	149.8	125	116	- 9
37.2	100.8	88	79	- 9
33.5	50.5	48	41	- 7
29.8	0.1	0	2	2
29.8	0.1	0	2	2
33.5	50.5	38	41	3
37.2	100.8	75	79	4
40.8	149.8	110	116	6
44.5	200.2	144	155	11
44.5	200.2	145	155	10
40.8	149.8	112	116	4
37.2	100.8	78	79	1
33.5	50.5	40	41	0
29.8	0.1	0	2	2
		rms deviation	6	In.H2O

Pre-test Calibration: 10-15-96
 Post-test Calibration: 03-12-97
 Evaluation Date: 03-21-97

Pre-test Calibration Results

A cursory check before testing showed that all gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

Noshok = 1 X (Standard), ± 2 In.H2O

fit: Standard, In.H2Og = $b_0 + b_1 \times (\text{Noshok, In.H2Og})$
 for DAS

b0	-1.699791
b1	1.296861
corr.coef.	0.994350

fit: Noshok, In.H2Og = $a_0 + a_1 \times (\text{Standard, In.H2Og})$
 for statistics

a0	2.1821188
a1	0.7624043
corr.coef.	0.9943503

POST CALIBRATION STATISTICAL DATA

a	2.18211883
b	0.76240433
SEE	660.95908
MSE	36.7199489
Sxx	99782.4633
sum(Xi^2)	300977.563
avg(X)	100.29833
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	39.743
W&T: Uncert., Wy low	13.656 In.H2O
W&T: Uncert., Wy high	13.653 In.H2O
Curve Fit: Uncert., We	17.908 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	18.35 In.H2O

RESPONSE (Noshok, In. H2Og)

i.e., Uncertainty in Post Cal. Curve Fit: 19 In.H2O

Figure D21: Uncertainty Analysis, Air Pressure Gauge AP7

Noshok Air Pressure Gauge, AP8
Secondary Standard Used For Calibration Was: SENSOTEC TR-1503
Measurement Uncertainty: $\pm 2\%$ of Reading

Pre-test Calibration: 10-15-96
Post-test Calibration: 03-12-97
Evaluation Date: 03-21-97

Post-test Calibration Results

Average Ambient Pressure =
 $(29.79+29.78+29.77)/3 = 29.78$ In.Hga

Standard		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.3	0	3	3
33.5	50.6	49	47	- 2
37.2	101.0	94	91	- 3
40.8	150.0	138	134	- 4
44.5	200.3	178	178	0
44.5	200.3	178	178	0
40.8	150.0	137	134	- 3
37.2	101.0	95	91	- 4
33.5	50.6	50	47	- 3
29.8	0.3	0	3	3
29.8	0.3	0	3	3
33.5	50.6	48	47	- 0
37.2	101.0	93	91	- 2
40.8	150.0	134	134	0
44.5	200.3	172	178	6
44.5	200.3	173	178	5
40.8	150.0	134	134	0
37.2	101.0	92	91	- 0
33.5	50.6	48	47	- 0
29.8	0.3	0	3	3

rms deviation 3 In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal. Data — Best Curve Fit Pre-Cal Line

Pre-test Calibration Results

A cursory check before testing showed that all
gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

Noshok = 1 X (Standard), ± 2 In.H2O

fit: Standard, In.H2Og = $b_0 + b_1 \times (\text{Noshok, In.H2Og})$

for DAS

b0	-2.821545
b1	1.139062
corr.coef.	0.998925

fit: Noshok, In.H2Og = $a_0 + a_1 \times (\text{Standard, In.H2Og})$

for statistics

a0	2.6666276
a1	0.8760281
corr.coef.	0.9989245

POST CALIBRATION STATISTICAL DATA

a	2.66662757
b	0.87602808
SEE	164.97288
MSE	9.1651599
Sxx	99782.4633
sum(Xi^2)	301523.918
avg(X)	100.43442
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	91.406
W&T: Uncert., Wy low	6.823 In.H2O
W&T: Uncert., Wy high	6.821 In.H2O
Curve Fit: Uncert., We	7.786 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	8.75 In.H2O

i.e., Uncertainty in Post Cal. Curve Fit: 9 In.H2O

Figure D22: Uncertainty Analysis, Air Pressure Gauge AP8

Noshok Air Pressure Gauge, AP9
Secondary Standard Used For Calibration Was: SENSOTEC TR-1503
Measurement Uncertainty: $\pm 2\%$ of Reading

Pre-test Calibration: 10-15-96
Post-test Calibration: 03-12-97
Evaluation Date: 03-21-97

Post-test Calibration Results

Average Ambient Pressure =
(29.80+29.78+29.79)/3 = 29.79 In.Hga

Standard		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.1	0	2	2
33.5	50.5	37	37	0
37.2	100.8	75	72	-3
40.8	149.8	109	107	-2
44.5	200.2	144	142	-2
44.5	200.2	145	142	-3
40.8	149.8	111	107	-4
37.2	100.8	78	72	-6
33.5	50.5	41	37	-4
29.8	0.1	0	2	2
29.8	0.1	0	2	2
33.5	50.5	37	37	0
37.2	100.8	71	72	1
40.8	149.8	104	107	3
44.5	200.2	135	142	7
44.5	200.2	136	142	6
40.8	149.8	105	107	2
37.2	100.8	74	72	-2
33.5	50.5	38	37	-1
29.8	0.1	0	2	2
		rms deviation 3 In.H2O		

Pre-test Calibration Results

A cursory check before testing showed that all
gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

Noshok = 1 X (Standard), ± 2 In.H2O

fit: Standard, In.H2Og = $b_0 + b_1 \times (\text{Noshok, In.H2Og})$
for DAS

b0	-2.301972
b1	1.425004
corr.coef.	0.997917

fit: Noshok, In.H2Og = $a_0 + a_1 \times (\text{Standard, In.H2Og})$
for statistics

a0	1.9083409
a1	0.6988318
corr.coef.	0.9979169

POST CALIBRATION STATISTICAL DATA

a	1.90834088
b	0.69883177
SEE	203.65371
MSE	11.3140950
Sxx	99782.4633
sum(Xi^2)	300977.563
avg(X)	100.29833
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	65.628
W&T: Uncert., Wy low	7.580 In.H2O
W&T: Uncert., Wy high	7.579 In.H2O
Curve Fit: Uncert., We	10.845 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	11.56 In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal. Data — Best Curve Fit ---- Pre-Cal. Line

i.e., Uncertainty in Post Cal. Curve Fit: 12 In.H2O

Figure D23: Uncertainty Analysis, Air Pressure Gauge AP9

Noshok Air Pressure Gauge, AP10
Secondary Standard Used For Calibration Was: SENSOTEC TR-1503
Measurement Uncertainty: $\pm 2\%$ of Reading

Pre-test Calibration: 10-15-96
Post-test Calibration: 03-12-97
Evaluation Date: 03-21-97

Post-test Calibration Results
Average Ambient Pressure =
 $(29.79+29.78+29.77)/3 = 29.78$ In.Hga

Standard		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.3	0	4	4
33.5	50.6	44	44	- 0
37.2	101.0	86	84	- 2
40.8	150.0	126	123	- 3
44.5	200.3	161	163	2
44.5	200.3	162	163	0
40.8	150.0	127	123	- 4
37.2	101.0	90	84	- 6
33.5	50.6	49	44	- 5
29.8	0.3	0	4	4
29.8	0.3	0	4	4
33.5	50.6	44	44	- 0
37.2	101.0	84	84	- 0
40.8	150.0	122	123	0
44.5	200.3	156	163	7
44.5	200.3	157	163	6
40.8	150.0	123	123	- 0
37.2	101.0	87	84	- 3
33.5	50.6	46	44	- 2
29.8	0.3	0	4	4
		rms deviation	4	In.H2O

Pre-test Calibration Results

A cursory check before testing showed that all
gauges indicated within ± 2 in. H₂O of a standard.

Therefore the Pre-Cal. Data Relation is:

$$\text{Noshok} = 1 \times (\text{Standard}), \pm 2 \text{ In.H}_2\text{O}$$

fit: Standard, In.H₂Og = $b_0 + b_1x(\text{Noshok}, \text{In.H}_2\text{Og})$
for DAS

b0	-3.870497
b1	1.253665
corr.coef.	0.997992

fit: Noshok, In.H₂Og = $a_0 + a_1x(\text{Standard}, \text{In.H}_2\text{Og})$
for statistics

a0	3.4088045
a1*	0.7944607
corr.coef.	0.9979917

POST CALIBRATION STATISTICAL DATA

a	3.40880453
b	0.79446066
SEE	253.72831
MSE	14.0960172
Sxx	99782.4633
sum(Xi^2)	301523.918
avg(X)	100.43442
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	66.842
W&T: Uncert., Wy low	8.461 In.H ₂ O
W&T: Uncert., Wy high	8.459 In.H ₂ O
Curve Fit: Uncert., We	10.648 In.H ₂ O
Cal. Equip. Uncert., Wc	4.000 In.H ₂ O
Total Uncertainty, Wt	11.37 In.H ₂ O

RESPONSE (Noshok, In. H₂Og)

○ Post-Cal. Data — Best Curve Fit Pre-Cal. Line

i.e., Uncertainty in Post Cal. Curve Fit: 12 In.H₂O

Figure D24: Uncertainty Analysis, Air Pressure Gauge AP10

Noshok Air Pressure Gauge, AP11

Secondary Standard Used For Calibration Was: SENSOTEC TR-1503
Measurement Uncertainty: $\pm 2\%$ of Reading

Pre-test Calibration: 10-15-96
Post-test Calibration: 03-12-97
Evaluation Date: 03-21-97

Post-test Calibration Results

Average Ambient Pressure =
(29.80+29.78+29.79)/3 = 29.79 In.Hga

Standard	Noshok
In.Hga	In.H2Og
In.H2Og	Best Fit (Best Fit)-(Noshok)
29.8	0.1
33.5	50.5
37.2	100.8
40.8	149.8
44.5	200.2
44.5	200.2
40.8	149.8
37.2	100.8
33.5	50.5
29.8	0.1
29.8	0.1
33.5	50.5
37.2	100.8
40.8	149.8
44.5	200.2
44.5	200.2
40.8	149.8
37.2	100.8
33.5	50.5
29.8	0.1
rms deviation 3 In.H2O	

Pre-test Calibration Results

A cursory check before testing showed that all
gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

Noshok = 1 X (Standard), ± 2 In.H2O

fit: Standard, In.H2Og = $b_0 + b_1 \times (\text{Noshok, In.H2Og})$
for DAS

b0	0.022659
b1	1.033237
corr.coef.	0.999084

fit: Noshok, In.H2Og = $a_0 + a_1 \times (\text{Standard, In.H2Og})$
for statistics

a0	0.1558289
a1	0.9660597
corr.coef.	0.9990840

POST CALIBRATION STATISTICAL DATA

a	0.15582885
b	0.96605967
SEE	170.84297
MSE	9.4912760
Sxx	99782.4633
sum(Xi^2)	300977.563
avg(X)	100.29833
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	99.053
W&T: Uncert., Wy low	6.943 In.H2O
W&T: Uncert., Wy high	6.941 In.H2O
Curve Fit: Uncert., We	7.185 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	8.22 In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal. Data — Best Curve Fit ---- Pre-Cal. Line

i.e., Uncertainty in Post Cal. Curve Fit: 9 In.H2O

Figure D25: Uncertainty Analysis, Air Pressure Gauge AP11

Noshok Air Pressure Gauge, AP12

Secondary Standard Used For Calibration Was: SENSOTEC TR-1503

Measurement Uncertainty: $\pm 2\%$ of Reading

Post-test Calibration Results

Average Ambient Pressure =

$$(29.79 + 29.78 + 29.77) / 3 = 29.78 \text{ In.Hga}$$

Standard		Noshok		
In.Hga	In.H2Og	In.H2Og	Best Fit	(Best Fit)-(Noshok)
29.8	0.3	0	3	3
33.5	50.6	55	52	- 3
37.2	101.0	103	100	- 3
40.8	150.0	152	148	- 4
44.5	200.3	196	196	0
44.5	200.3	197	196	- 0
40.8	150.0	152	148	- 4
37.2	101.0	105	100	- 5
33.5	50.6	56	52	- 4
29.8	0.3	0	3	3
29.8	0.3	0	3	3
33.5	50.6	52	52	- 0
37.2	101.0	99	100	1
40.8	150.0	145	148	3
44.5	200.3	189	196	7
44.5	200.3	192	196	4
40.8	150.0	146	148	2
37.2	101.0	104	100	- 4
33.5	50.6	53	52	- 1
29.8	0.3	0	3	3
rms deviation			3	In.H2O

RESPONSE (Noshok, In. H2Og)

○ Post-Cal. Data — Best Curve Fit ---- Pre-Cal. Line

Pre-test Calibration: 10-15-96

Post-test Calibration: 03-12-97

Evaluation Date: 03-21-97

Pre-test Calibration Results

A cursory check before testing showed that all gauges indicated within ± 2 in. H2O of a standard.

Therefore the Pre-Cal. Data Relation is:

$$\text{Noshok} = 1 \times (\text{Standard}), \pm 2 \text{ In.H2O}$$

fit: Standard, In.H2Og = $b_0 + b_1 \times (\text{Noshok, In.H2Og})$
for DAS

b0	-2.765482
b1	1.034067
corr.coef.	0.998751

fit: Noshok, In.H2Og = $a_0 + a_1 \times (\text{Standard, In.H2Og})$
for statistics

a0	2.9168161
a1	0.9646412
corr.coef.	0.9987511

POST CALIBRATION STATISTICAL DATA

a	2.91681614
b	0.96464124
SEE	232.35202
MSE	12.9084454
Sxx	99782.4633
sum(Xi^2)	301523.918
avg(X)	100.43442
Degrees Freedom	18
t(95% confidence)	2.101
Test Statistic, T	84.812
W&T: Uncert., Wy low	8.097 In.H2O
W&T: Uncert., Wy high	8.095 In.H2O
Curve Fit: Uncert., We	8.392 In.H2O
Cal. Equip. Uncert., Wc	4.000 In.H2O
Total Uncertainty, Wt	9.30 In.H2O

i.e., Uncertainty in Post Cal. Curve Fit: 10 In.H2O

Figure D26: Uncertainty Analysis, Air Pressure Gauge AP12