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INDEPENDENT VERIFICATION OF TANK VOLUME MEASUREMENTS BY PRESSURE-VOLUME AUTHENTICATION*

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ABSTRACT

Brookhaven National Laboratory has developed a portable pressure-volume authenticator** as a standard and means of checking the functionality and quality of bubbler-probe volumetric devices. The pressure-volume authenticator (PVA) consists of an automated electromanometer system that is controlled by a laptop computer, and a transportable volumetric artifact. A portable pressure gage is connected, via a scanivalve, to the operator's bubbler-probe system and independently measures all bubbler probes. The transportable volumetric artifact is a one-meter high vessel equipped with bubble-probes, computer controlled air-purge rotameters, and platinum resistance (RTD) thermometer. High quality measurements are obtained by use of a fast sampling technique and sophisticated software developed under this program. The computer software performs the following functions: a) instrument control, b) data acquisition, c) on-line graphical and numerical display of measurement data, and d) detailed data analysis. The device also may provide hands-on training for inspectors and plant operators in high quality volumetric data collection and analysis. A field demonstration of the automated electromanometer system was conducted on the PETRA input accountancy tank, JRC-Ispra in November 1991.

INTRODUCTION

Prior to the development of the pressure-volume authenticator (PVA), there did not exist a method for verifying volumetric instrumentation and measurements in nuclear process tanks. The portable pressure-volume authenticator may be considered a standard test device that is useable almost anywhere in any facility, and by substitution, provide traceability to international standards and a means of checking the functionality and quality of bubbler-probe volumetric devices. By means of inter-comparison of tank volume measurements between facilities, the PVA represents a significant advantage in terms of testing and independently validating volume measurements systems. The device provides direct mass measurements that are redundant to the plant operator's liquid-level measurements and therefore are a check on the accountability measurements.

DESCRIPTION OF THE METHOD AND INSTRUMENTATION

Bubbler-probe manometry is based on the measurement of the pressure that exactly balances the force due to the weight of the liquid above the bubbler-probe orifice.[1] The liquid level and density are measured and the liquid height is derived. The tank volume is a function of the height and volume measurement equation obtained previously during the calibration exercise. Redundant instrumentation that can independently monitor calibration conditions and measure tank volumes under operational conditions can enable improved measurement control and verification.

The pressure-volume authenticator is a miniaturized version of the BNL electromanometer system developed under the TASTEX program.[2][3] It consists of an automated electromanometer system that is controlled by a laptop computer, and a transportable volumetric artifact (Figure 1). A portable pressure gage is connected, via a pneumatic scanner, to the operator's bubbler-probe system and sequentially measures the bubbler probes. The pneumatic scanner, scanner controller, and the RS-232 control modules are contained in the metal case in the center of the figure.

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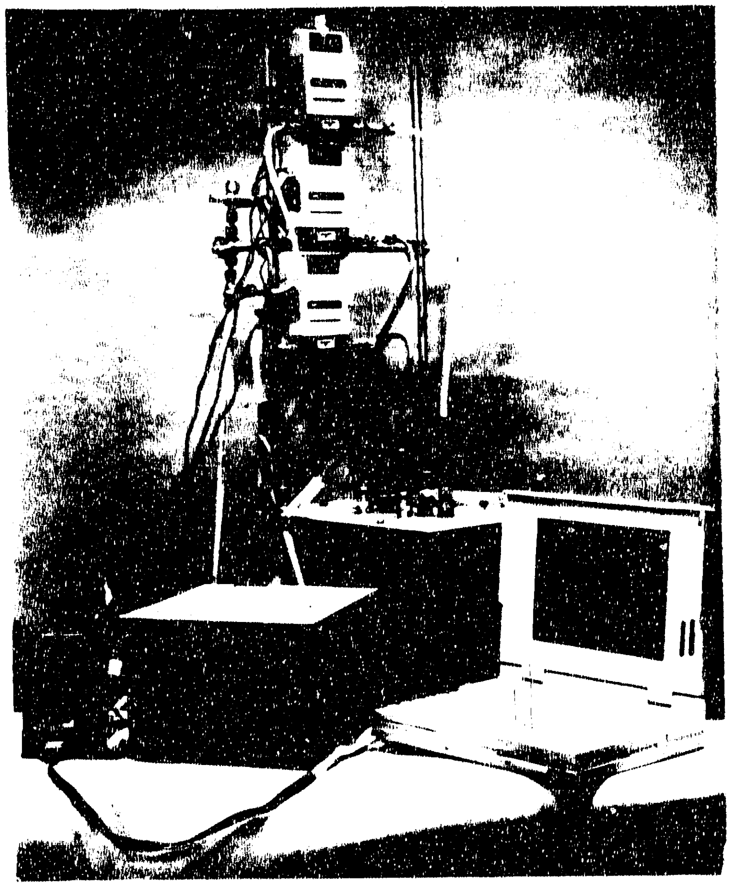

Figure 1. PVA Instrumentation

The transportable volumetric artifact is a one-meter high vessel equipped with bubbler-probes, computer controlled air-purge rotameters, and RTD thermometer (Figure 2). The volumetric artifact is equipped with carrying handles and an optional sight-glass attachment. Using one-meter extensions, the volumetric artifact can model the output of tanks of any height. A schematic diagram of the PVA is shown in Figure 3.

Primary considerations in the choice of PVA instrumentation were accuracy (comparable to the Ruska electromanometer) and portability. High pressure-measurement accuracy and short-term precision approaching 2 pascal is required to measure liquid density, a key manometry parameter, to 4 parts in 10,000. Two absolute and two differential portable pressure gages were evaluated under this study. Because of absolute gage sensitivity to short-term barometric changes, which can exceed 10 pascal, neither absolute gage was found to be applicable to PVA use. With the use of a fast sampling technique and sophisticated software developed under this program, the two differential pressure gages were judged to meet the design criteria under a wide range of operating conditions. The availability of highly developed laptop computers means that now all of the

Figure 2. PVA Tank

PVA instrumentation can easily be carried as hand baggage.

The reliability and versatility of the rotary pneumatic scanning technique under operating conditions has been documented.[4] PVA operating experience with computer controlled and readable mass gas flow meters has been good. Routine monitoring of gas-flow-rates is an important measurement control element in bubbler-probe manometry. Unbalanced gas flow rates can be a source of significant unaccounted-for measurement error.

The computer software performs the following functions: a) instrument control, b) data acquisition, c) on-line graphical and numerical display of measurement data, and d) selected data analysis. Options for data file export for advanced analysis include data base and spreadsheet capability.

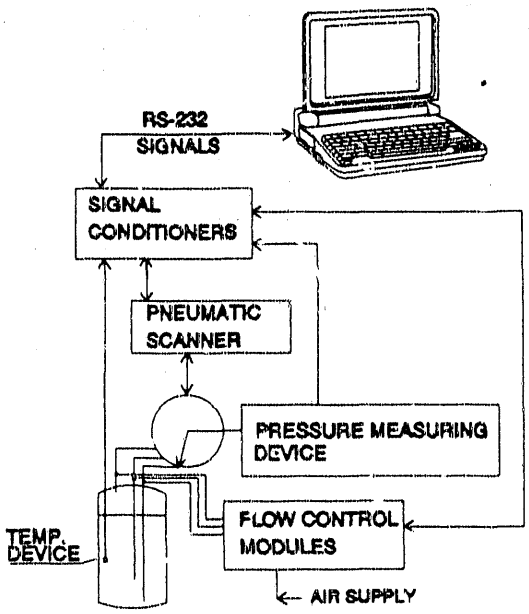

Figure 3. Pressure-Volume Authenticator

TEST RESULTS AND EVALUATION

Figure 4 is the monitor display for the PVA artifact calibration data showing the instrument readings and plots of the density and level probes. Typical standard deviation on the raw density and level probe readings, reflecting the size of the bubbles and based on the average of 150 readings, is 0.95 mm H_2O. However, the standard deviation on long-term measured zero, density and level values is 0.02. Following a period of testing to characterize instrument response and to validate the software, tank calibration, sensitivity test, and thermal expansion tests were performed. Repeated determinations of the probe separation (251.71 mm H_2O) and its standard deviation (0.02 mm H_2O) were made.

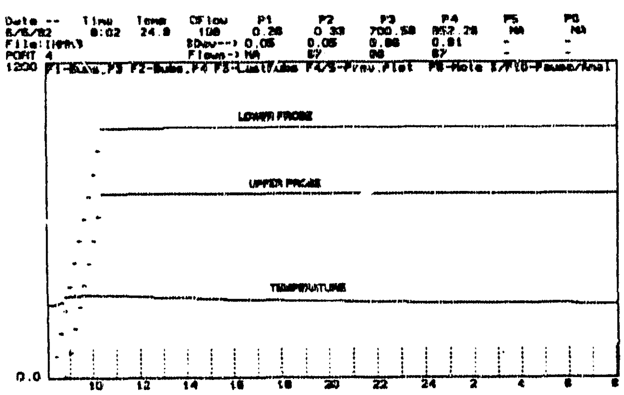

Figure 4. Graph of PVA Reading and Plots

CALIBRATION EXERCISE: INCREMENTAL ADDITIONS

Results of the incremental tank volume calibration of the PVA artifact, using a gravimetric prover (weighed increments), are shown in figures 5 - 10. The calibration data for the level probe are summarized in Figure 5. Figure 6 is a plot of the incremental slope (liters/millimeter), which is a straight line for the uniform, straight-walled cylinder tank. The linear least-squares plot is shown in Figure 7. Volume (liters) residuals as a function of height are shown in Figure 8. Changes in the residuals are due to volume displaced by the density and temperature probes and to the volume of the accessory connections.

Tank PVA_TK ; File A:\Tank\dbf\HD920605.DBF
Degree of Polynomial = 1
Number of Points = 11

Variable	Mean	St. Deviation
HEIGHT	517.5718	286.1570
VOLUME	28.7732	15.8274

Residual Sum of Squares = 0.000
Residual Mean Square = 0.000
Std Error of Estimate = 0.007

	Regression Coefficients	Standard Deviation Reg. Coefficients
A	0.18839003453622450000	0.00658171067672495106
B	0.05527136841510144000	0.00097834461068030976

INCREMENT	HEIGHT (mm)	CUM_VOLUME (liters)	INC_SLOPEV (l/mm)	PRED_VOL (liters)	RESIDUAL_V (liters)
0	84.34	4.830	0.000	4.850	-0.012
1	167.?4	9.444	0.055	9.450	-0.006
2	255.62	14.370	0.055	14.372	0.006
3	340.83	19.475	0.055	19.469	0.006
4	437.42	24.372	0.056	24.365	0.007
5	520.63	28.969	0.055	28.964	0.005
6	602.10	33.470	0.056	33.467	0.003
7	685.00	38.056	0.055	38.049	0.005
8	773.60	42.951	0.055	42.951	0.000
9	863.16	47.890	0.055	47.895	-0.005
10	949.57	52.?64	0.055	52.672	-0.008

Figure 5. Listing of Least Squares Results

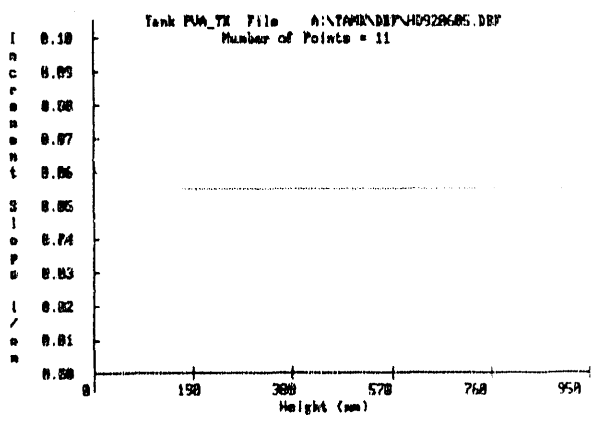

Figure 6. Incremental Slope Plot

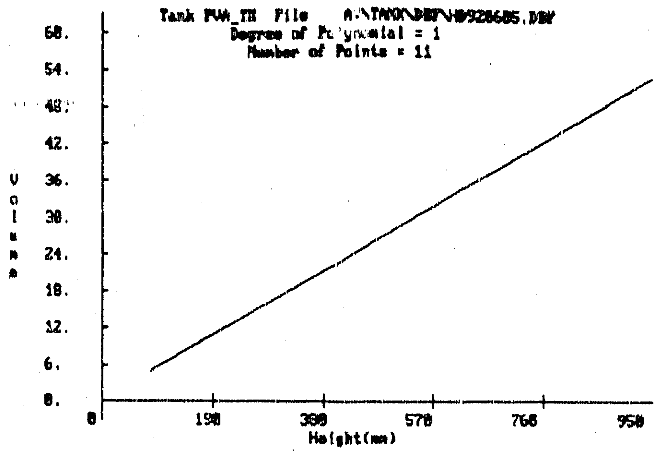

Figure 7. Plot of Calibration Data and Fitted Line

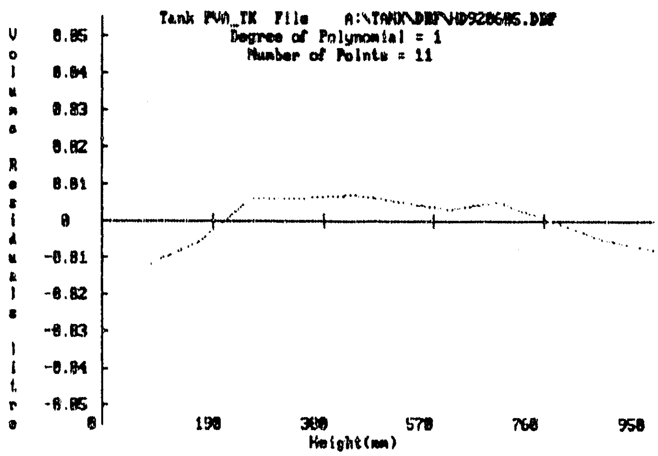

Figure 8. Plot of Residuals

The calibration data for the density probe are shown in Figure 9. Corresponding plots of the least squares line and volume residuals are shown in Figures 10, and 11.

Tank PVA_TK ; File A:\Tank\dbf\[illegible].DBF
Degree of Polynomial = 1
Number of Points = 9

Variable	Mean	St. Deviation
HEIGHT	352.3076	235.2378
VOLUME	33.5604	12.9936

Residual Sum of Squares = 0.000
Residual Mean Square = 0.000
Std Error of Estimate = 0.003

Regression Coefficients	Standard Deviation Reg. Coefficients
A = 14.116[illegible]	0.002[illegible]
B = 0.0552[illegible]	0.0000[illegible]

INCREMENT	HEIGHT (mm)	CUM_VOLUME (liters)	INC_SLOPEV (1/mm)	PRED_VOL (liters)	RESIDUAL_V (liters)
2	4.62	14.378	0.052	14.372	0.006
3	97.07	19.475	0.055	19.476	-0.001
4	184.71	24.372	0.056	24.374	-0.002
5	260.96	28.969	0.058	28.971	-0.002
6	350.44	33.470	0.050	33.473	-0.003
7	433.36	38.054	0.055	38.053	0.001
8	522.01	42.951	0.060	42.949	0.002
9	611.65	47.890	0.055	47.889	0.001
10	697.09	52.656	0.056	52.656	0.000

Figure 9. Upper Probe Listing of LS Results

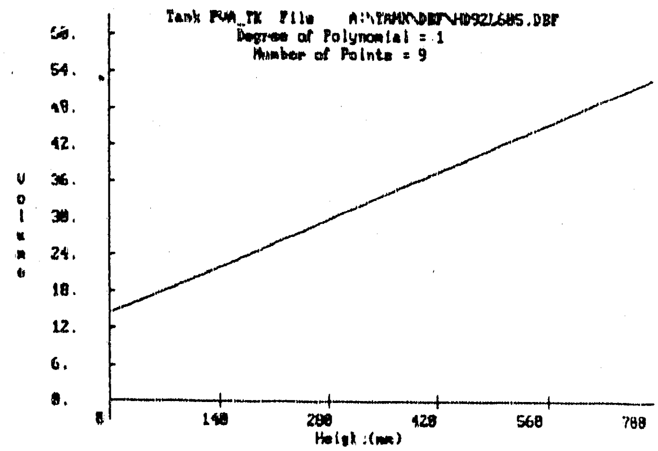

Figure 10. Upper Probe Fitted Line

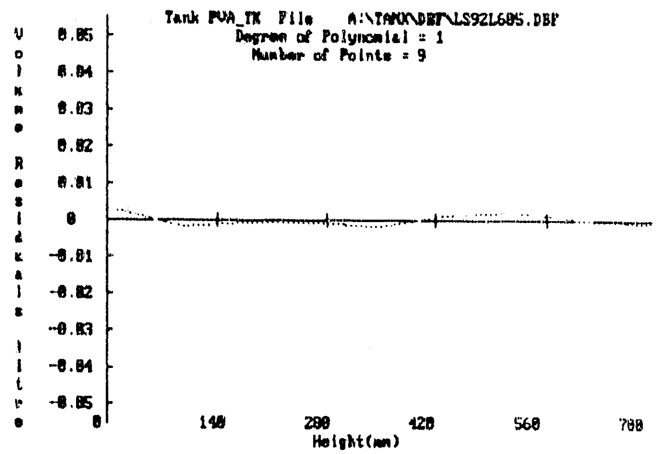

Figure 11. Upper Probe Plot of Residuals

The redundancy provided by a second calibration equation based on the density probe is used for calibration validation and measurement control purposes.

THERMAL EXPANSION TEST

Figure 12 shows the density and level bubbler-probe pressure changes as a function of temperature. The difference between the density and level probe curves is due to the opposing effects of the expansion of the tank and the liquid.[5]

- Tank expansion - An increase in temperature increases the cross-sectional area of the tank which lowers the liquid level. This is seen as an increase in probe readings as the tank cools.

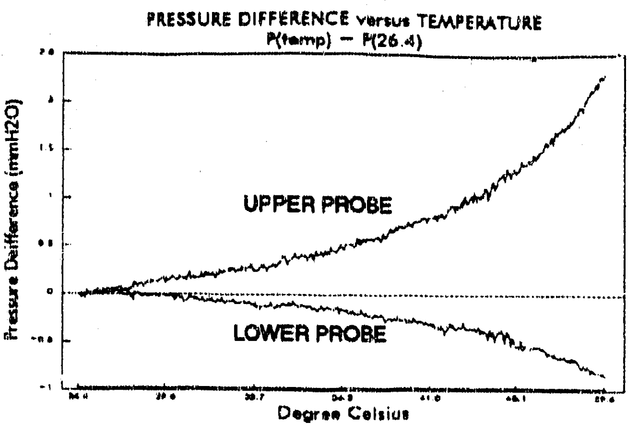

Figure 12. Plot of PVA Tank Cooling Data

- Liquid expansion - An increase in temperature expands the liquid thus moving a greater fraction of the total mass of liquid above the probe tip. This increases the probe reading as the temperature increases because a larger portion of the liquid in now sensed by the probe. During cooling, this is seen as a decrease in the probe readings.

Both probe readings are affected by the thermal expansion of the tank. As seen in Figure 12, this is the main effect on the lower probe (level).

The change in the fraction of liquid above the probe tip is due to liquid expansion, and is the principle component in the upper probe (density) reading. It has a negligible effect on the lower probe whose tip is located near the bottom of the tank. It is believed that because of the temperature relationship between the liquid volume and tank surface area for the small diameter tank used in this experiment, the cooling data curves are not straight lines.

It is shown that each probe has its own temperature correction coefficient. In fact, because of geometric complications, the temperature effects of each probe should be determined experimentally. The difference in the elongation of the probes relative to the tank and to another probe is a second order effect if fabricated from the same material (e.g., stainless steel).

FIELD DEMONSTRATION

Field demonstration of the PVA was conducted using the PETRA input accountability tank at Ispra. The instrumentation and laptop computer were carried as hand baggage and volume calibration and thermal expansion data were collected.[6] It is shown that the PVA can easily be used to collect on-line calibration and temperature effects data, and to validate the facility's calibration data and the analysis of these data. The report which discusses these results demonstrates mass transfer of solution with an accuracy of 0.1%. Demonstration of the PVA for use by the inspection agencies remains to be carried out.

SUMMARY AND CONCLUSIONS

A portable pressure-volume authenticator has been developed and tested. Laboratory and field demonstrations indicate potential for the PVA in validating facility bubbler-probe systems for measurement-control purposes and for its application during domestic and international inspections. The device also may provide hands-on training for inspectors and plant operators in high-quality volumetric data collection and analysis.

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DISCLAIMER

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