BNL-30269

DEMONSTRATION OF AN AUTOMATED ELECTROMANOMETER FOR MEASUREMENT OF SOLUTION VOLUME IN ACCOUNTABILITY VESSELS

Sylvester Suda, TSO
Bernard Keisch, TSO
Makoto Hayashi, PNC
Takayuki Onuma, PNC
Yoshihiro Fukuari, PNC

September, 1981

Technical Support Organization (TSO)
Brookhaven National Laboratory
Upton, New York 11973 USA

&

Power Reactor and Nuclear Fuel Development Corporation (PNC)
Tokai-mura, Ibaraki-ken, 319-11 JAPAN

*Research carried out under the auspices of the United States Department of Energy under Contract No. DE-AC02-76CH00016.

Table of Contents

List of Tables

DEMONSTRATION OF AN AUTOMATED ELECTROMANOMETER FOR MEASUREMENT OF SOLUTION VOLUME IN ACCOUNTABILITY VESSELS

S. Suda and B. Keisch
Brookhaven National Laboratory
Upton, New York 11973

M. Hayashi, Y. Fukuari, and T. Onuma
Power Reactor and Nuclear Fuel Development Corporation (PNC)
Tokai-mura, Ibaraki-ken, 319-11 JAPAN

Abstract

A system for measuring the liquid volume in input and plutonium product accountability vessels, based upon a desktop-computer-controlled electromanometer, was installed at the Tokai-mura reprocessing plant. In-tank temperatures, pressure measurements relating to volume and density, and load-cell weights are measured cyclically and recorded. The system feasibility was demonstrated through a series of tests including vessel calibration and the effects of thermal expansion, and through use during thirteen months of on-line plant operation. The value to the operator of the recording, display, replay, data handling, and report generation features of the system was demonstrated as was the enhanced precision of the electromanometer as compared to the conventional water-filled manometer system. The automated electromanometer system consists of a pneumatic scanner, a precision electromanometer, electronic scanner, a digital voltmeter, and a desktop computer with disc and tape mass storage, cathode-ray tube (CRT) graphics display, and printer output. The desktop computer is used to control the pneumatic and electronic scanners and the digital voltmeter and to log in the measurement data.

1. Purpose of the Task

The purpose of the program was to demonstrate the applicability of an automated electromanometer system, with capability for on-line processing of calibration and measurement data, for use with input and plutonium product accountability vessels at the Tokai plant.

2. Description of Technology, Equipment and Procedures

The automated electromanometer system is designed to provide precise, automated, on-line volume and density measurements (for accountability purposes) of input and product solutions in a reprocessing plant. It consists of a pneumatic scanner, a precision electromanometer, electronic scanner, a digital voltmeter, and a desktop computer with disc and tape mass storage, cathode-ray tube (CRT) graphics display, and printer output.[1] The desktop computer is used to control the pneumatic and electronic scanners and the digital voltmeter and to log-in measurement data. The components of the system are given in Figure 1.

The system provides unattended, semi-continuous (serial) measurement of the liquid level, temperature, and load cell weight and stores more than 24 hours of data on a flexible magnetic disc. Stored data may be retrieved, examined on the

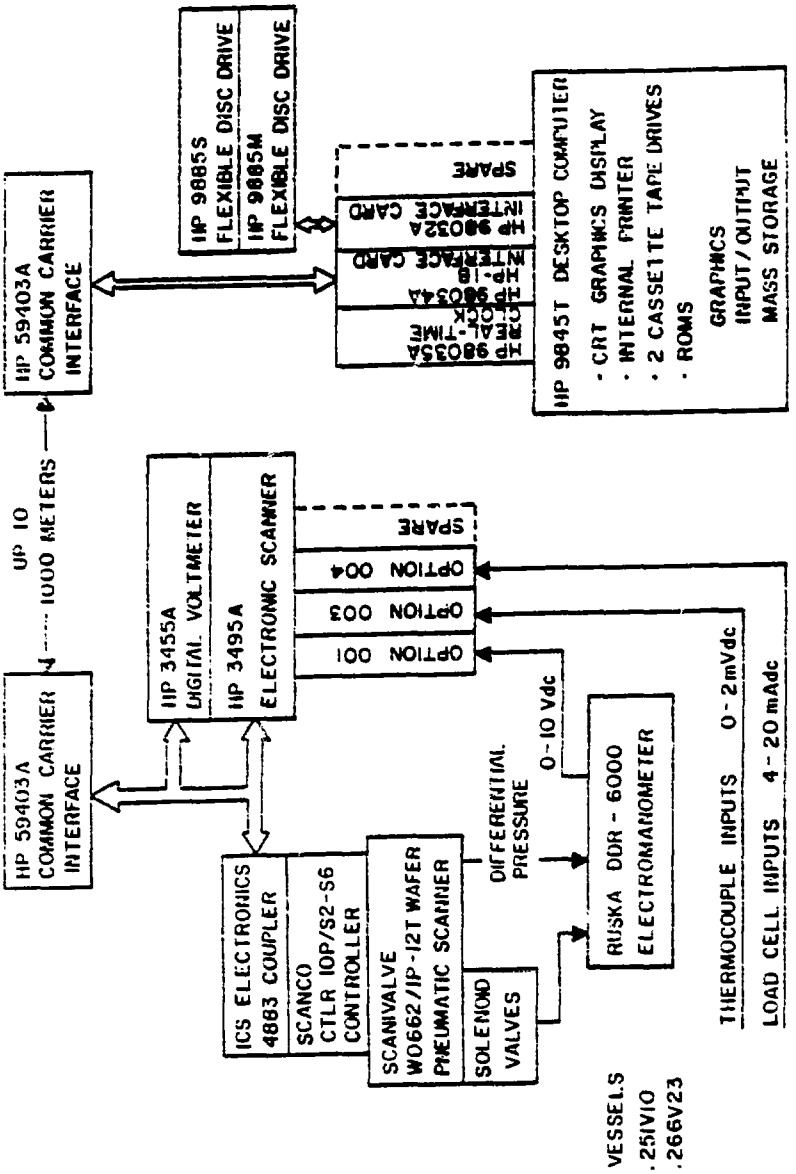


Figure 1. Block Diagram of the Electromanometer Instruments.

CRT display, and run through a data reduction and summary program which rapidly condenses one day's operating data, including all accountability transfers, to a several page summary report. The results thus obtained yield greater measurement accuracy than heretofore achieved, provide necessary plant operator and inspector data, and are presented in a convenient form.

The tank measurements in the Tokai reprocessing plant are the tank temperature, vapor head pressure relative to the process cell, liquid level pressures*, and five strain-gage voltages. Other pressure measurements made each data cycle are at the electromanometer "zero" and the pneumatic scanner "home" positions. The latter provides a leak check on the scanivalve liquid switch wafer.

For each cycle, the latest calculated values for the density, volume, computed mass, and load cell mass are displayed on the CRT along with the measurement data. On-line, hard copy is available to the control room operator at any time via function key request. In addition, visual displays of liquid level data for the system operation are available.

3. Description of Installation, Calibration and Testing

Demonstrations and acceptance testing of the automated electromanometer system were conducted at the Barnwell Nuclear Fuels Plant, Barnwell, South Carolina, in March 1979, for Japanese, IAEA, and French visitors. The system was installed in the Tokai reprocessing plant in August. Preoperational tests and tank calibration involving vessel 251V10 were performed in September 1979. Hardware and software upgrading of the electromanometer system to include measurements in the plutonium product vessel, 266V23 were made in August 1980.

Operational tests of the electromanometer were performed during the pre-guarantee (PG) campaign of November and December 1979, during the guarantee (G) campaign of January and February 1980, and during campaigns C-1 and C-2, April through November 1980.

The following three pre-operational tests were successfully performed during the system checkout.

3.1. Pre-calibration Test.

This test involved the stepwise filling of the tank 251V10, observing the full tank at steady state conditions, and the stepwise draining of the tank to the jet transfer heel while collecting measurement data at a rate of one cycle in approximately 3 minutes. The increment steps were at quartile levels and the sparger was turned on at each filling and emptying step. Measurement data were collected for 30 minutes prior to and after sparging. At the full tank step and after the sparging data were collected, the recirculating sampler was turned on for 20 minutes. This step was repeated prior to start of the emptying phase. A similar test was conducted after the connections to vessel 266V23 were made in August 1980.

---

*two and three dip-tube measurements are made, respectively, for vessels 266V23 and 251V10.

The pre-operational test was used to obtain experimental data regarding the sparger system holdup, the evaporation due to sparging, sampler line holdup, and line drain times. The information was required to establish the response characteristics of the measurement system.

3.2. Thermal Expansion Test.

This test involved the filling of tank 251V10 to the normal input batch level and steam heating the water to 55° C using the spray decontamination line. The temperature and bubbler probe data were collected at a rate of one cycle in 2.3 minutes during the tank cool down to 25° C.

The thermal expansion test was used to establish a temperature correction equation for each of the bubbler probes. An earlier test using heated UNH at the Barnwell Nuclear Fuels plant indicated that the effect of temperature is a function of the thermal expansion of the separation of the probe and of the tank, the volume below the effective tip of the probe, the total volume, and tank geometry. The results of these two tests which represent important new findings lead to a better understanding of temperature effects on liquid level measurements.[2] The results of the 251V10 thermal expansion test, summarized in Table 1, indicate that a temperature change of three degrees centigrade has an effect of about 0.1% at a volume of about 2000 liters.

3.3. Tank Calibration.

Checkout and testing of the calibration software were made using vessel 251V10 in September 1979. Three calibration runs were made. The calibration program collects data, makes the temperature-density calculations and performs data comparisons during the run. Statistical analyses were performed on the three sets of data using the calibration playback and polynomial regression programs after the calibration runs were completed.

The results of the 1979 calibration are summarized in Table 2. The Ruska-DVM system accuracy is based on electrical and pneumatic "Deadweight" piston gage calibrations and represents the overall error for the system. The vessel calibration results represent the random procedural measurement, and curve fitting errors. The vessel calibration results do not include bias that may exist due to inappropriate computational coefficients and procedural errors that are constant throughout the exercise and therefore not estimatable without an external reference point.

Computer averaging, over approximately 15 seconds, of the Ruska readings of the fluctuating pressures that are measured on the bubbler probes results in very stable liquid level and density measurement data and is a significant improvement over the data based on visual reading of the water manometer.

Table 1

PNC Thermal Expansion Test Experimental Data, Tank 251V10

Experimental Results:	Heated Tank	Reference	Difference
Temperature (°C)	54.3	25	29.3
Pressure Readings (P)*			
Major Probe	6569.6	6587.6	-18.0
Minor Probe	2563.7	2544.9	18.8
Major Probe Data			
Liquid Level (mm)	708.79	703.20	5.58
Volume (liters)	2231.66	2208.69	22.97
Summary of Effects:			
% Level Change		+ 0.79	
% Volume Change		+ 1.04	
% Volume Change Per °C		+ 0.03549	

* A Pascal (P) = 1 newton/meter^2 = 0.101974 mm H_2O @ 4° C.

Table 2

Summary of Calibration Results

Calibration	Measurement Errors (One standard deviation) Absolute	%
1. Ruska-DVM System Accuracy*		
Direct Reading	1.0 Pascal	0.003 Full Scale
2. Vessel Calibration (251V10)		
Probe separation	0.03 mm H_2O	0.0007
Combined runs (includes random procedural errors)	1.2 liters	0.03
3. Measurement Cycle Precision**		
Liquid level	0.10mm H_2O	0.017
Density		
. water	0.0002 g/cm^3	0.020
. UNH	0.0002 g/cm^3	0.014

* 5 psi (34474 Pascal) at 10 Volts d.c.
** 0.1 mm H_2O @ 4°C is approximately 1 pascal (newton/$meter^2$)

4. System Evaluation

During the period November 1979 through November 1980, routine measurements of the solution volumes in the input accountability tank, 251V10, were made using the automated electro-manometer system. Connections of the pneumatic lines and thermocouple cable were made to the plutonium product tank, vessel 266V23, in August 1980 at which time the computer programs were correspondingly modified.

The automated electromanometer provides the operator with an improved capability of record-ing the measurement data. The system capability of collecting data, as they are generated, on a quasi-continuous basis, proved to be particularly useful on those occasions when the accountability sampling and transfer out operations overlapped and therefore the quiescent conditions for accountability measurements were not present. When this occurred, transfer values based on earlier recorded data during a steady state period were far superior to those based on the PNC control room strip chart data.

The value of the data processing and summary reporting capabilities provided by the playback program, on a daily basis, was demonstrated. Numerical values at any chosen point in time are quickly retrieved and hard copies of the graphs and measurement data are provided. In addition, the playback program significantly improved and simplified the analysis of load cell data. The time saving of the playback program to the PNC was significant.

Data routinely collected, analyzed, and presented in summary reports include:

1. volume measurements
2. load cell versus electromanometer comparisons
3. hourly bubble pattern data

Examples of such summary reports are attached (Appendices).

Comparisons of the uranium input quantities to the process as measured by the water manometer and electromanometer for four campaigns are summarized in Table 3. A trend is observed in the differences between the quantities over the thirteen month period. This may be caused in part by different approaches to calculating temperature corrections for the two systems starting with the C-1 campaign. A close examination of changes made in the computational constants of the two systems might uncover the cause of the bias trends.

The agreement in the plutonium product quantities is considered good in view of the incomplete information on tank characteristics available when the measurement calculations for the electromanometer system were programmed.

Comparisons analysis of the density values for the C-1 and C-2 campaigns between the different density values are given in Table 4. Density measurements made by the laboratory, water manometer and electromanometer (Meas 1) are independent, the calculated density and Meas 2 are, respectively, functionally correlated with the laboratory and Meas 1 measurements. In general, looking at the individual density measurements for a batch, it appeared that there was good agreement between the density values, given the different reference

Table 3

Comparision of Transfer Quantities

Campaign	Differences* Before Transfer Out	After	Net
Vessel 251V10-Uranium(Kg)			
1. Pre-Guarantee	-17.1	-1.4	-15.7 (-0.33%)
2. Guarantee	-3.7	-1.4	-2.3 (-0.04%)
3. C-1**	162.8	15.5	147.3 (0.54%)
4. C-2**	109.2	6.0	103.2 (0.78%)
Vessel 266V23-Plutonium(g)			
5. C-2**	-147	59	-206 (0.24%)

* Water Manometer - Electromanometer

** Measured values are based on different equations and temperature correction techniques

TABLE 4

Analysis of Density Means (ANOVA)

Campaign/ Vessel	Number of Batches		Lab Density	Water Man	Calc Density	Electromanometer Meas 1	Electromanometer Meas 2	F-Value	F(.99)
C-1									
251V10	76	$\bar{x}$	1.3496	1.3495	1.3516	1.3558	1.3558	27.95*	13.7
		s	.0329	.0290	.0327	.0293	.0291		
C-2									
251V10	42	$\bar{x}$	1.3351	1.3403	1.3391	.3401	1.3485	44.66*	13.7
		s	.0156	.0145	.0153	.0151	.0161		
266V23	12	$\bar{x}$	1.5047	1.5043	1.5008	1.4975	---	21.92	27.1
		s	.0466	.0465	.0433	.0449			

* F test for equality of homoscedastic means was rejected at the = .01 level for vessel 251V10 for both campaigns.

temperatures, although some exceptions were noted.

The calculated (Calc) density is the laboratory density corrected to the temperature of the solution in the vessel. The equation is an empirical formula developed at the Barnwell Nuclear Fuel Plant in 1978 and involves values of the acid molarity and uranium concentration. The formula also includes the laboratory density which is assumed to be measured at 25°C. The PNC laboratory density is measured at 31°C. However, the laboratory density and the calculated density are in very close agreement at 28°C, which suggests that there is a 3°C bias in the equation or in the way it is being used at the computer program or in the tank temperature mesurements. The calculated density values at < 28°C and > 28°C have the approximate expected magnitudes and the correct direction relative to the laboratory density.

The electromanometer densities Meas 1 and Meas 2 for vessel 251V10 are determinations made on two lower probes relative to the same upper probe. Meas 1 is made using the shaped and special cut tip density probes installed in vessel 251V10. The initial inspection of the data suggested that this design feature yielded more stable results than an ordinary blunt cut tip used in Meas 2. The conjecture is not supported by statistical analysis.

Table 4 summarizes the results of the analysis of variance on the density measurements. The hypothesis of equal means for the five measurements made on each batch was rejected for both the C-1 and C-2 campaign for vessel 251V10. To discover which combination of means are significantly different, a paired sample analysis was performed. The results of the multiple comparison test of significance on the differences of the mass are given in Table 5. The significant paired mean differences are indicated with an asterisk.

An examination of the top rows of Parts I and II of Table 5 shows that the water manometer has shifted relative to the laboratory measurements. This is also the case for the calculated (Calc) density, a rather surprising result since none of the computational constants had changed. An analysis of the paired sample residuals shows that the differences are temperature related and that the temperatures were lower for the C-1 campaign than for the C-2 campaign in vessel 251V10. A tabulation of the large residuals observed in the intercomparisons made are given in Table 6. Note that the large residuals were associated with tank temperatures that are either less than 25°C or greater than 38°C with the exception of several values where the batch data show other factors effected the observations (e.g., C-1,4 and C-2,35). Table 5 and 6 show that the relationship between Meas 1 and Meas 2 also changed from one campaign to the next.

It is recognized that until the development of the Automated Electromanometer system, detailed analyses such as the above were not possible for lack of precise data and computer programs. Further validation of the computational constants and refinement of the data normalization techniques are suggested including a study of the validity and/or accuracy of in-tank temperature measurements at extreme ambients.

Because of the small data sample for vessel 266V23, the sensitivity of the tests were limited and no conclusion on biases or trends on the density is possible at this time.

Table 5

Paired Sample Analysis (Multiple Comparisons)

		WM	CD	EM-1	EM-2	Q = q.99(k,df)S $\sqrt{2/m}$
Part I	Lab	.0001	-.0020	-.0049*	-.0062*	M = 152
C-1	WM		-.0021	-.0050*	-.0063*	S^2 = 2.21746E-5
251V10	CD			-.0029*	-.0042*	q.99(5,300) = 4.60
	EM-1				-.0012	Q = .0025
Part II	Lab	-.0052*	-.0042*	-.0050*	-.0134*	M = 152
C-2	WM		-.0012	.0003	-.0081*	S^2 = 2.21405E-5
251V10	CD			.0010	-.0094*	q.99(5,164) = 4.71
	EM-1				-.0084*	Q = .0034
Part III	Lab	.0004	.0038	.0072	----	
C-2	WM		.0034	.0067	----	
266V23	CD			.0033	-----	

* denotes differences of means that are rejected at the α = .01 level

Table 6

Relationships of Outliers to Extreme Temperatures

Obs	NO.	Temp	Differences Between Laboratory Densities @ 31°C: Water Man	Calc Dens	Meas 1	Meas 1 at Tank Temp: Calc Dens	Meas 2
C-1	4	26.2	-.0580		-.0614	-.0602	
	16	23.2	-.0170		-.0257	.0225	
	21	21.5	-.0200		-.0278	.0234	
	29	24.6			-.0128	.0101	
	30	24.6			-.0147	.0123	all
	40	22.5			-.0108		<.005
	52	38.1	.0110	.0074			
	54	42.7	.0160	.0116	.0121		
	56	49.2	.0220	.0163	.0162		
	67	24.6			-.0096		
	73	24.4			-.0106		
C-2	1	24.0					-.0127
	2	25.9					-.0139
	3	27.2					-.0117
	4	23.6					-.0125
	5	21.4					-.0134
	6	23.8					-.0122
	7	23.3	-.0127		-.0132		-.0124
	8	22.3	-.0177		-.0175	.0134	-.0109
	9	25.1					-.0103
	10	24.0					-.0100
	11	23.0					-.0105
	12	21.2		all			-.0109
	14	22.9		<.005			-.0108
	16	20.1	-.0100				
	18	24.1			-.0137		
	19	20.9	-.0101				
	30	21.1	-.0110		-.0125		-.0130
	32	21.0	-.0100				
	35	22.5			.0394	-.0452	
	40	21.9	-.0110				
	41	21.3					-.0123

A summary of the density measurement methods with their errors is given in Table 7. With a few exceptions, the differences between the various density measurements are within the limits of error of the methods.

5. Assessment of Results

The objective of the program was to demonstrate the applicability of the electromanometer technique to volumetric measurements in the input and plutonium product accountability vessels in the Tokai reprocessing plant. Because of the inherent uncertainties in the present-day technique that involves water-filled manometers which are read by eye and data that are recorded by hand, development of instrumentation that provides digital readings and computerized recording and processing of the measurement data represents a significant breakthrough in terms of improved measurements and documented control of special nuclear materials for accountability purposes.

The advantages of the automated electro-manometer system are:

1. Digital data readout of the dip-tube pressure measurements
2. Overall measurement error on the order of 0.1% in the liquid density and volume.
3. On-line computerized acquisition, processing, storage, and analysis of the measurement data.
4. Visual (CRT) displays of current measurement values and time-response status plots.
5. Prompt and accurate hard-copy summary reports of the input and plutonium product volumes.

Transfer of technology to PNC was achieved with respect to the operation and maintenance of the instruments and with respect to the measurement and playback programs. Hardware and software were modified to pick up the load cell signals and playback of the load cell data is a routine operation.

6. Conclusions

Determination of the volume in the input accountability and plutonium product account-ability vessels can be made with greater ease and accuracy using the automated electro-manometer system than by using water-filled manometers.

It was demonstrated that the PNC control room operators were capable of running the electromanometer after about one week of hands-on instruction.

TABLE 7

Summary of Density Measurement Methods

Density (Average D = 1.365)	Method	Other Measured Components	Method error (2 st.D) Absolute	%
1. Laboratory density at 31°C	precise weighing of precisely known sample volume	Sample temperature	0.001 g/cm^3	0.07
2. Water manometer at 31°C	direct read	Manometer temperature Vessel temperature (t) Probe separation	0.007 g/cm^3	0.5
3. Calculated at 31°C	BNFP formula*	Laboratory density Laboratory temperature Acid molarity Uranium concentration Vessel temperature (t)	0.005 g/cm^3	0.37
4. Measured density 1 at t°C	liquid level 1 liquid level 2	Vessel temperature (t) Probe separation	0.0004 g/cm^3	0.03
5. Measured density 2 at t°C	liquid level 1 liquid level 2	Vessel temperature (t) Probe separation	0.001 g/cm^3	0.07

* Assumes a laboratory density at 25°C.

References

1. Suda, S., "An Automated Electromanometer System for Volume Measurement in Accountancy Tanks", Proceedings of the First ESARDA Symposium, April 1979, pp. 325-29.

2. Keisch, B. and Suda, S., "Temperature Effects in Dip-Tube Manometry", presented at the 21st Annual INMM Meeting, Palm Beach, Florida, June 30-July 2, 1980.

3. Nakajima, K., Koizumi, T., Yamanouchi, T., Watanabe, S. and Suyama, N., "Development and Demonstration of Safeguards Techniques in the Tokai Fuel Reprocessing Plant", Proceedings of IAEA Symposium on Nuclear Safeguards Technology, 1978, Vol. II, Vienna, Austria, pp. 701-732.

Appendix A LIQUID LEVEL DATA

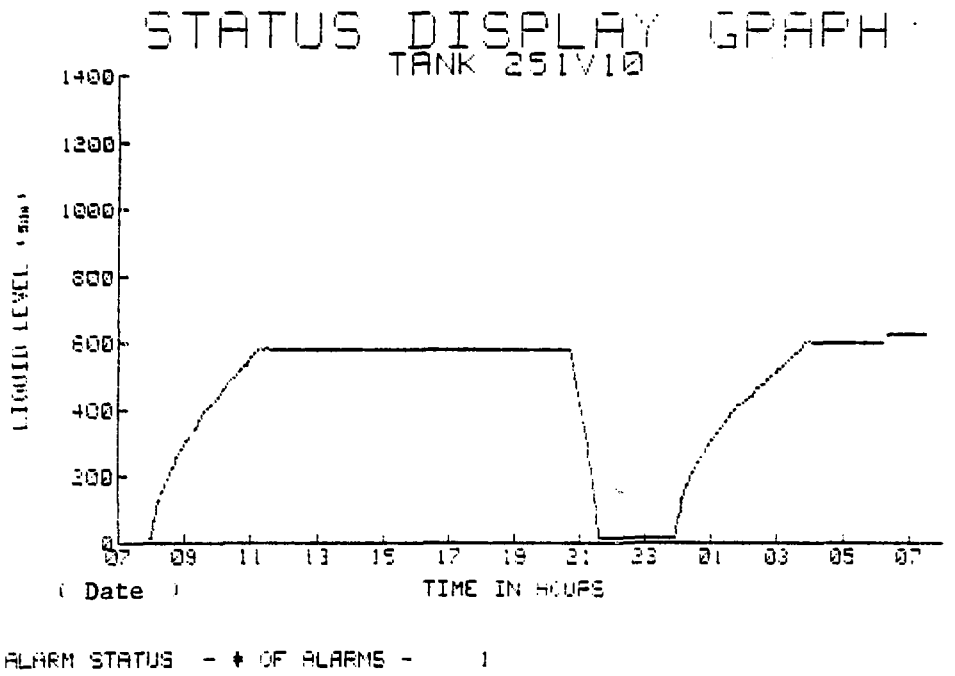


Figure A-1 Input Tank 251V10 Status Plot. Liquid Level Monitoring

Appendix A LIQUID LEVEL DATA

DATA SUMMARY REPORT (Date)

	POINT #1	POINT #2	POINT #3	POINT #4
TIME	18:00	19:00	20:31	21:37
TEMP (deg. C)	21.0	20.6	20.6	21.5
RUSKA 0 (mm)	.54	.54	.55	.50
VAPOR HEAD (mm)	-74.41	-74.76	-74.01	-74.40
LIQ. LEVEL 1 (mm)	235.71	235.79	235.99	-1.09
LIQ. LEVEL 2 (mm)	781.41	781.64	781.55	1.20
LIQ. LEVEL 3 (mm)	798.30	798.40	798.38	18.61
LOAD CELL R/D AVG(v)	3.4949	3.4906	3.4900	1.0353
LOAD CELL R/D A (v)	3.9993	3.9958	3.9920	1.2881
LOAD CELL R/D B (v)	2.9763	2.9682	2.9700	.8022
LOAD CELL R/D C (v)	3.0618	3.0577	3.0602	.8013
LOAD CELL R/D D (v)	3.9894	3.9908	3.9885	1.2548
CALC'D DENS. (g/cc)	1.3558	1.3560	1.3561	1.3554
MEAS D DENS. 1 (g/cc)	1.3736	1.3740	1.3733	0.0000
MEAS D DENS. 2 (g/cc)	1.3570	1.3571	1.3565	0.0000
VOLUME (liters)	1838.7	1838.3	1839.5	10.3
LOAD CELL MASS (kg)	2474.9	2470.5	2469.8	-44.6

DATA SUMMARY REPORT (Date)

	POINT #1	POINT #2	POINT #3	POINT #4
TIME	23:46	04:29	05:01	07:16
TEMP (deg. C)	22.6	23.6	22.2	20.8
RUSKA 0 (mm)	.50	.58	.56	.55
VAPOR HEAD (mm)	-75.58	-70.35	-73.30	-74.92
LIQ. LEVEL 1 (mm)	-1.09	261.82	261.64	293.82
LIQ. LEVEL 2 (mm)	1.51	905.22	903.44	933.76
LIQ. LEVEL 3 (mm)	19.25	922.24	920.64	950.69
LOAD CELL R/D AVG(v)	1.0346	3.6091	3.6092	3.7198
LOAD CELL R/D A (v)	1.3057	4.0916	4.0865	4.2041
LOAD CELL R/D B (v)	.8138	3.1459	3.1415	3.2229
LOAD CELL R/D C (v)	.7879	3.2002	3.2009	3.3036
LOAD CELL R/D D (v)	1.2719	4.0631	4.0701	4.2099
CALC'D DENS. (g/cc)	1.3545	1.3538	1.3549	1.3559
MEAS D DENS. 1 (g/cc)	0.0000	1.3679	1.3638	1.3611
MEAS D DENS. 2 (g/cc)	0.0000	1.3517	1.3483	1.3452
VOLUME (liters)	10.5	1920.5	1922.9	[illegible]
LOAD CELL MASS (kg)	-45.3	2591.8	2591.9	2705.2

Figure A-2 Accountability Transfers. Density, Volume and Load Cell measurements for selected points.

Appendix B LOAD CELL DATA

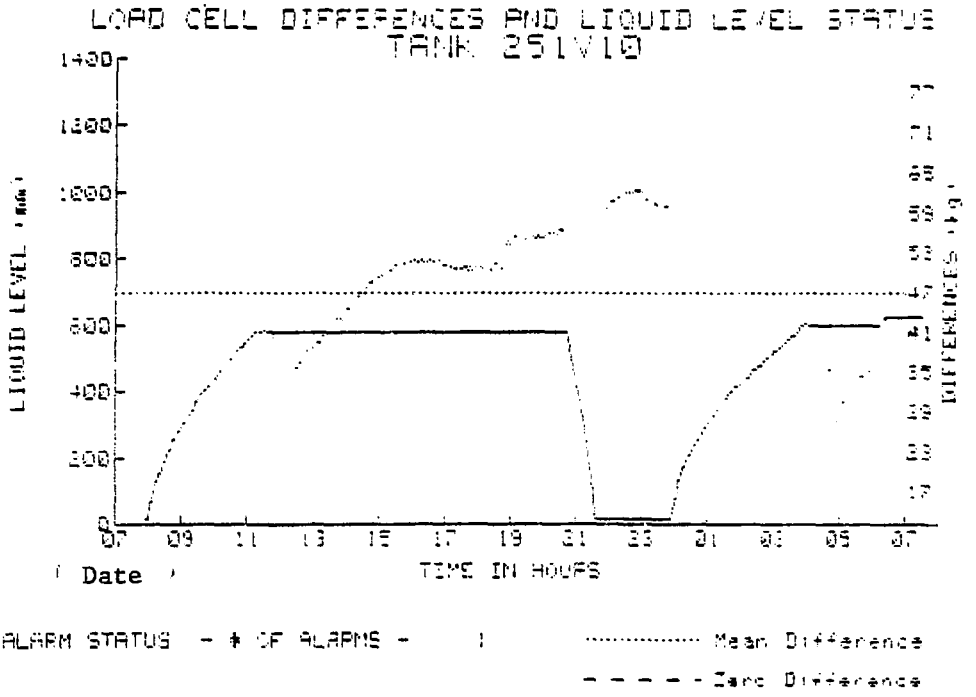


Figure B-1 Input tank 251V10 status plot:

Comparison of solution mass (kilograms) based on load cell measurements and solution volume (liters) based on liquid level measurements.

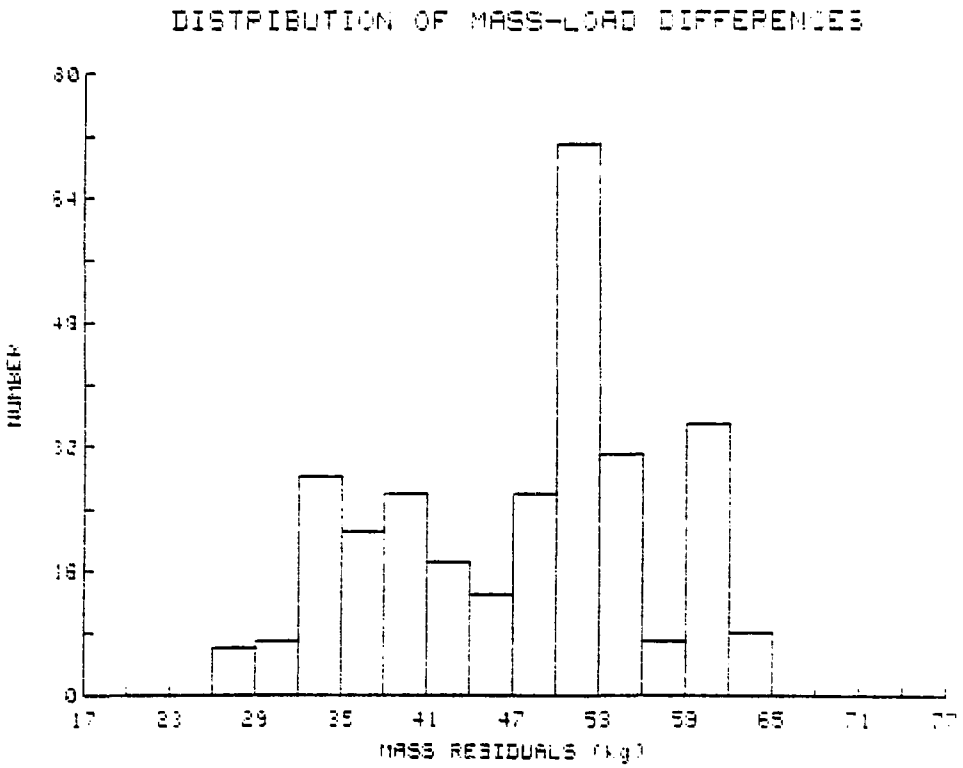
Appendix B LOAD CELL DATA

LOAD CELL-MASS COMPARISON

TANK # 1 (251V10)
Starting date for data- (date)

Number of valid data points- 287

Mean of differences- 47.25
Standard error (s)- 9.98



Starting date is (date)
TANK #(251V10)

Figure B-2 Frequency plot of kilograms solution: Differences between load cell and liquid level measurements.

Appendix C BUBBLE PATTERN DATA

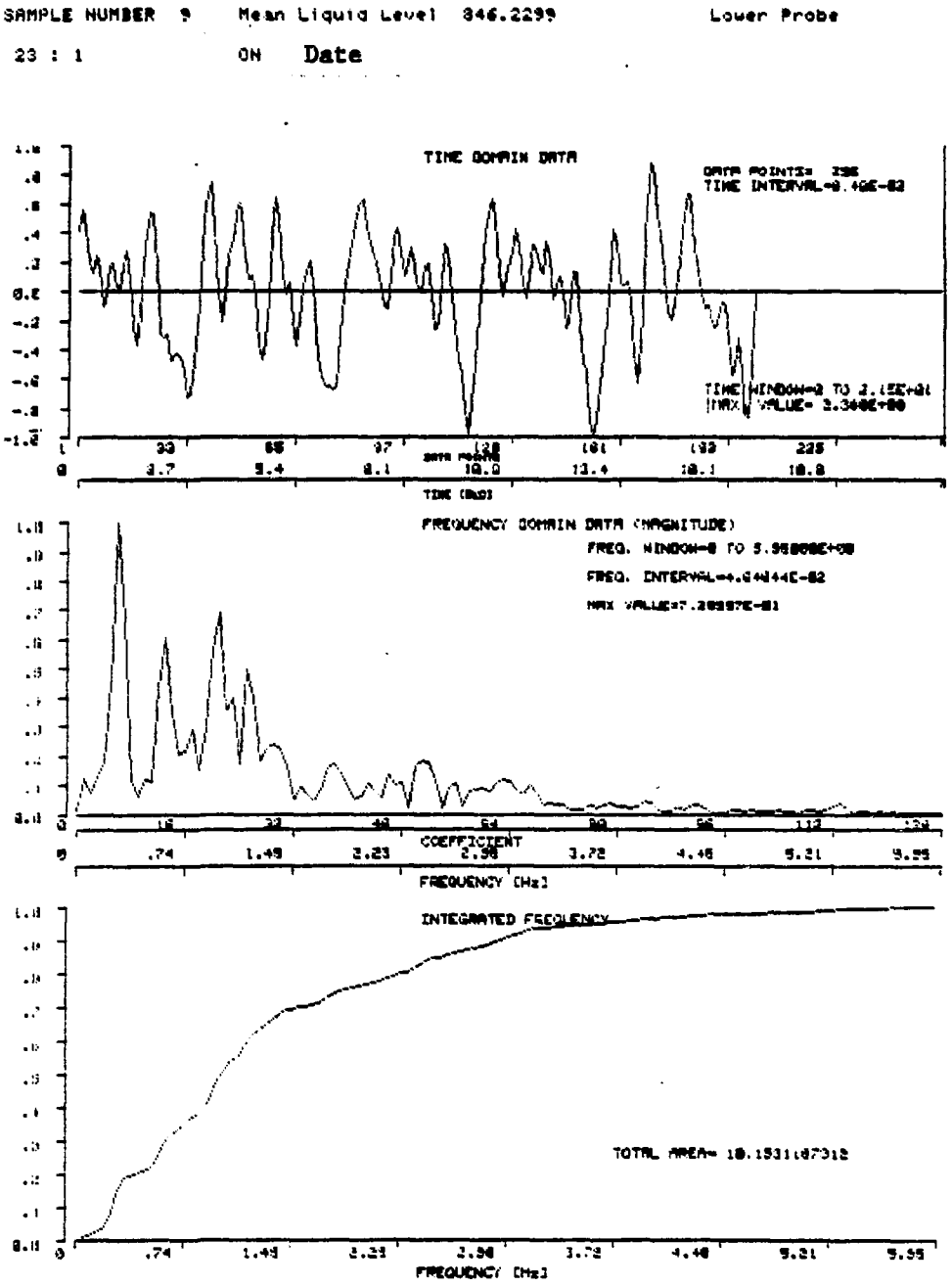


Figure C-1 Bubble Wave Form Pattern Analysis

Upper Plot: Raw Bubble Data

Middle Plot: Frequency plot using Fast Fourier transformations.

Lower Plot: Cumulative frequency