PNWD-3828
WTP-RPT-146 Rev. 0

Pulse Jet Mixer Controller and Instrumentation Testing

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February 2007

Prepared for Bechtel National, Inc.
under Contract No. 24590-101-TSA-W000-00004

LEGAL NOTICE

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Test specification:	24590-WTP-TSP-RT-05-002 Rev. 0
Test plan:	TP-RPP-WTP-428 Rev. 0
Test exceptions:	24590-WTP-TEF-RT-05-00002
	24590-WTP-TEF-RT-05-00003
	24590-WTP-TEF-RT-06-00001
	24590-WTP-TEF-RT-06-00002
	24590-WTP-TEF-RT-07-00001
R&T focus area:	Pretreatment & Vitrification
Test scoping statement(s):	B-100

for W. Tamosaitis 3/1/07
ACCEPTED FOR
WTP PROJECT USE

BATTELLE 75 YEARS OF INNOVATION

Battelle – Pacific Northwest Division
Richland, Washington, 99352

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Completeness of Testing

This report describes the results of work and testing specified by Test Specification 24590-WTP-TSP-RT-05-002, Rev. 0 and Test Plan TP-RPP-WTP-428 Rev. 0 as modified by test exceptions 24590-WTP-TEF-RT-05-00002, 24590-WTP-TEF-RT-05-00003, 24590-WTP-TEF-RT-06-00001, 24590-WTP-TEF-RT-06-00002, 24590-WTP-TEF-RT-07-00001. The work and any associated testing followed the quality assurance requirements outlined in the Test Specification/Plan. The descriptions provided in this test report are an accurate account of both the conduct of the work and the data collected. Test plan results are reported. Also reported are any unusual or anomalous occurrences that are different from expected results. The test results and this report have been reviewed and verified.

Approved:

Gordon H. Beeman, Manager
WTP R&T Support Project

2/9/07
Date

Testing Summary

The U.S. Department of Energy (DOE) Office of River Protection's Waste Treatment Plant (WTP) is being designed and built to pretreat and then vitrify a large portion of the wastes in Hanford's 177 underground waste storage tanks. The WTP consists of three primary facilities: pretreatment, low-activity waste vitrification, and high-level waste vitrification. The pretreatment facility receives waste feed from the Hanford tank farms and separates it into 1) a high-volume, low-activity liquid stream stripped of most solids and radionuclides and 2) a much smaller volume of HLW slurry containing most of the solids and radioactivity.

Many of the vessels in the pretreatment facility will contain pulse jet mixers (PJMs) that will provide some or all of the mixing in the vessels. This technology was selected for use in so-called "black cell" regions of the WTP where maintenance capability will not be available for the operating life of the WTP. PJM technology was selected for use in these regions because it has no moving mechanical parts that require maintenance. Vessels with the most concentrated slurries will also be mixed with air spargers and/or steady jets in addition to the mixing provided by the PJMs.

This report contains the results of tests conducted in a half-scale replica of the lag storage vessel constructed in one of the large tanks in the high bay of the Battelle – Pacific Northwest Division (PNWD) 336 Building test facility. The overall objectives of the work presented in this report are to generate sufficient experimental data to enable BNI to:

- Determine the selected WTP pressure transmitters ability to detect changes in the PJM drive and suction pressures required to properly control PJMs operations and safety functions
- Determine the effects of jet pump pair (JPP) supply air line length on pressure change detection, including the equivalent WTP piping configuration
- If unable to achieve acceptable results with existing control configuration, determine whether the deionized (DI) water wash line can be used as an alternative pressure measurement location.
- Determine the sensitivity of the control system to process changes, e.g., level, water, and simulant (rheology and density).

These tests used clay with rheological properties at the upper rheological bound and water that represented the lower rheological bound to provide data on various aspects of the WTP. The tests were conducted with a prototypic PJM control system. Data are provided for assessments of

- five different pressure transmitters
- various air-line lengths on the suction and drive legs of the PJM air supply
- use of a water flush line as an alternative pressure measurement location
- the sensitivity of the PJM control system to process changes such as tank level and rheology.

Although not an objective, the testing also included obtaining data to evaluate the effect of simulant type and level on the drive and suction times of the PJMs. These data were then used to develop a predictive model to estimate the time to overblow the PJMs.

Objectives

Table S.1 summarizes objectives and results of the PJM controller and instrumentation (C&I) testing.

Table S.1. Summary of Test Objectives and Results[(a)]

Test Objective	Objective Met?	Discussion
Determine ability of selected WTP pressure transmitters to detect changes in PJM drive and suction pressures required to properly control PJM operations and safety functions	Yes	The confidence peak information obtained from the various transmitters was carefully analyzed by BNI staff. They determined that the Weed and the Druck pressure transmitters provided better performance than the other transmitters (Foxboro 4-20 ma, Foxboro Foundation Fieldbus, ABB Foundation Fieldbus). Refer to Section 8 for the results of these tests.
Determine effects of JPP supply air line length on pressure change detection, including equivalent WTP piping configuration	Yes	Air supply line lengths up to 50 ft on the drive side and 125 ft on the suction side were evaluated. Results are presented in Section 7. Charge vessel full (CVF) is detected by the drive side pressure transmitter. Test results show that line length up to 50 ft has no significant effect on detection of CVF. A drive overblow event is detected by the suction line pressure transmitter. Testing results show that increasing JPP air supply line length has a detrimental effect on the ability of the control system to detect drive overblows. This difficulty resulted in testing the control system using the deionized (DI) water flush line for pressure measurements.
If unable to achieve acceptable results with existing controls configuration, determine if DI wash line can be used as alternative pressure measurement location	Yes	Tests conducted using the DI water wash line as an alternative pressure measurement location indicated that the pressure signal had a much greater magnitude and made it much easier for the PJM control system to detect a drive overblow event. These results are presented in Section 7 (also see discussion directly below).
Determine the sensitivity of the control system to process changes, e.g., level, water, and simulant (rheology and density)	Yes	The sensitivity of the control system to process changes such as simulant rheology and level is provided in Section 9. Results indicate that PJM control (CVF and drive overblow detection) is achievable with both Druck and Weed pressure transmitters over the range of simulant levels and types investigated. The CVF confidence signal is affected by simulant level and type. The drive overblow confidence signal was affected by simulant type, but no obvious trend was noted for varying the simulant level. The sensitivity of the control system to momentary changes in air and vent header pressure is presented in Section 10. Line pressure changes were induced by opening and closing the drive and suction valves on a pulse tube other than the one being controlled. Vent header pressure changes were induced by opening the header drain valve to reduce pressure and separately by blocking vent discharge. Results indicate that if PJMs are to be operated in different phases simultaneously, more testing is required to ensure that alternative phases would not cause false overblow and/or CVF detection.

(a) Test objectives and results associated with PJM mixing as specified in test specification 24590-WTP-TSP-RT-05-002 and Test Plan TP-RPP-WTP-428 Rev. 0 as modified by test exceptions 24590-WTP-TEF-RT-05-00002, 24590-WTP-TEF-RT-05-00003, 24590-WTP-TEF-RT-06-00001, 24590-WTP-TEF-RT-06-00002, and 24590-WTP-TEF-RT-07-00001 are discussed in WTP-RPT-155, *Assessment of Pulse Tube Mixing for Vessels Containing Non-Newtonian Slurries*.

Test Exceptions

A summary description of the test exceptions applied to the PJM C&I is shown in Table S.2

Table S.2. Test Exceptions

Test Exceptions	Description of Test Exceptions
24590-WTP-TEF-RT-05-00002	This test exception put a hold on the PJM controls testing.
24590-WTP-TEF-RT-05-00003	This test exception specified the requirements for releasing the hold on the PJM controls testing. It also canceled the following objectives: • Tune the PJM control algorithm for subsequent use in testing • Develop a methodology for tuning the PJM control algorithm for use in subsequent testing and during commissioning of the WTP. It also canceled the following success criterion: • Provide a methodology for testing and tuning the PJM control algorithm for use in subsequent testing and WTP commissioning. The test exception also added some scope associated with evaluation of the control system to respond to various operating scenarios. Some items were not completed at the direction of C&I staff and are not included in the report: item 1 (additional suction time required to move material 2 ft into air link line), item 4 (determine leak down rate), item 6 (collect raw data from pressure transmitters).
24590-WTP-TEF-RT-06-00001	This test exception specified additional mixing tests to be conducted to determine the number of full strokes required to fully mix PJM contents when the pulse tubes are operated at full-stroke. All results associated with pulse tube mixing are discussed in WTP-RPT-155, *Assessment of Pulse Tube Mixing for Vessels Containing Non-Newtonian Slurries*.
24590-WTP-TEF-RT-06-00002	This test exception specified an additional sampling port to be added to the test PJM to investigate the possibility of a stagnant zone in the pulse tube.
24590-WTP-TEF-RT-07-00001	This test exception deleted some of the additional scope specified in 24590-WTP-TEF-RT-05-00003 and specified that the results presented in this document should be published as a separate report, instead of combined with the results in WTP-RPT-155 *Assessment of Pulse Tube Mixing for Vessels Containing Non-Newtonian Slurries*

Results and Performance against Success Criteria

The research and technology success criteria are discussed in Table S.3.

Table S.3. Success Criteria

Success Criteria	How Testing Did or Did Not Meet Success Criteria
Establish pressure detection element and transmitter response to: PJM full of fluid, drive overblow, vent overblow, and aspiration for the WTP PJM system design envelope	Test results provide data on pressure detection element and transmitter response to CVF and drive overblow. The signals from a vent overblow were found to be too small for practical detection and control. The signal for aspiration with drive line length of 50 ft and suction line length of 125 ft also indicated that aspiration could not be detected.

Table S.3 (contd)

Establish effect of piping length on pressure detection element and transmitter response to PJM: full of fluid, drive overblow, vent overblow, and aspiration and define the maximum piping length (within current plant layouts limits) for detectable PJM response	The effect of line length on PJM control is reported in Section 7. Line length was found to play a far more important role in drive overblow detection than in CVF detection. Results also indicate that other means of overblow detection are needed for cases in which each PJM must be operated individually to establish drive times for various operating conditions. To improve drive overblow detection capability, a new approach involving measuring the pressure in the flush line was incorporated into the control algorithm. Drive overblows were successfully detected with the modified algorithm and pressure measurement in the flush line even when only one PJM was operating. The signals for vent overblow and aspiration were too small for practical detection when measuring the pressure change at the JPP.
Compare the performance of the WTP PJM pressure detection system with proposed alternatives	Data on performance of five different pressure transmitters are presented in Section 8. The confidence peak information obtained from the various transmitters was carefully analyzed by BNI staff, who determined that the Weed and Druck pressure transmitters performed better than others (Foxboro 4-20 ma, Foxboro Foundation Fieldbus, ABB Foundation Fieldbus).
Assess the reliability (probability) of accurately detecting PJM normal and non-normal test events	A statistical analysis of results was not completed due to an intermittent problem with the data logger for the PJM controller, which was found to occasionally rewrite the previous row of data instead of new values from the PJM control system. While many data were not affected, the large volume made it impractical to sort and select results that were not affected by this issue in the quantity required for a statistical analysis. Careful review of the data by PNWD and BNI staff indicates that the data logging problems do not prevent drawing broad conclusions regarding the performance of the transmitters or line length effect. In addition, the capacity of the plant-scale JPPs used in these tests was four times the flow requirements of the PJM nozzles. This creates non-prototypic pressure signals at the PJM controller and limits the usefulness of a statistical analysis for assessing plant prototypic behavior. Additional work in this area has been proposed, using a 4 PJM system with 4-inch nozzles that more closely matches the plant design. The need for additional work with the 4 PJM system is recommended in the section, "Discrepancies and Follow-on Tests."

Quality Requirements

Battelle – Pacific Northwest Division's (PNWD) Quality Assurance Program is based on the requirements defined in U.S. Department of Energy (DOE) Order 414.1A, Quality Assurance, and 10 CFR 830, Energy/Nuclear Safety Management, Subpart A—Quality Assurance Requirements (also known as the Quality Rule). PNWD has chosen to implement the requirements of DOE Order 414.1A and 10 CFR 830 Subpart A by integrating them into the Laboratory's management systems and daily operating processes. The procedures needed to implement the requirements are documented through PNWD's Standards-Based Management System.

PNWD implements the WTP quality requirements by performing work in accordance with the PNWD WTP Support Project quality assurance project plan (QAPjP) approved by the WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, Basic and Supplementary Requirements, NQA-2a-1990 Part 2.7, and DOE/RW-0333P Rev. 13, Quality

Assurance Requirements and Description. These quality requirements are implemented through PNWD's WTP Support Project (WTPSP) Quality Assurance Requirements and Description Manual.

As specified in Test Specification 24590-WTP-TSP-RT-05-002 Rev. 0, *Pulse Jet Mixer Controls Testing*, Bechtel National Incorporated's (BNI) QAPjP, PL-24590-QA00001, is not applicable because the work will not be performed in support of environmental/regulatory testing, and the data will not be used as such. Also, the DOE/RW-0333P Rev 13 QARD was not imposed by the Test Specification because the work is not high-level-waste quality affecting.

In spite of steps taken to ensure the integrity of the data, an intermittent data logging issue was uncovered during the review of the data files obtained with the PJM controller data logger. It was found that occasionally the data logger did not receive new data from the OLE[a] process control (OPC) server, so it duplicated previous data. This problem is thought to be due to the OPC server occasionally being a scan behind the PJM controller. The PJM controller, OPC server, and data logger were set at 250-ms scan intervals. If the data logger asked the OPC server for new data at the end of the interval and the OPC server hadn't updated from the PJM controller yet, the OPC server gave the data it had (last scan data) to the data logger.

The large volume of data collected during the testing made it impractical to sort through and select results that were not affected by this issue in the quantity required for a rigorous statistical analysis. Therefore, plots of selected portions of the data are included to provide qualitative information. This issue is not apparent in plots of the data because the variation from one data sampling event to the next is generally small. Careful review of the data by PNWD and BNI staff indicates that the data logging problems do not prevent drawing broad conclusions regarding the performance of the transmitters or line length effects because the trends remain the same, but the peak confidence values were in some cases affected.

Prior to testing, the PJM controller and associated software was verified and validated by BNI before using it. The BNI-furnished PJM pressure control software dedicated for C&I PJM testing was provided to PNWD as Quality Affecting Software as defined and controlled within BNI procedures.[b] The software was determined to be Quality Affecting software by WTP QA surveillance before it was transferred to PNWD for use. PNWD implemented the software and confirmed its functionality[c] in accordance with the PNWD QA program. WTP QA performed a surveillance of the software implementation before it was used for data collection.[d]

Experiments that were not method-specific were performed in accordance with PNWD procedures QA-RPP-WTP-1101, "Scientific Investigations," and QA-RPP-WTP-1201, "Calibration Control System," ensuring that sufficient data were taken with properly calibrated measurement and test equipment to obtain quality results.

(a) OLE stands for Object Linking and Embedding

(b) Mills WC to GH Beeman. December 7, 2005. "Transmittal of QAS Software for Pulse Jet Mixer Controls Testing," CCN:133507.

(c) TI-RPP-WTP-429, Pre-FAT Test Plan/Test report, 12/9/05.

(d) 24590-WTP-SV-QA-06-014, BNI/WTP QA Surveillance Report, "PJM Testing–Software Review and Release for Testing, 1/12/06."

Reportable measurements of distance were made using standard commercially available equipment (e.g., tape measure, scale) and needed no traceable calibration requirements. All other test equipment generating reportable data were calibrated according to PNWD's WTPSP QA program. The DASYLab software used to acquire data from the sensors was verified and validated by PNWD WTPSP staff before use, and BNI conducted an acceptance surveillance of the verification and validation activities with no problems noted.

PNWD addresses internal verification and validation activities by conducting an independent technical review of the final data report in accordance with PNWD procedure QA-RPP-WTP-604. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based, and that the reported work satisfies the objectives of the Test Plan. This review procedure is part of PNWD's WTPSP QA Requirements and Description Manual.

Simulant Use

Two simulants were used in this testing and were selected to bound the expected rheological properties to be encountered in the WTP. Water was used to provide a fluid with rheological properties at the lower bound. A kaolin-bentonite clay mixture was selected to provide a fluid with rheological properties at the upper bound. The clay simulant used was selected based on actual waste slurry rheology measurements that indicate the WTP non-Newtonian waste stream can be represented by a Bingham plastic rheology model, which is represented by

$$\tau = \kappa\dot{\gamma} + \tau_y \tag{S.1}$$

where

τ = shear stress

κ = consistency factor

$\dot{\gamma}$ = shear rate or strain rate

τ_y = Bingham yield stress, the assumed minimum stress required to initiate fluid movement as determined by a flow curve obtained by fitting rheological data using a Bingham plastic rheological model.

The non-Newtonian waste stream upper bounding rheological values of τ_y = 30 Pa and κ = 30 cP were identified based on limited data from actual waste slurries that can be represented by a Bingham plastic rheology model (Poloski et al. 2006). These values provide the basis for the simulant used for this testing. Additional information on the selection and development of the kaolin-bentonite clay simulant may be found in Poloski et al. (2004).

Discrepancies and Follow-on Tests

Additional testing with the 4-PJM system is recommended to provide data to meet the success criteria: assess the reliability (probability) of accurately detecting PJM normal and non-normal test events.

A mismatch between the capacity of the JPPs and the volumetric flow through the PJM nozzles arises because the JPPs are full size (plant prototypic), while the PJM geometry is half scale. The nozzles have a 2-inch inside diameter, which is one-half the full-scale nozzle diameter of 4 inches. At a constant nozzle velocity, the volumetric flow rate is proportional to the nozzle area and proportional to the square of the nozzle diameter. This means that the capacity of the JPPs was four times the flow rate through the nozzles, resulting in nonprototypic pressure signals at the PJM controller and limited usefulness of a statistical analysis for assessing plant prototypic behavior.

Aspiration and vent overblow could not be detected when measuring the pressure change at the JPP. This is possibly because of the mismatch between the capacity of the JPPs and the volumetric flow through the PJM nozzles. If detection of aspiration and vent overblow are important to the WTP, additional testing should be conducted with the 4-PJM system using pressure measurements from the flush line.

A statistical analysis of the results was not completed due to an intermittent problem with the data logger for the PJM controller. The data logger was found to occasionally rewrite the previous rows of data instead of the new values provided by the PJM control system. While many of the data were not affected, the large volume made it impractical to sort through and select results that were not affected by this issue.

Additional testing with the 4-PJM system is therefore recommended to obtain data for a reliability assessment. The 4-PJM system includes pulse tubes with a plant prototypic nozzle diameter of 4 inches. The JPP capacity will be reasonably matched to the volumetric flow requirements for the pulse tubes. Different data logging hardware and software should be used and should be rigorously tested to ensure that all data are captured correctly.

An operational issue associated with slurry creep was encountered during the testing, when clay deposits were observed throughout the air lines, the JPP rack, and the vent system due to slurry creep and carryover. While the system was not always operated in a prototypic manner and did not have a slurry wash-down system to minimize slurry creep, this issue warrants additional investigation to support mitigation efforts in the WTP. Also, upon request by the client, included in this report is some discussion about sparger plugging. This occurred during the testing of gas retention and release in 2005 and was not reported in Bontha et al. (2005). The spargers plugged for an estimated 4 ft on several occasions and required a significant effort to unplug. The plugs were driven out with a PVC pipe.

Summary References

Bontha JR, CW Stewart, DE Kurath, PA Meyer, ST Arm, CE Guzman-Leong, MS Fountain, M Friedrich, SA Hartley, LK Jagoda, CD Johnson, KS Koschik, DL Lessor, F Nigl, RL Russell, GL Smith, W Yantasee, and ST Yokuda. 2005. *Technical Basis for Predicting Mixing and Flammable Gas Behavior in the Ultrafiltration Feed Process and High-Level Waste Lag Storage Vessels with Non-Newtonian Slurries*. PNWD-3676 (WTP-RPT-132 Rev. 0), Battelle – Pacific Northwest Division, Richland, Washington.

Poloski AP, PA Meyer, LK Jagoda, and PR Hrma. 2004. *Non-Newtonian Slurry Simulant Development and Selection for Pulsed Jet Mixer Testing.* PNWD-3495 (WTP-RPT-111 Rev. 0), Battelle – Pacific Northwest Division, Richland, Washington.

Poloski AP, ST Arm, OP Bredt, TB Calloway, Y Onishi, RA Peterson, GL. Smith, HD Smith. 2006. *Final Report: Technical Basis for HLW Vitrification Stream Physical and Rheological Property Bounding Conditions.* PNWD-3675 (WTP-RPT-112 Rev. 0), Battelle – Pacific Northwest Division, Richland, Washington.

Contents

Figures

Tables

Acronyms and Abbreviations

BNI	Bechtel National, Inc.
C&I	Control and Instrumentation
CVF	charge vessel full
D	diameter of the supernate tank (half-scale lag storage tank)
DAS	data acquisition system
DOB	drive overblow
DOE	U.S. Department of Energy
FF	Foundation Fieldbus
H	height of slurry in the supernate tank (half-scale lag storage)
HLW	high-level waste
HSLS	half scale lag storage tank
ID	Internal diameter
ITS	important-to-safety
OPC	OLE for process control
JPP	jet pump pairs
PJM	pulse jet mixer
PNWD	Battelle – Pacific Northwest Division
PRESCON	UK AEA proprietary technology for PJM control
QA	quality assurance
QARD	Quality Assurance Requirements Document
R&T	Research & Technology
RPP	River Protection Project
UK AEA	United Kingdom Atomic Energy Agency
WTP	Waste Treatment Plant

1.0 Introduction

1.1 Pulse Jet Mixers and Waste Treatment Plant Mixing

The U.S. Department of Energy (DOE) Office of River Protection's Waste Treatment Plant (WTP) is being designed and built to pretreat and then vitrify a large portion of the wastes in Hanford's 177 underground waste storage tanks. The WTP consists of three primary facilities: pretreatment, low-activity waste vitrification, and high-level waste (HLW) vitrification. The pretreatment facility receives waste feed from the Hanford tank farms and separates it into 1) a high-volume, low-activity liquid stream stripped of most solids and radionuclides and 2) a much smaller-volume HLW slurry containing most of the solids and most of the radioactivity.

Many of the vessels in the pretreatment facility will contain pulse jet mixers (PJMs) that will provide some or all of the mixing in the vessels. This technology had been selected for use in so-called "black cell" regions of the WTP where maintenance capability will not be available for the operating life of the WTP. PJM technology was selected for use in these regions because it has no moving mechanical parts that require maintenance. The vessels with the most concentrated slurries will also be mixed with air spargers and/or steady jets in addition to the mixing provided by the PJMs.

PJMs consist of several pulse tubes, which are primarily large cylindrical tubes with one end tapered down to a nozzle with a diameter smaller than that of the tube. The other end of the pulse tube is connected to an air/vacuum line. In slurry mixing applications, several of these pulse tubes are incorporated into the mixing vessel and operated either in series or in parallel to achieve the desired mixing. Pulse jet mixing technology represents a simple method to mix slurries using compressed air to achieve the desired operation.

The vessels with the PJMs are expected to contain tank waste slurries with a range of solids concentrations. The dilute slurries are expected to exhibit a Newtonian rheology. The most concentrated slurries are expected to exhibit a non-Newtonian rheology, which is generally characterized with a Bingham plastic model.

1.2 Mechanism of PJM Operation

Figure 1.1 illustrates PJM operation in a single pulse-tube system. The PJM cycle consists of three phases: 1) suction, where slurry is withdrawn from the mixing vessel into the pulse tube by application of a vacuum, 2) drive, where slurry is ejected back into the mixing vessel under pressure, and 3) vent, where the compressed air inside the pulse tube is released by venting to the atmosphere. This cycle is repeated until the tank contents are adequately mixed.

PJM operation is controlled by opening and closing the valves supplying air to the jet pump pairs (JPP), which in turn control the air flow to the pulse tube. Four different events are of importance when considering a control system for the operation of PJMs: 1) charge vessel full, 2) drive overblow, 3) vent overblow, and 4) aspiration. These four items are discussed below.

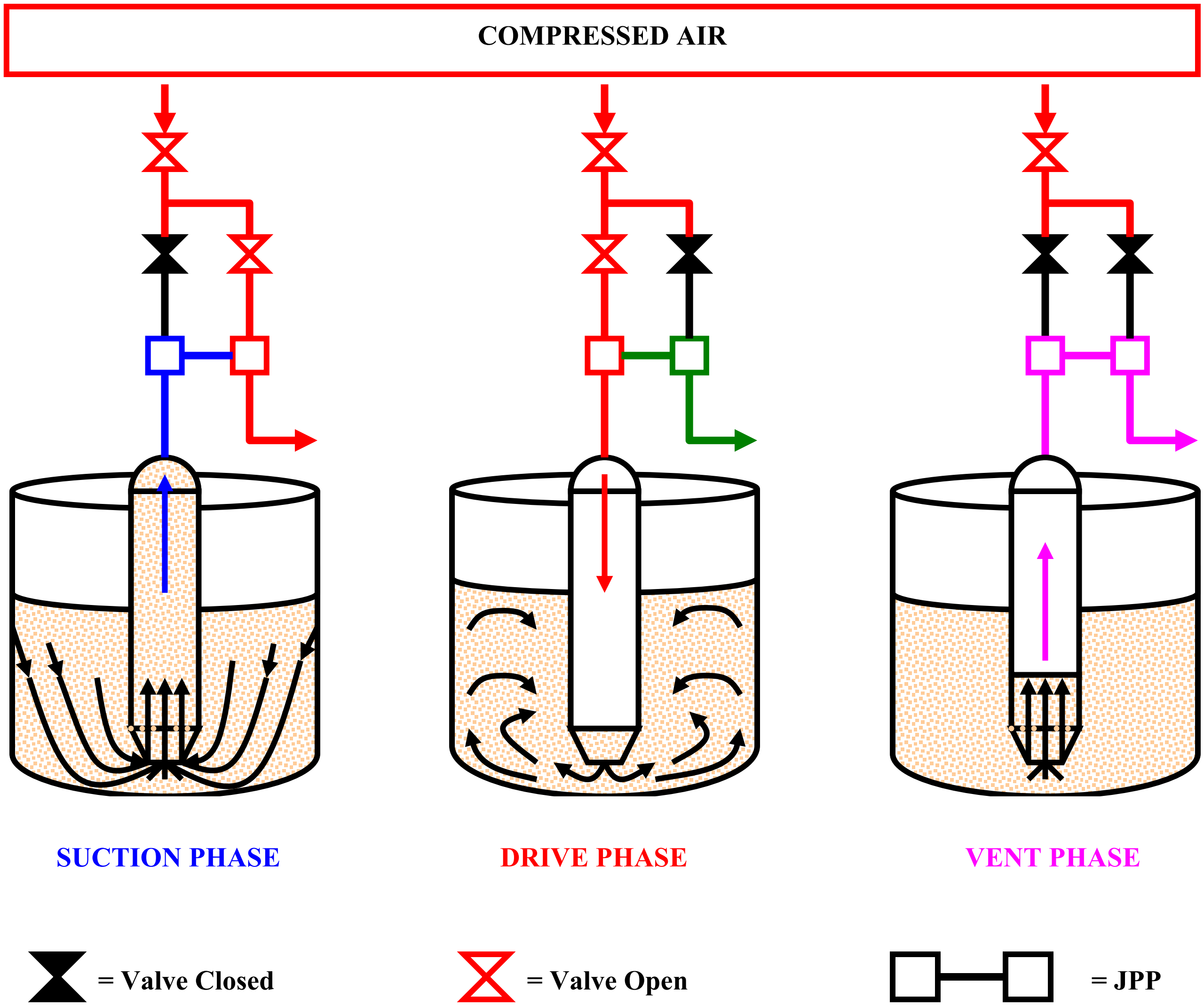

Figure 1.1. Schematic of the Different Phases in a PJM Cycle Control of PJM Operation

1.2.1 Charge Vessel Full

Charge vessel full (CVF) detection corresponds to the event in a PJM operational cycle when the pulse tube is full and the suction phase can be terminated. Accurate CVF detection is important in PJM operation because 1) it ensures that the PJMs are full before the drive phase begins, 2) it minimizes the amount of slurry being drawn into the air lines above the PJMs, thereby reducing slurry creep[(a)] and 3) it ensures that all PJMs are full prior to the drive phase. In addition to minimizing the amount of slurry in the air vacuum lines, early CVF detection also helps reduce compressed air use and maximize the time the PJMs are engaged in mixing.

(a) Slurry creep represents the phenomenon of slurry slowly creeping up the air lines and eventually into the JPPs and associated vent systems. Reducing slurry creep is of critical importance to plant operation because the faster the material creeps up the air lines, the more frequently the air lines will need to be washed down.

1.2.2 Drive Overblow

A drive overblow event represents the condition when a PJM is in the drive phase and the slurry and liquids are completely expelled from the pulse tube. This allows a significant volume of pressurized air to escape from the pulse tube nozzle. Drive overblow detection is critical to PJM operation because the pressurized air escaping from the PJM will create a significant pressure pulse inside the tank. Such pressure pulses have the potential to affect the lifetime of the tank internals. Consequently, it is important to have a PJM control system that minimizes the possibility of drive overblows.

1.2.3 Vent Overblow

Another kind of overblow, known as the vent overblow, occurs when the slurry and liquids are completely expelled from the pulse tube after the drive valve is closed. A vent overblow occurs due to residual pressure in the pulse tube as well as residual motion of the slurry. The major difference between the two kinds of overblows is that the volume of air escaping from the PJM during a vent overblow is less than that during the drive overblow.

1.2.4 Aspiration

If the slurry level in a vessel is lowered beyond a minimum point, the level will fall below the bottom opening in the pulse tubes, and air can be entrained into the pulse tube during the suction phase. This is known as aspiration. At tank levels below the aspiration point, PJM operation will not be possible because the pulse tubes will not fill. Accurate determination of when the PJMs are aspirating is important to plant operation because it will help reduce compressed air use and minimize slurry creep and carryover. The control system is designed to stop the PJMs if aspiration is detected.

1.3 Objectives of Testing

The objectives of the PJM control system tests are to generate sufficient experimental data to enable BNI to:

- Determine the ability of the selected WTP pressure transmitters to detect changes in the PJM drive and suction pressure required to properly control PJM operations and safety functions
- Determine the effects of JPP supply air line length on pressure change detection, including the equivalent WTP piping configuration
- Determine whether the deionized water (DI) wash line can be used as an alternative pressure measurement location if unable to achieve acceptable results with the existing controls configuration
- Determine the sensitivity of the control system to process changes, e.g., level, water, and simulant (rheology and density).

1.4 Scope of Testing

The PJM controller algorithm uses pressure measurement at the JPP rack as the primary means of detecting CVF, drive overblow, vent overblow, and PJM aspiration. Therefore, successful implementation of the control algorithm depends on 1) the magnitude of the pressure change and 2) the type of transmitter chosen and its ability to respond quickly to a change in the system pressure. The former is affected by the JPP rack design (i.e., length of piping between the location of the pressure change and the measurement location) and test conditions (i.e., simulant type and fill level, JPP pressures), while the latter is affected by pressure transmitter selection (sensor type and electronics such as analog 4-20 mA units, foundation fieldbus (FF) units, etc.). The testing program was designed to address all these issues.

In this regard, a series of tests was conducted in a half-scale replica of the lag storage vessel at the Battelle – Pacific Northwest Division's (PNWD) 336 Building Test Facility. These tests were conducted with a clay simulant and then water to evaluate the PJM control system over the full range of rheological properties expected in the vessels with PJMs. Water was used to simulate a low-viscosity Newtonian fluid. A clay slurry containing ~28 wt% of an 80/20 mixture of bentonite and kaolin in water was used to simulate a high-viscosity, non-Newtonian slurry with a yield stress of ~30 Pa (based on the Bingham plastic rheological model). Five different pressure transmitters (two project-preferred transmitters along with three others) were evaluated by connecting them to the system in an identical manner. Tests were conducted at high and low fill levels with clay and water to evaluate the effect of simulant properties and level in the tank. The effect of air supply line length between the JPP rack and the pressure transmitters was investigated by installing various line lengths on the drive and suction legs of one of the pulse tubes.

The scope of work presented in this report covers the following main aspects of the controller and instrumentation testing: 1) PJM tuning, 2) assessment of JPP line length on pressure transmitter response, 3) PJM control (particularly drive overblow detection) using pressure measured in the PJM water flush line, 4) assessment of the sensitivity of the control system to process changes, and 5) exploratory testing. In addition, the report also covers operational issues and observations made during the present testing. The following is a brief description of the above listed topics.

1. PJM tuning: Before applying the control logic to operate the PJMs, certain parameters or "System Constants" within the code need to be specified. The values of these system constants depend on the specific PJM/JPP/tank/simulant configuration being used and need to be specified or determined during commissioning. The system constants included setting the jet pump drive and suction air pressures and establishing confidence thresholds for detecting PJM CVF, PJM aspiration, PJM drive overblow, and PJM vent overblow. Such parameter adjustments or settings constitute tuning the PJM controller. The tuning was conducted using the Druck pressure transmitter with no (0 ft) pipe extension between the JPP and the pressure transmitter. Primary tuning of the PJM control parameters was performed using clay simulant with a sufficiently full tank.[a] Results of the PJM tuning process are discussed in Section 6. As the simulant type and level changed, some tuning parameters had to be changed to ensure proper PJM operation during testing. These adjustments are discussed in the appropriate section of the results.

(a) he maximum simulant fill level used in the present testing was ~60-inches (as measured from the tank rim). This level was set primarily based on concerns regarding slurry spillover during the overblow phase of testing.

2. Assessment of JPP Line Length on Pressure Transmitter Response: Previous United Kingdom Atomic Energy Agency (UK AEA) experience suggests that a maximum of 15 ft of piping should be used between the pressure transmitters and the JPP. The WTP design requires up to 44 ft of piping between the pressure transmitter and the drive side of the JPP and up to134 ft between pressure transmitters and the suction side of the JPP. The air line creates an additional volume between the JPP and the pressure transmitters and can significantly dampen the pressure signal used to control the PJMs. To evaluate the effect of line length, a series of tests was conducted in which the length of the air line between the pressure transmitter and the JPP was varied. The effect of air lines up to 50 ft on the drive leg and 150 ft on the suction leg was assessed. Results are presented in Section 7.

3. Assessment of Flush Line Pressure for PJM Control: In addition to assessing the effect of line length, using pressure measurements via the demineralized water flush line was also investigated as an alternative means of achieving PJM control (particularly for drive overblow detection). These results are also presented in Section 7.6.

4. Pressure Transmitter Performance: The effect of the type and electronics of the pressure transmitter selection on PJM control was tested using the following five pressure transmitters: 1) Foxboro analog, (2) Foxboro FF, (3) ABB FF, (4) Weed, and (5) Druck. Pairs of these pressure transmitters were attached to both the drive and suction side of the JPP for PJM #5. The pressure transmitters were attached in an identical manner using spool pieces. For these tests, the length of the air line between the pressure transmitters and the JPPs was essentially constant so the effect of the pressure transmitter response time could be isolated. The results of this assessment are discussed in Section 8.

5. Sensitivity of Control System to Process Changes: The sensitivity of the control system to process conditions (i.e., simulant type and level in tank) were determined using two simulants (clay and water) at three different fill heights. These results are presented in Section 9.

6. Exploratory Testing: Pressure variations induced by the WTP ventilation system and asynchronous PJM operation have the potential to affect the operation of the PJM control system. This potential was investigated by inducing pressure transients in the vent system and by operating one PJM slightly out of phase with the other PJMs. The results of these tests are presented in Section 10.

7. Enhancements to PJM Control Strategy: While performing the tests described in this report, several possible enhancements to the PJM control strategy were identified. These enhancements, discussed in Section 11, should be considered for incorporation into the PJM control strategy.

8. Variation of Drive and Suction Times: Crucial to the control of the PJM operation is the variation of the drive and suction times with the type and fill-level of the simulant. In Section 12, experimental data investigating the effect of simulant type and level on the drive/suction times and a model to predict the drive overblow time are presented.

9. Operational Issues and Observations: During the testing, operational issues associated with slurry creep were encountered when clay deposits were observed throughout the air lines, the JPP rack, and the vent system due to slurry creep and carryover. This issue is presented in Appendix B. Also, upon request by the client, included in Appendix B is some discussion about sparger plugging. This occurred during the testing of gas retention and release in 2005 and was not

reported in Bontha *et al*. 2005. The spargers plugged for an estimated 4 ft on several occasions and required a significant effort to unplug. The plugs were driven out with a PVC pipe.

2.0 Quality Requirements

Battelle – Pacific Northwest Division's (PNWD) Quality Assurance Program is based on the requirements defined in U.S. Department of Energy (DOE) Order 414.1A, "Quality Assurance," and 10 CFR 830, "Energy/Nuclear Safety Management," Subpart A—Quality Assurance Requirements (also known as the Quality Rule). PNWD has chosen to implement the requirements of DOE Order 414.1A and 10 CFR 830 Subpart A by integrating them into the Laboratory's management systems and daily operating processes. The procedures needed to implement the requirements are documented through PNWD's Standards-Based Management System.

PNWD implements the WTP quality requirements by performing work in accordance with the PNWD WTP Support Project (SP) quality assurance project plan (QAPjP) approved by the WTP Quality Assurance (QA) organization. This work was performed to the quality requirements of NQA-1-1989 Part I, "Basic and Supplementary Requirements," NQA-2a-1990 Part 2.7, and DOE/RW-0333P Rev. 13, "Quality Assurance Requirements and Description." These quality requirements are implemented through PNWD's WTPSP *Quality Assurance Requirements and Description Manual*.

As specified in Test Specification 24590-WTP-TSP-RT-05-002 Rev. 0, "Pulse Jet Mixer Controls Testing," BNI's QAPjP, PL-24590-QA00001, is not applicable because the work will not be performed in support of environmental/regulatory testing, and the data will not be used as such. Also, DOE/RW-0333P Rev 13 QARD was not imposed by the test specification because the work is not high-level waste quality affecting.

In spite of steps taken to ensure the integrity of the data, an intermittent data logging issue was uncovered during the review of the data files obtained with the PJM controller data logger. The data logger was found to occasionally not receive new data from the OPC (OLE for process control)[a] server, thus resulting in duplicate data being logged. This problem is thought to be due to the OPC server occasionally being a scan behind the PJM controller. The PJM controller, OPC server, and data logger were set at 250 ms scan intervals. If the data logger asked the OPC server for new data at the end of the interval and the OPC server hadn't updated from the PJM controller yet, the OPC server gave the data it had (last scans data) to the data logger.

The large volume of data collected during the testing made it impractical to sort through and select results that were not affected by this issue in the quantity required for a rigorous statistical analysis. Therefore, plots of selected portions of the data are included to provide qualitative information. This issue is not apparent in plots of the data because the variation from one data sampling event to the next is generally small. Careful review of the data by PNWD and BNI staff indicates that the data logging problems do not prevent drawing broad conclusions regarding the performance of the transmitters or line length effects because the trends remain the same, but the peak confidence values were in some cases affected.

(a) OLE stands for Object Linking and Embedding.

Prior to testing, the PJM controller and associated software was verified and validated by BNI. The BNI-furnished PJM pressure control software dedicated for control and instrumentation (C&I) testing was provided to PNWD as quality-affecting software, as defined and controlled within BNI procedures.[a] The software was determined to be quality-affecting by WTP QA surveillance before it was transferred to PNWD. PNWD implemented the software and confirmed its functionality[b] in accordance with the PNWD QA program. WTP QA performed a surveillance of the software implementation prior to software use for test data collection.[c]

Experiments that were not method-specific were performed in accordance with PNWD procedure QA-RPP-WTP-1101, "Scientific Investigations," and QA-RPP-WTP-1201, "Calibration Control System," ensuring that sufficient data were taken with properly calibrated measurement and test equipment to obtain quality results.

Reportable measurements of distance were made using standard commercially available equipment (e.g., tape measure, scale) and needed no traceable calibration requirements. All other test equipment generating reportable data were calibrated according to the PNWD WTPSP QA program. The DASYLab software used to acquire data from the sensors was verified and validated by PNWD WTPSP staff prior to use, and BNI conducted an acceptance surveillance of the verification and validation activities with no problems noted.

PNWD addresses internal verification and validation activities by conducting an independent technical review of the final data report in accordance with PNWD procedure QA-RPP-WTP-604. This review verifies that the reported results are traceable, that inferences and conclusions are soundly based and that the reported work satisfies the Test Plan objectives. This review procedure is part of PNWD's WTPSP Quality Assurance Requirements and Description Manual.

(a) Mills WC to GH Beeman, "Transmittal of QAS Software for Pulse Jet Mixer Controls Testing," CCN:133507, December 9, 2005.
(b) TI-RPP-WTP-429, Pre-FAT Test Plan/Test report, 12/9/05.
(c) 24590-WTP-SV-QA-06-014, BNI/WTP QA Surveillance Report, "PJM Testing – Software Review and Release for Testing, 1/12/06."

3.0 PJM Control Approach

The strategy used to control the operation of the PJMs has been developed primarily by UK AEA. It has been adapted to meet the WTP plant operational and safety requirements. This section presents the basic concepts used in the development of the control strategy.[a] Also presented is a discussion of the impact of the plant design on achieving PJM control and the modifications made to overcome the operational limitations observed during the current testing.

3.1 Controls Concept

The PJM control strategy is shown schematically in Figure 3.1. Here, depending on the stage of the PJM cycle, the controller opens or closes the drive and the suction valves, V_d and V_s, respectively. This in turn affects the pressure measured on the drive (P_j) and suction (P_r) side of the JPP, as shown in Figure 3.1.

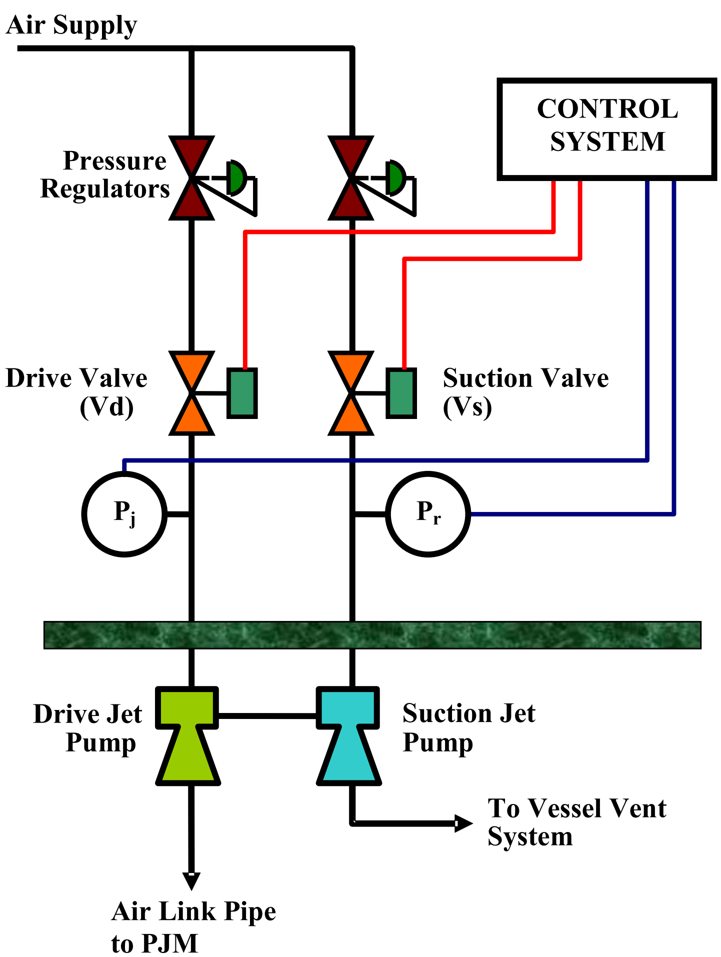

Figure 3.1. Schematic of the PJM Controller Implementation Arrangement

(a) For more detailed information about the UK AEA control strategy, please see Dean A. 9/14/2004. "PRESCON Control Algorithm Design Guide."24590-QL-POA-MPEO-00002-14-01 Rev. 0.0, UK AEA, UK.

During the PJM operation, the transient pressures P_r and P_j exhibit characteristic changes that are indicative of the occurrence of the events of CVF, drive overblow, vent overblow, and aspiration. The UK AEA control system is designed to recognize these changes and triggers the opening or closing of the appropriate valves to continuously operate the PJM.

To determine the occurrence of the various PJM events during the suction, drive, and vent phases, the control system computes two key variables labeled “gain” and “confidence.” The gain for the three phases is shown below:

Suction phase: gain = P_j/P_r
Drive phase: gain = P_r/P_j
Vent phase: gain = $(P_j/P_d)^{½}$

In these equations, P_r and P_j are as defined previously, and P_d is the final value of the drive pressure at the end of the drive phase. In control logic terms, the gain can be viewed as a transfer function obtained by dividing the output by the input. Depending upon the PJM operational phase, the suction and drive pressures are used as the input and/or output variables for the gain calculation. The variable “confidence” can be viewed as a statistical parameter calculated from the variance in the gain and is used to differentiate random fluctuations in the pressure signals from the changes that occur during the various PJM events of CVF, drive overblow, and vent overblow.

In the following sections, typical profiles for the drive and suction pressures and the computed gain and confidence during the suction, drive, and vent phase are provided.

3.1.1 Suction Phase and Charge Vessel Full

During the suction phase, the drive valve (V_d) is closed, and the suction valve (V_s) is open. Therefore, P_r measures the supply pressure, and P_j detects the pressure in the air link-line to the pulse tube. Figure 3.2 shows an example[(a)] of the resultant transients P_r and P_j measured during a typical PJM suction phase, and Figure 3.3 shows the calculated gain and confidence profiles. In Figure 3.2, the suction pressure is shown on the primary y-axis, while the drive pressure is shown on the secondary y-axis. The same is the case with Figure 3.3, where the gain is shown on the primary y-axis and the confidence on the secondary y-axis.

It can be seen in Figure 3.2 that during the suction phase, the suction pressure (P_r) remains fairly constant throughout the drive phase, and the drive side pressure (P_j) gradually decreases as a vacuum builds up in the pulse tube. As the liquid level in the pulse tube rises above the top of the pulse tube and into the air link-line, the drive pressure decreases more rapidly because of a sudden reduction in the pipe diameter between the pulse tube and the air link-line. This translates to a sudden depression in the gain

(a) Examples used in Section 3 are taken from "PRESCON Control Algorithm Design Guide," by A. Dean, 9/14/2004. 24590-QL-POA-MPEO-00002-14-01 Rev. 0.0, UK AEA, UK.

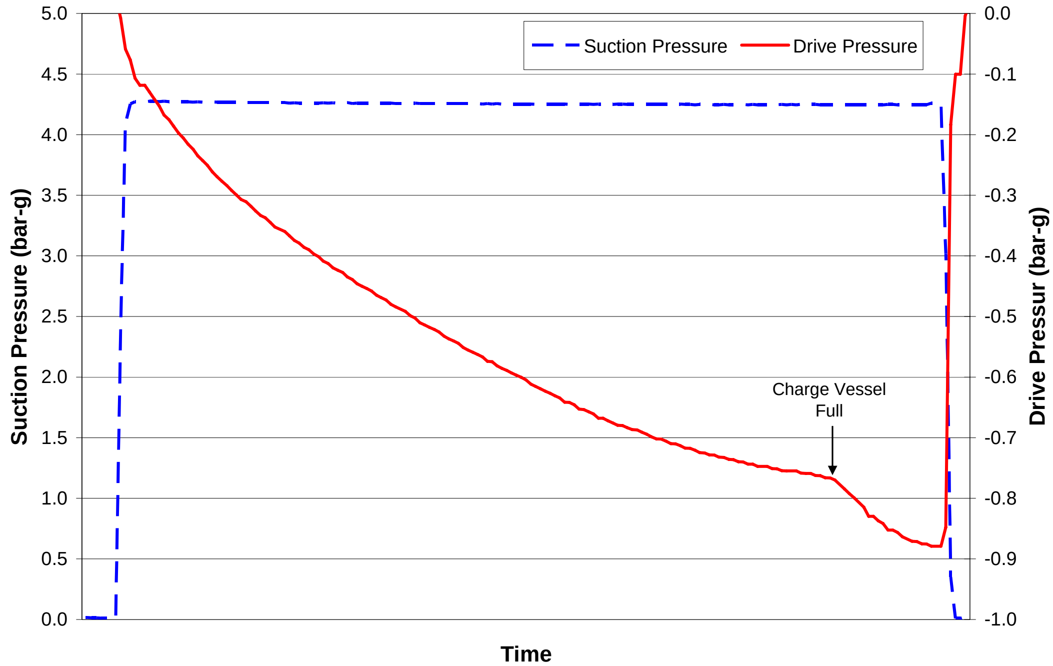

Figure 3.2. An Example of Typical Drive and Suction Pressure Profiles During the Suction Phase

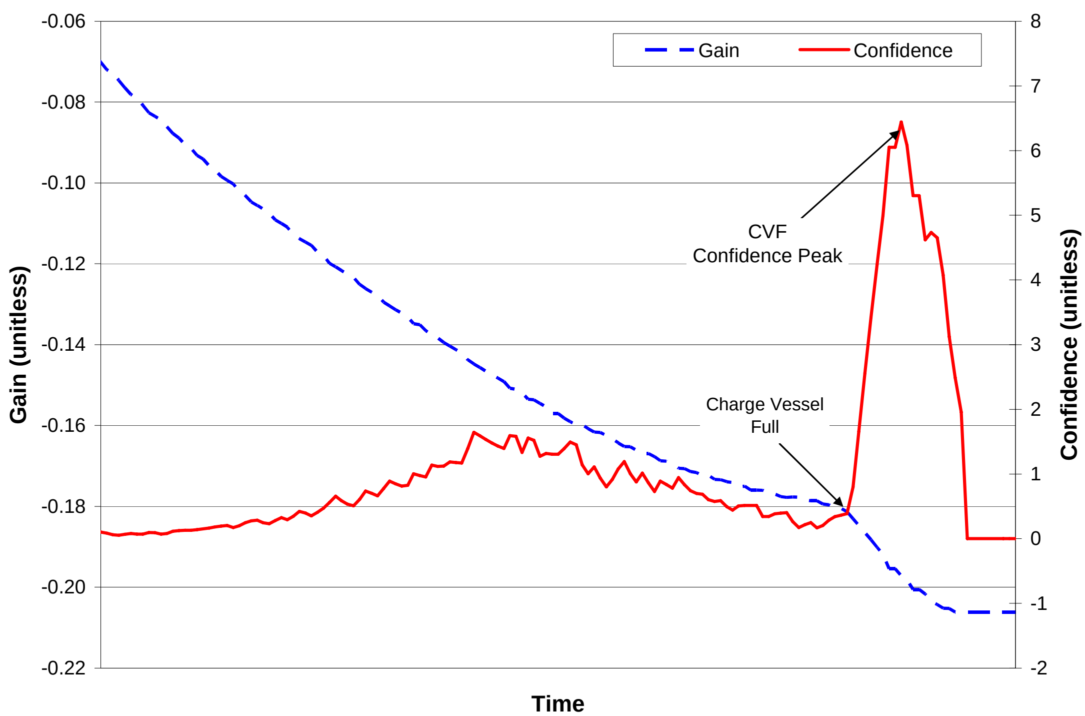

Figure 3.3. An Example of the Typical Gain and Confidence Profiles During the Suction Phase

and a sharp increase in the confidence, as shown in Figure 3.3. The control algorithm looks for the peak in the confidence to determine that the charge vessel is full and to terminate the suction phase.[a]

3.1.2 Drive Phase and Drive Overblow Detection

During the drive phase, the drive valve (V_d) is open, and the suction valve (V_s) is closed. In this situation, P_j measures the supply pressure, and P_r detects the pressure from the JPP to the vessel ventilation system. Figure 3.4 shows an example of the resultant transients P_j and P_r measured during a typical drive phase, and Figure 3.5 shows the calculated gain and confidence. In Figure 3.4, the drive pressure is shown on the primary y-axis while the suction pressure is shown on the secondary y-axis. The same is the case with Figure 3.5, where the gain is shown on the primary y-axis, and the confidence is shown on the secondary y-axis.

As discussed in the introduction, a drive overblow refers to an overblow that occurs when the drive valve is still open when all the liquid is gone from the charge vessel. When a drive overblow occurs, there is a drop in the intermediate port pressure of the suction jet pump. As can be seen from Figure 3.4, the suction pressure change is relatively small. This pressure drop is measured by P_r and subsequently shows as a decrease in gain (Figure 3.5). The confidence level spikes and indicates that the drop in gain is real and allows the control algorithm to detect the drive overblow.

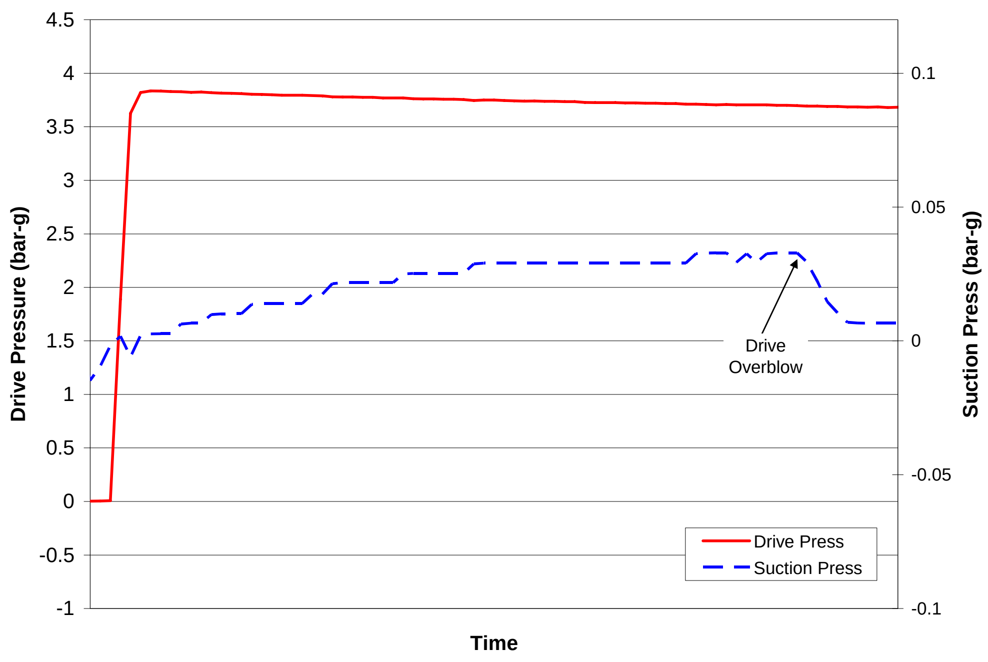

Figure 3.4. Example of Typical Drive and Suction Pressure Profiles During the Drive Phase with Drive Overblow

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(a) In actuality, the confidence value is compared to a confidence threshold value determined during the PJM tuning process. If the confidence is greater than the threshold, the CVF is ascertained; otherwise, the suction valve remains open until the confidence threshold value has been reached or the gain value reaches a percent of the maximum gain calculated during the first suction phase (i.e., a maximum gain is attained).

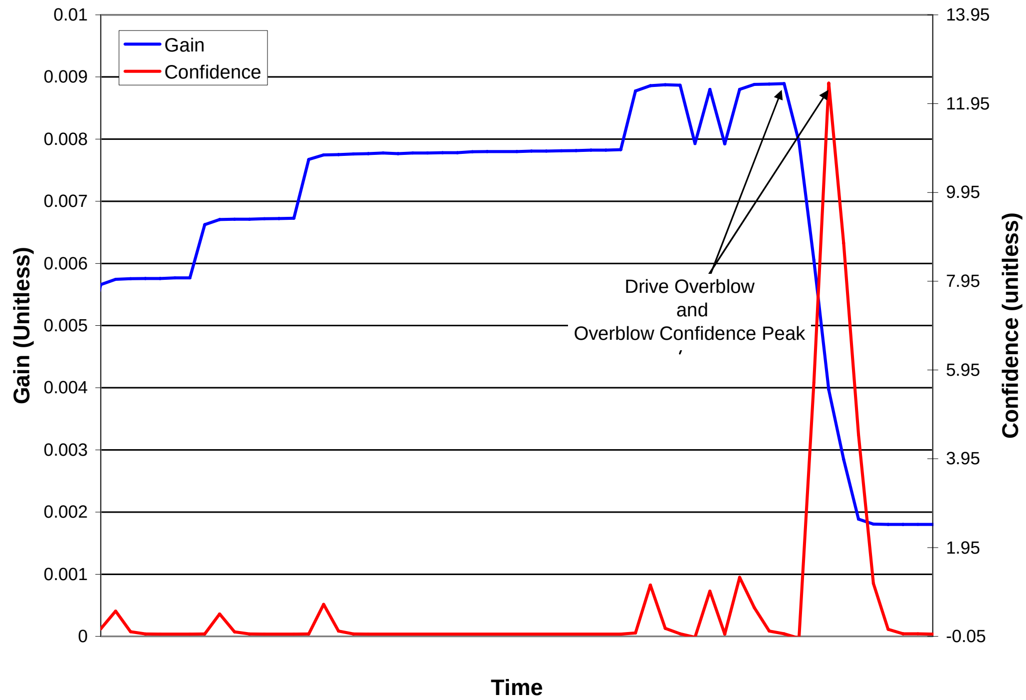


Figure 3.5. Example of Typical Gain and Confidence Profile During Drive Phase with Drive Overblow

3.1.3 Vent Phase and Vent Overblow

During the vent phase, both the drive valve (V_d) and the suction valve (V_s) are closed. In this situation, both P_r and P_j decrease gradually as the pressure in the air link-line to the pulse tube decays. Figure 3.6 shows an example of the transients P_r and P_j measured during a typical PJM vent phase, and Figure 3.7 shows the calculated gain and confidence. In Figure 3.6, the drive pressure is shown on the primary y -axis while suction pressure is shown on the secondary y-axis. The same is true in Figure 3.7, where the gain is shown on the primary y-axis and the confidence on the secondary y-axis.

It can be seen from the pressure profiles in Figure 3.6 that both pressures decay gradually, and the occurrence of a vent overblow disrupts this gradual decay. When this happens, the vent overblow will be detected by a resulting decrease in gain and an increase in confidence value, as illustrated in Figure 3.7.

3.1.4 Aspiration

Aspiration occurs when the slurry level at any point during the suction phase is below the PJM nozzle. In this situation, air enters into the pulse tube and prevents further filling of the charge vessel. Figure 3.8 shows an example of the pressure transients P_j and P_r during aspiration, and Figure 3.9 shows the calculated gain and confidence. Also shown in Figure 3.9 are the computed values of the variable the deviation, which is a precursor in calculating the confidence and is useful in ascertaining PJM aspiration. It can be seen from Figure 3.8 that the pulse-tube pressure, as indicted by the drive pressure, gradually

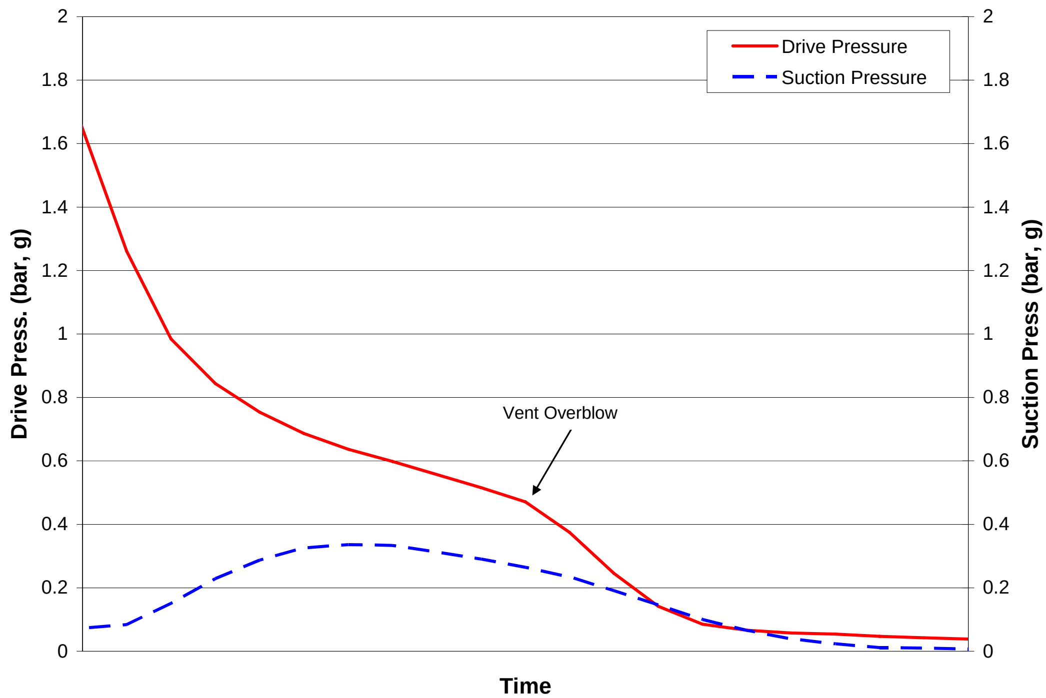


Figure 3.6. Example of Typical Drive and Suction Pressures During the Vent Phase with Vent Overblow

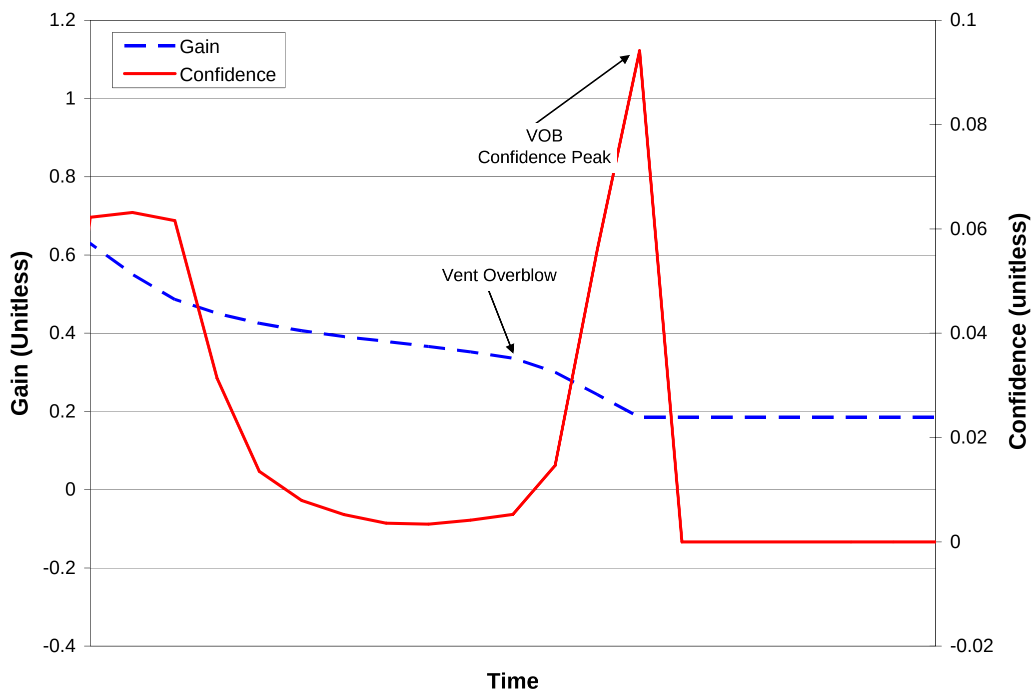


Figure 3.7. Example of Typical Gain and Confidence Profiles During Vent Phase with Vent Overblow

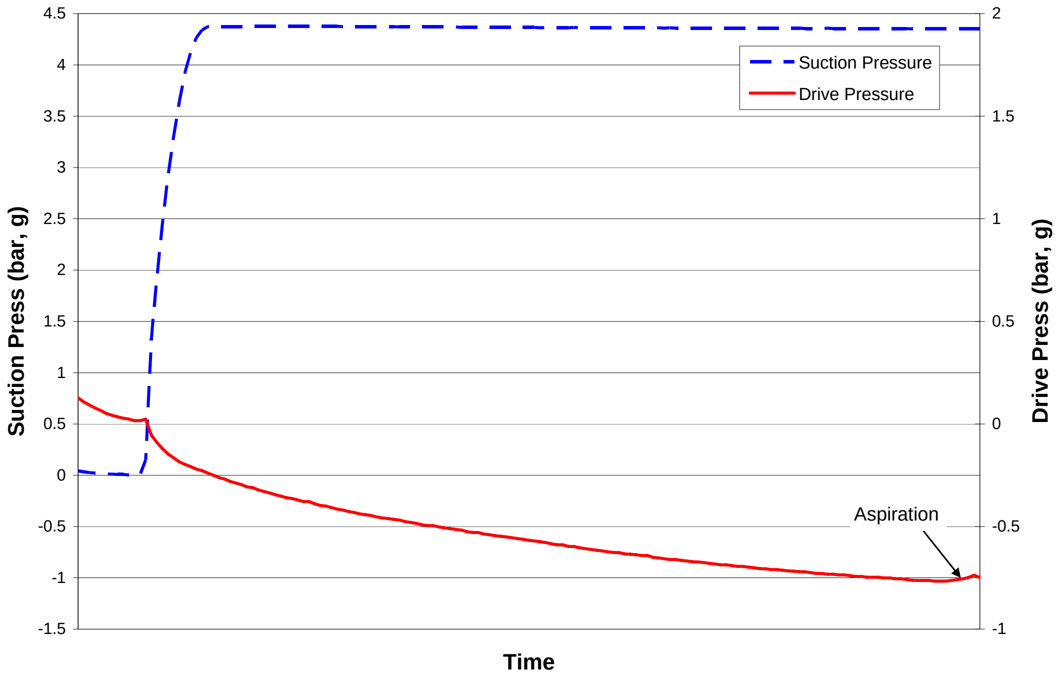


Figure 3.8. Example of Typical Drive and Suction Pressure Profiles During Aspiration

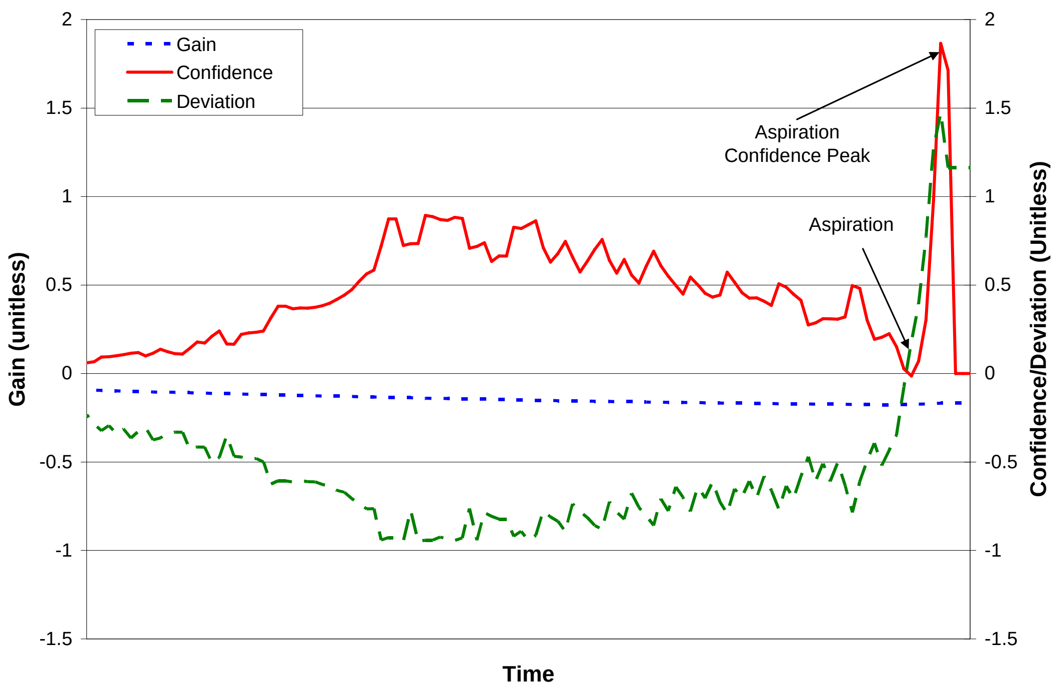


Figure 3.9. Example of Typical Gain, Confidence, and Deviation Profiles During PJM Aspiration

decreases until the aspiration point, when it does not change any further, indicating that the pulse tube is aspirating. Aspiration is detected when the calculated deviation value exceeds a certain threshold value determined during the tuning. Under normal suction phase conditions, the deviation is a negative value, but during aspiration, the deviation becomes positive. This is illustrated in Figure 3.9.

3.2 Implications of Piping and Pressure Transmitter Selection

It can be seen from the above discussion that accurate measurement of the pressures at the drive and suction sides of the JPP are critical to the controller's ability to detect CVF, drive and vent overblows, and PJM aspiration. Placing PJM racks too far from the JPPs could prevent detection of the pressure transients used to control the PJMs because long line lengths can significantly dampen the pressure changes.

Past UK AEA experience suggests that a 15-ft maximum length of piping between the control rack air supply valve and the JPP should be used. However, the current WTP design calls for estimated maximum line lengths of 44 ft on the drive side and 134 ft on the suction side.[(a)] This extra piping may result in dampening out the pressure changes used for PJM control.

In addition, the capability to detect pressure transients for PJM control may also be affected by the response time of the transmitters. The standard Foxboro pressure transmitters selected by the WTP Project have a relatively slow response to pressure change. Detecting changes in the drive and suction pressure is essential to proper control of the PJMs, including proposed PJM safety functions. Foxboro FF transmitters are preferred for non-important-to-safety (non-ITS) application. However, the FF conversion may introduce unacceptable delays into the system over and above those caused by the long plant piping lengths and the inherent transducer first-order lag.

The present testing program was designed to address both pipe length added to the JPP rack design and pressure-transmitter selection. The JPP assembly of one of the PJMs in the half-scale lag storage (HSLS) test configuration in the 336 Building test facility was modified to include the extra lengths of piping needed. In addition to the FF and non-FF transmitters manufactured by the WTP Project-selected vendor (Foxboro), other transmitters such as the Weed (used for ITS systems) and Druck were tested to determine their suitability for use in the WTP. Table 3.1 lists the details of the various transmitters tested.

Table 3.1. Pressure Transmitters Used During PJM Controller Testing

Manufacturer	Model	Output	Range (Bar)	Accuracy (% of span)	Resp. Time[(a)] (ms)
Foxboro	IAP 20-T22	4-20 mA	0.7–21	±0.06	500
Foxboro	IAP 20-F22D	FF	0.7–21	±0.05	500
Weed	N97R-PA	4-20 mA	0–13.6	±0.25	200
Druck	PTX 611	4-20 mA	0–10	±0.08	12
ABB	264VSP	FF	0.4–24	±0.075	110

(a) Time constant; i.e., time from a step change in the measured pressure until the output signal has changed 63% of the input change.

(a) Email communication from H. Webber, 6/19/2006, entitled "FW: Line Lengths for I&C to JPP."

3.3 Pressure Transmitter in Flush Line

In preparation for the possibility that none of the pressure transmitters included in the JPP rack would enable PJM control, pressure measurements were made at the end of 100 ft of 1-inch piping, representing the water flush line in the plant design. The pressure transmitter used in this case was a Druck Model PTX-611.

A new way of calculating the gain value was needed to adapt the PJM controller software to recognize the drive overblows using the signal from the flush-line pressure transmitter. The following equations were used to calculate the gain for the flush line overblow detection algorithm:

Total = total+ flush pressure
Average = total/samples
Gain = average - last flush pressure

The remaining portion of the drive overblow algorithm is the same as the UK AEA method described in Section 3.1.2.

4.0 Equipment Description

The controller tests were performed using the HSLS test stand in PNWD's 336 Building test facility. A detailed description of the existing test equipment and configuration is presented in Bontha et al. (2005), and a brief summary is presented in this section. Changes that were made to the test configuration to meet the controller test objectives are included in the discussion.

4.1 HSLS Tank

The HSLS tank housing the PJM/sparger assembly is a cylindrical stainless steel vessel of 12.75-ft inner diameter (ID) and 15-ft height (H).[a] The bottom of the tank is a 2:1 ellipse with minor and major IDs of 3 ft and 12.75 ft, respectively. A catwalk or observation bridge is present about 3 ft above the top of the tank. This bridge contains a 2 × 2.5-ft covered port for installing test equipment. Another catwalk about 40 ft from the top of the tank supports the air hoses to the PJMs. There is an observation deck along a 60º section of the circumference of the tank about 3 ft below the rim of the tank. The HSLS tank is positioned on three load gauges to monitor the weight of the tank and its contents (the catwalks are not attached to the tank).

4.2 PJM Assembly

The PJM assembly is a cluster of eight PJMs with seven pulse tubes spaced equally around the center PJM on a pitch diameter of 64 inches. A shroud around the perimeter PJMs prevents the slurry from entering the space between the PJMs. The shroud has a fill port at the top and a drain (with plug) at the bottom. It is filled with water to reduce buoyancy.

The downward-pointing center PJM nozzle is 3 ± 0.5 inches above the tank floor. The nozzles of the perimeter PJMs point outward at an angle of ~45º from vertical and are 3.5 ± 0.5 inches from the tank floor. A plan view of the HSLS tank is provided in Figure 4.1. It shows the location of the PJMs, spargers, and the test PJM on which all of the testing for pressure transmitter's response were performed.

4.3 Sparger Assembly

In addition to the PJMs, the HSLS tank is equipped with a set of seven spargers equally spaced around the perimeter at a pitch diameter of 110 inches (see Figure 4.1) and an elevation of ~ 6 inches from the tank floor. The sparger tubes are made from a 1.5-inch schedule 10 stainless steel pipe (1.682 inch ID) with four 45º triangular cutouts equally spaced at the discharge end.

The air flow to the spargers is regulated through a manifold located on the mezzanine adjacent to the HSLS tank. The manifold consists of two lines for regulating the air flow under normal (main) operation and idle operation. Sparger air flow is switched from the main flow to the idle flow loop manually using ball valves installed in the headers of the two flow loops.

(a) The actual operating height of the tank is 14 ft, 10 inches (or 178 inches) due to a 2 inch wall thickness.

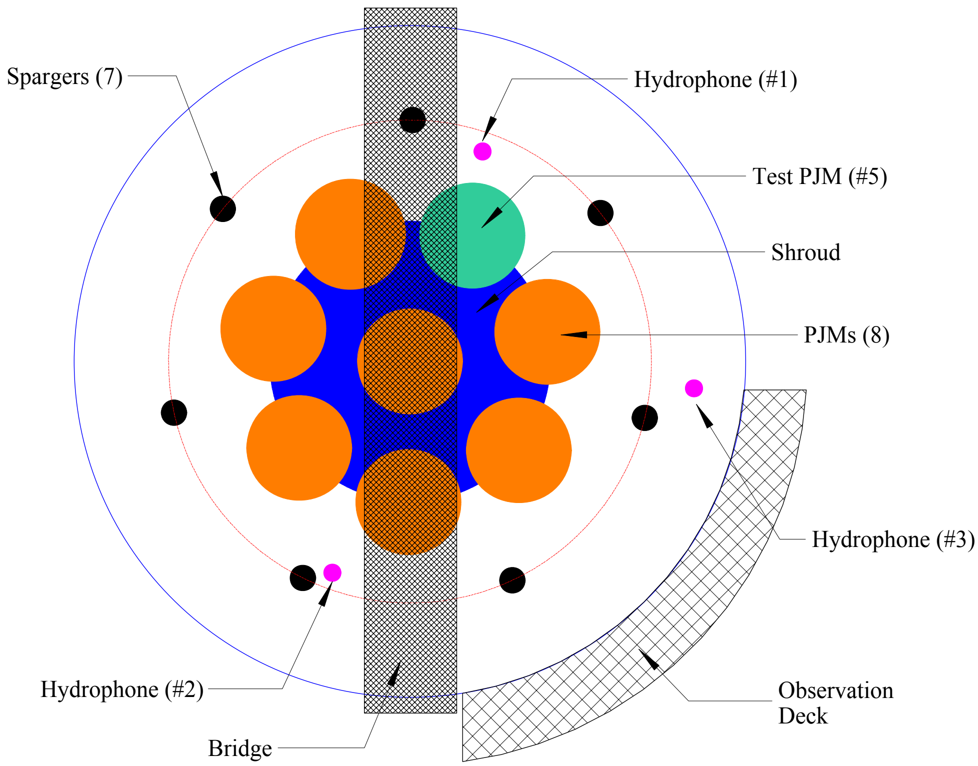


Figure 4.1. Plan View of the HSLS Tank Showing the PJMs, Spargers, and the Hydrophone Locations

Flow meters on the primary and idle flow lines for each of the spargers, along with pressure gauges and temperature sensors at the inlets and outlets of the flow meters, enable conversion of the air flow rates from standard cubic feet per minute (scfm) to actual cubic feet per minute (acfm) at the sparger nozzle. During the current testing, the main spargers were used to homogenize the tank contents before a test started, adjust rheology, and add background noise for the controller operation.

4.4 JPP Assembly

During operation of the PJMs, a vacuum is applied to fill the pulse tubes with the simulant. The slurry is then expelled from the pulse tubes with compressed air. The suction and discharge of the simulant to and from each of the eight pulse tubes is regulated by a set of eight JPPs mounted on two skids at ground level beside the tank.

The configuration of a typical JPP operating a PJM is shown in Figure 4.2. It consists of two legs known as the drive leg and suction leg. The airline to the pulse tube connects to the drive leg, and the vent header connects to the suction leg. Valves in front of the two legs of a JPP allow the flow of air through the drive leg or the suction leg of the JPP. The sequence and duration of the valve opening and closing are regulated by the controller. During the drive phase, the drive side valve is opened and compressed air enters the pulse tube to push the slurry out. At the end of the drive phase, both the drive and suction valves are closed. At this point, the compressed air from the pulse tube escapes through the vent, and therefore this phase is also known as the vent phase. During the suction phase, compressed air

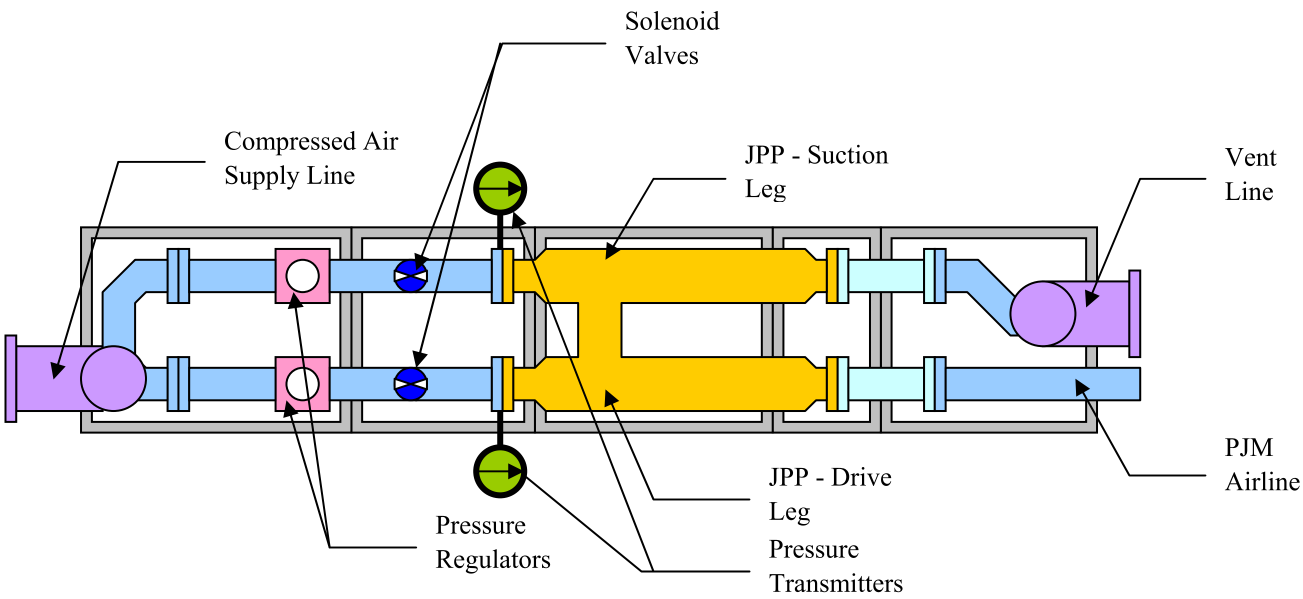


Figure 4.2. Schematic of a Typical JPP and Associated Equipment

flows through the suction leg of the JPP, which in turn creates a vacuum in the drive leg. This helps draw the slurry into the pulse tube. The PJM cycle consisting of the drive, vent, and suction phases is continuously repeated during the PJM operation.

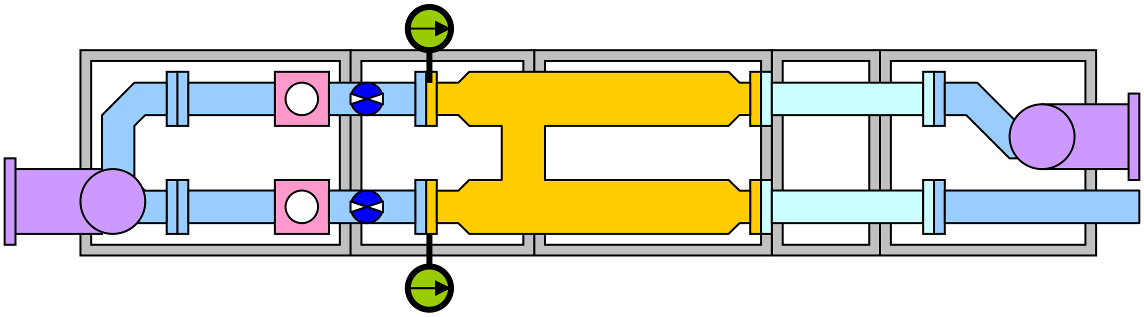
4.5 Air Supply System

The air supply system consists of a 1600-cfm compressor (delivering at an outlet pressure of 150 psig) connected to six 250-gal air receiver tanks. The air from the receiver tanks passes through an air filter to feed the two JPP skids and the sparger manifold. Part of the air from the filter is also routed to a 50-cfm air dryer that feeds the air actuated valves on the JPP skids and the BNI bubbler system also located in the HSLS (not shown in Figure 4.1).

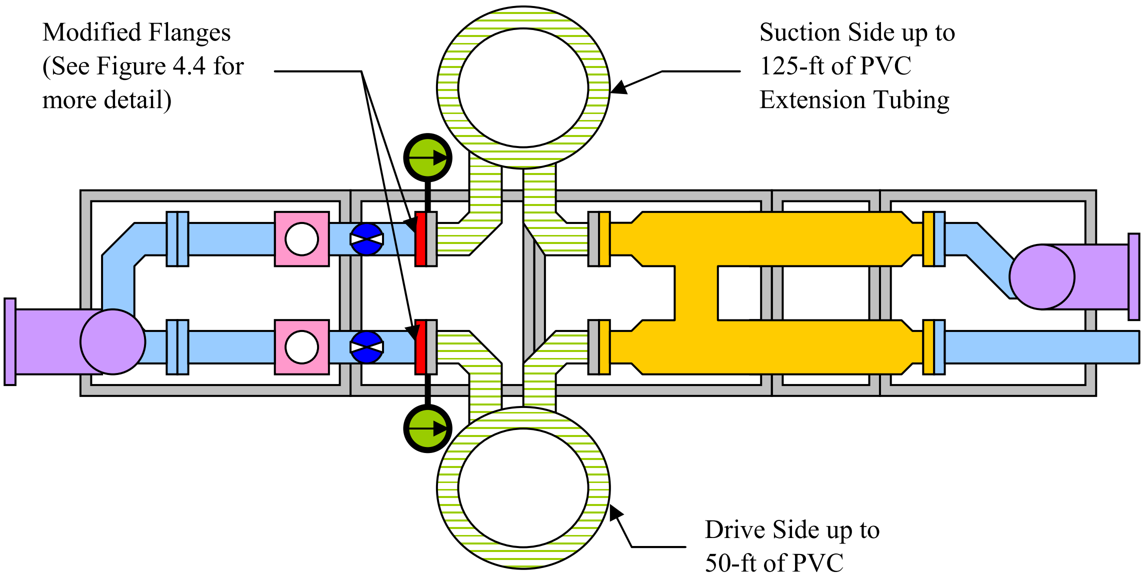
4.6 JPP Assembly Piping Modification

The BNI strategy for controlling the PJM operation uses the pressures measured on the air supply side of the drive and suction legs of the JPP. A detailed description of the control strategy is provided in Section 3. In this section, the modifications made to the JPP configuration to simulate the prototypic plant conditions are presented.

The current plant designs call for the inclusion of 2-inch schedule 40 stainless steel piping up to 44 and 134 ft long between the pressure transmitters and the drive and suction legs of the JPP, respectively. Including these lengths of piping will affect the pressure measured by the pressure transmitters at the beginning of these lines and thereby the ability to control the PJMs. To include the needed piping and study its effect on the PJM control, the JPP of PJM #5 was modified. The original configuration and the modifications made are shown in Figure 4.3 and discussed below.



(a). **Configuration of PJM#5 JPP before modification**



(b). **Configuration of PJM#5 JPP after modification.**

Figure 4.3. Schematic of the PJM #5 JPP Configuration Before and After Modification

In the original HSLS configuration, the rack containing the JPP to PJM #5 is arranged in two 1-ft-long spools. This is schematically shown in Figure 4.3a for PJM #5. To include the PVC extension tubing, the spool pieces included between the JPP for PJM #5 and the vent header were removed and the JPP decoupled from the flanges holding the pressure transmitters.[a] The JPP was then moved outward, and in the space created the extension tubing of the required length was connected. The final configuration after modification is also schematically shown in Figure 4.3b. The required pipe length was added in the form of a wire reinforced 2-inch ID (2.382-in OD) PVC tubing.[b] The required pipe length

(a) When the manifold was disassembled to insert the extra pipe length, the buildup of material from previous testing was examined and photographed. The photographs are presented and discussed in Section 11, Operational Issues and Observations.
(b) Manufactured by New Age Industries, South Hampton, Pennsylvania, under the trademark Vardex.

was formed from tubing sections of 10-, 15-, 25-, and 50-ft that were joined together with cam-lock fittings and coiled in the form of a bundle that was set on the floor adjacent to the JPP skids.

4.7 Pressure Transmitter Inclusion on the JPP Skid

In addition to testing the effect of the line length on the PJM controller, the current testing also focused on determining whether any of the pressure transmitters identified for plant operation will enable PJM control. The make and model of the different transmitters tested are listed in Table 4.1.

Table 4.1. Pressure Transmitters Evaluated for PJM Control

Manufacturer	Type	Model/Product number
Druck	Analog	PTX-611
Foxboro	Analog	IAP 20-T22D21F-M1L1B1T
Foxboro	Foundation Fieldbus	IAP-20-F22D03F-M1
ABB	Foundation Fieldbus	264VS
Weed	Analog	N97R-PA-1-N-430

For all of the pressure transmitters to have the same pressure at the measurement location, they were mounted on to the flange head on the front end of the extension tubing included on the drive and suction legs of the JPP of PJM #5. A schematic of the modifications made to the flange head to incorporate the five pressure transmitters is shown in Figure 4.4. All pressure tap connections were made at right angles to the centerline of the flange. In addition, all holes through the orifice flange were made smooth with no protruding internal blurs resulting from the drilling. Finally, 3/8-inch-OD PVC tubing of the same length (within ±0.5 inch) was used for all transmitters to connect the pressure tap point and the transmitter. These pressure tap requirements conform to the ASME procedure MFC-8M-2001 (see ASME 2001, Section 7.1, Pressure Taps).

4.8 Pressure Transmitter in the Flush-Line

In addition to testing the five pressure transmitters mounted on the extension pipe of the JPP, measurement of the pressure inside the pulse tube was also made using a Druck PTX-611 pressure transmitter mounted at the end of a 100-ft section of a 1-inch OD PVC tube connected to the air supply line of PJM #5.[a] This is shown schematically in Figure 4.5.

(a) The 100-ft length represents the expected maximum length of the PJM water flush line in the WTP design.

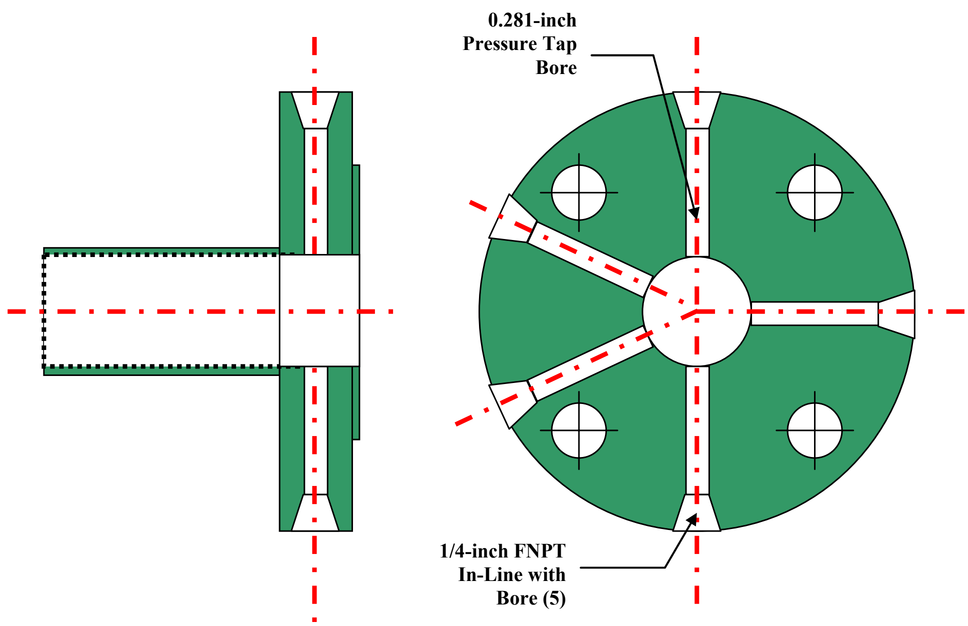


Figure 4.4. Schematic of the Flange Modifications for Pressure Transmitter Installation

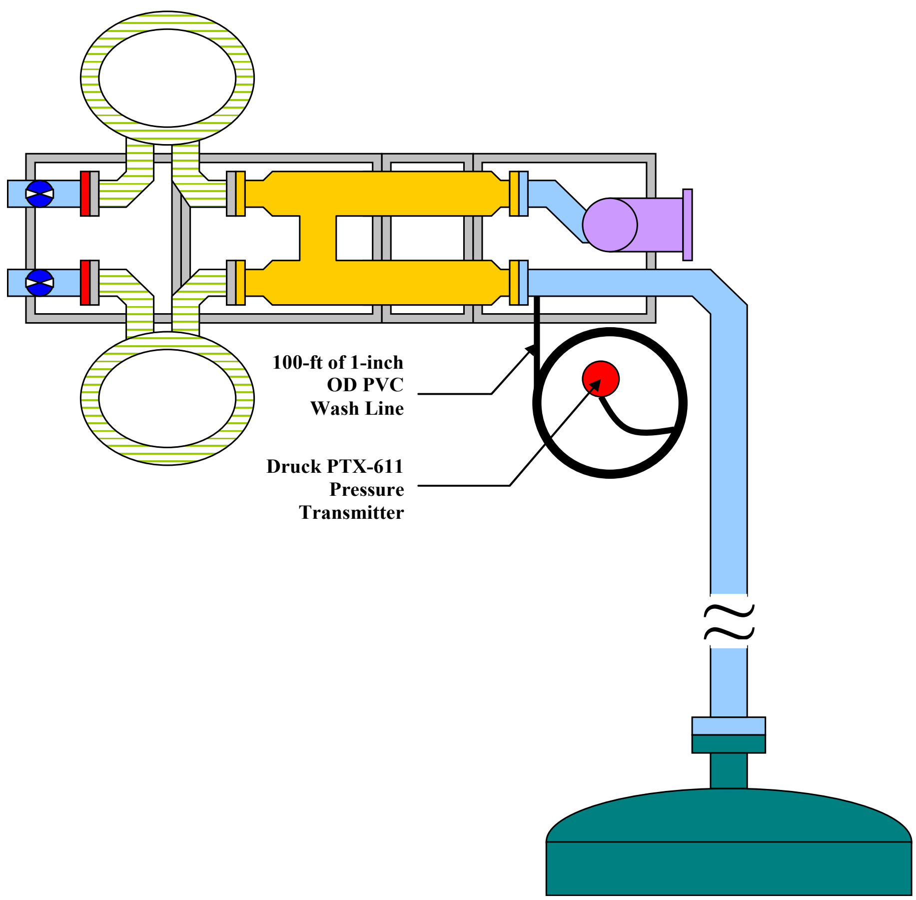


Figure 4.5. Schematic of the Pressure Transmitter Mounting on the Water Flush Line

5.0 Experimental Approach

The controller testing was performed with a clay simulant and with water to encompass the upper and lower bounds of the waste streams encountered in the WTP. In addition, with both the clay simulant and water, tests were performed at a high and a low simulant tank fill level to bound the operational range of the PJMs. This section describes the simulants and the various instruments and data acquisition systems (DAS) used to collect and log the experimental data.

5.1 Clay Simulant

The upper bound of the WTP waste stream rheology was simulated using a clay simulant consisting of 80% kaolin clay (EPK Feldspar pulverized) and 20% bentonite clay (WYO-Ben Big Horn CH-200) mixed at a solids loading of approximately 27 wt%. This simulant has a Bingham yield stress of ~30 Pa and a consistency of ~30 cP. The technical basis for the development and selection of this simulant is provided in Poloski et al. (2004). This simulant has been used successfully in previous PJM/sparger testing in the Applied Process Engineering Laboratory (APEL) and 336 Building test stands (Poloski et al. 2004, Bontha et al. 2005).

Before the start of a test, it was verified that the simulant rheology had been measured at most three days prior to the test date and that the yield stress was within the target range of 30 ± 5 Pa, as specified in the test plan. If the simulant rheology was verified more than three days before the test, the simulant was mixed for about 30 minutes with all PJMs and the spargers on full-flow. Then a sample was taken and the rheology verified. If the rheology of the sample was greater than the target range of 30 ± 5 Pa, the required amount of dilution water to bring the rheology to within the target range was added, and the tank was again mixed for about 30 minutes with all PJMs and spargers on full-flow.[a] After dilution, another sample was taken to verify that the rheology was within the target range.

The simulant rheology was measured using a TA Instruments (New Castle, DE) Model AR 2000 rheometer with a concentric cylinder sensor. This model is a controlled stress rheometer equipped with an air bearing and a Peltier plate for temperature control. All rheograms were obtained at 25^{o}C. The instrument is performance checked with calibration standard oils at least once a month. During controller testing this was performed three times, and each time the instrument tested well within the required ±10% of the known standard value.

5.2 Water Simulant

The lower bound of the WTP waste stream rheology was simulated using water. This water was essentially from the third rinse of the tank after the clay was removed and the tank was rinsed thoroughly with water containing small traces of clay (estimated at <0.1%) and with a density of ~1.001 g/cm^3.

(a) The required amount of dilution water was determined from past experience with the same simulant and was equal to 500 lb of water for a ~2 Pa drop in ~100,000 lb of the clay simulant.

5.3 Instrumentation

Several instruments were used to monitor the PJM operation during the controller testing. They are classified into PNWD-provided instruments and BNI-provided instruments. The two categories are discussed below.

5.3.1 PNWD Instrumentation

The PNWD provided instruments consisted of PJM charge vessel pressure sensors, tank/PJM charge vessel level sensors, flow, pressure, and temperature sensors on the sparger manifold, and hydrophones to detect overblows. These instruments are classified as either primary or secondary. The primary and secondary PNWD instruments used in the testing are listed in Tables 5.1 and 5.2, respectively. The primary instruments, which are used for collecting NQA-1 data, include the pressure transmitters located in a pipe cross above the pulse tubes. Secondary instruments provided additional information for operating equipment and troubleshooting. Any information obtained with these instruments was for indication only. An example of a secondary instrument is the capacitance level probe in the PJMs, which gave the test operator an indication of the fill/discharge behavior of the simulant in the pulse tubes.

Another example is the hydrophones used to detect overblows. In this testing, a set of three hydrophones were used. The hydrophones were located 132 ± 6 inches from the tank rim. Hydrophone 1 was closest to the test PJM #5, and hydrophone 2 was farthest. The approximate radial positions of the hydrophones are shown in Figure 4.1. The hydrophone data were collected to demonstrate the occurrence of an overblow event during the testing and the information was for indication only.

Table 5.1. List of the Primary Analytical Instruments Provided by PNWD

Parameter	Sensor Type	Manufacturer	Model	Qty	Calibrated Range	Unit	Accuracy
PJM pressure	Pressure transmitter	E+H PMP	135-A4G01R4R	8	0 to 150	psia	± 0.75 psia

5.3.2 BNI Instrumentation

The BNI-provided primary instrumentation is listed in Table 5.3. It consists of the pressure transmitters that measure drive and suction pressure at the JPP and pressure in the water flush-line of PJM #5.

5.4 Data Acquisition

During the controller testing, different data acquisition approaches were used to record the signal from the instruments. Figure 5.1 shows the flow of the signal from the PNWD-provided instruments to PNWD DAS-1 and DAS-2. Figure 5.2 shows the flow of the signals from BNI-provided instrumentation to DAS-3.[a] The computer clocks for the DAS-2 and -3 systems were manually synchronized each day to within ±1 second of the clock on the DAS-1 system. The following describes each DAS and the information that was recorded.

(a) DAS-3 was part of the PJM control system.

Table 5.2. List of Secondary Analytical Instruments Provided by PNWD (for indication only)

Parameter	Sensor Type	Manufacturer	Model	Qty	Range	Unit	Accuracy
Sparger Inlet Air Pressure	Pressure transmitter	Cecomp	F4L100PSIA	7	0 to 100	psia	± 0.25 psia
Sparger Outlet Air Pressure	Pressure transmitter	Cecomp	F4L30PSIA	7	0 to 30	psia	± 0.075 psia
Sparger Air Inlet Temperature	Type T thermocouple	Eustis	MCT41U60000M0	3	0 to 200	°C	± 1 °C
Sparger Air Outlet Temperature	Type T thermocouple	Eustis	MCT41U60000M0	3	0 to 200	°C	± 1 °C
Main Sparge Air Flow Rate	Rotameter	Hedland	H791B-100-EL	7	10 to 100	scfm	± 2 scfm
PJM Level	Capacitance level probe	Drexelbrook	700-0002-057	8	0 to 144	Inches	± 1% Nom.
Tank Surface Level	Laser level transmitter	Optech	Sentinal 3100	4	0.2 to 150	m	± 5 mm
Tank Temperature	Type J thermocouple	Superior Sensors	SA2-J412-1U-168	2	-100 to 300	°C	± 2 °C
Tank Weight	Load cells	BLH	Z-Blok, 100K lb	3	0 to 300k	lb	± 100 lb
JPP Regulator Pressure (drive)	Pressure transmitter	Cecomp	F4L100PSIA	8	0 to 100	psia	± 0.25 psia
JPP Regulator Pressure (suction)	Pressure transmitter	Cecomp	F4L100PSIG	8	0 to 100	Psig	± 0.25 psi
Barometric Pressure	Pressure transmitter	Cecomp	F4L30PSIA	1	0 to 30	psia	± 0.075 psia
Ambient Temperature	Type T thermocouple	Eustis	MCT41U60000M0	3	0 to 200	°C	± 1°C
Overblow	Hydrophones	Brüel and Kjær	8104	3	1 to 120	kHz	±8db

Table 5.3. List of Primary Instrumentation Provided by BNI

Parameter	Sensor Type	Manufacturer	Model/Product number	Qty	Calibrated Range (c)	Unit	Accuracy
PJM 1-4 & 6-8 JPP pressure	Pressure transmitters	Druck[(a)]	PTX-611	14	0 to 7	Bar-a	±0.008 bar-a
PJM# 5 JPP pressure	Pressure transmitters	Druck[(a)]	PTX-611	2	0 to 7	Bar-a	±0.008 bar-a
	Pressure transmitters	Foxboro 4 to 20 mA[(a)]	IAP20-T22D21F-M1L1B1T	2	0 to 7	Bar-a	±0.06% of span
	Pressure transmitters	Foxboro FF[(b)]	IAP20-F22D03F-M1	2	0 to 7	Bar-a	±0.05% of span
	Pressure transmitters	ABB FF[(b)]	2600 T series (264VS)	2	0 to 7	Bar-a	±0.075%
	Pressure transmitters	Weed 4 to 20 mA	N97R-PA-1-N-430	2	0 to 7	Bar-a	0.25% of span

(a) Analog transmitter with a current output.
(b) Digital transmitter using the Foundation Fieldbus protocol.
(c) The actual range (span) is 0-10 Bar absolute.

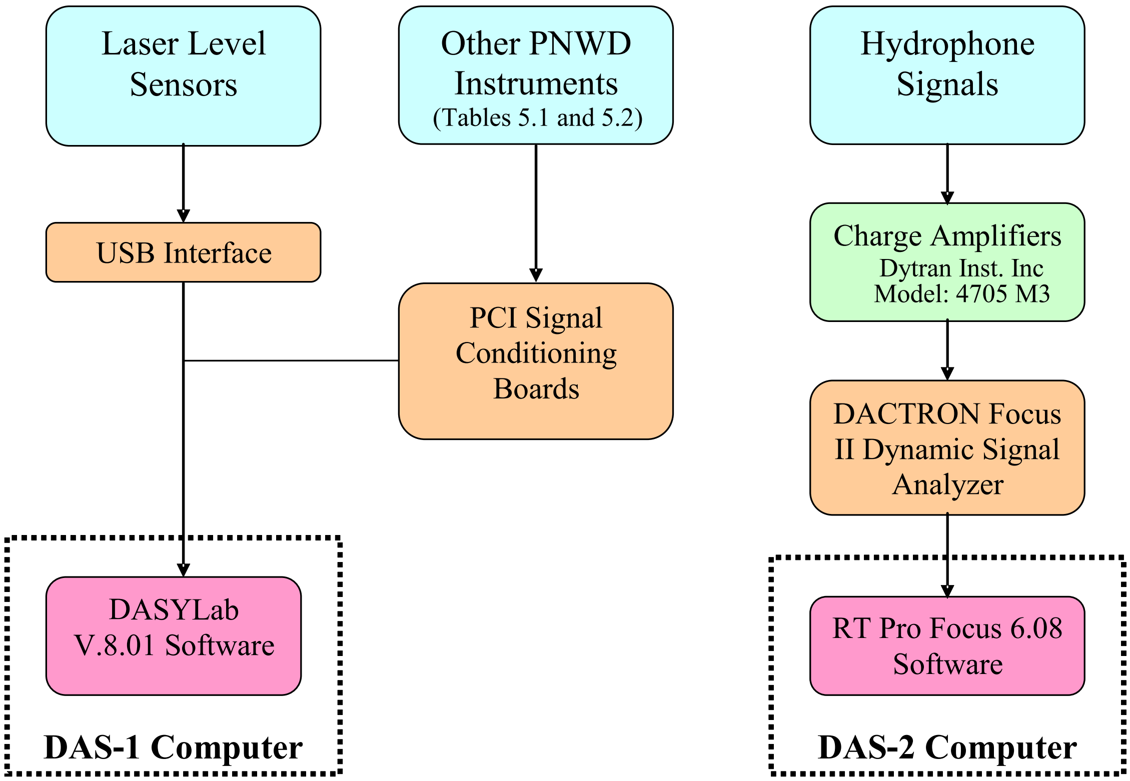


Figure 5.1. Signal Flow from PNWD Instruments to PNWD DAS-1 and DAS-2

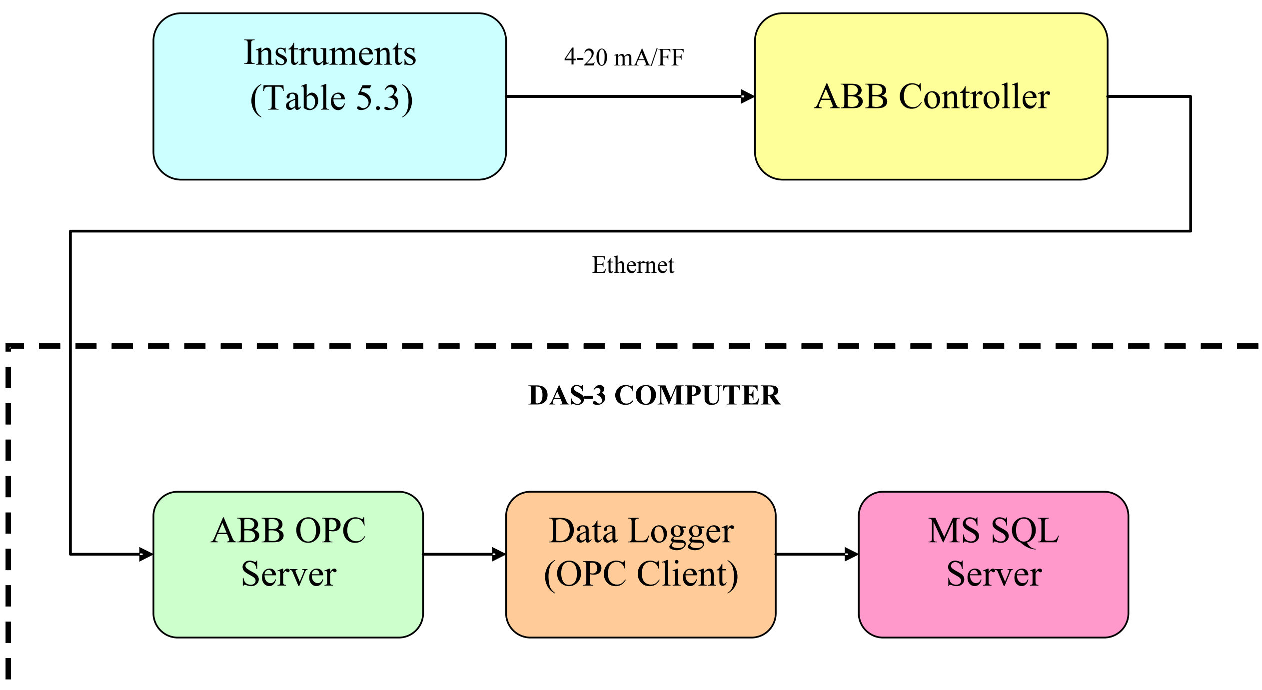


Figure 5.2. Signal Flow from BNI Instruments to BNI Controller and DAS-3

5.4.1 DAS-1

Except for the hydrophone data, all signals from the PNWD instruments listed in Tables 5.1 and 5.2 were monitored continuously and recorded digitally on the DAS-1 computer using DASYLab Version 8.0 DAS software. All DAS-1 channels were sampled at 100 Hz frequency and the data averaged over 0.1-second intervals. These 0.1-second averages were electronically recorded in the PJM data log file and saved as an ASCII file. Each electronic entry in the file included a date and time stamp.

5.4.2 DAS-2

The signal from three hydrophones located in the tank was monitored continuously and recorded on the DAS-2 computer using DACTRON FOCUS II signal analyzer and RT Pro Focus, Version 6.08 software. Each hydrophone datum was sampled and recorded at 32 Hz and saved as a text file. Each hydrophone datum contains the start/stop date and time of sampling, elapsed time.

5.4.3 DAS-3

All signals from the BNI instruments listed in Table 5.3, along with the computed confidence values for each transmitter (see Section 3 for more detail), were monitored continuously and recorded digitally on the DAS-3 computer using Microsoft SQL Enterprise Manager Version 8.0 server and Microsoft Management Console 2 Version 5.1 software. The data were sampled and recorded at a frequency of 4 Hz.

5.4.4 Data Backup

All electronic data files written to the DAS-1, DAS-2, and DAS-3 computers were copied to and stored on a password-protected server on the PNWD intranet. Duplicate raw data files were maintained on removable media for backup in case the PJM server went down.

6.0 PJM Tuning

Prior to applying the control logic to operate the PJMs, certain parameters or system constants within the code need to be specified. The values of these system constants are dependent on the equipment configuration and need to be determined experimentally. In this section, the system constants, the approach used to determine the constants (often referred to as PJM tuning), and the values of the constants for the 8-PJM HSLS configuration at the 336 Building are presented. Throughout the discussion, the system constants are represented in italic type. For more detailed information on the inner workings of the algorithm, see Section 3, PJM Control Approach, or the UK AEA PJM Design Guide.[a]

6.1 Initial Settings

The default values used for the various control parameters and their typical range are listed in Table 6.1. At the start of the PJM tuning process, the control parameters for all PJMs are set to the default values.

Table 6.1. Initial Settings of the Control Parameters for Each PJM

Parameter	Initial Values	Range	Parameter	Initial Values	Range
aspdevthres	4.7	0.0-9.9	*nompr*	TBD [(a)])	0.00-9.90 Bar-g
Atmospheric	1.0	1.0 Bar-a	*ovbwtifrac*	1	0.7-1.3
dovbwconthres	7	0.0-9.9	*rfdtifrac*	0.9	0.50-1.00
dovbwstart	0.1	0.0-0.99	*stabthres*	3.0	0-10
drvmasktime	4	0.00-10.00 sec	*suckmaskgain*	-0.05	-0.50-0.00
endsucnfrac	0.8	0.5-0.99	*suckmasktime*	5	0.00-10.00 sec
fsuckmaskgain	-0.12	-0.50-0.00	*supplyvar*	0.15	0.00-0.20
gainthres	0.98	0.80-0.99	*ventendpres*	0.3	0.0-9.9 Bar-g
gsteadythres	0.0005	0.0001-0.01	*ventmasktime*	1	0.00-10.00 sec
maxovbws	3.0	1-9	*vfullconthres*	6.5	0.0-9.9
maxventime	20	5-99 sec	*vfullstart*	0.25	0.00-0.99
mingain	-0.065	-1.0-0	*vovbwconthres*	1.2	0.0-9.9
nomdrivetime	TDB [(a)]	0.00-100.00 sec	*vsettletime*	2	0.00-10.00 sec
nompj	TDB [(a)]	0.00-9.90 Bar-g	*zeroerror*	0.05	0.00-1.00
(a) Values set based on the target operating conditions during testing.					

6.2 Nominal Drive and Suction Pressure

In Table 6.1, the parameters *nompj* and *nompr* are the nominal drive pressure and nominal suction pressure, respectively. These values tell the algorithm what the drive pressure should be during the drive

(a) Dean A. 9/14/2004. "PRESCON Control Algorithm Design Guide." 24590-QL-POA-MPE0-00002-14-01 Rev. 0.0E, UK AEA, UK.

phase and, similarly, what the suction pressure should be during the suction phase. The parameter *supplyvar* is used to define a percentage the actual pressure can be above or below the nominal value before it will shut down the PJM. The parameter *zeroerror* is used to determine how much the pressure readings can be off from zero before a phase is actually started.

Although the JPP used in the current testing was prototypic of the WTP, the charge vessel was half-scale. This created a conundrum regarding the JPP skid operating conditions during the controller testing. For example, the test specification required that, to mimic the worst-case scenario for plant operation, the JPP skid should be operated such that the pressure inside the pulse tubes was 7.0 ± 0.5 psig. However, this resulted in much smaller pressures at the JPP than those that are typical of the full-scale PJMs.

Consultation with UK AEA staff[(a)] indicated the mass flow rate of air in and out of the PJM and the JPP vent are the most important variables for characterizing the system response rather than the pulse tube pressure (see Section 3 for a description of the PJM control approach). Therefore, during a majority of the controller tests, the JPP skid was operated at conditions such that the mass flow rate of air was similar to that expected in plant operation. These conditions corresponded to a set point pressure of 4.0 ± 0.5 and 4.5 ± 0.5 bar-g at the drive and suction side of the JPP, respectively. At these JPP pressures, the PJM pressures are significantly greater than those expected during plant operation. The pressure inside PJM #5 was set close to the plant limiting condition of 7 ± 0.5 psig only during a few selected tests with the flush-line transmitter.

Once the drive and suction pressure for a particular test or sequence of tests was established, the following procedure was used to set the nominal drive and suction pressures on each PJM controller faceplate:[(b)]

1. The target values of *nompj* and *nompr* were entered into the PJM faceplate of the PJM being tuned.
2. The suction valve operation in the controller was set to Manual and opened.
3. The suction pressure regulator on the JPP was gradually adjusted until the suction pressure transmitter read by the controller was within ±0.1 bar-g of the target value of *nompj* setting on the PJM faceplate. During this process, care was taken not to overfill the charge vessel. If needed, the suction valve was closed and the drive valve was opened manually to lower the fluid level in the charge vessel level.
4. These same steps were repeated to set the drive pressure. Here too, care was taken not to keep the drive valve open too long since an over blow would occur. If necessary, the drive valve was closed and the suction valve was manually opened to refill the charge vessel.
5. After the pressures for the drive and suction were adjusted to the target, the regulators were locked down to eliminate accidental resetting of the pressure.
6. The parameter *supplyvar* on the PJM faceplate was adjusted if necessary.

(a) UK AEA provides BNI with technical expertise and consultant services regarding PJM operation in the WTP.
(b) A PJM faceplate is a tab available on the PJM controller screen that lists the various system constants being used for that PJM. The faceplate enables the operator to input and/or change the system constants if required.

6.3 Charge Vessel Full Parameter Setting

The instant the charge vessel is finished filling is determined by analyzing the rate of change of the suction gain, which is defined as the ratio of drive pressure to the suction pressure. The following procedure was used for determining CVF confidence threshold parameter *vfullconthres* for each PJM:

1. The *gainthres* parameter on the PJM faceplate was set to 1.0.
2. The *vfullconthres* parameter on the PJM faceplate was set to 9.9.
3. The *nomdrivetime* parameter on the PJM faceplate was set to half its default value for the tank being commissioned (to prevent overblow of the un-tuned system).
4. The PJM was started in pressure control mode and allowed to run for a minimum of five cycles and then stopped.
5. Suction and drive pressures, gain, and the confidence values were graphed versus time for about five cycles.
6. From the graphs, the peak average peak confidence value where gain and drive pressures take a sudden dip was noted.
7. The *vfullconthres* parameter on the PJM faceplate was set to 80% of the average confidence value.

6.4 CVF Tuning Results

All initial PJM tuning tests were performed using the clay simulant with a Bingham yield stress of 30 ± 5 Pa and a fill height of 60 ± 2 inches (as measured from the tank rim).[a] Figure 6.1 shows the typical profiles for CVF detection with PJM #1. In this graph, the calculated confidence and suction pressure are plotted on the primary y-axis and the drive pressure on the secondary y-axis. As explained in Section 3 and shown in Figure 6.1, during the suction phase, the drive pressure gradually decreases as a vacuum builds up in the pulse tube. Then, as the liquid level rises above the top of the pulse tube and into the air link-line, the drive pressure decreases far more rapidly due to the sudden change in the horizontal cross-sectional area between the pulse tube and the air link-line. This translates to a sudden depression in the gain (not shown in the figure) and a sharp increase in the confidence. From the graph it can be seen that the peak value of the confidence for CVF detection ranged from 3–4. Therefore, the *vfullconthres* parameter for PJM #1 was set to 2.5, which was approximately 80% of the average confidence value. The *vfullconthres* values for the other PJMs were determined in a similar manner and are listed in Table 6.2.

6.5 Drive Overblow Parameter Setting

During the drive phase, compressed air is supplied to the drive jet pump. The resulting high pressure in the charge vessel drives the process liquid out. During normal operations, the charge vessel is only partially emptied during the drive phase. Some of the remainder of the liquid is expelled in the following

(a) This level corresponds to an H/D of 0.77.

vent phase by the expanding drive air. A drive overblow occurs when all of the fluid is expelled from the pulse tube while the system is still in the drive phase.

The occurrence of an overblow in the drive phase is detected by observing a drop in the intermediate port pressure of the drive jet pump via the suction pressure transmitter. The rapid drop in suction pressure at overblow causes a similar drop in gain (suction pressure/drive pressure). This generates a confidence peak that exceeds the set threshold value.

The following procedure was used for determining drive overblow confidence threshold parameter *dovbwconthres* for each PJM:

1. The *dovbwconthres* parameter on the PJM faceplate was set to 99.9.
2. The PJM operation was started in pressure control mode and the *nomdrivetime* parameter was increased until an overblow occurred.
3. After overblow conditions were established, the PJMs were operated for a minimum of five cycles and then stopped.
4. The suction and drive pressures, gain, and the confidence values are graphed versus time for approximately five overblow cycles.
5. From the graphs, the peak average peak confidence value where gain and suction pressure take a sudden dip was noted.
6. The *dovbwconthres* parameter was set to 80% of the average confidence value.

6.6 Drive Overblow Tuning Results

Figure 6.2 shows the typical profiles for the drive overblow detection with PJM #1. In this graph, the calculated confidence and drive pressure are plotted on the primary y-axis and the suction pressure on the secondary y-axis. When a drive overblow occurs, the air-link pressure drops suddenly to a value slightly greater than that necessary to overcome the hydrostatic head of the fluid in the tank outside the PJM nozzle. This causes the pressure in the air link-line as measured by the suction line pressure transmitter to decrease and thereby the confidence to peak. The average value of the confidence peak for drive overblow detection was on the order of 10. Therefore, the *dvobconthres* parameter for PJM #1 was set to 80% of the average confidence value, or equal to 8. The *dvobconthres* values for the other PJMs were determined in a similar manner and are listed in Table 6.2.

6.7 Vent Overblow Parameter Setting

The vent phase follows the drive phase, allowing the high-pressure drive air to escape or vent from the charge vessel before reapplying suction. The pressure in the charge vessel decays smoothly from the end of the drive phase toward atmospheric (or the pressure of the vent system). The occurrence of vent overblows affects this decay and in theory can be detected in a manner similar to the drive overblow. In practice, the vent overblows could not be detected due to insufficient pressure changes in the system, so the tuning could not be completed.

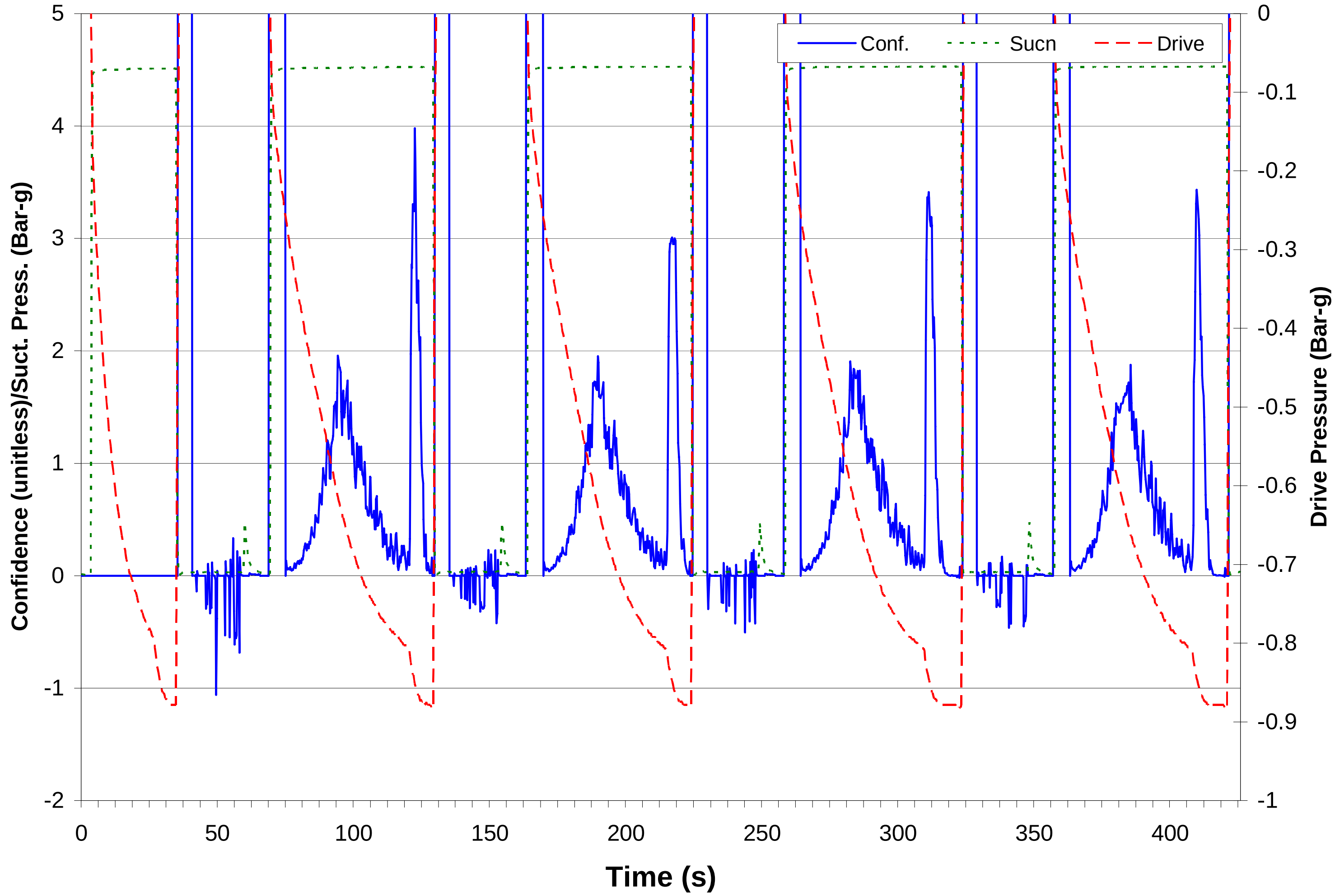


Figure 6.1. Typical Confidence, Suction, and Drive Pressure Profiles During CVF Tuning of PJM #1

Table 6.2. Final Values of the Tuning Parameters of All the PJMs

Name	Initial Values	Final Values								Range
		PJM 1	PJM 2	PJM 3	PJM 4	PJM 5	PJM- 6	PJM 7	PJM 8	
aspdevthres	4.7	4.7	4.7	4.7	4.7	4.7	4.7	4.	4.7	0.0-9.9
Atmospheric	1.0	1	1	1	1	1	1	1	1	1.0 Bar-a
dovbwconthres	7	4	3	3	3	5	2.5	3	4	0.0-9.9
dovbwstart	0.1	0.25	0.25	0.1	0.25	0.25	0.25	0.1	0.1	0.0-0.99
drvmasktime	4	4	4	4	4	4	4	4	4	0.00-10.00 sec
endsucnfrac	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.5-0.99
fsuckmaskgain	-0.12	-0.18	-0.18	-0.18	-0.18	-0.18	-0.18	-0.18	-0.18	-0.50-0.00
gainthres	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.98	0.80-0.99
gsteadythres	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005	0.0001-0.01
maxovbws	3.0	8	10	10	10	10	10	10	10	1-9
maxventime	20	20	20	20	20	20	20	20	20	5-99 sec
mingain	-0.065	-0.065	-0.065	-0.065	-0.065	-0.065	-0.065	-0.065	-0.065	-1.0-0
nomdrivetime	13	13	13	13	13	13	13	13	13	0.00-100.00 sec
nompj	4	4	4	4	4	4	4	4	4	0.00-9.90 Bar-g
nompr	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	0.00-9.90 Bar-g
ovbwtifrac	1	1	1	1	1	1	1	1	1	0.80-1.00
rfdtifrac	0.9	1	1	1	1	1	1	1	1	0.50-1.00
stabthres	3.0	7	7	7	7	7	7	7	7	0-10
suckmaskgain	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.05	-0.50-0.00
suckmasktime	5	5	5	5	5	5	5	5	5	0.00-10.00 sec
supplyvar	0.15	0.3	0.25	0.25	0.25	0.3	0.25	0.25	0.25	0.00-0.20
ventendpres	0.3	0.1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.0-9.9 Bar-g
ventmasktime	1	1	1	1	1	1	1	1	1	0.00-10.00 sec
vfullconthres	6.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5	0.0-9.9
vfullstart	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.00-0.99
vovbwconthres	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0.0-9.9
vsettletime	2	2	2	2	2	2	2	2	2	0.00-10.00 sec
zeroerror	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.00-1.00

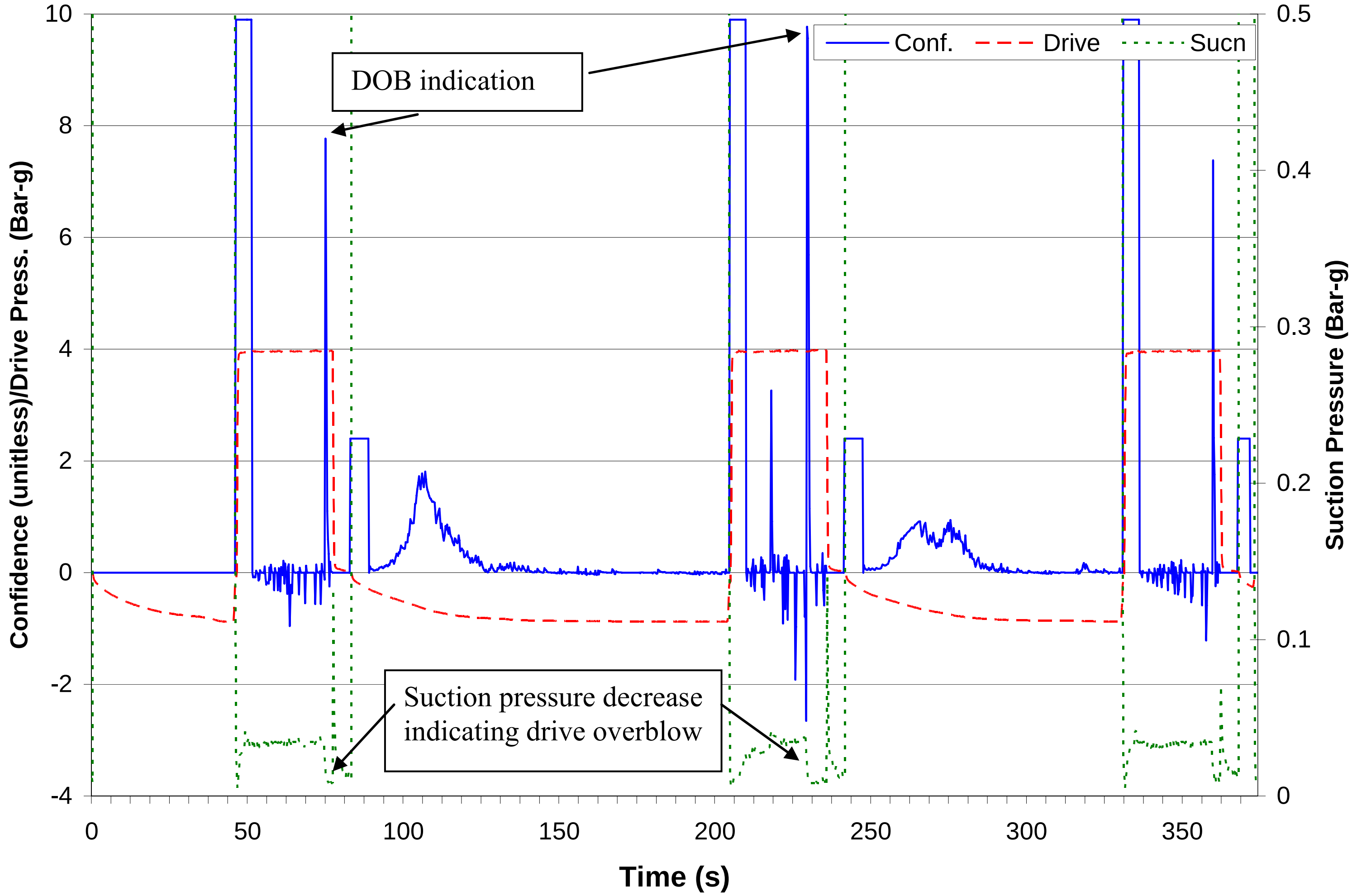


Figure 6.2. Typical Confidence, Suction, and Drive Pressure Profiles During Drive Overblow Tuning of PJM #1

6.8 Aspiration Parameter Setting

If the slurry level in a vessel is lowered beyond a minimum point, the level will fall below the bottom opening in the pulse tubes, and air can be entrained into the pulse tube during the suction phase. This is known as aspiration. At tank levels below the aspiration point, PJM operation will not be possible because the pulse tubes will not fill. Accurate determination of when the PJMs are aspirating is important to the plant operation because it will help reduce compressed air use and minimize slurry creep and carry over. When air is sucked into the charge vessel it causes a break in the vacuum in the charge vessel, resulting in positive deviation peaks. When this peak exceeds a threshold value, the system reports aspiration.

Tuning for aspiration was not performed during the tuning tests with 0 ft of line length between the JPP and the pressure transmitters due to temporary space limitations for storing the simulant. The aspiration test was performed with 50 and 125 ft of piping between the pressure transmitters and the drive/suction side of the pressure transmitter of PJM #5. The results are presented in Section 7.

7.0 Effect of Line Length on PJM Control

Accurate capture of the pressure changes at the drive and suction side of the JPP is critical to the controller's ability to detect CVF, drive and vent overblows, and PJM aspiration. Because long line lengths can significantly dampen the pressure changes, placing PJM racks too far from the JPPs could prevent detection of the pressure transients used to control the PJMs. The WTP design requires line lengths up to a maximum of 44 ft of piping between the pressure transmitter and the drive side of the JPP, and up to 134 ft between the pressure transmitter and the suction side of the JPP. This extra piping may result in dampening out the pressure changes used for PJM control. Therefore, the initial part of the testing was focused on establishing the effect of line length on PJM control.

As mentioned in Section 6, PJM Tuning, the vent overblow detection was not possible due to the extremely low confidence signals even at 0 ft of piping between the pressure transmitters and drive/suction sides of the JPP. Therefore, no vent overblow testing with the extended piping was performed, and the discussion of the results in this section only covers the effect of line length on the CVF, drive overblow detection, and aspiration.

7.1 Experimental Conditions

All line length studies for CVF and drive overblow were performed using the clay simulant with a Bingham yield stress of 30 ±5 Pa and a fill height of 60 ±2 inches (as measured from the tank rim).[a] For aspiration, the simulant level was pumped to a level low enough that aspiration occurred during the suction phase. Maximum line lengths of 50 ft on the drive side and 125 ft on the suction side were used. The approach used to increase the line length on both drive and suction sides is presented in Section 4, Equipment Description.

To ensure that only the test PJM (#5) experienced an overblow during the drive overblow tests, the PJM controller conditions were set such that the PJM #5 stopped refilling before the other PJMs. In this way, when the drive phase started, PJM #5 had a lower fill level than the other PJMs. With a sufficiently long drive time, this resulted in a drive overblow in PJM #5.

7.2 Data Logging Problems

Before the results are presented, it should be mentioned that during the analysis of the pressure/ confidence trends, we realized that there was an intermittent data logging problem throughout the testing. The data logger was found to occasionally not receive new data from the OPC server, and it duplicated previous data. This problem is thought to be due to the OPC server occasionally being a scan behind the PJM controller. The PJM controller, OPC server, and data logger were set at 250 ms scan intervals. If the data logger asked the OPC server for new data at the end of the interval and the OPC server hadn't updated from the PJM controller yet, the OPC server gave the data it had (from the last scan) to the data logger. The large volume of data collected during the testing made it impractical to sort through and select results that were not affected by this issue in the quantity required for a statistical analysis to

(a) A fill height of 60 inches from the tank rim corresponds to an H/D of ~0.77.

establish the overall performance of the controller. Therefore, plots of selected portions of the data are included to provide qualitative information. This issue is not apparent in plots because the variation from one data sampling event to the next is generally small. Careful review of the data by PNWD and BNI staff indicates that the data logging problems do not prevent drawing broad conclusions regarding the performance of the transmitters or line length effects because the trends remain the same, but the peak confidence values were in some cases affected.

7.3 CVF Detection

The CVF event is detected by the drive side pressure transmitter. Because the maximum line length between the drive side of the JPP and the pressure transmitters is only 44 ft, the effect was investigated using line lengths of 0 and 50 ft. The results are shown in Figures 7.1 and 7.2. During both tests, only six of the eight PJMs were operational (due to limitations in the air supply system, PJMs #2 and #8 were turned off). In both of the graphs, the calculated confidence and suction pressure are plotted on the primary y-axis and the drive pressure on the secondary y-axis. The data in the graphs represent the response observed with the Weed pressure transmitter. Similar results were observed with the other pressure transmitters, although the magnitudes of the confidence valves were somewhat different.

It can be seen from Figures 7.1 and 7.2 that, as the line length increases from 0 to 50 ft, the peak confidence value for CVF detection remains approximately within the range of 5 to 8. In addition, the false peak magnitudes were significantly smaller to enable the setting of the *vfullconthres* (see Section 6, PJM Tuning, for variable definition) value for CVF detection. Similar results were obtained with all of the other pressure transmitters tested. CVF detection was not a problem with only one PJM operating (data not shown). The results indicate that pipe lengths of up to 50 ft between the JPP and the drive pressure transmitter do not present any signal dampening problems for CVF detection.

7.4 Drive Overblow Detection

A drive overblow event is detected by the suction side pressure transmitter. Because the maximum line length between the suction side of the JPP and the pressure transmitters is 134 ft, the effect was investigated using 0, 50, 75, 100, and 125-ft lengths of piping between the suction side and the pressure transmitters. The results are shown in Figures 7.3 through 7.8. During the first five tests, six of the eight PJMs were operational, whereas in the last test (Figure 7.8), only the test PJM (#5) was operational.

In all of the graphs, the calculated confidence and drive pressure are plotted on the primary y-axis and the suction pressure on the secondary y-axis. For all plots, the x-axis represents the time. The data in the graphs represent the responses observed with the Weed pressure transmitter. Similar results were observed with the other pressure transmitters, although the magnitudes of the confidence valves were somewhat different.

It can be seen from the data in Figures 7.3 through 7.7 that as the line length increases the drive overblow confidence peaks decrease from a mean value of ~8 at 0 ft of piping to ~2 at 125 ft of piping. Another interesting observation was that there was no confidence signal for 125 ft of piping when PJM #5 was operating alone. This effect is shown in Figure 7.8. In the latter case, the lack of a confidence peak makes it impossible to set the value of *dvobconthres* for drive-overblow detection.

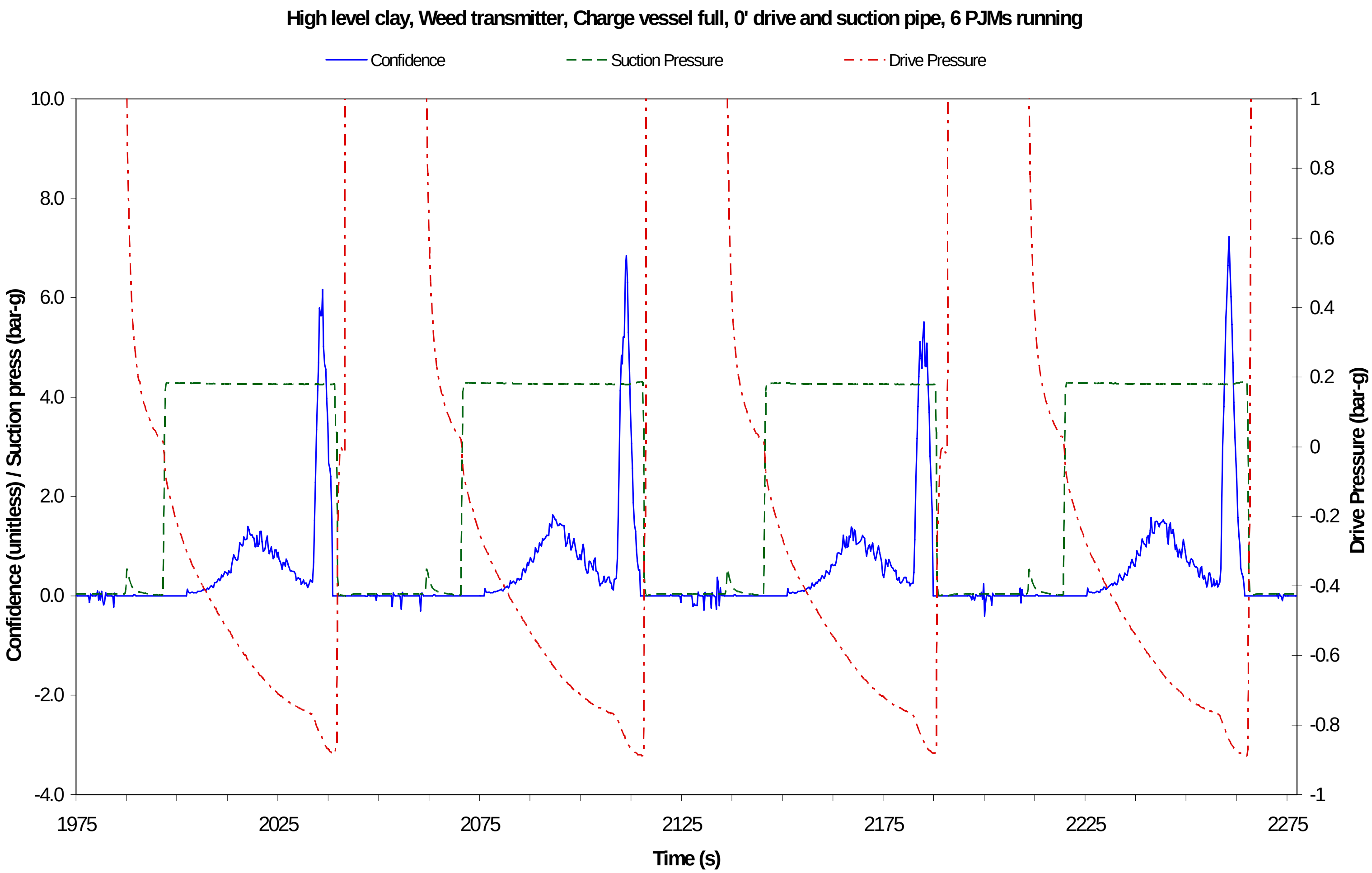


Figure 7.1. Pressure and Confidence Trends for CVF Detection with the Weed Pressure Transmitter and 0 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at a high fill level with six PJMs operating.)

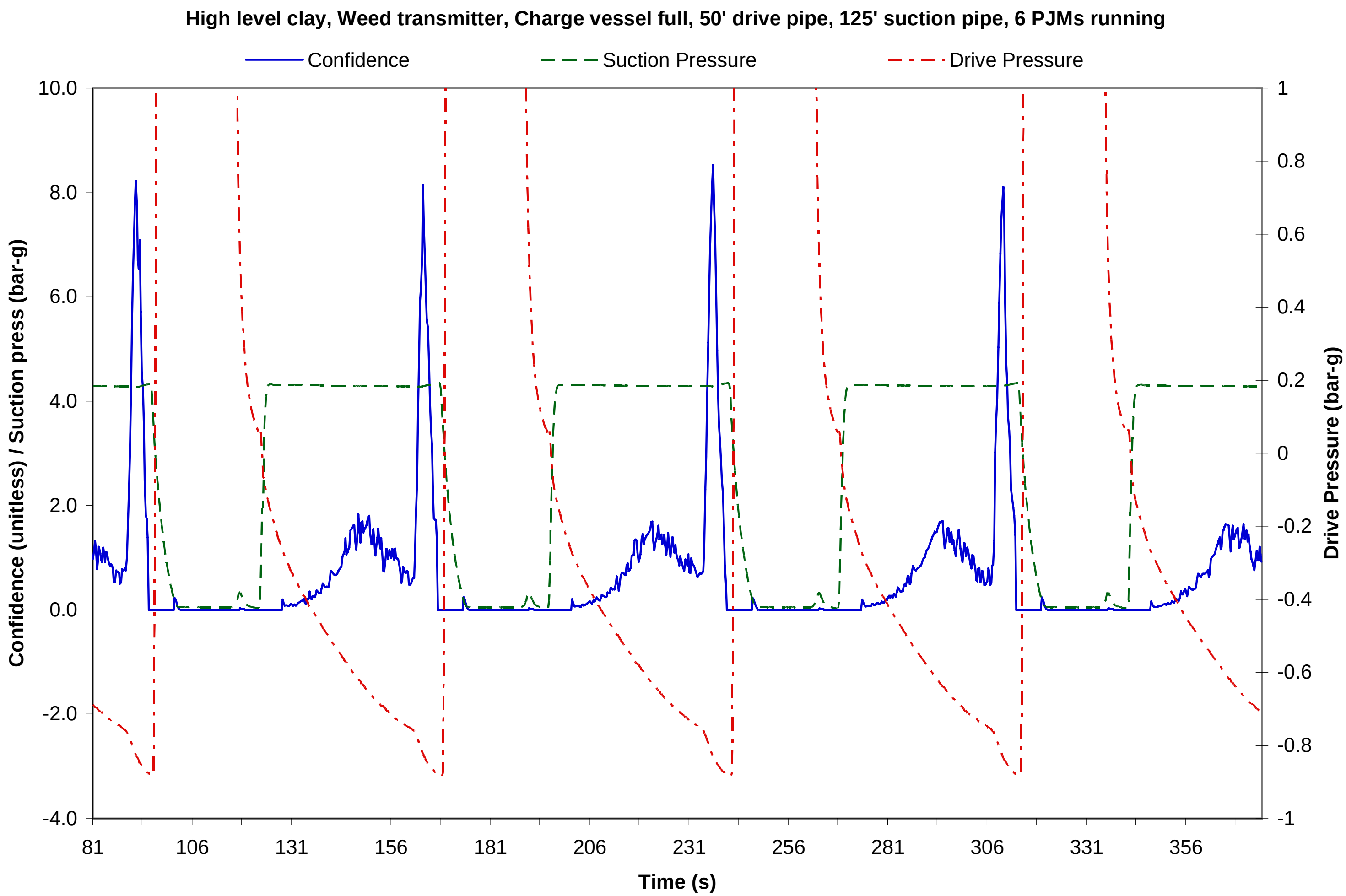


Figure 7.2. Pressure and Confidence Trends for CVF Detection with the Weed Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during clay simulant testing at a high fill level with six PJMs operating.)

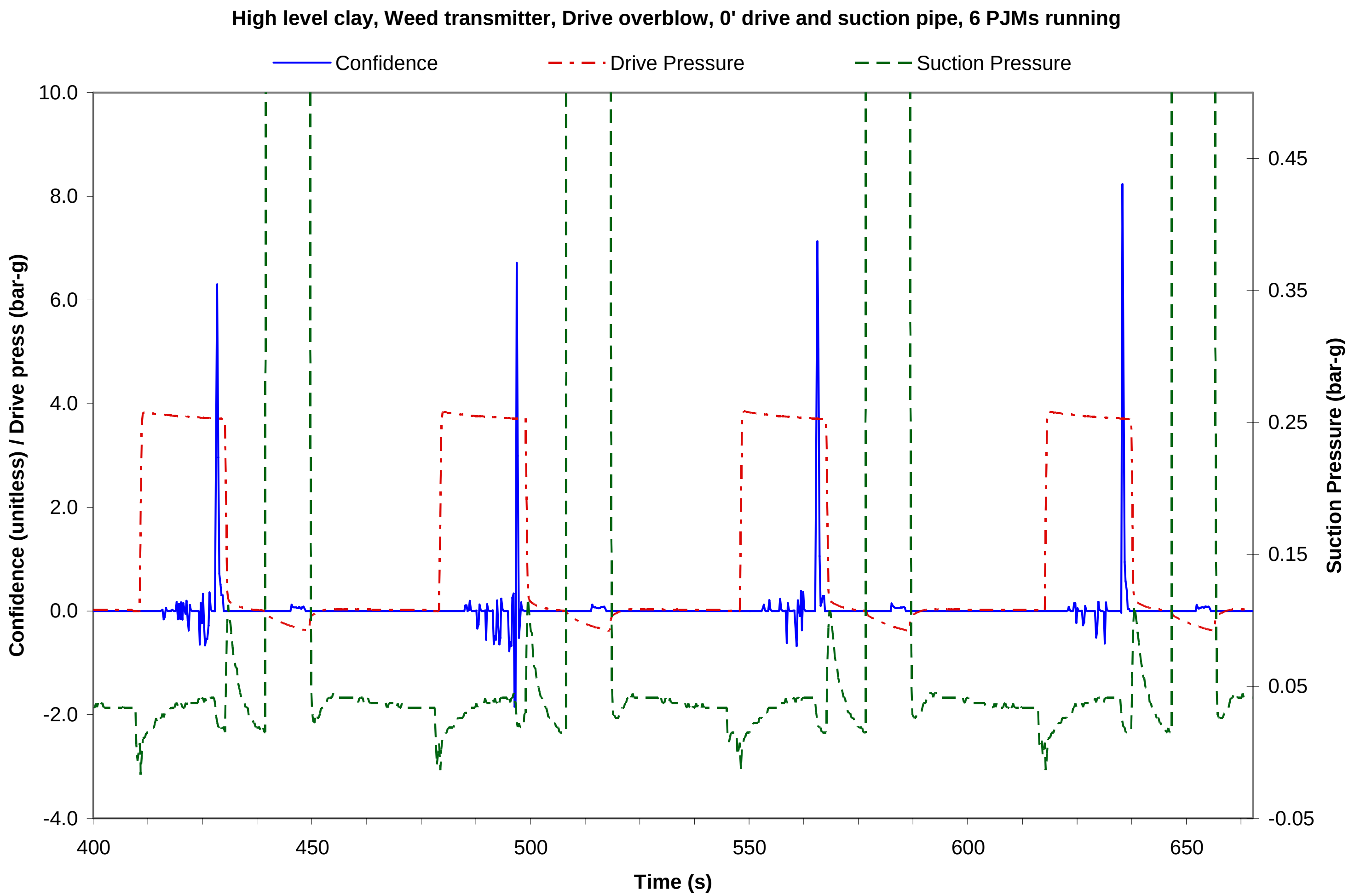


Figure 7.3. Pressure and Confidence Trends for Drive Overblow Detection with the Weed Pressure Transmitter and 0 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at a high fill level with six PJMs operating.)

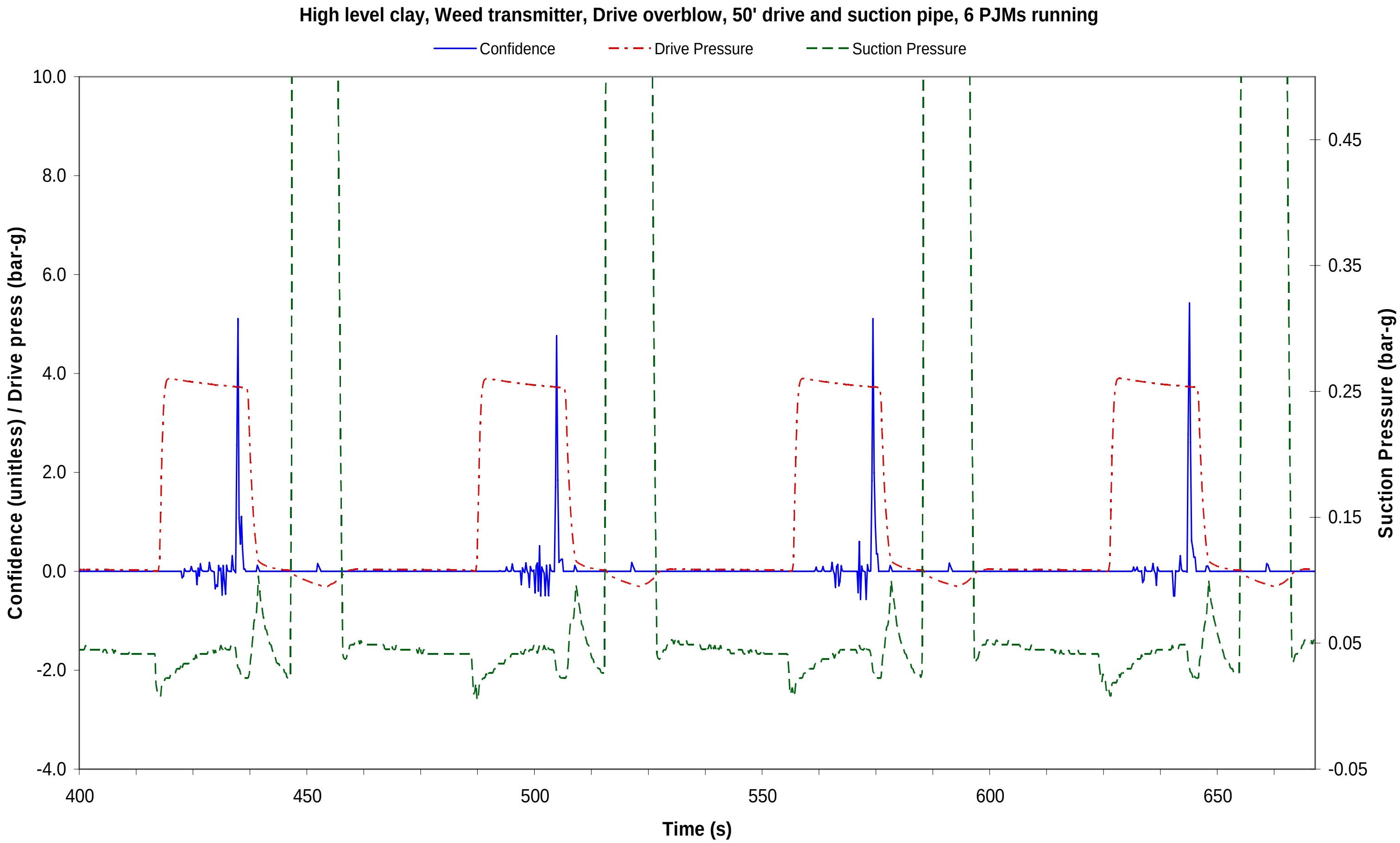


Figure 7.4. Pressure and Confidence Trends for Drive Overblow Detection with the Weed Pressure Transmitter and 50 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at a high fill level with six PJMs operating.)

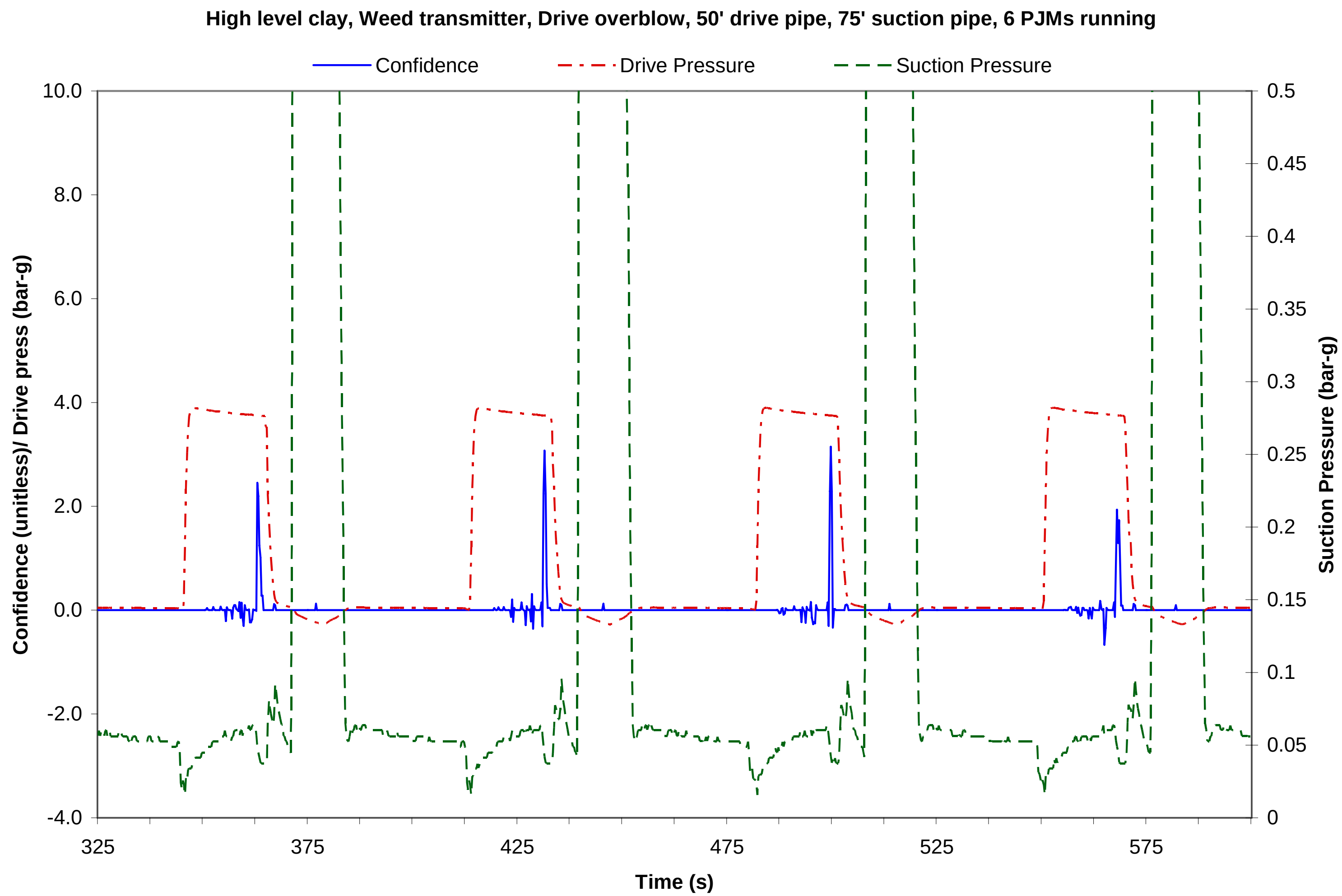


Figure 7.5. Pressure and Confidence Trends for Drive Overblow Detection with the Weed Pressure Transmitter and 75 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at a high fill level with six PJMs operating.)

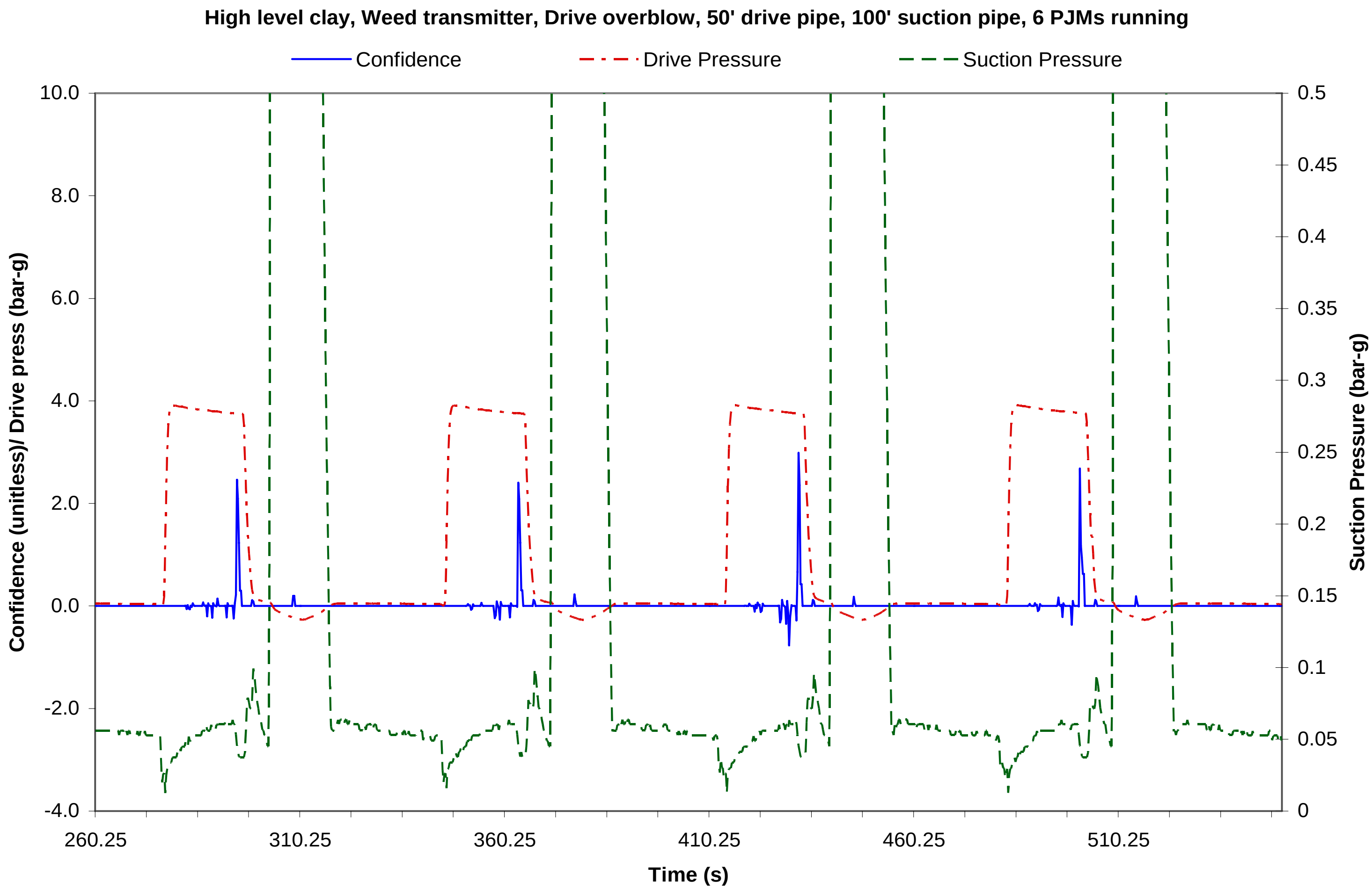


Figure 7.6. Pressure and Confidence Trends for Drive Overblow Detection with the Weed Pressure Transmitter and 100 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at a high fill level with six PJMs operating.)

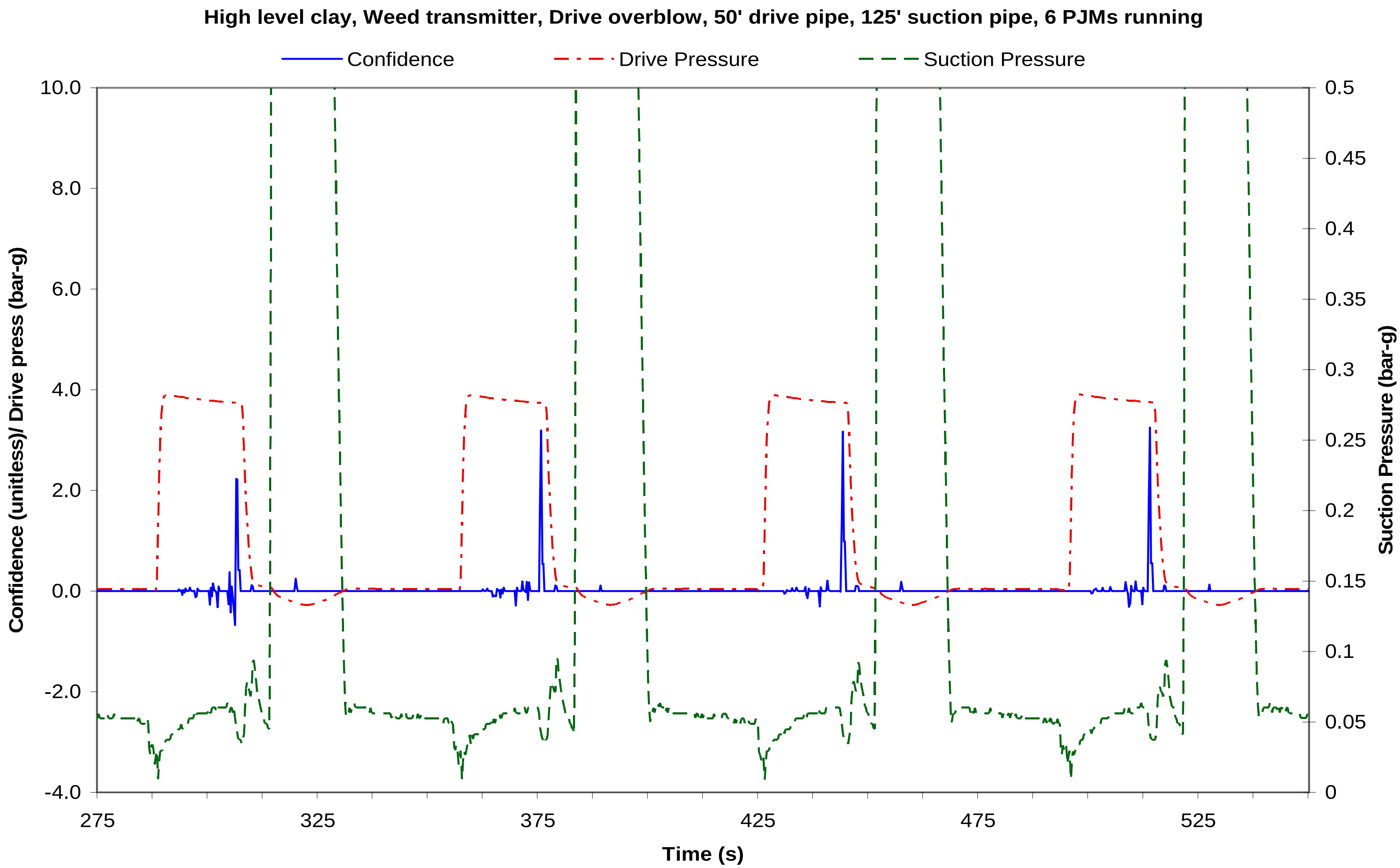


Figure 7.7. Pressure and Confidence Trends for Drive Overblow Detection with the Weed Pressure Transmitter and 125 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at a high fill level with six PJMs operating.)

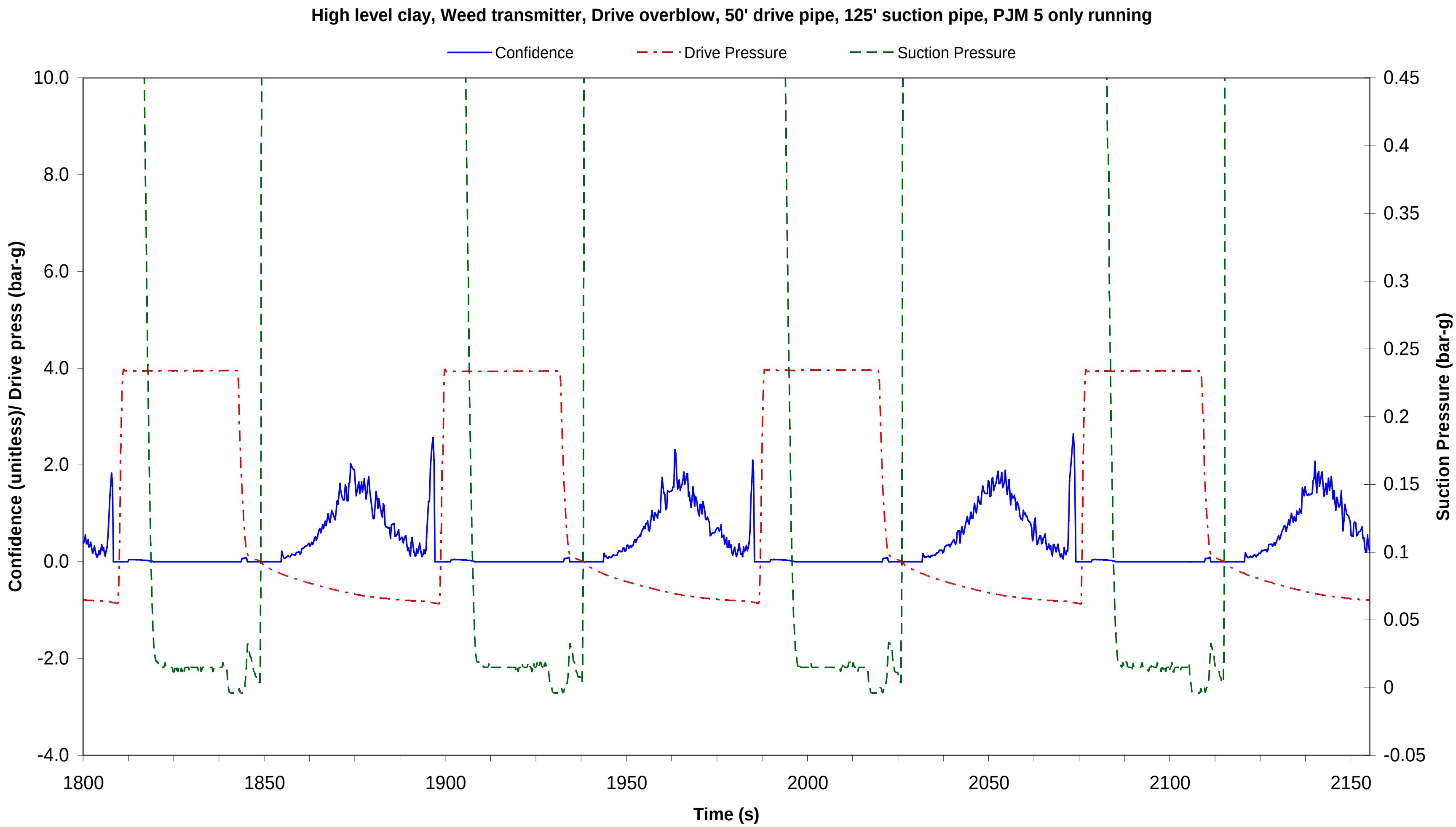


Figure 7.8. Pressure and Confidence Trends for Drive Overblow Detection with Weed Pressure Transmitter and 125 ft of Piping Between Suction Leg of JPP and the Transmitter. (Data obtained during clay simulant testing at high fill level with only PJM #5 operating.)

These figures indicate that drive overblow detection becomes more and more difficult as the line length increases to plant maximum design value. In addition, the results also indicate that with the present maximum pipe length range it is practically impossible to operate any of the PJMs alone, a case important to the "scout" mode of PJM operation necessary for plant operations to establish the controller drive time to prevent overblows. Also, testing with line lengths longer than 125 ft was not pursued because an alternative approach was required.

Because operation of a single PJM is envisioned as part of WTP operations, it was decided to investigate using the transmitter in the flush line to detect overblows. These results are presented in Section 7.6.

7.5 Aspiration Detection

If the slurry level in a vessel is lowered beyond a minimum point, the level will fall below the bottom opening in the pulse tubes and air can be entrained into the pulse tube during the suction phase. The results of the aspiration test using the Druck transmitter are shown in Figure 7.9. By comparing the curve for the deviation before and after aspiration it can be seen that there is no observable difference. This indicates that aspiration could not be detected at the specified conditions. A similar result was obtained using the Weed transmitter at the same test conditions.

7.6 Drive Overblow Detection with Pressure Transmitter in Flush Line

To detect drive overblows, the UK AEA algorithm looks for a small drop in the suction pressure at the JPP. The results presented in Section 7.4 show the pressure drop was typically on the order of 0.02 bar from a transmitter with a range of 0 to 7 bar-a. The algorithm incorporates measures to prevent process or electronic noise from causing a false positive for the drive overblow event, but this necessary feature appears to sometimes filter out the true overblow signature, especially with only one PJM running. On the other hand, with the flush line pressure measurement, the magnitude of the pressure drop is expected to be larger.[a] To use this larger signal, a modified algorithm was developed to employ flush line pressure to detect drive overblows (see Section 3.3 for discussion of algorithm modifications). The flush line pressures were measured with a Druck PTX-911 model pressure transmitter. Specifications of the transmitter are the same as those used to measure the pressure on the drive and suction side of the JPP (see Table 3.1 for details of the pressure transmitter).

These results for overblow detection using the flush line transmitter are presented in Figures 7.10 and 7.11. The data were collected with the clay simulant at a fill height of 60 ± 2 inches (measured from the tank rim). The data in Figure 7.10 represent the condition when six of the eight PJMs are operating, and the data in Figure 7.11 show the case when only PJM #5 was operating. In both graphs, the primary y-axis shows the drive pressure at the JPP and the pressure measured in the flush line. The right side axis (secondary y-axis), shows the calculated confidence values. It can be seen from the data in the figures that the flush line pressure is unaffected by the number of PJMs operating simultaneously. Also, it can be seen that when an overblow occurs, the magnitude of the pressure drop is on the order of 0.5 bar. Such a

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(a) The pressure drop recorded by the flush-line pressure transmitter during an overblow will typically be the difference the PJM pressure during the drive phase and the hydrostatic head of liquid above the nozzle in the tank.

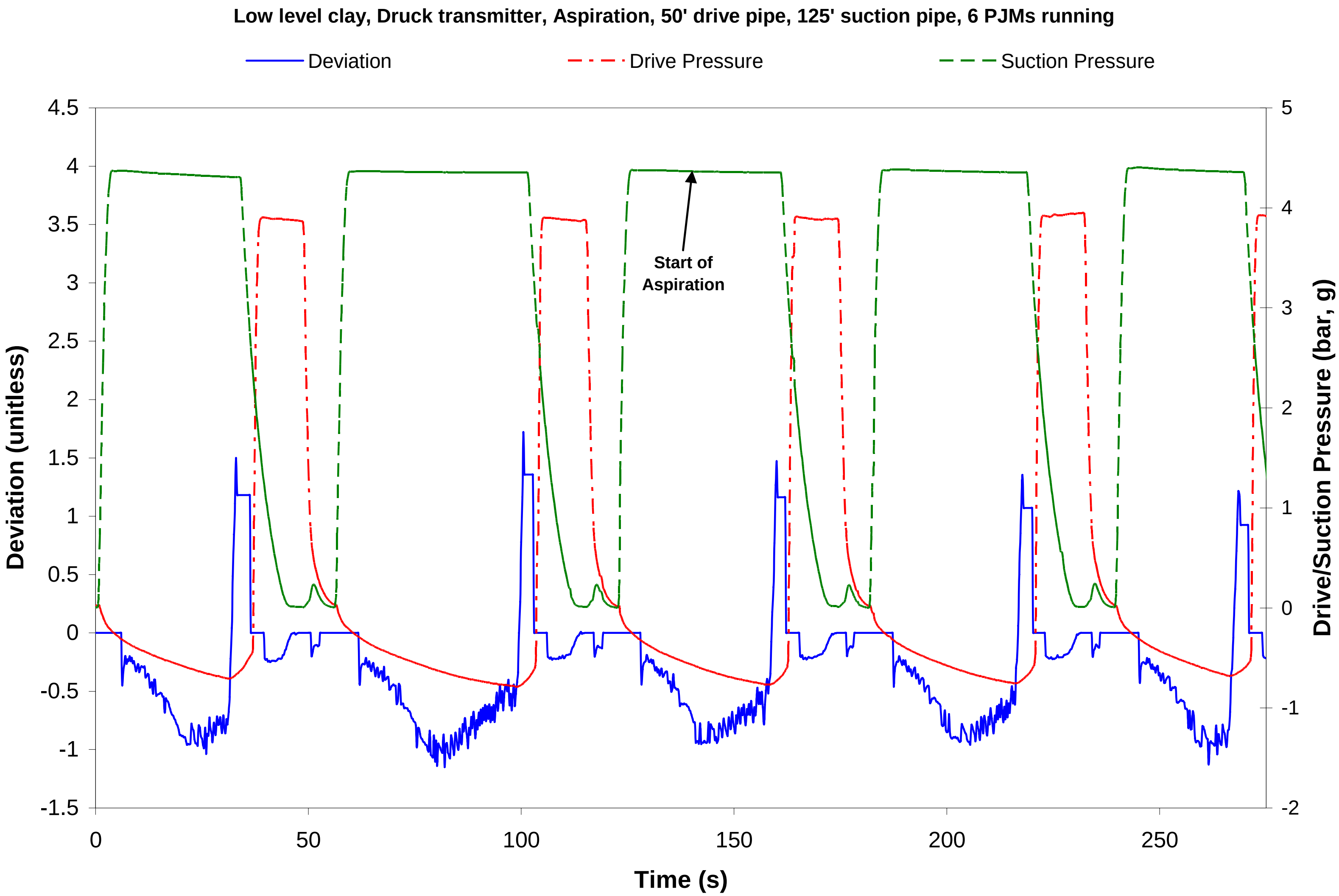

Figure 7.9. Pressure and Confidence Trends for Aspiration Detection with Druck Pressure Transmitter and 125-ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at a very low level with six PJMs running.)

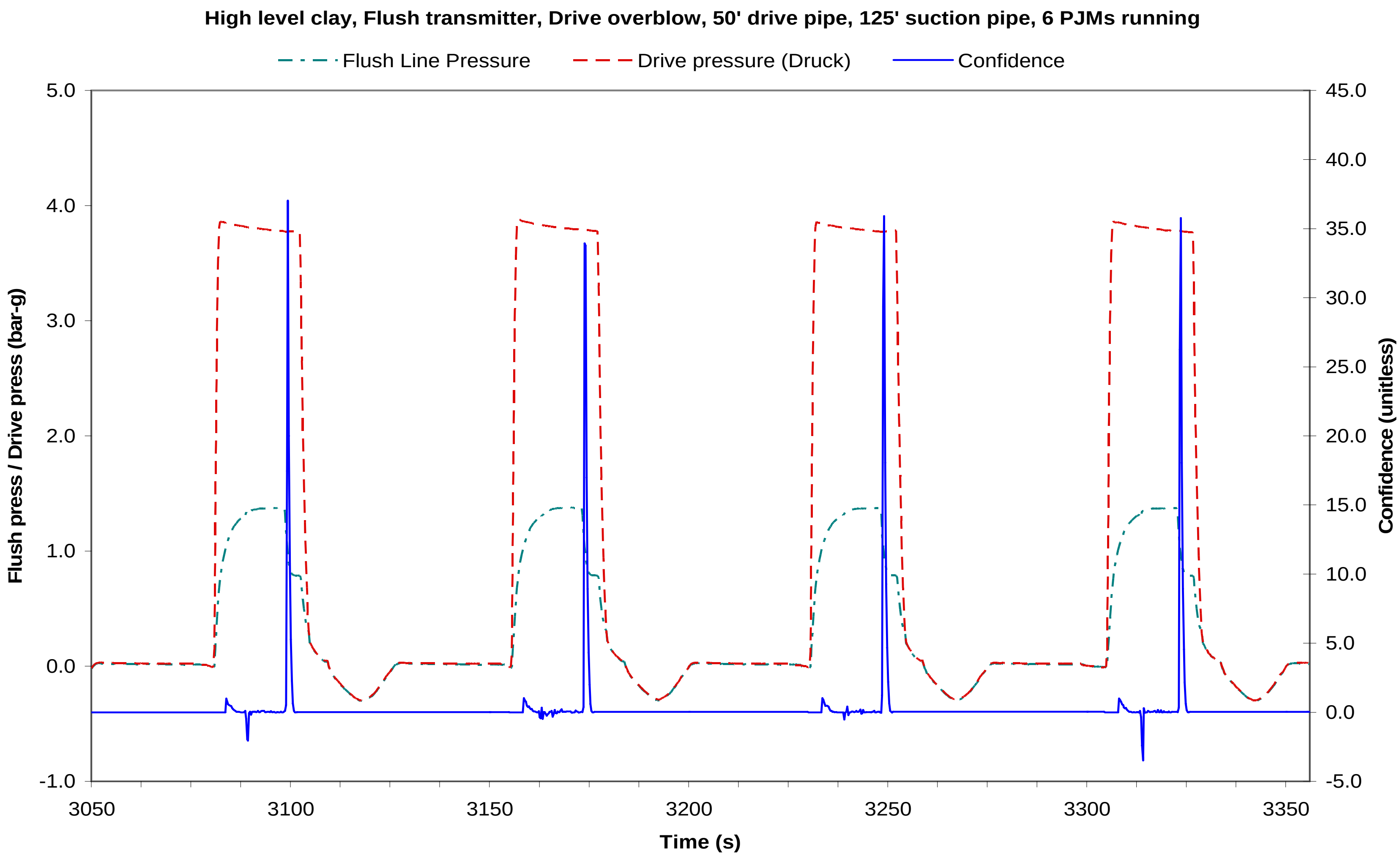

Figure 7.10. Pressure and Confidence Trends for Drive Overblow Detection with the Flush Line Transmitter at the End of 100 ft of ¾-inch Piping PJM Air Link Line. (Data obtained during clay simulant testing at a high fill level and six of the eight PJMs operating.)

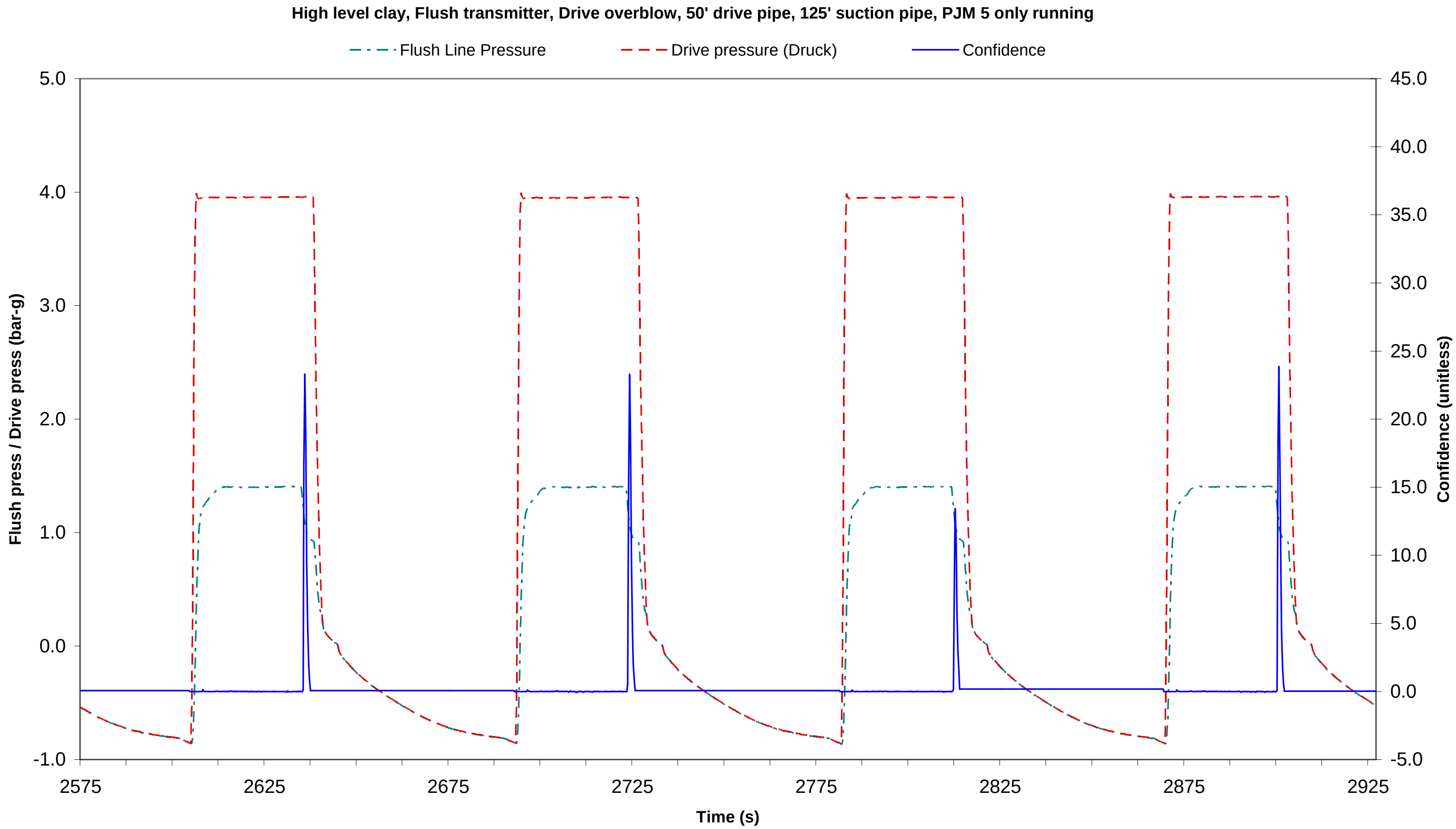

Figure 7.11. Pressure and Confidence Trends for Drive Overblow Detection with the Flush Line Transmitter at the End of 100 ft of ¾-inch Piping PJM Air Link Line. (Data obtained during clay simulant testing at a high fill level and only PJM #5 operating.)

large pressure drop is easy to detect and is reflected by the sharp peak in the confidence values in both figures. Although the peak value of the confidence was slightly lower when only one PJM is operating, its magnitude is still several orders of magnitude higher than the confidence value detected with the pressure transmitter on the suction side of the JPP. Similar results were obtained during all of the test conditions evaluated during the present testing. These results are presented in Section 9 in the discussion about the effect of simulant level and type.

Because of the larger magnitude of the pressure drop in the flush line during a drive overblow, it is anticipated that the Weed transmitter would not have difficulty detecting the same change. The exception would be detecting a drive overblow shortly before the drive valve closes, where the slower response of the Weed transmitter may result in reduced ability to detect the overblow. If the planned overblow testing results in a requirement to detect overblows with the safety system, the pressure signatures from the Druck transmitters can be used as an input in a lab simulation to determine the overall safety system response. Appropriate damping could be applied to the Druck signals, then the resulting signals could be input to a Triconex system. A nuclear qualified Ametek transmitter with a response time similar to the Druck transmitter is on the market if the simulation indicates the Weed transmitter does not provide acceptable response.

7.7 Conclusions

The results indicate that line length plays a far more important role in drive overblow detection than it does in CVF detection, primarily due to the significantly longer piping on the suction side of the JPP. In addition, the results also indicate that other means of overblow detection are necessary for the cases when each PJM has to be operated individually to establish the drive times for various operating conditions. To improve the drive overblow detection capability, a new approach involving measurement of the pressure in the flush line was incorporated into the control algorithm. Drive overblows were successfully detected with the modified algorithm and pressure measurement in the flush line even when only one PJM was operating. Finally, data logging problems precluded statistical analysis of the data to establish confidence thresholds for CVF and drive overblow detection.

Vent overblow detection was not possible due to the extremely low confidence signals even with 0 ft of piping between the pressure transmitters and drive/suction sides of the JPP. Thus, no vent overblow testing was performed with the extended piping. Also the results indicate that aspiration detection is not possible with the current configuration of the pipe lengths between the JPP and the pressure transmitters.

8.0 Pressure Transmitter Performance

In Section 7, it was shown that drive overblow detection is more significantly affected than CVF detection due to the extra length of piping between the JPP and the suction side pressure transmitters. In this section we further investigate this effect in terms of the performance of the different pressure transmitters being considered for use in the WTP.

8.1 Experimental Conditions

A list of the various pressure transmitters evaluated along with transmitter model and other relevant data is presented in Section 3. The details of the equipment modification, such that all pressure transmitters see the same pressure, are presented in Section 4. All pressure transmitter data presented in this section were taken from the water testing with a fill height-to-diameter ratio (H/D) of 0.77 (i.e., the height of the simulant in the tank was 60 ±2 inches as measured from the tank rim). Maximum line length of 50 ft on the drive side and 125 ft on the suction side were used. Finally, for all pressure transmitter performance data shown, only six of the eight PJMs were operational due to limitations in the air supply system (i.e., PJMs #2 and #8 were turned off).

To ensure that only the test PJM (#5) experienced an overblow during the drive overblow tests, the PJM controller conditions were set so that the PJM #5 stopped refilling before the other PJMs. In this way, when the drive phase started, PJM #5 had a lower fill level than the other PJMs. With a sufficiently long drive time, this resulted in a drive overblow in PJM #5.

8.2 Results

Typical representative performance curves of the various pressure transmitters tested for drive overblow detection are shown in Figures 8.1 through 8.5. In all of the graphs, the calculated confidence and drive pressure are plotted on the primary y-axis and the suction pressure on the secondary y-axis.

The confidence peak information obtained from the various transmitters was carefully analyzed by BNI staff, who determined that of the five pressure transmitters tested, the Druck and Weed transmitters perform better than the Foxboro and ABB transmitters in detecting overblows. For example, the peak average confidence values for the Weed and the Druck were on the order of 8 to 14 (see Figures 8.3 and 8.4), respectively, while those for the Foxboro 4-20 and Foxboro FF were on the order of ~1 to 2 (see Figure 8.1 and 8.2) with several overblow peaks missing. This is probably due to the slower response time of the Foxboro units. Typically the confidence calculated from the Foxboro transmitters resulted in lower peaks, and in some cases no peaks, for drive overblow events. (In Figures 8.1 and 8.2, several overblows were not detected at the 125-ft suction pipe length.) Although the data for the ABB transmitter (Figure 8.5) showed good overblow confidence values, a careful examination of other data sets by BNI staff revealed that the ABB transmitters were less likely to provide reliable overblow detection than the Weed and Druck transmitters.

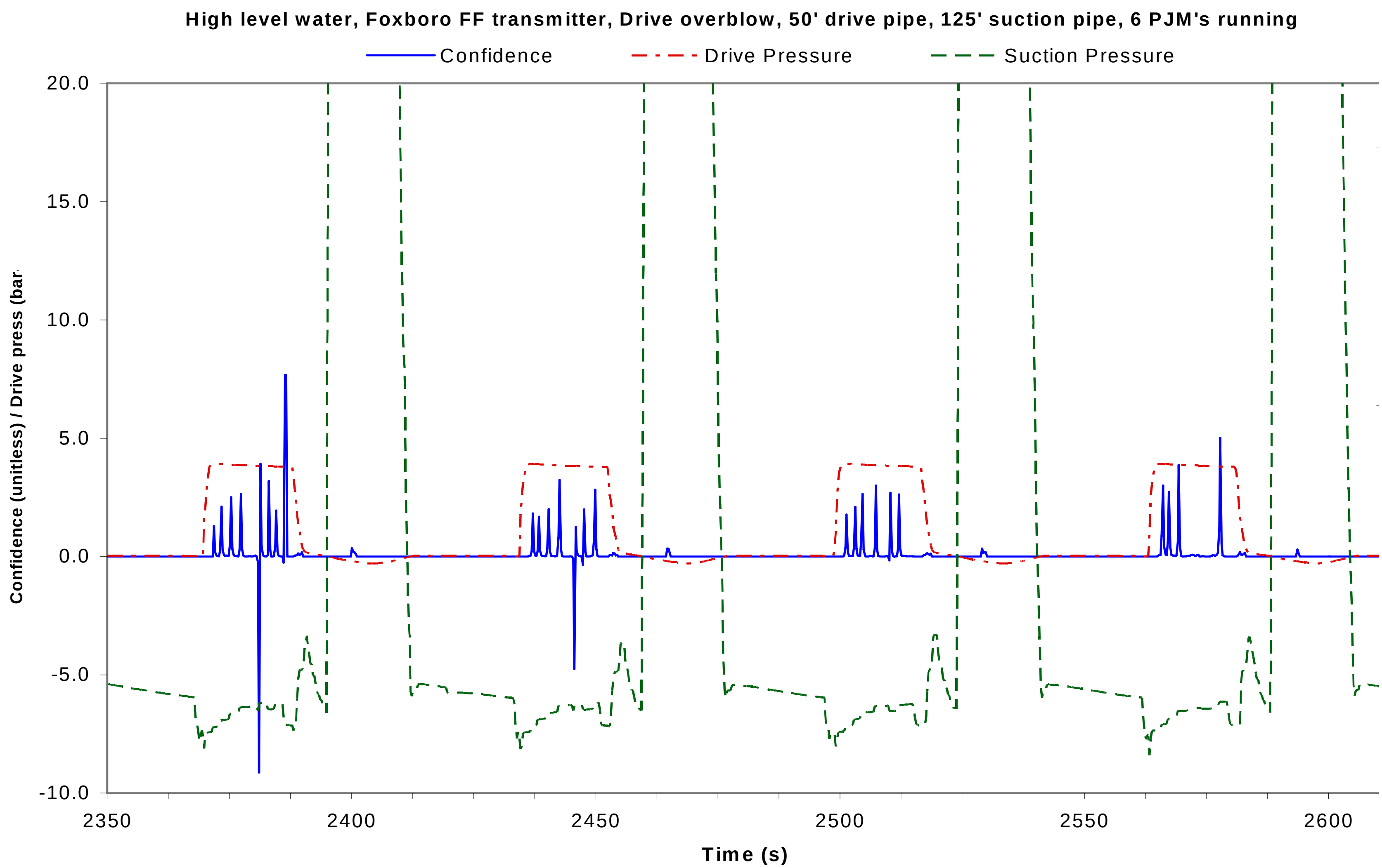

Figure 8.1. Pressure and Confidence Trends for Drive Overblow Detection with the Fox FF Pressure Transmitter and 50/125 ft of Piping Between the Drive/Suction Legs of the JPP and the Pressure Transmitter, Respectively. (Data were obtained during water simulant testing at a high fill level with six PJMs operating.)

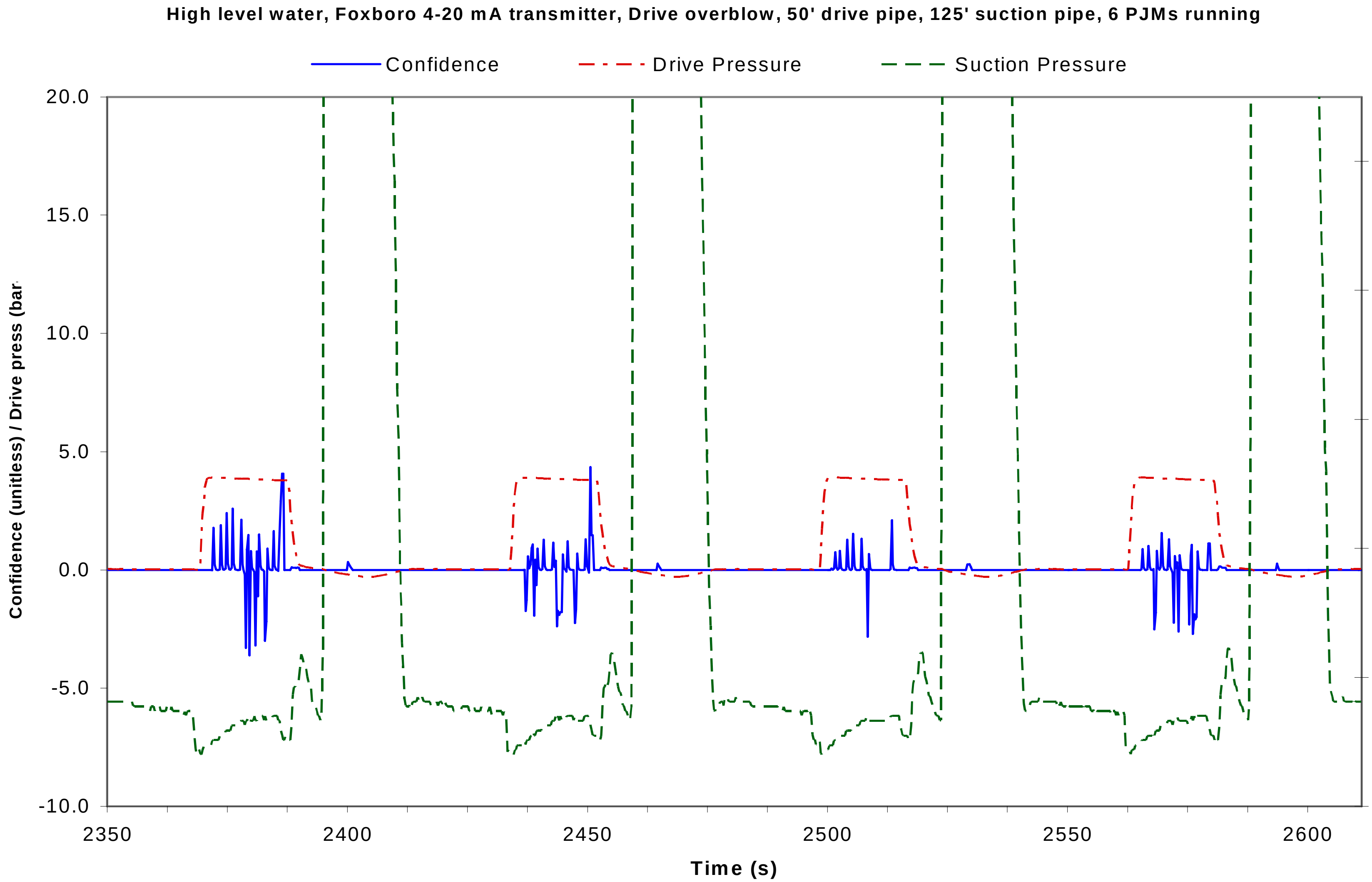

Figure 8.2. Pressure and Confidence Trends for Drive Overblow Detection with the Fox 4-20 mA Analog Pressure Transmitter and 50/125 ft of Piping Between the Drive/Suction Legs of the JPP and the Pressure Transmitter, Respectively. (Data were obtained during water simulant testing at a high fill level with six PJMs operating.)

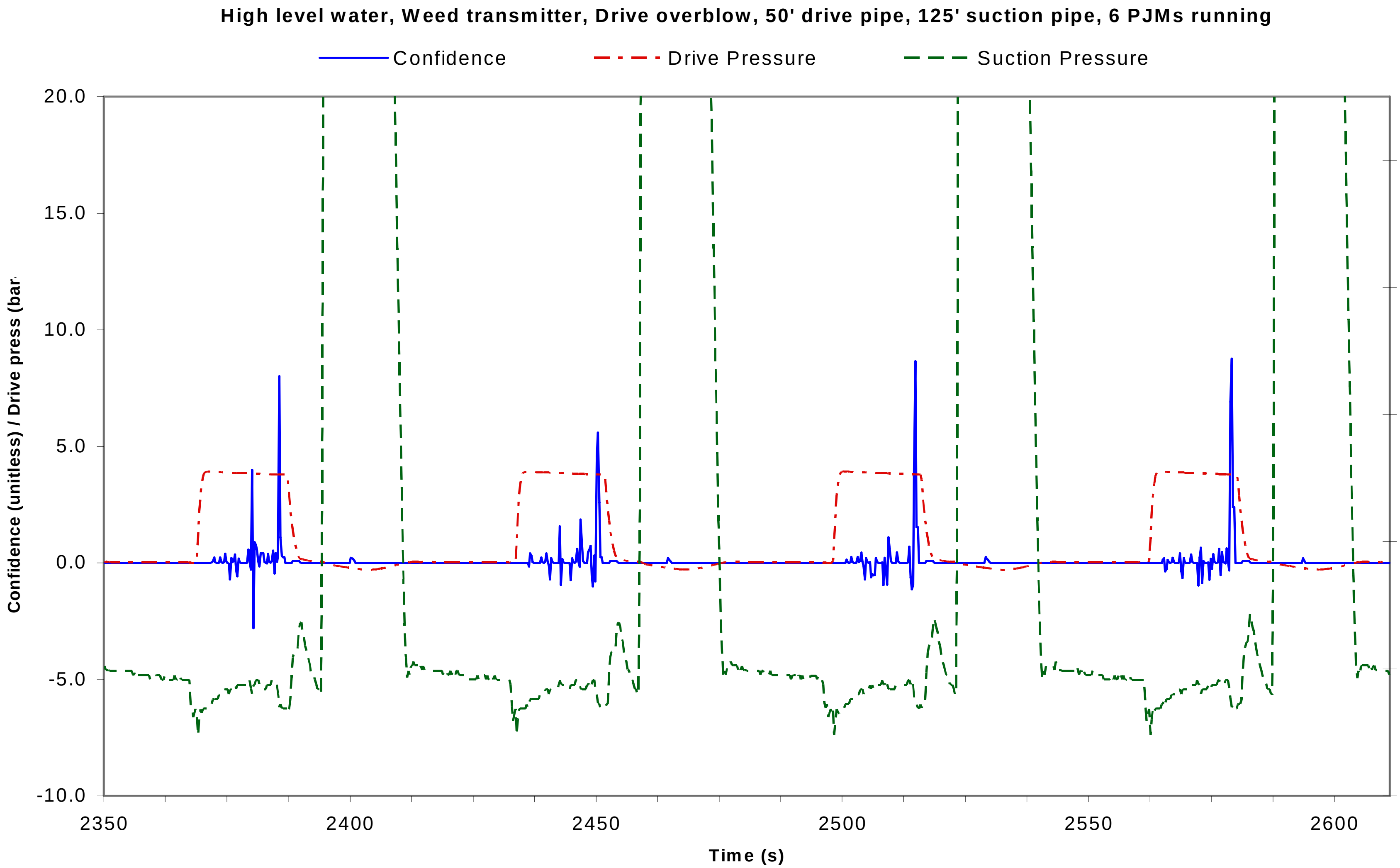

Figure 8.3. Pressure and Confidence Trends for Drive Overblow Detection with the Weed 4-20 mA Analog Pressure Transmitter and 50 and 125 ft of Piping Between the Drive/Suction Legs of the JPP and the Pressure Transmitter, Respectively. (Data were obtained during water simulant testing at a high fill level with six PJMs operating.)

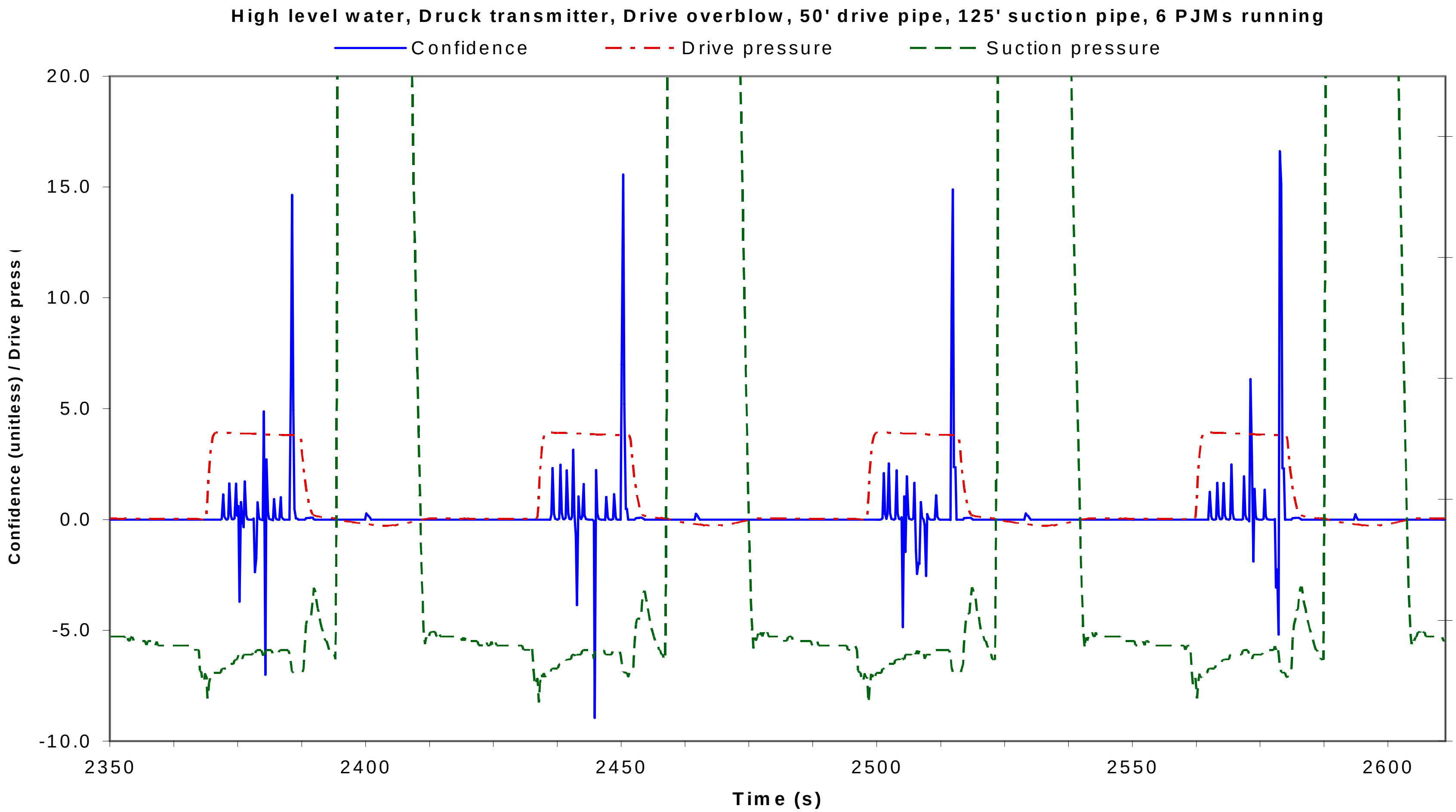

Figure 8.4. Pressure and Confidence Trends for Drive Overblow Detection with the Druck 4-20 mA Analog Pressure Transmitter and 50 and 125 ft of Piping Between the Drive/Suction Legs of the JPP and the Pressure Transmitter, Respectively. (Data were obtained during water simulant testing at a high fill level with six PJMs operating.)

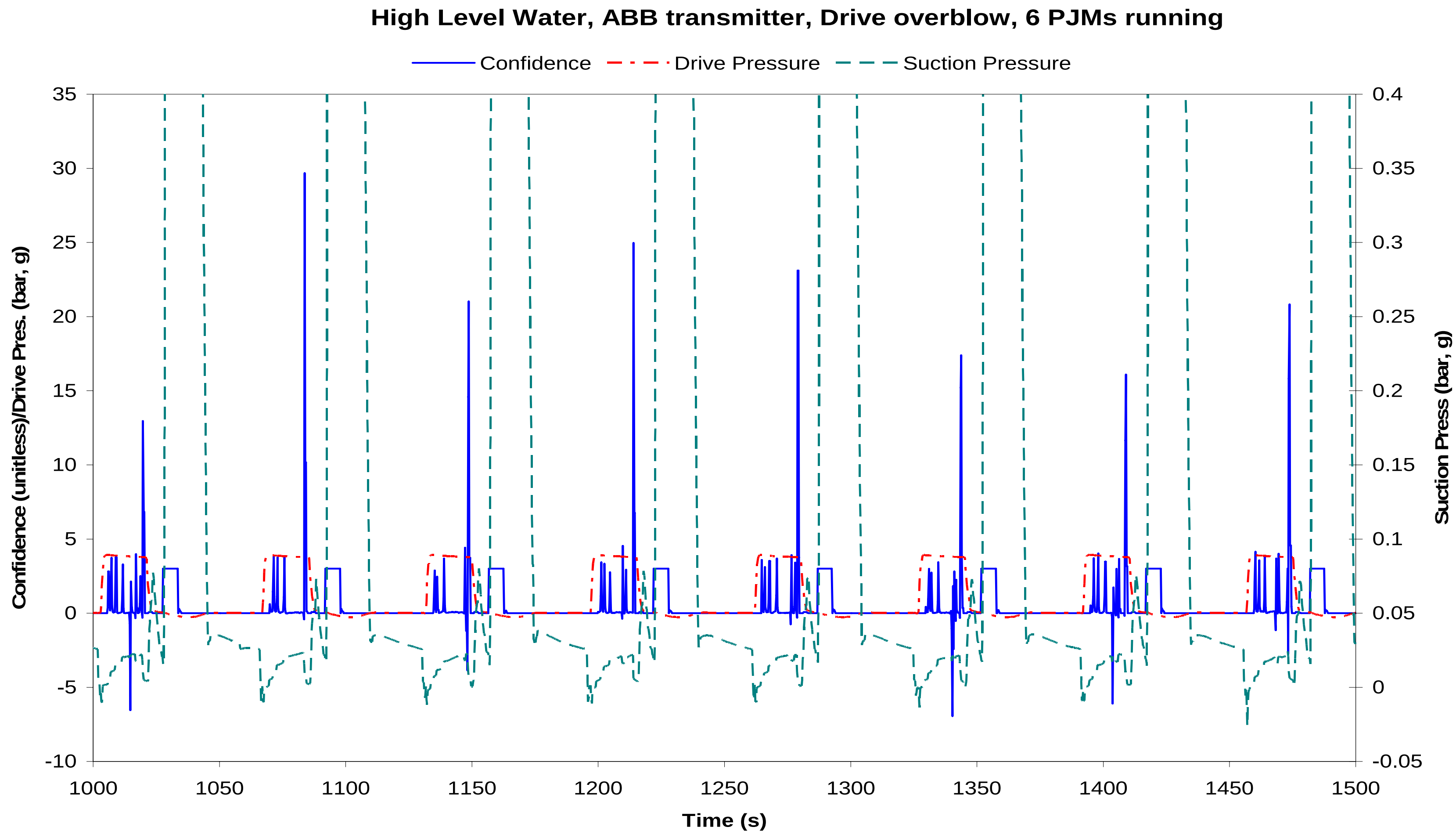

Figure 8.5. Pressure and Confidence Trends for Drive Overblow Detection with the ABB Pressure Transmitter and 50/125 ft of Piping Between the Drive/Suction Legs of the JPP and the Pressure Transmitter, Respectively. (Data were obtained during water simulant testing at a high fill level with six PJMs operating.)

8.3 Summary

BNI staff's evaluation of all the transmitter performance indicates that the Druck and Weed transmitters performed significantly better than the others. BNI's analysis also showed that the slower response time of the Foxboro units is thought to have resulted in low or nonexistent confidence peaks and made it difficult to detect overblow events. The ABB transmitter was less likely to provide reliable overblow detection than the Weed and Druck transmitters. Based on these observations, BNI has determined that Druck transmitter will provide the best response for non-safety PJM applications, while the Weed transmitter will provide adequate response for safety applications.

9.0 Sensitivity of Control System to Process Changes

In this section, the effects of the simulant type and fill level on CVF detection are presented using the data obtained from the Druck and Weed pressure transmitters located on the drive side of the JPP. On the other hand, the effect of the simulant type and fill level on drive overblow detection is presented using the data obtained form the Druck transmitter located on the flush line.

9.1 Experimental Conditions

The ability of the controller to detect CVF and drive overblow was determined using two different simulants (clay and water) at three H/D ratios, 0.77, 0.57, and 0.31. Maximum line length of 50 ft on the drive side and 125 ft on the suction side were used. Also, for all pressure transmitter performance data shown, only six of the eight PJMs were operational during the CVF testing due to limitations in the air supply system (i.e., PJMs #2 and #8 were turned off). Finally, as mentioned in Section 7, operating only one PJM at a time is considered the worst case for the drive overblow detection because this represents the condition of the lowest back pressure in the suction leg of the JPP. Therefore, this condition, (only PJM #5 operating), was used as test case to demonstrate the effect of simulant fill level and simulant type on drive overblow detection.

9.2 Results for CVF Detection

The pressure and confidence trends for the Weed pressure transmitter during the CVF detection runs at simulant H/D ratios of 0.77 (high), 0.57 (mid), and 0.31 (low) with clay and water are shown in Figures 9.1 to 9.6, respectively. The same results for the Druck pressure transmitter are shown in Figures 9.7 to 9.12. In all of the graphs, the suction pressure and confidence are plotted on the primary y-axis and the drive pressure on the secondary y-axis.

The following observation can be made from the confidence data in shown in Figures 9.1 to 9.12:

1. Both the Weed and Druck transmitters are able to detect CVF over the range of simulant levels and simulant types investigated. This is indicated in the plots by the fact that the peaks in the confidence values are significantly above the false confidence peaks.
2. A careful examination of all the data by BNI indicated that for CVF detection, the Druck transmitter performs slightly better than the Weed transmitter in all cases. This is indicated by the slightly higher peak confidence values using the Druck transmitters relative to the Weed transmitters.
3. The CVF signal is significantly affected by the simulant level as indicated by the fact that the peak value of the confidence decreases as the simulant level decreases.
4. The CVF signal is affected by the simulant type. This is indicated by the observation that the peak values of confidence obtained with water are generally greater than those obtained with clay.

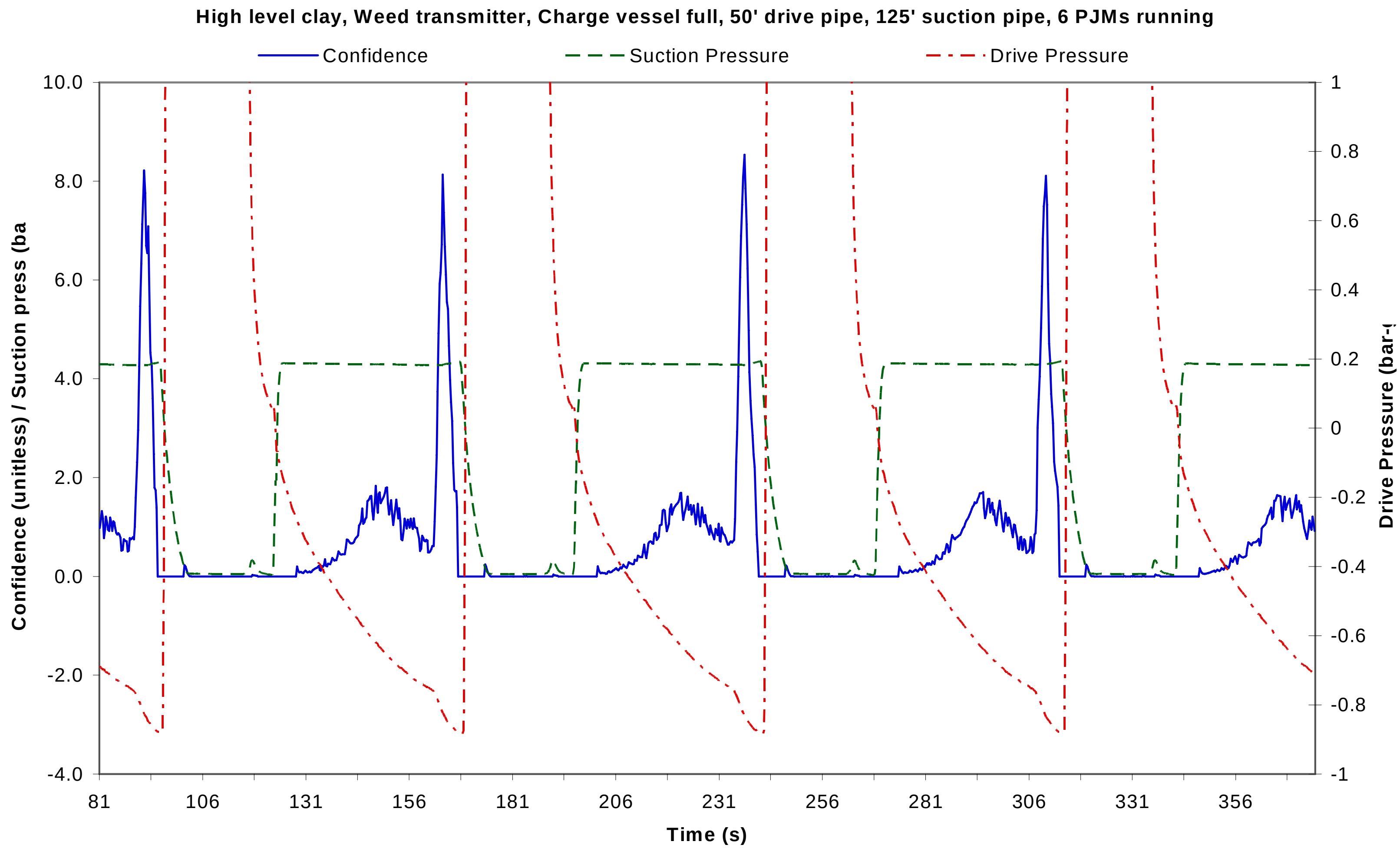

Figure 9.1. Pressure and Confidence Trends for CVF Detection with the Weed Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during clay simulant testing at a high fill level with six PJMs operating.)

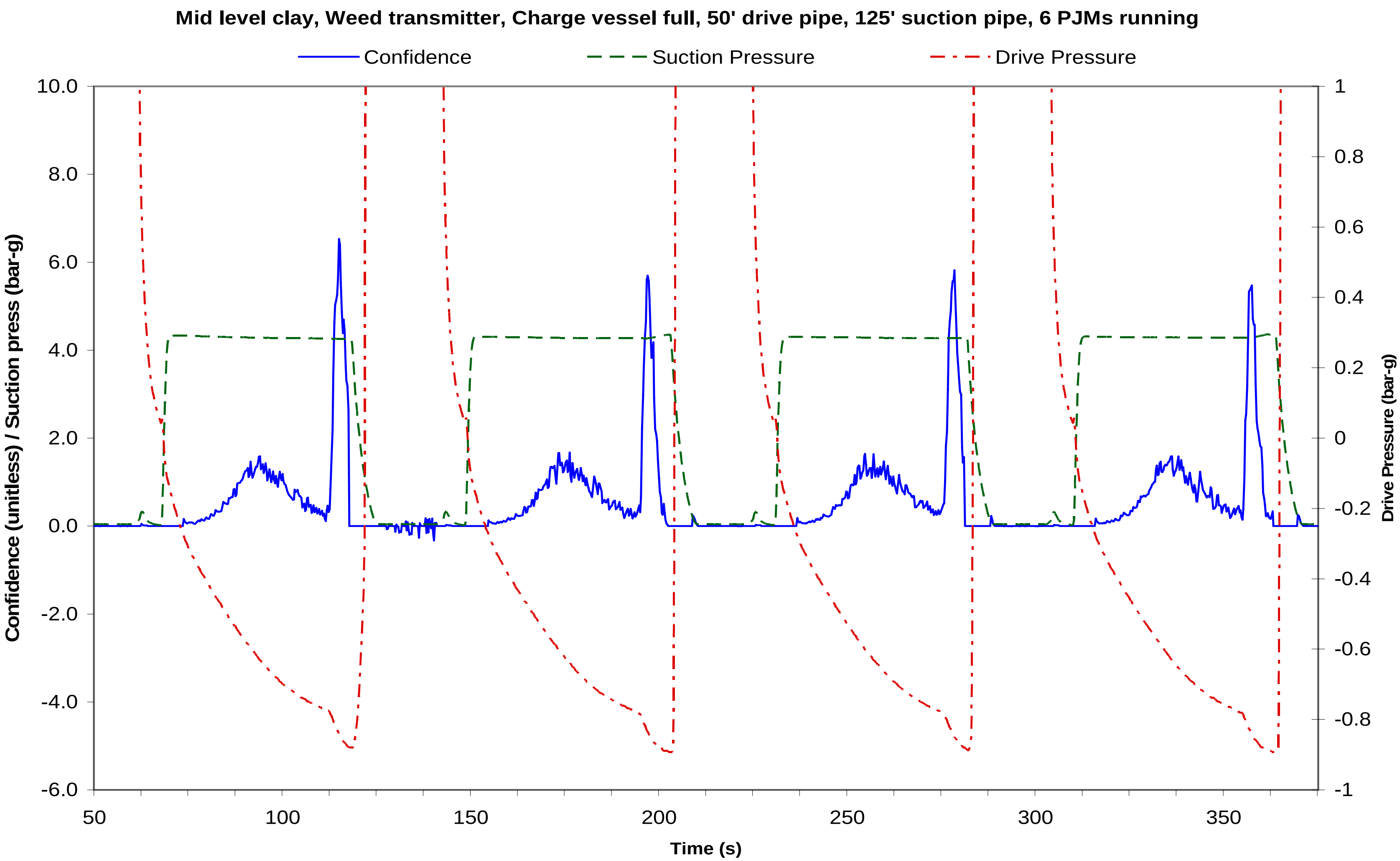

Figure 9.2. Pressure and Confidence Trends for CVF Detection with the Weed Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during clay simulant testing at a mid fill level with six PJMs operating.)

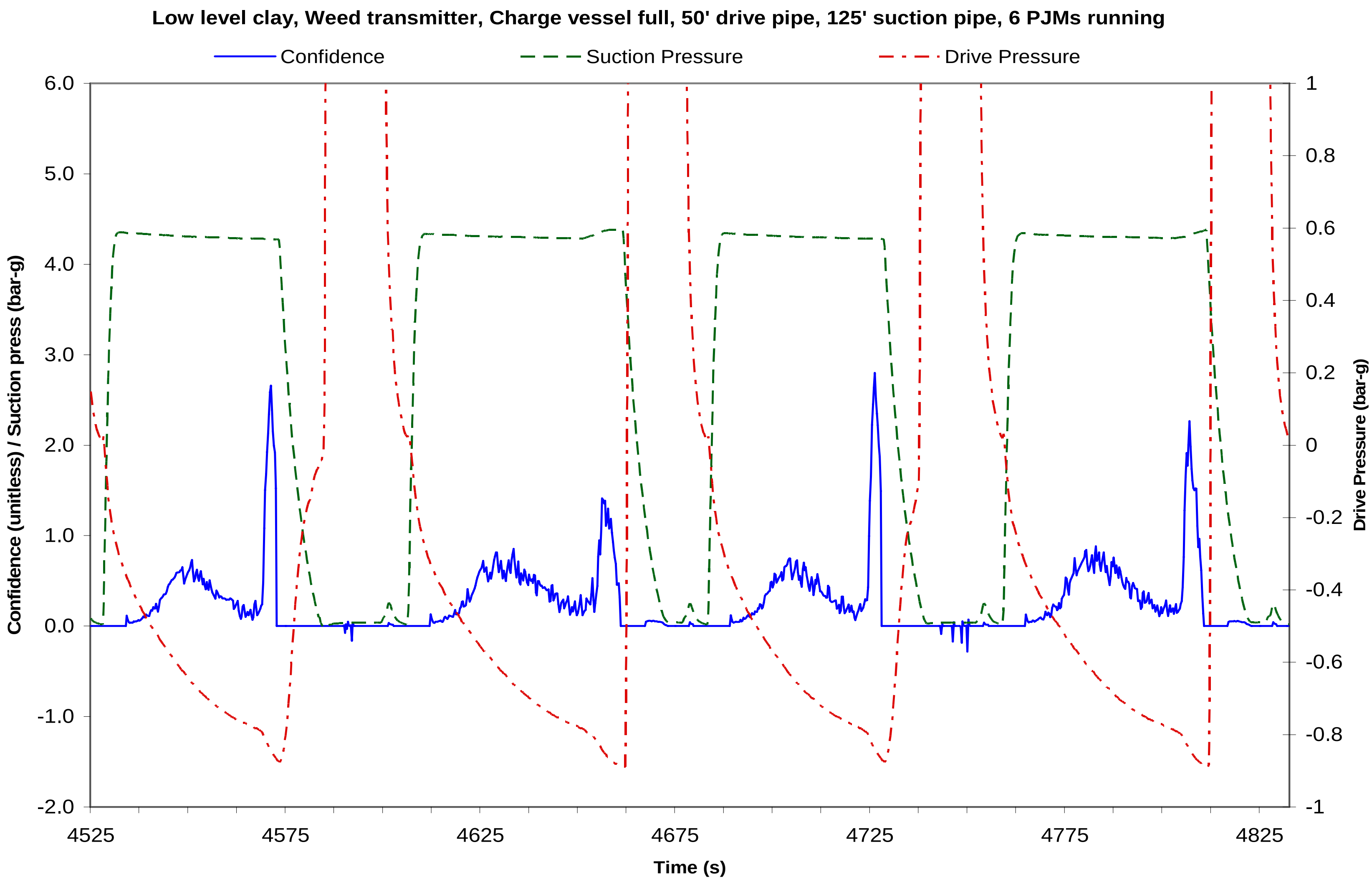

Figure 9.3. Pressure and Confidence Trends for CVF Detection with the Weed Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during clay simulant testing at a low fill level with six PJMs operating.)

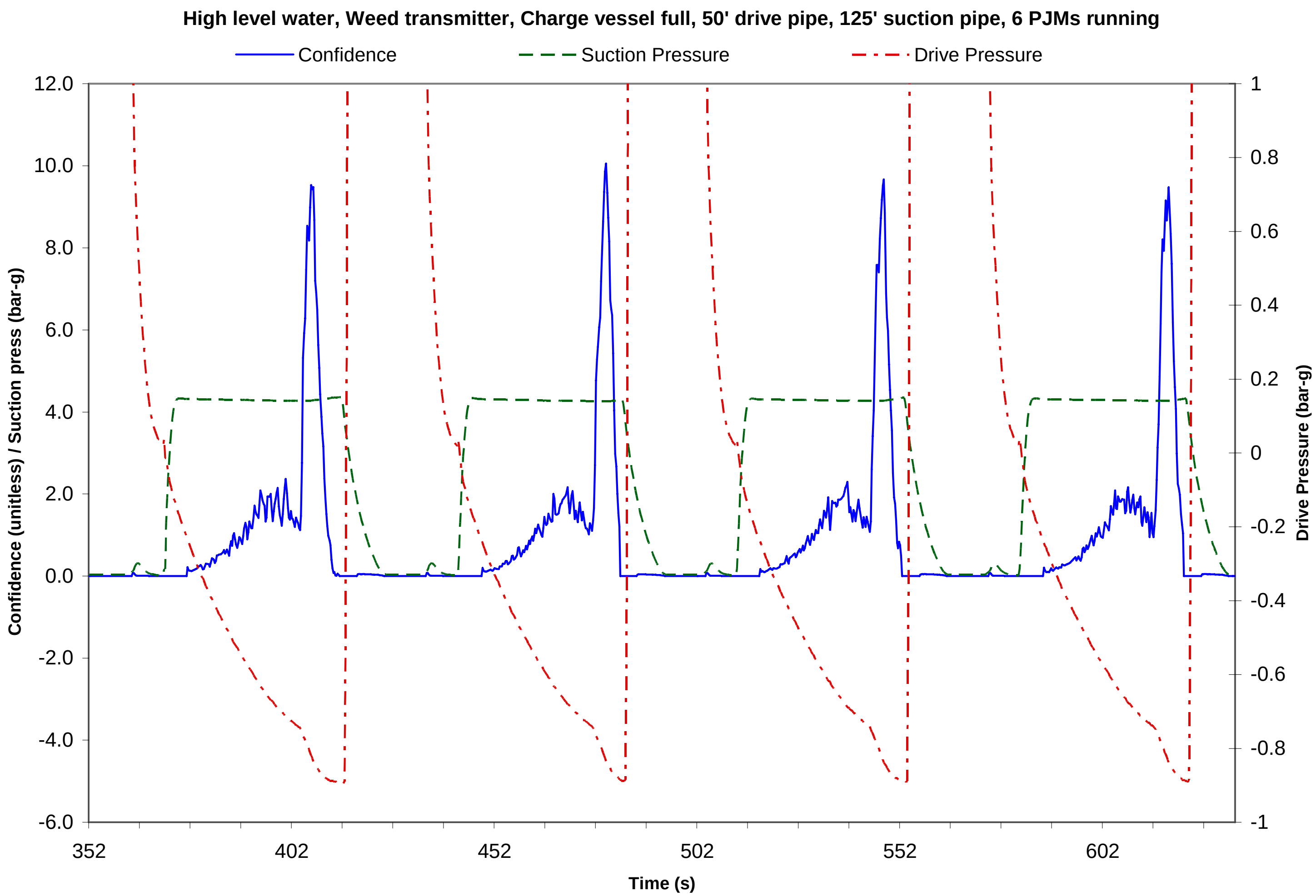

Figure 9.4. Pressure and Confidence Trends for CVF Detection with the Weed Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during water simulant testing at a high fill level with six PJMs operating.)

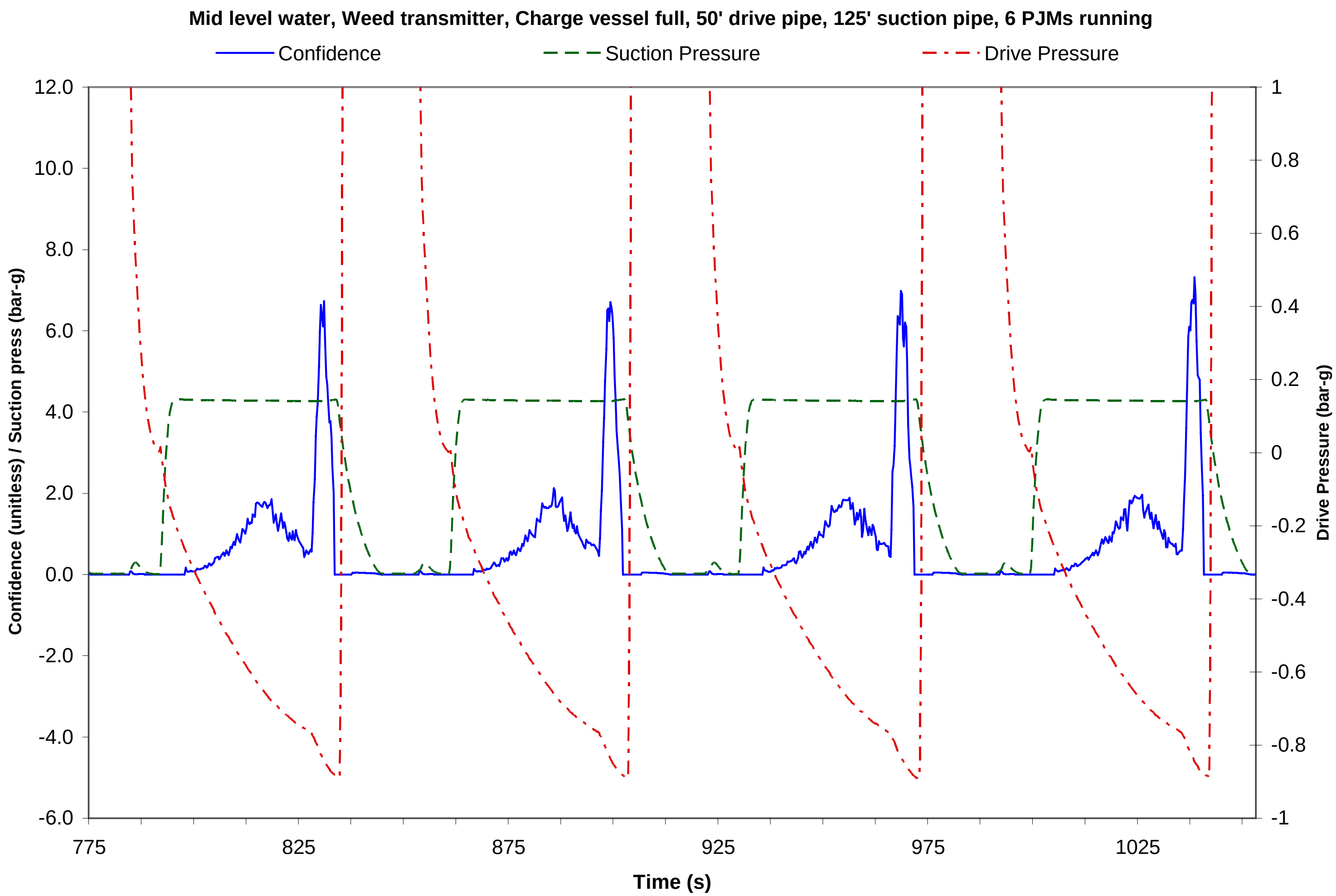

Figure 9.5. Pressure and Confidence Trends for CVF Detection with the Weed Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during water simulant testing at a mid fill level with six PJMs operating.)

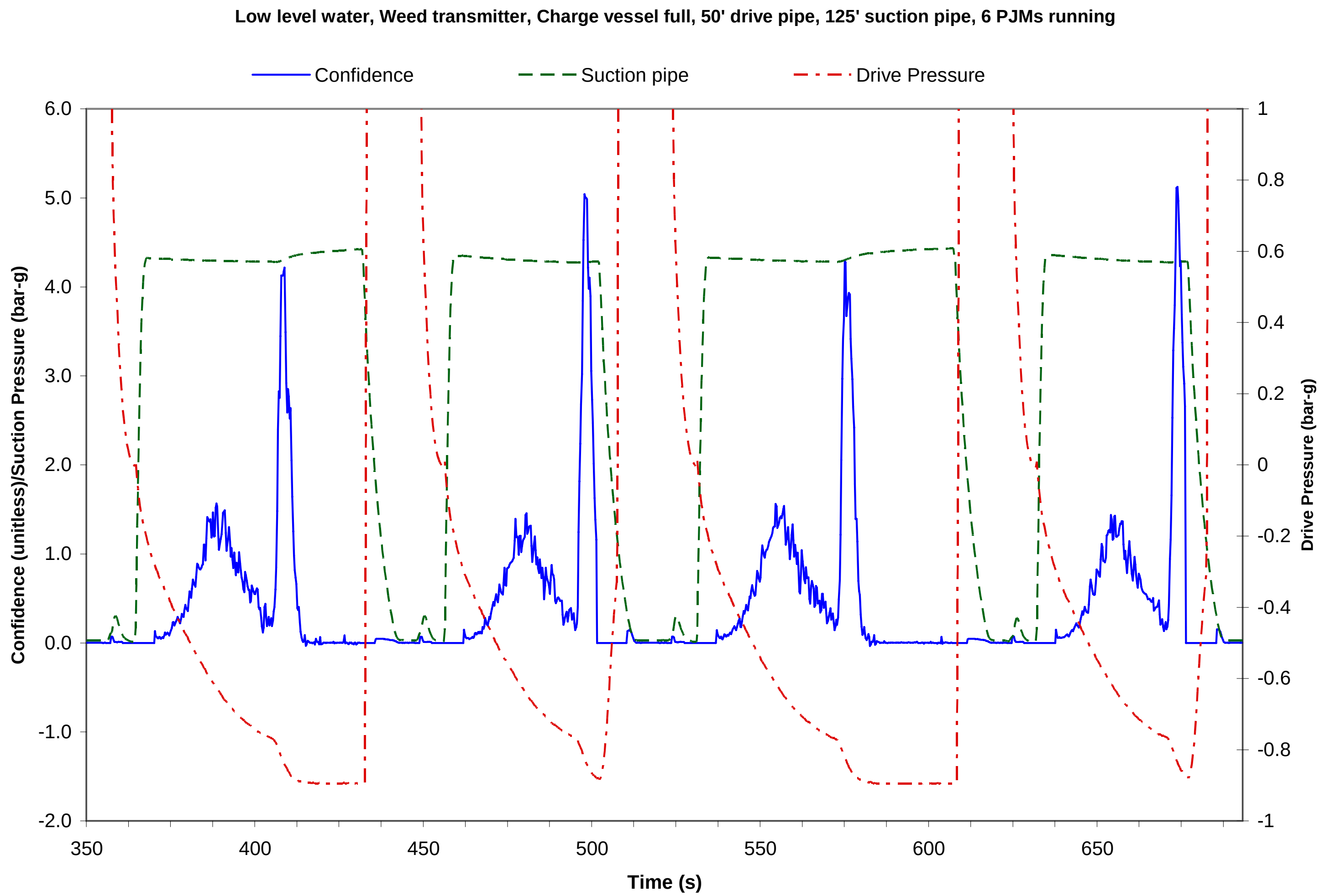

Figure 9.6. Pressure and Confidence Trends for CVF Detection with the Weed Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during water simulant testing at a low fill level with six PJMs operating.)

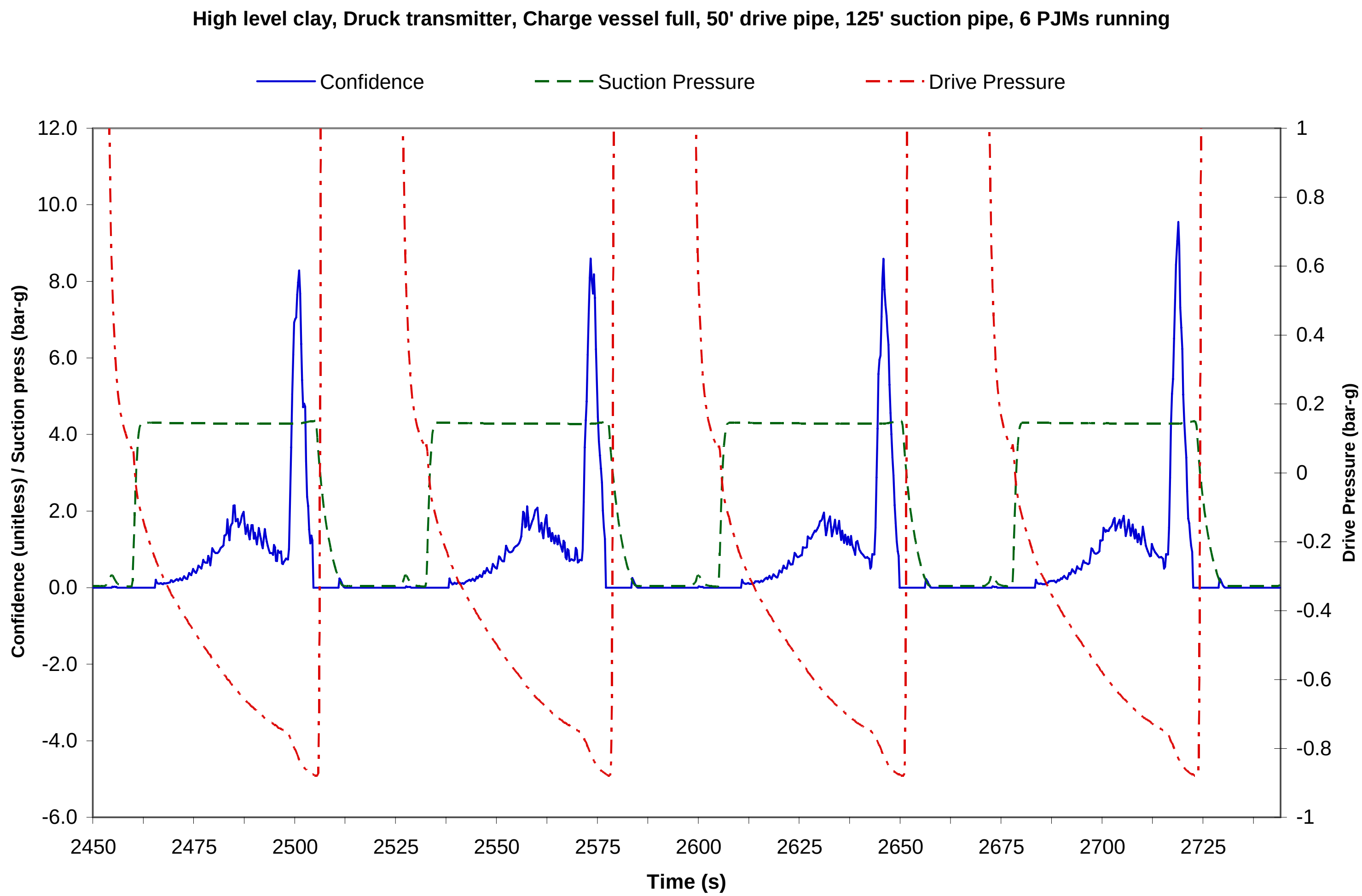

Figure 9.7. Pressure and Confidence Trends for CVF Detection with the Druck Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during clay simulant testing at a high fill level with six PJMs operating.)

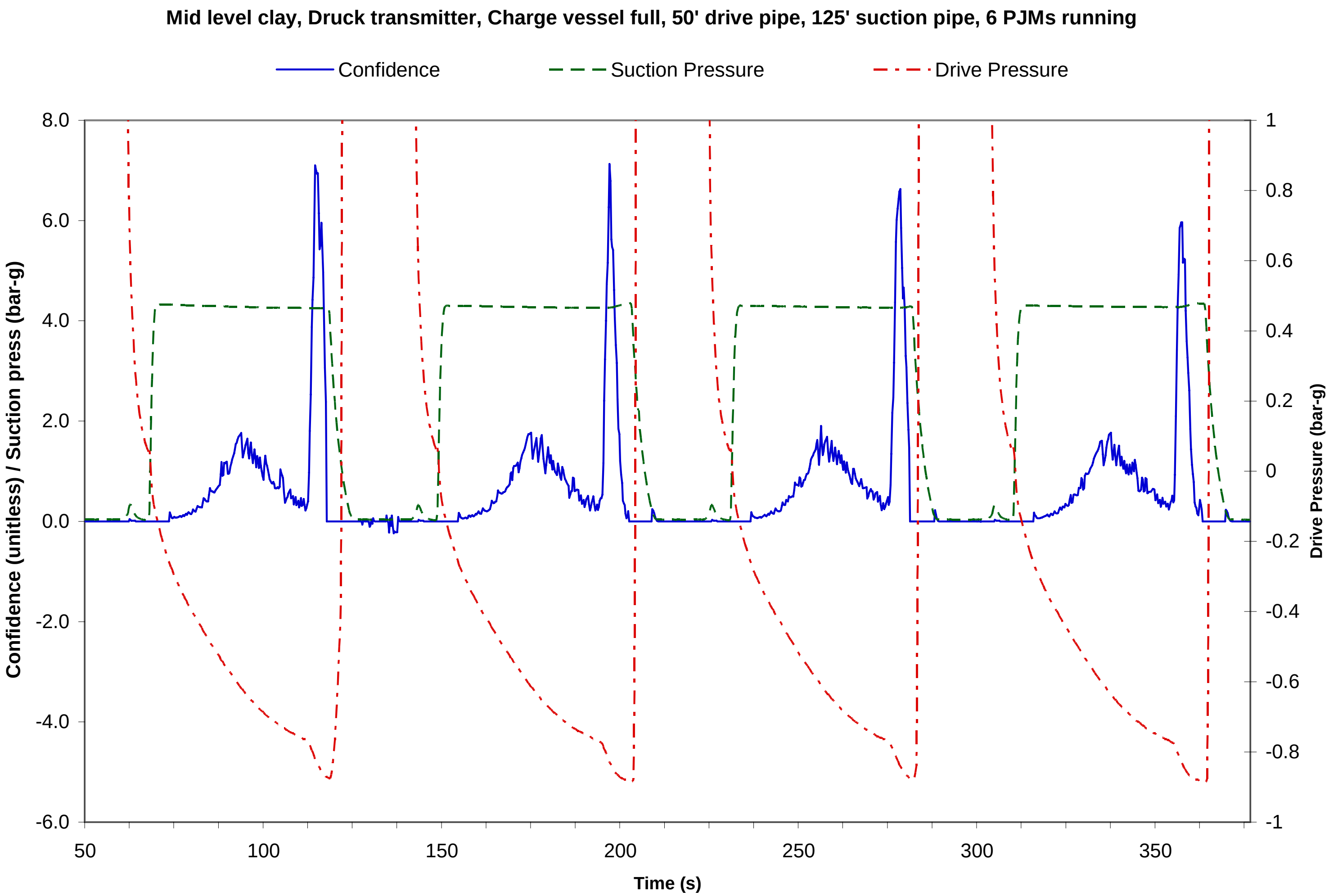

Figure 9.8. Pressure and Confidence Trends for CVF Detection with the Druck Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during clay simulant testing at a mid fill level with six PJMs operating.)

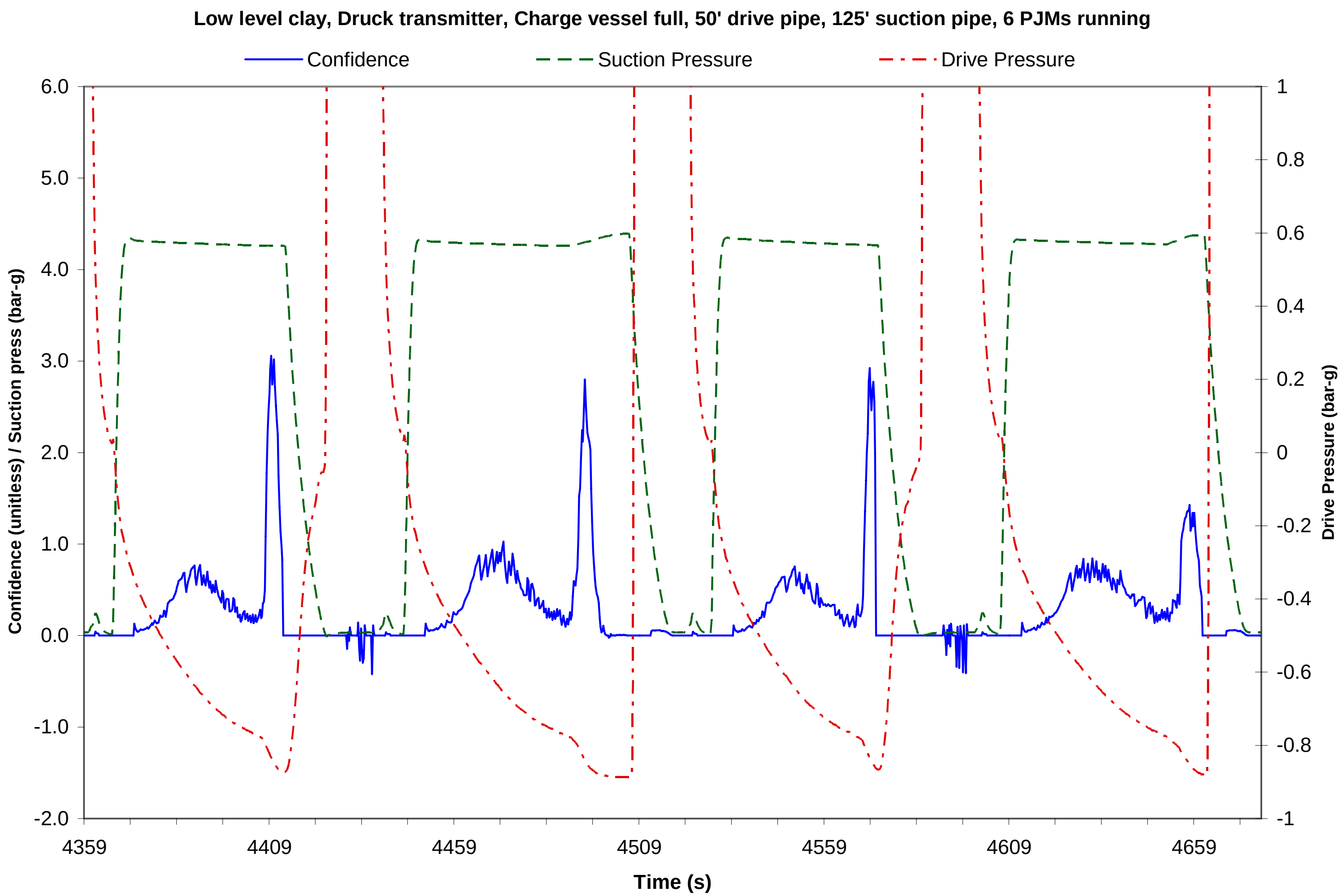

Figure 9.9. Pressure and Confidence Trends for CVF Detection with the Druck Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during clay simulant testing at a low fill level with six PJMs operating.)

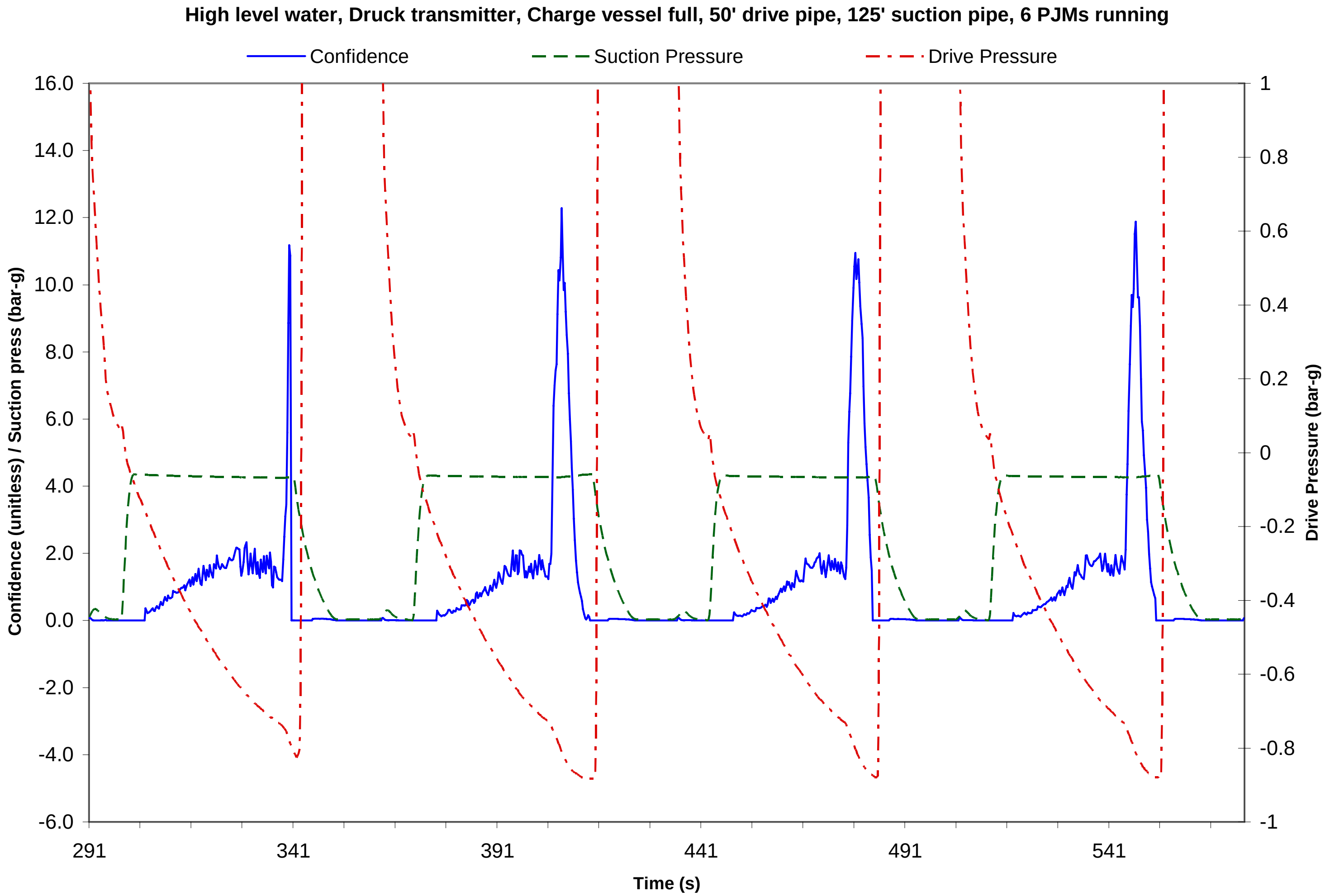

Figure 9.10. Pressure and Confidence Trends for CVF Detection with the Druck Pressure Transmitter and 50 ft of Piping Between Drive Leg of JPP and the Transmitter. (Data were obtained during water simulant testing at a high fill level with six PJMs operating.)

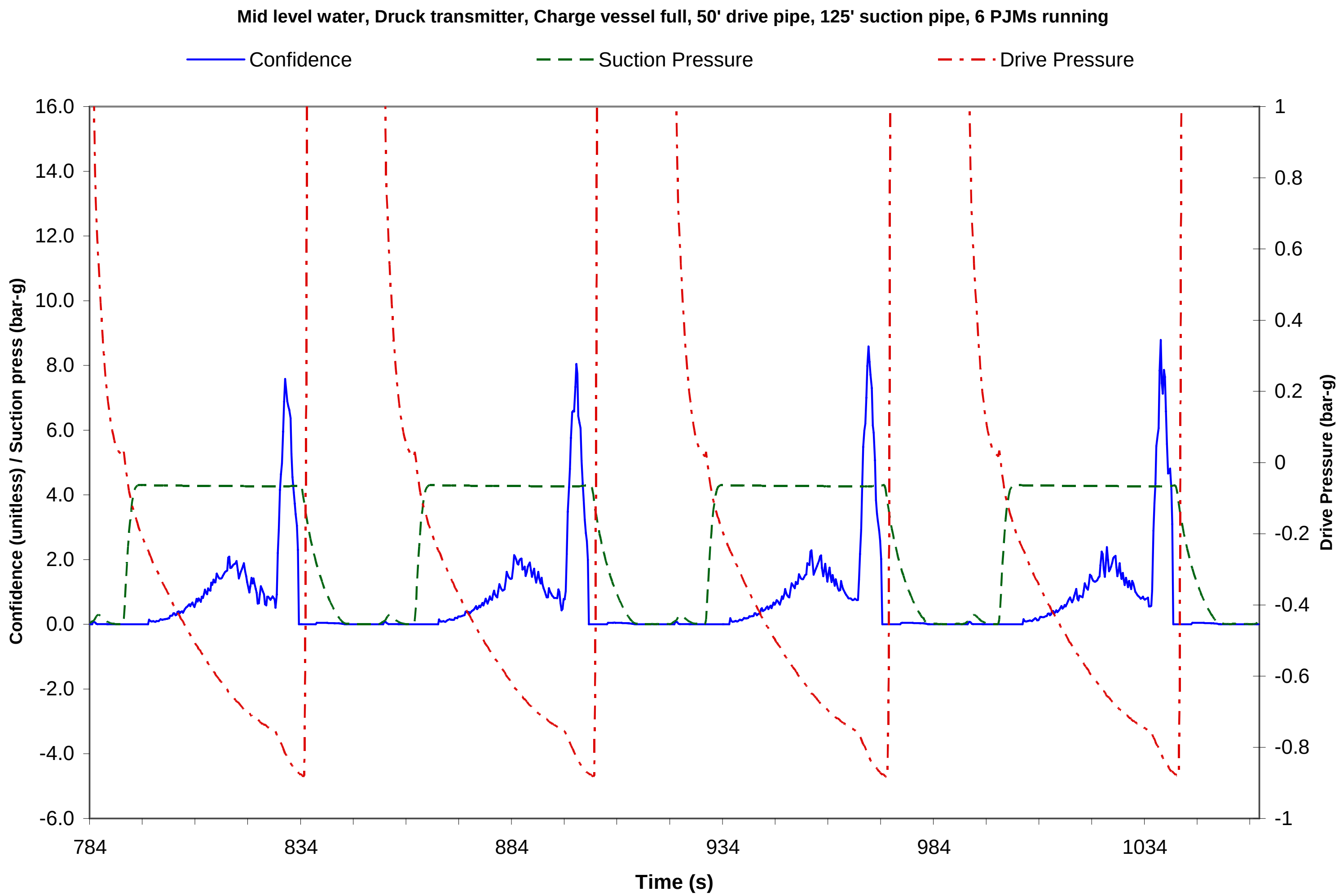

Figure 9.11. Pressure and Confidence Trends for CVF Detection with the Druck Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during water simulant testing at a mid fill level with six PJMs operating.)

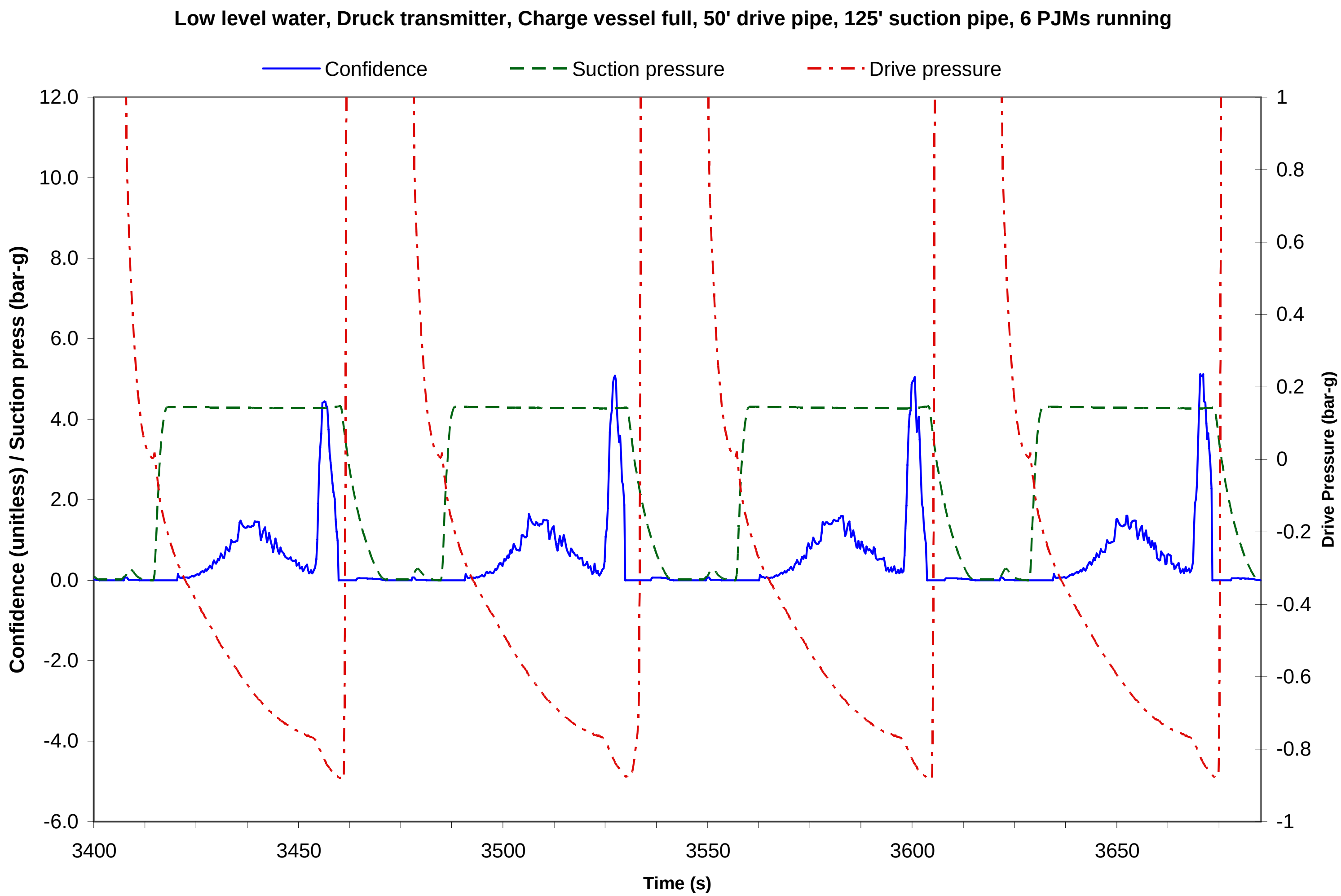

Figure 9.12. Pressure and Confidence Trends for CVF Detection with the Druck Pressure Transmitter and 50 ft of Piping Between the Drive Leg of the JPP and the Transmitter. (Data were obtained during water simulant testing at a low fill level with six PJMs operating.)

5. Figure 9.4 shows false confidence peaks for CVF on the order of 1.5 to 2 in the last 20% of the cycle, when the algorithm is looking for the CVF event. Figure 9.3 shows a true confidence peak of about 1.5 on the second cycle but with lower false peaks. In the first case, the tank held water at the high level; in the latter case, clay at the low level. It appears that a detectable response is present in all cases, but the thresholds for determining a charge vessel full event may need to be changed as a function of level and/or density. Also, the peaks resulting when only one PJM is running are lower than those when six PJMs are running (compare Figures 7.1 and 7.8 in Section 7). Further testing during the WTP commissioning phase will be needed to determine whether the thresholds need to be changed as a function of level, density, and/or the number of PJMs running.

9.3 Results for Drive Overblow Detection

The pressure and confidence trends obtained with the Druck transmitter in the flush line are shown in Figures 9.13 to 9.18. In all of the graphs, the flush line pressure is shown on the primary axis and the confidence value on the secondary y-axis. The following conclusions can be made from the drive overblow confidence data in the figures:

1. Using the pressure readings from the flush line, the controller will be able to detect drive overblow over the range of simulant levels and simulant types investigated. This is indicated by the significant peaks in the confidence value as the overblow occurs.
2. There is no obvious trend for the effect of simulant level on the drive overblow confidence peak. This could be a manifestation of the pulse tube pressure, which controls the flush line transmitter response and thereby the drive overblow confidence peak.
3. The drive overblow confidence peak is significantly lower in clay than it is in water. This is due to the increase in hydrostatic head opposing the pressure inside the PJM due to the higher density of the clay simulant.
4. During PJM tuning, flush line drive overblow confidence threshold parameters should be set with the highest-density slurry at maximum fill.

9.4 Summary

The results indicate that PJM control (i.e., CVF and drive overblow detection) is achievable with both the Druck and Weed pressure transmitters over the entire range of simulant properties and levels investigated. The confidence values for both the CVF and drive overblow are affected by the simulant properties with water resulting in generally greater peak confidence values.

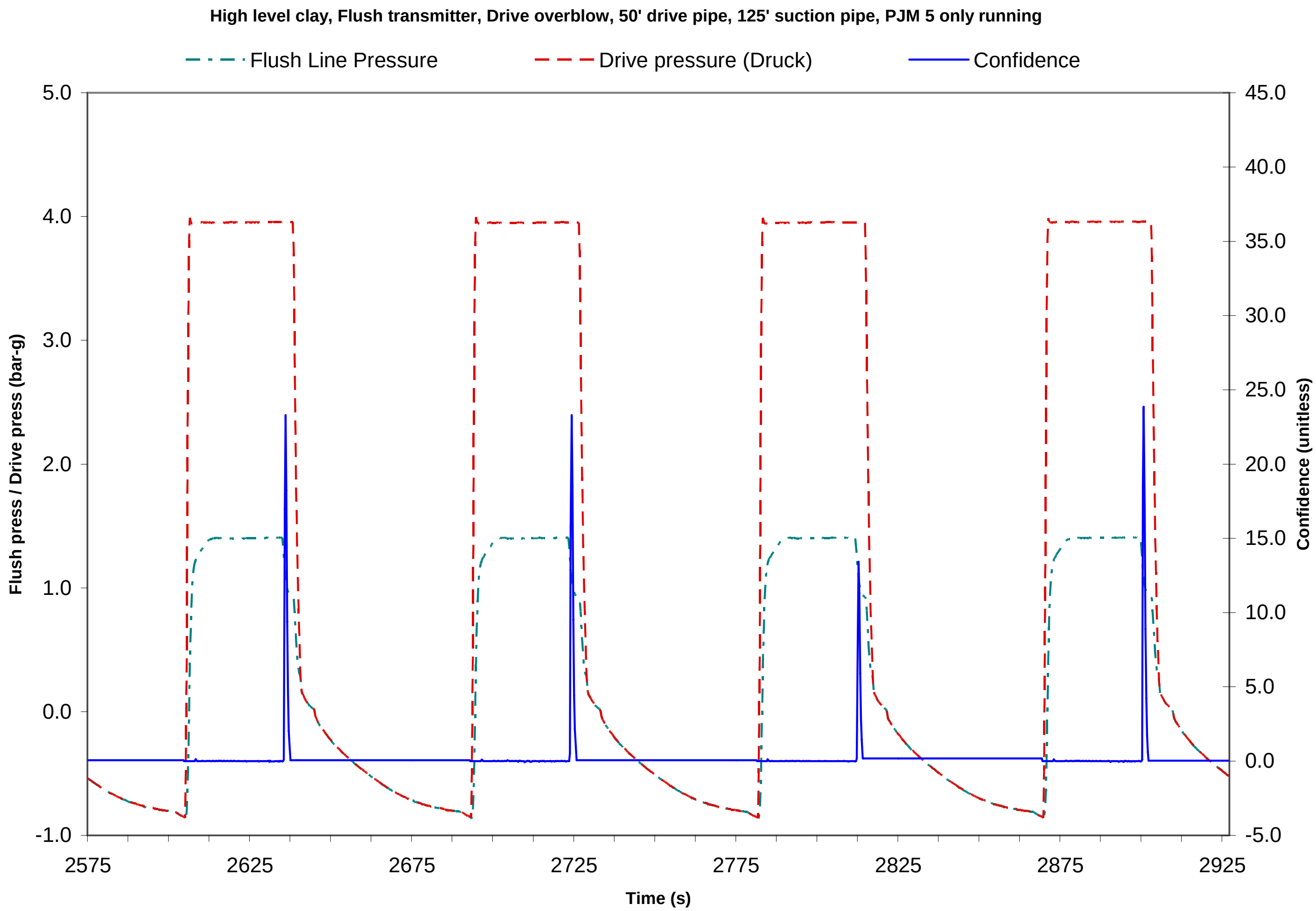

Figure 9.13. Pressure and Confidence Trends for Drive Overblow Detection with the Druck Pressure Transmitter and 125 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at high fill level with six PJMs operating.)

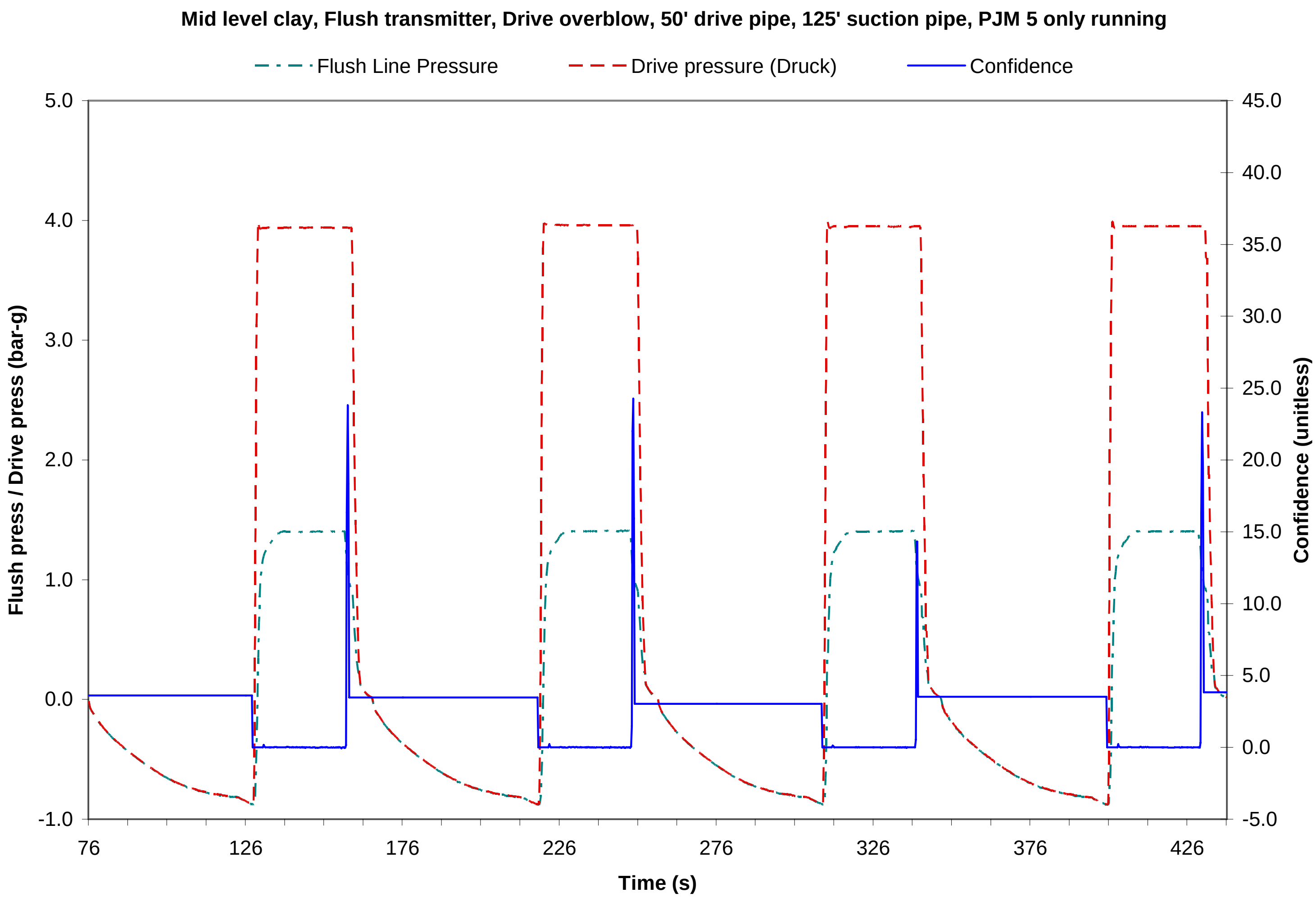

Figure 9.14. Pressure and Confidence Trends for Drive Overblow Detection with the Druck Pressure Transmitter and 125 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at mid fill level with six PJMs operating.)

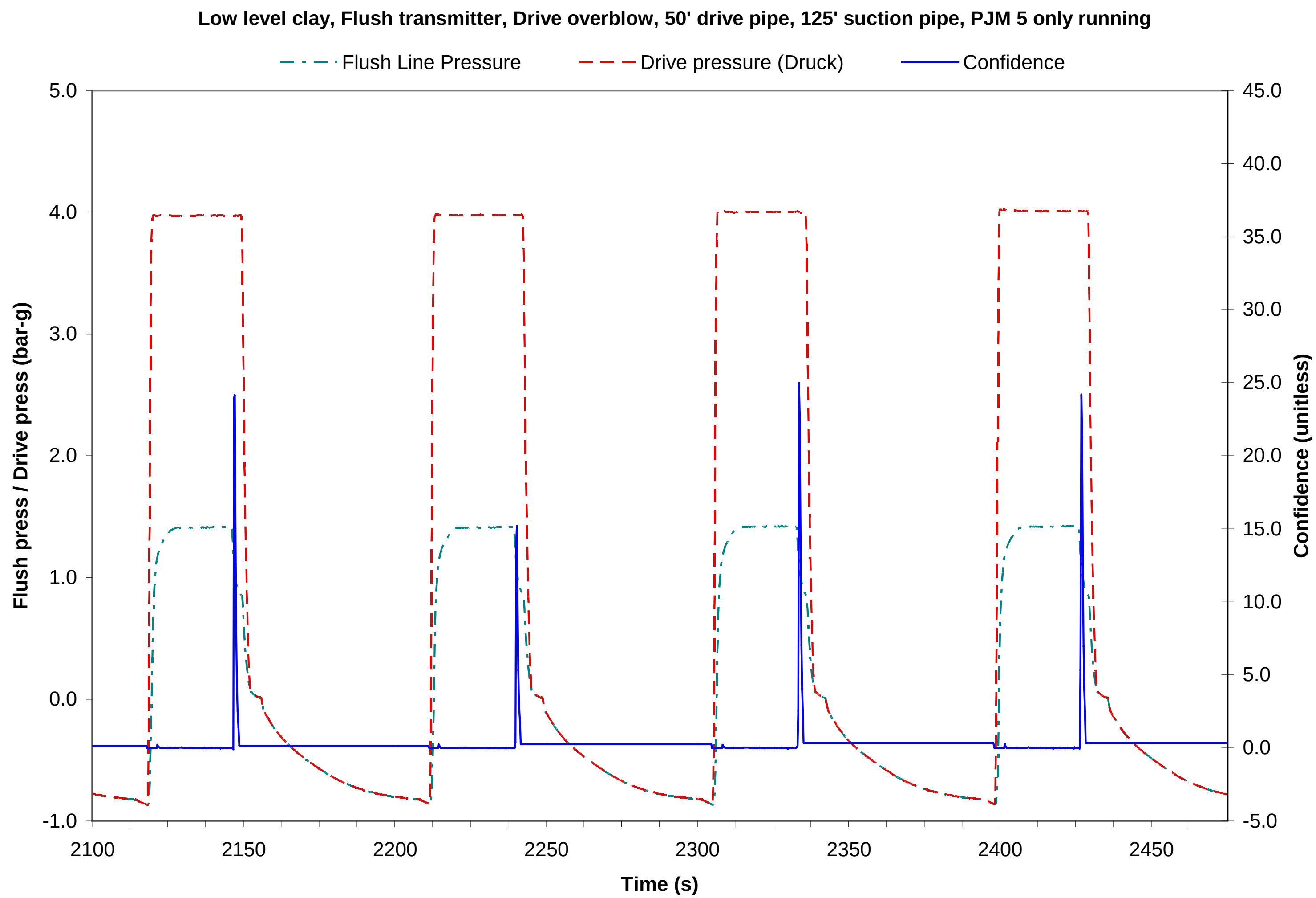

Figure 9.15. Pressure and Confidence Trends for Drive Overblow Detection with the Druck Pressure Transmitter and 125 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during clay simulant testing at a low fill level with six PJMs operating.)

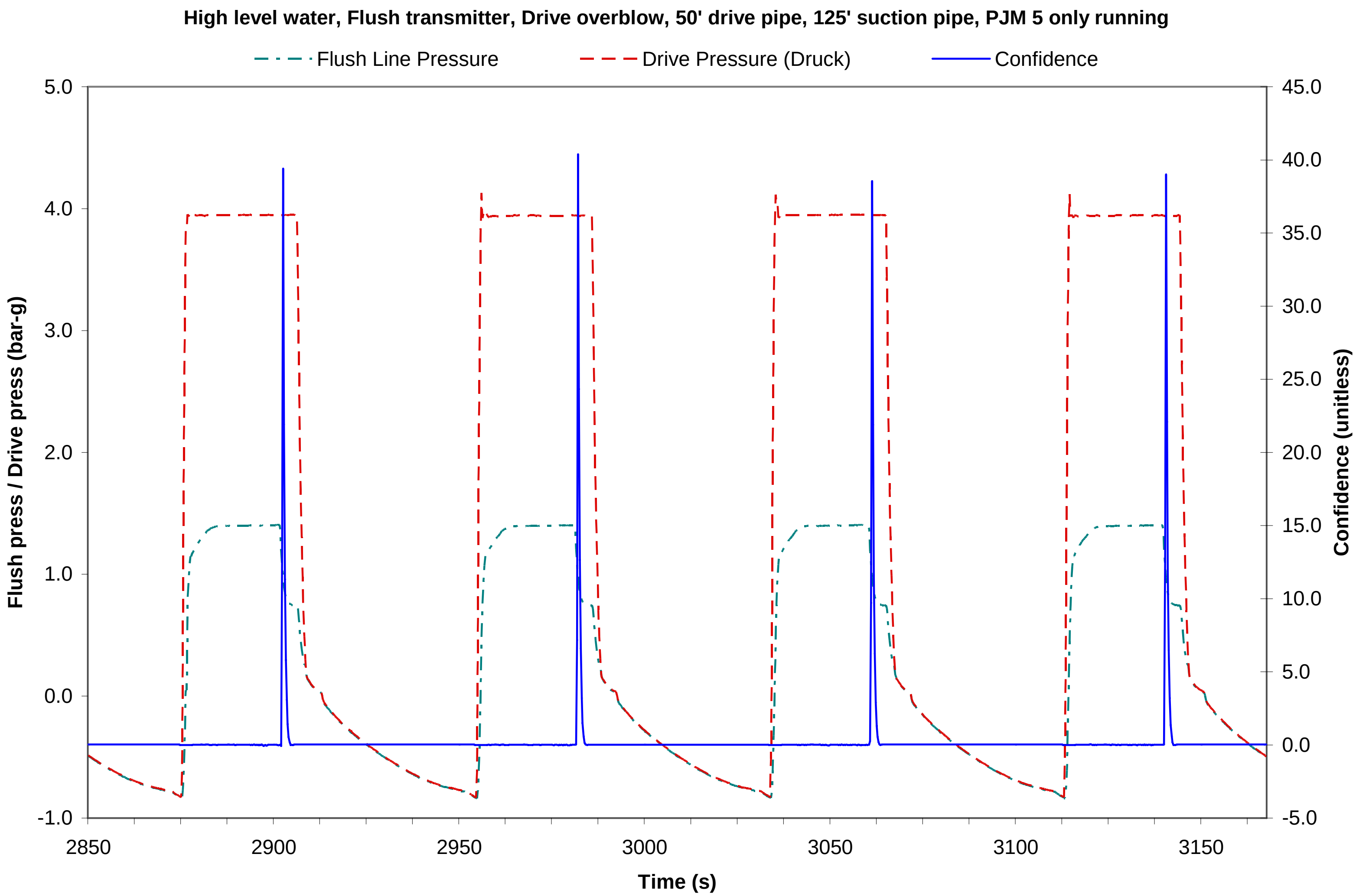

Figure 9.16. Pressure and Confidence Trends for Drive Overblow Detection with the Druck Pressure Transmitter and 125 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during water simulant testing at a high fill level with six PJMs operating.)

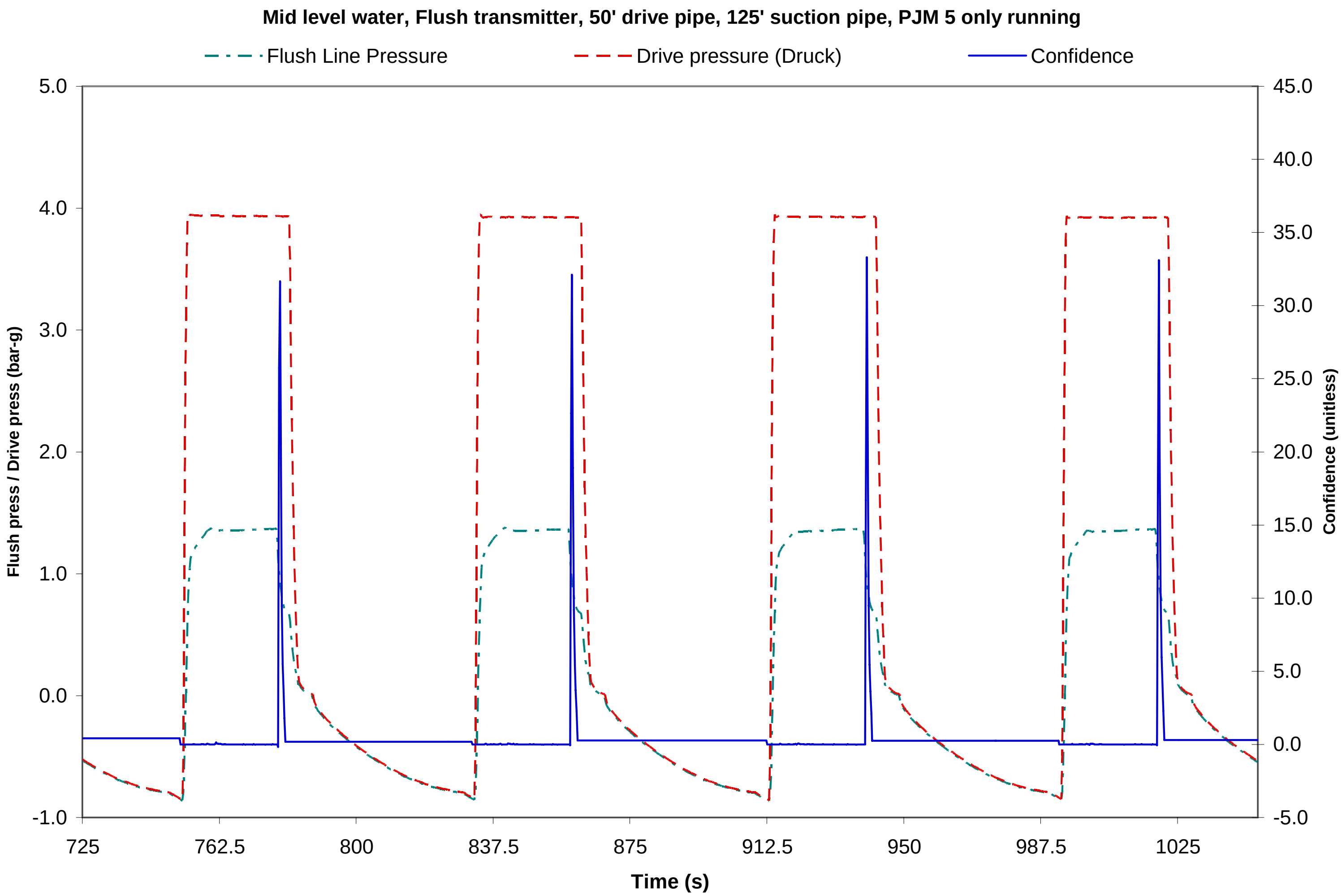

Figure 9.17. Pressure and Confidence Trends for Drive Overblow Detection with Druck Pressure Transmitter and 125 ft of Piping Between the Suction Leg of the JPP and Transmitter. (Data obtained during water simulant testing at a mid fill level with six PJMs operating.)

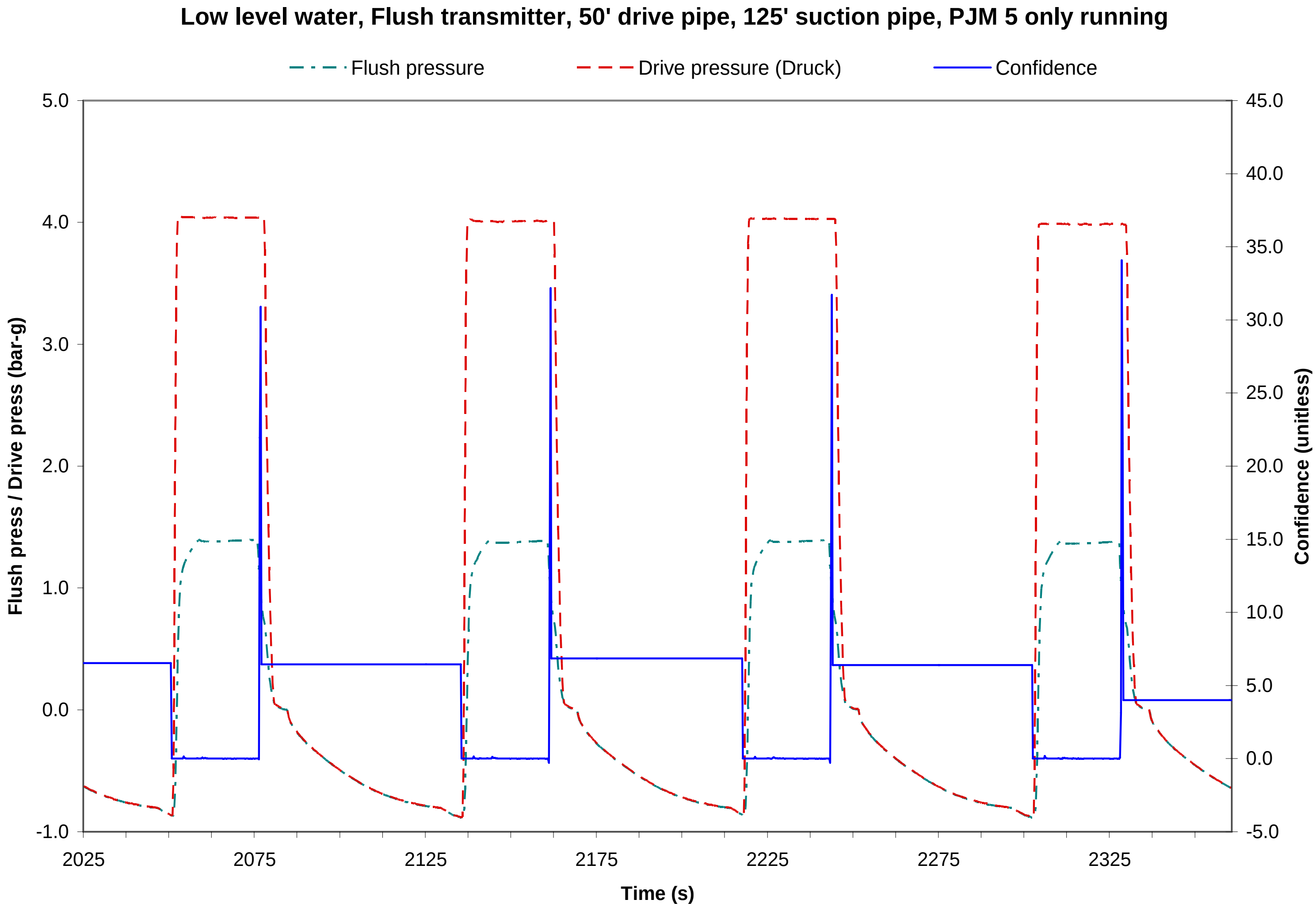

Figure 9.18. Pressure and Confidence Trends for Drive Overblow Detection with Druck Pressure Transmitter and 125 ft of Piping Between the Suction Leg of the JPP and the Transmitter. (Data obtained during water simulant testing at low fill level with six PJMs operating.)

10.0 Results of Exploratory Testing

The PJM control algorithm requires the detection of very small changes in differential pressure between the suction and drive pressure sensors. The suction pressure sensor is positioned in the system in such a way that it is affected by changes in back pressure in the vent header. PJM operation in WTP facilities may produce large enough back pressure transients in the vent system that PJM operation of vessels connected to the same header may be affected. This experiment was intended to generate pressure transients in the test system vent header to simulate this potential effect.

10.1 Experimental Conditions

The exploratory tests were conducted using clay simulant at an H/D of ~0.77. The air line length was 50 ft on the drive side and 125 ft on the suction side. Six of the eight PJMs were operational during the testing due to limitations in the air supply system (i.e., PJMs #2 and #8 were turned off). Finally, as discussed in Section 7, operating only one PJM at a time is considered the worst case for the drive overblow detection because this represents the condition of the lowest back pressure in the suction leg of the JPP. Therefore, this condition, PJM #5 only operating with the Druck transmitter, was used as a test case to demonstrate the effect of simulant fill level and type on drive overblow detection.

10.2 Effect of Vent Header Pressure

This test attempted to cause a false positive on the CVF and overblow detection signals by operating PJM #5 "out of sync" with the other PJM(s) to cause momentary negative and positive fluctuations in the air header pressure by opening and closing the other PJM valves while PJM #5 is looking for CVF and overblow signals. To accomplish this, the drive and suction valves for PJM8 were cycled while PJM #5 was operating. Four separate tests runs were made:

1. Opening and closing PJM #8 suction valve while PJM #5 was in drive phase (Figure 10.1)
2. Opening and closing PJM #8 drive valve while PJM #5 was in drive phase (Figure 10.2).
3. Opening and closing PJM #8 suction valve while PJM #5 was in suction phase (Figure 10.3).
4. Opening and closing PJM #8 drive valve while PJM #5 was in suction phase (Figure 10.4).

As the graphs indicate, all four tests caused enough background noise in the confidence value to cause problems with both CVF and overblow detection. Thus, if PJMs are going to be operated in different phases simultaneously, more testing is needed to ensure that the alternative phases would not cause false overblow and/or CVF detection.

10.3 Effect of Asynchronous Operation

This test attempted to cause a false positive on the CVF signal by abrupt changes in the vent header pressure by opening the header drain valve to reduce pressure (Figure 10.5) and blocking part of the vent discharge (Figure 10.6). The plots do not show any indication of induced pressure fluctuations, and it is concluded that neither of these tests were successful in causing an early CVF indication.

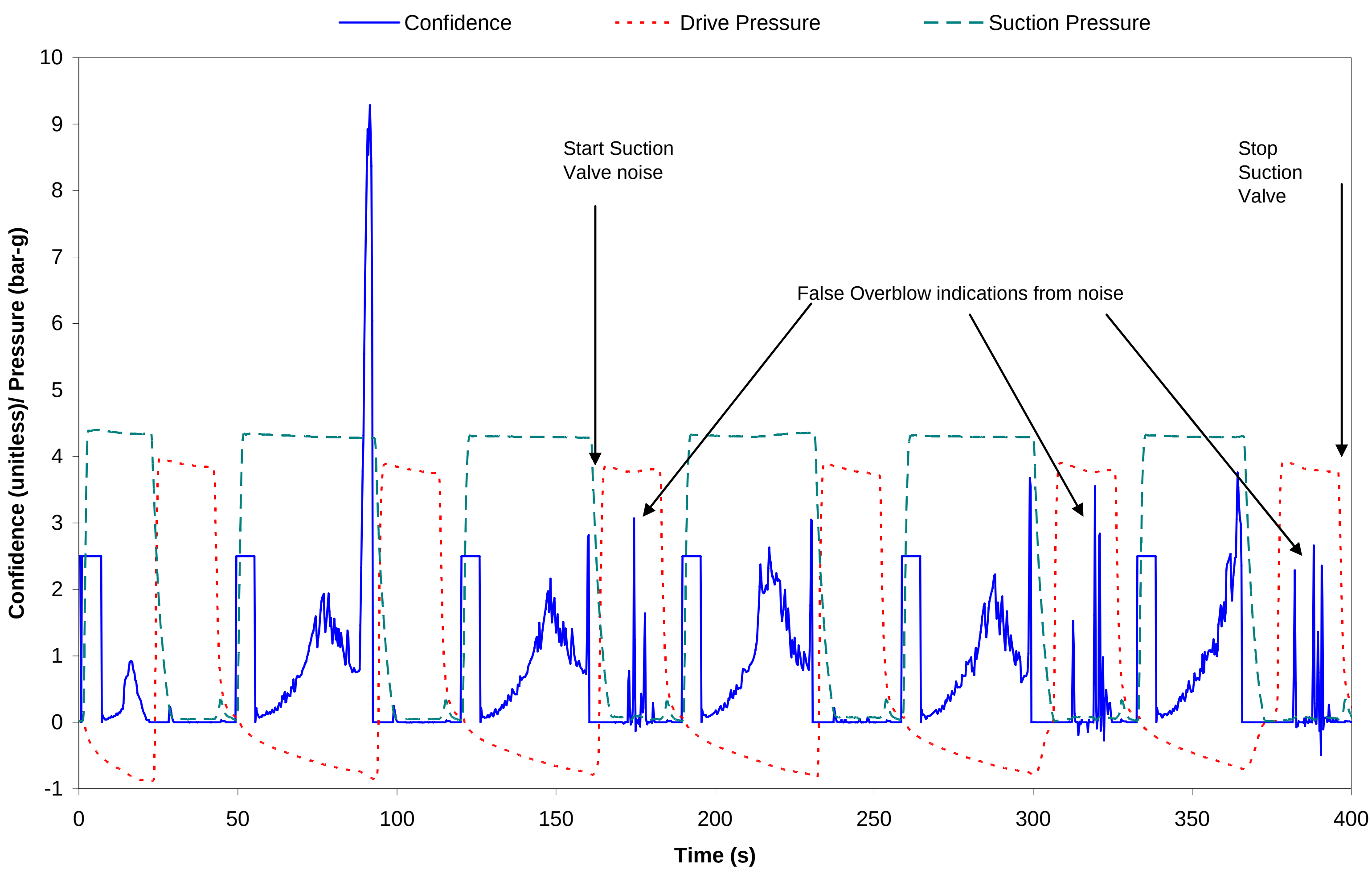

Figure 10.1. Pressure and Confidence Results for Drive Overblow Detection with the Druck Pressure Transmitter on PJM #5 (suction valve noise during drive phase; clay simulant testing at the high fill level with six PJMs operating)

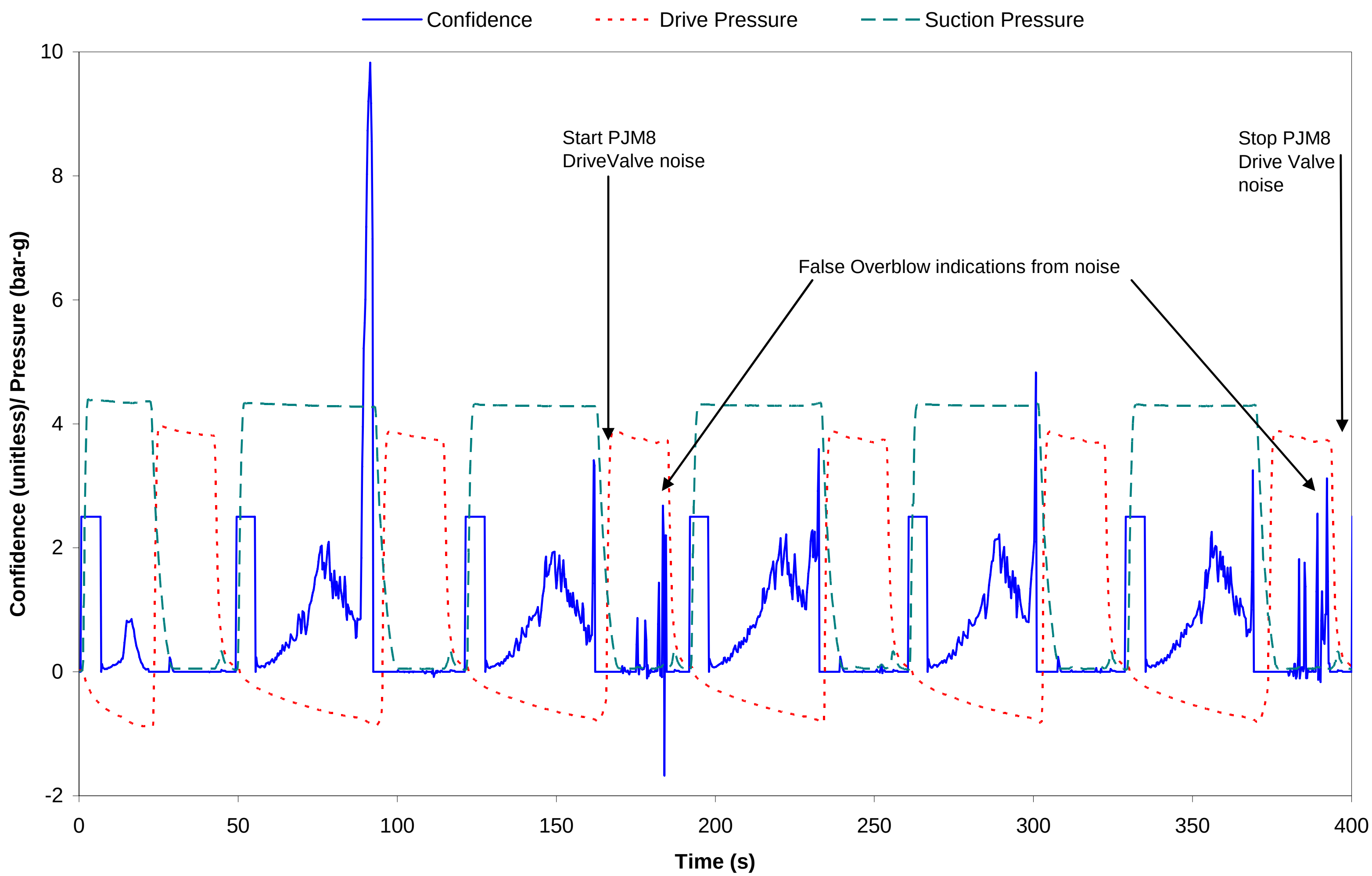

Figure 10.2. Pressure and Confidence Results for Drive Overblow Detection with the Druck Pressure Transmitter on PJM #5 (drive valve noise during drive phase; clay simulant testing at the high fill level with six PJMs operating)

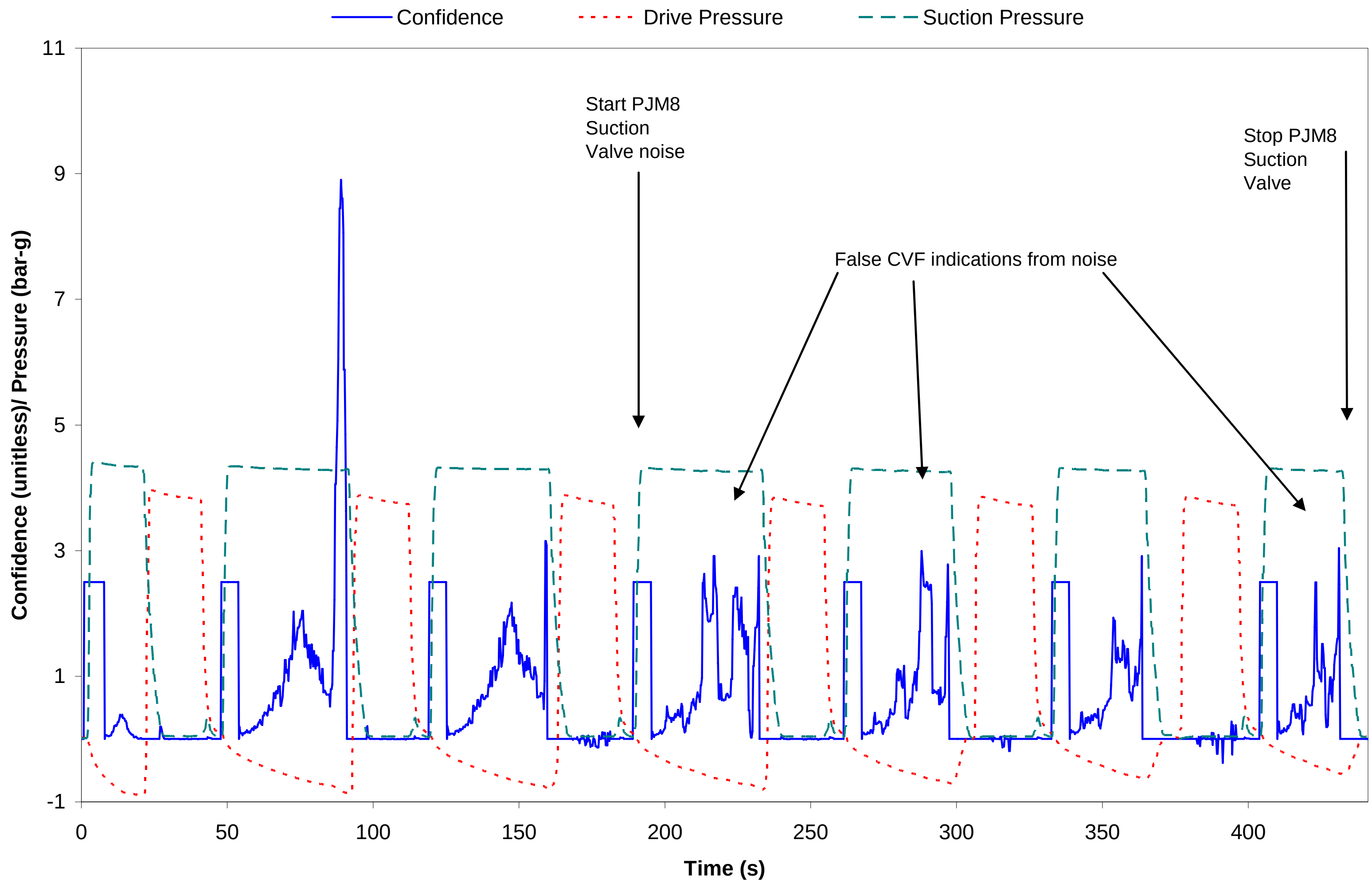

Figure 10.3. Pressure and Confidence Results for CFV Detection with the Druck Pressure Transmitter on PJM #5 (suction valve noise during suction phase; clay simulant testing at the high fill level with six PJMs operating)

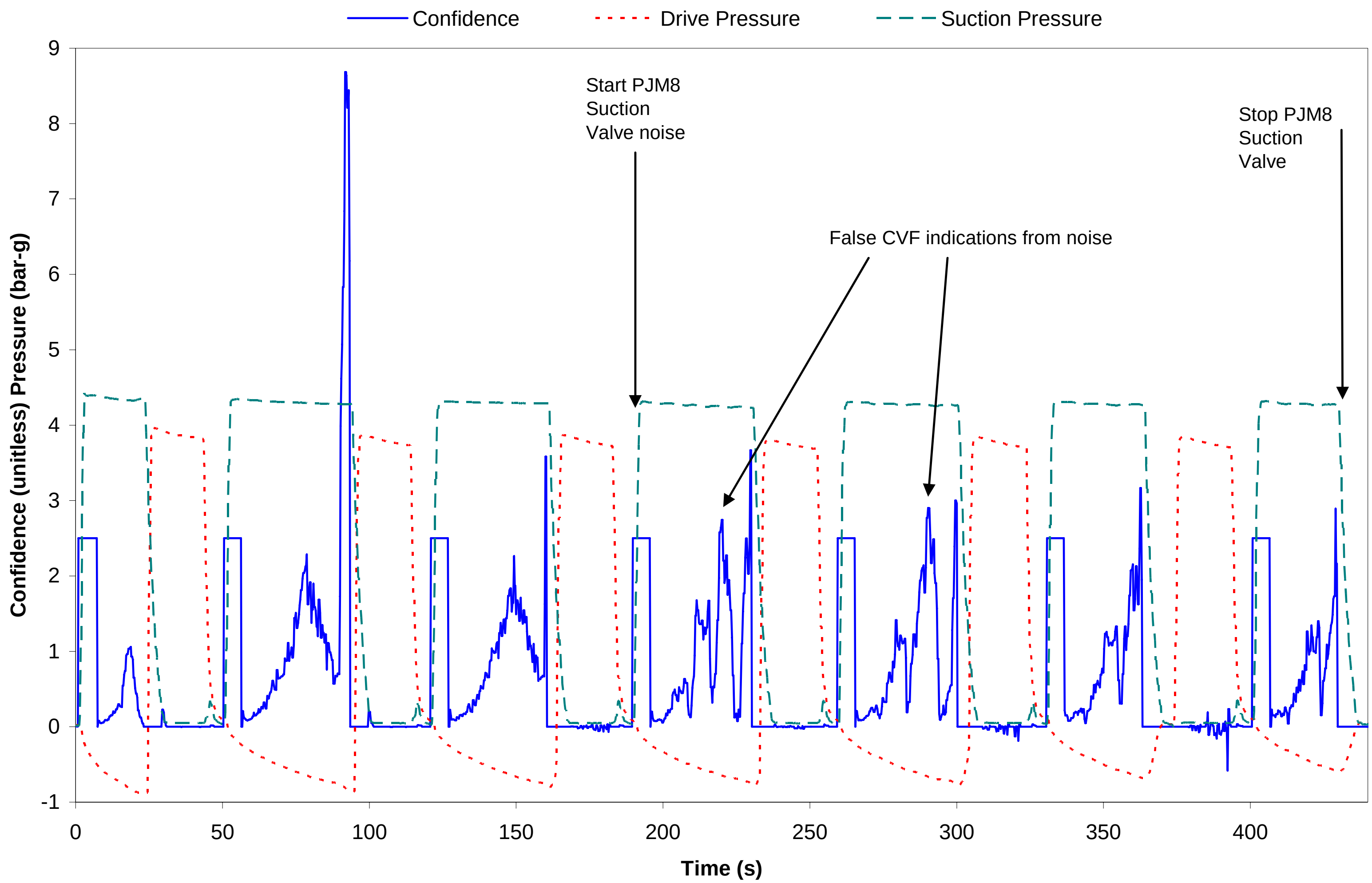

Figure 10.4. Pressure and Confidence Results for CFV Detection with the Druck Pressure Transmitter on PJM #5 (drive valve noise during suction phase; clay simulant testing at the high fill level with six PJMs operating)

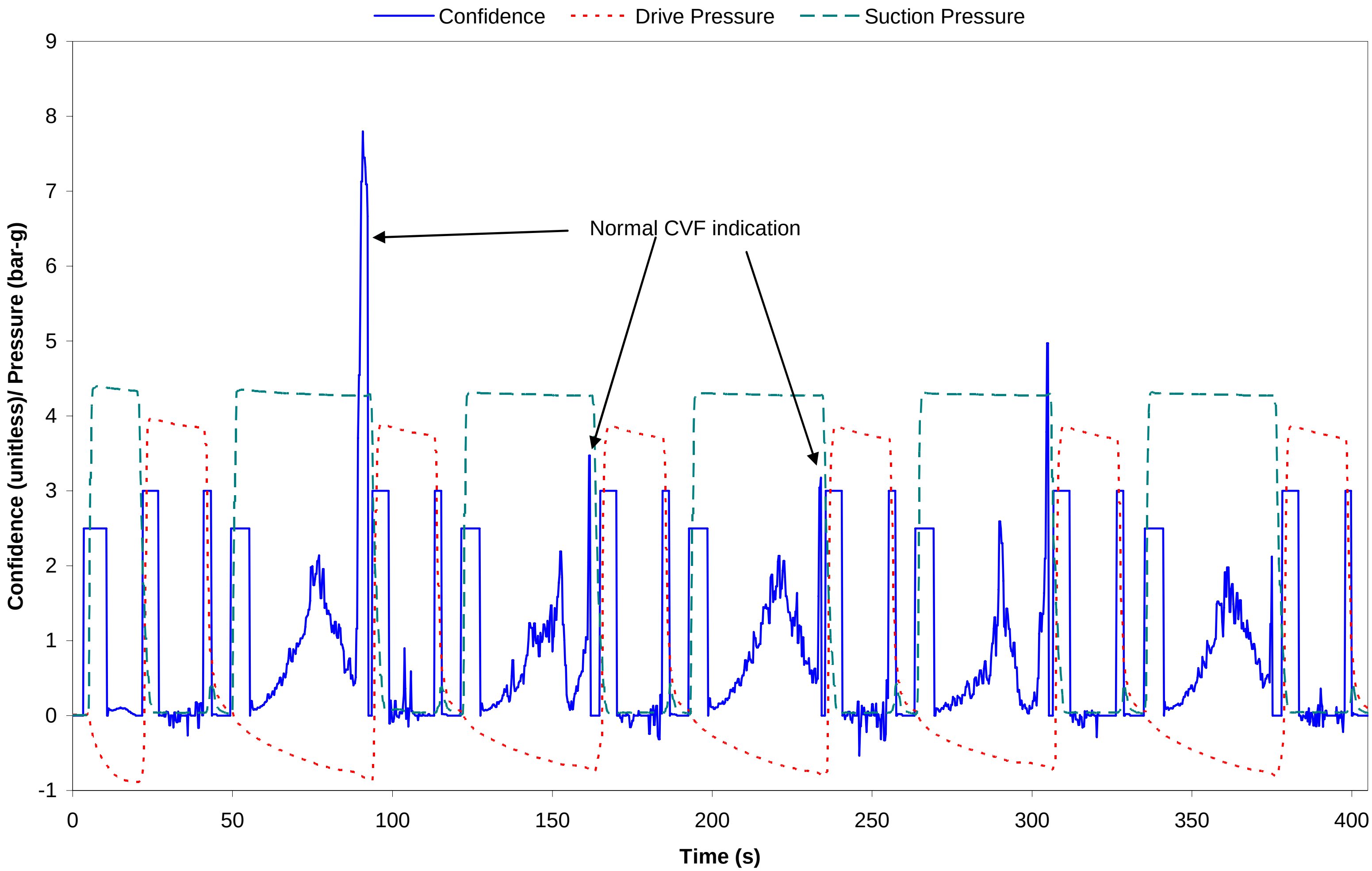

Figure 10.5. Pressure and Confidence Results for CFV Detection with the Druck Pressure Transmitter on PJM #5 (asynchronous operation blow-down valve; clay simulant testing at the high fill level with six PJMs operating)

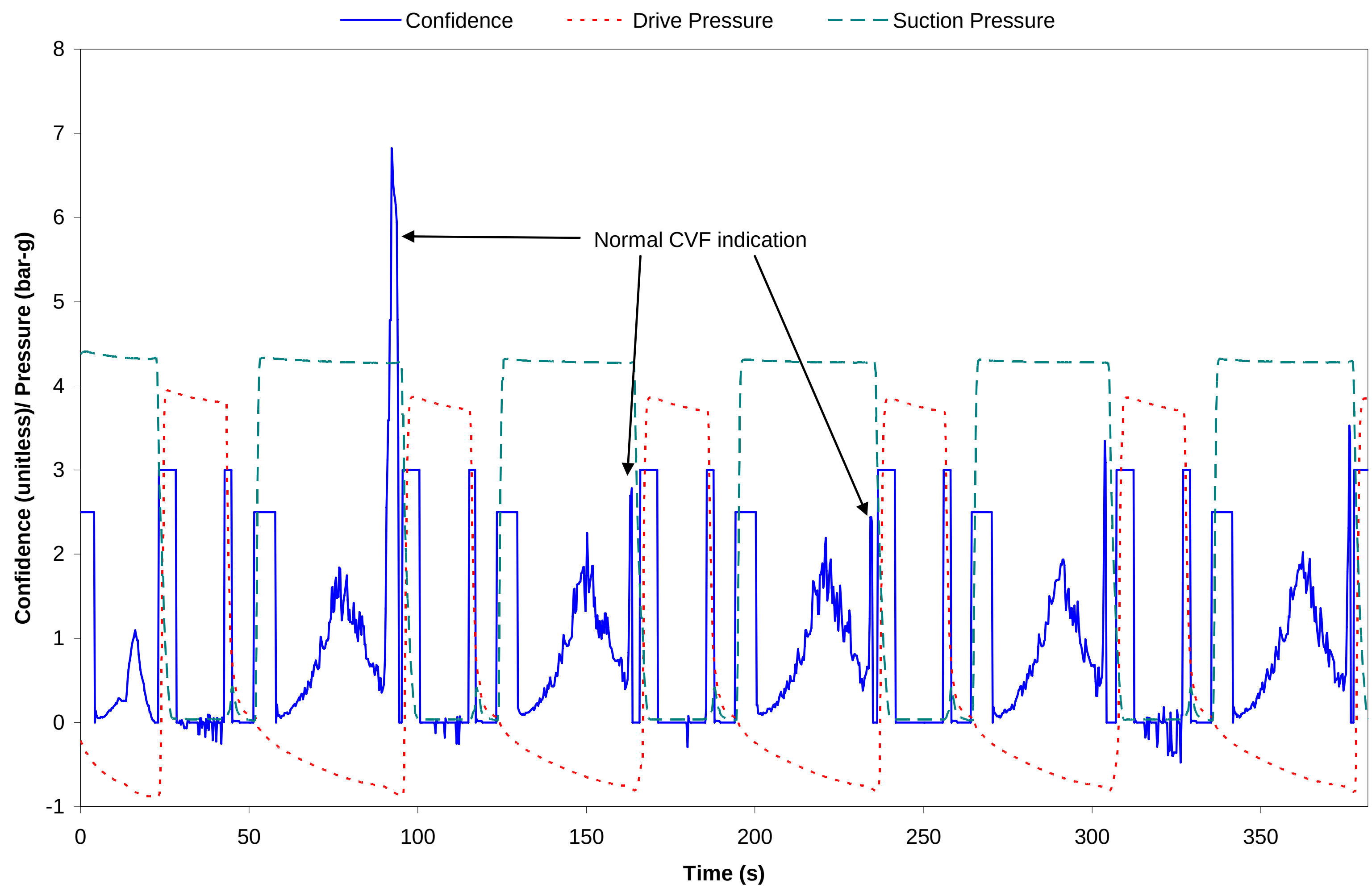

Figure 10.6. Pressure and Confidence Results for CFV Detection with the Druck Pressure Transmitter on PJM #5 (asynchronous operation vent blocking; clay simulant testing at the high fill level with six PJMs operating)

11.0 Possible Enhancements to PJM Control Strategy

During the course of performing the tests described in this report, a number of possible enhancements to the PJM control strategy were identified. These enhancements should be considered for incorporation into the PJM control strategy. Additional testing will likely be required to test some of these enhancements. The following is a list of items that were discovered that could lead to a more robust and stable control strategy for the PJMs.

- When running the PJMs in synchronous mode (all firing together), the current strategy is to close the suction valve when a PJM reaches CVF and then wait for all the operating PJMs to reach CVF before simultaneously starting the drive cycle for all PJMs. The problem with this method is that, if the tank level is below the top of the PJMs, as soon as the suction valve is closed the level inside the PJM begins to drop, trying to reach equilibrium with the tank level. Thus when the PJM enters the drive phase it is no longer full and could possibly overblow. The solution is to keep all PJMs in suction mode (suction valve open) until all operating PJMs have reached CVF or until a maximum time limit has been reached. This will keep the PJMs full until the drive cycle begins.
- It is possible that a PJM could receive a false CVF detection before the PJM is actually full. This could happen when the CVF gain threshold is incorrectly set and could lead to an overblow because the PJM would not be full when it enters the drive phase. The solution is to add a minimum suction timer to the suction phase logic. This timer would not allow a PJM to finish its suction phase (even if it receives a CVF detection) until the minimum time had been met. This would remove the possibility of acting on a false CVF indication before the PJM was full.
- During testing it was noted that the confidence value for detecting CVF decreased with decreasing tank level. This could cause false detection of CVF at high tank levels or missed CVF detection at low levels. A possible solution is to have the CVF threshold value change based on tank level. As the tank level goes down, the confidence value used to determine CVF would decrease.
- During testing it was noted that the time it takes to drive the liquid out of the PJM changes with fluid properties (e.g., density, viscosity) and tank level. Thus a drive time set for high level and high density could cause an overblow with water at a low level. A solution is to alter the drive time based on fluid properties (density, etc.) and tank level. In Section 12 of this report is a discussion of predicting the drive time using Bernoulli's equation with density and level as inputs.
- The suction phase uses a mask time to avoid false early detection of CVF. This mask time is based on a percentage of the last suction phase time. The initial normal suction phase only has a time from the first suction phase, which operates longer than a normal suction phase in order to determine the maximum gain achievable on that PJM. Thus, the first suction time would be too long and inconsistent to use as the basis for the first normal suction phase mask time. A suction time mask that can be set by the operator could be added for the first cycle of the normal suction phase. This would allow the first normal suction phase to operate with a more reasonable mask time and help to eliminate false CVF detection before the PJM is full.
- If the previous normal suction phase ended on maximum gain or timed out, that time would be too long to use for the mask time on the next suction phase. It is suggested that if the last normal suction phase ended by either maximum gain or time out, the suction mask time should not be updated and the last good value should be used.

- The UK AEA algorithm uses the absolute value of the confidence to determine whether an overblow event has occurred. During testing it was noted that all true overblows resulted in only positive confidence values, while significant background noise in the confidence value were negative. It is suggested that only positive confidence values be used for determining overblow events.
- If an overblow is detected in one PJM while the others are still in drive phase, all PJMs need to be stopped.
- During testing with the flush line transmitters it was found that a trend of all flush line pressures was a great tool to determine how the PJMs are operating. It is suggested that the human machine interface for the PJMs include a trend that contains all PJM flush line pressures on the same trend at an update rate of at least 500 ms.

12.0 Predicting Drive/Suction Times for Control of PJMs

Parameters crucial to the control of the PJM operation are the variation of the drive and suction times with the type and fill level of the simulant. The development of a correlation between these parameters and the simulant density and fill height may allow the prediction of drive and suction times to be incorporated into the PJM control strategy and minimize the occurrence of overblows. The objectives of the tests presented in this section were to: 1).experimentally evaluate the relationship between the drive and suction time to the simulant type and fill height and 2). develop a correlation between the simulant density/fill height above the nozzle and the suction and refill times. These results are presented in this section.

12.1 Experimental Conditions

All tests were performed with only PJM #5 operating while varying the fill height and the simulant type (density) in a sequential manner. To compare the drive and refill times obtained, all other parameters such as JPP drive and suction pressure, as well as the line length between the JPP and the drive valve (50 ft) and suction valve (125 ft), were maintained constant. During the drive overblow tests, each drive was continued until there was an overblow to ensure that the complete volume of the PJM was expelled during the tests.

In the present study, two data sets were obtained. One set was obtained using the clay simulant and a yield stress of 33 Pa, consistency of 25 cP, and density of about 1.2 g/mL; the other was obtained using water.

12.2 Analysis

Figure 12.1 shows the drive phase of the PJM cycle. These data were obtained using the clay simulant with a fill H/D of 0.6 and only PJM #5 operating. Marked on the figure are the times when the drive valve opens and when overblow occurs. The drive time was determined by the difference in the times between the drive valve opening and the start of the over blow.

Figure 12.2 shows the suction phase of the PJM cycle. These data were also obtained with the clay stimulant, a fill H/D of 0.6, and only PJM #5 operating. Marked on Figure 12.2 are the times when the suction valve opens and the time for the PJM to be completely full. The refill time is determined from the period when the suction valve opens to the point at which the PJM is full. In both plots, the level shown in the PJM was determined using a capacitance probe inserted down the center of the pulse tube.

12.3 Results

The drive and suction times were calculated for a minimum of ten cycles during each fill height and simulant type condition. These results are summarized in Tables 12.1 and 12.2 for the drive time and suction times, respectively.

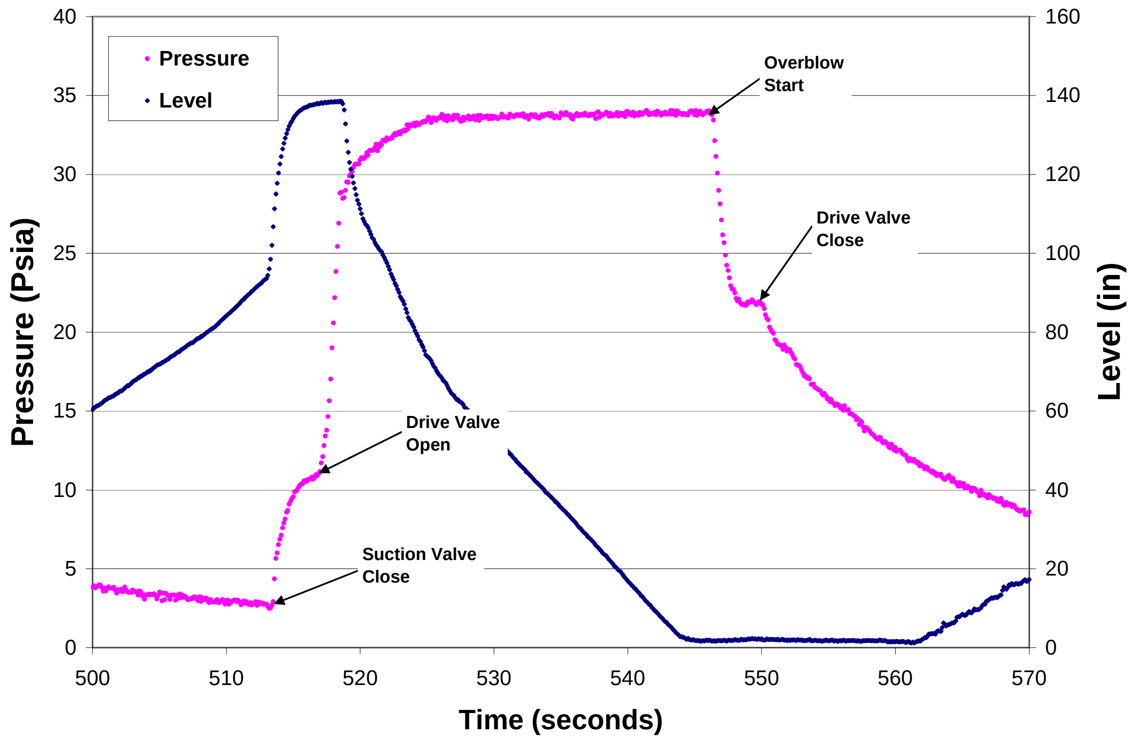

Figure 12.1. Illustration of the Drive Phase During the PJM Cycle. (Data obtained with clay stimulant, a fill H/D of 0.6, and only PJM #5 operating.)

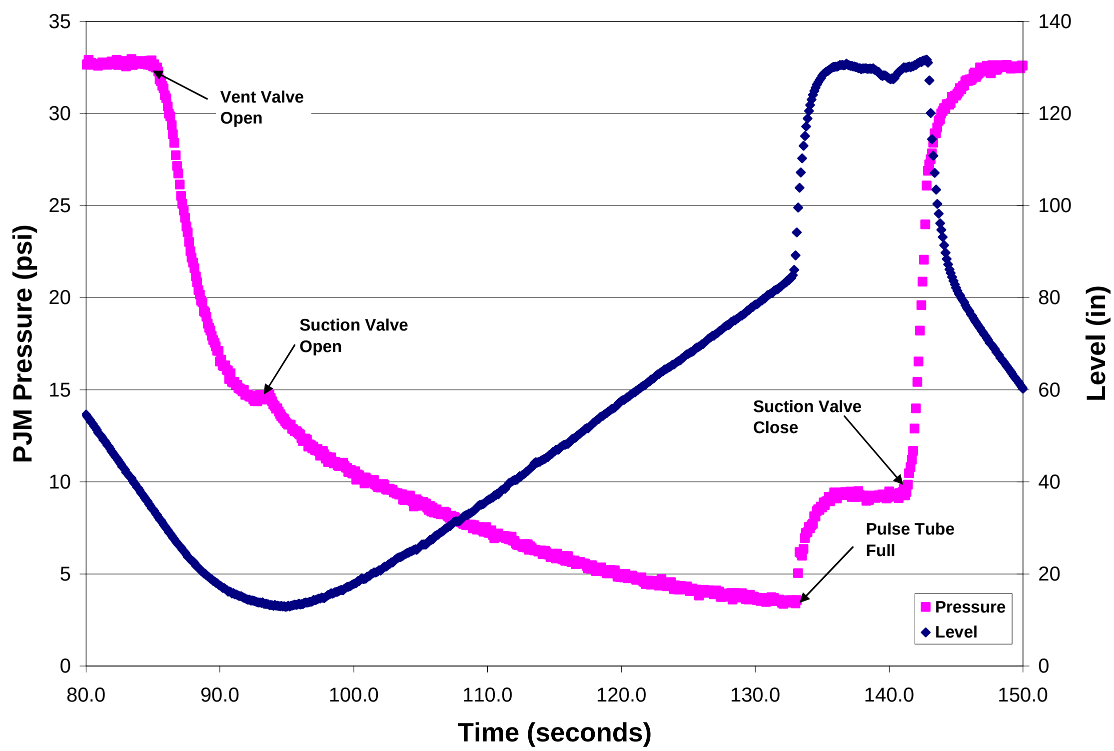

Figure 12.2. Illustration of the Suction Phase During the PJM Cycle. (Data obtained with clay stimulant, a fill H/D of 0.6, and only PJM #5 operating.)

Table 12.1. Drive Times Determined from the Static Pressure Head (ρgh) Tests

Simulant	Fill Height (inches from Tank Rim)	Simulant Height above bottom of pulse tube cone (inches)	ρgh (psi)	Dive Time (sec)	StdDev (sec)
Clay	60	99	4.26	29.5	0.18
	90	69	2.97	28.3	0.08
	130.5	28.5	1.23	27	0.05
Water	63	96	3.44	25.9	0.05
	89.5	69.5	2.49	25.4	0.09
	131	28	1.00	24.3	0.09

Table 12.2. Suction Times Determined from the Static Pressure Head (ρgh) Tests

Simulant	Fill Height (inches from Tank Rim)	Simulant Height above bottom of pulse tube cone (inches)	ρgh (psi)	Suction Time (sec)	StdDev (sec)
Clay	60	99	4.26	41.1	0.3
	90	69	2.97	42.9	0.3
	130.5	28.5	1.23	45.7	0.3
Water	63	96	3.44	35.8	0.3
	89.5	69.5	2.49	37.5	0.4
	131	28	1.00	39	0.4

The data in Tables 12.1 and 12.2 are plotted as a function of ρgh and shown in Figures 12.3 and 12.4 for the drive and suction times of the PJM, respectively. From Figures 12.3 and 12.4 it can be seen that, except for the case of the suction times with clay, the suction and drive times vary linearly with ρgh.

12.4 Modeling the Time to Overblow

Bontha et al. (2005) have derived and verified a Bernoulli-based model that describes the dynamic height of a non-Newtonian fluid in a PJM vessel during operation. The equation presented by Bontha and coworkers can be converted to a new coordinate system that uses the nozzle height as the zero reference point as shown in Figure 12.5.

$$z_1 + \frac{\dot{z}_1^2}{2g} + \frac{P_1}{\rho g} = z_2 + \frac{\dot{z}_2^2}{2g} + \frac{P_2}{\rho g} + K_L \frac{\dot{z}_0^2}{2g} \qquad (12.1)$$

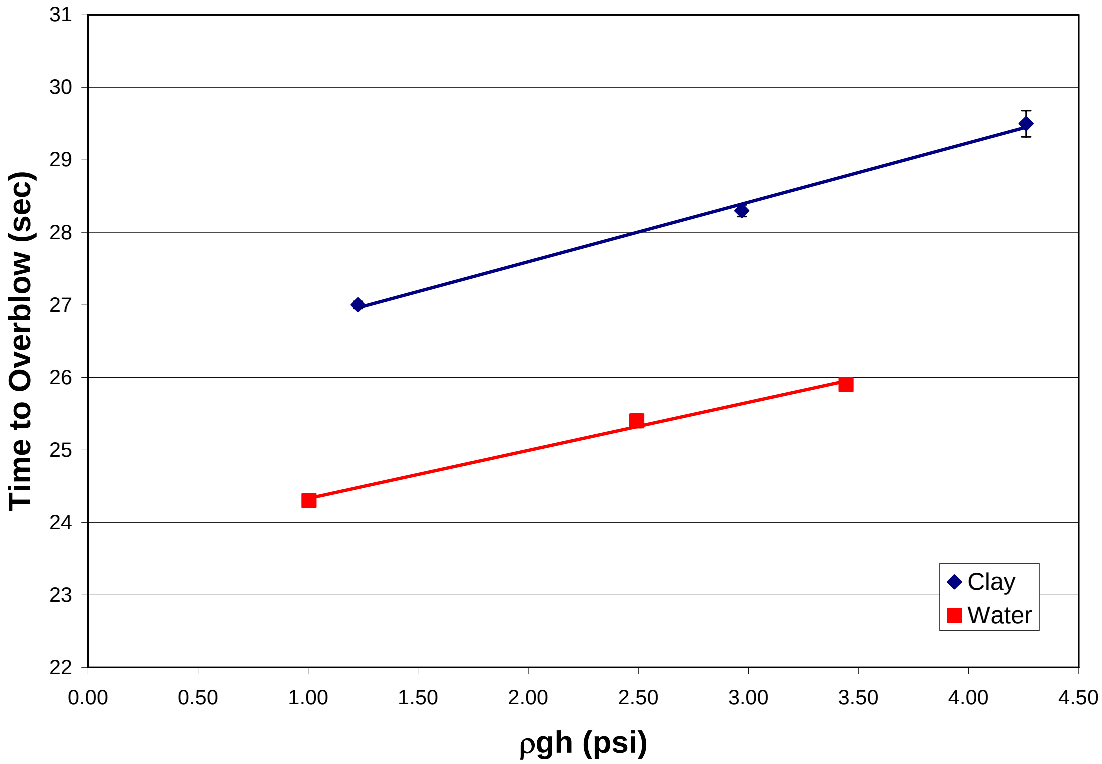

Figure 12.3. Drive Time Versus ρgh Profiles for Clay and Water Simulants at Different Fill Heights

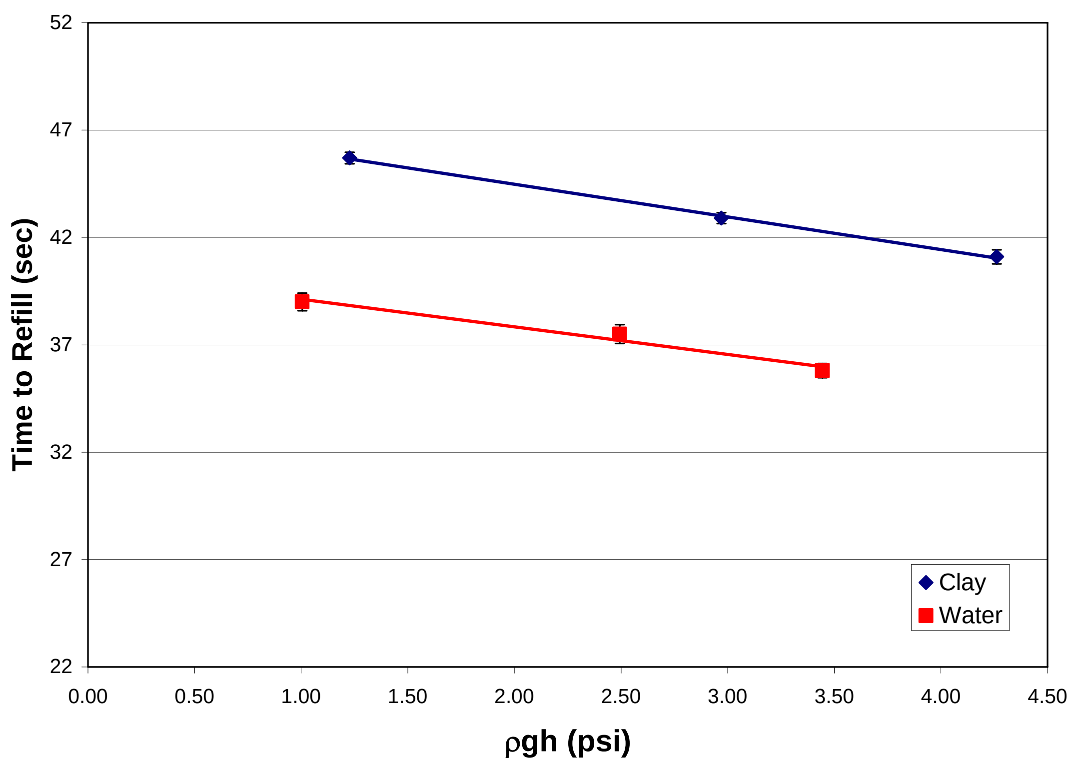

Figure 12.4. Suction Time Versus ρgh Profiles for Clay and Water Simulants at Different Fill Heights

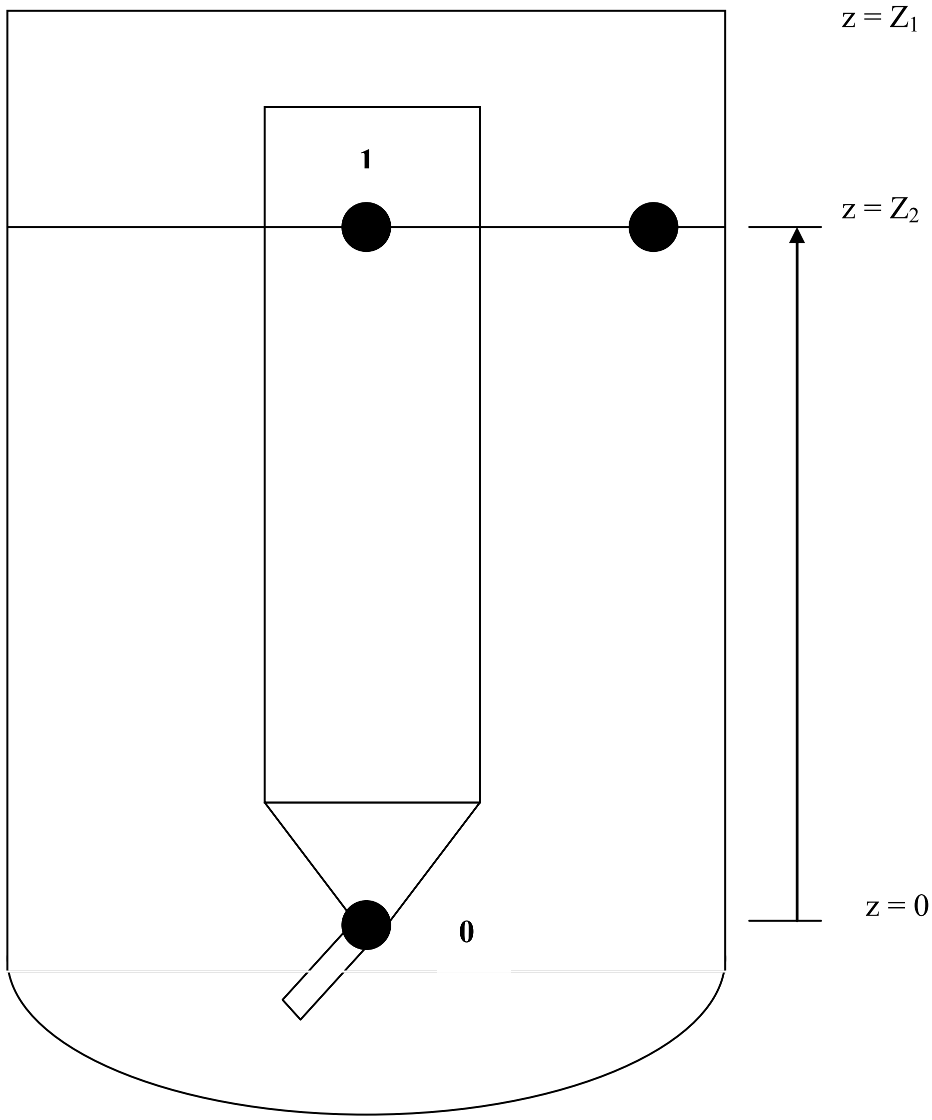

Figure 12.5. Diagram of PJM Model System with Single Pulse Tube

where

P_1, P_2	= pressure in the pulse tube and vessel overhead space, respectively
z_1	= instantaneous position of pulse tube fluid level
z_2	= instantaneous position of vessel fluid level
$\dot{z}_1$	= instantaneous velocity of pulse tube fluid level
$\dot{z}_2$	= instantaneous velocity of vessel fluid level and $\dot{z}_2 = -\frac{A_{PJM}}{A_{\tan k}}\dot{z}_1$
$\dot{z}_0$	= instantaneous velocity of the fluid through the PJM nozzle and $\dot{z}_0 = \frac{A_{PJM}}{A_0}\dot{z}_1$
ρ	= fluid density
g	= acceleration of gravity

K_L = friction form loss coefficient for flow through the nozzle region, likely different for forward or backward flow

A_{PJM} = cross-sectional area of the pulse tube

A_{tank} = cross-sectional area of the vessel

A_0 = cross-sectional area of the PJM nozzle.

The loss coefficient through the nozzle is assumed to be based on system geometry and independent on fluid rheological properties. Turian et al. (1998a, 1998b) found that the non-Newtonian loss coefficients "approached asymptotic values at high flow rates which were the same as the values for highly turbulent flow of water." Consequently, this appears to be a sound assumption when the flow through the nozzle is in a highly turbulent condition.

By making appropriate substitutions for the velocity terms, defining x = z_1 and z_{20} being the fluid height in the vessel and when the PJM is empty, these equations can be condensed to the form:

$$\dot{x}^2 = ax + bu \tag{12.2}$$

where

$$a = \frac{\left(1 + \frac{A_{PJM}}{A_{\tan k}}\right)}{C_N} \tag{12.3}$$

$$b = \left(\frac{1}{\rho g C_N}\right) \tag{12.4}$$

$$C_N = \frac{1}{2g}\left[\left(\frac{A_{PJM}}{A_{\tan k}}\right)^2 - 1 + K_L\left(\frac{A_{PJM}}{A_o}\right)^2\right] \tag{12.5}$$

$$u = P_1 - P_{atm} - \rho g z_{20} \tag{12.6}$$

Taking the square root of Eq. (12.2) produces

$$\dot{x} = \pm(ax + bu)^{1/2} \tag{12.7}$$

The positive form of the equation is used during the refill cycle, while the negative sign is used during the discharge cycle. Note that parameters *a* and *b* will change depending on whether the fluid is refilling or discharging from the PJM tube. Separating variables and taking the integral of this equation while assuming constant *u* (i.e., pulse tube pressure, P_1) produces the following:

$$\int_{x_1}^{x_2} \frac{1}{(ax + bu)^{1/2}} dx = \pm\int_{t_1}^{t_2} dt \tag{12.8}$$

$$\left(ax_2 + bu\right)^{1/2} - \left(ax_1 + bu\right)^{1/2} = \pm \frac{a}{2}\Delta t \tag{12.9}$$

Solving for Δt leads to

$$\Delta t = \pm \frac{2}{a}\left[\left(ax_2 + bu\right)^{1/2} - \left(ax_1 + bu\right)^{1/2}\right] \tag{12.10}$$

$$\Delta t = \pm \left[\left(\frac{4}{a}x_2 + \frac{4b}{a^2}u\right)^{1/2} - \left(\frac{4}{a}x_1 + \frac{4b}{a^2}u\right)^{1/2}\right] \tag{12.11}$$

Alternatively, the new position in the pulse tube, x_2, can also be solved over a given period of time at constant pulse tube pressure:

$$x_2 = x_1 \pm \left(ax_1 + bu\right)^{1/2}\Delta t + \frac{a}{4}\Delta t^2 \tag{12.12}$$

The average velocity over this time at constant pulse tube pressure can be determined as follows:

$$\dot{x} \cong \frac{x_2 - x_1}{\Delta t} = \pm\left(ax_1 + bu\right)^{1/2} + \frac{a}{4}\Delta t \tag{12.13}$$

From Figures 12.1 and 12.2, the assumption of constant pulse tube pressure appears valid during the drive phase, while the suction phase shows a slow decrease in pulse tube pressure as gas is evacuated from the pulse tube. Consequently, application of the above equations to these data is limited to the drive cycle only. Further application to actual WTP process vessels will need to consider the adequacy of the constant pressure assumption by evaluating gas flow-rates to and from the pulse tubes via the JPPs.

Equations (12.1) through (12.13) are only valid when the PJM pulse tube level is in the cylindrical section of the pulse tube. A different set of equations would need to be derived to model the liquid level in the conical section of the pulse tube. Because the volume of fluid in the conical section is small compared with the cylindrical volume, this correction is expected to be small over an entire drive cycle. Consequently, no correction for the conical section of the pulse tube is applied in these calculations.

If x_L is the length of the pulse tube at t_1=0, and x_2 is the nozzle height in the pulse tube (i.e., zero), the constants in Eq. (12.11) can be combined to find the predicted overblow time, t_{ob}:

$$t_{ob} = \left[\left(C_1\frac{u}{\rho g} + C_2\right)^{1/2} - \left(C_1\frac{u}{\rho g}\right)^{1/2}\right] \tag{12.14}$$

$$C_1 = \frac{4b\rho g}{a^2} = \frac{4}{a^2 C_N} \tag{12.15}$$

$$C_2 = \frac{4x_L}{a} \qquad (12.16)$$

It should be noted that C_1 and C_2 depend only on system geometry. As such, plots of t_{ob} as a function of $u/\rho g$ should be independent of fluid properties, allowing systems tested using the same PJM configuration to be described by a single master curve.

Assuming the $\rho g z_{20} \cong \rho g h$, a drive pressure P_1= 34 psia (for the present tests) and atmospheric pressure for P_2= 14.7 psia, $u/\rho g$ was calculated from the data presented in Table 12.1. A plot of this parameter against the time to overblow t_{ob} is shown in Figure 12.6. A regression was performed to determine the constants C_1 and C_2 from Eq. (12.14) that provide the best fit to the data. The results indicate a strong correlation between the model equation and experimental data.

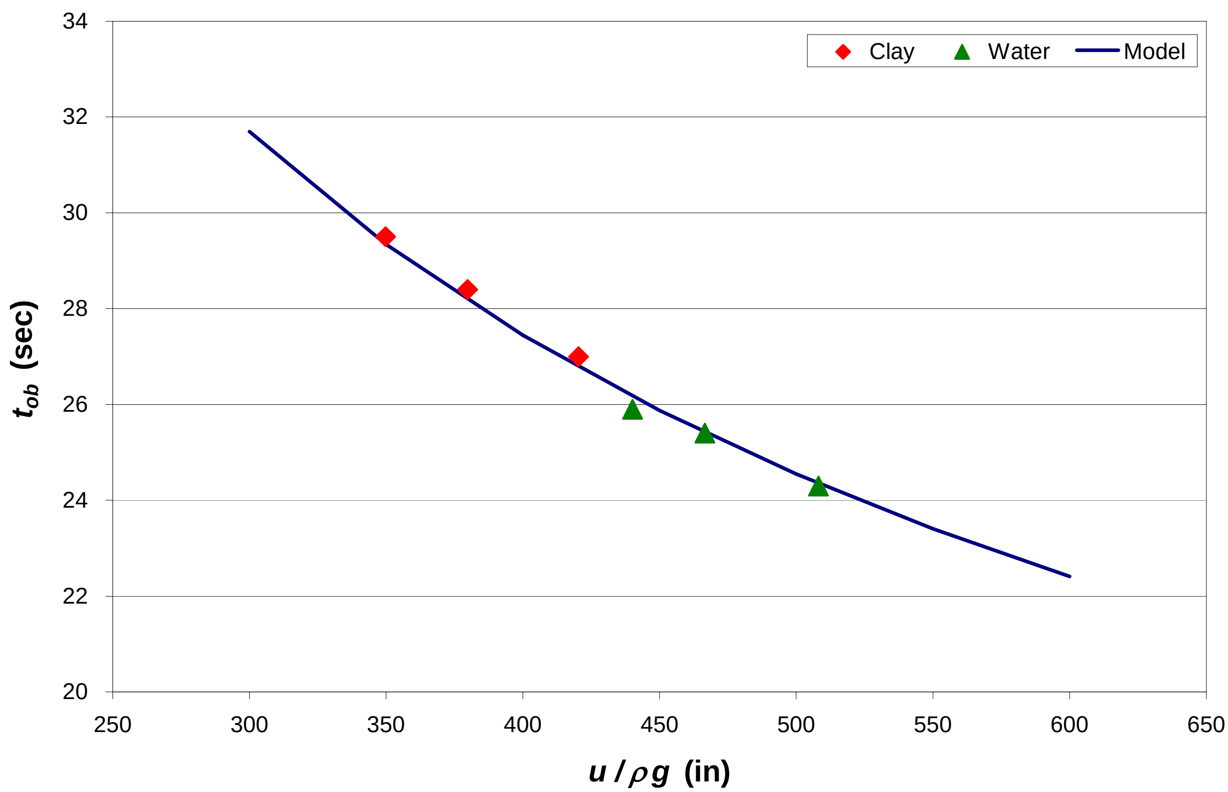

Figure 12.6. Time to PJM Overblow for Clay and Water Simulants at Different Fill Heights (see Table 12.1). Model data (Eq. 12.14) have best fit constants of $C_1 = 1.4\text{x}10^{12}$ sec^2/in and $C_2 = 1.3\text{x}10^9$ sec^2 and (R^2 =0.993).

13.0 References

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Appendix A

Test Log and Data File Names
for Controller and Instrumentation Tests

Table A.1. Test Log and Data File Names for C&I Tests with Clay Simulant

Date	Test Description	Simulant			Piping Lengths		JPP Operating Conditions		PJM Cycles	Data File Names		
		H/D	Yield stress (Pa)	Consistency (cP)	Drive (ft)	Suction (ft)	Drive pressure (bar-g)	Suction pressure (bar-g)		DAS-1 (PJM)	DAS-2 (hydrophone)	DAS-3 (BNI)
1/9/2006	PJM tuning	0.56	38.5	28.1	0	0	4	4.5	5	CTRL-P-060109_X.ASC	N/A	060109 data
1/10/2006	PJM tuning	0.56	38.5	28.1	0	0	4	4.5	5	CTRL-P-060110_X.ASC	N/A	060110 data
1/11/2006	PJM tuning - reliability test	0.57	28	20.0	0	0	4	4.5	103	CTRL-P-060111_X.ASC	N/A	060111 data
1/17/2006	Prep for TI-434	0.79	35	24.4	0	0	4	4.5	N/A	CTRL-P-060117_X.ASC	N/A	060117 data
1/18/2006	PJM #5 operation at 0-ft pipe length	0.78	36.6	25.6	0	0	4	4.5	32 (CVF) 39 (DOB)	CTRL-P-060118_1.ASC; CTRL-P-060118_2.ASC	HD1 Jan 17, 2006 11-10-23.TXT; HD2 Jan 17, 2006 11-10-23.TXT; HD3 Jan 17, 2006 11-10-23.TXT	060118 data
	Adding 50 ft of ext. piping	0.78			50	50	4	4.5	N/A	N/A	N/A	
1/19/2006	PJM operation with 50-ft ext. piping	0.77	35.9	27.1	50	50	4	4.5	31	CTRL-P-060119_1.ASC	N/A	060119 data
	DOB detection	0.77			50	50	4	4.5	31	CTRL-P-060119_2.ASC	HD1 Jan 19, 2006 11-34-13.TXT; HD2 Jan 19, 2006 11-34-13.TXT; HD3 Jan 19, 2006 11-34-13.TXT	
	CVF detection	0.77			50	50	4	4.5	33	CTRL-P-060119_3.ASC	N/A	
	OPT1: blocking vent	0.77			50	50	4	4.5	5 to 10	CTRL-P-060119_4.ASC	N/A	
	OPT2: open vent bleed valve	0.77			50	50	4	4.5	5 to 10	CTRL-P-060119_5.ASC	N/A	
	OPT3: open/close vent valve bleed rapidly	0.77			50	50	4	4.5	5 to 10	CTRL-P-060119_6.ASC	N/A	
	OPT4: fill 1 PJM while others in drive	0.77			50	50	4	4.5	5 to 10	CTRL-P-060119_7.ASC	N/A	
1/20/2006	Increase ext. piping - suction side 150 ft	0.76	36	27.1	50	150	4	4.5	-	N/A	N/A	060120 data
	DOB detection	0.76			50	150	4	4.5	35	CTRL-P-060120_1.ASC; CTRL-P-060120_2.ASC	HD1 Jan 20, 2006 10-30-24.TXT; HD2 Jan 20, 2006 10-30-24.TXT; HD3 Jan 20, 2006 10-30-24.TXT	
	CVF detection	0.76			50	150	4	4.5	34	CTRL-P-060120_3.ASC	N/A	

BNI = Bechtel National, Inc. DOB = drive overblow H/D = height to diameter ratio PJM = pulse jet mixer
CVF = charge vessel full DAS = data acquisition system JPP = jet pump pair

Table A.1 (contd)

Date	Test Description	Simulant			Piping Lengths		JPP Operating Conditions		PJM cycles	Data File Names		
		H/D	Yield stress (Pa)	Consistency (cP)	Drive (ft)	Suction (ft)	Drive pressure (bar-g)	Suction pressure (bar-g)		DAS-1 (PJM)	DAS-2 (hydrophone)	DAS-3 (BNI))
1/23/2006	Decrease ext piping - suction side 100 ft	0.76	34.5	27	50	100	4	4.5	-	N/A	N/A	060123 Data
	DOB detection with 50/100-ft piping	0.76			50	100	4	4.5	15	CTRL-P-060123_1.ASC; CTRL-P-060123_.ASC	HD1 Jan 23, 2006 13-52-44.TXT; HD2 Jan 23, 2006 13-52-44.TXT; HD3 Jan 23, 2006 13-52-44.TXT	
	DOB detection with 50/125-ft piping	0.76			50	125	4	4.5	15	CTRL-P-060123_3.ASC	HD1 Jan 23, 2006 14-56-12.TXT; HD2 Jan 23, 2006 14-56-12.TXT; HD3 Jan 23, 2006 14-56-12.TXT	
	DOB detection with 50/75-ft piping	0.76			50	75	4	4.5	15	CTRL-P-060123_4.ASC	HD1 Jan 23, 2006 15-28-23.TXT; HD2 Jan 23, 2006 15-28-23.TXT; HD3 Jan 23, 2006 15-28-23.TXT	
1/24/2006	Ross tests with 50/125-ft piping	0.77	34.5	27	50	125	4	4.5		CTRL-P-060124_1.ASC	N/A	060124 Data
1/25/2006	Reliability test DOB detection with 50/125-ft piping	0.76	32.9	25.6	50	125	4	4.5	100	CTRL-P-060125_1.ASC	HD1 Jan 25, 2006 10-20-58.TXT; HD1 Jan 23, 2006 11-20-04.TXT; HD2 Jan 25, 2006 10-20-58.TXT; HD2 Jan 23, 2006 11-20-04.TXT; HD3 Jan 25, 2006 10-20-58.TXT; HD3 Jan 23, 2006 11-20-04.TXT;	060125 Data
	Reliability test CVF detection with 50/125-ft piping	0.76			50	125	4	4.5	100	CTRL-P-060125_2.ASC	N/A	
1/26/2006	Blower attached to vent test and video recording		33.2	25	50	125	4	4.5	-	CTRL-P-060126_1.ASC; CTRL-P-060126_2.ASC	HD1 Jan 26, 2006 09-27-32.TXT; HD1 Jan 26, 2006 09-58-23.TXT; HD2 Jan 26, 2006 09-27-32.TXT; HD2 Jan 26, 2006 09-58-23.TXT; HD3 Jan 26, 2006 09-27-32.TXT; HD3 Jan 26, 2006 09-58-23.TXT	060126 Data
	Pump-down to mid-level with 50/125-ft piping	0.78 (start) 0.56 (end)			50	125	4	4.5		CTRL-P-060126_3.ASC	HD1 Jan 26, 2006 11-32-40.TXT; HD2 Jan 26, 2006 11-32-40.TXT; HD3 Jan 26, 2006 11-32-40.TXT	
	PJM#5 only DOB with CVF with 50/125-ft piping	0.56			50	125	4	4.5	15	CTRL-P-060126_4.ASC	HD1 Jan 26, 2006 12-11-19.TXT; HD2 Jan 26, 2006 12-11-19.TXT; HD3 Jan 26, 2006 12-11-19.TXT	
	CVF detection with 50/125-ft piping	0.56			50	125	4	4.5	15	CTRL-P-060126_5.ASC	N/A	
	DOB detection with 50/125-ft piping	0.56			50	125	4	4.5	15	CTRL-P-060126_6.ASC	HD1 Jan 26, 2006 13-35-19.TXT; HD2 Jan 26, 2006 13-35-19.TXT; HD3 Jan 26, 2006 13-35-19.TXT	
	PJM#5 only DOB with CVF and ext piping 50/50	0.56			50	50	4	4.5	15	CTRL-P-060126_7.ASC	HD1 Jan 26, 2006 14-08-52.TXT; HD2 Jan 26, 2006 14-08-52.TXT; HD3 Jan 26, 2006 14-08-52.TXT	

Table A.1 (contd)

Date	Test Description	Simulant			Piping Lengths		JPP Operating Conditions		PJM cycles	Piping Lengths	Data File Names	
		H/D	Yield stress (Pa)	Consistency (cP)	PJM cycles	Suction (ft)	Drive pressure (bar-g)	Suction pressure (bar-g)		DAS-1 (PJM)	DAS-2 (hydrophone)	DAS-3 (BNI))
1/26/2006	Pumpdown to low-level with 50/125-ft piping	0.56 (start) 0.27 (end)			50	125	4	4.5		CTRL-P-060126_8.ASC	HD1 Jan 26, 2006 15-38-09.TXT; HD2 Jan 26, 2006 15-38-09.TXT; HD3 Jan 26, 2006 15-38-09.TXT	
	PJM#5 only DOB with CVF and 50/125-ft piping	0.27			50	125	4	4.5		CTRL-P-060126_9.ASC	HD1 Jan 26, 2006 15-51-03.TXT; HD2 Jan 26, 2006 15-51-03.TXT; HD3 Jan 26, 2006 15-51-03.TXT	
1/27/2006	Level adjustment	0.27 (start) 0.31 (end)	33.2	25	50	125	4	4.5		N/A	N/A	060127 Data
	DOB detection (low level) with 50/125-ft piping	0.31			50	125	4	4.5		CTRL-P-060127_1.ASC	HD1 Jan 27, 2006 10-07-02.TXT; HD2 Jan 27, 2006 10-07-02.TXT; HD3 Jan 27, 2006 10-07-02.TXT	
	CVF detection (low level) with 50/125-ft piping	0.31			50	125	4	4.5		CTRL-P-060127_2.ASC	N/A	
2/1/2006	Aspiration test	0.30 (start) 0.14 (end)	34	26.1	50	125	4	4.5		CTRL-P-060201_1.ASC	N/A	060201 Data
	Pump up to low level	0.14 (start) 0.29 (end)			50	125	4	4.5			N/A	
	DOB testing – flush line – low level	0.29			50	125	4	4.5	9	CTRL-P-060201_2.ASC	N/A	
	DOB testing – PJM#5 alone – flush line – low level	0.29			50	125	4	4.5	15	CTRL-P-060201_2.ASC	N/A	
	Pump up to mid level	0.29 (start) 0.57 (end)			50	125	4	4.5		CTRL-P-060201_2.ASC	N/A	
	DOB testing – flush line – mid level	0.57			50	125	4	4.5	12	CTRL-P-060201_2.ASC	N/A	
	DOB testing – PJM#5 alone – flush line – mid level	0.57			50	125	4	4.5	8	CTRL-P-060201_2.ASC	N/A	
	Pump up to high level	0.57 (start) 0.76 (end)			50	125	4	4.5		CTRL-P-060201_2.ASC	N/A	

Table A.1 (contd)

Date	Test Description	Simulant			Piping Lengths		JPP Operating Conditions		PJM cycles	Data File Names		
		H/D	Yield stress (Pa)	Consistency (cP)	PJM cycles	Suction (ft)	Drive pressure (bar-g)	Suction pressure (bar-g)		DAS-1 (PJM)	DAS-2 (hydrophone)	DAS-3 (BNI))
2/1/2006	DOB testing - flush line - high level	0.76			50	125	4	4.5	12	CTRL-P-060201_3.ASC	N/A	
	DOB testing - PJM#5 alone - flush line - high level	0.76			50	125	4	4.5	6	CTRL-P-060201_4.ASC	N/A	
2/2/2006	Pump down to mid-level	0.76 (start) 0.57 (end)	34	26.1	50	125	4	4.5	-	-	N/A	060202 Data
	DOB detection - flush line - mid level	0.57			50	125	4	4.5	7	CTRL-P-060202_1.ASC	N/A	
	DOB detection - PJM 5 alone-flush line-mid level	0.57			50	125	4	4.5	11	CTRL-P-060202_1.ASC	N/A	
2/8/2006	Software mod. for flush line verification tests	0.55 (start) 0.30 (end)	-	-	50 (st) 30 (fn)	125 (st) 50 (fn)	4	4.5		CTRL-P-060208_1.ASC; CTRL-P-060208_2.ASC; CTRL-P-060208_3.ASC	N/A	060208 Data
2/27/2006	PJM 5 slow OVB	0.77	33.3	25	50	125	18.8 psia in PJM	4.5	2	CTRL-P-060227_1.ASC	N/A	060227 Data
	DOB testing - PJM 5 alone - 7 psig inside PJM	0.77			50	125	21.8 psia in PJM	4.5	10	CTRL-P-060227_2.ASC	N/A	
	DOB testing	0.77			50	125	4	4.5	104	CTRL-P-060227_3.ASC	HD1 Feb 27, 2006 14-25-02.TXT; HD1 Feb 27, 2006 15-17-07.TXT; HD1 Feb 27, 2006 15-49-59.TXT; HD2 Feb 27, 2006 14-25-02.TXT; HD2 Feb 27, 2006 15-17-07.TXT; HD2 Feb 27, 2006 15-49-59.TXT; HD3 Feb 27, 2006 14-25-02.TXT; HD3 Feb 27, 2006 15-17-07.TXT; HD3 Feb 27, 2006 15-49-59.TXT;	
2/28/2006	DOB testing - PJM 5 Alone	0.78	33.3	25	50	125	4	4.5	95	CTRL-P-060228_1.ASC	HD1 Feb 28, 2006 09-49-24.TXT; HD1 Feb 28, 2006 11-11-05.TXT; HD2 Feb 28, 2006 09-49-24.TXT; HD2 Feb 28, 2006 11-11-05.TXT; HD3 Feb 28, 2006 09-49-24.TXT; HD3 Feb 28, 2006 11-11-05.TXT;	060228 Data
	DOB testing	0.78			50	125	4	4.5	98	CTRL-P-060228_2.ASC	HD1 Feb 28, 2006 13-23-56.TXT; HD2 Feb 28, 2006 13-23-56.TXT; HD3 Feb 28, 2006 13-23-56.TXT;	

Table A.1 (contd)

Date	Test Description	Simulant			Piping Lengths		JPP Operating Conditions		PJM cycles	Data File Names		
		H/D	Yield stress (Pa)	Consistency (cP)	PJM cycles	Suction (ft)	Drive pressure (bar-g)	Suction pressure (bar-g)		DAS-1 (PJM)	DAS-2 (hydrophone)	DAS-3 (BNI))
2/28/2006	Pump down to mid-level	0.78 (start) 0.58 (end)		25	50	125	4	4.5	-	-	N/A	060228 Data
	DOB testing	0.58			50	125	4	4.5	10	CTRL-P-060228_3.ASC	HD1 Feb 28, 2006 14-29-56.TXT; HD2 Feb 28, 2006 14-29-56.TXT; HD3 Feb 28, 2006 14-29-56.TXT;	060228 Data
	DOB testing - PJM 5 alone	0.58			50	125	4	4.5	10	CTRL-P-060228_4.ASC	HD1 Feb 28, 2006 14-52-04.TXT; HD2 Feb 28, 2006 14-52-04.TXT; HD3 Feb 28, 2006 14-52-04.TXT;	060228 Data
	Pump down to low level	0.58 (start) 0.31 (end)			50	125	4	4.5	-	-	N/A	060228 Data
	DOB testing - PJM 5 alone - 7 psig inside PJM	0.31			50	125	21.8 psia in PJM	4.5	10	CTRL-P-060228_5.ASC	HD1 Feb 28, 2006 16-16-36.TXT; HD2 Feb 28, 2006 16-16-36.TXT; HD3 Feb 28, 2006 16-16-36.TXT;	060228 Data
3/1/2006	DOB testing	0.31	33.3	25	50	125	4	4.5	92	CTRL-P-060301_1.ASC	HD1 Mar 01, 2006 10-09-56.TXT; HD1 Mar 01, 2006 10-47-15.TXT; HD2 Mar 01, 2006 10-09-56.TXT; HD2 Mar 01, 2006 10-47-15.TXT; HD3 Mar 01, 2006 10-09-56.TXT; HD3 Mar 01, 2006 10-47-15.TXT;	060301 Data
	DOB testing - PJM 5 alone	0.31			50	125	4	4.5	92	CTRL-P-060301_2.ASC	HD1 Mar 01, 2006 13-15-11.TXT; HD2 Mar 01, 2006 13-15-11.TXT; HD3 Mar 01, 2006 13-15-11.TXT;	

Table A.2. Test Log and Data File Names for C&I Tests with Water

Date	Test Description	Water H/D	Piping Lengths		JPP Op. Conditions		PJM Cycles	Data File Names		
			Drive (ft)	Suction (ft)	Drive Pressure (bar-g)	Suction Pressure (bar-g)		DAS-1 (PJM)	DAS-2 (Hydrophone)	DAS-3 (BNI)
3/7/2006	PJM tuning	0.75	50	125	4	4.5	6	CTRL-P-060307_1.ASC	-	3/7/2006 Data
	DOB testing	0.75	50	125	4	4.5	110	CTRL-P-060307_2.ASC; CTRL-P-060307_3.ASC;	HD1 Mar 07, 2006 13-12-52.TXT; HD2 Mar 07, 2006 13-12-52.TXT; HD3 Mar 07, 2006 13-12-52.TXT; HD1 Mar 07, 2006 13-14-52.TXT; HD2 Mar 07, 2006 13-14-52.TXT; HD3 Mar 07, 2006 13-14-52.TXT;	
	DOB testing - PJM 5 alone - 7 psig inside PJM	0.75	50	125	21.8 psia in PJM 5	4.5	10	CTRL-P-060307_5.ASC	HD1 Mar 07, 2006 16-06-12.TXT; HD2 Mar 07, 2006 16-06-12.TXT; HD3 Mar 07, 2006 16-06-12.TXT;	
3/8/2006	DOB testing - PJM 5 alone	0.75	50	125	4	4.5	91	CTRL-P-060308_1.ASC	HD1 Mar 08, 2006 09-39-01.TXT; HD2 Mar 08, 2006 09-39-01.TXT; HD3 Mar 08, 2006 09-39-01.TXT; HD1 Mar 08, 2006 11-31-46.TXT; HD2 Mar 08, 2006 11-31-46.TXT; HD3 Mar 08, 2006 11-31-46.TXT;	3/8/2006 Data
	CVF testing	0.75	50	125	4	4.5	94	CTRL-P-060308_2.ASC	-	
3/9/2006	Pump down to mid level	0.75 (start) 0.58 (end)	50	125	4	4.5	-	CTRL-P-060309_1.ASC	HD1 Mar 09, 2006 13-46-46.TXT; HD2 Mar 09, 2006 13-46-46.TXT; HD3 Mar 09, 2006 13-46-46.TXT;	3/9/2006 Data
	DOB testing - PJM 5 Alone	0.58	50	125	4	4.5	16	CTRL-P-060309_2.ASC	HD1 Mar 09, 2006 14-13-32.TXT; HD2 Mar 09, 2006 14-13-32.TXT; HD3 Mar 09, 2006 14-13-32.TXT;	
	DOB testing	0.58	50	125	4	4.5	21	CTRL-P-060309_3.ASC	HD1 Mar 09, 2006 14-41-11.TXT; HD2 Mar 09, 2006 14-41-11.TXT; HD3 Mar 09, 2006 14-41-11.TXT;	
	CVF detection	0.58	50	125	4	4.5	21	CTRL-P-060309_4.ASC	-	
	DOB testing - PJM 5 alone - 7 psig inside PJM	0.58	50	125	21.8 psia in PJM 5	4.5	11	CTRL-P-060309_5.ASC	HD1 Mar 09, 2006 15-38-12.TXT; HD2 Mar 09, 2006 15-38-12.TXT; HD3 Mar 09, 2006 15-38-12.TXT;	

Table A.2 (contd)

Date	Test Description	Water H/D	Piping Lengths		JPP Op. Conditions		PJM Cycles	Data File Names		
			Drive (ft)	Suction (ft)	Drive Pressure (bar-g)	Suction Pressure (bar-g)		DAS-1 (PJM)	DAS-2 (Hydrophone)	DAS-3 (BNI)
3/13/2006	Pump down to low level	0.58 (start) 0.31 (end)	50	125	4	4.5	-	CTRL-P-060313_1.ASC	HD1 Mar 13, 2006 10-13-05.TXT; HD2 Mar 13, 2006 10-13-05.TXT; HD3 Mar 13, 2006 10-13-05.TXT;	3/13/2006 Data
	DOB testing	0.31	50	125	4	4.5	95	CTRL-P-060313_3.ASC	HD1 Mar 13, 2006 15-00-27.TXT; HD2 Mar 13, 2006 15-00-27.TXT; HD3 Mar 13, 2006 15-00-27.TXT; HD1 Mar 13, 2006 15-46-45.TXT; HD2 Mar 13, 2006 15-46-45.TXT; HD3 Mar 13, 2006 15-46-45.TXT;	
3/14/2006	DOB testing, PJM 5 alone	0.31	50	125	4	4.5	91	CRTL-P-060314_1.ASC	HD1 Mar 14, 2005 09-16-08.TXT; HD2 Mar 14, 2005 09-16-08.TXT; HD3 Mar 14, 2005 09-16-08.TXT; HD1 Mar 14, 2005 10-23-35.TXT; HD2 Mar 14, 2005 10-23-35.TXT; HD3 Mar 14, 2005 10-23-35.TXT;	3/14/2006 Data
	CVF testing	0.31	50	125	4	4.5	91	CRTL-P-060314_2.ASC	-	
	DOB testing - PJM 5 alone - 7 psig inside PJM	0.31	50	125	21.6 psia in PJM	4.5	20	CRTL-P-060314_3.ASC	HD1 Mar 14, 2005 12-57-09.TXT; HD2 Mar 14, 2005 12-57-09.TXT; HD3 Mar 14, 2005 12-57-09.TXT;	

Appendix B

Operational Issues

Appendix B – Operational Issues

B.1 Slurry Creep and Carryover

Clay deposits have been observed throughout the air lines, the JPP rack, and the ventilation system due to slurry creep and carryover. Slurry creep represents the phenomena of slurry slowly migrating up the air lines and eventually into JPPs and the associated vent systems. Entrainment of aerosols and bulk transport of slugs may also contribute to the migration of material into the JPPs. Reducing slurry creep and carryover is of critical importance to plant operation because the faster the material creeps up the air lines, the more frequently the PJMs need to be shut down to wash the airlines. This section includes qualitative observations of the slurry creep and carryover phenomena observed in the 336 facility test equipment.

The air lines from the PJM rack consist of Goodyear Tigerflex wire-reinforced PVC hose with a nominal inside diameter of 2 inches. These air lines hang from a point near the ceiling of the 336 facility such that the hose is roughly 50 ft above the top of the pulse tubes. This elevation is provided to prevent slugs of simulant from carrying over into the PJM rack during the suction phase. The total hose length between the PJMs and the JPP rack is about 100 ft. The air lines are connected to the top of the pulse tubes via a 2-inch pipe cross and a 4-ft spool piece of 2-inch pipe. The 336 facility test stand does not have a wash-down system that would limit slurry creep.

Near the end of the refill of the pulse tubes (suction phase), the tank contents are drawn 10–15 ft up into the air lines to each PJM by the applied vacuum. Most of the material drawn into the air lines is expelled during the subsequent drive phase, but a coating of material remains on the inside surface of the air lines. During the next refill phase, the air flow moving up the air lines toward the JPPs carries some of the material farther up the air line. There may also be some aerosols generated by the air flow, but the opaque nature of the clay simulant makes direct observation difficult.

During the course of the PJM testing, clay deposits have been observed throughout the air lines, in the JPP rack, and into the vent system. Partially dried clay nuggets have been collected in the parking lot beneath the vent line from the JPP rack. These nuggets are typically on the order of ¼ to ⅜ inch in diameter. Partial obstruction of the JPPs was also observed and is thought to be due to slurry creep or carryover. While the PJMs were operating normally, one of the PJMs (usually #3) would suddenly stop filling during one of the cycles, which often led to an overblow on the subsequent cycle. During these events, the suction pressure readings would show insufficient vacuum in the pulse tube, indicating that the JPP was plugged or partially plugged. The plugs were removed via mechanical means, which involved striking the JPP with a rubber mallet and then cleaning out the drain plug on the vent header. The size of the material removed via the drain line ranged from dust to approximately ⅜-inch-diameter agglomerates of clay. Cleaning was typically required every one to two days, although there were occasions where cleaning was required several times in one day.

The JPP on PJM #5 and the associated piping was thoroughly inspected during the modifications to install the spool piece for the transmitter. As shown in Figure B.1, a piece of dried clay was found in a 90^{o} elbow in the air line from the PJM. The location of this elbow is on the building wall and within a few feet of the JPP rack. During inspection of the disassembled JPP, minor amounts of clay were

Figure B.1. Clay Deposit in 90° Elbow of the Air Line from PJM #5

observed on the walls of the JPP. These deposits amounted to little more than dust. A more significant piece of clay was observed stuck to the wall near the cross piece on the JPP. It appeared that about 30 to 40% of the pipe cross section was blocked by the dried and hardened clay.

Slurry creep could potentially be more extensive in the plant because the air velocities during suction will be larger. The JPP rack and the hose diameter are full scale, while the PJMs and nozzles are half-scale with one-fourth of the flow through the nozzle. Therefore air line velocities will be roughly four times greater at full scale than they are in the half-scale lag storage (HSLS) test stand. These greater air velocities will likely increase the extent of slurry creep and carryover.

B.2 Sparger Plugging and Clay Accumulations

The majority of the sparger plugging observations presented in this subsection were made during the HSLS testing (see Bontha et al. 2005) but were not presented in the cited report and are included here upon the request of the client. In addition, observations made during the controller testing are included in this section.

During the HSLS testing (Bontha et al. 2005), the spargers were blocked by a clay plug that needed to be removed. A section of a plug is shown in Figure B.2. To remove the plug, a PVC pipe was rammed down the inside the sparge tube to drive out the plug. Some of the plug was forced into the PVC pipe and some of the plug was likely extruded into the vessel contents, where it was mixed back into the bulk of the clay slurry. The total length of a typical plug was estimated at about 4 ft, based on the length of PVC pipe that was inserted into the sparge tube before significant resistance was noted.

Figure B.2. Partial Section of a Clay Plug from a Sparge Tube

During the controller testing, while the clay simulant was being transferred from the tank in preparation for water testing, significant accumulations of semi-solid clay were observed around the bottom of each sparge tube. These accumulations consisted of donut-shaped clumps of material approximately 3 inches wide (i.e., thickness from sparge tube to edge of donut). The donut appeared to be about 3 inches thick in the vertical direction. It is speculated that these deposits were caused by evaporation as the dry air was bubbled through the sparge tubes.

During much of both the HSLS and the controller and instrumentation testing, the air flow through the sparge tube was not prototypic, so it is not known whether plugs or donuts of material would normally form. During the HSLS testing, the air flow through the spargers was either the standby flow (3 scfh per sparge tube) when testing was not being conducted, or full flow (19 acfm) when the tests were being conducted. Also, for long periods after the HSLS testing and before starting the controller testing, the spargers were mostly off. Finally, during the controller testing, the spargers were either full on when the days testing was in progress and off when the days testing was completed.

B.3 Summary

Operational issues associated with slurry creep and sparger plugging were encountered during the testing, when clay deposits were observed throughout the air lines, the JPP rack, and the vent system due to slurry creep and carryover. While the system was not always operated in a prototypic manner and did not have a slurry wash-down system to minimize slurry creep, this issue warrants additional investigation to support mitigation efforts in the WTP. During the HSLS testing, the spargers plugged for an estimated 4 ft on several occasions and required a significant effort to unplug. The plugs were driven out with a PVC pipe.

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