Non-Stop SIR Detects Leaks and Monitors Meter Accuracy

"Warren Rogers reports on the four-week evaluation of the performance of his real-time continuous SIR in controlled testing performed in a specially equipped facility."

Precise fuel inventory management
Statistical inventory reconciliation (SIR) involves statistical analyses that enable the user to (1) separate out and quantify changes in fuel inventory that are not "leak-related" and (2) react appropriately to those changes that are compatible with leakage. SIR systems include computer technology that works in conjunction with automatic tank gauges (ATGs) and other devices. SIR systems are used not only for leak detection but also for fuel inventory management. The author of this article, Warren Rogers (president of Warren Rogers Associates, Inc., and the father of SIR), is recognized world-wide as the expert on the subject. Additional insight into SIR and the man who developed the technology can be found in two past PE&T feature articles: "Third Party Testing Results for Statistical Inventory Reconciliation," by Warren Rogers, Feb. 1998; and "Sir Warren Rogers: King of Leak Detection by the Numbers," by Jaime Kammerzell, Oct. 2000).
In July 2000, Warren Rogers Associates, Inc. (WRA) undertook a formal evaluation of the performance of its real-time continuous SIR system in a controlled test at a specially equipped test facility. The purpose of the testing, which took four weeks to complete, was to induce the effects of operational stock measurement errors into the system under controlled circumstances and to measure the response of a real-time continuous SIR system in measuring the effects of those errors.

From both a leak detection and a precision inventory management standpoint, the most interesting element of the testing was the evaluation of the continuous inventory reconciliation system's detection of emergent variations in meter miscalibration during multiple meter usage. This capability has obvious applications in reducing the incidence of avoidable stock losses through "meter giveaways" and avoiding the cost of excessive on-site calibration measurements. In addition, this capability has important implications for improving the performance of line leak detection measures.

Before getting into the details of the testing project, let's take a look at some of the basics of how continuous SIR is used to detect leaks and to put precision into fuel inventory management.

Leaks and Inventory levels
In the United States, "leak detection" refers to a variety of methods, including fuel stock control techniques, designed to detect leaks in tanks and associated lines. Regulatory performance standards

delineate how leak detection methods should perform.

Other countries use "precision inventory management" as the standard to which stock control methods and risk minimization strategies are evaluated. "Precision inventory management" uses accurate and detailed accounting for inventory variances. Whereas the primary objective of leak detection is environmental protection, the principal objective of precision inventory management is to enhance the efficiency and profitability of fueling facilities.

Continuous reconciliation is a technique for achieving both leak detection and precision inventory management. Continuous reconciliation applies hybrid ATG/SIR and analytical methods in an automated system to detect leaks as well as other sources of inventory errors.

Continuous reconciliation for precision inventory management is an automated system. It measures and records product inventory and reconciles the inventory on hand with volumes received and dispensed, achieving accuracy well beyond that attainable by the various measuring devices used. The system includes an on-site processor, or data acquisition and transfer device, that continually records product levels and sale volumes. The system can be used with existing ATG systems and distinguishes between the product volumes actually dispensed and received and the volumes recorded as having been dispensed or received. It also accounts for unrecorded or undocumented deliveries or losses from inventory.

This is an installation of a WRA On-Site Processor interfaced with Dresser Wayne Dispensing Equipment and a Veeder Root tank gauge.

This is an installation of a WRA On-Site Processor interfaced with Tokheim dispensing equipment and a Emco Electronics tank gauge.

While it may seem that there are differences in the objectives of leak detection and precision inventory management, the means of achieving them are fundamentally the same in a continuous reconciliation procedure. In short, to achieve precision inventory one must account for leakage if it exists. Similarly, to achieve leak detection, the method meets the objectives of precision inventory management because it must identify and quantify all of the other sources of inventory gain or loss that are, in turn, the sources of inventory inaccuracies.

The inaccuracies endemic in traditional inventory practices result largely from industry practices that, to a great degree, emanate from economic considerations. The primary objective of precision inventory management is to provide a means of eliminating those errors while retaining the economic benefits that accrue from the practices that cause them. Following are summaries of the errors that can be accommodated by WRA's continuous reconciliation system.

Measurement of volume on hand-Because there is no direct means of measuring volume in a storage tank, the continuous reconciliation system measures the height or level of product in each tank with an ATG probe. Two sources of errors in the measurement of volume on hand are accommodated by the continuous reconciliation system.

First is the random measurement error that is a function of the tank probe design. The continuous reconciliation system measures and reports the magnitude of this error. When a large change in probe error magnitude is calculated, then this is indicative of degradation in probe or ATG control panel performance. The second source of error is in the conversion of product height to volume, where errors result from variations in actual vs. nominal tank dimensions or from the common industry practice of not placing a tank perfectly horizontal in the ground.

An analysis of the inventory data will reveal the presence of these two kinds of problems, identify their nature and provide the means of correcting them. Correction of tank geometry variations is necessary to obtain proper volume conversions for each specific tank in service and represents the essential first step in precision inventory management.

Delivery errors-It is not common industry practice, particularly at retail facilities, to meter the transfer of product from a transport to a storage tank system. In light of this, the continuous inventory system computes delivered volumes by sensing the onset of a delivery. When the delivery is complete, the system delays the calculation of the amount of the actual delivery by waiting for the post-delivery turbulence to subside. It then gathers a set of pre-delivery and post-delivery sales and corresponding tank volume measurements and conducts a regression analysis to calculate the volume delivered, typically to an accuracy of + 0.50 gallons.

This system also permits the operator to perform a delivery audit by inputting the bill of lading volume and temperature recorded at the terminal rack. If that is done, the system reports the volume of shrinkage or expansion (occurring enroute to the site and upon mixing with in-tank product) and the actual volume of any underdelivery or undocumented drop.

Unrecorded additions or removals-An unrecorded addition of product, such as a return of product during a "proving-can test," or an unrecorded removal of product, such as theft, are gains or losses that persist in an inventory record and are identified as such.

Dispenser miscalibration-A continuous inventory system monitors dispenser calibration for each hose position. This is an improvement upon conventional calibration practices and has ramifications for advancing the technology of volumetric line leak detection.

Temperature-A continuous reconciliation system uses the ATG probe to measure product temperatures. All volumes (sales, deliveries, and inventory on hand) are converted to net values so that, in effect, the inventory system becomes a "mass balance" system. Because this adjustment is introduced dynamically, multiple minute-to-minute readings become practical and are conducted.

This bottom load rack was diagnosed with a -3.5% underdelivery by analysis of multiple sites inventory records.

The continuous reconciliation system has many desirable attributes for the maintenance of a precise fuel management program and, under most circumstances, is essential if precision inventory management is to be attained. The system functions entirely independent of on-site staff interaction and has robust diagnostic capabilities because it constantly monitors gauge performance, hose-by-hose dispenser calibrations, system counting accuracy, and system software stability. All transactions are temperature compensated and the system computes delivered volumes to any desired level of accuracy. As discussed in the next section, the four-week testing of the continuous SIR system has confirmed the performance of the system and provided interesting new information about meter accuracy and calibration.

Testing confirms performance

The July 2000 testing involved "planting" operational stock measurement errors into the test apparatus, under controlled circumstances, and measuring the analytical system's response to the effects of those errors. The instrumented facility for the test was located at Murray Equipment Company in Fort Wayne, Indiana(Figure 1).

Figure 1: Test Facility at Murray Equipment Company Overview and Meter Test Stands

The test equipment consisted of a 2,000-gallon Xerxes underground storage tank, from which product height was measured. Product height was measured throughout the four- week testing period using two of the more common magnetostrictive gauging systems that are presently marketed.

The tank supplied product through a pressurized piping system to the inlets of six test stands equipped with Total Control Systems' Model 682 positive displacement meters. A solenoid valve controlled the meter discharges. The discharged product flowed through a manual control valve that could route discharged product between a 2000 gallon holding tank, a 5 gallon test measure, a 100 gallon test measure, and 500 gallon proving tank. This configuration enabled us to withdraw precise amounts of product from the UST, temporarily store it, and then return it to the UST in a controlled and measurable manner.

An important component of the testing was to evaluate the performance of the meter accuracy algorithms. The problem of determining meter accuracy from the data generated by the OSP system is complicated by the fact that the meter readings generated by the system can consist of single or multiple readings from every possible configuration of meters discharging simultaneously. A single observation, therefore, consists of the individual volumes registered on each of the meters activated during a transaction period and the corresponding sum of the volumes actually discharged or registered as being discharged through product measurements made using the tank probe.

The data is organized into blocks consisting of observations generated by the identical meter subsets. For each such subset of meters it is then possible to estimate the percentage of the total gallons registered on the meters in that subset which is actually discharged from the tank. Consistency conditions then allow determination of the percentage of registered volume that is actually being discharged through each individual meter. Additionally, line leak rates can be determined and distinguished from meter inaccuracies by incorporating the leak as though it was an additional meter discharging a fixed volume per unit of time whenever the lines are pressurized.

Consequently, the principal test of meter drift algorithms was to verify that meter miscalibration could be identified while several different meters were being used to dispense product. To mirror a conventional fuel system operation, it was necessary to ensure that the meters operated at random over random durations of time. To accomplish this, the solenoid valves at each meter and at the pump were controlled from a personal computer with software configured to start and to stop the meters at random intervals and for random durations of time.

The first phase of testing consisted of modeling the tank geometry by running several cycles of product through the tank and by identifying the tank geometry variation. Once the tank geometry was modeled, the test of the meter drift algorithms began. The system was cycled and values of meter calibrations and any deviations in meter calibration were recorded.

First the calibration accuracy program was allowed to stabilize with zero error settings being recorded with suitably small confidence bounds. Then a +9 cubic inch error was imposed on one meter (meter 3). Figure 2 displays graphically how the analytical system reacted to show the increasing calculated effects of the meter miscalibration, approaching the +9 cubic inch error imposed, and ultimately stabilizing at that value. The figure also displays how the confidence bounds around the calculated calibration error progressively narrows with time, thereby providing an early alert that statistically significant meter drift is taking place.

Figure 2: Meter Drift Analysis Calculations Following Imposition of ± 10 cubic inch error

Continued testing of the meter drift analysis was performed with induced meter errors ranging down to 2 cubic inches, including tests in which countervailing values (plus/minus) were applied to the various meters. An example of calculations of meter calibration values for all six meters is shown in Figure 3. Multiple tests were performed using each of the two types of ATG's available and meter calibration values were established reliably to within 0.75 cubic inches.

Figure 3: Evaluation of Meter Drift Analysis on All Six Test Meters

In addition to the meter drift analyses, tests were performed to validate the performance of the continual reconciliation system in identifying the following effects:

• Delivery discrepancies
• Losses through remote fills
• Water incursion
• Induced leakage

• Check valve malfunctions (suction and pressure systems)

When the meter accuracy algorithm of the continuous reconciliation system is activated, accurate estimates of overall system and line leaks are separately and independently generated. As a refinement to the performance of current line leak detectors, this system continuously monitors the lines for leakage throughout all time periods when dispensing is taking place and the lines are pressurized. Leak rate estimates are extremely accurate and the potential for false alarms is minimized.

The upshot of this controlled evaluation is that, with no replacement of existing hardware and without expensive on-site testing and calibration, the feasibility of a system to provide continuous real-time monitoring of meter accuracy and real-time monitoring for system and/or line leaks has been demonstrated.

Note: The technologies described in this article are covered by US Patent 5,757, 664 and pending US and international patent applications. Randy Collins, Bill Jones, and Mike Lenox of WRA developed the experimental design and oversight of the field testing of the system described. The cooperation and support of the people at Murray Equipment Company is gratefully acknowledged.

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