

Assessment of Sampling Systems for Monitoring Water Vapor in Natural Gas Streams

FINAL REPORT

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March 2006

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Abstract

Research has been conducted to assess the usefulness of various sampling and delivery methods in transporting a representative sample of a natural gas stream for analysis of moisture content. Three sampling configurations commonly used by the natural gas industry were evaluated, including a sample system with a regulated probe heated above ambient conditions, the same system held at a constant temperature simulating ambient conditions, and a heated sample system incorporating a membrane filter. Each configuration was used to transport samples of distribution-quality natural gas with levels of water vapor within common tariff limits, as well as samples of a water-saturated stream of methane simulating a common dehydration system upset. The time response of samples in each configuration to step changes in water vapor content between these two conditions was also evaluated. Measurements were performed using both manual chilled mirror dew point testers and automated analyzers.

For samples within tariff limits, the gas samples accurately reflected moisture conditions in the source stream. At moisture levels above 20 pounds per million standard cubic feet (lb/MMscf), large disagreements were observed between manual and automated measurements of the same stream, but both types of instruments identified the gas streams as having moisture content well above the tariff limit. Tests of the response time of the sample stream to changes in the source stream showed that the use of higher sample flow rates, equipment heating above ambient conditions, and proper regulation of samples to lower pressures will minimize the response time of a sampling system to a change in moisture levels. The sampling methods and equipment tested in this research may be useful in identifying moisture levels in a natural gas stream that can lead to hydrate formation, or to liquids condensation in the line that may lead to pipeline corrosion. For the collected samples to provide accurate moisture measurements, causes of instability identified in the research, such as transients in equipment temperatures, must be eliminated or minimized.

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Acknowledgments

The success of this project was possible only through the aid of many individuals and representatives to the Pipeline Research Council International (PRCI) Measurement Technical Committee, and the authors wish to thank them for their assistance. Foremost are the members of the PRCI Moisture Sampling Advisory Group, which guided the project scope of work and defined the goals:

- Angela Floyd (Panhandle Energy), chair
- David Bromley (BP)
- Craig Chester (Williams)
- David Dannhaus (Fesco)
- Bill Haddad (Ametek)
- Zaki Husain (ChevronTexaco)
- Don Mayeaux (A+ Corporation)
- Joe McMenamin (SpectraSensors)
- Margo Myers (Thermo)
- Bob Rayburn (Texas Gas Transmission)
- Bill Ryan (El Paso)
- Jim Witte (El Paso)

Many of these group members, along with John Paul Ruiz of SpectraSensors, took time from their schedules to witness the tests.

Many other contributions of manpower were made during the planning stages of the project. William Ryan of El Paso and Ron Brunner of the Gas Processors Association (GPA) are thanked for their help in drafting the moisture sampling survey. Ron Brunner of GPA, Mike Whelan of PRCI, Debbie Ellis and Ali Quraishi of the American Gas Association, and Zaki Husain, Cariann Kuryla and Fred Van Orsdol with the American Petroleum Institute are all thanked for their help in distributing the survey. The authors are also grateful to Lonnie Grady of Enterprise Products and Wayne Wenger of Kinder-Morgan helped gather info on alternative test sites.

Industry members also provided help in the form of hardware and manpower. The authors would like to thank Bill Haddad of Ametek and Joe McMenamin of SpectraSensors for providing the automated moisture analyzers and GO heated regulators used in the tests; Don Mayeaux of A+ Corporation for providing the Genie filter test article; Jim Witte of El Paso for providing the Welker Sentinel filter used as part of the saturated stream generator; and David Fish of Welker Engineering for providing sample probes. The authors extend particular gratitude to David Dannhaus and Eddie Garcia of Fesco Ltd. for providing their expertise and manpower for the chilled mirror measurements.

Last but not least, the authors would like to thank the Metering Research Facility technical staff, Roland Martinez, Michael Robertson, and John Sullenger, without whose efforts and advice the accomplishments of this project would not have been possible.

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1. INTRODUCTION

1.1 BACKGROUND AND INDUSTRY NEEDS

The ability to accurately detect water vapor in natural gas streams will become more important to the gas industry as gas quality takes on increased importance. Accurate data on the water vapor content of natural gas streams is needed to identify potentially corrosive operating environments before significant damage to natural gas pipelines can occur. Standardized and practical tools are needed for managing gas quality, for checking conformance with tariffs, and for reducing lost and unaccounted for gas volumes through identifying changes in gas composition.

A recent report on the costs of corrosion to the U.S. economy (Koch *et al.* [2001]) noted that the capital costs for replacement of existing pipeline infrastructure due to all types of corrosion total just over \$2 billion per year. A significant fraction of this can be attributed to corrosion caused by the presence of moisture. Improvements in moisture sampling that would allow corroded pipe replacements to be avoided would save the natural gas industry millions of dollars per year in pipeline replacement expenditures. Ice and hydrates in pipelines and control systems also lead to increased operating costs. These can potentially be reduced by improvements in moisture sampling that allow conditions for ice and hydrate formation to be avoided. From a safety standpoint, frozen control systems and pipeline blockage by ice or hydrates can be very dangerous conditions. Improvements in the ability to avoid these conditions would benefit the industry by reducing the potential for costly and catastrophic pipeline failures.

No standards currently exist for methods of sampling for moisture content. Currently, several methods are used by the natural gas industry as “go/no-go” indicators for detecting the presence of water vapor. Other gas sampling methods exist for quantifying water vapor content, but information is needed on their accuracy, particularly through independent evaluations of the methods.

1.2 PROJECT OBJECTIVES

Research funded by Gas Technology Institute (GTI) and Pipeline Research Council International (PRCI) for 2003 and 2004 (George *et al.* [2005a]) began work to assess the state-of-the-art of sampling for water vapor determination in natural gas applications. To continue that work, the objective of the research described in this report was to document the usefulness of various sampling and delivery methods in transporting a representative sample of a natural gas stream for analysis of moisture content. All sampling methods have been tested using the same reference method of measuring moisture content, so as to evaluate the sampling methods fairly.

Specific objectives of the research were as follows:

- Identify sampling methods and equipment with potential applications for avoiding pipeline corrosion or identifying the potential for hydrate formation.
- Provide guidance for the preparation of a standard for moisture sampling and analysis methods.

- Document the performance level of various moisture sampling systems and methods through a series of tests under ideal operating conditions and one easily produced adverse operating condition.
- Identify sampling equipment and methods (if any) that are capable of delivering representative samples of a moisture-laden natural gas stream to the reference measurement device, allowing the samples to be accurately analyzed.

1.3 TECHNICAL APPROACH

The scope of work for the project was organized into three technical phases. In Phase 1, existing moisture sampling methods and systems were selected for evaluation under a test protocol. The previous GTI/PRCI-sponsored research (George *et al.* [2005a]) was successful in identifying several existing moisture measurement instruments commonly used by the natural gas industry. In Phase 1, the manufacturers of these instruments, members of the PRCI Measurement Technical Committee, and other industry representatives were surveyed. The participants were asked to identify the specific sampling methods and equipment that they use to *deliver* natural gas samples to their instruments. This information, along with descriptions of sampling methods in Gas Processors Association (GPA) and American Petroleum Institute (API) standards, was used to define the three most common methods and equipment configurations used by the industry for moisture sampling. The survey and results are described in Chapter 2 of this report.

Phase 2 of the project generated a test protocol for evaluation of the moisture sampling methods chosen in Phase 1. The protocol took into consideration the capabilities of the test facility, the sampling methods to be evaluated, and the practicality of tests under adverse sampling conditions. The test protocol for natural gas sampling methods (George *et al.* [2004]) that has recently been included in the sixth edition of the API Manual of Petroleum Measurement Standards, Chapter 14.1 (American Petroleum Institute [2006]), was used as a model for this test protocol. It is intended that the basic structure of this protocol will also be useful in future evaluations of moisture sampling methods and devices.

The protocol was created to test the sampling methods selected in Phase 1 for their ability to transport representative samples of different gas streams to an analyzer or chilled mirror device. Two extremes of sample conditions were incorporated into the protocol: (1) samples of a water-saturated stream of methane, and (2) samples of distribution-quality natural gas with levels of water vapor below the common tariff specification of 7 pounds per million standard cubic feet (7 lb/MMscf). The second case represents the normal operating condition of transmission and distribution pipelines, while the first case simulates a common system upset or the result of introducing undehydrated gas to a stream. Introduction of both of these streams in turn to a sampling system can be considered a basic test of the ability of the sampling equipment to transport samples to an analyzer undistorted. The test protocol was structured to also allow an evaluation of the time response of sampling equipment to step changes in water vapor content between these two conditions. Chapter 3 of this report describes the specific objectives of the test protocol, as well as the test facilities and apparatus involved in this research.

Phase 3 encompassed the tests of sampling methods selected in Phase 1, using the test protocol devised in Phase 2. Tests were conducted of two natural gas sampling configurations: a

sampling setup incorporating a heated regulator, and a sample setup incorporating a membrane filter. Tests were performed in the regulated setup with and without active heating of the sample line and regulator, in order to assess the impact of equipment heating on sample accuracy. Samples were delivered by each sampling system and method to a Bureau of Mines chilled mirror dew point tester, so that the water vapor content of each sample could be determined using the standard method specified in standard ASTM D1142 (ASTM International [1995]). Results from each sampling method or system were compared to measurements of moisture content taken using a second chilled mirror device and a standard sample delivery system as specified by API Chapter 14.1. The comparisons illustrate the potential of each sampling method for obtaining representative samples of the natural gas stream and its moisture content. On-line, real-time moisture analyzers were also included in the tests to determine the response time of each sampling system to step change in moisture content between test conditions. Chapter 4 of this report presents the results of the tests in Phase 3, including evaluations of the accuracy and response times of measurements made with each sampling method.

Finally, Chapter 5 summarizes the findings of the research, and identifies those sampling methods and equipment with acceptable accuracy and potential application in avoiding pipeline corrosion or hydrate formation.

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2. INDUSTRY SURVEY OF MOISTURE SAMPLING METHODS

The first step in the project was to select the sampling methods and equipment to be evaluated during the research. So that research results would be relevant to the industry's needs, a survey was devised to identify sampling methods and equipment configurations used by the natural gas industry. The two or three most common equipment configurations would then be selected, built, and tested for their ability to deliver representative gas samples for accurate moisture analysis, and for the speed of their response to changing moisture levels in the sample stream.

In 2004, the Gas Processors Association (GPA) began a survey of users of moisture analyzers to gather similar information. Due to low participation, the results of that survey were never published. However, GPA kindly provided SwRI personnel with their original questionnaire, which was used as a model for a new survey. This survey was distributed to members of the PRCI Measurement Technical Committee, the API 14.1 Working Group, the API Committee on Petroleum Measurement, the American Gas Association (AGA) Transmission Measurement Committee, GPA Technical Committees, and manufacturers of automated sampling devices. The questionnaire as distributed by SwRI appears in Appendix A, along with a list of the responses.

2.1 SURVEY RESULTS

A total of twelve survey responses were received. Nine of the responses were from companies that buy, sell and/or deliver natural gas, while the other three responses were from manufacturers and/or vendors of moisture sampling and analysis equipment. All twelve respondents are involved with the natural gas transmission industry; about half are also involved in production, gathering, and distribution. Three responses were received from representatives of the same company, but each representative was responsible for activities in different portions of the natural gas industry and in different regions of the country, so all three surveys were included in the tally. The results have been blinded, so as not to identify the companies that provided the information.

Standards and guidelines used by the respondents to design and install moisture sampling systems include API Chapter 14.1 (6 respondents), ASTM D5454 and/or D5503 (2 respondents), and recommendations provided by the manufacturer of the analyzer in use (3 respondents). Most items taken into account by the respondents when selecting sample locations in a pipeline are flow disturbances – primarily elbows and valves, but also headers, tees, flow conditioners and orifice plates. A common rule among the respondents is to place the sample point 5 to 8 pipe diameters downstream of flow disturbances. Two respondents specifically avoid stagnant areas or “null points” when locating sample points. One respondent uses equipment access and pigging issues as their primary criteria for locating sampling points, rather than flow disturbances. The majority of sampling locations use ¾” or 1” NPT threadolets. Raised-flange locations are occasionally used for “hot taps.”

All respondents use or recommend sampling probes for moisture sampling. Several respondents use more than one type of probe. The probes used or recommended by respondents are fairly evenly distributed among four types:

- A+ Genie probe regulators
- Welker regulated probes (various models)
- YZ probes
- Fabricated straight-tube probes without regulators

Common probe lengths range from the center of the pipe to the center two-thirds of the pipe. To transport the sample from the probe to an automated analyzer or chilled mirror dew point tester, all respondents use either 1/8" or 1/4" tubing. All but one of the respondents allow bends in the tubing, but typically no more than three or four. Elevation changes, tight bends, and liquid "traps" are avoided. Other considerations given to ambient conditions in building a sample system include the addition of heat trace (8 responses), heated enclosures (7 responses), explosion-proof housings (6 responses) and cooled enclosures (3 responses); on the other hand, two respondents do not use heat trace or heated enclosures.

With regard to devices between the probe and analyzer, all but one of the respondents place filters in their sampling line; all twelve note that valves and regulators are also in the line between the sample point and the analyzer. About half state that pressures are reduced to low levels before analysis (ranging from 5 to 35 psig). Two regulate the sample pressure to the maximum allowable pressure at their moisture analyzer, while one manufacturer recommends that the sample be analyzed by their unit at line pressure. Requirements of the analyzers (such as direct concentration measurements or partial pressure devices) drive these different pressures at the regulator outlet. Four of the respondents specifically place filters for glycol in their moisture sample lines. After analysis, all twelve respondents vent their samples to atmosphere. Three also flare the sample stream or recommend doing so.

2.2 SELECTION OF TEST ITEMS AND VARIABLES

Based on the survey results, and the potential effect of including or excluding certain items from a sampling system, the following items were proposed for testing to evaluate their impact on measured water vapor content:

- Heat trace
- Regulated vs. unregulated probes
- Filters for glycol
- Membrane filters

Unfortunately, not all sampling configurations could be tested within the project scope and budget. After review by the API Chapter 14.1 Working Group and the PRCI project Advisory Group, it was decided to include only the use of heat tracing and membrane filters as specific variables. It was also decided to split the test apparatus into two legs: one with a regulator at the outlet of the sample probe, the other with a membrane filter but no regulator. The selection of a small number of test articles allowed for more effort in the project scope and budget to be spent on other sampling variables, such as sampling flow rate and transients in moisture content.

3. TEST FACILITIES, HARDWARE AND PROCEDURES

3.1 SPECIFIC TEST OBJECTIVES

With the identification of sampling hardware and methods commonly used in the field, a list of methods to be tested could now be incorporated into a moisture sampling test protocol. The specific objectives of the tests that resulted remained constant throughout the project; indeed, the test conditions, variables to be tested, and the test facility itself underwent several changes to better meet these objectives.

As a minimum, the tests were to address the following issues:

- Accuracy of the moisture content of samples collected using:
 - Unheated regulated probes.
 - Regulated probes with heat trace to compensate for Joule-Thomson (J-T) cooling.
 - Membrane filters.
- How this equipment changes the response of a moisture analyzer to step changes in moisture content in the pipeline.
- How changes in sample flow rate affect the accuracy of the moisture samples.

The project Advisory Group recommended that as resources permitted, the tests should also work to address:

- Repeatability of moisture content over multiple samples.
- Accuracy of moisture samples collected from a saturated gas stream when free liquids are in the pipeline.
- Effect of sample tube length on the accuracy of moisture samples.
- Effect of sample pressure on the accuracy of moisture samples.

Unfortunately, due to changes in the project test plan, none of these optional items could be addressed.

During the planning stages, the following criteria for success of the project were identified:

- Successfully identifying sampling equipment or techniques that minimize the response time of an analyzer or dew scope to moisture transients.
- Successfully identifying equipment, techniques and conditions that can cause moisture measurement errors.

As will be seen later, both success criteria were met for this project.

3.2 TEST FACILITIES

3.2.1 Selection of Test Facility

Initially, tests of the moisture sampling technologies were planned for the SwRI Multiphase Flow Loop (MRF). This facility is a recirculating closed loop capable of flowing mixtures of

natural gas, water, crude oil, condensates, refined liquid and fresh water. Flows up to 4,680 actual cubic feet per hour (acfh) in pipe diameters up to 4" are possible; test pressures up to 3,600 psig and temperatures from 40 to 120°F can be sustained with active temperature and pressure control. Initial plans called for the Multiphase Flow Loop to circulate a moisture-saturated reference stream, while a separate source of dry methane would be connected to the sampling equipment to simulate the opposite extreme in moisture content.

As plans progressed, however, it was noted by the PRCI project Advisory Group that the original test plan would provide no useful data on equipment performance when moisture levels are near tariff limits (6 to 7 lb/MMscf). The Multiphase Flow Loop at SwRI is restricted to operating in water-saturated flows or flows with low amounts of water and hydrocarbon liquids. It was agreed that the operational issues being addressed by the research were useful, but that a new test facility should be chosen to allow sampling tests with gas streams of lower moisture content.

Several alternatives to the Multiphase Flow Loop were suggested, including:

- Drawing samples from cylinders of certified gas blends with known moisture content.
- Drawing samples from a 10-gallon constant-pressure reservoir used in previous research at the MRF.
- Drawing samples from the test loop used for SwRI's hydrocarbon dew point experiments in early 2005 (George *et al.* [2005b]).
- Drawing samples from the SwRI Metering Research Facility (MRF) Low Pressure Loop (LPL) or High Pressure Loop (HPL).
- Performing tests at a natural gas pipeline field site with well-characterized moisture content.

Because of the intent to evaluate sampling methods and equipment used in the field, including common sampling probes, the first three alternatives were discarded.

Information was gathered on two field sites within two hours' travel of the MRF, one operated by Kinder Morgan, the other by Enterprise Production. A moisture analysis was also performed of gas in the MRF HPL, chosen over the LPL for its test conditions most resembling pipeline conditions. It was determined that all three candidate sites, including the HPL, would experience variation in the baseline moisture level in the pipeline as ambient temperature varied during the day and affected the amount of moisture adsorbed on the pipe walls. The Kinder Morgan site was rejected, since its moisture levels were at the low end of the range of interest, at or below 3 lb/MMscf. The other two sites exhibited moisture levels in the range of interest (3 to 6.3 lb/MMscf for the HPL, 3 to 8 lb/MMscf for the Enterprise site).

3.2.2 Metering Research Facility High Pressure Loop

The MRF High Pressure Loop was selected as the new test site, based on its location at SwRI and the higher expense involved with transporting equipment to an offsite test location. Both the High Pressure Loop and the Low Pressure Loop at the MRF provide research services for flow meter design, development, testing and calibration in facilities that simulate actual field operating conditions. The ability to control line pressure, gas temperature and flow rate in the

HPL, as well as the traceability of calibrations and measurements at the MRF, provided repeatable and accurate test conditions for the research. The MRF HPL uses distribution-grade natural gas as the flowing medium, and is capable of testing meters at flow rates from 3,600 to 107,000 acfh and at line pressures from 190 psia to approximately 1,000 psia. This facility is a recirculating loop driven by a centrifugal compressor.

3.2.3 Data Acquisition

The pressure at three locations in the test setup was measured using Rosemount model 3051G pressure transmitters. The temperature at two locations in the test setup was measured using Weed 100 Ω platinum resistance temperature detectors (RTDs) with Rosemount model 3144P temperature transmitters. All instrument data were collected during this test program using an Agilent 34970A data acquisition system.

3.3 TEST SETUP

As discussed above, all testing was conducted in the SwRI Metering Research Facility's High Pressure Loop. This closed loop system operates with pipeline quality natural gas at a maximum pressure of 1,100 psig.

3.3.1 Sampling Apparatus

A schematic of the reference and test system can be found in Figure 3-1 on the next page, while photographs of the systems as eventually built for the tests are shown in Figure 3-2. Two standard, 3/8-inch O.D. sample probes were installed in the 16-inch Schedule 80 pipe. The probes were inserted to sample from the center one-third of the pipe. The upstream sample probe was used for the reference system, while the downstream sample probe was used for the test system. One-quarter-inch Whitey model SS-33VF4 ball valves (BV101 and BV103) were utilized to isolate the flow loop from the reference and test system.

The reference system, isolated from the test system by BV102 and/or BV104 (Whitey model SS-83KS4 with PCTFE seats), was set up to continuously sample and analyze the moisture content of the natural gas flowing in the flow loop. The reference dew scope and the reference moisture analyzer were installed as close as possible to the sample probe. The pressure in most of the reference sampling system was maintained at the pipeline pressure (except immediately upstream of the moisture analyzer) and the temperature was maintained well above the pipeline and ambient temperatures.

During the test program, the test articles were supplied with either pipeline quality natural gas or saturated methane. The saturated methane was generated on site. High-pressure methane gas (99%+ pure, less than 10 ppm water vapor) was supplied from a gas cylinder (see Figure 3-2). The pressure was then reduced (using CV101) to the pipeline pressure, and was forced through a 1,000-cc sample cylinder filled with deionized water. A sintered element was placed at the inlet of the sample cylinder, increasing the contact area between the methane and water. The saturated gas then flowed through a Welker Sentinel filter to knock out free liquid in the gas

stream. The temperature and pressure of the gas were measured immediately upstream and downstream of the filter/separator, respectively.

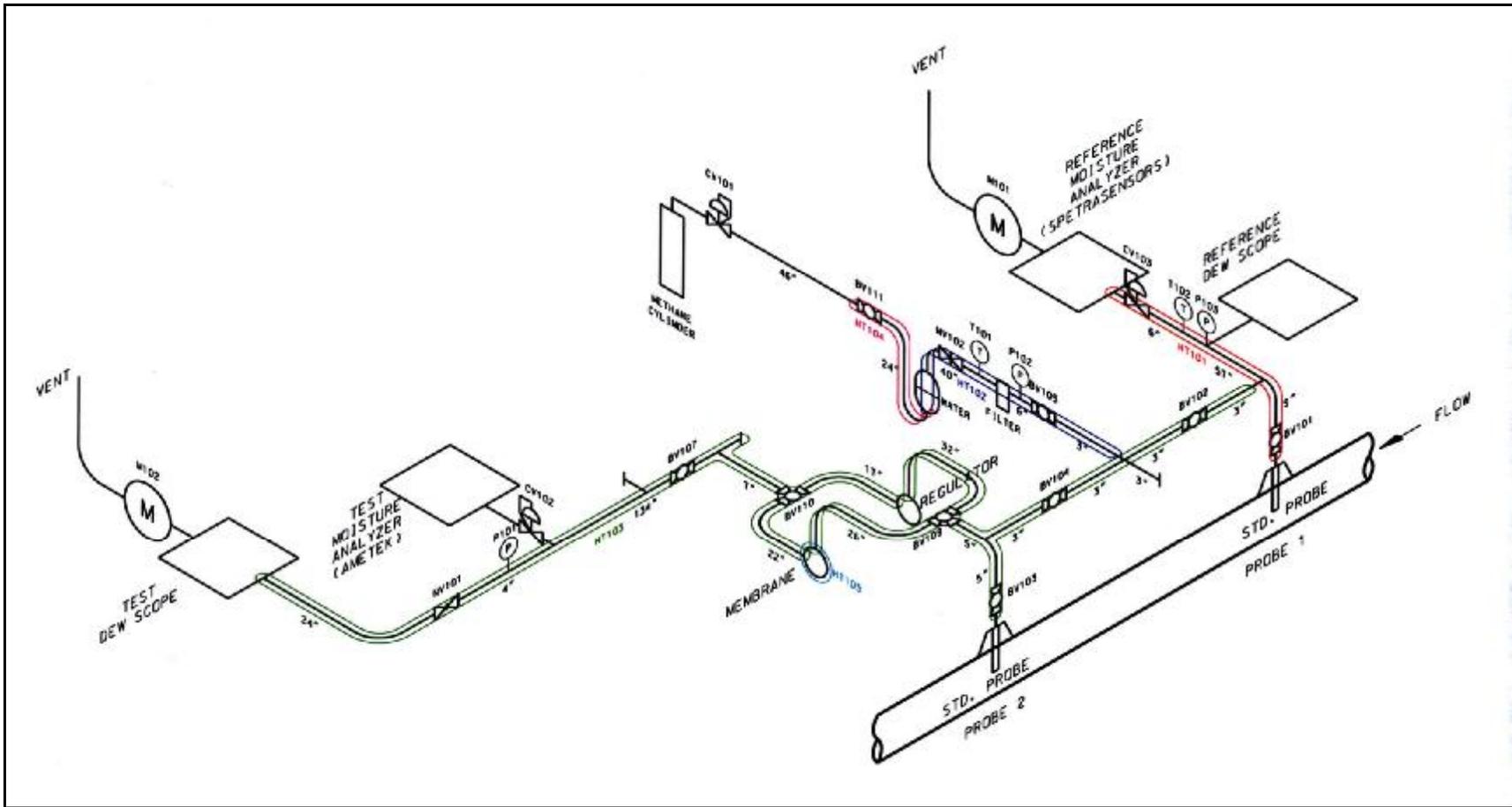


Figure 3-1. Schematic of the reference and test system.

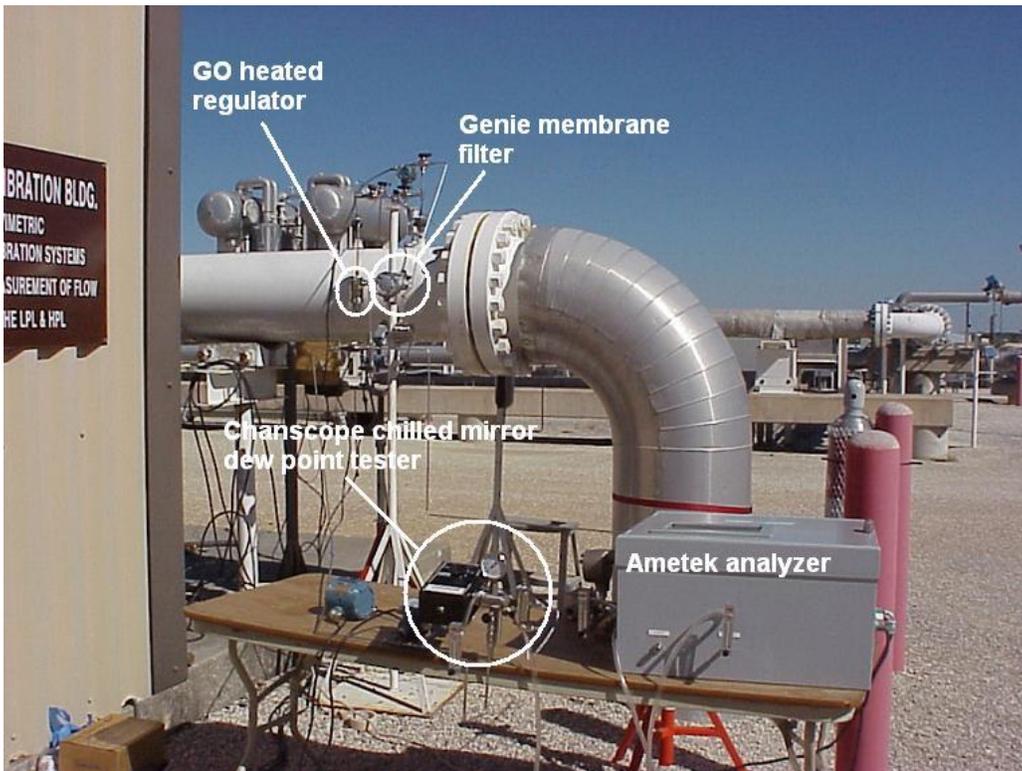
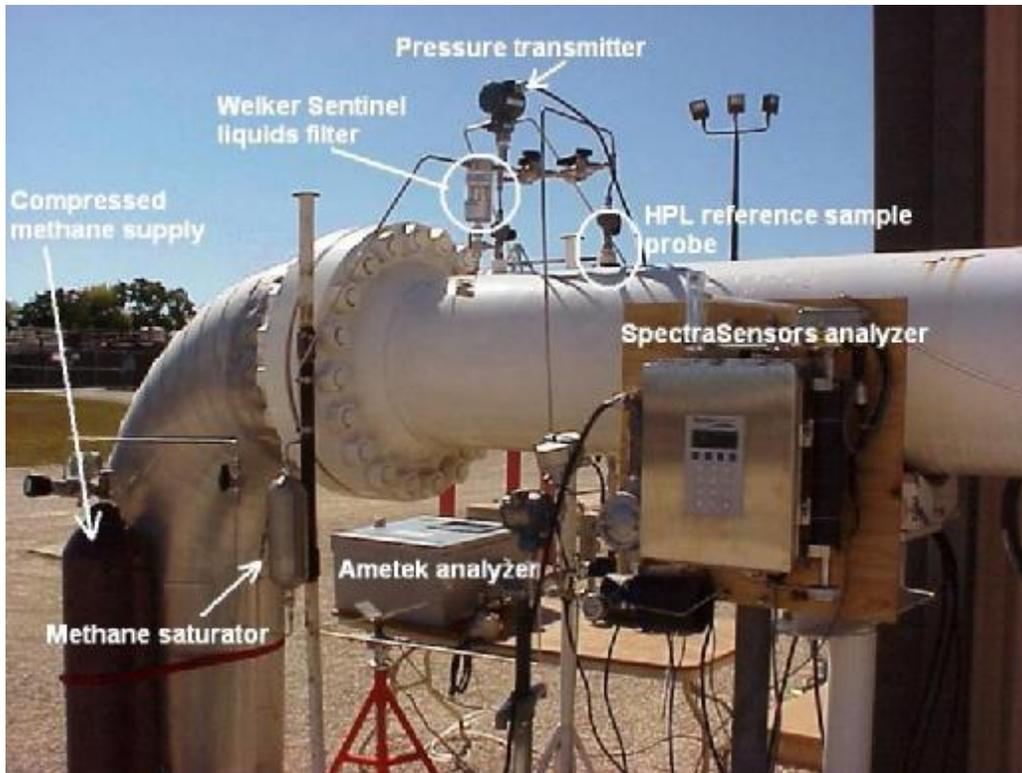


Figure 3-2. The reference and test sampling systems mounted on the MRF High Pressure Loop prior to being insulated.

The sampling system was designed and built so that one test article could be tested while the other test article remained installed, thus eliminating the need to “dry down” the sample system after switching from one test article to the other. Three-way valves, Whitey model SS-83XKS4 with PCTFE seats (BV109 and BV110) were used to switch back and forth from one test article to the other.

All tubing in the sampling system was 3/8-inch O.D. seamless 316 stainless steel with a 0.035-inch wall thickness, and was heat traced and insulated. The length of each tubing segment is shown in Figure 3-1. Although the length of tubing and the actual volume (actual cubic feet) for each of the test legs were the same, the amount of gas in each test leg was different (Table 3-1). Since the pressure downstream of the test regulator was reduced to approximately 50 psig, the mass of gas (or, equivalently, the volume of gas in cubic feet at standard temperature and pressure) in the test leg containing the regulator was approximately one-fifth the mass (or standard volume of gas) in the test leg containing the membrane filter. The standard volumetric flow rate was the same through both test legs, but because the leg containing the regulator held a smaller standard volume of gas, a sample would require less time to flow from one end of the regulator leg to the other. Consequently, moisture would take less time to adsorb or desorb at the equipment walls, and equilibrium would be reached sooner.

Table 3-1. Length and volume of sample tubing in each test leg.

LOCATION	REGULATOR			MEMBRANE FILTER		
	Length (inches)	Volume (acf)	Volume (scf)	Length (inches)	Volume (acf)	Volume (scf)
From Probe to Test Device	45	6.63×10^{-4}	0.03*	39	5.74×10^{-4}	0.03*
From Test Device to Analyzer	157	2.31×10^{-3}	0.003**	163	2.40×10^{-3}	0.12*
Total	202	2.97×10^{-3}	0.033	202	2.97×10^{-3}	0.15

* Calculated at 735 psig and 110°F

** Calculated at 50 psig and 110°F

3.3.2 Heat Trace Systems

All of the regulators used during this test program were heated. In addition, all of the tubing was heat traced and insulated. Five different heat trace systems were utilized.

- The first heat trace system (HT101) was used to keep the reference sample system above the pipeline and ambient temperatures. This system was typically set at approximately 120°F.
- The second heat trace system (HT102) was used to keep the saturated methane gas stream above ambient temperature. This system was typically set at 80°F.
- The third heat trace system (HT103) was used to keep the test system at a constant temperature, and to isolate the test conditions from the ambient temperature as much as possible. This system was set at either 70°F or 110°F, depending upon the required test conditions.

- The fourth heat trace system (HT104) was used to keep the dry methane gas entering the saturation vessel above ambient temperature. This system was typically set at 80°F.
- The fifth heat trace system (HT105) was used to keep the membrane filter at the test temperature. This system was typically set at 110°F.

3.3.3 Test Articles

Testing was conducted with two different test articles under the following conditions:

1. Heated regulator set at approximately 70°F.
2. Heated regulator set at approximately 110°F.
3. Membrane filter, heat traced at approximately 110°F.

The electrically heated regulator utilized for this testing was manufactured by GO Regulator, model HPR-2. This regulator was constructed of 316L stainless steel and had an electroplated body with better than 25 R_a finish in the diaphragm cavity. During the test program, the outlet pressure of this regulator was set at approximately 50 psig, and the temperature was set at either 70°F or 110°F.

The membrane filter utilized for this testing was manufactured by A+ Corporation, and was a Genie Supreme™ Model 123 HP with a Type 5 membrane. The filter housing was made of 316 stainless steel, rated for a maximum working pressure of 2,000 psig, and contained a Viton® O-ring. The filter housing was heated to approximately 110°F by HT105 and insulated.

3.3.4 Chilled Mirror Apparatus

A ChanScope II dew point analyzer, manufactured by Chandler Engineering, was used to verify the dew point temperature of not only the pipeline gas (reference), but also the test gas stream (Figure 3-3). The dew scope was operated by experienced personnel from FESCO, Ltd.



Figure 3-3. A Chandler ChanScope II chilled mirror dew point tester identical to the units used in this research.

3.3.5 Automated Moisture Analyzers

As the test plan was changed to better meet the test objectives, it was found that the final test facility (the HPL) would experience variations in the baseline moisture level in the pipeline due to ambient temperature variations. Given this, it was proposed that real-time automated moisture analyzers be used to directly monitor baseline moisture levels in the pipeline at line pressure. The transients in moisture content in the HPL and in the sampling system during changes between saturated and low moisture levels were monitored using two different automated moisture analyzers. A SpectraSensors model SS 2000 moisture analyzer was used to continuously monitor the moisture content of the pipeline gas (the reference system). The inlet pressure to this analyzer was set to approximately 3 psig, and the gas flow rate through the analyzer was constant at approximately 20 scfh. An Ametek 3050-OLV moisture analyzer was used to monitor the transients during switches from a pipeline quality natural gas to a saturated methane gas and back. The inlet pressure to this analyzer was set to approximately 30 psig, and the gas flow rate through the analyzer was either 0.3 scfh or 2.1 scfh, depending upon the required test condition.

3.4 TEST CONDITIONS

In order to meet the objectives of the test program, tests were conducted at a variety of different conditions. The test conditions are summarized in Table 3-2. This test matrix was used to determine the effect of different sampling equipment, heat trace temperatures, and sampling flow rates upon the response time of the sampling system due to a step change in the inlet conditions. During the tests, the pipeline pressure varied from approximately 500 psig to 800 psig, and the pipeline temperature varied from approximately 70°F to 80°F.

Table 3-2. Test matrix for evaluation of moisture sampling methods.

	HEATED REGULATOR AT 110°F		HEATED REGULATOR AT 70°F		MEMBRANE FILTER AT 110°F	
	Low Flow Rate (0.3 scfh)	High Flow Rate (2.1 scfh)	Low Flow Rate (0.3 scfh)	High Flow Rate (2.1 scfh)	Low Flow Rate (0.3 scfh)	High Flow Rate (2.1 scfh)
Increasing Moisture Content	X	X	X	X	X	X
Decreasing Moisture Content	X	X	X	X	X	X

3.5 TEST PROCEDURE

The test procedure is composed of two general procedures. One procedure was used for tests of sampling system accuracy and response with increasing moisture content, while the other procedure described tests with decreasing moisture content. The detailed test procedure may be found in Appendix B. Summaries of the procedures are below.

3.5.1 Procedure for Tests with Increasing Moisture

1. With the test system actively sampling pipeline gas and the moisture content stabilized, measure the dew point temperature of the gas using the chilled mirror device.
2. Set the Ametek moisture analyzer to analyze methane.
3. Switch the sample system inlet gas stream from the pipeline gas to the saturated methane source.
4. Allow the moisture content (as read by the Ametek moisture analyzer) to stabilize.
5. Measure the dew point temperature of the gas using the chilled mirror device.

3.5.2 Procedure for Tests with Decreasing Moisture

1. With the test system actively sampling the saturated methane stream and the moisture content stabilized, measure the dew point temperature of the gas using the chilled mirror device.
2. Set the Ametek moisture analyzer to analyze natural gas.
3. Switch the sample system inlet gas stream from the saturated methane supply to the pipeline gas.
4. Back flow through the saturated methane system with the pipeline gas to minimize the potential for excess moisture to contaminate the test results.
5. Allow the moisture content (as read by the Ametek moisture analyzer) to stabilize.
6. Measure the dew point temperature of the gas using the chilled mirror device.

4. TEST RESULTS

This chapter discusses the results obtained during the test program of moisture sampling methods. The results that were obtained provide useful information on the effect of sampling system design on the accuracy of moisture measurements. In addition, transient tests were conducted that showed the time response of systems with different items of sampling equipment to moisture changes. These tests also demonstrated the effect of the choice of test article, equipment temperature, and sample flow rate upon the time response. Example data plots are presented in this chapter to illustrate findings; a complete set of individual data plots can be found in Appendix C.

During tests, personnel from Fesco Ltd. performed measurements of water vapor dew point using two ChanScope II dew point testers. One ChanScope was used periodically throughout the test program for measurements of the moisture content of the HPL reference stream. The second was used for measurements of the moisture content of samples sent through the sampling systems before and after specific transient tests. Using the sample line pressure and the measured dew point temperature in each case, the moisture content was determined using ASTM standard D1142 (ASTM International [1995]). The moisture content determined from the ASTM standard and the dew point measurement was then compared to the moisture content of the same stream measured by the moisture analyzers. In order to maintain stable and accurate moisture measurements of the HPL reference stream, the reference dew scope was not used to take measurements of the saturated methane stream before it entered the sampling system.

In Section 4.1, comparisons between chilled mirror measurements of the HPL reference stream and HPL gas sampled by the various systems are compared to assess the impact of the sampling hardware on sample moisture accuracy. Comparisons of chilled mirror measurements and automated analyzer measurements of the same streams are made in Section 4.2. Sections 4.3 and 4.4 use data obtained over time from the Ametek moisture analyzer to identify those sampling system design variables that can improve the time response of the system to changes in moisture content.

4.1 EFFECT OF SAMPLE HARDWARE ON MOISTURE MEASUREMENT ACCURACY

Measurements made with the manual chilled mirror devices at the HPL and at the terminus of the sampling system can be compared in some instances. These comparisons indicate whether the equipment in the sampling system or the temperature of the sampling line are influencing the accuracy of the measured moisture levels of samples obtained with the system. From first principles, it should be expected that a sampling system in equilibrium will produce a moisture measurement that agrees with the moisture level of the source stream. If the sampling system is in equilibrium, the moisture flow rate into the system will equal the moisture flow rate out. Measured differences between the source and the sample moisture content in such a case would be caused by experimental errors or biases between the instruments on either end of the sample system.

In four cases, such comparisons were possible. All four cases involved samples taken by the sampling system with the GO heated regulator. For two cases, the regulator and sampling lines

were heated to 110°F, while for the other two cases, the equipment was heated to a constant temperature of 70°F. ChanScope measurements were taken of the HPL stream at the reference sample point, and of the sample stream drawn from the HPL through the sampling system, within 45 minutes of one another. The SpectraSensors analyzer indicated stable moisture content during each period.

Figure 4-1 compares the chilled mirror measurements at each end of the sampling system to one another. The diagonal black line represents the condition of zero disagreement between the two measurements. For the comparisons with the sampling system at “ambient” temperatures (the black points), the differences between the two ChanScope measurements were not consistent in magnitude or direction. In one case, the reference chilled mirror, sampling gas directly from the HPL, yielded a moisture level higher than the test mirror measuring samples that had passed through the regulated sample line. In the other case, the reference sample was found to have a lower moisture level than the sample that had passed through the regulator. Since the error bars for both points do not overlap the “zero disagreement” line, the differences can be considered statistically significant.

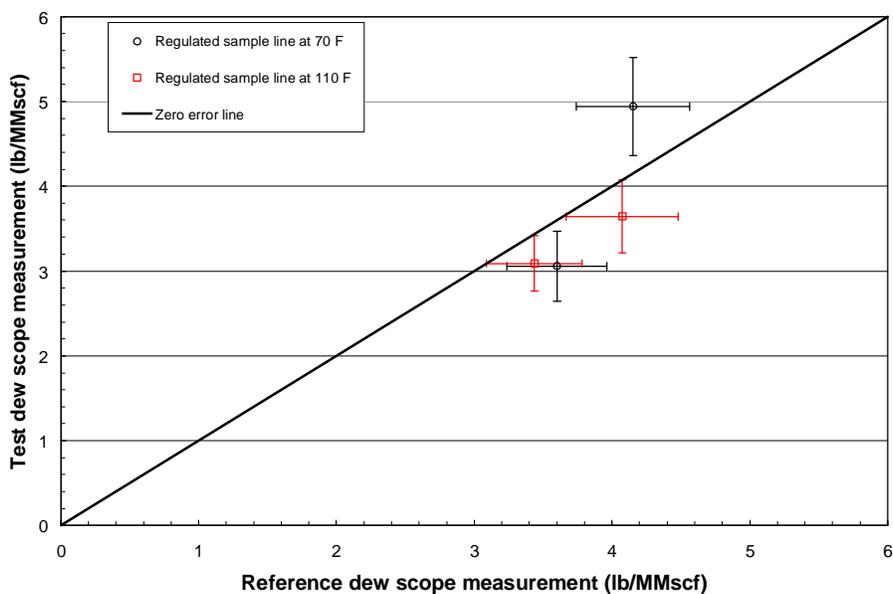


Figure 4-1. Comparison of moisture measurements in HPL reference gas made by chilled mirror dew scopes at the HPL sample point and the outlet of the sample test apparatus.

For the comparisons with the sampling system at 110°F (the red points), the differences between the two ChanScope measurements were consistent in both magnitude and direction. In both cases, the reference chilled mirror measurement yielded a moisture value about 0.4 lb/MMscf below that of the mirror sampling the reference stream through the sample system. Further, the error bars for both points intersect the “zero disagreement” line, and the differences are not considered significant. From a measurement perspective, the differences in all the comparisons in Figure 4-1 are less than 1 lb/MMscf. If these measurements had been taken in a

custody transfer situation, both parties would be confident that the stream was below the common custody transfer limit of 7 lb/MMscf, and the quality of the gas stream would not be in question.

No further comparisons of moisture sample accuracy were possible with the chilled mirror data. However, similar comparisons are possible using the automated moisture analyzers, as will be discussed in Section 4.3 and Appendix C. In these cases, the agreement between the analyzers is also on the order of 1 lb/MMscf.

4.2 COMPARISON OF MEASUREMENTS MADE BY CHILLED MIRROR AND AUTOMATED ANALYZER

As shown in Chapter 3, the test apparatus paired a moisture analyzer with a ChanScope chilled mirror dew point tester at two different locations. Between the two, a total of 33 separate chilled mirror measurements were recorded. Figure 4-2 and Figure 4-3 compare the moisture content measured by the moisture analyzers during each chilled mirror measurement to the moisture content determined from the chilled mirror dew point temperature measurement and ASTM D1142. The vertical error bars represent the quoted uncertainty of the moisture analyzers used for each reading. The horizontal error bars represent the uncertainty of the moisture measurements made with the chilled mirror devices. The latter were computed using the correlation between dew point temperature and moisture level from ASTM D1142, and the established uncertainty in chilled mirror dew point temperature measurements (Warner *et al.* [2001]). The diagonal black line again represents the condition of zero disagreement between the two measurements.

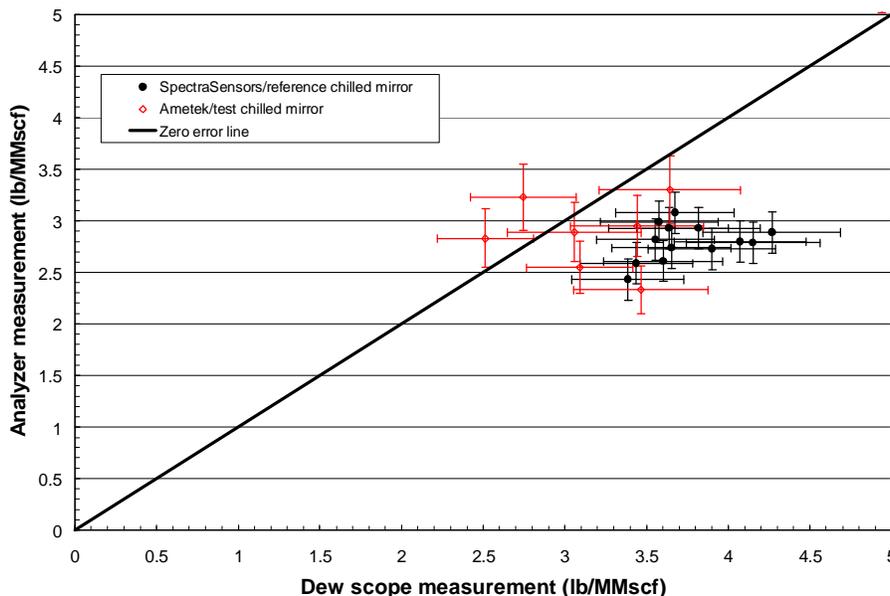


Figure 4-2. Comparison of moisture measurements of the HPL reference gas made by chilled mirror dew scopes and automated analyzers.

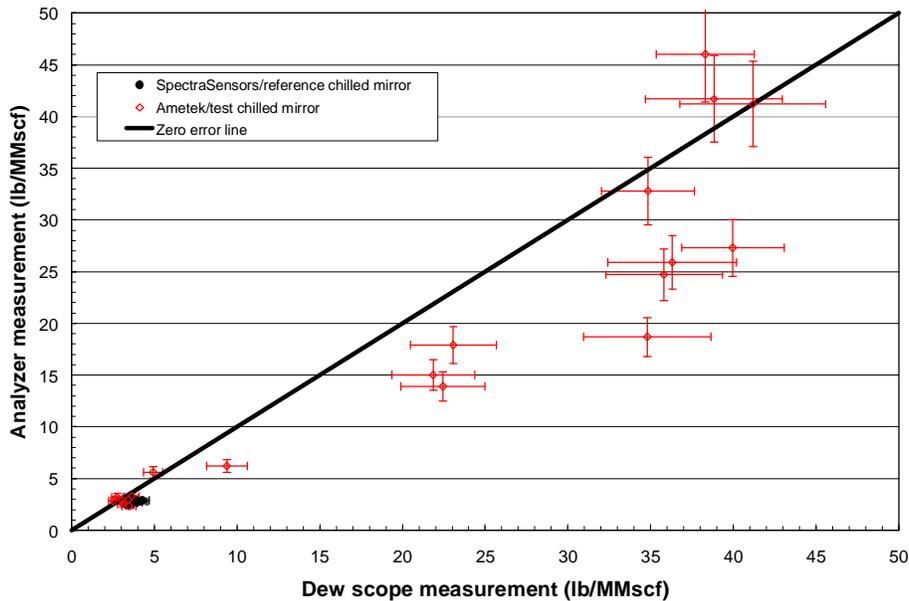


Figure 4-3. Comparison of moisture measurements of both the HPL reference gas and saturated methane, made by chilled mirror dew scopes and automated analyzers.

The data points in Figure 4-2, all below a moisture level of 5 lb_m/MMscf, were collected from the HPL reference sample probe (black symbols) and from the test system as HPL gas was flowing through the sampling hardware just prior to tests with the saturated methane stream (red symbols). All SpectraSensors measurements underpredict the chilled mirror measurements, but by no more than 1.2 lb_m/MMscf. In comparing the Ametek measurements with those of its companion chilled mirror, the automated device measures higher levels in some cases, lower levels in others, and in cases where the error bars overlap the diagonal line, agrees with the chilled mirror to within experimental error. These data also appear in Figure 4-3, where the additional data points above 5 lb_m/MMscf moisture content (as measured by the chilled mirror) represent data collected from the test system as saturated methane flowed through the test system and moisture levels had stabilized. Again, the Ametek measurements are not consistently biased with respect to the chilled mirror, but are sometimes high, sometimes low, and in some cases agree to within experimental error.

Figure 4-4 shows the absolute and relative disagreement of the automated moisture measurements with the chilled mirror measurements under the same conditions. Note that in each comparison, the samples analyzed by the chilled mirror and the automated device travel through the same tubing until a junction separates the lines to the two instruments. The length of tubing not shared by the two instruments is 6” in the case of the reference line, 28” in the case of the test setup. Because the lengths of unshared tubing are small and do not contain low spots or other moisture “traps,” they would be expected to cause little or no disagreement between the paired devices.

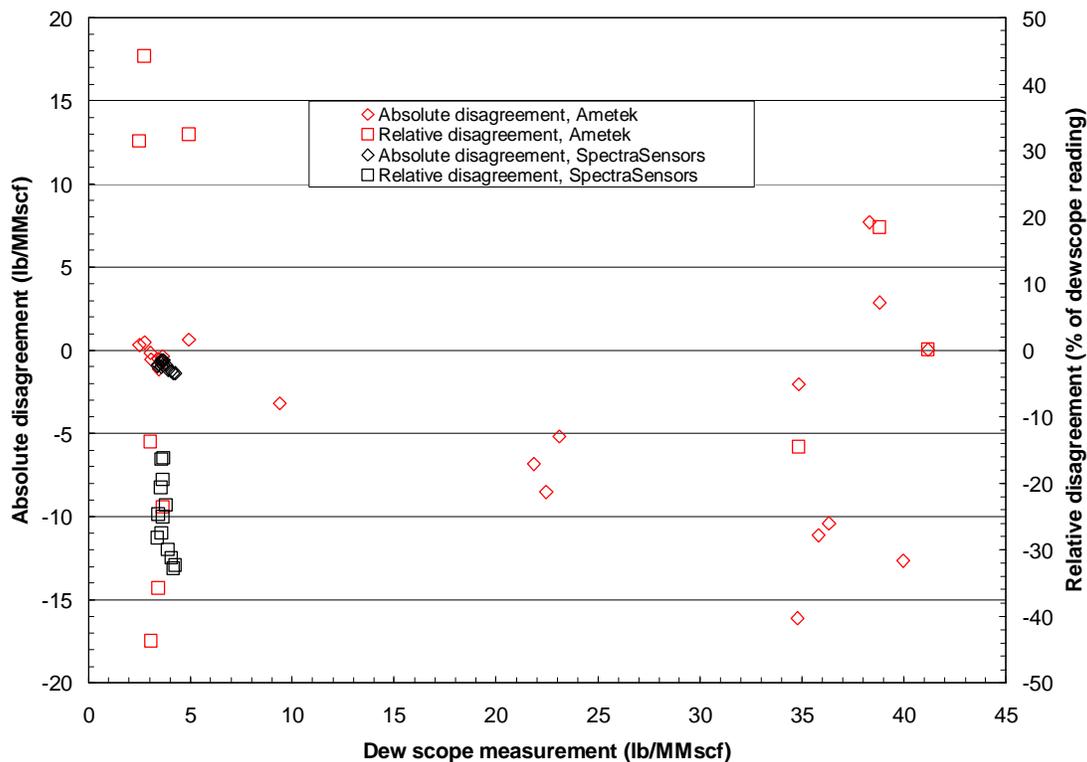


Figure 4-4. Absolute and relative disagreements between chilled mirror and automated analyzer measurements.

For the data below approximately 5 lb_m/MMscf, the absolute disagreement is rather small, usually 1 lb_m/MMscf or less, but the relative disagreement is fairly large due to the low moisture content. Because the absolute disagreement is small, measurements from both devices in these cases would agree that the moisture content of the stream being sampled is well below the typical industry tariff limit of 7 lb_m/MMscf. If the different instruments were used by different parties involved in the sale of such gas, no dispute would be expected over its quality.

For the data above 5 lb_m/MMscf, the majority of the points in Figure 4-4 show fairly large absolute and relative errors. In many of these cases, moisture levels measured by the analyzer were lower than the values measured by dew scope, with the differences outside experimental error as shown in Figure 4-3. The Ametek moisture analyzer that performed these measurements was programmed for self-calibration against an internal moisture standard once each day. The internal standard, traceable to NIST, provided a reference flow with a moisture content of 2 lb/MMscf. It is suspected that small changes in the analyzer calibration factor, made to bring the unit into calibration at this low level, may have been magnified at larger moisture levels and led to the large disagreements in Figure 4-4. In all but one case, however, measurements from both devices agreed that the stream moisture content was well above the typical industry tariff limit of 7 lb_m/MMscf, and again, no dispute would be expected that the gas was of unacceptable quality.

Under one test condition, the disagreement between the chilled mirror value (about 9 lb_m/MMscf) and the analyzer value (about 6 lb_m/MMscf) would require further investigation to confirm whether the gas stream would fall above or below common moisture tariff limits. While moisture levels in the MRF High Pressure Loop do reflect common pipeline conditions, the specific levels in the gas supplied by the gas distribution service during tests were well below tariff limits, and tests in the HPL were only possible with the reference stream at 3 to 5 lb_m/MMscf. Because the purpose of this study was to evaluate sampling hardware and systems, rather than moisture analyzers, further tests of the instruments at moisture levels around 7 lb_m/MMscf are suggested as a future research project to investigate the accuracy of the automated analyzers relative to the chilled mirror devices at this level.

4.3 TIME RESPONSES TO MOISTURE CHANGES

One of the objectives of this test program was to determine what sampling equipment or techniques minimize the response time of an instrument to moisture transients. A number of transient tests were conducted in which the moisture content at the sampling system inlet underwent a step change from a low moisture content to a high moisture content, and from a high moisture content to a low moisture content.

Figure 4-5 shows the typical response to a moisture increase for the sample system using a heated regulator (set at 110°F) sampling at a low flow rate (0.3 scfh). The plot shows that the moisture content of the gas in the HPL (the reference stream) was very stable throughout the test period at a level of approximately 2.8 lb_m/MMscf. At 10:39, the inlet to the test sampling system was switched from the pipeline quality gas to moisture-saturated methane. For approximately 10 minutes, the moisture content measured by the moisture analyzer increased only slightly. At approximately 10:50, the moisture content measured by the moisture analyzer began increasing rapidly, and continued to rise rapidly, for approximately 10 minutes. The moisture reading then rose more slowly, but still increased by several lb_m/MMscf over the next hour. For this test, the measured moisture content leveled off at approximately 20 lb_m/MMscf, and the sample system took about one hour and 40 minutes to reach this steady state.

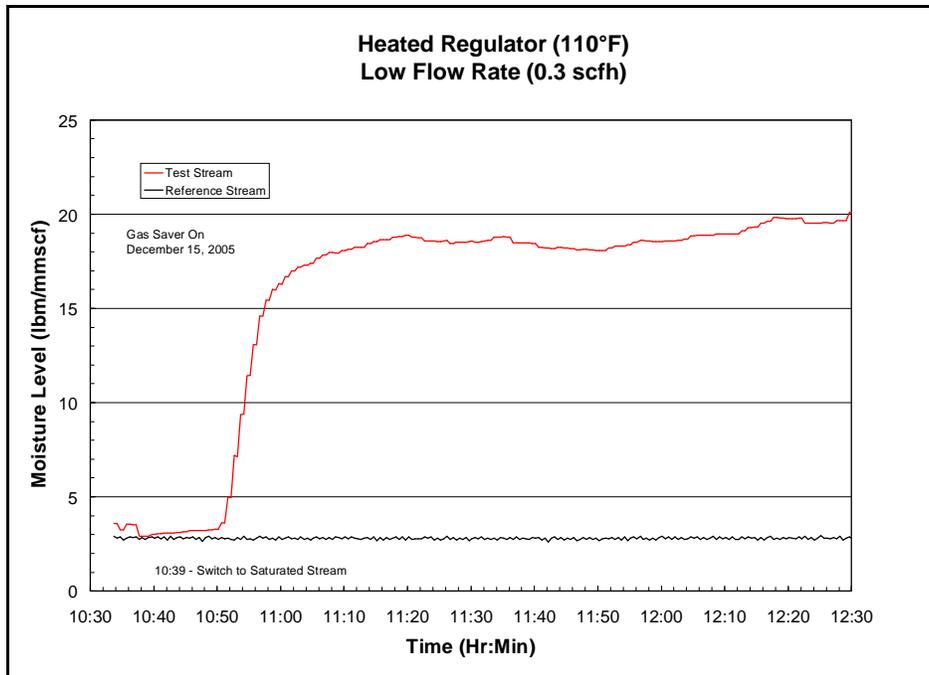


Figure 4-5. Time response of the regulated sample line heated to 110°F to an increase in moisture content at a low flow rate.

Figure 4-6 shows the response to a moisture increase for the sample system using a heated regulator (set at 110°F) sampling at a high flow rate (2.1 scfh). The plot shows that the moisture content of the gas in the HPL (the reference stream) was again very stable throughout the test period at a level of approximately 2.8 lb_m/MMscf. At 8:05, the inlet to the test sampling system was switched from the pipeline quality gas to saturated methane. The moisture content measured by the moisture analyzer responded to this change almost immediately and increased rapidly for several minutes. Again, the rate of change in reading then became slower, and the moisture reading increased approximately 10 lb_m/MMscf over the next 40 minutes.

The oscillations in the measured moisture content are due to cycling of the heat trace system about the set point of 110°F. This example demonstrates the impact of temperature stability in a sampling system. The fluctuations in the wall temperature of the sampling equipment produced a cycle in which moisture adsorbed and desorbed from the walls and set up oscillations of ±1 lb/MMscf in the measured moisture content. Later tests employed a heat trace controller with a smaller dead band to minimize these oscillations.

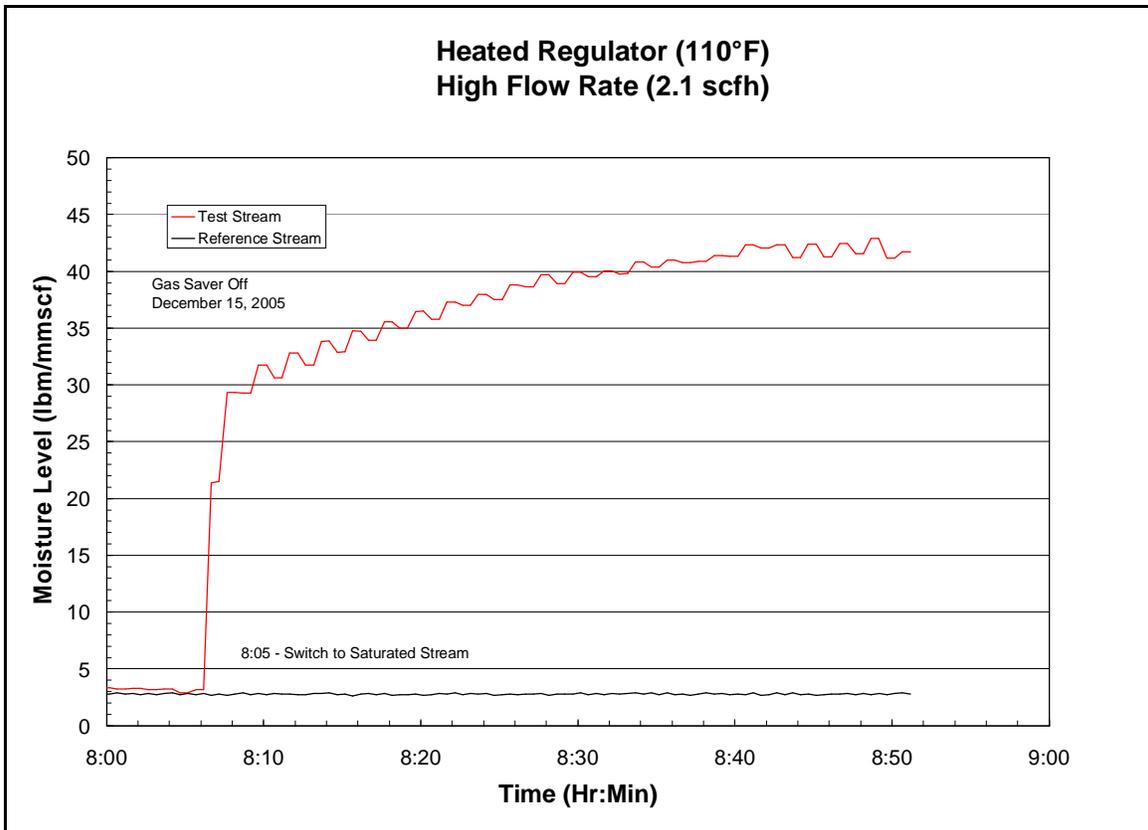


Figure 4-6. Time response of the regulated sample line heated to 110°F to an increase in moisture content at a high flow rate.

For this test, the measured moisture content leveled off at approximately 42 lb_m/MMscf, and the sample system took approximately 40 minutes to reach a steady state, only 40% of the stabilization time of the same setup at the lower flow rate of 0.3 scfh. Note that the delay between the introduction of the saturated gas stream and the first response by the analyzer was much shorter for the higher sample flow rate. Note, also, the tendency of the sample moisture level to rise rapidly at first, then to “decelerate” and approach equilibrium levels more slowly. Care should be taken in identifying slow moisture transients after the first rapid change, so that moisture measurements are not made during a period of slow change and assumed to represent equilibrium conditions.

Figure 4-7 shows the typical response to a moisture decrease for the sample system using a heated regulator (set at 110°F) sampling at a high flow rate (2.1 scfh). The plot shows that the moisture content of the gas in the HPL (the reference stream) was very stable throughout the test period at a level of approximately 2.8 lb_m/MMscf. At 9:29, the inlet to the test sampling system was switched from the saturated methane to the pipeline quality gas. Over the next 70 minutes, the measured moisture content dropped from approximately 19 lb_m/MMscf to 3 lb_m/MMscf. Comparing results of Figure 4-6 and Figure 4-7, the equipment temperature, sample flow rate and reference moisture level are nominally identical, but it is seen that an increase in moisture content of 39 lb_m/MMscf produces a stable reading in about half the time as a decrease in

moisture content of only 16 lb_m/MMscf. As will be seen throughout this chapter, the response time of every sampling system to a decrease in moisture content is slower than its response time to a moisture increase. The size of the difference is not consistent, however, even for the same sampling configuration.

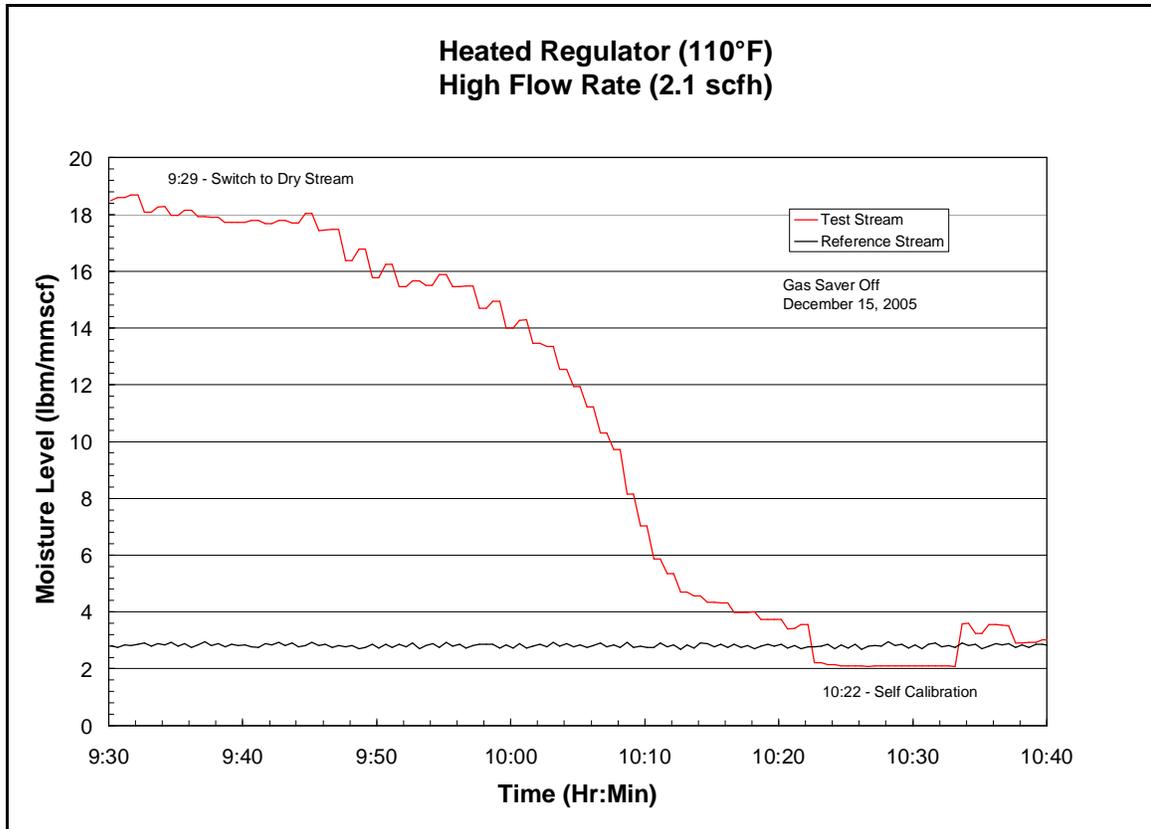


Figure 4-7. Time response of the regulated sample line heated to 110°F to a decrease in moisture content at a high flow rate.

The reading of 2.1 lb_m/MMscf between 10:22 and 10:33 was caused by an automatic self-calibration by the moisture analyzer, rather than a shift in the baseline moisture content. Note that after the calibration cycle, the moisture level registered from the sample line returned to its previous value.

The three plots presented above show the regulated sampling system's typical response to a step change in the moisture content. Plots of the regulated sampling system's response to transients at all test conditions, as well as plots of the filtered system's responses, may be found in Appendix C. Note that each graph in Appendix C also contains a trace of the moisture levels in the HPL as measured by the SpectraSensors analyzer during the same test period. Comparisons of the two analyzer readings at the beginning or end of each test period show that disagreements in moisture levels measured at the inlet and outlet of each sampling system are no more than 1 lb/MMscf. This is of the same order of magnitude of the disagreements between

chilled mirror measurements of the HPL reference gas taken at the same two test locations, as discussed in Section 4.1.

4.4 IMPACT OF SAMPLING HARDWARE ON SYSTEM RESPONSE TIME

In addition to the tests with the regulated sample setup discussed above, a number of transient tests were conducted with the membrane filter configuration at the conditions shown in the last two columns of Table 3-2. This section compares the response of the regulated sample setup to the response of the setup incorporating a membrane filter under similar test conditions. The performance of the regulated sample line at different temperatures is also discussed.

To compare the equipment responses on one plot, the data were normalized and the start of each transient was synchronized. The x-axis represents the time since the step change in the moisture content was initiated. The y-axis represents the percent of maximum moisture content measured during the test period for each test.

Figure 4-8 shows the response of the different test systems at a high flow rate (2.1 scfh) to increasing moisture content. For this high flow rate, the data show that the sample line with the membrane filter produced a significantly longer response time than both the heated and “unheated” regulated sample line. (The “unheated” regulated system was actually kept at a constant temperature of 70°F to simulate a system at ambient temperature.) The slower response time of the filtered sampling system is likely due to the fact that much more of the filtered system is at high pressure. As discussed in Section 3.3.1, the standard volume of gas in the system with the membrane filter is approximately five times the standard volume of gas in the system with the regulator, and at a given standard flow rate, the filtered system takes longer to deliver a given sample volume from the sample point to the instrument.

While the difference in the filtered and regulated systems was significant, the difference in response times of the regulated system at different temperatures was minimal. Tests were performed with the heated regulator and heat trace at temperatures of 110°F, well above ambient, and 70°F, a typical ambient condition. The relative moisture levels measured over time by the analyzer under both conditions follow each other closely, indicating that sample system temperature had no bearing on the response time in this case.

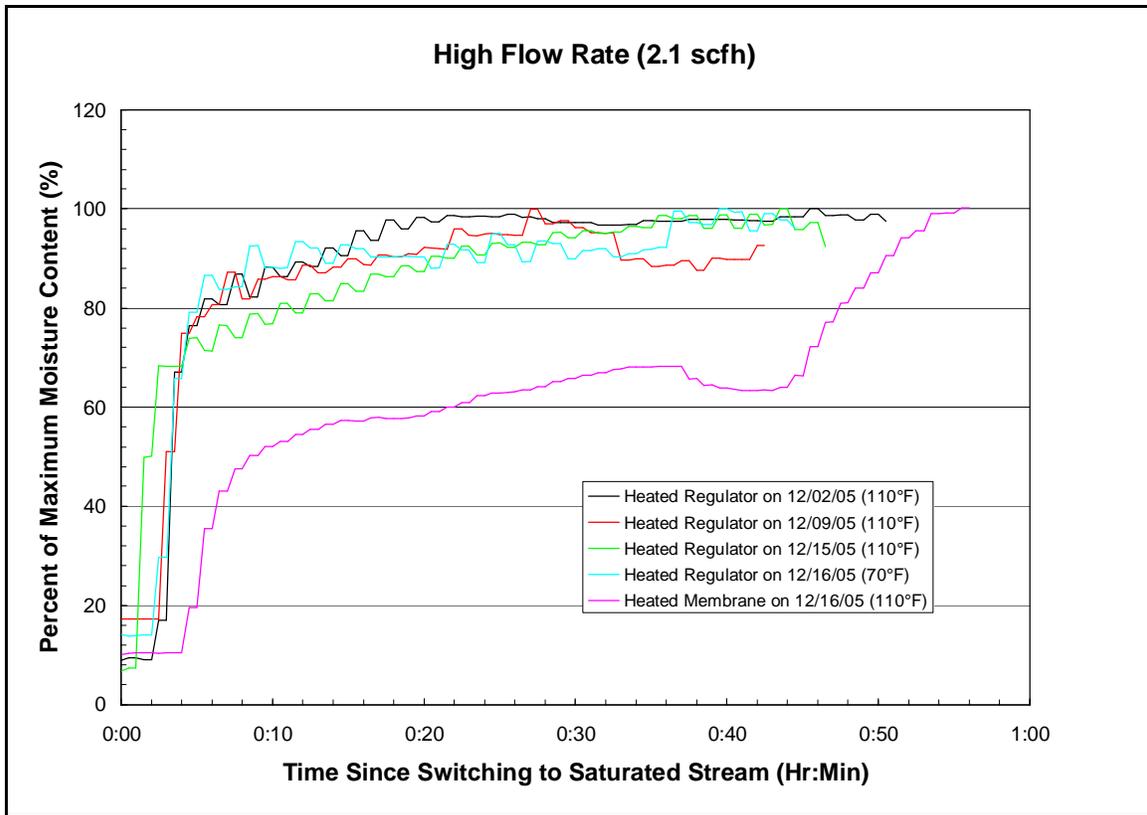


Figure 4-8. Time responses of both sample test systems to an increase in moisture content at a high flow rate.

Figure 4-9 shows the effect of the different test articles on the system response at a high flow rate (2.1 scfh) with decreasing moisture content. Once again, the sample line with the membrane filter had a longer response time than the regulated sample line, and the temperature of the regulated sample system had no effect. In comparing Figure 4-8 and Figure 4-9, note that the stabilization times for both configurations are larger for a moisture decrease than for a moisture increase. For a moisture decrease, the regulated sample line requires up to one hour to stabilize, while the setup with the membrane filter requires up to three hours. For a moisture increase, the regulated system is stable within 30 to 40 minutes, while the filtered system requires about one hour to reach its final moisture level.

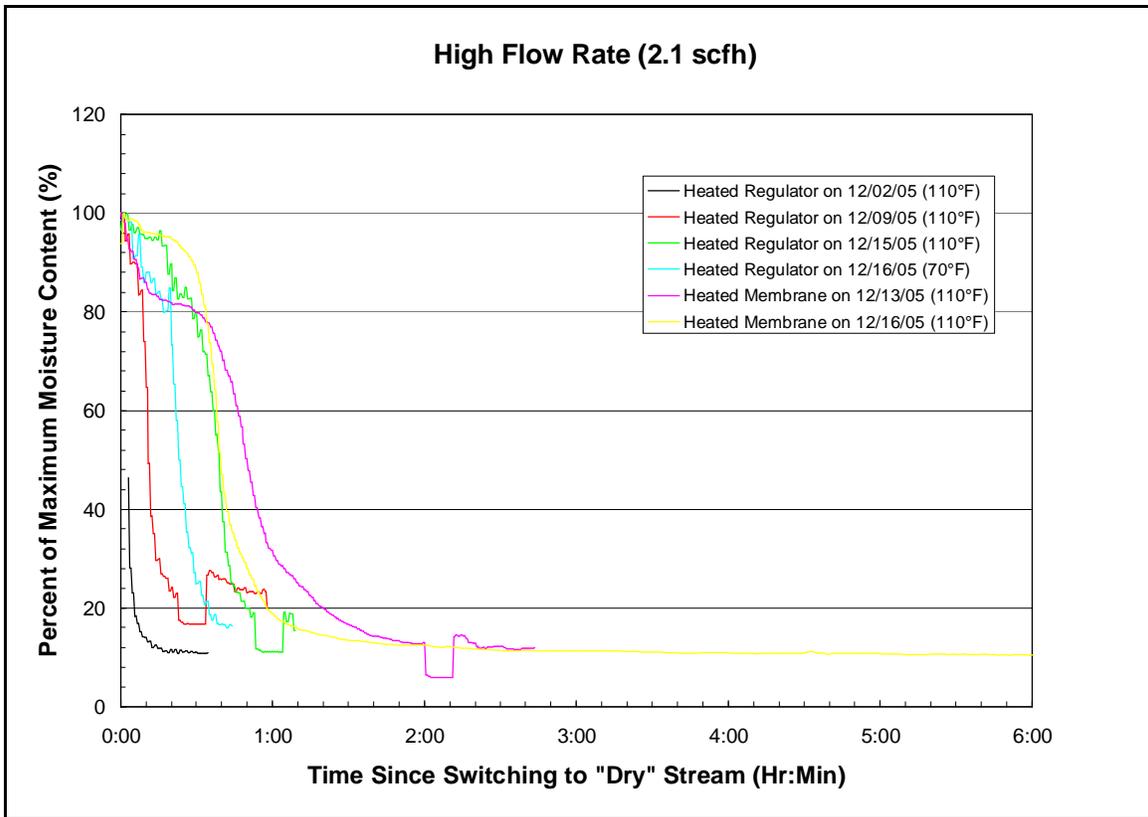


Figure 4-9. Time responses of both sample test systems to a decrease in moisture content at a high flow rate.

Figure 4-10 shows the effect of the different test articles on the system response at a low flow rate (0.3 scfh) with increasing moisture content. Figure 4-11 shows the effect of the different test articles on the system response at a low flow rate (0.3 scfh) with decreasing moisture content. Again, the time for the regulated sample line to stabilize to the new moisture level is consistently less than the stabilization time for the setup incorporating the membrane filter. Also as before, the sampling systems stabilize more quickly after a moisture increase than after a moisture decrease. Note in Figure 4-11 that at the low flow rate, the absence of heating above ambient conditions appears to double the stabilization time of the sample system after a moisture drop. This combination of a low flow rate and a decrease in moisture content produced the only significant difference in response times between the regulated system at 110°F and 70°F. This suggests that heating a moisture sampling system would be beneficial where other conditions can combine to produce slow system response times.

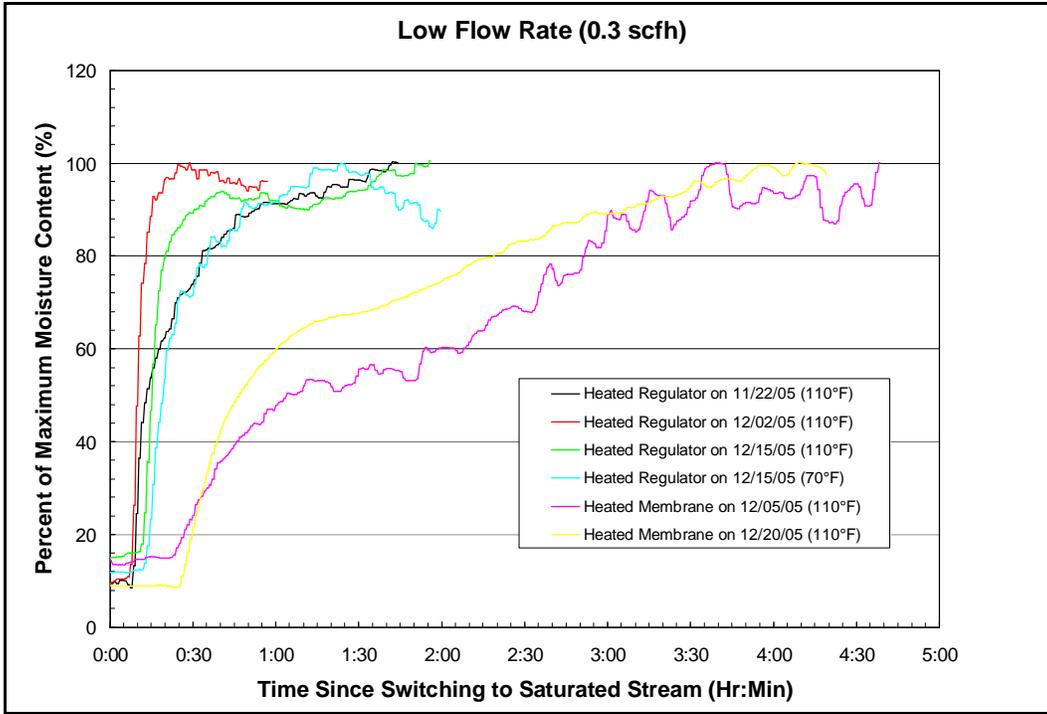


Figure 4-10. Time responses of both sample test systems to an increase in moisture content at a low flow rate.

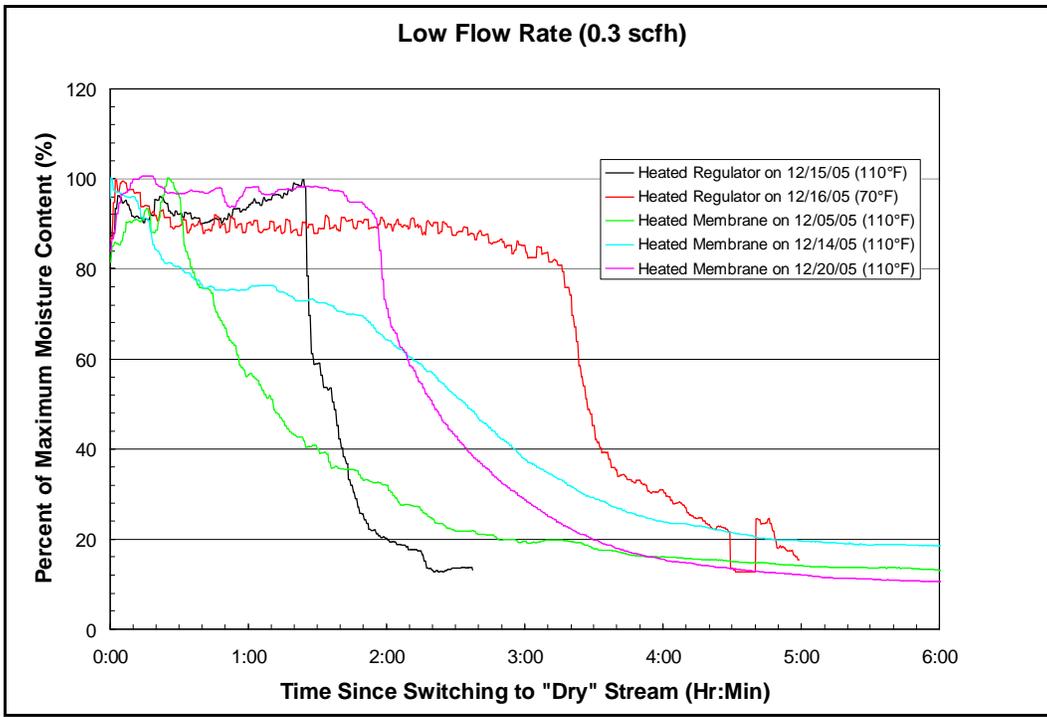


Figure 4-11. Time responses of both sample lines to a decrease in moisture content at a low flow rate.

4.5 IMPACT OF SAMPLE FLOW RATE ON SYSTEM RESPONSE TIME

In this section, results of the same tests reviewed in the previous section are reorganized and viewed from a different perspective. Each of the six graphs in this section compares the system response times for a given sampling system, heating condition, and moisture gradient, but trends are compared as a function of sample flow rate. As expected, these graphs clearly show that each sampling system responds more quickly to a step change in moisture content when the sampling flow rate is higher.

Table 4-1 reports the approximate stabilization times of each test as obtained from these graphs. Comparison of the times listed in the table also shows that the response time of every sampling system to a decrease in moisture content is slower than its response time to a moisture increase, and that the regulated system responds faster to a change in moisture content than the system containing the membrane filter without a significant pressure cut.

Table 4-1. Approximate stabilization time of moisture levels at each test condition.

	HEATED REGULATOR AT 110°F		HEATED REGULATOR AT 70°F		MEMBRANE FILTER AT 110°F	
	Low Flow Rate (0.3 scfh)	High Flow Rate (2.1 scfh)	Low Flow Rate (0.3 scfh)	High Flow Rate (2.1 scfh)	Low Flow Rate (0.3 scfh)	High Flow Rate (2.1 scfh)
Increasing Moisture Content	1 hr 45 min	45 min	test incomplete	40 min	6 hrs	1 hr
Decreasing Moisture Content	2 hr 20 min	1 hr 10 min	~ 5 hrs	45 min.	8 hrs	3 hrs

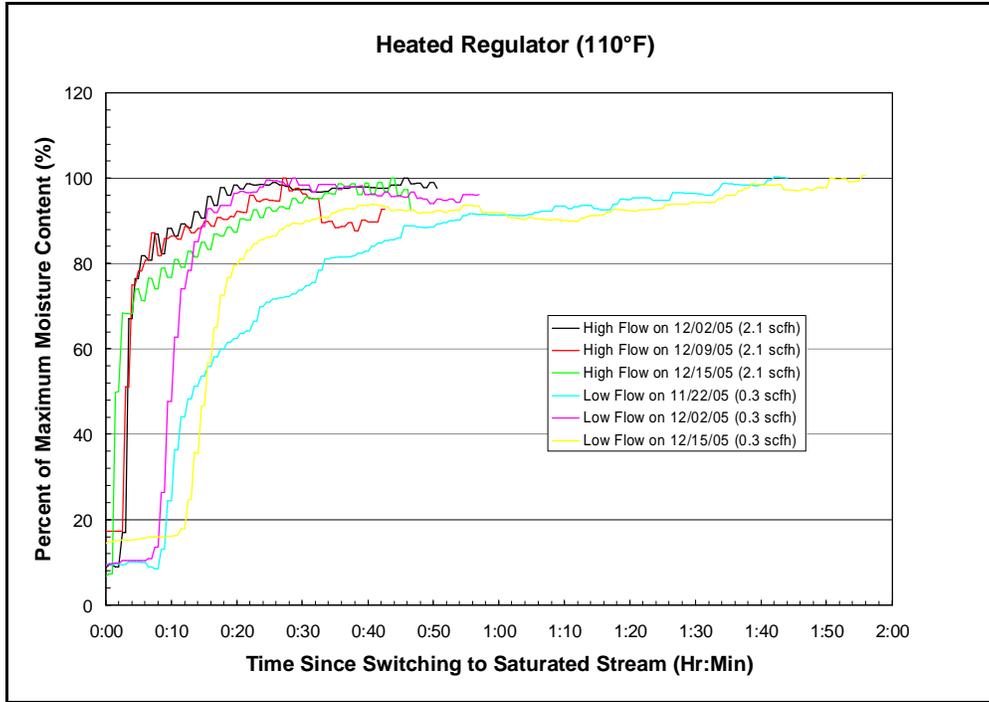


Figure 4-12. Time responses of the regulated sample system at 110°F to an increase in moisture content at different sample flow rates.

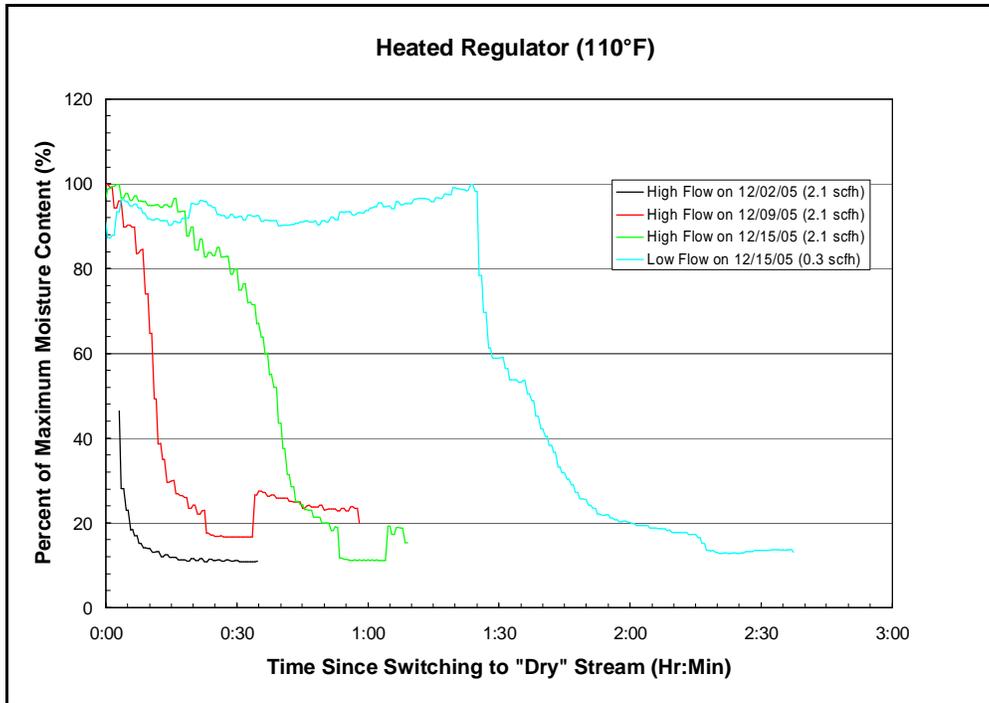


Figure 4-13. Time responses of the regulated sample system at 110°F to a decrease in moisture content at different sample flow rates.

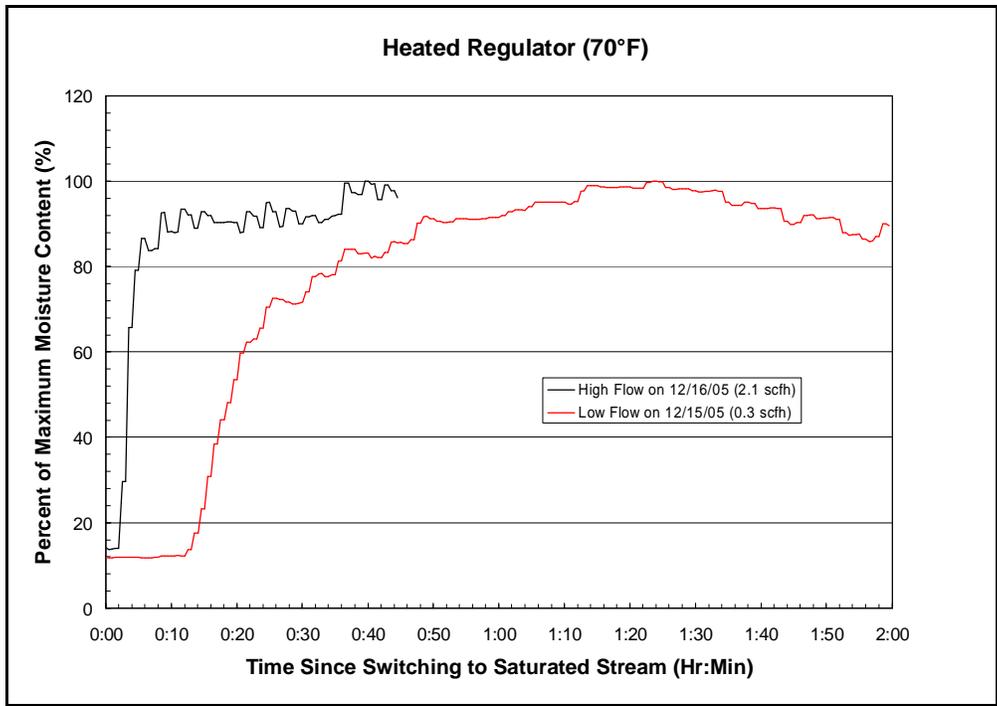


Figure 4-14. Time responses of the regulated sample system at 70°F to an increase in moisture content at different sample flow rates.

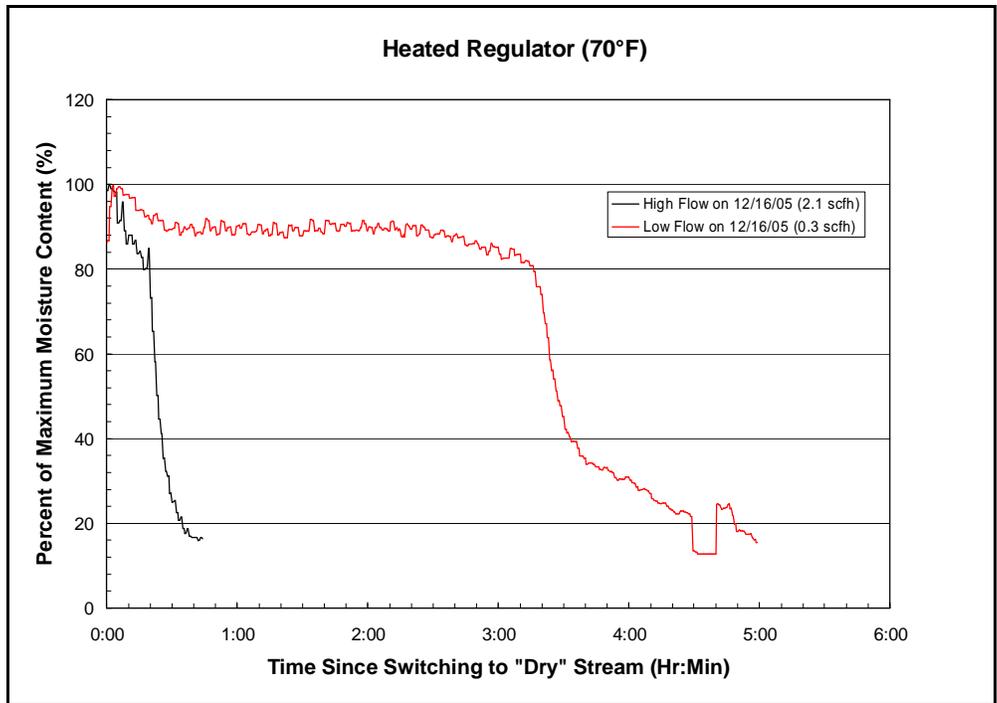


Figure 4-15. Time responses of the regulated sample system at 70°F to a decrease in moisture content at different sample flow rates.

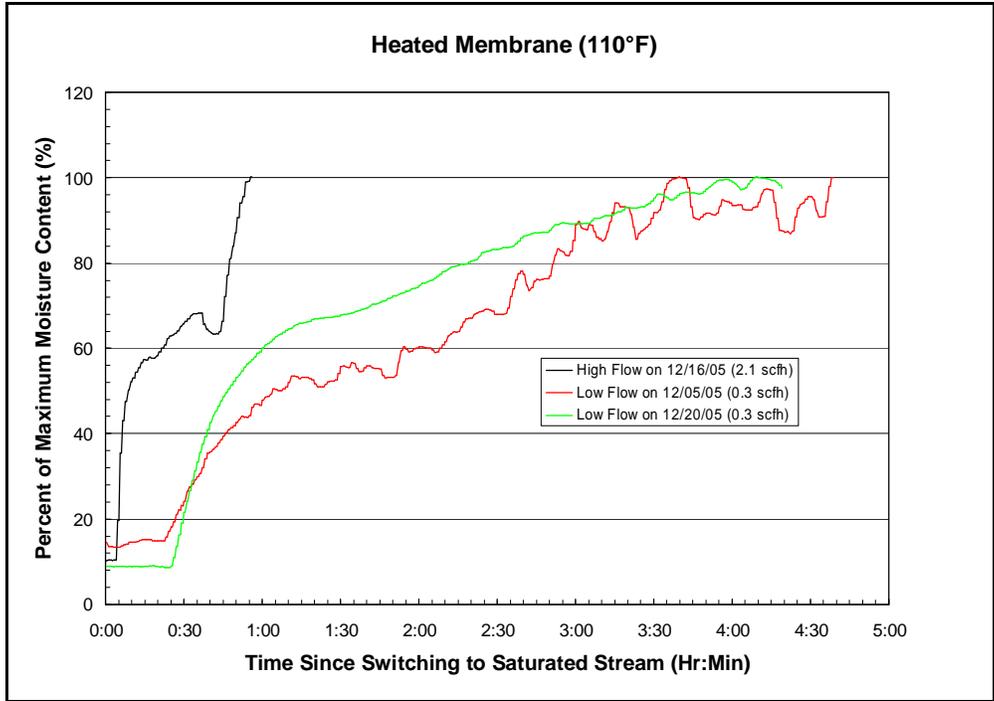


Figure 4-16. Time responses of the membrane filter sample system at 110°F to an increase in moisture content at different sample flow rates.

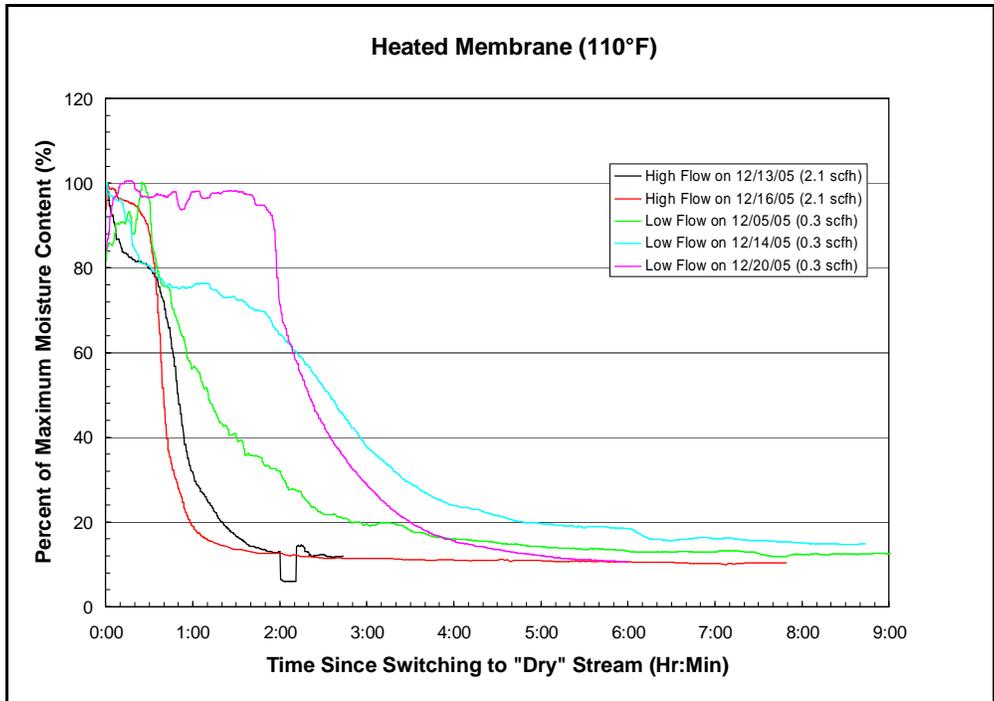


Figure 4-17. Time responses of the membrane filter sample system at 110°F to a decrease in moisture content at different sample flow rates.

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5. CONCLUSIONS

As discussed at the beginning of this report, the purpose of this research was to evaluate the performance level of various moisture sampling system equipment and methods through a series of tests under ideal and adverse operating conditions. After a survey to identify sampling methods and equipment configurations used by the natural gas industry, tests were performed to address the accuracy of the moisture content of samples collected using three different systems:

- A regulated probe and sample line at a constant temperature of 70°F, simulating ambient conditions.
- A regulated probe and sample line heated to 110°F to compensate for J-T cooling.
- A sample line incorporating a membrane filter.

Tests were also performed to assess how this equipment changes the response of a moisture analyzer to step changes in moisture content in the pipeline, and how changes in sample flow rate affect the accuracy of the moisture samples.

From the results of these tests, the following observations were made.

- In natural gas streams with moisture levels below the common tariff limit of 7 lb/MMscf, moisture measurements were made of the reference stream and of samples collected using each equipment configuration. Manual chilled mirror devices and automated moisture analyzers were used for measurements in both locations. Reference stream measurements and sample measurements made with the same type of device agreed to within 1 lb/MMscf. This suggests that once moisture levels in the sampling equipment have stabilized to levels below the tariff limit, the gas sample will accurately reflect conditions in the source stream.
- In many tests, measurements of the reference stream or the sample stream were made with both a Bureau of Mines manual chilled mirror device and an automated analyzer. At moisture levels of 5 lb/MMscf and below, disagreements between the manual and automated devices on the order of 1 lb/MMscf or less were observed. These disagreements would not be large enough to bring either of the measurements, or the quality of the gas stream itself, into question by parties involved in a custody transfer situation. At moisture levels above 20 lb/MMscf, larger disagreements (up to 15 lb/MMscf in some instances) were observed between the manual and automated devices. These statistically significant differences are attributed to the use of a low-level internal moisture standard (2 lb/MMscf) during self-calibration of the automated analyzer. Despite these differences, both instruments would identify the gas stream as being of unacceptable quality, so that appropriate action could be taken in a field setting. Because the scope of work did not consider gas streams at moisture levels between 5 and 20 lb/MMscf, a separate project is suggested to assess the accuracy of automated analyzers under these conditions.
- Tests were performed to determine the response time of the analyzed sample stream to step changes in the moisture level of the supply gas. In several cases, the moisture level of the stream passing through the sampling test apparatus rose rapidly at first,

then decelerated and approached equilibrium levels more slowly. Care should be taken to identify such slow moisture transients after a rapid change in moisture levels, so that moisture measurements made during a period of slow change are not assumed to represent equilibrium conditions.

- The response time of every sampling test system to a decrease in moisture content was found to be slower than its response time to a moisture increase. In a field installation, it can be expected that a moisture increase due to a process upset will be detected more quickly than the restoration of moisture levels to normal conditions after the problem has been eliminated.
- The sample system including the membrane filter produced a significantly longer response time than both the heated and unheated regulated sample line. The slower response time of the filtered sampling system is attributed to its higher sample line pressure. At a given standard flow rate, the filtered system with its higher mass of gas takes longer to deliver a given sample volume from the sample point to the instrument.
- The temperature of the regulated sample system was found to impact the stabilization time of moisture samples only at the low flow rate and with decreasing moisture content. This suggests that heating a moisture sampling system above ambient conditions is beneficial where other conditions can slow down system response times.
- As expected, test results show that each sampling system responds more quickly to a step change in moisture content when the sampling flow rate is increased.

The following conclusions address the overall goals and success criteria for the project:

- At moisture levels below the common gas quality limit of 7 lb/MMscf, all three sampling systems tested were able to deliver representative samples of the natural gas stream to a measurement device. Measurements of the moisture content of the delivered samples agreed with measurements of the reference stream to within 1 lb/MMscf.
- At moisture levels above 20 lb/MMscf, differences between manual and automated measurements of the sample moisture content did not allow conclusions to be drawn about the absolute accuracy of the measurements. Still, samples taken of streams above this level can be recognized as being well above transmission gas quality limits, and recognized as posing the potential for liquid condensation or hydrate formation in the pipeline being sampled.
- At moisture levels of 7 lb/MMscf and below, all the sampling systems tested in this project will deliver samples with representative moisture content after an appropriate stabilization period. The advantages of one element of sampling equipment over another lie in their effect on the time required for the sample moisture level to stabilize after a moisture transient in the pipeline.

- Of the three systems tested, the system with a regulated probe, regulated sample line and active equipment heating produces the fastest response time. The use of a pressure regulator is specifically recommended for its impact on response time to transients, provided that equipment heating is sufficient to prevent Joule-Thomson cooling in the regulator and condensation of moisture from the sample.
 - A regulated sample configuration without heating ranks second among the systems tested, since at low flow rates, a lack of heating was found to slow stabilization times.
 - A sample system with high pressure throughout the sample line, such as the system with a membrane filter at pipeline pressure, will consistently produce the slowest response times, and would be ranked lowest of the three systems tested.
- Test results show that the use of higher sample flow rates, within the limits of the manual or automated moisture instrument, will minimize the response time of a sampling system to a change in moisture levels independent of the hardware used. The use of a pressure regulator to decrease sample system pressure and increase the velocity of gas through a sampling system can also minimize the response time of an analyzer or dew scope to moisture transients. However, the use of a heated regulator or heat trace is strongly recommended with pressure regulation to offset the effect of Joule-Thomson cooling and prevent moisture condensation in the sample system. The use of heating to warm a moisture sampling system above ambient conditions will also help to offset other factors that can slow down system response times.
 - During the tests, transients in moisture level were identified as a potential source of measurement error. Fluctuating moisture levels were observed during tests that were caused by oscillations in heat trace controllers. Inaccurate measurements may also be made during a period of slow change that is misidentified as an equilibrium condition. Such slow changes were observed long after a step change in pipeline moisture content, particularly following a step decrease in moisture. In the field, such conditions may occur after a dehydration unit begins operation, or as morning sunlight heats exposed sampling equipment. To avoid measurement errors of this type, repeated or continuous moisture measurements over a period of several hours are recommended.
 - The sampling methods and equipment tested here (sample systems with regulators or membrane filters) may be useful in identifying moisture content of a natural gas stream that can lead to hydrate formation, or to liquids condensation in the line and potential pipeline corrosion. For the collected samples to provide accurate moisture measurements, causes of instability such as changing equipment temperatures must be eliminated or minimized. High flow rates and constant equipment temperatures are recommended for fastest response times. Additional tests of the methods and equipment are recommended to address the accuracy of samples above 5 lb/MMscf.

- The data presented in this report is available as guidance for a potential standard for moisture sampling and analysis. In particular, the test procedure in Appendix B provides a model for testing sampling equipment and methods under optimum and adverse conditions.

6. REFERENCES

American Petroleum Institute [2006], *Manual of Petroleum Measurement Standards*, Chapter 14 – Natural Gas Fluids Measurement, Section 1 – Collecting and Handling of Natural Gas Samples for Custody Transfer, Washington D.C., Sixth Edition [in press].

ASTM International [1995], ASTM Standard D 1142, Standard Test Method for Water Vapor Content of Gaseous Fuels by Measurement of Dew Point Temperature, West Conshohocken, Pennsylvania.

George, D. L., Hart, R. A., and Nored, M. [2004], *Evaluation of a Proposed Gas Sampling Method Performance Verification Test Protocol*, Southwest Research Institute report to the U.S. Minerals Management Service.

George, D. L., Barajas, A. M., Kelner, E., and Nored, M. [2005a], “Metering Research Facility Program, Natural Gas Sample Collection and Handling – Phase IV,” GRI Topical Report GRI-03/0049, Gas Research Institute, Des Plaines, Illinois, USA, January 2005.

George, D. L., Burkey, R. C., and Morrow, T. B. [2005b], “Metering Research Facility Program, Natural Gas Sample Collection and Handling – Phase V,” GRI Topical Report GRI-05/0134, Gas Research Institute, Des Plaines, Illinois, USA, March 2005.

Koch, G. H., *et al.* [2001], *Corrosion Costs and Preventative Strategies in the United States*, report to Federal Highway Administration, Office of Infrastructure Research and Development, Report FHWA-RD-01-1562001.

Warner, H. R. Jr., *et al.* [2001], “Hydrocarbon Dewpoint Determination of Lean Natural Gases,” *Proceedings of the Gas Processors Association Eightieth Annual Convention*, San Antonio, Texas, USA, published by the Gas Processors Association, Tulsa, Oklahoma, USA.

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APPENDIX A: MOISTURE SAMPLING SURVEY RESULTS

The following is a summary of the responses received to a survey of sampling systems and methods for monitoring water vapor in natural gas streams. A total of twelve responses were received. Nine of the responses were from companies that buy, sell and/or deliver natural gas, while the other three responses were from manufacturers and/or vendors of moisture sampling and analysis equipment. Three responses were received from representatives of the same company, but each person is responsible for activities in different portions of the natural gas industry and in different regions of the country, so all three surveys have been included in this summary.

The responses in this summary have been blinded, so as not to identify the companies that participated. Items preceded by an * are responses quoted from a survey, and are included in tallies listed for that question.

1. Please describe your responsibilities for your company.

- a. Are you responsible for moisture or water vapor monitoring and/or sampling work for your company?

Yes (9)
No (1) (Identified someone in the company to address items in survey)
Purchase and/or design of equipment only (2)

- b. Are you an end-user of moisture monitoring and sampling equipment, or an equipment manufacturer?

End-users (9)
Manufacturers (3)

If you are an end-user, please describe the equipment you use for obtaining representative samples from a natural gas stream. If you represent a manufacturer of moisture analyzers or are an industry consultant, please describe the equipment you recommend to users of moisture analyzers for obtaining representative samples from a natural gas stream.

2. For what portion of the natural gas industry do you design and use (or recommend) moisture sampling systems? Check all that apply.

5	Offshore production	
5	Onshore production	
6	Gathering	
12	Transmission	
5	Distribution	
3	Other. Please describe:	<div style="border: 1px solid black; padding: 5px;"> <ul style="list-style-type: none"> * storage fields * cryogenic gas plant inlets and deliveries * NLG liquefaction </div>

3. How does your company currently monitor (or recommend that users monitor) moisture content of the flowing gas stream?

7 Manual inspection or sampling (manual chilled mirror device)

12 Online or spot analyzers:

Brand and model:	<p>Several respondents use more than one brand and model.</p> <p>Ametek (1)</p> <p>Chandler MoistureChek 2000 (2)</p> <p>Cosa (1)</p> <p>Kahn (2)</p> <p>Length-of-stain tubes (1)</p> <p>Meeco (6)</p> <p>Michell (1)</p> <p>Panametrics (5) (includes Models 280 and 880, Moisture Series I and II)</p> <p>SpectraSensors laser-based unit (6)</p> <p>Vaisala (1)</p>
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How often is the analyzer calibrated or verified?

<p>Annually (4)</p> <p>Monthly (1)</p> <p>Certified annually, verified monthly (1)</p> <p>Annually for sweet gas, semi-annually for sour gas (1)</p> <p>Panametrics annually, others only when failed (1)</p> <p>Varies with manufacturer and type (1)</p> <p>After sensor reconditioning (1)</p> <p>As needed to maintain measurement accuracy (1)</p> <p>No response (2)</p>
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4. Describe the following characteristics of your most common (or commonly recommended) sampling system.

a. Location of sample point relative to risers, meters, or other equipment or piping features.

<ul style="list-style-type: none"> * 8 D downstream with a minimum of 5 D upstream. * "Second tap downstream of measurement." * Place at least 8 pipe diameters from any device causing aerosols or significant pressure drop. Probe should not be installed within the "AGA internal projection controlled meter tube region" directly upstream or downstream of an orifice plate or meter. * Downstream meter tube ~ 6" downstream of the thermowell. For gas samplers, 5 to 8 diameters downstream of valves, T's, Elbows, swirl generators, headers. * Located in meter run (at appropriate lengths downstream of measuring element), pipeline gate settings (usually in crossovers to avoid problems with pigging) * First tap at the receipt point, downstream of block valve, upstream of meters. * Usually on meter run downstream of orifice plate. Tee off of gas sample/chromatograph line. * Generally in the meter run, downstream of the primary element. Installation in headers is not recommended. System does have some mainline sample points not associated to a specific meter station. * Downstream of orifice meter runs, top side of horizontal piping, and as far away from elbows as possible. * On top of pipe, at a point where a representative sample is available, and the moisture measurement is needed. * Debatable but I feel that sampling from a point after a region of turbulent flow is best. * Refer to API Chapter 14.1 recommendations.
--

b. What flow disturbances are considered when a sample point is selected?

Headers (2)	Regulators (1)	Elbows/"bends" (7)
Pipe orientation (1)	Tees (2)	Orifice plates (2)
Control valves (5)	Pipe fittings (1)	Flow conditioners (2)
Thermowell (1)	"Swirl generators" (2)	Non-uniform flow (1)
Stagnant areas (1)	Branch connections (1)	Mainline null points (1)
Use what is available (1)	None (1)	

* Respondent citing "none" named equipment access and avoiding pigging issues as dominant considerations.

c. What is the most common size of sample port?

1/8 inch NPT (1)
1/4 inch NPT (1)
1/2 inch NPT (3)
3/4 inch NPT (7)
1 inch NPT (6)
1 1/4 inch NPT (1)
Raised flanges (3)

* One respondent uses a mixture of 0.5, 0.75 and 1" threadolets.
 * One respondent uses 1" for stinger probes and 1 1/4" for Genie probe regulators.

d. Is a sample probe used? Yes No

Brand, size and type of probe:	<p>Some respondents use more than one brand and type.</p> <p>Genie probe regulator (4)</p> <p>Genie probe regulator w/ glycol filter (1)</p> <p>Genie probe regulator w/ moisture membrane (1) (note that the use of a membrane to filter moisture would be counterproductive in moisture sampling applications)</p> <p>Welker, various models (4)</p> <p>YZ (3)</p> <p>Regulated probes with 2-micron particle and membrane filters (1)</p> <p>Stinger/straight tube probes made with stainless steel tubing, no regulator (3)</p> <p>"Insertion probe" (1)</p> <p>Probes inserted through a valve (1)</p> <p>Manufacturer's design (1)</p> <p>* One respondent uses several types, including A+ Genie probe regulators for meter run taps, and Welker AIPs and probe regulators for mainline taps.</p>
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Common probe length:	<p>Half the pipe diameter (2)</p> <p>~40% of line ID (1)</p> <p>Center one-third of pipe (3)</p> <p>Center two-thirds of the pipe (1)</p> <p>Top one-third of pipeline (1)</p> <p>Other (4):</p> <p>* 4" or 7", depending on pipe diameter</p> <p>* 18"</p> <p>* 9" for mainline</p> <p>* 4" to 10"</p>
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e. Is a sample line used to move the sampled gas to the analysis point? Yes No

Standard tubing diameter: 1/8" (8)
 1/4" (7)
 * One respondent selects tube diameter according to the analyzer brand (Meeco & Chandler = 1/8"; Laser = 1/4"; Vaisala in the line, no sample)
 * One respondent states that sample line diameter is either 1/8" or 1/4" depending on line length.

Maximum length of tubing: 100 feet (1)
 50 feet (2)
 30 feet (1)
 20 feet (1)
 Varies (1)
 No maximum length (2)
 Short as practical (3)
 Depends on moisture level – low moisture = short lengths (1)

Is the sample line straight, or are bends allowed? How many?
 * Bends are allowed with no low spots. The sample line has a minimum requirement of 1" rise per lateral foot.
 * Bends are kept to a minimum, but allowed.
 * Bends are allowed, sometimes numerous.
 * Bends are OK, but not liquid traps.
 * Bends allowed – maybe 4 on average.
 * Varies, prefer a straight line, avoiding dips.
 * Bends required to get to analyzer, velocity is slight so bends not a factor.
 * No more than three bends of the tubing.
 * Three or four bends are allowed.
 * Bends are allowed as necessary. Tight-radius bends are discouraged.
 * Bends are fine. Most important is heat tracing to avoid any risk of condensation.
 * Not ever considered.

f. What considerations are given to ambient conditions? Check all that apply.

- 8 Heat trace
- 7 Heated enclosures
- 6 Explosion proof housing
- 5 Other. Please describe:

* Insulation blankets on insertion probes (heated as well)
 * Div 2 or IS rated
 * Sun shades; air conditioned, division 2 buildings; proximity to chromatographs and other analysis equipment.
 * Cooled enclosures where ambient temperatures are high.
 * Most commonly an IS loop installation is used. Cooling of sampling system enclosure for hot installations (such as deserts).

 Two respondents gave no response here or stated that they very rarely use heat trace or heated enclosures.

g. What equipment is placed in the sample line between the sample point and analysis device? Check all that apply.

11	Filters	* One respondent specifies a particular brand of membrane filters.
1	Dropout pots	
12	Valves	
		* One respondent uses only fully opening ball valves. * Stainless steel straight pattern ball valves, or equivalent, are specified by one respondent for use in sampling systems.
12	Regulators. How much of a pressure cut is taken?	
		* Insertion probes have in-situ pressure cuts to approx. 15 psig * 600 to 800# in the pipe * Line pressure down to approximately 20# * From line pressure to ~ 15 psig * Line pressure to 5 psig * Down to analyzer's max allowable pressure * Depends on manufacturer's recommendations * Max, 900# to 20#; typical, 500# to 20# * Sometimes > 1000 psi * No more than 300 psi without heating * Normally we measure water dew point at full line pressure. * Depends on analyzer, but typically from line pressure to 35 psi.
7	Other. Please describe:	
		* On long sample lines a speed loop is installed with a constant vent to assure a representative sample is presented to the analytical measurement device. * Second cut regulator (in case first cut fails) and pressure gauges. * Use a sample conditioning assembly sold by the moisture analyzer manufacturer (sketch includes a coalescing filter, a membrane filter and a glycol filter – dlq) * Glycol/amine removal * Membrane gas/liquid separator * 'Glyorb' cartridge in line. * Pressure gauges, relief valves, glycol absorbents, membrane probes, membrane separators

- h. Is the sample system used for other online samplers, such as an active hydrocarbon GC or a detector for oxygen, carbon dioxide, or sulfur? What kinds of samplers?

No (7)
No response (1)
Yes (4):
* In some cases yes; but typically, we try to have a separate sample line for the GC. The moisture analyzer could be on the same sample system with as many as 4 other types of analyzers.
* All the above.
* Water and sulfur analyzers will share the same sample line. The company generally keeps this line and the line to the BTU chromatograph separate.
* Sometimes the sample is taken on to a GC, after pressure reduction.

- i. After analysis, how is the sample disposed of?

12	Vent
3	Flare
1	Returned to line

1	Other. Please describe: * 300cc bottles released to atmosphere then steam cleaned.
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5. What GPA, API or other standards do you use or recommend to design and install moisture sampling apparatus?

API 14.1 (6) ASTM D5454 (2) ASTM D5503 (1) Equipment manufacturer recommendations and experience (3)

6. Please describe any of your other considerations in designing and installing a pipeline moisture sampling apparatus.

Two respondents included an extensive list of specs and performance requirements for their sampling systems. Others included the following statements: * Some means to avert the effect of liquid contamination. * Power, oil or glycol in line, and free liquids. * Line gas pressure, line gas temperature, ambient temperatures, sample pressure allowed by apparatus and moisture level of gas. * Header locations / multiple delivery points. * Type of flow computer or RTU, piping configuration and meter type, location of mixing points upstream of the analyzer, analyzer function (monitoring or shut down), pipeline tariff restrictions (7 lbs. H ₂ O/MMSCF), customer requests and requirements, customer data requests. * Access, ease of maintenance, reliability, and cost. * Hydrocarbon dew point. Our analyzers do not like to see liquid in the sample.

7. Please include a sketch or drawing of the typical sampling layout that you use or recommend. You may attach it as a separate page when you return the survey by fax, or you may insert it in this document or attach it as an electronic file if you return the survey by e-mail.

* Seven respondents included equipment layout drawings. These were used for guidance in building the test systems for this research.
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APPENDIX B: MOISTURE SAMPLING TEST PROCEDURE

Moisture Sampling Test Procedure
Andy Barajas and Darin George
11/21/05

A diagram of the test system with valve designations can be found in Figure 3-1 in the body of this report.

1. Isolate the reference system from the test system.
 - a. Close BV102 and BV104.
2. Continuously record pressures and temperatures during the test period.
3. Continuously record the moisture content from the reference moisture analyzer during the test period.
 - a. Open BV101.
4. Determine the moisture content of the reference line by measuring the dew point temperature from the reference line using the dew scope (initially every two hours). If the moisture content remains stable, determine less often.
5. Test with heated regulator and heat trace (**70°F**), with regulator preset to 50 psig.
 - a. At a high sampling flow rate (2.1 scfh), determine the time response with increasing moisture content.
 - i. Set the gas saver option on the Ametek moisture analyzer to “off”. Flow through sampling system should now be approximately 2.1 scfh.
 - ii. Ensure that BV102, BV104, and BV105 are closed.
 - iii. Position BV109 and BV110 to flow through the test regulator.
 - iv. Open BV103.
 - v. Ensure that moisture content, as measured by the Ametek moisture analyzer, is stable.
 - vi. Determine the moisture content of the test line by measuring the dew point temperature from the test line using the dew scope.
 - vii. Change the gas option on the Ametek moisture analyzer from natural gas to methane.
 - viii. Slowly open BV111, NV102, and BV105.
 - ix. Set CV101 so that P102 and P103 are approximately the same.
 - x. Make step change in moisture content by starting the flow of saturated methane. Close BV103 and open BV104.
 - xi. Continue until the moisture content in the test line (measured by the Ametek moisture analyzer) reaches a maximum and stabilizes.
 - xii. Determine the moisture content of the test line by measuring the dew point temperature from the test line using the dew scope.
 - b. At a high sampling flow rate (2.1 scfh), determine the time response with decreasing moisture content by flowing from the pipeline.
 - i. Change the gas option on the Ametek moisture analyzer from methane to natural gas.
 - ii. Open BV103.
 - iii. Close NV102 and BV111.
 - iv. Back flow through the Welker filter.

- v. Open and close BV104 and BV105 numerous times while back flowing through the Welker filter to eliminate any moisture that might get trapped in the seat of the ball valves.
 - vi. Close BV104 and BV105 and open BV102 so that pipeline quality gas is on the backside of BV104.
 - vii. Continue until the moisture content in the test line (measured by the Ametek moisture analyzer) reaches a minimum and stabilizes.
 - viii. Determine the moisture content of the test line by measuring the dew point temperature from the test line using the dew scope.
- c. At a low sampling flow rate (0.3 scfh), determine the time response with increasing moisture content.
- i. Set the gas saver option on the Ametek moisture analyzer to “on.” Flow through sampling system should now be approximately 0.3 scfh.
 - ii. Ensure that BV102, BV104, and BV105 are closed.
 - iii. Position BV109 and BV110 to flow through the test regulator.
 - iv. Open BV103.
 - v. Ensure that moisture content, as measured by the Ametek moisture analyzer, is stable.
 - vi. Determine the moisture content of the test line by measuring the dew point temperature from the test line using the dew scope.
 - vii. Change the gas option on the Ametek moisture analyzer from natural gas to methane.
 - viii. Slowly open BV111, NV102, and BV105.
 - ix. Set CV101 so that P102 and P103 are approximately the same.
 - x. Make step change in moisture content by starting the flow of saturated methane. Close BV103 and open BV104.
 - xi. Continue until the moisture content in the test line (measured by the Ametek moisture analyzer) reaches a maximum and stabilizes.
 - xii. Determine the moisture content of the test line by measuring the dew point temperature from the test line using the dew scope.
- d. At a low sampling flow rate (0.3 scfh), determine the time response with decreasing moisture content by flowing from the pipeline.
- i. Change the gas option on the Ametek moisture analyzer from methane to natural gas.
 - ii. Open BV103.
 - iii. Close NV102 and BV111.
 - iv. Back flow through the Welker filter.
 - v. Open and close BV104 and BV105 numerous times while back flowing through the Welker filter to eliminate any moisture that might get trapped in the seat of the ball valves.
 - vi. Close BV104 and BV105 and open BV102 so that pipeline quality gas is on the backside of BV104.
 - vii. Continue until the moisture content in the test line (measured by the Ametek moisture analyzer) reaches a minimum and stabilizes.
 - viii. Determine the moisture content of the test line by measuring the dew point temperature from the test line using the dew scope.

6. Test with heated regulator and heat trace (**110°F**), with regulator preset to 50 psig. Repeat step 5, except with regulator and heat trace set to approximately 110°F.
7. Test with heated membrane filter and heat trace (**110°F**). Repeat step 6, except flowing through the membrane filter instead of the regulator.

APPENDIX C: TIME RESPONSES OF SAMPLE SYSTEMS UNDER TEST

The graphs on the following pages present the moisture content over time of samples delivered to the Ametek analyzer as the sample stream was switched from the HPL reference stream to the saturated methane stream or vice-versa. One representative time trace from a test of each combination of sampling hardware, sample flow rate, equipment temperature, and transient direction is included.

Comparison of the times required for the moisture level delivered by the equipment to stabilize in each case supports the trends described in Chapter 4: (1) the response time of every sampling system to a decrease in moisture content is slower than its response time to a moisture increase; (2) the regulated system responds faster to a change in moisture content than the system containing the membrane filter without a significant pressure cut; (3) each sampling system responds more quickly to a change in moisture content of the source stream with the sample flow rate is increased. Table C-1 reports the approximate stabilization times of each test for comparison. For the case of the regulated line at 70°F, a low sample flow rate and increasing moisture content, the heat trace system shut down at approximately 17:20 due to loss of electricity, and stability was not reached within the first eight hours.

Table C-1. Approximate stabilization time of moisture levels at each test condition.

	HEATED REGULATOR AT 110°F		HEATED REGULATOR AT 70°F		MEMBRANE FILTER AT 110°F	
	Low Flow Rate (0.3 scfh)	High Flow Rate (2.1 scfh)	Low Flow Rate (0.3 scfh)	High Flow Rate (2.1 scfh)	Low Flow Rate (0.3 scfh)	High Flow Rate (2.1 scfh)
Increasing Moisture Content	1 hr 45 min	45 min	-	40 min	6 hrs	1 hr
Decreasing Moisture Content	2 hr 20 min	1 hr 10 min	~ 5 hrs	45 min.	8 hrs	3 hrs

Note that each graph also contains a trace of the moisture levels in the HPL as measured by the SpectraSensors analyzer during the same test period. At those times when both the SpectraSensors unit and the Ametek unit are analyzing gas samples originating from the HPL, a comparison of the two moisture readings is useful. From conservation principles, once the sampling system is in equilibrium, the moisture flow rate into the system will equal the moisture flow rate out, and the moisture content of the HPL stream (measured by the SpectraSensors unit at the reference line) should equal the moisture content of the sample stream measured by the Ametek analyzer through the sampling system under test. Differences may be due to experimental error, biases related to the different calibrations of the two units, or distortions of the sample flowing through the sampling system under test at the time. Comparisons of the two analyzer readings at the beginning or end of each graph, however, reveal that disagreements

between the two units are no more than 1 lb/MMscf. This is of the same order of magnitude of the disagreements between chilled mirror measurements of the HPL reference gas taken at the same two test locations, as discussed in Section 4.1. Although the magnitude of bias between the two analyzers is not known, it can be stated that any distortion of the moisture content by the sampling apparatus is on the order of 1 lb/MMscf.

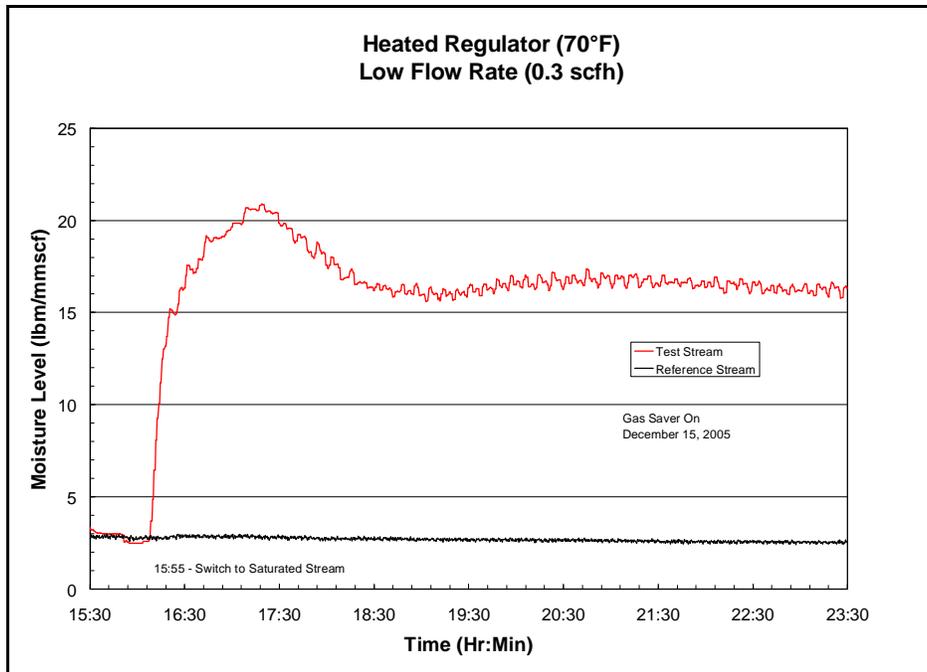


Figure C-1. Time response of the regulated sample line heated to 70°F to an increase in moisture content at a low flow rate.

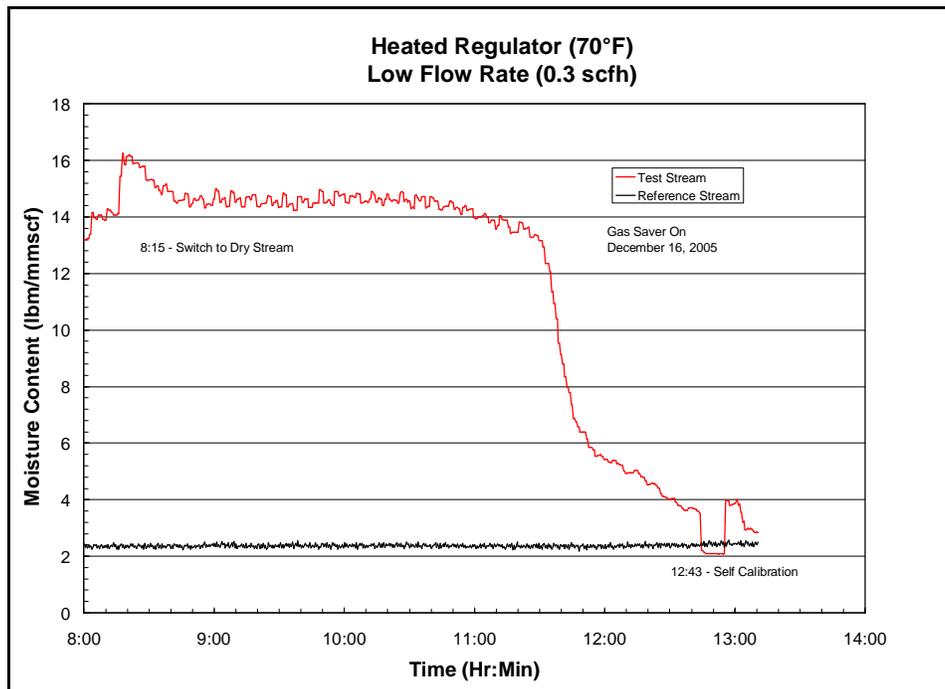


Figure C-2. Time response of the regulated sample line heated to 70°F to a decrease in moisture content at a low flow rate.

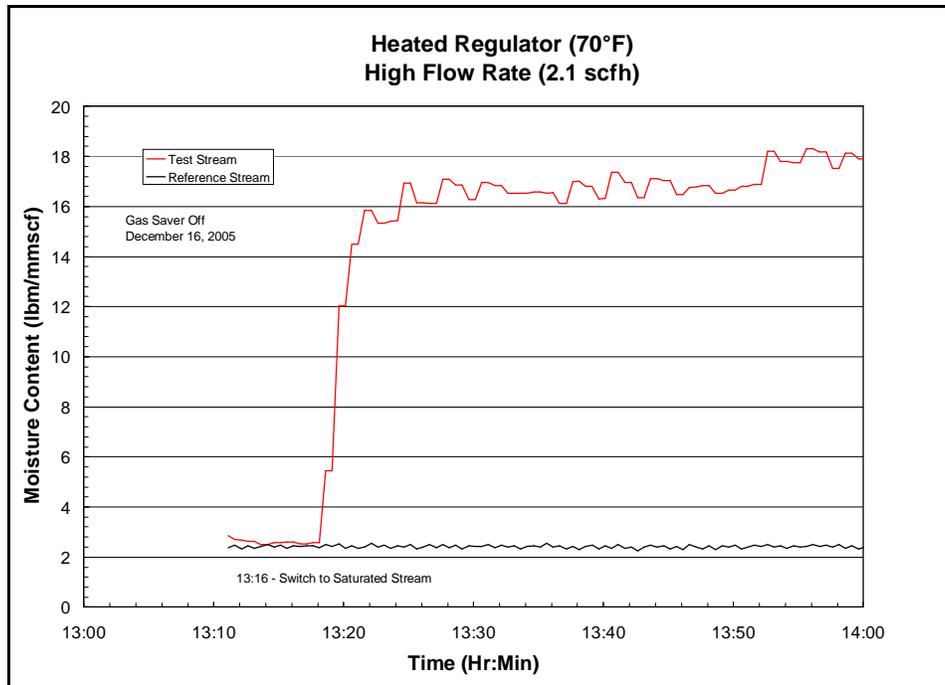


Figure C-3. Time response of the regulated sample line heated to 70°F to an increase in moisture content at a high flow rate.

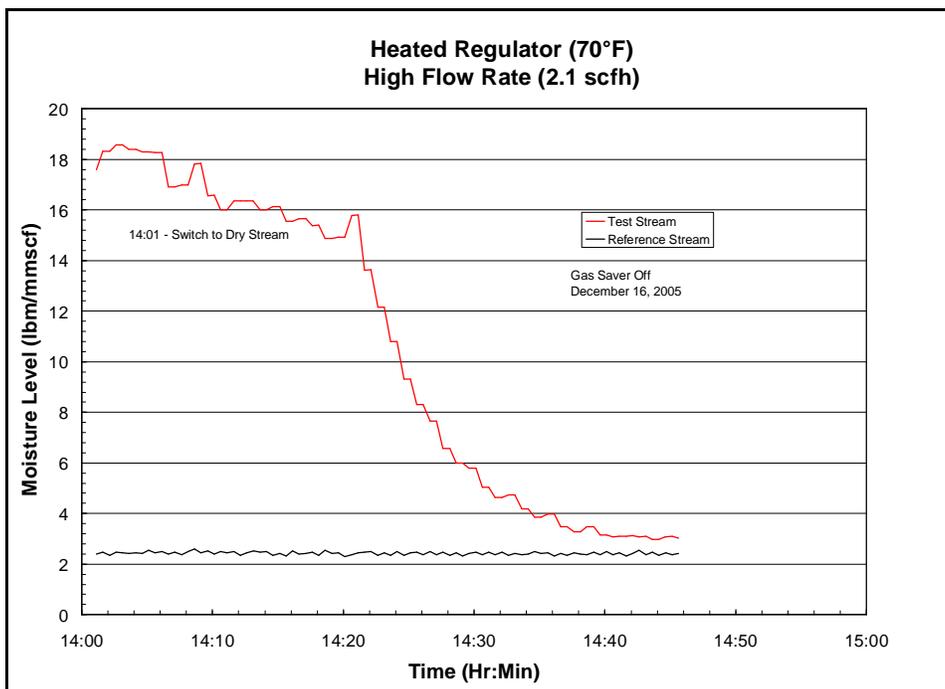


Figure C-4. Time response of the regulated sample line heated to 70°F to a decrease in moisture content at a high flow rate.

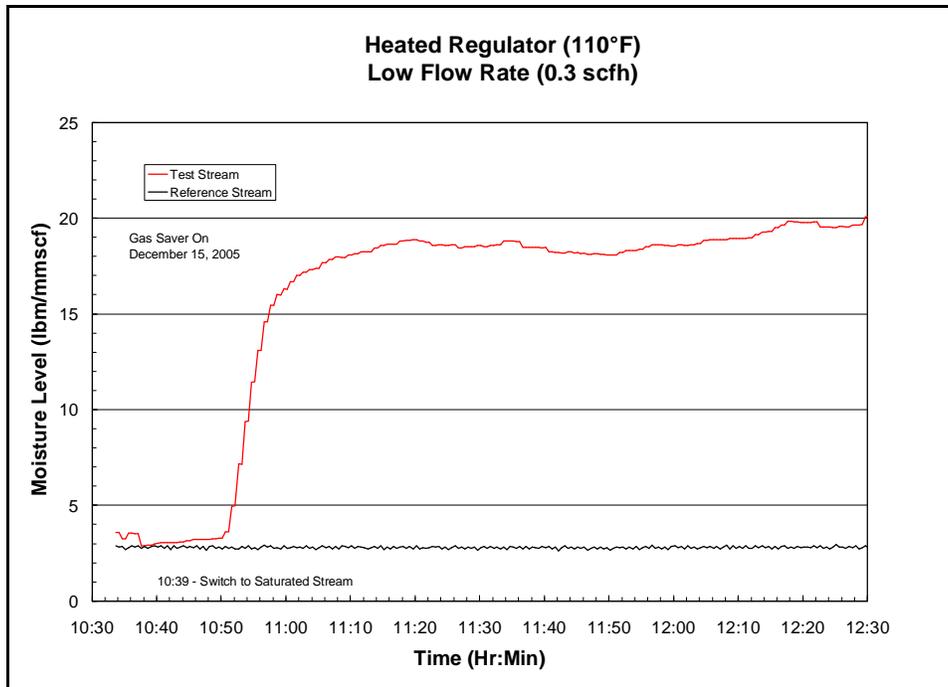


Figure C-5. Time response of the regulated sample line heated to 110°F to an increase in moisture content at a low flow rate.

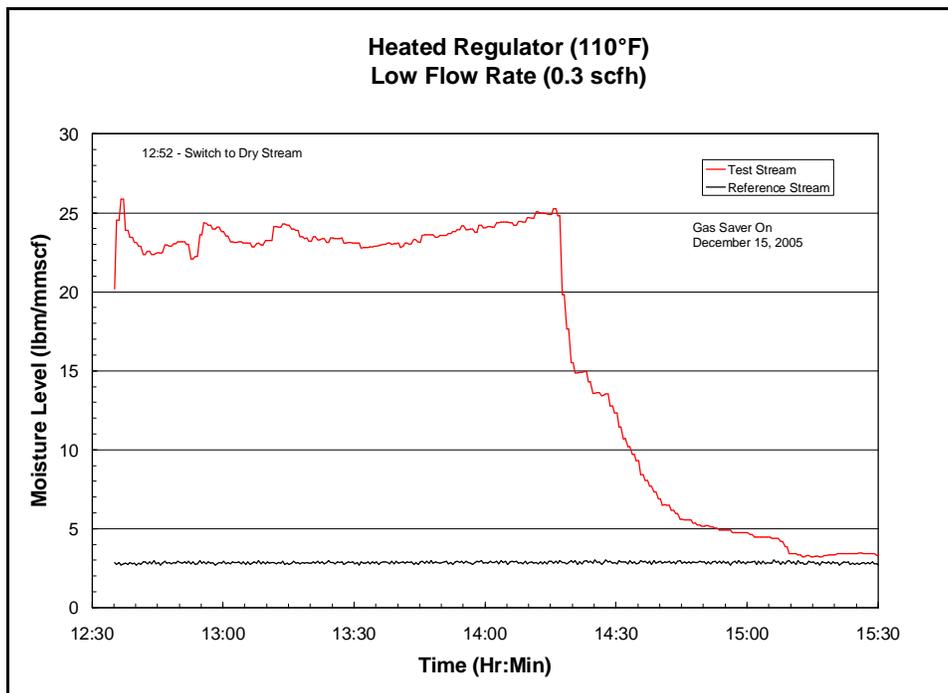


Figure C-6. Time response of the regulated sample line heated to 110°F to a decrease in moisture content at a low flow rate.

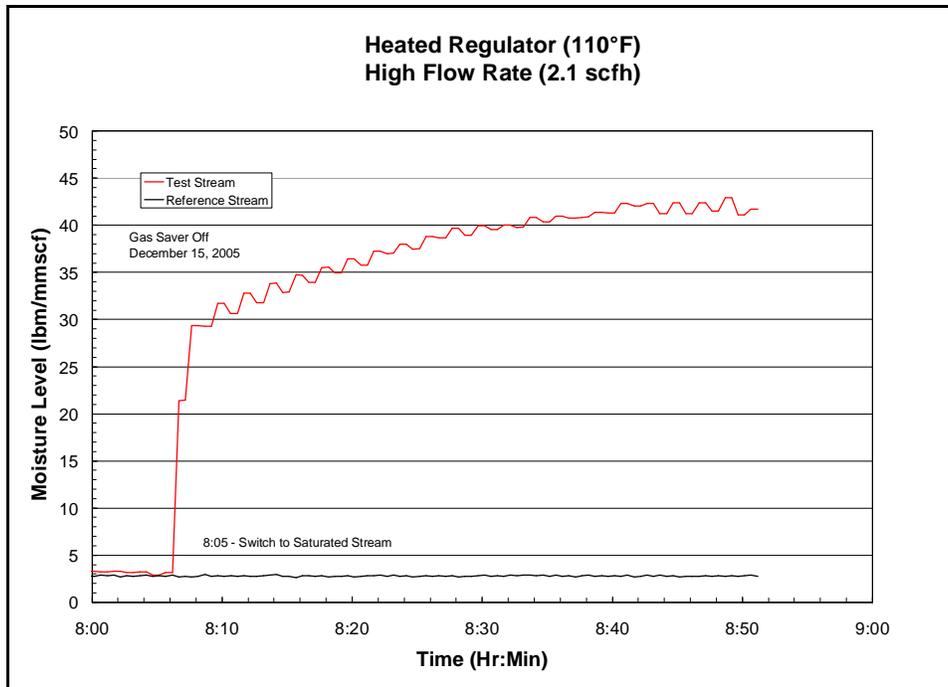


Figure C-7. Time response of the regulated sample line heated to 110°F to an increase in moisture content at a high flow rate.

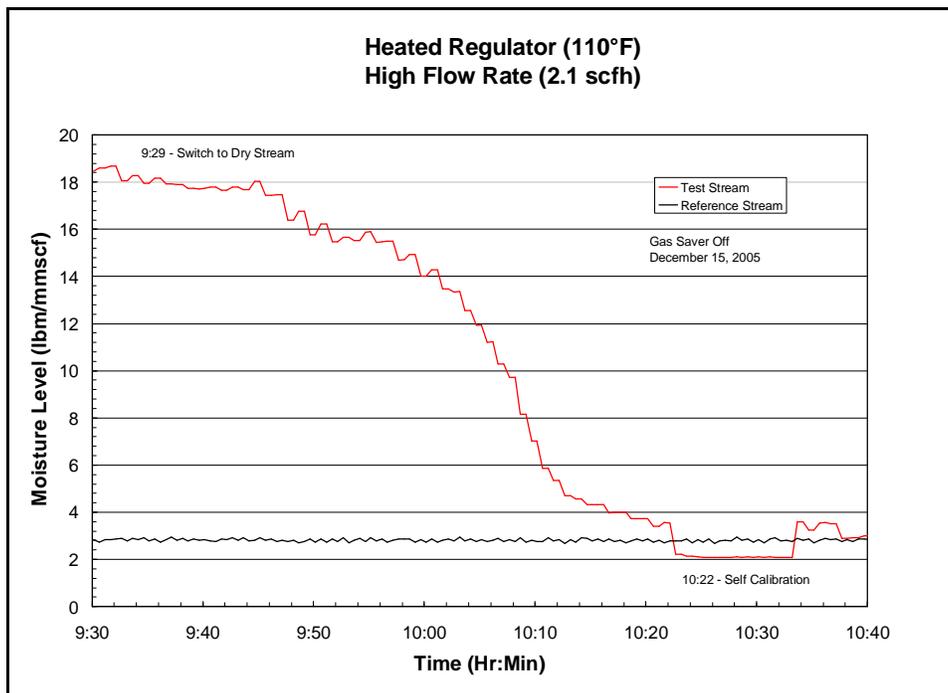


Figure C-8. Time response of the regulated sample line heated to 110°F to a decrease in moisture content at a high flow rate.

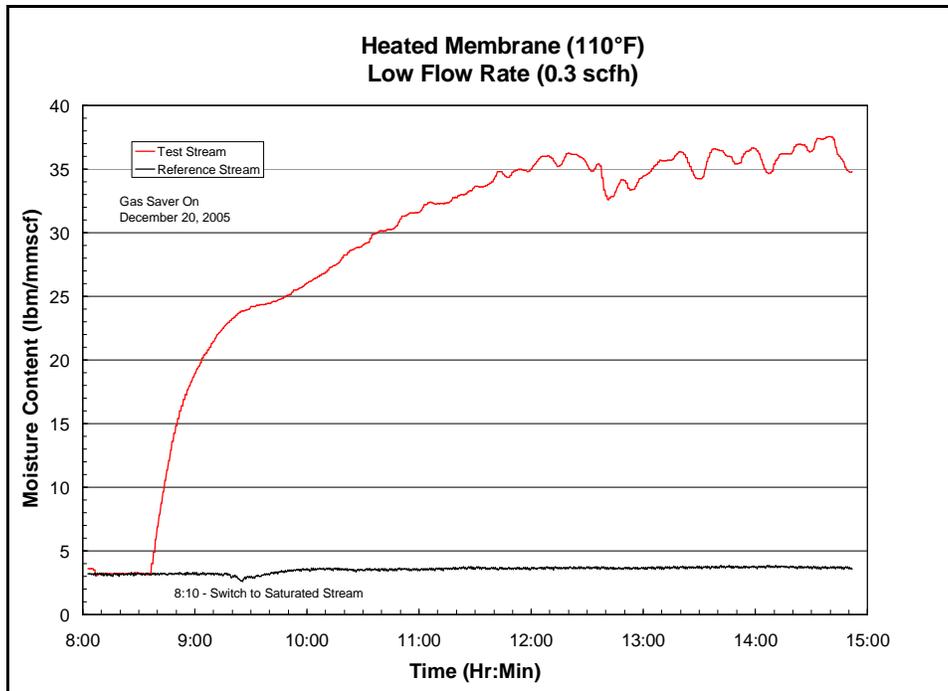


Figure C-9. Time response of the sample line with a membrane filter heated to 110°F to an increase in moisture content at a low flow rate.

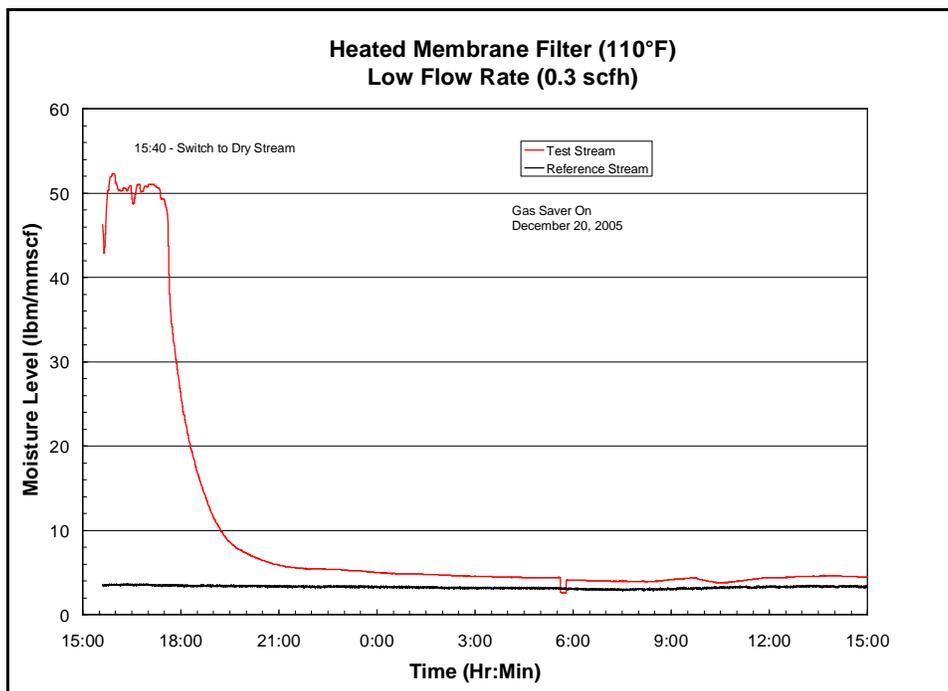


Figure C-10. Time response of the sample line with a membrane filter heated to 110°F to a decrease in moisture content at a low flow rate.

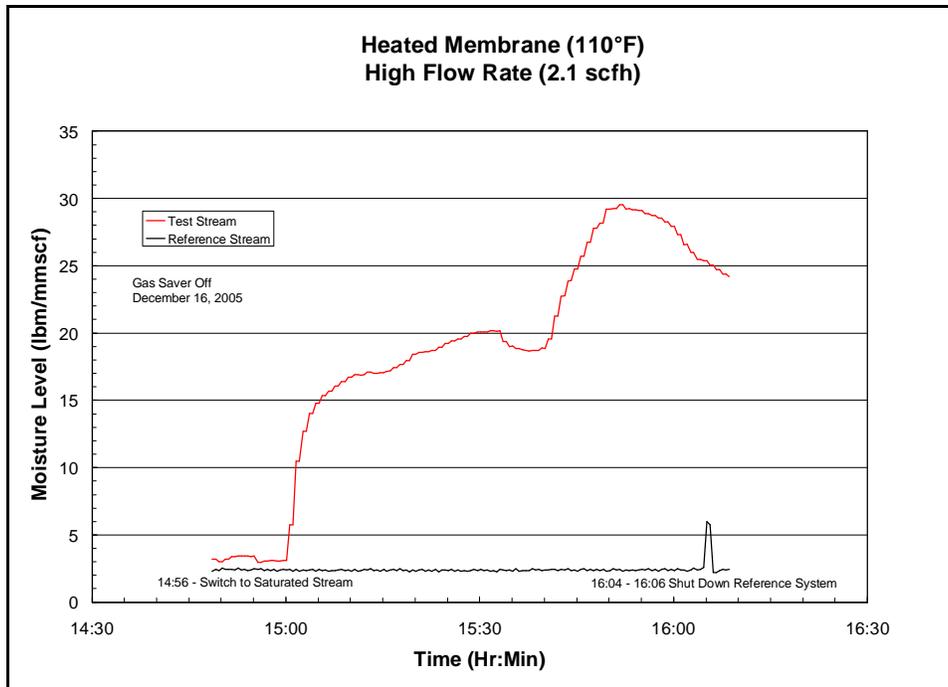


Figure C-11. Time response of the sample line with a membrane filter heated to 110°F to an increase in moisture content at a high flow rate.

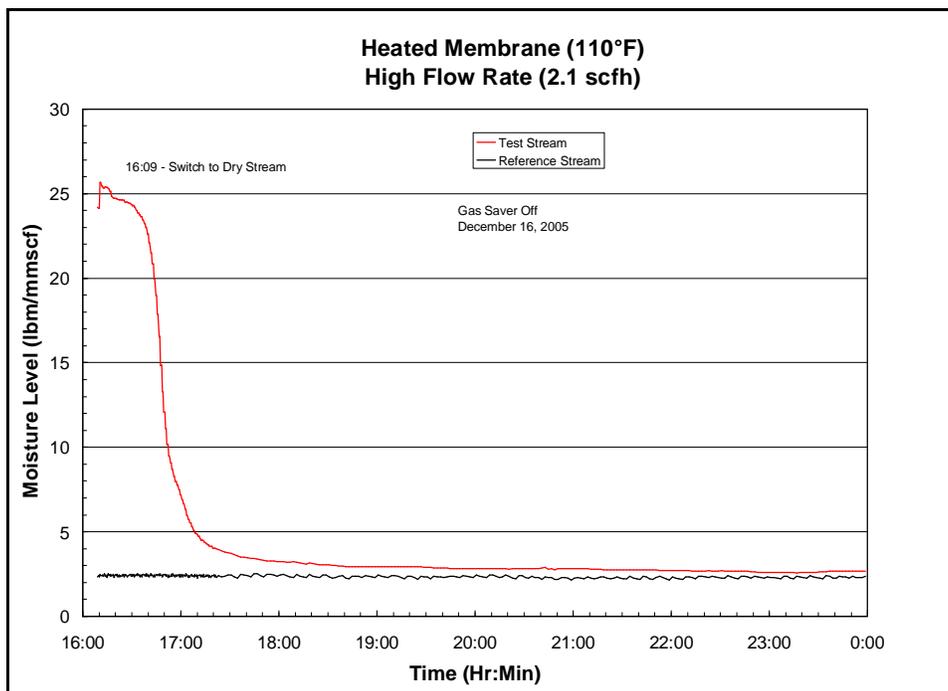


Figure C-12. Time response of the sample line with a membrane filter heated to 110°F to a decrease in moisture content at a high flow rate..