ANNEX IX
Production Measurements Research Projects

CONTENTS

Section **Page**

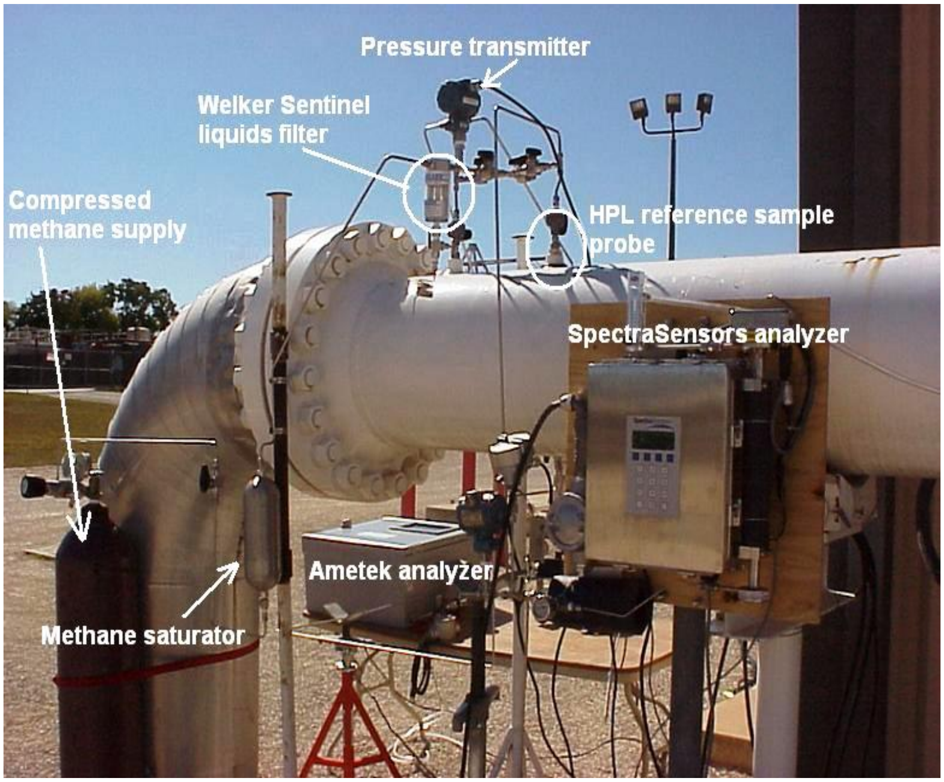
IX.1 SUMMARY OF PROJECTS

This section of the report provides a summary of some significant recent research initiatives and challenges particular to accurate measurement of liquids on production facilities. More detailed summaries of these reports are provided in a later section of this Annex.

IX.1.1 PROJECT NO. 533 – ASSESSMENT OF SAMPLING SYSTEMS FOR MONITORING WATER VAPOR IN NATURAL GAS STREAMS

The effectiveness of typical natural gas sampling and delivery systems for analyzing moisture content was assessed. 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 at the time of the study, 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 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.



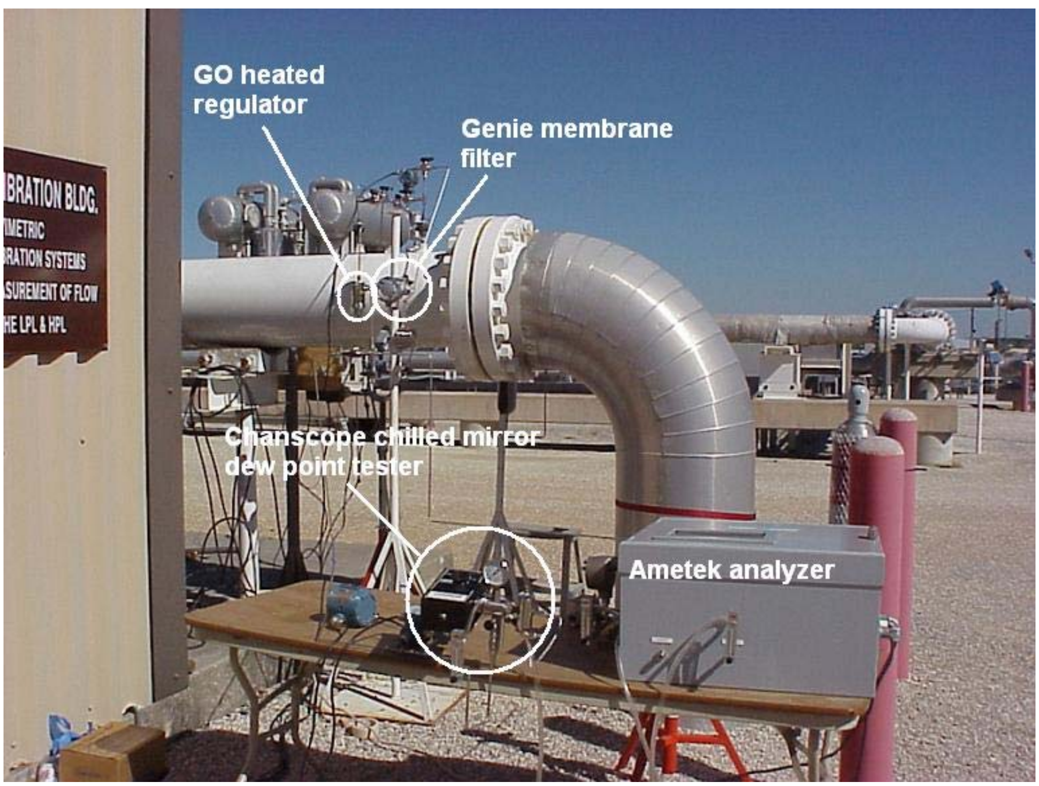


Figure IX.1: The reference apparatus and test sampling systems

IX.1.2 PROJECT NO.534 - DEVELOPMENT OF ACCURATE METHODS FOR PREDICTING HYDROCARBON DEW POINTS

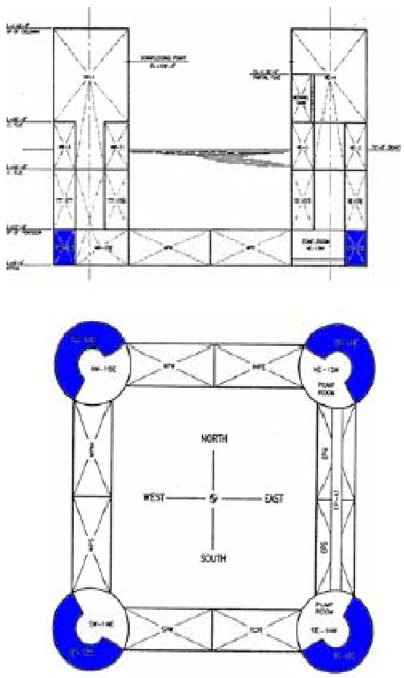
This report indicates that many different calculation methods are available for computing hydrocarbon dew points of natural gas streams from gas chromatograph analyses. These various methods often produce results that are inconsistent from one to another, and for some gas streams, have been found to significantly under-predict hydrocarbon dew point temperatures. This project evaluated the accuracy of several characterization methods, used with common equations of state, in predicting hydrocarbon dew points for a wide range of production, transmission, and distribution gases. In this report, several approaches have been evaluated for predicting hydrocarbon dew points of natural gas streams using compositional data available from field gas chromatographs.

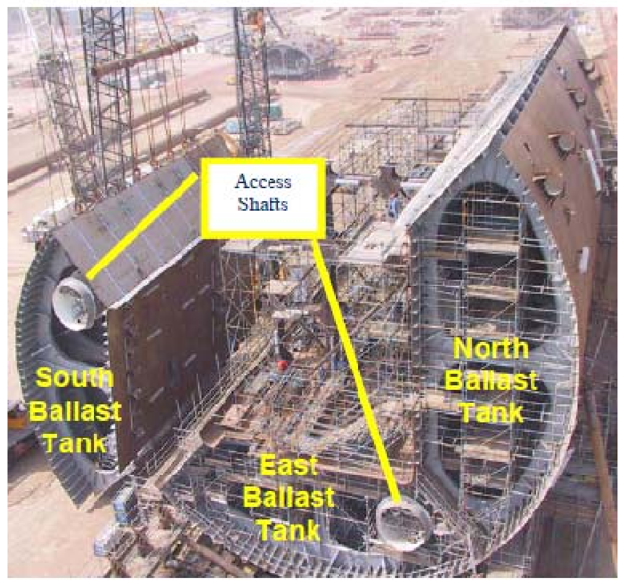
In this report, the primary objectives were to evaluate the accuracy of several C6+ characterization methods used with generic equations of state to predict dew points for a wide range of production, transmission, and distribution gases, and to identify the characterization methods that produce the most accurate predictions for this range of gas compositions. Characterizations were tested using the GERG-2004 equation of state, and the Peng-Robinson and Soave-Redlich-Kwong (SRK) cubic equations of state. The SRK equation of state was found to have advantages over the other equations in predicting dew points. An adaptation of a Gaussian characterization method used by the energy industry was recommended, as it best simulated actual distributions of hexane and heavier components. Also, a method of adjusting the Gaussian characterizations to predict dew points within ±5°F was pursued.

IX.1.3 PROJECT NO.535 - ACCURACY OF LIQUID LEVEL SENSORS

BMT believes that the accurate measurements of the liquid level in a partially filled tank are crucial for detecting the leakage, overfilling, and the dynamic loading, particularly due to sloshing. They also believe that only careful CFD modeling of this phenomenon, based on accurate real measurements, can lead to the solutions appropriate for defining the liquid level sampling intervals. CFD model was validated using the full-scale motion data from Spars.

Using the Spar and TLP full-scale motions, extracted from real measurements, the liquid motion in ballast tanks will be simulated using CFD methods and the liquid level will be predicted at the location where the real liquid level measurement were taken. The measured and simulated results will be compared in both the time and frequency domains. This comparison makes it possible to identify the periods where the real measurements might lack accuracy due to inadequate sampling time. The comparisons with the measured liquid level data to evaluate the accuracy of the liquid level sensors are also provided in this report





TLP

SPAR

Figure IX.2: Typical Tanks on Production Platforms

IX.2 PRODUCTION MEASUREMENT RESEARCH PROJECTS

IX.2.1 PROJECT NO. 533 – ASSESSMENT OF SAMPLING SYSTEMS FOR MONITORING WATER VAPOR IN NATURAL GAS STREAMS

IX.2.1.1 Introduction

IX.2.1.1.1 Background

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.

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.

IX.2.1.1.2 Technical Scope

The scope of work for the project was organized into three technical phases. In Phase One, existing moisture sampling methods and systems were selected for evaluation under a test protocol, and 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.

Phase Two of the project generated a test protocol for evaluation of the moisture sampling methods chosen in Phase One. 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.

Phase Three encompassed the tests of sampling methods selected in Phase One, using the test protocol devised in Phase Two. Tests were conducted of two natural gas sampling configurations: a sampling setup incorporating a heated regulator, and a sample setup incorporating a membrane filter.

In summary, technical scope of the project was 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.

IX.2.1.1.3 Study Limitations

- 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
- As stated in the report, 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.

IX.2.1.2 Project Conclusions

IX.2.1.2.1 Key Conclusions and Results

- The followings address the overall conclusions and results 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.
- 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.

IX.2.1.2.2 OSER Goals

The aim of this project was to document the performance level of various moisture sampling systems 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:

IX.2.1.2.3 Recommendations

The authors recommended:

- 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. 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.

IX.2.1.3 Current State of Knowledge

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.

IX.2.2 PROJECT NO. 534 – DEVELOPMENT OF ACCURATE METHODS FOR PREDICTING HYDROCARBON DEW POINTS

IX.2.2.1 Introduction

IX.2.2.1.1 Background

The hydrocarbon dew point (HDP) of a gas stream can be determined either experimentally, using a chilled mirror dew point tester, or analytically, using composition data from a gas chromatograph and an equation-of-state model. The use of data from an on-site gas chromatograph (GC) is often faster and more convenient, since portable chilled mirror dew point testers must be taken to a particular test site and used by a trained operator. Many different methods are available to the gas industry for calculating hydrocarbon dew points from GC analyses. These include different equations of state, different software packages, and different characterizations used to complete analyses of the heavy hydrocarbon components in the gas blend. However, there is still a critical need to know how well these different approaches can predict dew points that agree with existing experimental data over the full range of natural gas mixtures handled by the gas industry.

In this report, the accuracy of the Peng-Robinson and Soave-Redlich-Kwong equations of state were evaluated using several different methods of characterizing heavy hydrocarbons and various commercial software packages. While a universal characterization method for the heavier hydrocarbon components in a gas blend was not identified, several methods were found to consistently produce inaccurate results. The research reported here completes the evaluation of analytical dew point determination methods. The study has used the results of experiments to help complete a study of the accuracy of common equations of state in predicting hydrocarbon dew points. This study focuses primarily on "characterization methods," methods of correctly approximating the individual percentages of the heavier hydrocarbon components in a given gas blend in order to produce the most accurate predictions.

IX.2.2.1.2 Technical Scope

The scope of work in this study is divided into major tasks as follows:

Evaluate the accuracy of several characterization methods as used with generic equations of state in predicting hydrocarbon dew points for a wide range of production, transmission, and distribution gases.

Identify methods of characterizing heavy hydrocarbons that produce the most accurate dew point predictions for a wide range of natural gases from limited compositional data. In particular, identify characterization methods appropriate for production gases that have previously shown disagreement with results of earlier characterizations. If no existing methods are found with acceptable uncertainties, identify the information needed to derive an accurate characterization method for gases of interest.

Unfortunately, not all equation of state software packages available to the natural gas industry allows the user to tune component properties. Instead, the approach of this study is to find characterizations of normal paraffin that best reproduce observed hydrocarbon dew points using standard properties and parameters. Therefore, the development of improved interaction parameters or new equations of state were not included in the scope of work.

IX.2.2.1.3 Study Limitations

Many different equations of state, software packages, and heavy hydrocarbon characterizations are available to compute hydrocarbon dew points. The choice of characterization method has been identified as the largest source of potential error. However, the use of the actual gas composition with common cubic equations can consistently under-predict dew point temperatures for rich gases at high pressures, sometimes by as much as 25°F. This suggests that the equation of state parameters for various natural gas components may be inaccurate, or may not be valid for all the compositions or conditions of interest.

In this project, during the search for characterization methods, several were identified but set aside as impractical for use by the natural gas industry. It is noted that a constraint in defining pseudo components for petroleum characterizations is that the molecular weight and specific gravity of the characterized mixture must equal the measured properties for the heavy hydrocarbon fraction being characterized. This has led to many correlations for estimating properties of the heavy fraction, most of which require data on specific gravity, molecular weight and/or normal boiling points as input. Such measured fraction properties would be available during a petroleum distillation process, but not from a GC analysis of a natural gas stream. As a result, most petroleum characterization methods cannot be used by the natural gas industry, or must be significantly modified to use only available data.

IX.2.2.2 Project Conclusions

IX.2.2.2.1 Key Conclusions and Results

This project began in 2001 and sought to assess the accuracy of various analytical methods used to determine the hydrocarbon dew points of production, transmission, and distribution natural gas mixtures. Initial evaluations were limited by the amount of acceptable phase behavior data available for comparisons. A small set of hydrocarbon dew point data was collected through a literature search in 2002 and 2003 and used to evaluate common methods of computing hydrocarbon dew points.

Approximately 1800 comparisons were performed using the various characterization methods, equations of state, and documented gas compositions and dew points. The SRK equation of state was found to have advantages over the other equations in predicting dew points. An adaptation of a Gaussian characterization method used by the petroleum industry was recommended, as it best simulated actual distributions of hexane and heavier components. A method of adjusting the Gaussian characterizations to predict dew points within ±5°F was pursued.

However, limited experimental dew point data from the literature prevented the research from successfully creating a generally acceptable method. It is recommended that users gather field dew point data for their own gas streams to tune their characterizations and predict the most accurate dew points using the Gauss-gamma characterization method. Additional research is needed to collect more dew point data with defensible uncertainties to resolve remaining hydrocarbon dew point prediction issues.

IX.2.2.2.2 OSER Goals

Hydrocarbon dew points are often used as a measure of the quality of a natural gas stream, and as a criterion for assessing compliance with transportation tariffs. Accurate hydrocarbon dew points will be crucial in the future in accommodating the introduction of LNG and marginal gas supplies into the natural gas transmission network. However, limited experimental dew point data from the literature prevented the research from successfully creating a generally acceptable method.

This report addressed this issue and provided guidance for the preparation of an American Petroleum Institute standard for calculating hydrocarbon dew points. This project also suggested technique in the petroleum industry is to tune the properties of each component used in a heavy hydrocarbon characterization, so that calculations with the new component distribution and component properties best match observed data.

IX.2.2.2.3 Recommendations

The authors recommended procedure for predicting hydrocarbon dew points of a pipeline gas stream using the Gauss-gamma characterization, C6+ analyses from a field GC, and field dew point measurements are:

1. During a scheduled field site visit, measure the hydrocarbon dew point of the gas stream using a Bureau of Mines chilled mirror device. Take measurements at multiple pressures if possible.

2. If a current field GC analysis of the stream at that location is available, record the C6+ or C9+ analysis from the GC.

3. Use the measured dew points to determine if heating of sampling equipment is necessary, and then obtain a spot sample of the stream for extended laboratory analysis to C9+, or out to C12+ if possible.

4. Use the C9+ laboratory analysis, along with the SRK equation of state, to compute dew points for the gas stream. No one software package is recommended over another, but the default binary interaction parameters should be used.

5. If the computed dew points of Step 4 predict the measured dew points with sufficient accuracy, use the distribution of hexane and heavier components from the lab analysis as the C6+ fraction characterization to predict dew points from future C6+ GC data.

6. If the C9+ laboratory analysis does not reproduce the measured data to within the desired accuracy, use the C6+ field analysis of the gas stream and the Gauss-gamma method. Repeat the dew point calculations using these Gauss-gamma characterizations.

7. Compare dew points computed using the various Gauss-gamma distributions to the measured dew points. Select the characterization that most closely predicts the observed

dew points. Use this characterization with future C6+ GC analyses to predict dew points at this location.

8. If any indications are found that the heavy hydrocarbon composition has changed at this location, the process should be repeated.

In this report, it is also suggested that users gather field dew point data for their own gas streams to "tune" their characterizations and predict the most accurate dew points. Meanwhile, some researchers have suggested creating entirely new equations of state to address dew point accuracy issues, a goal which would also require new dew point data. Additional data is also a necessity for assessing methods of measuring hydrocarbon dew points, such as automated devices now entering the natural gas marketplace.

IX.2.2.3 Current State of Knowledge

Two of the most common equations in use by the natural gas industry, both of which were applied in this work, are the Peng-Robinson EOS and the Soave-Redlich-Kwong EOS. Both are referred to as "cubic equations" because they can be rewritten as cubic polynomials in the specific volume term v. Indeed, both of these equations can be written in the same algebraic form, simply using different values for some of the parametric coefficients.

During this project, a new equation of state from Germany was introduced to the natural gas community. This EOS, known as GERG-2004, is intended for use in computing gas, liquid, and vapor-liquid equilibrium conditions, and is being considered by the industry for use in hydrocarbon dew point prediction. At the request of the Project Advisory Committee, this equation was also evaluated for its accuracy in predicting observed dew points. Section 3.2 briefly reviews this equation of state and its range of validity.

IX.2.3 PROJECT NO. 535 – ACCURACY OF LIQUID LEVEL SENSORS

IX.2.3.1 Introduction

IX.2.3.1.1 Background

Any motion of the free surface inside container is called sloshing. It is known that partially filled tanks experience liquid movement that can be observed as motions of the free surface in the form of standing waves or sloshing. The cause of sloshing can be any disturbance. It can be induced by motions of the container or by pressure disturbance above the free surface or inside the body of liquid. In ship transportation and oil production, the global motions of the vessels can cause liquid sloshing.

In this case, the liquid motions strongly correlate with the motions of offshore platform, if the liquid motion resonant periods are close to the platform motion periods. MMS has indicated that the common MMS practice of sampling the liquid levels in the tanks on some platforms, such as Spars and TLPs, using 20-second intervals might not be good enough, and thus this sample rate needs to be re-evaluated.

IX.2.3.1.2 Technical Scope

The scope of work in this study is divided into four major tasks as follows:

- Full-scale measurement data acquisition and designation
- System identification and data preparation for numerical modeling
- Numerical, CFD modeling and simulations
- Data reduction and reporting

IX.2.3.1.3 Study Limitations

In this study, tank fluids are limited to water. The only available real-time measurements that have been archived on the offshore platforms are the ballast tank levels. Some other tank level data, such as the levels in oil-water-gas separators and fuel tanks either are not permanently recorded or they are not available. Thus, for this study we use measurements of the water level in the ballast tanks to calibrate the effectiveness of the CFD code.

In summary, the existing CFD CFX code can be successfully used to model and predict the behavior of a liquid in ballast tanks on spars and TLPs. However, the cases that we discussed here are specific to the ballast tanks on the most common offshore platforms: spars and TLPs. If different types of platforms or ships, e.g., the LNG carriers, with tanks of different shapes and internal compartmentalization are of interest, the liquid sloshing dynamics can be of different nature. Consequently, the conclusions derived from this study can be different.

Types of platforms are limited to spar and TLP. These types of platforms are not only the most typical deepwater platforms but also their principles of operation and effectiveness to sustain in a harsh environment are quite different: Natural responses of a spar are at relatively low frequencies whereas responses of a TLP are at relatively high frequencies; both frequencies are beyond the normal wave frequency range, thus the effects of the platform motion excitation frequencies are minimized.

Nevertheless, the CFD is a powerful method, computationally time demanding, but if modeled correctly, the sloshing effects can be predicted reliably and the time delays can be incorporated into the alarm system to prevent spurious alarms.

IX.2.3.2 Project Conclusions

IX.2.3.2.1 Key Conclusions and Results

- The full-scale global motions of oil platforms at the location of a liquid tank have been derived from available real measurements on three deep ocean oil platforms: Medusa and Front Runner Spars and Marlin TLP.
- In addition to the platform global motions that represent the main driving force for liquid commotion in the ballast tanks, the characteristic parameters of liquid motion -- elevation and frequencies -- are identified.
- The occurrence of sloshing in a tank has been identified in full-scale liquid level data using the methods such as wavelets and coherence spectra.
- The equivalent numerical CFD models have been built that match very fine details of the ballast tank prototypes. Not only was the overall geometry modeled, but also the structural members inside the tanks were modeled to capture complicated interferences between the liquid and the tank.
- The CFD model was validated using Medusa Spar data. Blind calculation of the liquid level in one of the Medusa Spar ballast tanks was performed. The analytical and measured results of the liquid levels in time domain match very well.
- The full-scale measured liquid level data are available only at one location in a tank. CFD calculations have been expanded for multi-point sensor system arrangement at five locations around the circumference and at the middle of the tank. Analytical results show that the location where the liquid level is calculated (measured) has a significant influence on the capability to detect liquid sloshing.
- Comparisons of full-scale and simulated data show a high degree of confidence for the numerical CFD modeling

- Compare simulated data for different liquid levels in a tank and identify trend in the results.

IX.2.3.2.2 OSER Goals

The BMT Scientific Marine Services Inc pioneering Integrated Marine Monitoring Systems (IMMS) have been provided to over 30 deepwater platforms across the Gulf of Mexico, West Africa, Newfoundland, and Brazil. These systems employ field proven technology that integrates all elements of platform monitoring—often operated independently—into a single system, thus ensuring that all operating performance variables can be analyzed together.

IX.2.3.2.3 Recommendations

The authors recommended:

- Results show that sampling interval can affect the accuracy of dynamic liquid level measurements if the sampling intervals are longer than the excitation disturbances. In the case of an offshore platform, whether a Spar or a TLP, the platform motions correlate well with waves (even though the platform motions are negligibly small) within the expected wave period range of 4 to 15 seconds. Thus, a 20-second sampling interval that is of the main concern for MMS is too long for the dynamic measurements of the liquid level in a tank.
- It is not recommended to set the liquid level sensors to operate at intervals that are longer than half the expected wave period (2 seconds). The sampling intervals that are in place on the platforms used in this study are appropriate. For some other platforms and different types of tanks, the longest allowable sampling intervals should be determined based on either the measurements or a careful CFD modeling. The appropriate solution for recommending the sampling rates that would not trigger false alarms should be defined on a case by case basis, taking into account the nature of the problem and the geometry of the tank.
- On the other hand, if the primary goal is to monitor the amount of liquid in the tank for leaking, it is recommended to use longer sampling intervals. This would result in smoother and more stable running average values, so the free surface sloshing would not affect the level regulators. If the sampling time was reduced, the results would be just the opposite. However, the criteria for sampling rate need to be determined based on actual tank properties and the purpose of liquid level measurement.

IX.2.3.3 Current State of Knowledge

The sampling rates for the liquid level measurements are much lower (longer sampling time intervals) than the sampling rates for the motion data. However, these relatively low sampling rates for liquid level measurements in the tanks are at least two to ten times higher than the target sampling rate of 0.05 Hz (20 seconds) that MMS wants to be investigated. Thus, the numerical, CFD model can be validated for the sampling frequencies as high as the sampling rate for the input motion data. The comparisons with the measured liquid level data to evaluate the accuracy of the liquid level sensors are possible only for up to 0.5 Hz.