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Subsea Deepwater Measurement – Technology Gaps and Solutions

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1 INTRODUCTION

As early as 1999 when Gulf of Mexico Deepwater projects passed the one-mile water-depth mark, the importance of good flow measurement on the deep sea floor was apparent. In contrast to the comparatively simple exploration and production operations carried out on the continental shelf, similar work in deepwater is exponentially more challenging. A good example of this is the recently started Perdido development in the Alaminos Canyon region of the GoM, about 350 kilometers south of the city of Galveston, Texas near the boundary with Mexican waters. Shell operates the Perdido Regional Development (35%) on behalf of partners Chevron (37.5%) and BP (27.5%). As illustrated in the Figure 1 shown below, there are currently three fields in development, all being produced back to a common set of production facilities on the Perdido Regional Spar. Wells in the Great White, Silvertip, and Tobago developments are in water depths ranging from 2360 to 2940 meters.

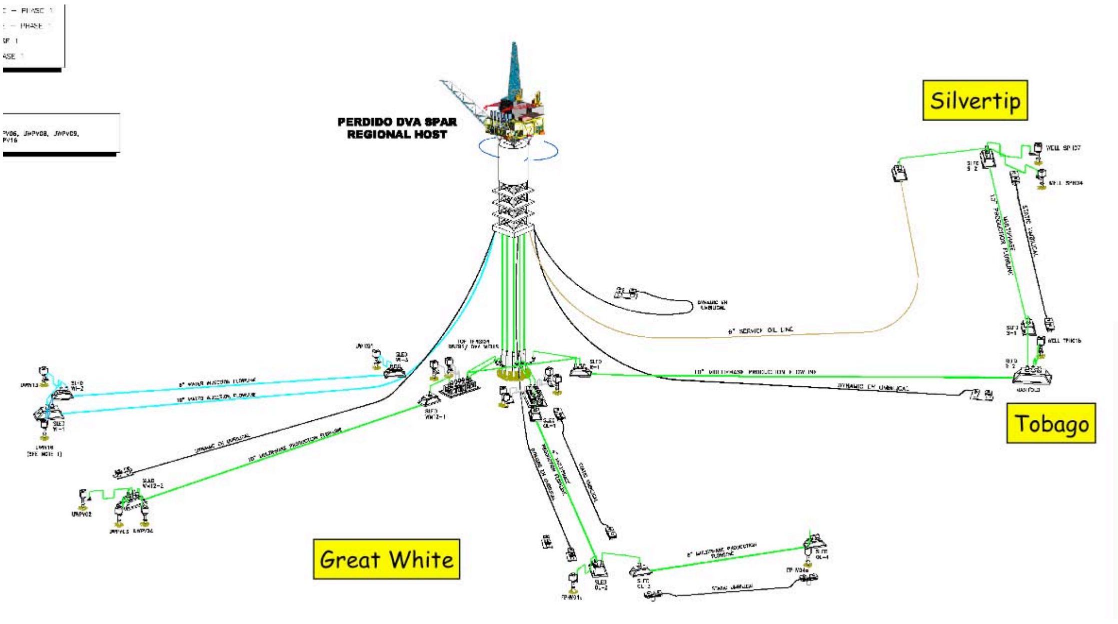

Figure 1. Schematic of the Perdido Regional Development.

The level of technical difficulty in creating this deepwater production system is truly enormous. In addition to the water-depth records that the spar platform and individual wells will set, a number of other problems required solutions to efficiently produce the hydrocarbons. The commingling of wells both within and among fields required multiphase measurement on many, though not all wells. Electrically submersible pumping systems (ESP) were required to enable the production, which necessitated subsea caissons as separators of liquid and gas. Additional innovations were required to complete this complicated production system. While the Perdido development is indeed a difficult and complicated system, it is certain that future developments will be equally challenging, often more so.

The implications on measurement techniques and technology of challenging developments like Perdido are considerable, and have been recognized for a number of years. Beginning in the first half of the 1990’s, operators in the GoM began to realize that measurement technology was ill equipped to deal with these future deepwater requirements, and began to discuss what could be done. A group of measurement specialists representing several of the major operators decided to address the issues collectively rather than individually.

In Q3 of 2005, after a one-day DeepStar workshop to identify deepwater measurement gaps, a CTR for DeepStar funding was submitted and approved, resulting in the two-year Project 8302, *Improved Multiphase Metering for Subsea Tiebacks*. These gap investigations brought together skills from operators, engineering companies, and vendors to address the issues. The project goals were, however, somewhat limited by budget; funding was not sufficient to perform laboratory experiments, build prototype equipment, etc.

During its final year, the DeepStar 8302 Steering Committee decided to extend the research by submitting a CTR to the Research Partnership to Secure Energy for America (RPSEA). Because the need for new exploration and production technology is large and growing, the US Department of Energy (DoE) established RPSEA in 2006 to fund promising approaches to innovative E&P technology. Recognizing that improved deepwater measurement is a critical need in the development of America’s reserves, RPSEA in 2008 awarded a contract to the Letton-Hall Group for Project DW1301, *Improvements to Deepwater Subsea Measurement*, to address gaps in deployment and use of multiphase and wet gas meter technology in deepwater production systems. The DeepStar work had been a key precursor to the RPSEA effort – essentially the “pre-project” to DW1301, in which the stage was set. More on the DeepStar Project 8302 can be found in Reference [1].

Six DW1301 Tasks were identified as pivotal in closing the gaps:

- **Deepwater Subsea Sampling.** Development of methods for standardized deepwater well fluid sampling
- **ROV-Assisted Subsea Measurement.** Development of techniques for conveyance by ROV of clamp-on measurement to the sea floor
- **HP/HT Sensor Qualification.** Development and qualification of DP sensors for HP/HT applications
- **Evaluation of Flow Modelling.** Evaluation of the effectiveness of wellbore flow models, such as virtual flow meters
- **Meter Fouling Effects.** Understanding of how fouling of meters affects their response
- **Metering System Uncertainty**. Development of tools to model uncertainties in a subsea-topside measurement system

Work on these six tasks began in October 2008 and is scheduled to conclude in Q1 2011.

2 WHY SUBSEA MEASUREMENT? WHY IS IT DIFFICULT?

Before considering the specifics of the RPSEA Project DW1301, the reasons for subsea measurement should be reviewed. In particular, the question of why measurement should be made at the sea floor rather than topside should be answered.

Although there are many reasons for subsea metering, the most universal is simply this: the world of deepwater production is driven by economics. The cost of equipment rules how the fluids will be produced and conveyed to the surface, forcing measurement practices to adapt to this reality. Given the fact that the cost of deepwater, high-pressure oil or gas flowlines are typically $5 – 10 million per kilometer, the business driver here is clear, viz., minimize the need for subsea pipelines in any given situation. By commingling production as soon as feasible, test lines are eliminated, saving tens of millions of dollars.

The implications of commingling on well flow measurement are significant, however. Tests on Individual wells through production flowlines are simply not practical, mostly due to the cost of deferring production. Thus, one is inevitably led to the conclusion that in deepwater scenarios some form of local subsea measurement is the only practical way to get individual well rates.

But one must question how reliably the measurement of multiphase flow from each well can be made. Can a meter that was installed on a well at the startup of the field be relied upon to give reasonable oil, gas, and water flow rates measurements five, ten, or twenty years later? Is it possible that something will change? Might the properties of the produced fluids have changed? Perhaps the well has produced substances that now coat the inner walls of the meter, and if so would the normal meter response be altered?

The important point is that conditions likely will change with the passage of time. Whether due to the properties of the fluid or the condition of the meter itself, responses of multiphase flow meters change over time, and not always in a small way. When one considers the possible costs of poor measurement, understanding what is required for proper flow rate measurement is clearly of crucial importance.

3 ADDRESSING THE GAPS

All six major Tasks have been underway for the past two years. Although the final results of each have not been compiled yet, example results from each are provided in what follows.

3.1 Deepwater Subsea Sampling

In this task, existing sample systems and conceptual designs of sampling systems deployed via ROV were reviewed for their potential as standardized sampling systems. From a total of eleven different ideas that were considered, the concept selected for implementation is shown in the schematic of Figure 2. This candidate system was designed and fabricated, and has undergone testing at both the SwRI multiphase reference flow loop in San Antonio, Texas, and the Oceaneering ROV Subsea Simulation Facility in Morgan City, Louisiana.

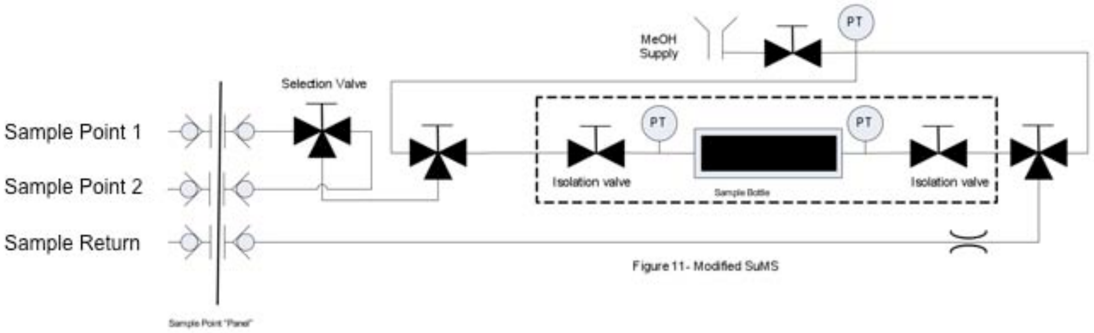

Figure 2. Sampling concept chosen for implementation.

In the schematic the three-way valves permit the selection of the appropriate sample point from either of the two in the figure, or from the MeOH flushing supply as shown. This flow-through concept was that selected from among the eleven that were considered, but is by no means the only form of sampling system that can be accommodated by the design, nor are there limitations on the numbers of sampling points that could be used.

A key objective of this Task is to encourage a market for innovative deepwater sampling services. Draft standards for sampling interfaces and operations are being developed and will be provided as task deliverables. The intent is to encourage other ROV operators and providers of sampling equipment to offer sampling services for the industry.

A possible rendition of the system as it is being carried by an ROV to a wellhead tree is shown in Figure 3 below. The front and rear of the actual prototype ROV-conveyed sampling panel while it was in test at SwRI are shown in Figure 4.

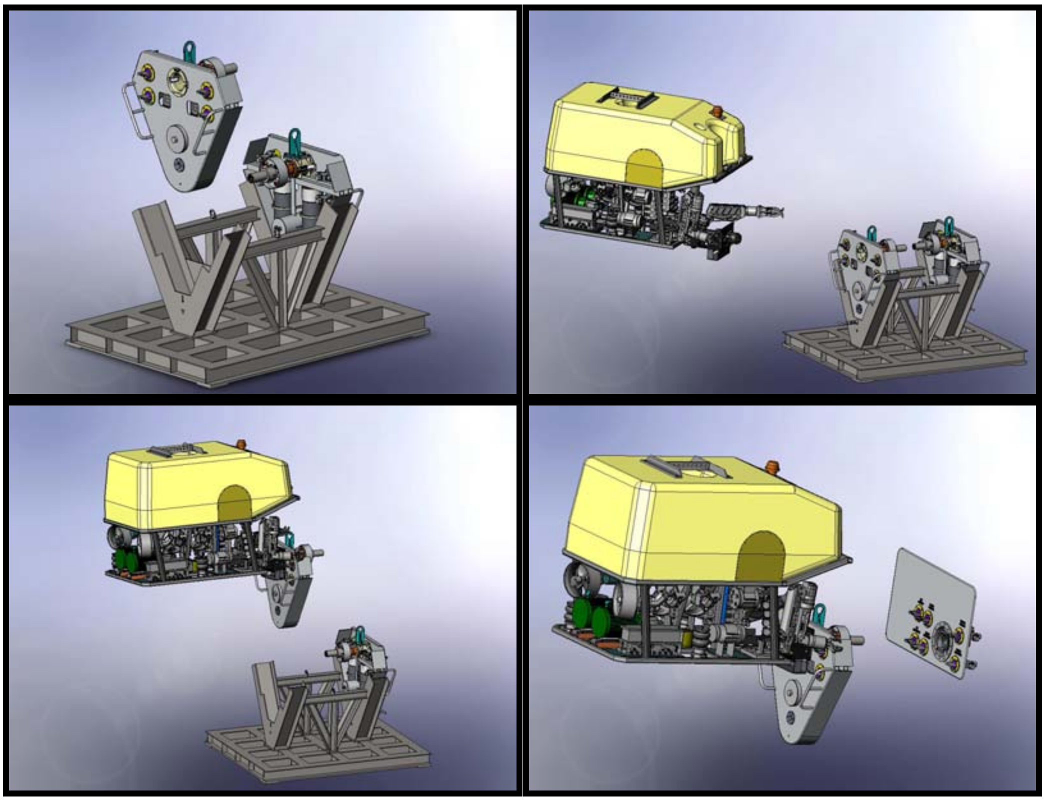

Figure 3. Operational concept showing subsea sampler module and deployment frame, ROV approach to deployment frame, sampler module retrieval, and tree panel approach.

Figure 4. Front and rear of ROV-conveyed sampling panel, sample bottle shown on right.

3.2 ROV-Assisted Subsea Measurement

The goal of this task is to develop methods through which supplementary measurement can be delivered to a subsea metering site to verify the proper operation of a multiphase meter already in place in the subsea pipework.

As was the case with the subsea sampling task, a major objective here is also to develop and document standard interfaces between the metering equipment and the ROV, in order that other meter vendors and ROV operators can use the results to become market participants.

Much consideration was given to constraints on the measurement equipment, resulting in the development of a path forward for deployment of increasingly complex measurement systems at deepwater subsea locations as documented in [2]. After much deliberation, the approach taken for this work was that of a clamp-on meter, i.e. one in which there is no penetration of the pipe wall. In the current work the device was not deployed at an arbitrary point in the pipework, but required a landing zone, a portion of pipework equipped so that the meter clamps on in the same location and orientation each time it is used.

A diagram of the operational concept is shown in Figure 5. Once the ROV has successfully placed the unit on the landing zone and established a clamp to the pipe, the source and detector units are pushed forward into their proper position on the sides, and measurement activity can begin.

The measurement device chosen for developing and demonstrating the methodology in a prototype system was the Neftemer multiphase flow meter, which consists of a gamma ray absorption system coupled with innovative data processing algorithms. More about the Neftemer offering can be found at http://www.neftemer.com/ or in Reference [3].

The Neftemer meter, which had never seen service offshore, was marinized in a prototype system similar to that shown in Figure 5. The prototype system has undergone testing both at the SwRI multiphase reference flow loop in San Antonio, Texas, and at the Oceaneering ROV Subsea Simulation Facility in Morgan City, Louisiana. In Figure 6 are shown the assembled, marinized prototype and the setup for testing the unit at SwRI.

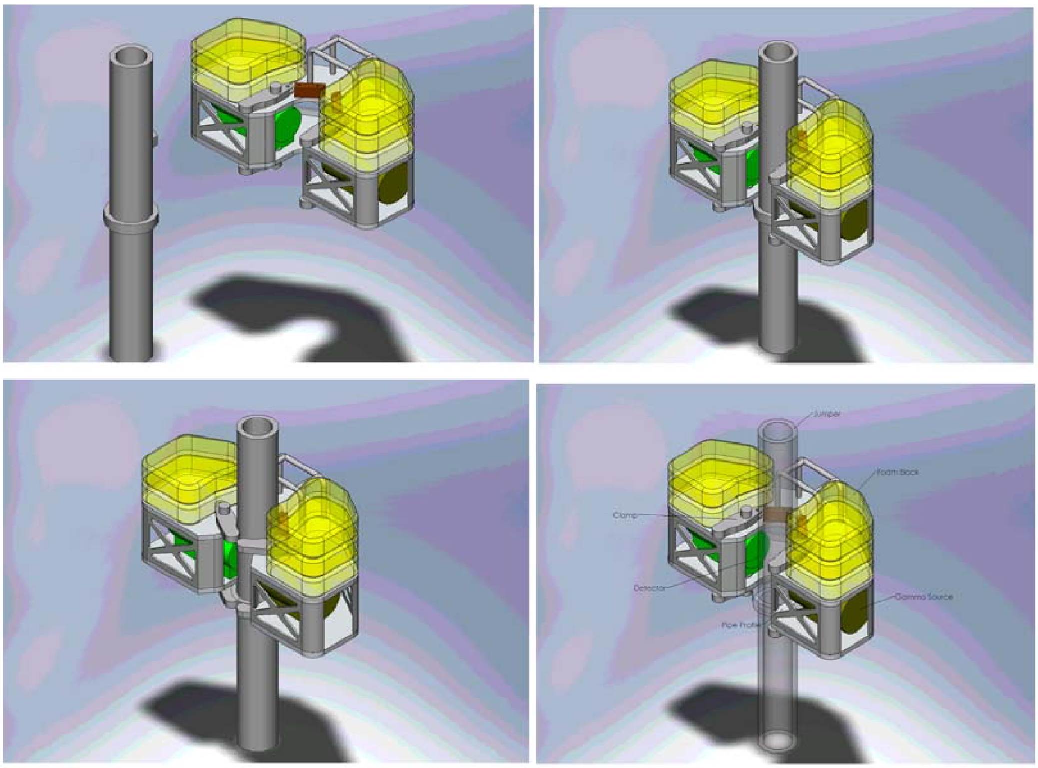

Figure 5. Concept of ROV measurement conveyed to vertical pipe with landing zone. The yellow sections are flotation foam; green source and detector elements are shown beneath.

Figure 6. On left, marinized ROV-conveyed Neftemer meter in delivery frame. Flow test setup at SwRI shown on right, with wooden tank for submersion of meter during tests.

3.3 HP/HT Sensor Qualification

Most of today’s subsea multiphase and wet-gas flow meters are limited in operational environment to a maximum temperature of 125°C and pressure of 10,000 psi. To qualify for operating pressures of 15,000 psi and temperatures of 250°C, the flow meters must be tested at 22,500 psi, which requires improvements in the design of their mechanical components. Both pressure and temperature limits are daunting, especially for differential pressure (DP) sensors, a key component in virtually every multiphase or wet gas meter.

The goal of the task is thus to develop prototypes of packaged HP/HT sensor cells, using micro machined silicon components, for DP measurement in the “extreme” HP/HT operating range. The cell will include a line-pressure sensor to correct the DP measurement for common-mode effects. Prototypes of the sensor cells will be packaged as transmitter assemblies for HP/HT testing.

A reasonable question one might ask is why DoE and RPSEA should develop a component that is normally purchased commercially by meter vendors. The simple answer is that this market for high-performance DP sensors will be quite small, probably fewer than 1000 units over the life of the product, and therefore not very attractive for makers of such devices.

Samples of the micro-machined silicon differential and line pressure sensors are shown in Figure 7 below. In Figure 8 is shown the prototype oil-filled cell that houses both elements.

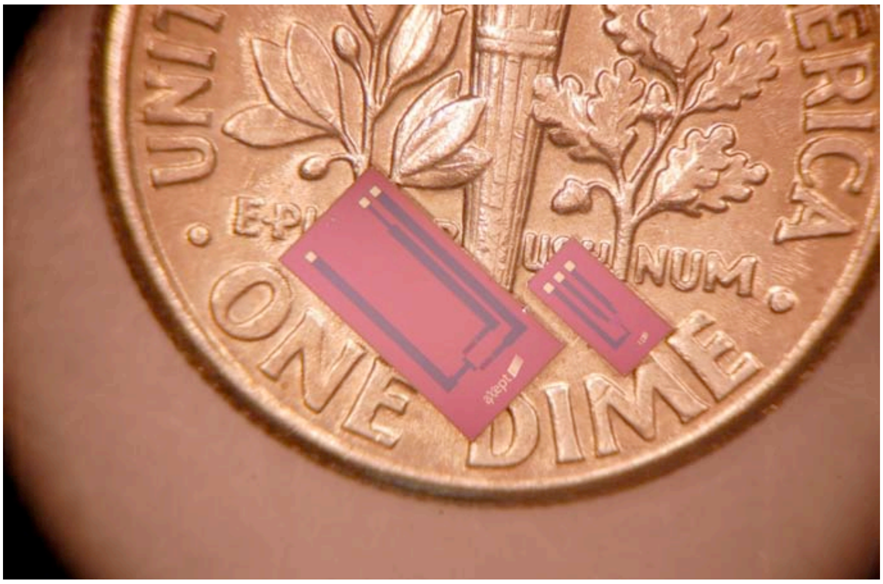

Figure 7. HP/HT differential and line pressure sensor prototypes

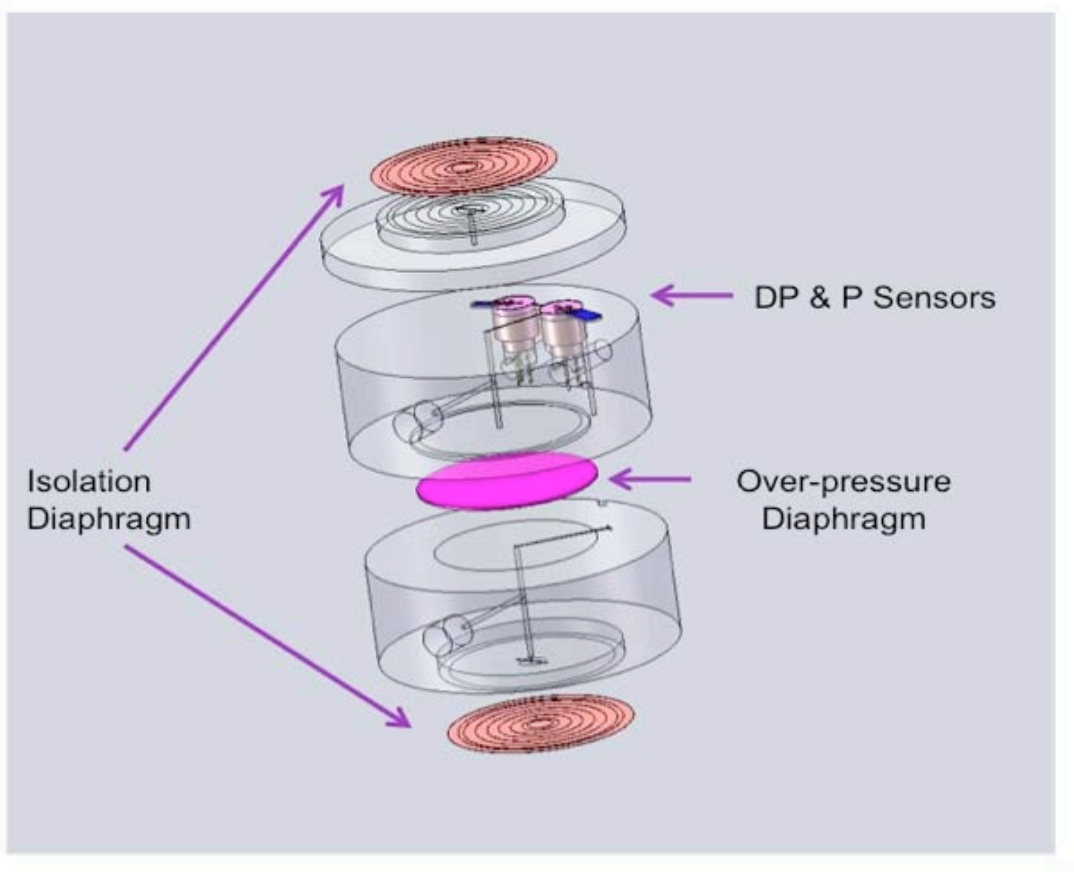

Figure 8. Exploded view of cell containing xHP/HT sensor chips.

3.4 Evaluation of Flow Modelling

The objective here is to address the gap in documented studies of virtual flow meter (VFM) technology by critically evaluating the performance of current VFMs. This is being done by comparing the predictions of VFMs with simulated field data constructed from commonly used flow models. The intent of these evaluations is to document the performance of VFMs as a group, and as generic sub-groups within the larger family, identifying areas of strength and weakness. If successful, the effort will encourage the utilization of VFM technology in monitoring or allocation applications, in those cases where it is an appropriate fit.

Originally it was intended to perform the evaluations using actual field data from flow meters and other measurement sources. Unfortunately, getting actual field data proved so difficult that the decision was made to use only simulated data in the current effort.

In order to enlist the active cooperation of the commercial VFM vendors, the results of the investigations will be presented in an anonymous fashion, avoiding the identification of specific vendors.

3.5 Meter Fouling Effects

This work addresses gaps in understanding the ways in which production alteration of meters affects their response. It is well known from field operations that meters can become fouled or altered by deposits of scale, wax, asphaltenes, and hydrates, as well as from the processes of corrosion and erosion. The effects of these on measurement are not well understood, thus the primary objective of the work has been to understand their nature and magnitude.

The original plan was to perform experiments to evaluate the effects of alteration on some commonly used multiphase meter elements such as Venturi, Cone, and wedge. Alteration mechanisms would be either deposition (scale or wax) or erosion. The Task Working Group (WG) agreed that scale was the major deposition problem in deepwater, and that erosion was the next most important issue. For these reasons, these were the two phenomena chosen for investigation. Through the generosity of ConocoPhillips, a sand erosion experimental data set for a Venturi meter was made available at the start of work. Additionally, the WG made a key decision early on to augment the laboratory measurements through the use of Computational Fluid Dynamics (CFD).

The resultant research program has included both lab and CFD experiments run on Venturi, cone, and wedge meters, for both scale build-up and erosion effects, the latter in both liquid and gas mixtures.

For more details on the use of CFD in this task the reader is referred to [4].

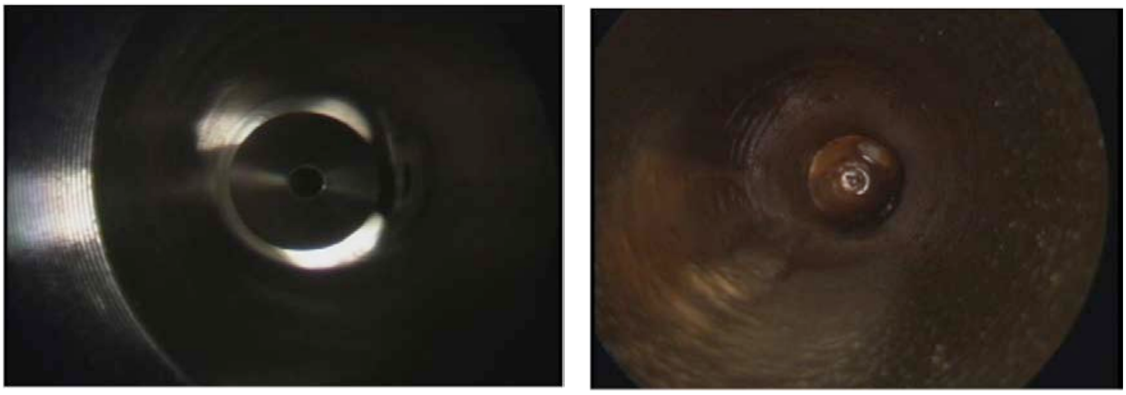

Figure 9. Interior of a cone meter and its associated pipework before and after scale deposition on its surfaces

An example of the kinds of experimental results achieved is shown in Figure 9 above, with the deposition of scale on the interior surfaces of a cone meter. The work, performed at Intertek's facilities in Houston, demonstrated the dramatic effect scale can have on the response of the three kinds of devices tested, with the measured discharge coefficient reduced by as much as 35% in some cases.

3.6 Metering System Uncertainty

The intent of this task is to develop methods to provide users the ability to calculate the uncertainty in flow measurement at the subsea meter, at the topside separator, and at other points in between. Merging carefully developed models of multiphase flow with separator and meter models in a unified system provides a useful tool for the production engineer.

Figure 10 illustrates some of the components used by the tool. Uncertainty performance of the various components of the system – downhole and subsea pressure and temperature sensors, subsea or topside multiphase meters, a length of tieback pipeline, a topside separator with single-phase flow and watercut meters – are input into the system through spreadsheets, as is the system geometry.

The tool uses separate models for gas-dominant and liquid-dominant systems. Base Cases have been built to cover typical subsea measurement system configurations. The tool will provide both a Forward Model, used primarily for uncertainty estimation, and a Backward Model, mainly used to attempt to identify a source of material imbalance in the system, if the balance is outside its expected bounds.

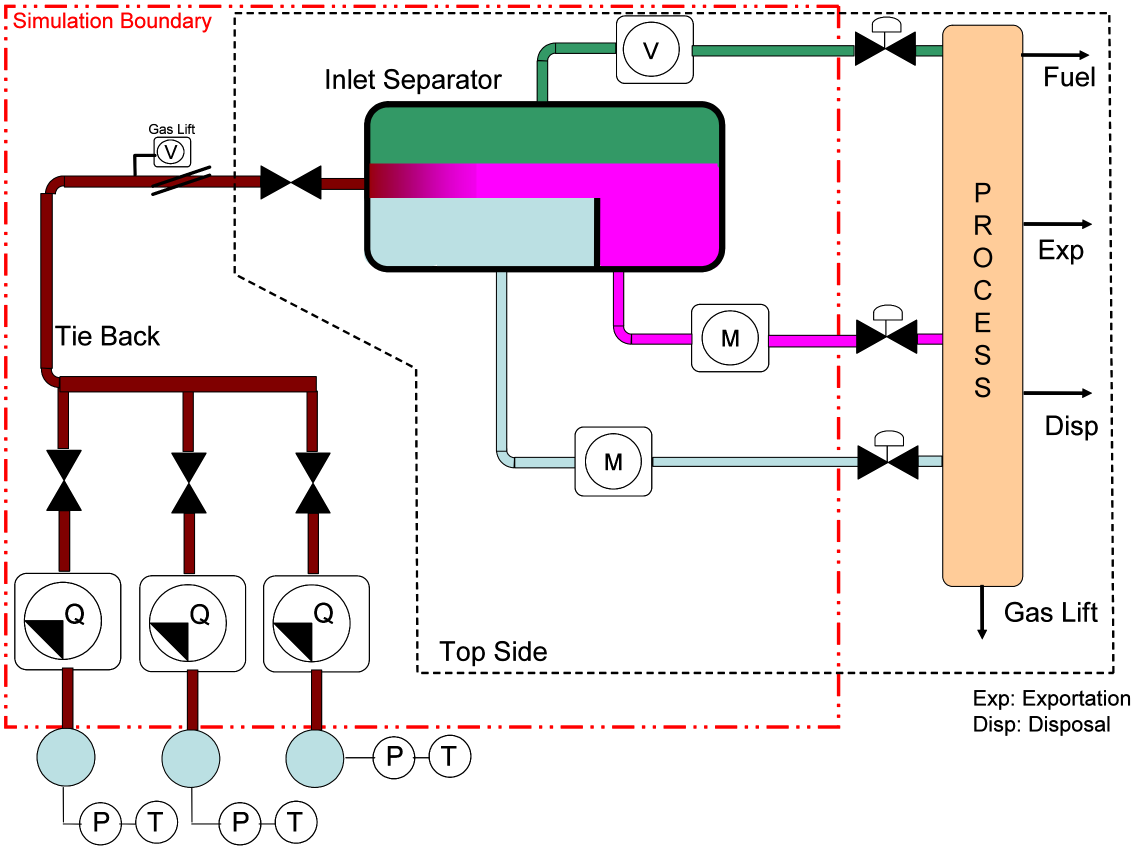

Figure 10. Production system diagram showing uncertainty components.

4 FUTURE OF DEEPWATER MEASUREMENT

Having said this, there is still work to be done in several of the deepwater measurement task areas. For example:

- Deepwater Subsea Sampling. Development of a refined version of the prototype deepwater subsea sampling system. Create guides and other tools for use by those who must understand when and how to use the system. Field tests of applications that utilize the DW1301 system, probably on land.
- ROV-Assisted Subsea Measurement. Re-work of the delivery system based on test results. Extension of the DW1301 clamp-on measurement system to

brownfields, and to more typical deepwater conditions. Incorporating another sensor package should be considered.

- HP/HT Sensor Qualification. Development of prototype downhole DP/P/T gauges using DW1301 xHP/HT differential pressure sensors by making them available to vendors of commercial downhole pressure gauges.
- Evaluation of Flow Modelling. Completion of the performance evaluation of wellbore flow models (Virtual Flow Meters, or VFMs) begun in DW1301 using real well data (DW1301 has used only numerically simulated data).
- Meter Fouling Effects. New methods for using the DP measurements to indicate fouling on the interior of a meter could be developed – DP diagnostics.

5 CONCLUSIONS. ACKNOWLEDGEMENTS.

There can be no doubt that programs such as the RPSEA DW1301 have contributed much to improve our understanding and capabilities. By bringing the major deepwater operating companies together, numerous key technical issues have been resolved. Further, because this was accomplished with their cooperation, and because these same operators work together as partners in large deepwater applications in the Gulf of Mexico and beyond, it is more likely that the deepwater community at large will accept the directions chosen.

There are many examples in the deepwater Gulf of Mexico that serve to underscore the need for technological improvements in deepwater oil and gas exploration and production operations. Complex activities in field developments such as Perdido will be the norm in the future, and will undoubtedly require even better measurement and control than what is described here. R&D activities such as those of the DW1301 Project therefore are essential if these future needs are to be addressed.

The authors would like to acknowledge the US Department of Energy and RPSEA, which have provided the impetus and major funding for the work described here. We also salute the member companies of the DW1301 Joint Industry Project, who provided not only financial support for the project, but who also contributed the expertise of their brightest and best subsea and measurement engineers. DW1301 JIP member companies are: BP, BHP, Chevron, ConocoPhillips, Shell, Statoil, and Total.

Thanks also go to our expert sub-contractors Oceaneering International, Multiphase Systems Integration, axept, and Neftemer, Ltd.

Finally, we want to acknowledge our colleague, the late Rich McCoy of Oceaneering, whose numerous innovative contributions populate both the Deepwater Sampling System and ROV-Conveyed Measurement designs.

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