RPSEA

Technology Status Assessment

Document Number10121-4304-01.02

More Improvements to Deepwater Subsea Measurement

SUBCONTRACT No. 10121-4304-01

August 10, 2012

Winsor Letton, Chief Operating Officer
Eric Kelner, Vice President
Co-Principal Investigators
Letton Hall Group
10497 Town and Country Way, Suite 300
Houston, Texas 77024

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Winsor Letton, III

Winsor Letton, Principal Investigator

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More Improvements to Deepwater Subsea Measurement
SUBCONTRACT No. 10121-4304-01
Technology Assessment

Summary

This RPSEA Project 10121-4304-01 Technology Assessment addresses its five distinct tasks. In each case, we are pushing the technological boundaries for that area. This will be explained in the pages that follow, but it is summarized here:

- Subsea sampling was an area virtually unexplored prior to the initiation of RPSEA's Project 07121-1301. Since that time early work has been done by Shell, Total, and Chevron, as well as by some vendor companies. The work in 4304 will help drive the technology forward in several ways.
- Subsea measurement will break new ground in three areas: (1) ROV assisted sensor measurement through a production pipe, (2) clamp-on metering through a "transparent" section of pipe, and (3) measurement of the density of drilling fluid returns at a BOP.
- The differential pressure (DP) gauge developed as part of Project 1301 will be repackaged into a sensor system that can be deployed downhole. There currently is no way to measure DP downhole other than by using two absolute pressure gauges – an unsatisfactory solution.
- Virtual Flow Meters (VFMs) are production flow models, the performance of which is still largely uncharted over a range of conditions. This activity will attempt to shed light on technology that has not been well proven up to now.
- Another key result of the work of 1301 was demonstration of the linkage between meter fouling – specifically erosion and scaling of the meter bodies – and measurement performance. That unique work will now be followed by the inverse problem, i.e., can the presence of fouling be detected through some form of measurement, which will also be unparalleled if it can be accomplished.

Details are provided in the paragraphs that follow on the assessment of the individual task technologies.

Task 5.0 - Subsea Sampling

State of the Technology

As discussed in the proposal, subsea sampling of fluids in situ has been done before, but with limited success. Previous efforts relied on sampling systems integrated with the multiphase flow meter. Examples are Framo's 1999 integration of a liquid sampling system with a multiphase meter, and the 2003 "autonomous metering station" from Christian Michelsen Research Several efforts to develop subsea sampling systems are underway. In 2010, a flow-through system in which samples sufficient to support multiphase meters was disclosed. Other recent developments include the MARS PS liquid sampling system by Cameron, and the Mirmorax Subsea Process Sampling System. Shell, Total and Chevron have conducted work in the area of subsea sampling. Shell has published information on their Subsea Multiphase Sampler (SuMS). The system is a flow-through system, employing "liquid-biased" sampling and using a single cylinder. The system has been tested under subsea conditions.

Overview of the Current RPSEA Technology

The subsea sampling system developed during Project 1301 is a flow-through system using two sample cylinders - one for accumulating the liquid (oil and water) sample, and one for accumulating the gas sample. Results from fluid and Remotely Operated Vehicle tests showed the system performed generally as expected:

- The flow laboratory tests showed the system was able to collect sufficient amounts of fluid under various combinations of oil, gas and water, however the ability to collect a "representative" sample (as defined by the DW1301 Task Group) was not proven.
- The thermodynamics analysis showed that it was possible to avoid hydrates and wax formation during sampling.
- Additional tests, under simulated subsea conditions, established the ability of an ROV operator to successfully manipulate the system onto the production fluid interface and make fluid connections; however, manipulating the system and coupling it to the interface with an ROV was somewhat difficult.

Additionally, the effort identified the main issues to be addressed in a sampling *best practices* guideline, and provided a straw-man standard. However, additional investigation is required to provide defensible, industry-consensus best practices guide for subsea fluid sampling.

Development Strategies

This work will include a refinement of the existing sampling system and production fluid interface designs in order to address the issues discovered during testing of the prototype system and to provide improved performance. A further assessment of sampling best practices and sample point location selection will be incorporated into a revised *Sampling Best Practices* document.

The general development strategy for the sampling system will follow a requirements-driven approach:

- At the initial workshop, the original set of requirements will be reviewed, along with the Technology Readiness Level (TRL). Requirements will be added, removed and refined, based on Joint Industry Project member consensus. A target TRL will be established.
- The existing technology will be reassessed with consideration given to the revised set of requirements. The group will assess what is needed to achieve the target TRL.
- The system will be redesigned, based on the revised requirements and target TRL.
- A new system will be fabricated, with confirmation that the revised set of requirements are met and that the system will meet the target TRL.
- The system will be tested to confirm the TRL.

The approach to developing the Sampling Best Practices document will involve background research and simulations or experimentation. Joint Industry Project members will be involved throughout the document development process.

- At the initial workshop, the document produced in the previous project will be reviewed to develop consensus on the general outline, knowledge gaps and areas open to investigation. Industry's guidance with respect to the investigation will ensure the effort is targeted at the subjects most relevant to sampling in the subsea environment.
- Background research to identify any work done in the area of subsea sampling practices will be conducted.
- Investigations using Computational Fluid Dynamics and/or experimentation will be conducted to provide insight to the multiphase sampling process.
- Results of the interactions with the Joint Industry Project members, the background research and the investigations will be incorporated into a revised *Sampling Best Practices* document intended to provide guidance in subsea sampling.

Future Expectations

It is expected that this effort will stimulate additional interest in subsea sampling and lead to commercialization of the subsea sampling system. It is hoped that the production fluid interface will become an accepted standard used by operating companies and manufacturers, increasing demand for subsea sampling and innovation of subsea sampling systems. Further, it is hoped that service companies will eventually provide subsea sampling services to operating companies.

The expectation for the Sampling Best Practices document is that it will become an accepted industry standard and used to inform operators, manufacturers and service providers of the critical issues in subsea sampling and the most accepted methods for providing samples suitable for use in multiphase metering.

Task 6: ROV Assisted Measurement

State of the Technology

Wetted Sensor Metering

RPSEA Project 1301 introduced the first ROV-Assisted deepwater metering device and meter conveyance system in which a sensor is positioned on the outside of the flowline to sense flow through the pipe wall. The sensor was powered and supplied with hydraulic pressure via ROV umbilical, and manipulated with ROV articulated robotic arm. Landing and locking in place was achieved with visual alignment using video and gravity for positioning. The ROV was required to remain tethered to the meter as long as metering takes place. The meter would return to a fail-safe disengaged position if hydraulic pressure were lost. The sensor was transported to and from the surface in a rack/basket. Available sensors to read flow through typical deepwater pipe wall thickness are very limited. Gamma density measurements were chosen for test in 1301.

The present task proposes to install the sensor into a dedicated sensor landing site which puts the sensor in contact with the process fluid. Several additional technologies may be used if the sensor is wetted by process fluids. The present task proposes use of infrared sensor to measure watercut at point in flow line. A system exists for installing this sensor into pressurized flow line topsides, but this has never been attempted subsea.

There have been cases reported in which a “hot-tap” was made into a pressurized flow line subsea. This involved drilling a hole in the pipe, sealing it off, and fitting and welding in place a fitting, such as a Weldolet. This type of operation is risky and reserved for emergencies, or as a last resort. A solution is needed for a safe and routine process of installing and removing a sensor from the flow line.

Transparent Section Metering

Flow line sections transparent to measurement devices have been developed for topside conditions, but not for underwater or subsea conditions.

The present task proposes to use electrical capacitance tomography to evaluate flow rates and regimes. Using 8 or 12 external electrodes, the capacitance between electrode pairs is measured in a rapid sequence to determine the permittivity distribution, which is used to image the flow through a non-metallic pipe section. Work in the task will develop technology to make the measurement underwater, and to achieve a reliable and repeatable positioning mechanism. The task will also examine non-metallic materials suitable for pipe construction.

BOP Fluid Density Measurement

BOP measurement does not exist at this point in time. Fluid densities in the returns line are measurable on surface, usually by hand, but can be done by instrumentation. Such fluid density instruments have not been designed for subsea installation or installation on a BOP. Fluid density measurement in the drilling environment presents additional challenges due to the high density, non-Newtonian properties and presence of solids in the fluid.

The present task will test two different fluid density devices which can be installed on a take-off line from the BOP. Included will be development of the installation rig-up for measurement test, calibration and measurement evaluation procedures, and a test of the sensor system with drilling fluids in a mockup arrangement in representative conditions.

Development Strategies

The development of the subsea sensor installation mechanism will use the topsides install system as a basis for design. Work with the lead contractor, Oceaneering, with experience in subsea ROV manipulations will enable the adaptation of the design into a system that is suitable for deepwater environment. The system will be tested under water in an ROV test tank.

The development of the measurement system on transparent pipe section will make use of a proven technology for tomographic flow evaluation on non-metallic pipe. The development will focus on the marinization of the measurement system for a deepwater environment. The materials investigation will propose measurement section design and fabrication options. The system will be tested underwater with representative flowing conditions.

The development of the drilling fluid measurement on the BOP will make use of a recent development in ultrasonic measurement for the evaluation of fluid density, as well as a simple and proven technology of gradiomanometry. Both devices will be built as prototypes and tested in a mock-up flow loop mimicking drilling riser conditions just above the BOP.

Future Expectations

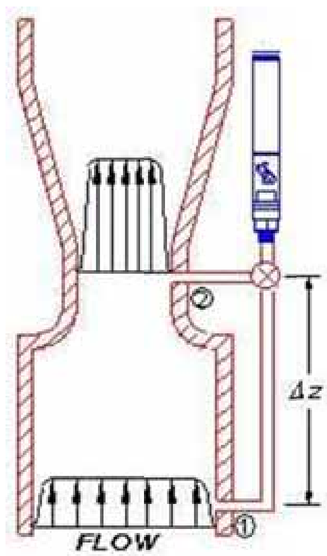
Following this research project, in which the feasibility of such measurements in deep water is demonstrated, it is expected that the three devices will find interest from the JIP and other operators to make field ready prototype systems for more extensive application and reliability testing. This second phase of technology development and testing is what is normally required to assess a TRL for field use.

Task 7 – Downhole Flow Measurement

State of the Technology

There is a need to accurately measure well flow rate, not just at the wellhead but also downhole. The most common manner of measuring mass flow rate uses differential pressure (DP) measurement. While absolute pressure (P) sensors that can operate within downhole environments are available, DP sensors are preferable for these downhole measurements, but have not been available up to now. In the past, attempts at downhole DP measurements were made using two absolute pressure sensors, which is difficult, introducing uncertainty due to small measured DP at high pressure.

Another problem with this approach is that it is limited by long-term drift occurring in the two transducers. Drift between two P sensors can be offset by periodically zeroing the two gauges, but this requires the well to be shut in. One manufacturer has attempted to eliminate this problem by using a single P sensor and switching the inputs from across a Venturi, as shown in the illustration below.



This complicates the structure of the device and limits the reliability of the downhole device by the functioning of the valve. Therefore, this approach is better suited for retrieval devises, rather than permanent gauges.

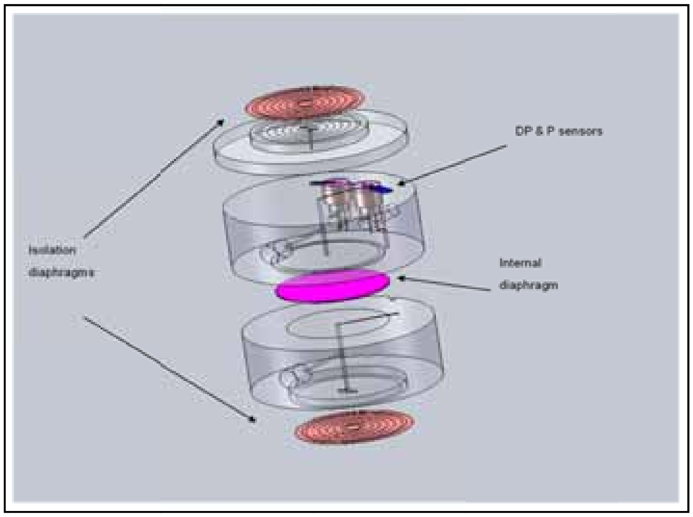
Another consideration is the operational limitation of high temperature and pressure. Conventional downhole gauges are typically limited to 150 deg C and 10,000 psi. Some vendors offer quartz P sensors that operate to 175 deg C. These requirements make them marginal in many downhole applications.

Another technology that is being tested for downhole temperature and pressure measurement is an optical fiber Bragg grating based sensor that can measure highly varying pressure and temperature excursions in hydrocarbon wells. Several of these sensors can be connected on a single optical cable and interrogated from topside. The P/T limitation on these devices is currently the same as that of conventional sensors. It does not appear that this technology has been applied to DP measurement.

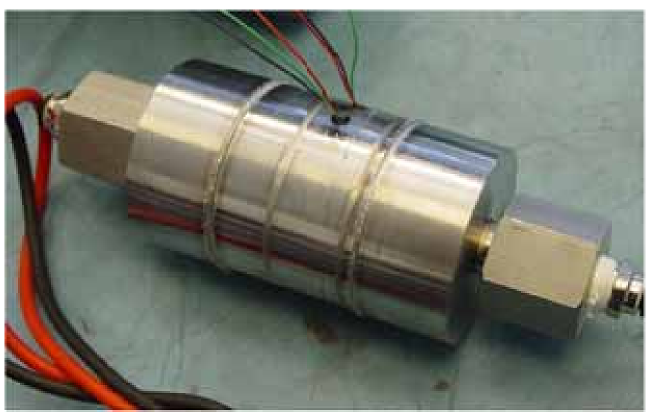
Overview of the Current RPSEA Technology

By utilizing the HP/HT P and DP sensors developed in the RPSEA 07121-1301 program, a downhole measurement system (P and DP) can be developed and demonstrated. While such a measurement capability would greatly enhance normal production measurement, it might also be beneficial in early detection of a well inflow event before it could be sensed by other traditional methods, such as comparison of flow rates in and out of the well. This could be performed downhole or at intermediate points (e.g. zones) in the well, and could complement the methods being developed in Task 6 for density detection at the mudline.

This illustration shows the HP/HT cell developed in the RPSEA 07121-1301 program.



This oil-filled sensor cell was developed to extend the range of subsea flowmeters for operation in HP/HT conditions. The completed cell, shown in the following picture, was successfully tested at 250 deg C and 22,500 psi.



For the downhole application, this 2-inch diameter cell must be reduced to a cell and remote pressure diaphragms less than 0.75-inch in diameter. Fortunately, there remain numerous P and DP sensor chips in die-packs from the previous 1301 development, as shown in the example below.

Development Strategies

The greatest challenge for the downhole permanent DP gauge development will be the redesign and fabrication of the smaller diameter sensor enclosure. The general development strategy for this will follow a requirements-driven approach:

- Organize the working group (WG) for this task with representatives from the JIP;
- Reach agreement with a manufacturer of downhole measurement systems (gauges) to participate in this task;
- Conduct a web-based Workshop to finalize specifications;
- Selected subcontractor (ATK) to submit schedule and cost proposals to meet task requirements; issue Purchase Order to ATK;
- P and DP sensor die from Project 07121-1301 to be tested by ATK for use with this task's prototypes;
- ATK to submit oil-filled cell design for approval; the WG and downhole system manufacturer to review proposed design;
- ATK to fabricate and conduct initial testing on two prototype DP cells;
- If required, a modification to the cell design will be made;
- Tested prototypes will be tested by the downhole system manufacturer in test systems at downhole conditions;

Future Expectations

It is expected that this effort will allow the use of a single downhole DP sensor for flow measurement during production of single- or multiphase fluids. This will enhance well production monitoring and potentially improve safety by providing an early-warning of an unexpected downhole inflow event. It can be envisioned that a true DP downhole sensor may also be utilized to monitor mud density in the manner to be addressed in Task 6. If successful, this task will certainly lead to commercialization of the first downhole system utilizing a true DP sensor.

Task 8.0: Evaluation of Flow Models

State of the Technology

Virtual Flow Metering (VFM) has become an integral part of field production optimization strategies particularly subsea. Hydraulic models are used to estimate flow measurement of gas, oil, or water streams. The models are based on the physical principles of flow in porous media (reservoir rock), in tubulars (wellbore), across restrictions (choke), and in the jumper to receiving manifold. Independent variables such as pressure and temperature and choke position are the main input to any VFM, along with knowledge of phase behavior from industry correlations or PVT modeling.

The last two decades witnessed significant efforts in the development and improvement of VFM predictions, mainly due to availability of computing power and the ability of VFMs to reduce the cost of flow metering when compared to other subsea techniques, such as multiphase meters or dedicated test lines.

Due to increased complexity of the modeling techniques, whether homegrown by operators, or offered by service providers and vendors, it has been difficult to assess the relative performance of different models. It is therefore important that comparative benchmarking studies are conducted using both simulated and real data and supported by reference flow measurements. Other than a first attempt in Project 1301 in which only simulated data was available, we are not aware of any comparable work done in this area to help users evaluate the strengths and weaknesses of commercial models in different applications and model-tuning scenarios.

Development Strategies

To achieve the goals outlined in the proposal to RPSEA, different approaches are being considered for the key component – to obtain field data from live sensors in a producing well. The priority is to seek the support of an operator – hopefully a JIP member – who would provide access to live sensors and production data, or alternatively we ourselves would install sensors in a (possibly land) well to perform the comparative studies using models from different vendors.

In parallel contacts will be sought with VFM suppliers to ensure their active participation in the study. This could include internal in-house models developed by operators.

Future Expectations

The ultimate goal is to evaluate the most commonly used flow models using real sensor data and actual flow measurements. Different tuning schemes will be used to quantify the models’ sensitivity to number, quality and type of sensors.

By drawing general conclusions from the tests, operators and regulators will better understand where VFMs can be used and at what level of performance.

Task 9.0 - Diagnosis of Meter Fouling

State of the Technology

The current state of technology for using sensor measurements to measure the condition of pipe or meter internals with respect to erosion or deposits can be summarized:

1. External wall thickness measurements:
    - NDT methods (e.g. ultrasonic) have been used to make measurements of wall thickness, and could be used to address erosion issues.
2. Gamma densitometer techniques:
    - Single and dual-energy gamma densitometers may respond to scale build-up and wall erosion so that they could be used for diagnostic purposes.
3. Multiphase flow meter diagnostics:
    - Multiphase flow meter manufacturers have experience with erosion and scale detection for their specific meters.
4. Extra differential pressure measurement:
    - Work with single-phase fluids has suggested the use of additional taps may yield useful information on the condition of differential meters.
5. Sand monitors:
    - Current subsea acoustic sand monitoring methods have shown the ability to detect the presence of sand in the flow. Whether it can be used in quantifying erosion or scale formation effects is not known.
6. Erosion and fouling detection via modeling:
    - Data validation, data reconciliation and virtual metering should prove useful, especially when used with complementary measurement technologies (e.g. multiphase or wet-gas meters).

Development Strategies

The JIP WG will address all of these approaches and any others that may be identified, and prioritize them according to desirability, budget, and likelihood of success. The two deemed most likely to succeed will be pursued in detail.

For the sensor techniques (1 to 5):

- Consider the practicality of their being adapted to HP/HT applications.
- Consider design concepts for imbedded, fixed or clamp-on measurements.
- Conceptual approaches will be developed and reviewed.

The last technique (6) relies on existing meters, sensors, and sophisticated software in the complete system, from subsea to surface, which has the advantage of requiring no sensor development.

Future Expectations

Results of this effort will be adoption of techniques that can be used commercially to predict the onset of fouling and the consequent reduction in meter performance.