North Sea FLOW Measurement Workshop

Paper 7.1

First Ever Complete Evaluation of a Multiphase Flow Meter in SAGD and Demonstration of the Performance Against Conventional Equipment

Bruno Pinguet
Schlumberger

Fernando Gaviria
SUNCOR Energy

Laurie Kemp
SUNCOR Energy

John Graham
SUNCOR Energy

Cal Coulder
SUNCOR Energy

Carlos Damas
Schlumberger

Karima Ben Relem
Schlumberger

TÜV SÜD

nel technology for life

First Ever Complete Evaluation of a Multiphase Flow Meter in SAGD and Demonstration of the Performance Against Conventional Equipment

Bruno PINGUET, Schlumberger
Fernando GAVIRIA, Laurie KEMP, John GRAHAM and Cal COULDER, SUNCOR Energy
Carlos DAMAS and Karima BEN RELEM, Schlumberger

---

1 INTRODUCTION

Suncor and Schlumberger have been working over several years to establish the performance of multiphase flow meters and determine the accuracy and reliability of flow-testing equipment for thermal heavy oil production, the first test was carried out in 2007. The test marked the first successful application of multiphase flow metering in Canadian thermal recovery operations.

The initial introduction leads to selection of a well for its dynamic conditions and production history factors such as flowrate, line pressure, line temperature, and fluid properties and allowed the connection of the MPFM (the Vx) in series with an existing test separator.

The multiphase initial objectives were to measure the well's oil, water, steam, and gas flowrates, understand the well's SAGD dynamics, and the impact of changes in ESP frequency to experience different production conditions, including line pressure, flowrates, phase fractions and ratios, i.e., Water/Liquid Ratio (WLR). Finally, to study the Vx's sensitivity and performance against a valid reference by defining the results for stability, dynamic response, repeatability and reproducibility. This leads to several papers presented in different conferences (Ref [1-3], and in the meantime to work closer to define what should be the optimal test of a cluster to have a full understanding of the technology and the potential for permanent installation.

In 2009, a second and more advanced field trial was initiated. A pad was selected as the location for this field test due to the large number of good producing wells and ideal set up of the conventional equipment. The MPFM was connected in series with the conventional test separator and the test was divided into three stages to fully evaluate the safety, reliability, accuracy, and advantages of the MPFM over the conventional test separator equipment.
During the first stage, 9 wells were tested during the months of October and December 2009, ensuring that the MPFM was challenged against the full range of operating conditions of the SAGD wells. During two months of extensive well testing and fluid sampling, no safety incidents were encountered and the MPFM reported well production rates continuously and without any performance degradation even during the extreme cold ambient temperatures recorded at the well site.
To demonstrate the reproducibility of the flow measurements using the MPFM, a second stage was completed, this time shortening the flow period from 12 hours to 6 hours and then be able to demonstrate the capability to do more well tests per month per well with the same quality data. Then, with the Vx meter only, the data of the 12 hours testing were reprocessed for 4 hours showing a very good consistency in the results with the 12 hours test.
Results, from the second stage of the test confirmed that the data is identical for a 12 hours test versus the 6-hour test versus the 4 hours test and has very good repeatability and prove the robustness and independence of the flow regime. These results seem to reveal that testing for shorter period of time and more frequently gives more information and is likely preferred to be able to optimize production.
A third phase more dedicated to optimization potential and the impact of changing chokes, steam injected rates and other numerous parameters was done but it will be only briefly mentioned in this paper.

2 PROBLEM AND PROPOSED SOLUTION

The SAGD process presents one of the most challenging environments for flow rate metering in the industry. Produced fluids are often characterized by unstable flow regimes, high temperatures, emulsified foamy oil, as well as the presence of H2S and abrasive sand particles. As such, the capture of good data is extremely difficult.

Timely and accurate well production data is required for the validation process of the reservoir model and for confirmation of production predictions. Additionally, the oil company could potentially utilize this valuable information to adjust the operation for optimum performance. Currently, the industry attempts to meet this need using “test separators”, which employ the basic principle of gravity of the various phases that produce through the wellhead. Additional standard equipment, such as a water-cut meter, Coriolis, and orifice plate technologies are then employed to obtain the measurements.

However, it is well known that there are many issues, which compromise the accuracy and utility of the data retrieved by this conventional equipment. First, as oil and water density contrast is very low, the gravitation process is not effective and do not allow for proper separation of the gas and liquid phases. Second, there are issues regarding the proper measurement of the mix of steam vs. natural gas, of oil vs. water, and with known errors from gas entrainment within the liquid lines. Lastly, because many wellheads share a single test separator, flow measurements from each individual well can only be periodically obtained. Some additional backpressure may also affect the estimated well production.
These factors lead to a limited understanding of each well’s performance and a negligible capability for optimization. Thus, it is desired to find a technology that could replace the separator system with a real time and accurate metering system.

The primary goal of this collaboration is to develop production techniques that will improve the productivity and recovery factors of viscous oil sand reservoirs in Canada, starting with Suncor’s Firebag Asset. Firebag is located 140 kilometers northeast of Fort McMurray, Alberta, Canada (Figure 1). The first barrel of bitumen produced from this operation was processed in January 2004.

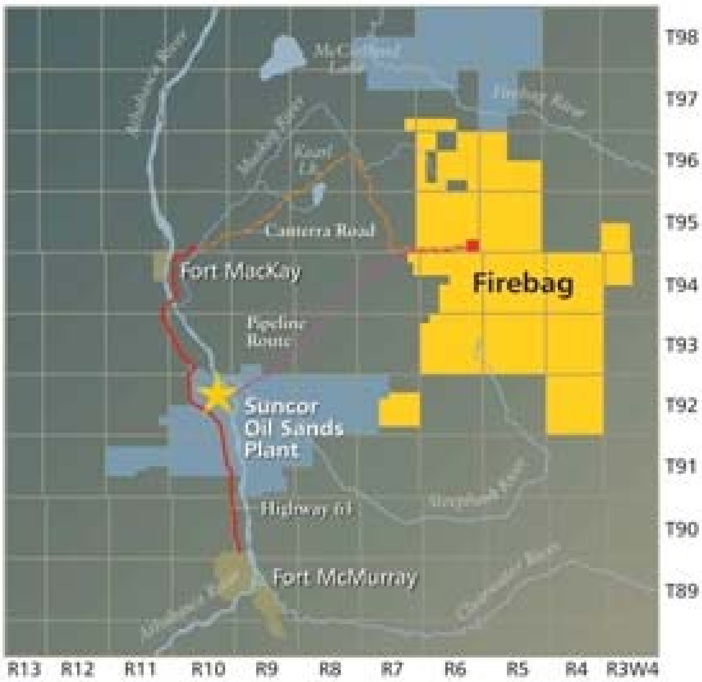

Figure 1: Field location

With a viscosity of millions of centipoises [cP], the oil is not producible through ordinary cold production practices. Rather, the bitumen is extracted via an advanced and complicated recovery technique known to the industry as SAGD (Steam Assisted, Gravity Driven).

From this basis, a collaborative project plan was developed with the mission to bring optimized workflows and new technologies to Firebag that will achieve a reduction in Steam-to-Oil (SOR) of at least 0.50 while reducing the environmental footprint. The project was planned to complete three phases, each with a deliverable during a calendar year:

- Phase One: Enable Firebag to have real-time accurate production flow data
- Phase Two: Working with this data, enable the operation with advanced monitoring, automation, and optimization systems
- Phase Three: Once optimization techniques are available, add the capability for active/adaptive completion technologies (e.g. steam injection control)

Figure 2: Field Operation and Equipment Proposed

Only after completion of the phase#1 successfully, the project could advance to Phase 2 of the aforementioned mission to significantly reduce Firebag's SOR and environmental impact. To answer all different issues rose above and if this is possible, the solution will be based on a system without any separation. This paper presents the fieldwork that was conducted during Q4, 2009 and completes the deliverable for Phase One.

It is proposed to replace the centralized test separator system with a Multiphase Flow Meter (MPFM), shared either by many wells or ideally at each wellhead for full real time capability. Such a set up could provide a step change in performance and a reduction in surface footprint. In addition, continuous well flow measurements could be used to optimize the artificial lift performance, maximize oil production, and improve the energy balance. If this present a step change in SAGD conditions, Vx technology has been already accepted in conventional field development. Approval for allocation in North Sea has been done (Norway through NPD, UK with DTI) or Gulf of Mexico (USA with MMS).

Schlumberger has successfully developed an advanced MPFM, based on the "Vx technology" and available as mobile unit (PhaseTester used for this test) and permanent unit

PhaseWatcher that may provide an ideal solution. Originally designed for challenging deep-water markets, this multiphase flowmeter has been used in hundreds of applications and has proven to be reliable and accurate. Over the past few years, this device has been introduced to the SAGD/Thermal environment via several field trials in Western Canada and Mexico. Because of these learning, many improvements (e.g. increasing the temperature rating) have since been commercialized.

3 PROPOSED SOLUTION

An overview on the basic operational principles of MPFM devices was given in 2008 at the World Heavy Oil Congress [2] and is partially reproduced below for convenience. At a minimum, all MPFM devices will output the oil, water, and gas flow rates at line conditions. These outputs are derived using either a physical or an empirical model. However, industry reports production at standard conditions and therefore the flow rates at line conditions need to be converted to standard condition using PVT correlations or more properly named "fluid behaviour model". Capturing this flow behaviour can be done by simply looking at few macro parameters: Volume factors (bo, bg, bw), Gas dissolved in Oil (Rst), Gas Dissolved in Water (Rwst), and the water phase condensation (rgwmp).

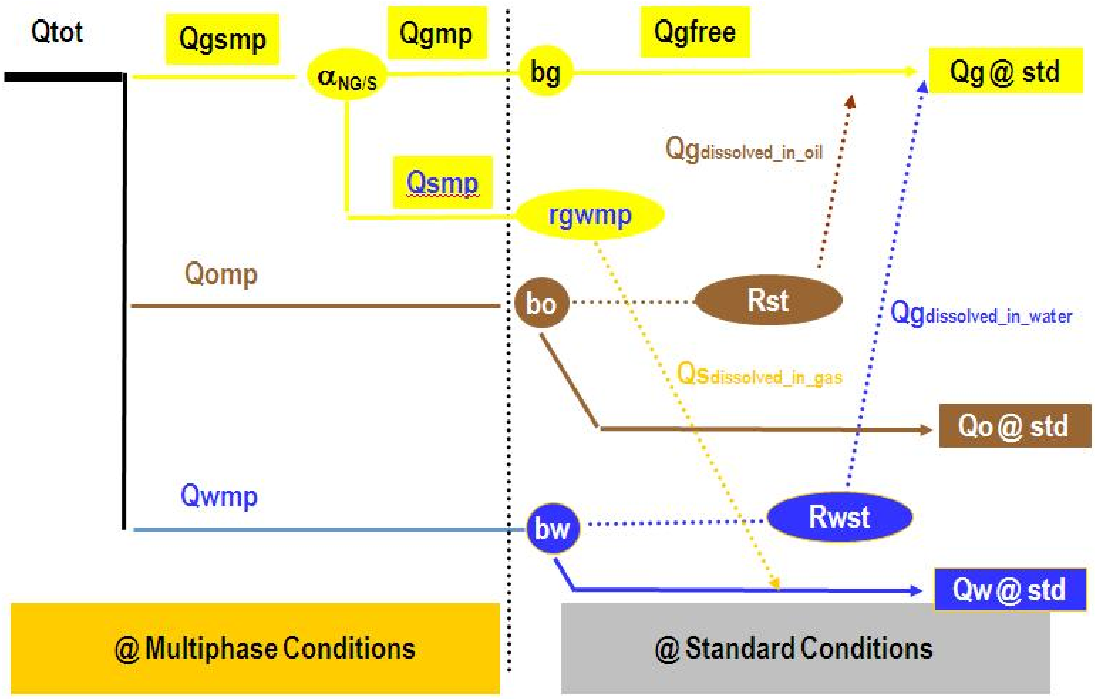

Figure 3: Field Operation and Equipment Proposed

Of course the knowledge of the density of each fluid at line conditions will be necessary and can be obtained based on the above parameters and the knowledge of the dead water and oil and specific gravity of the gas.

In the SAGD environment, it is a combination of a few simple and basic measurements done at the well site or through some laboratory analysis, or information available through a PVT report, which will be used to tune the EOS (usually build for a pad or a flied following the homogeneity of the reservoir). The combination of the accuracy of the representation of the mass or volume converted from line to standard conditions with the intrinsic accuracy of the multiphase flow meter (specific to each technology and then multiphase manufacturer) provides the global accuracy of the measurement of live effluent. The physical principle and model has been done by a review systematically of each implication to work in SAGD. This is the result of 10 years of focus and understanding in details of the Vx technology.

The Vx multiphase flowmeter (figure 4) contains three main modules:

- An advanced multiphase flow model of the fluid mechanics,
- A robust measurement of the total mass flow rate based on the well-known Venturi design, and differential pressure concept
- A robust fraction meter measurement based on established nuclear technology, to produce in real-time fraction measurement of oil. Water and gas without any separation and being not sensitive to the phase distribution (emulsion, foam, droplets flow, water contents...).

A detailed explanation of the specific data flow processing routine and various assumptions made within the Vx technology can be found in the referenced documents [2]. However, a summary is listed below for convenience:

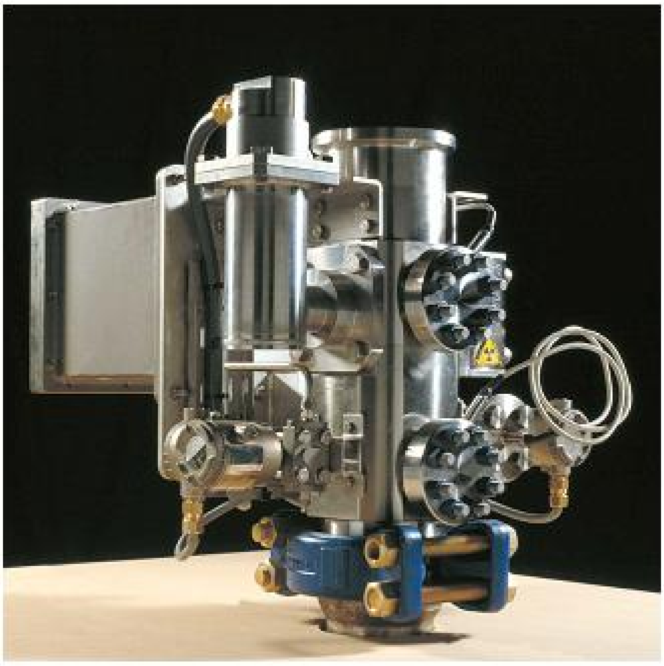

Figure 4: Field Operation and Equipment Proposed

Two basic measurements are made in the Venturi section:

- Differential pressure across the Venturi (ΔP), and
- A multi-energy gamma-ray fraction meter, which provides fraction of each constituent of the mixture (αo, αw, αg).

Additionally, there are sensors that measure process fluid pressure at the Venturi throat, fluid temperature upstream of the Venturi section, and ambient temperature.

It is essential here to mention some fundamentals of the fluids mechanics to be able to have an accurate multiphase flow meter in general. First, the flow is turbulent or chaotic and then it is necessary to have a system working at a frequency much higher than several 10th of Hz. Second, the different fraction measurement needs to be correlated; this means that from a recording time point of view all measurements should be done at the same time. Third, because the flow is turbulent then the timing is important and because the fluid is a live fluid then the acquisition should be done at the same space. Fourth, this recording should be done at the same pressure and temperature. With an example is easy to understand, if for example the water holdup was done in one place at a certain pressure and temperature or done somewhere else at different pressure and temperature then the condensed water will be different and then the overall calculation of the water content could be either overestimated or underestimated,

The Vx technology is built on a few physical hypotheses: No slippage inside the liquid phase, a semi-empirical model of the gas-liquid slippage based on extensive research and experiences made at low pressures (from 1 to 30 bar) with immiscible fluid, and finally a model of a "shape factor" for multiphase environment.

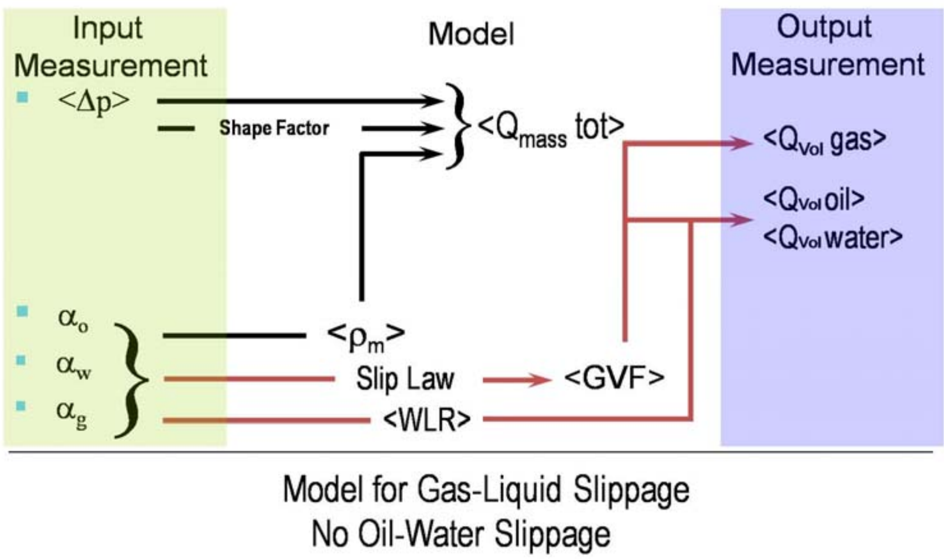

Figure 5: Field Operation and Equipment Proposed

Similar to the common dataflow for all MPFM devices, the specific Vx schematic is shown Figure 5. As already mentioned the volumetric flow rates at standard conditions are the main outputs and computed from the flow rates at line conditions using either a PVT software package or a correlation (as it is currently done for the separator).

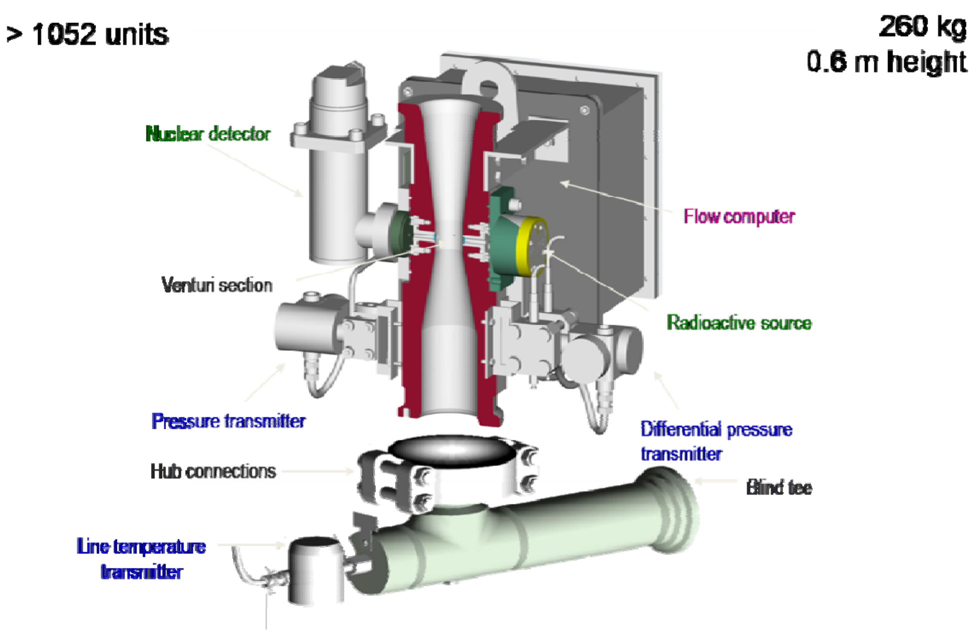

Figure 6: Field Operation and Equipment Proposed

The Vx technology is the simplest combination of sensor and technology available on the market today with only 4 sensors and none of them in direct contact with the fluid avoiding the high temperature stress.

An additional challenge for SAGD operations is to monitor at surface: Steam (i.e. Vapour of water), Natural Gas evolved from the Oil, Bitumen, and then Water (Liquid form). This means there are four phases versus the traditional three at line conditions. Therefore, it is necessary to use additional information to obtain this fourth phase measurement. The Vx device can provide four phase measurements and split the fractions of Steam and Natural Gas by using a dedicated Equation Of State (EOS) package based on the knowledge of the fluid properties. This allows keeping the multiphase flow meter design as simple as possible without additional sensors, cost, and maintenance program.

The Vx technology has a unique application within SAGD operations due to the use of a specific heating device, which allows the entire nuclear-based instrument to be kept at a specific temperature, and can handle any fluctuation of the fluid temperature passing through with minimum impact on the accuracy of the fraction measurement.

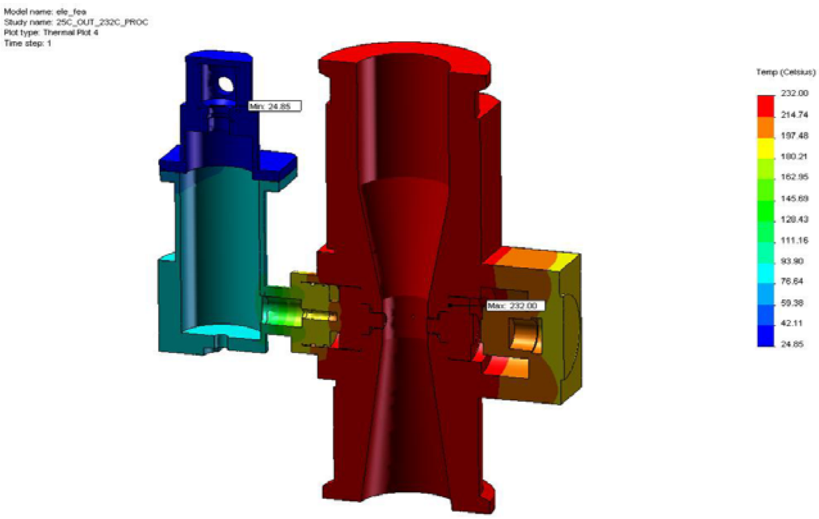

Figure 7: Field Operation and Equipment Proposed

Extensive testing has demonstrated that under the harsh conditions (no wind, ambient temperature at 25 degC, and flow temperature at 232 DegC) the sensor will not exceed 80-90 DegC in the worst conditions when the electronic has been designed to handle more than 100 degC in normal operation. In addition, The structural design of the Vx Multiphase Flow meters complies with the reference codes and standards of Canada or International.

The key points of the Vx Technology are summarized below:

- No Tuning Factor due to a proper understanding of the fluid mechanics
- No Separation by construction
- No Flow Calibration the measurement being based on physics principle
- No issues with Foams or Emulsions due to nucleonic technique of measurement
- Improve water detection and accurate BSW monitoring (either oil or water continuous phase)
- Continuous rate measurements
- No moving parts
- Different sizes: 29mm, 52mm, 88mm (100 – 150,000 bpd)

- Due to the Venturi principle used in the Vx technology an extremely low back pressure
- Compact solution (<300 kg, 2 feet tall)
- No Sensor in direct contact with the fluid
- Full sampling capabilities (optional)

The Figure 12 presents a comparison in footprint between the conventional Test Separator, the Vx PhaseTester (periodic applications) and the Vx PhaseWatcher (permanent installations).

Figure 8: Field Operation and Equipment Proposed

4 MOTIVATION FOR A SECOND TRIAL Vx TEST

As described above, the Vx technology was used for the first time in SAGD in 2007 at the Suncor Firebag Project. This represented the first introduction of the technology to SAGD environments and was published in different conferences around the world in 2008 (Ref. [1-3]).

The decision to initiate a second Vx field trial with Suncor and finalize the introduction of Vx for SAGD was a result of the completion of several new improvements of the test separator and a tighter focus on the metrological performance comparison versus 2007. Additionally, the first Vx Trial in 2007 was specific to a single well in the SAGD pad. The second trial is covering a much wider range of wells and operating conditions in order to prove the accuracy and reliability of the Vx flowmeter in all conditions encountered during a SAGD project operation.

Schlumberger has been working with another operator throughout 2008. During this particular project, extensive testing was done and both parties were able to challenge the Vx Technology and conventional equipment to review how a multiphase flow meter could be becoming a reference measurement in SAGD operations (Ref [4]).

The main improvements after the 2007 Vx trial are summarized below:

- Design and implementation of a sampling equipment to collect Gas-Steam samples at line conditions and be capable to measure the steam and natural gas ratio
- Design and implementation of a sampling equipment to collect liquid samples at line conditions to be used as reference WLR measurement due to lack of robust conventional sensor for SAGD conditions
- A comprehensive review of the fluid properties behavior, development of the full PVT to handle either 3 or 4 phase in SAGD at the well site (Oil, Natural Gas, Vapor of water, Water)
- A complete review with Engineering center of the future improvement to do in the commercial software to be SAGD compliant (fluid behaviour and 4th phase compliant)
- Starting the process of an entire review by DNV of the equipment for SAGD operation as a permanent multiphase flow meter
- Improvement of the Vx WLR measurement at line conditions through a new algorithmic process
- A proper understanding and a written procedure to handle dead sample to provide the Reference
- An update of the EOS generator (PVT Pro) for SAGD field and taking into account the steam ratio
- Validation of the Vx measurement at higher temperature then 190 DegC
- Validation of the Vx measurement in environment with water and high H_2S content in SAGD
- Demonstration of the good accuracy in PCP conditions
- Review of the performance in details of the multiphase flow meter (flow rates) versus conventional equipment and definition of the strong and weaker point of the multiphase solution versus conventional equipment (Ref. [4]).
- Use in unstable conditions to capture the flow dynamic and also in stable production to see the same performance than the separator
- Use in the large concentration of CO_2 (> 9%)
- Sensitivity analysis and what should be the maintenance program to define to keep the same level of uncertainty in permanent application through the Vx advisor software.

Based on this significant list of technical improvements, it was agreed by both parties that performing a second Vx trial at Firebag will bring value to both companies and would help reaffirm the capabilities of the Vx technology for SAGD conditions.

4.1 Qualifications & test Objectives

In order to qualify the Vx Technology for SAGD operation, a series of field tests were conducted at Suncor's Firebag asset during Q4, 2009. The Vx Multiphase flow meter was connected in series with the conventional test separator and the test was divided into three stages with review of the performance at the end of each stage before progressing to next stage and described as follows:

Stage #1: Benchmark (Vx vs. Test Separator)
This first stage will be to compare the performance of the Vx MPFM against the currently utilized test separator.

1. Demonstrate Vx installation procedure and set up process
2. Demonstrate gas and multiphase sampling capability
3. Benchmark Meet or exceed all metrics currently employed by the operator
    1. Accuracy & repeatability of all flow measurements (expected to be within 5%)
    2. Frequency of test duration (12 hrs or less)
    3. Capability to test each well head at least twice per week
    4. Capability to derive Gas/oil Ratio (GOR) and Steam/Oil Ratio (SOR)

5. No failures or reliability issues
6. Safety

Stage #2: Advanced Vx Capabilities
This stage focus on additional capabilities versus current test separator.

1. Evaluate shorter test duration cycles (e.g. 4 hours vs. the current separator 12 hour cycle)
2. Demonstrate accurate measurements of both natural gas and water vapor

Stage#3: Optimization Techniques
This last stage focuses on gaining an insight into the potential for optimization, which will be the basis for the next two phases of the project.

1. Evaluate Vx dynamic response capabilities
2. Explore the potential for production optimization

4.2 Installation

The Pad which was selected for this field test due was upgraded lately and has a large number of good producing wells and ideal set up of the conventional equipment. Wells were producing either naturally or by artificial lift (ESP pump). The presence of a 10” by-pass manifold on the pad production line and the capability to easily modify the current installation by implementing two 8” spools to connect to the Vx meter was a non-negligible factor. The metrological equipment of this PAD had also been totally updated or reviewed before this test.

For commodity and cost savings, the Vx mobile unit (“PhaseTester”) was used. However, it should be noted that the permanent unit (“PhaseWatcher”) utilizes the same technology but it is lighter and more compact. The only difference between these two tools is the mobility. For the duration of the three-stage program, 9 of 11 wells were tested. The remaining two other wells were not accessible or not producing at that time.

Figure 9: Field Operation and Equipment Proposed

The Vx meter was connected downstream of the test separator due to the design. Well effluents exiting from the test separator were recombined before flowing to the MPFM.

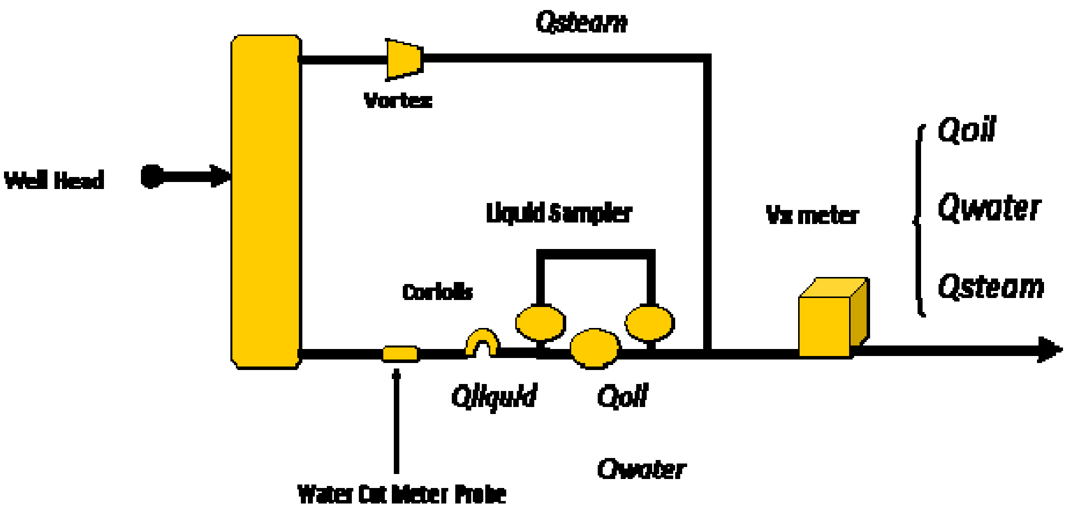

Figure 10: Field Operation and Equipment Proposed

The schematic (Fig. 10) illustrates the basic set up of the test separator and associated reference meters. As the two streams exit the separator, the gaseous phase is routed through a vortex meter in order to measure steam flow and is recombined with the fluid flow later. The liquid flows at the bottom first through water cut meter probe, then through a Coriolis meter and liquid sampler bypass.

It should be noted that the flowrate measurements accuracy could be affected due to some limitation associated with several required assumptions (listed below), but also intrinsic errors cause by various sensors. As conclusion the separator results should not be considered to be exact (like any others measurements) but the most correct one if the hypothesis and equipment are fully within their working envelope.

Assumptions or additional data required for the current test separator system:

- Gas line is assumed to be only water vapor (no natural gas) leading to a production of 2% more of condensed water in average
- Salinity input is required to get water-cut measurement due to the microwave technology used and this equipment seems to be very sensitive to the salinity parameter
- No gas is assumed to be passing through the liquid line
- No liquid is assumed to be passing through the gas line
- A Liquid Sampler by-pass is set to verify Water-cut Meter, and in average through the data obtained it is more than 8% absolute error that can be noted with in some cases more than 20% absolute deviations.

4.3 Multiphase Meter Settings

The setting of the multiphase flowmeter is based on a few input parameters that are essentially associated with the nuclear fraction measurement device. The mass attenuation parameter is an intrinsic parameter of the fluid composition and it is used to calculate each phase fraction flowing through the venturi throat. It is strongly recommended in SAGD operation that the mass attenuation determination for the first commissioning is performed in the base (more control conditions) and then confirmed on site. However, it is possible to get these intrinsic properties from the fluid composition. The mass attenuation is constant whatever the temperature and pressure. Moreover, it is not dependent of the long chain of alkans and then a composition in C5+ or C9+ is good enough.

Once a liquid sample is retrieved, the oil is separated from the water and processed in order to obtain the most accurate mass attenuation data for each phase. From this sample, the specific gas, oil, and water points are utilized to set the meter. Then when the commissioning (i.e., configuration file downloaded to the meter) is finished, then a map as illustrated below is available. Each point of the triangle represents 100% of each phase, and then any mix of the 3 phases will be within the triangle defined by the APEXES of oil, water, and gas (Figure xx).

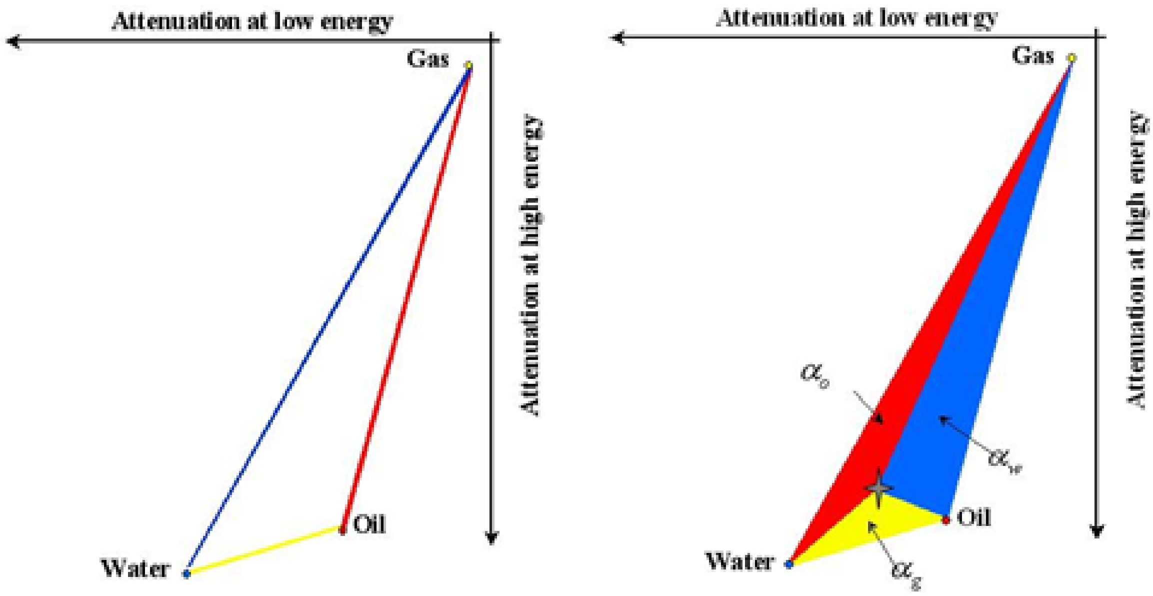

Figure 11: Field Operation and Equipment Proposed

Based on the composition obtained from Suncor (via Hysis) a VxFluidsID (i.e. fluid behaviour based on the EOS) was generated after recombination of the sample at reservoir conditions and used as a generic basis of the PVT behavior for the entire pad. It should be noted that a large concentration of H2S is coming from this type of oil and above 10%. The entire table set of the Vx Fluids IDs associated with the oil, water and gas properties are not presented in this document. But it should be known that they are automatically downloaded to the multiphase flow meter and represent the conversion of the different parameters from line to standard conditions and vice versa. Specific care was taken to account not only for water in liquid form, but also in vapor form.

5 OVERALL RESULTS

5.1 Dynamic Response Stage #1

During the Stage#1 of the Vx field trial, the meter was operated in “blind mode”, meaning that three phase flow measurements were successfully delivered in real time prior to the knowledge of the flowrate reference (i.e. separator test). Then, post-processing of the data was performed to report 4 phase flow measurements: Oil, water, natural gas and vapor flow rates. This was not implemented yet in the software version.

The figure 12 demonstrates the dynamic response to the flow of the Vx compared to the separator. The separator operating pressure is indicated in green, the Vx line pressure in blue, and line temperature in red. The high accuracy or performance is achieved via an optimal design of the inline venturi with a blind “T” for flow conditioning and then eliminating the issue due to change in flow conditions upstream of the meter. Moreover, this conditioning process allows getting faster thermo equilibrium at any conditions. The separator’s large vessel dampens the flow profile because of the need to keep the backpressure constant. The pressure profile reveals that the separator pressure profile is flat while in reality there is a pressure fluctuation during the test.

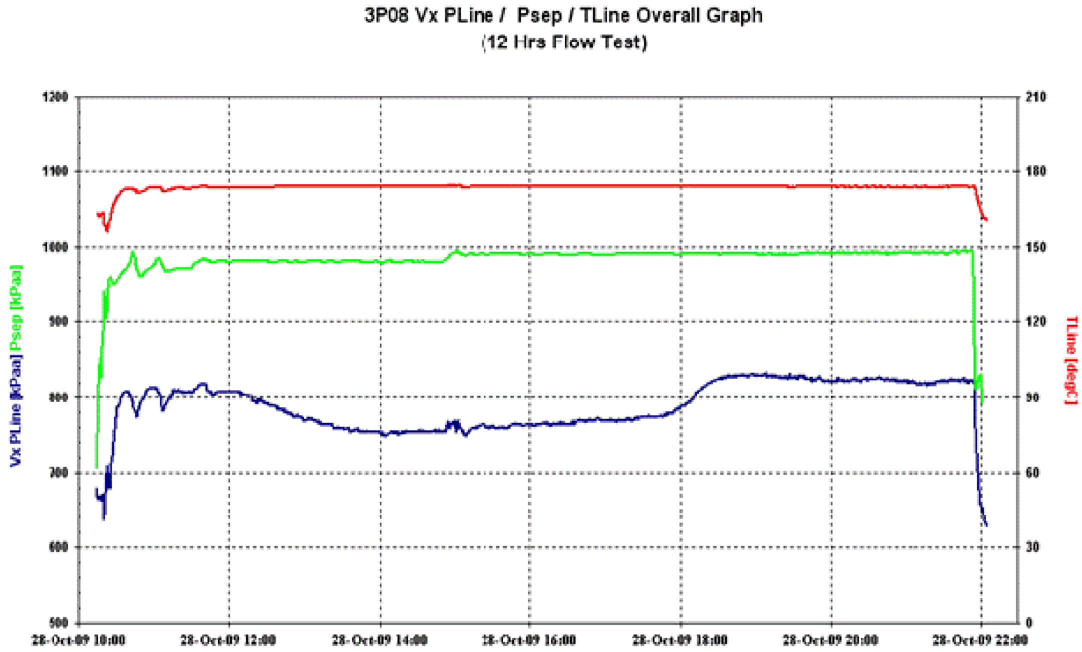

Figure 12: Field Operation and Equipment Proposed

The red line above confirms that wells were tested at an average of 180 °C flowing temperature or above. This demonstrates the capability of the Vx to operate at SAGD conditions.
The figure 13 shows a typical well recording versus time. A comparison Separator water cut, and Vx WLR is shown.

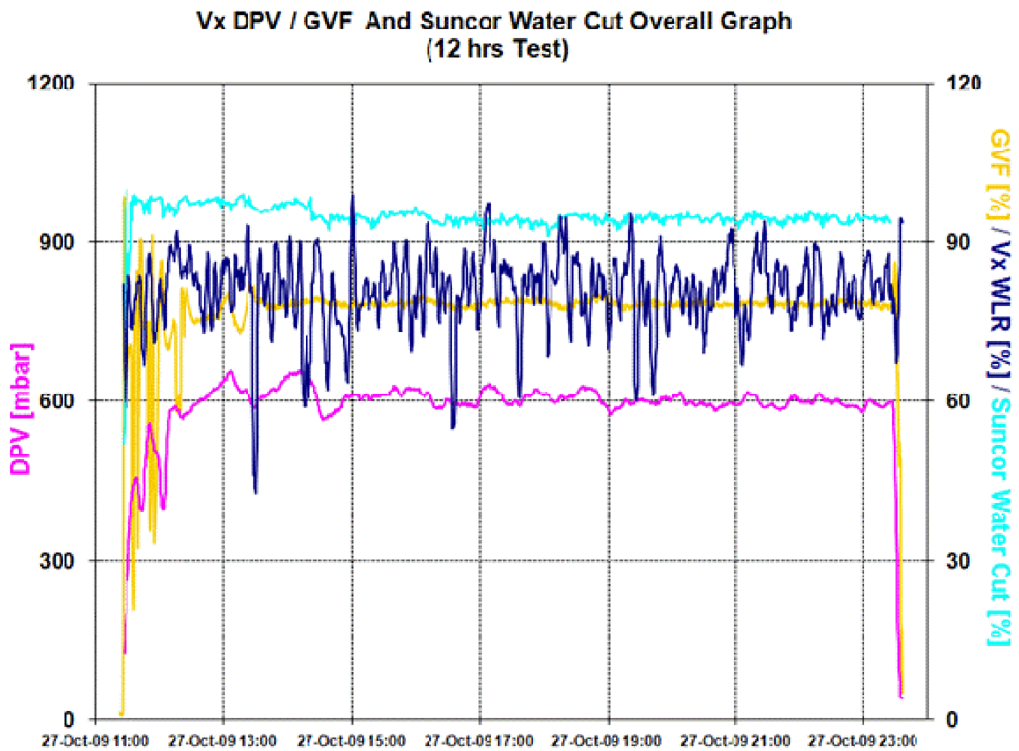

Figure 13: Field Operation and Equipment Proposed

The results from the Vx measurements indicate that the flow is turbulent and the WLR is never constant and always fluctuating. This could explain some of the large discrepancy between the reference water cut and the liquid sampling procedure (used as conventional system today inside SUNCOR) if unfortunately both comparisons are not synchronized. This aspect of the flow dynamic is important since it could affect the validity range of the test data and, therefore, the duration of each test.

The table 1 & 2 below present an overall performance summary for Stage 1 for all nine tested wells combined.

Table 1 – Measurement from Separator and Vx meter

Qmass Sep [kg/s]	Qliquid Sep [m3/h]	Density Liquid Sep [kg/m3]	CWE Sep Cor [m3/h]	WLR sep [%]	WLR sep* [%]	Qmass Vx [kg/s]	Qliquid Vx [m3/h]	Density Liquid Vx [kg/m3]	WLR Vx [%]	CWE Vx [m3/h]	CWE Vx [m3/h]
88.2	353.6	896.4	12.8	88.8	77.2	89.6	355.8	905.7	79.5	10.7	10.7

Table 2 – Comparison Separator – Vx Meter

Vx - Sep	Δ Qmass [%]	Δ Qliquid [%]	Δ Density Liquid [%]	Δ CWE [m3/h]	Δ WLR* [%]	Steam injected [kg/s]
12Hr	1.59	0.62	1.04	-0.04	**2.0**	196.3

*Corrected Values by using the proration factor for the entire field having no access to a proration factor ratio of the pad

The comparison between the Vx and separator WLR measurements shows a larger discrepancy on average for all the wells using raw data from the reference water cut meter. Vx reports consistently lower WLR values than the test separator in the blind test mode. Further examination revealed that the pro-ratio factors of the entire field were indicating an over-production of water and under-production of oil, i.e. the water cut at the separator was too high. In conclusion, there is a significant error with the current water cut meter installed and the technology proposed. The only way to try to do reconciliation is to correct based on the proration factor which was done and presented in the table 1 & 2.

It should be noted that in parallel 50% of the liquid samples collected have been analyzed in laboratory, and compared with the Vx measurements. They are well within the specification with in average 1% absolute error based on the analysis of few wells. It should be noted that with the same wells, there is large a discrepancy between the manual sampling done at the separator and the WLR read from the water cut meter, and then confirmation the correction applied above.

To summarize the main results from Stage#1:

- Continuous flow measurements provided for each well revealed good dynamic response
- Benchmarked resulted between the Vx meter and the test separator equipment are similar
- Total liquid mass flow rates are better than 2%
- Liquid densities are within 1%
- Recalculated WLR within 2%
- WLR within 1% versus half of the samples analyzed to demonstrate the WLR validation form the Vx.
- No safety or reliability issues during Vx meter testing

5.2 Measurement Reproducibility Stage #2

To demonstrate the reproducibility of the flow measurements using the Vx technology, a second test was completed, and this time shortening the flow period from 12 hours to 6 hours. It is important to mention that only, Well A, B and C were the wells that preserved the same flowing conditions (frequency, tubing choke size, tubing, and casing steam injection rate) during both tests. This set of data is highlighted inside the Table 3.

Due to the fluctuation of the initial conditions it was then proposed to playback, the data initially recorded over 12 hours but only during the 4 first hours. This will then show the stability of the measurement and then the capability to establish the performance of a well on a shorter period. It can be also interesting to note that the recorded raw data can always be playback at any time. This could be instrumental for SUNCOR to demonstrate to ERCB the performance of the well or be able to recompute data if a wrong setting was done on a multiphase Vx meter, this is a unique feature of the technology.

With the Vx meter only, the data of the 12 hours testing were reprocessed for only 4 hours showing a good agreement with the original 12 hours test. This supports the idea that the well tests, if only done periodically, can be significantly shortened from the current separator-based operation.

Table 3 – Overall performance with 12, 8 and 4 hours recording

Well	Tubing Choke Size %			Frequency Hz			Tubing Steam Rate m3/hr			Casing Steam Rate m3/hr			GVF %		
	12hr	6hr	4hr	12hr	6hr	4hr	12hr	6hr	4hr	12hr	6hr	4hr	12hr	6hr	4hr
A	45	45	45	39	39	39	4.0	4.0	4.0	10.0	10.0	10	95	96	96
B	55	55	55	41	41	41	4.0	4.1	4.0	8.0	8.0	8.0	97	97	97
C	100	100	100	0	0	0	6.0	6.0	6.0	34.0	34.0	34.0	98	98	98
D	45	100	45	56	54	56	4.0	5.0	4.0	35.0	16.0	35.0	78	80	78
E	35	40	35	53	50	53	8.0	4.0	8.0	35.3	8.0	34.0	62	68	62
F	45	40	45	55	55	55	8.0	4.0	8.0	25.0	8.0	25.0	21	56	23
G	52	50	52	54	52	54	8.0	4.0	8.0	21.9	7.9	22.2	50	49	48
H	40	40	40	49	49	49	8.0	4.0	8.0	20.0	7.9	19.9	79	77	79
I	65	65	65	57	55	57	4.0	4.0	4.0	7.9	10.9	8.0	78	79	78

Only the wells highlighted in gray kept exactly the same operating conditions during both tests.

As an example, well production measurements for one well is plotted (see Figure 14, 15, and 16) for the 12 hours, 6 hours, and 4 hours tests. The line temperature is presented in red, line pressure in blue, liquid flow rate in yellow and gas flow rate in light blue.

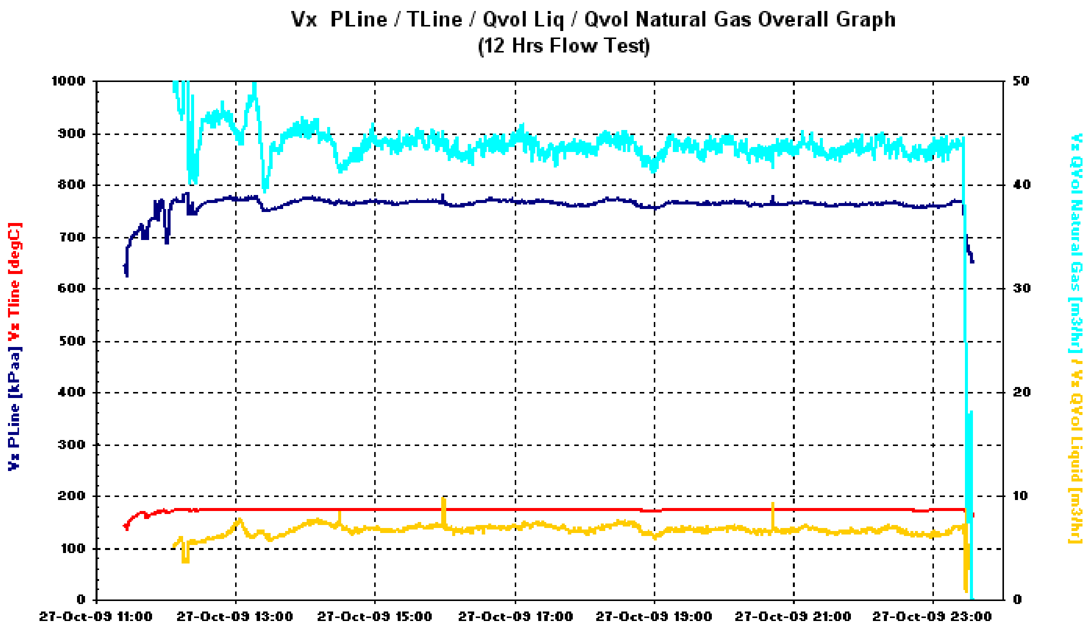

Figure 14: Pressure, Temperature, Gas & Liquid flow rate over 12 hours

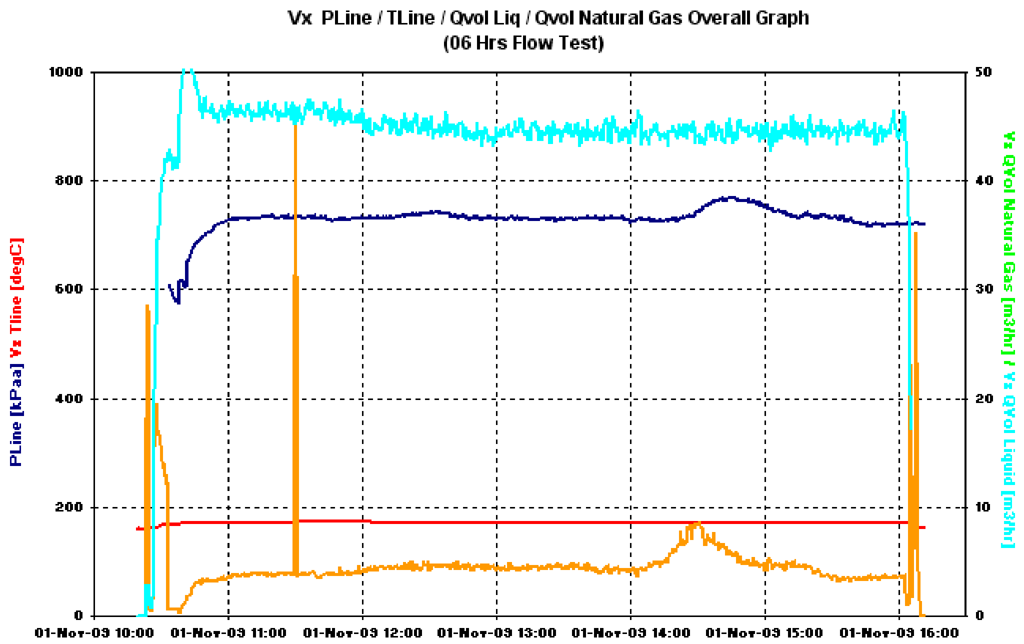

Figure 15: Pressure, Temperature, Gas & Liquid flow rate over 6 hours

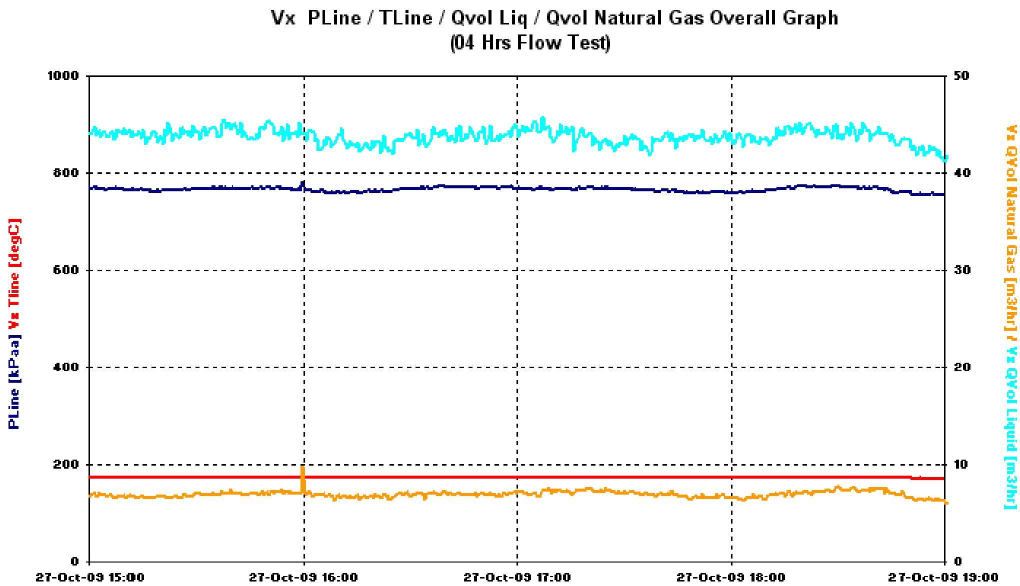

Figure 16: Pressure, Temperature, Gas & Liquid flow rate over 4 hours

Table 4 presents a comparison summary on a well-by-well basis for the 12-hour, 6-hour, and 4-hour tests.

Table 4 - The Table Pressure, Temperature, and Condensed Water Equivalent for 12, 8 and 4 hours

Well	Vx Pline (kPaa)			Vx Tline (DegC)			CWE (m3/h)		
	12hr	6hr	4hr	12hr	6hr	4hr	12hr	6hr	4hr
A	656.4	661.6	647.9	167.4	167.6	167.8	1.21	1.30	1.23
B	804.9	799.1	813.0	178.2	178.2	178.2	2.56	2.56	2.59
C	855.7	851.6	850.4	183.1	183.0	183.2	3.75	3.71	3.75
D	838.2	772.5	838.4	176.6	174.5	176.6	0.80	0.77	0.79
E	857.2	771.9	857.5	175.6	172.8	175.5	0.39	0.47	0.40
F	766.3	667.4	767.0	168.2	164.9	168.2	0.40	0.18	0.40
G	788.7	685.9	762.9	174.1	166.6	174.2	0.26	0.18	0.24
H	764.8	736.8	765.6	172.2	171.7	172.2	0.66	0.59	0.66
I	757.6	736.4	757.6	172.3	171.5	172.3	0.66	0.64	0.67

Table 5 – Liquid Mass Flow rate, WLR comparison for 12, 6 and 4 hours

Well	Liquid Mass (kg/s)			WLR		
	12hr	6hr	4hr	12hr	6hr	4hr
A	4.1	3.8	4.0	59.4	44.3	59
B	5.3	5.2	5.2	77.4	71.8	71.8
C	5.4	5.4	5.4	80.7	77.3	81.7
D	12.8	11.8	13	84.2	79.7	83.5
E	13.6	13.2	13.5	84.3	82.9	81.4
F	9.7	10.0	9.6	85.7	84.6	85.1
G	16.3	13.2	16.3	79.7	82.4	79.6
H	11.0	11.2	11	80.6	81.3	81.3
I	11.4	10.9	11	83.9	78.6	83.5

WLR measurement performance decreases with a GVF increasing, when the GVF average over 10 seconds is above 96-98%, a cut off value has been applied in this case (i.e. No calculation of WLR measurement if the value is above of the cut-off) in order to reduce the noise associated with the measurement. It should be noted that a sluggy behavior will be more favorable and will guarantee a better performance even if in average the GVF was above 96-99%.

The presented data above confirms that the measurement are identical for a 12 hours test versus the 6 hour test and even so the conditions may not have been entirely identical there is a good repeatability over 4 hours test. These results reveal that testing for shorter period of time and more frequently is providing the same level of confidence in the measurement, and then it is possible to do more frequent tests and then get a better performance of the production of each well over time.

5.3 Gas/Oil Ratio Reporting

The natural gas and vapor inside the flow stream could be obtained with an equation of state developed specifically for SAGD operation for SUNCOR. IA summary of the results for the vapor phase and SOR results (average of the 12hrs test) is shown below.

Table 6 – Total Gas, Natural Gas and GOR measurements

Well	Total Gas Flowrate [Sm3/h]	Natural Gas Flowrate [Sm3/h]	GOR [Sm3/Sm3]
A	1496.0	39.4	7.3
B	3428.8	15.0	1.6
C	5118.2	26.6	2.5
D	1111.4	1.3	0.3
E	587.4	14.9	1.8
F	93.43	2.1	0.9
G	441.4	2.92	0.2
H	912.7	6.9	1.1
I	900.4	6.5	1.2

5.4 Sampling Verification

The table below presents a comparison of WLR measurements from Vx, Separator, Vx Sample, and Manual Samples for each of the four sampled wells.

Table 7 – Comparison Vx measurement, sampling at the Vx, Separator Measurement and sampling at the separator

Well	Vx Sample	Vx Real-Time	Separator Real-time	Manual Sampling	GVF
A	85	69	93	56	96
B	73	77	80	72	98
C	77	80	79	72	80
D	74	79	80	80	81

It is important to mention that well B was a natural lifted well and this is the primary reason of an average GVF around 98%. This well was also very challenging to test. The Vx real-time measurement reported in this table was calculated over the same 15 minutes period of time when the Vx and Separator samples were taken except for the cases above 96%.
For the wells with a GVF below 96%, the results show a good match of the Vx real time WLR measurements with the reference samples.

5.5 Test Conditions

One of the important reliability considerations was to ensure that the Vx flow meter could operate at the extreme cold conditions during the winter season without any performance issues. During the second month of the Vx trial at Firebag ambient temperatures close to -40C were happening. The figure 32 shows a thermometer recording an ambient temperature (without wind chill factor) of -37.1 C at the well site.

Figure 17: Field conditions in Canada in December

The meter itself has been used most of the time with or without hot air supply and working in the range of -15 to +15 DegC without showing any change in the performance. Data Recording beyond -20 DegC (ambient temperature at the meter) has been also done in exceptional cases and have demonstrated the robustness of the Vx technology in winter conditions, the issue being if working to too low temperature being to plug the small liner very quickly.

The Figure 18 shows additional views of the test conditions at Suncor Firebag. The truck was equipped with a logging cabine and was self autonomous (electricity, warning system).

Figure 18: Field Operation Deployment

It will be recommended to leave the meter like in other cold country either in container (Alaska or Kazakhstan Design). Due to the high temperature of the flow, the ambient temperature inside the box will be kept at least in the range of -15 degC to 15 degC in the worst case and then this will not need any additional heating as demonstrated in the qualification test.

4.6 Summary

As demonstrated during this trial, the Vx technology provided better accuracy compared to the test separator data and allowed for more frequent well testing and then better well performance monitoring. The flow dynamics could be better monitored and understood in real time with fast acquisition measurements instead of the conventional test separator methods. An overall summary of the performance of the Vx meter versus the separator and the short duration test is shown below in the table below. This represents the average of the entire pad (9 of the 11 wells):

Table 8 – Overall production of the 9 wells for separator and Vx with 12 and 6 hours recording

Sep & Vx	Qmass Sep [kg/s]	Qliquid Sep [m3/h]	Density Liquid Sep [kg/m3]	CWE Sep Cor [m3/h]	WLR sep* [%]	Qmass Vx [kg/s]	Qliquid Vx [m3/h]	Density Liquid Vx [kg/m3]	WLR Vx [%]	CWE Vx [m3/h]	CWE Vx [m3/h]
12Hr	88.2	353.6	896.4	12.8	88.8	89.6	355.8	905.7	79.5	10.7	88.2
6Hr	82.6	331.8	898.1	12.9	86.4	85.3	337.9	907.9	75.9	10.4	82.6

Table 9 – Overall comparison of the 9 wells for separator and Vx with 12 and 6 hours recording

Vx - Sep	Δ Qmass [%]	Δ Qliquid [%]	Δ Density Liquid [%]	Δ CWE [m3/h]	Δ WLR [%]	Steam injected [kg/s]
12Hr	1.59	0.62	1.04	-0.04	2.0	196.3
6Hr	3.27	1.84	1.08	-0.05	-1.3	113.3

Table 10 - Overall production of the 9 wells for Vx with 12 and 4 hours recording

Vx12 Vx4	Qmass Vx12 [kg/s]	Qliquid Vx12 [m3/h]	Density Liquid Vx [kg/m3]	CWE Vx12 [m3/h]	WLR Vx12 [%]	Qmass Vx4 [kg/s]	Qliquid Vx4 [m3/h]	Density Liquid Vx4 [kg/m3]	CWE Vx4 [m3/h]	WLR Vx4 [%]
Total	89.3	355.7	905.7	10.7	79.5	89.5	353.9	912.6	10.7	78.5

Table 11 - Overall comparison of the 9 wells for separator and Vx with 12 and 6 hours recording

Vx12 Vx4	Δ Qmass [%]	Δ Qliquid [%]	Δ Density Liquid [%]	Δ CWE [m3/h]	Δ WLR [%]	Qgas [m3/h]	D Qgas [m3/h]	GVF [%]
	-0.11	-0.51	0.76	0.04	-1	284.7	2.8	76.5

There are comparable results measured by Vx meter and by test separator equipment:

- Total liquid mass flow rates are better than 2%
- Liquid densities are within 1%
- WLR Vx versus WLR separator recalculated is within 2%

6 OPTIMIZATION

SAGD well production is composed of and controlled by many man-made variables that are not found in conventional production operations. These range from initial steam injection – for steam chamber creation and oil heating, to ramp up – with gas lift injection, steam lift, gas lift, electro-submersible pumps (ESP) / progressive cavity pumps (PCP) lift, to blow down and also to break through.

In artificial lift systems, a variety or mechanical and systemic components can limit optimization of system usage. For example, artificial lift components may be blocked, damaged, sized improperly, or operated at less-than-optimal rates.
Maintaining the ESPs within a good envelope of operation is critical to optimization. A real-time optimization SAGD framework could be used to detect certain specific mechanical or systemic problems at the pump, identify the cause of underperformance, and take preventive measures that can increase the ESP run-life and decrease production downtimes.
ESPs are working in a harsh environment and it is advisable to reduce as much as possible the mechanical stress and/or large flow rate variations. ESP performance is altered by frequency changes due to changing production conditions; it is important to try to work in the best operating range, which leads to have the proper sizing. Optimization is also linked to efficiency, which is not only performance, but also efficient use of power.

With Vx technology, it is possible to perform real-time production optimization by adjusting the frequency control of the pump based on the Vx response. The Vx technology can deliver real-time production information since no stabilization of flow periods is required. The Vx is also not dependant on flow regimes and its high-speed acquisition frequency provide results even when the well production is unstable, giving the full picture of the flow dynamics when the frequency of the ESP is changed for optimization purposes.

When available, real-time flow measurements obtained from the Vx can be applied against a reservoir simulation/well model. Discrepancies between the measured data and the model can be used to determine factors contributing to sub-optimal SAGD performance and make decisions in a timely manner.

The protocol for Stage #3 was to test the West side of Pad. The pump running frequencies was to adjust from the initial operating frequency in 2 Hz intervals or so every three hours in order to capture a representative range of performance of the pump and well system.

The main objective of this stage of the test was to investigate the response of the Vx measurements to changes in the pump frequencies steam injection rates and chokes. If real-time measurements can be obtained, this opens the door for a future implementation of a SAGD optimization method that can result in increased productivity, less energy consumption and increased ESP run life.

Five wells were selected for the optimization trial, this stage of the trial consisted of a 12 hours baseline test at a fixed frequency and tubing pressure set point followed by another 12-hour test with a frequency change every four hours. A minimum of three frequency changes were made per well. Each frequency change was only made after the well had stabilized, and only if there was room on the pump curve to make the next frequency change. We show you a typical raw data curve.

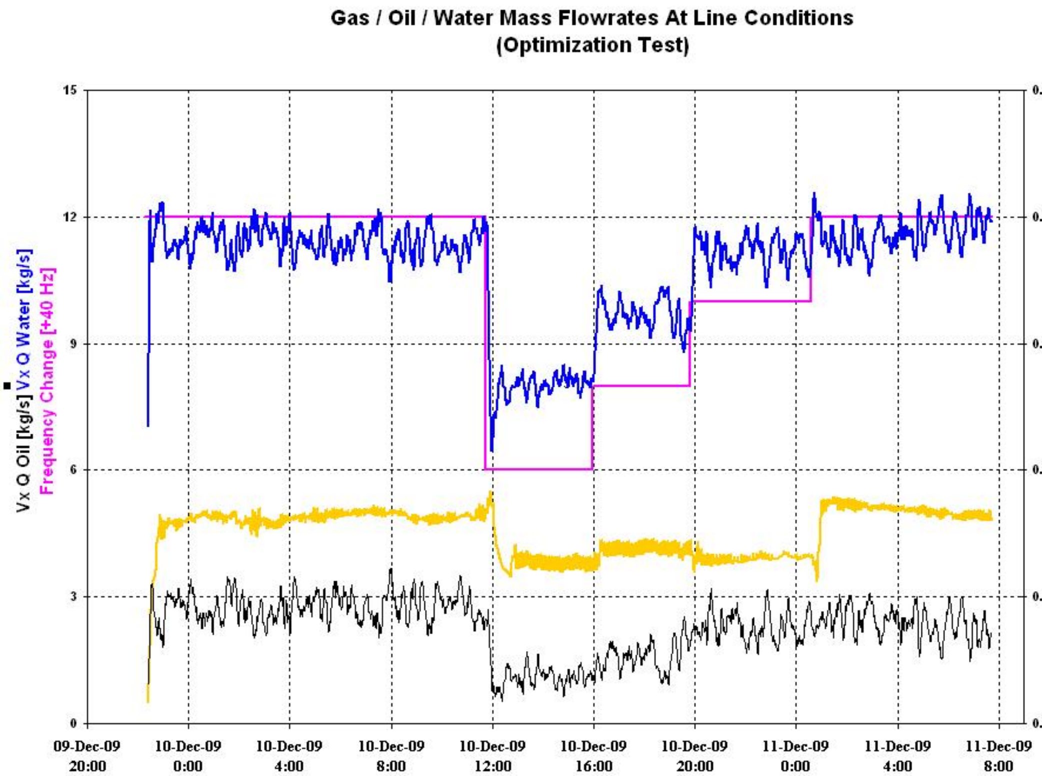

Figure 19: Concept of optimization of each well (data recorded vs. Time)

7 SUMMARY

This paper presents the results of an extensive evaluation on the use of Multiphase Flowmeters (MPFM) based on the Vx Technology to monitor production flow rates in SAGD wells at the Suncor Firebag Project.

The collaboration between Schlumberger and SUNCOR to test and qualify the multiphase technology started in 2007, when a single-well field trial was carried out at the Firebag project facilities. This was the first introduction of the technology to SAGD environments. In 2009, a second and more advanced field trial was initiated. A pad was selected due to the large number of good producing wells and ideal set up of the conventional equipment.
9 wells from Pad 103 were tested during the months of October and December 2009, ensuring that the MPFM was challenged against the full range of operating conditions of the SAGD wells. During two months of extensive well testing and fluid sampling, no safety incidents were encountered and the MPFM reported well production rates continuously and without any performance degradation even during the extreme ambient temperatures recorded at the well site.
Flow measurements between the MPFM and the Test Separator for the same stable flow periods revealed consistent results between both equipments. Total liquid mass flow rates are within +/- 2% and liquid densities within +/- 1% on average.
The comparison between the Vx and separator Water-Liquid Ratio (WLR) measurements showed a discrepancy for all the wells comparing the raw data. The Vx reports consistently lower WLR values than the test separator. Further examination revealed that the pro-ratio factors were indicating a fair over-production of water and under-production of oil for the entire field, i.e. the water cut at the separator was too high. In conclusion, there is a significant error with the current water-cut meter at the opposite of the Vx Technology.

In order to obtain a more accurate reference for comparison, the information about the pro-ratio factor for the entire field was used to back-calculate what should have been the WLR separator-based measurement, resulting in WLR Vx versus the recalculated WLR (from separator) to be within 2%.If the Vx had been used in this field during the test period (using the data from the Vx) one would have obtained a proration factor (for this pad) between 1.02 and 0.98 for oil and water over the two months (production sold versus what was reported by Vx).
To demonstrate the reproducibility of the flow measurements using the Vx technology, a second stage was completed, this time shortening the flow period from 12 hours to 6 hours. Then, with the Vx meter only, the data of the 12 hours testing were reprocessed for 4 hours showing a very good consistency in the results with the 12 hours test.The main conclusions of the test are as follows:

8 CONCLUSIONS

The main conclusions of the test are first that all the initial objectives given for the testing program were met or exceeded. Second, the Vx multiphase meter managed to demonstrate all the operating requirements required by Suncor operations. The uncertainties of all the phases are as per below:

- Uncertainty of within +/- 2% (after correction of the reference measurement based on a global back allocation factor)
- Uncertainty of minimum +/- 2% on Liquid rate
- Uncertainty of +/- 2% on Total Gas Flowrate (due to wet gas conditions and assuming that it is only steam)

Third, the Vx technology was capable to capture the entire dynamic of the flow: Start-up, intermittent and pulsing flow. The meter was used above 180oC in this test. By the order of accuracy form the output of the meter, the sequence is as follows: Total mass (or volumetric) flow rate, liquid mass (or volumetric) flow rate, gas mass (or volumetric) flow rate, GVF, GLR, then WLR, and associated oil and water flow rate.

The Vx meter reveals good dynamic response, repeatability and accuracies of the flow rates and has shown promise to be able to be used as an optimization tool. This is likely the result of the design and robustness of the Vx meter, summarized with some key features such as no Tuning Factor, no Separation, no Flow Calibration, no issues with Foams or Emulsions, no moving part, no sensors in direct contact with the fluid, and improve water detection and accurate BSW monitoring.

4 REFERENCES

[1] Performance of Combination of a Venturi and Nuclear Fraction Meter in SAGD Production Operations. Hompoth, Daniel, et al. Edmonton : s.n., 2008. World Heavy Oil Congress. 2008-422

[2] Multiphase Metering: Importance of Fluid Property Knowledge in SAGD Operations. Hompoth, Daniel, Pinguet, Dr. Bruno and Guerra, Elsie. Edmonton : s.n., 2008. World Heavy Oil Congress. 2008-421

[3] SAGD Production Optimization: Combination of ESP and Multiphase Metering Bruno G. Pinguet, Elsie Guerra and Colin Drever,Schlumberger. Edmonton : s.n., 2008. World Heavy Oil Congress. 2008-424

[4] Conventional metering issues for thermal in situ production of extra heavy oils and improvement of a commercial nucleonic multiphase meter for such applications. V. Arendo F. Dang and B. Pinguet, PH. Pechard, JL. Roudil. Margarita Island : World Heavy Oil Congress, 2009. 2009-327