Case Studies in Non-Nuclear Multiphase Flow Meters
Well-Testing Applications
in Alberta’s Oil Sands, Niobrara, Bakken and Eagle Ford Basins

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Overview

- Review of a Canadian regulator approval process for a multiphase meter well testing installation in Alberta
- Niobrara, Bakken & Eagle Ford Installations examples & learnings
2 Field Trial Program

In an effort to improve metering accuracy and optimize resource recovery, ConocoPhillips conducted a field trial program to evaluate MPFM technology for its Surmont SAGD heavy oil operations. For this field trial, ConocoPhillips installed and tested the Agar MPFM-50 with FFD₉ and has replicated, as close as possible, the testing procedures and flow conditions expected in future pad operations.

ConocoPhillips began the field trial on February 12th, 2013 and the test ran through to March 25, 2013. The test was conducted in accordance with the stated procedure agreed upon with the ERCB in Application No. 173221. During the test, a net 748 hours of testing time was logged with the Agar MPFM. All 17 producing wells on Pad 102 flowed through the MPFM, which included 16 ESP wells and 1 gas lift well. To better replicate the range of gas lift wells, a gas crossover line was installed at the wellhead on an ESP well for gas injection into the emulsion line.

Prior to completing the test Agar held a 1 day training session with Operations and Maintenance personnel at Surmont. The training included theoretical as well as practical training with the meter and sampler. The results from the MPFM were compared against the test separator for water cut and emulsion flow, and against samples taken across the MPFM for water cut (WC). The table below summarizes the testing results:

<table>
<thead>
<tr>
<th>Comparison</th>
<th>Absolute Error</th>
<th>Relative Error (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volume Flow Rate (vs. Test Separator)</td>
<td>7.96 m3/d</td>
<td>2.40%</td>
</tr>
<tr>
<td>Water Cut (vs. Test Separator)</td>
<td>3.59%</td>
<td>5.47%</td>
</tr>
<tr>
<td>Water Cut (vs. Sampling)</td>
<td>4.01%</td>
<td>6.02%</td>
</tr>
</tbody>
</table>

The results satisfy the requirements of Directive G17 and are in line with ConocoPhillips expectations. Given the successful trial results at both low and high gas void fractions, ConocoPhillips is seeking ERCB approval for utilization of the Agar MPFM-50 with FFD₉ in lieu of test separation for the infill wells on Pad 102.
Testing Plan

- Minimum equivalent of one month (744 hours) of testing. Test results compared to test separator.
- Run testing at the current standard testing schedule; 8 hours on test per well, 1 hour purge time between wells.
- Coriolis on Pad 102 will be used as the reference mass/volume flow rate readings. MPFM data will be compared to the coriolis and WC readings.
  - Standard correlations will be used to compensate for small differences in P&T; this is expected to account for less than 1% difference in liquid streams.¹
- Each time an MPFM metered well is put into test, water cut will be determined by collecting a pressurized sample at the throat of the MPFM with a sampling skid. The sampling skid and sampling procedure have already been evaluated at Pad 102 and proved to provide representative samples on a consistent basis. To maintain consistency between samples and average measurements, ConocoPhillips will pay special attention to process stability (based on instantaneous instrument readings).
- One test will be specifically designed to evaluate meter performance during “upset” conditions. Transient performance (ex. start-up and changing wells) will be assessed to improve ConocoPhillips’ understanding of the metering system’s behavior and allow for optimization of future testing procedures.
- The MPFM vendor (Agar) will provide basic theoretical training to office and field personnel before the meter is tested. During testing, Agar will provide hands on training with the meter and software required for operation to field personnel. This will ensure safe and accurate operation during MPFM testing and will aid in preparing ConocoPhillips personnel for commercial implementation.

¹ The information presented below was collected from Application # 1744341, submitted by ConocoPhillips to the Alberta Energy Regulator on April 2013, AER approval #9426R.
2.4 **Agar MPFM Technical Operations**

The Agar MPFM-50 is a complete system that integrates commonly used oilfield measurement technologies. Agar combines these devices to accurately measure the flow rates for oil, water and gas in a multiphase environment. The Agar MPFM-50 consists of 5 major components as shown in Figure 1:

- A. Coriolis meter
- B. Agar OW-200 water cut meter
- C. Agar ID-201 interface detector
- D. Dual venturi meter
- E. Pressure transmitters

*Figure 1: Agar MPFM-50 Components*
7.1 Construction

ConocoPhillips Canada conducted its MPFM field test upstream of test separator V-2201 outside building 2200 on Pad 102. This location utilized the existing tie in points which were necessary to transport emulsion flow through the Agar MPFM-50 with FFD® and then into test separator V-2201. A simplified testing schematic is depicted in Figure 45.

![Simplified Testing Schematic](image)

Figure 45: Simplified Testing Schematic

The information presented below was collected from Application # 1744341, submitted by ConocoPhillips to the Alberta Energy Regulator on April 2013. AER approval #9426R.
2.8 Error Definitions

Data from the MPFM was compared to the test separator and to sampling data. In evaluating the success of the Agar multiphase flow meter during testing, ConocoPhillips applied the following metrics:

Absolute Error = |MPFM – Reference|

Average Absolute Error = \frac{\sum_{i=1}^{N} |\text{MPFM} - \text{Reference}|}{N}

Relative Error = \frac{100 \times |\text{MPFM} - \text{Reference}|}{\text{Reference}}

Average Relative Error = \frac{\sum_{i=1}^{N} 100 \times |\text{MPFM} - \text{Reference}|}{N \times \text{Reference}}

Where ‘N’ = Number of well tests.
The information presented below was collected from Application # 1744341, submitted by ConocoPhillips to the Alberta Energy Regulator on April 2013.
AER approval #9426R.
Gas Lift / Gas Jumper Test

Figure 48: Well R Gas Cross-over Line

Figure 23: Gas Cross-over Trials shown with GVF

Figure 24: Test Separator Coriolis Density vs. GVF

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Gas Lift / Gas Jumper Test

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Gas Lift / Jumper Test

Throughout the Agar MPFM trial, Well I was the only gas lift well on Pad 102. The MPFM displayed a high degree of accuracy for both water cut and emulsion rate on this well. Gas lift wells are typically characterized by liquid slugging and GVF swings. Well I, depicted below from 11:45 to 19:45, demonstrates the irregular nature of emulsion flow from GL wells.

![Graph showing Gas Lift Well Emulsion Rates](image)

When plotting the Agar MPFM and test separator water cuts against the sampled water cuts, it is evident that the MPFM reads water cut very accurately for gas lift Well I. The average GVF for this well is approximately 85%. The MPFM averaged a water cut of 73.04% during sampled well tests, at an average error of 2.29%. The test separator averaged a water cut of 63.97% during sampled well tests at an average error of 11.01%. The GVF range for historical gas lift wells at Surmont range anywhere from 65%-85% GVF. Table 7 shows the ranges of gas lift flow rates from wells on Pad 102 while they were on gas lift (before conversion to ESP).

![Graph showing Well I MPFM & Test Separator WC vs. Sampled WC](image)
The information presented below was collected from Application # 1744341, submitted by ConocoPhillips to the Alberta Energy Regulator on April 2013, AER approval #9426R.
Niobrara & Bakken Installations
Niobrara Test Facility Arrangement

Flare

AGAR MPFM-50

Test Sep Stage 1

Test Sep Stage 2

Water

Water
## Niobrara Installation - Tank Comparative Testing

<table>
<thead>
<tr>
<th>Test Information</th>
<th>AGAR MPFM-50</th>
<th>TANK Volume Reference</th>
<th>Volume Deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Oil Volume</td>
<td>Water Volume</td>
<td>Gas volume</td>
</tr>
<tr>
<td>Date</td>
<td>BBLS</td>
<td>BBLS</td>
<td>SCFD</td>
</tr>
<tr>
<td>5-Feb</td>
<td>80.91</td>
<td>587.13</td>
<td>316.81</td>
</tr>
<tr>
<td>6-Feb</td>
<td>80.69</td>
<td>584.01</td>
<td>320.50</td>
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<tr>
<td>7-Feb</td>
<td>82.83</td>
<td>580.75</td>
<td>320.24</td>
</tr>
<tr>
<td>8-Feb</td>
<td>81.99</td>
<td>577.41</td>
<td>318.38</td>
</tr>
<tr>
<td>9-Feb</td>
<td>83.09</td>
<td>574.75</td>
<td>318.33</td>
</tr>
<tr>
<td>10-Feb</td>
<td>75.10</td>
<td>506.58</td>
<td>286.22</td>
</tr>
<tr>
<td>11-Feb</td>
<td>81.05</td>
<td>558.87</td>
<td>314.63</td>
</tr>
<tr>
<td>12-Feb</td>
<td>84.36</td>
<td>552.28</td>
<td>314.84</td>
</tr>
</tbody>
</table>
Eagle Ford - PAD A Meter
Eagle Ford High GVF MPFM
Eagle Ford High GVF MPFM
Eagle Ford High GVF MPFM

Watercut vs Watercut Deviation

Separator Control Problem

Campaign 1
Campaign 2
Eagle Ford High GVF MPFM
Eagle Ford High GVF MPFM - Daily Flow Profile Comparison over Three Years
Eagle Ford MPFM - Identification of Water Migration

- **Std Gas Flow (mcfd)**
- **Liquid flow (bpd)**
- **Oil Flow (bpd)**
- **Water Cut (%)**
Eagle Ford MPFM - Identification of Frack Water Migration
Eagle Ford - from Initial Evaluation to Operation-PAD A, Well 1 Comparative Trends
Eagle Ford - from Initial Evaluation to Operation
PAD A, Well 2 Comparative Trends
Eagle Ford - Well Test Summary
Comparison over 5 days, after flow back separator hand over

<table>
<thead>
<tr>
<th>Test Dates</th>
<th>AGAR GAS</th>
<th>AGAR OIL</th>
<th>AGAR WATER</th>
<th>AGAR LIQUID</th>
<th>AGAR WC</th>
<th>TEST GAS</th>
<th>TEST OIL</th>
<th>TEST WATER</th>
<th>TEST LIQUID</th>
<th>TEST WC</th>
<th>Gas</th>
<th>Oil</th>
<th>Water</th>
<th>Liquid</th>
<th>WC</th>
</tr>
</thead>
<tbody>
<tr>
<td>4/16-4/21</td>
<td>5173</td>
<td>5251</td>
<td>2198</td>
<td>7413</td>
<td></td>
<td>4877</td>
<td>5441</td>
<td>2142</td>
<td>7584</td>
<td>28.3%</td>
<td>5.1%</td>
<td>-4.2%</td>
<td>2.6%</td>
<td>-2.3%</td>
<td>1.4%</td>
</tr>
<tr>
<td>4/06-4/11</td>
<td>4109</td>
<td>4768</td>
<td>2469</td>
<td>7237</td>
<td></td>
<td>4041</td>
<td>4895</td>
<td>2352</td>
<td>7247</td>
<td>32.5%</td>
<td>1.7%</td>
<td>-2.6%</td>
<td>5.0%</td>
<td>-0.1%</td>
<td>1.7%</td>
</tr>
<tr>
<td>4/21-4/26</td>
<td>4801</td>
<td>4616</td>
<td>2097</td>
<td>6713</td>
<td></td>
<td>4617</td>
<td>4818</td>
<td>1911</td>
<td>6730</td>
<td>28.4%</td>
<td>4.0%</td>
<td>-4.2%</td>
<td>9.7%</td>
<td>-0.2%</td>
<td>2.8%</td>
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<tr>
<td>4/11-4/16</td>
<td>2979</td>
<td>3377</td>
<td>1750</td>
<td>5127</td>
<td></td>
<td>2950</td>
<td>3497</td>
<td>1919</td>
<td>5416</td>
<td>35.4%</td>
<td>1.0%</td>
<td>-3.4%</td>
<td>-8.8%</td>
<td>-5.3%</td>
<td>-1.3%</td>
</tr>
</tbody>
</table>
Eagle Ford MPFM Summary of Phases and Fractions Uncertainties for 5 Days Tests Real-Time Data - PAD A
Eagle Ford MPFM Summary of Phases and Fractions Uncertainties for 5 Days Tests
Real-Time Data - PAD B

<table>
<thead>
<tr>
<th>Well A - Aug 1 - Separator Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas %</td>
</tr>
<tr>
<td>-1.3</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Well B - Aug 2 - Separator Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas %</td>
</tr>
<tr>
<td>3.5</td>
</tr>
</tbody>
</table>
Conclusions & Recommendations

- In choosing a method for field evaluation, special care needs to be taken to validate the pre-test reference assumptions, and take corrective action if deemed necessary.

- A comprehensive field test will examine the MPFM performance in all stages of well’s life, since each of these stages will have distinctive dynamic flow characteristics.

- Constant communication and collaboration between technology provider and E&P company is key for successful implementation.