Multiphase Flow Measurement System of High-GOR Applications

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1. Abstract

This paper presents the findings from an installation at Prudhoe Bay which was started up on October 22, 1998. This system consists of a MFI Multiphase Meter, a partial separation separator and a coriolis effect flow meter. The separator is used to widen the operating envelope of the multiphase meter. The control of the separator, data acquisition and final calculations are done by the MFI Meter.

Since the system has a very wide operating envelope it can be used on groups of wells with widely divergent flow rates. This particular system is designed for accurate flow measurements with GOR's up to 80 000 scf/bbl and it can handle liquid flow rates in the range 100–15 000 bbl/d. The accuracy of the oil flowrate is typical within 5% and the gas flow rate is measured within 2-3%.

The key element of the system is the MFI multiphase flow meter which is used to measure the multiphase flow in the "liquid leg" of the compact separator. Unlike most well test systems, the measurements of the liquid line are not adversely affected by gas carry under. In fact, it works best with gas flowing in the liquid line.

Operation and control of the system is greatly simplified by the fact that the primary goal of the separator is to remove the liquid from the gas. The separator is designed to remove down to 5 ppm over the full range of flow rates. The excitation voltage of the coriolis meter is used to detect carryover down to 2-3 ppm. This variable is also used in the control logic and changes the vapor leg flow rate to eliminate carryover.

2. MFI MultiPhase Meter

The MFI Multiphase Meter uses a unique, patented microwave technology. However, the fundamental physical principals involved are simple. Multi-Fluid's technological platform is based on the ability to adopt and apply these fundamental principals to the challenging technological task of measuring fractions and flow rates of different components flowing simultaneously in a pipe, without any prior separation of the phases.

The sensor is a compact, straight spool piece with no moving parts and no pressure drop as shown in figure 1. The MFI Multiphase Meters perform all measurements and calculations in a field mounted electronics, consequently, only final results are transmitted from the field using simple analogue or digital outputs. With this architecture, the MFI Meters can be used as stand-alone, remotely operated devices without the need for support facilities. This can dramatically reduce the cost of installing and using multiphase meters in remote or unmanned facilities.

Instantaneous oil, water and gas fractions are measured using a patented microwave measurement device for measuring mixture dielectric properties and a commercial Cs 137 gamma densitometer for measuring mixture density.

The meter functions over the full 0 - 100% water cut range. Separate sensors are not required for low and high water cut measurements. The microwave measurement system has unparalleled sensitivity. The microwave sensor works by measuring a characteristic microwave frequency that is inversely proportional to the square root of the mixture dielectric constant. A change from 100% gas to 100% water can result in a change in the measured microwave frequency of over 100 to 1. As a result, the meter can measure the water cut, oil flow rate, and water flow rate of multiphase mixtures with superior accuracy, particularly at high GVF. The composition meter accurately measures component volume fractions several times per second. Thus, it is possible for it to function with any flow regime in the line, even intermittent plug flow. Another benefit of ´real-time´ measurement is that the meter can be used to determine which flow regime is present in the line. Many other multiphase techn ologies integrate raw data over tens of seconds to get meaningful results, thereby losing useful real-time information.

The primary element for measuring multiphase flow velocity is a microwave based Cross-Correlation Meter. This device uses two identical microwave sensors (such as used in the composition sensor) separated by a known distance in the pipe to measure velocity. By statistically comparing measurements from the upstream sensor with those of the downstream sensor using cross-correlation methods, one can determine the mean transit time for the mixture to move between the sensors. The sensor spacing and the measured transit time give velocity. Roxar has developed a slip flow model to determine respectively the gas and liquid velocities from the measured velocity using, among other inputs, the statistical data from the composition meter to characterise the flow regime. These two velocities are combined with the readings from the composition meter to obtain the actual oil, water and gas flow rates. The Cross-Correlation Meter has a number of advantages compared to other multiphase velocity meters (including Venturi Tubes):

- Turn-down ratio of up to 35:1
- No moving parts
- High sensitivity.
- It also functions with zero water cut and fine bubble flow such as might be present during early production.
- No differential pressure taps and tubing that can foul, partially fill or leak, or dP transmitters that can drift
- Easily used in high pressure systems without sacrificing accuracy

An optional element for measuring multiphase flow velocity is a Venturi meter. The suitability of a Venturi is assessed on a case-by-case basis. The beta ratio for the Venturi meter is tailored for each application to maximize the turndown ratio and thus improve accuracy. It is possible to achieve a turndown ratio up towards 10: 1 in mass flow terms. Combining the X-Correlation Meter with a Venturi gives some redundancy. The MFI Meter can continue functioning even if either the Venturi Meter or the X-Correlation Meter should fail. Either velocity meter can be used to measure liquid and gas velocities. The venturi can also be used as an element within the MMS (MultiPhase Management System) as a part of preventive maintenance routines.

3. MFI High Gas System

The MFI High Gas System has been developed in cooperation with ARCO Alaska, Inc. This system consists of a partial separation separator with downstream instrumentation containing a MFI MultiPhase Meter and a coriolis effect gas flow meter. The separator is used to widen the operating envelope of the multiphase meter and increase the accuracy of the measurements at conditions with wells having high GORs. The control of the separator, data acquisition and final calculations are done by the MFI Multiphase Meter. A drawing of the complete system is shown in figure 2.

The system consist of the following components:

- A cyclone with one inlet and two outlets, one for gas and one for gassy liquid.
- A MFI Multiphase Meter to measure oil, water and gas in the multiphase outlet line.
- A coriolis meter to measure the separate gas flow and detect liquid carry over.
- Two control valves, one in each of the outlet lines, to control the flow rates in the respective outlets.
- A differential pressure transmitter attached between the liquid and gas outlet of the separator to detect excessive liquid levels in the separator.

3.1 Cyclone Separator
A standard cyclone can be used as the inlet separator. For the systems installed at Prudhoe Bay, a two-stage separator as shown in figure 3 is used. The separator is a two-stage cyclone with an inner and outer gravity spin. Most of the liquid is separated out at the outer gravity spin defined by the total diameter of the separator. The gas with some remaining liquid is then sucked into the inner cyclone thus spinning at a higher velocity. The remaining liquid in the gas evacuates from the inner cyclone through a small slot in the wall of the inner cyclone. The liquid and some gas from the second stage is sucked through the “liquid carry over” pipe section which is terminated near the low pressure area in the first stage vortex.

3.2 Control Algorithm
Unlike most separator systems for which level control is the object of the system control algorithm, the MFI High Gas System controls the flow rates in the liquid line and gas line to ensure best possible accuracy of the total measurement. The system is specifically designed to operate with significant volumes of gas carry under in the liquid line. Consequently, the liquid level in the separator is effectively zero under most normal operating conditions.

Instead of controlling level, the system controls the relative volume of gas flowing in the liquid and gas lines respectively by adjusting one of the control valves to alter the differential pressure balance in the two flowing lines. In this manner, it ensures that the multiphase flow conditions in the liquid line are such that the MFI Meter delivers optimal accuracy. Similarly, it ensures that sufficient gas volumes are flowing through the gas meter to ensure that it achieves best possible measurement accuracy. In summary, the MFI High Gas System achieves optimum accuracy for any given inlet flowing condition by controlling the flow rate of the gas in the respective flow lines.

Liquid carry over in the gas leg can be detected by two means. When two phase flow is present in the coriolis meter, the amount of energy required to resonate the tubes increases. Consequently, the tube excitation voltage is a good measure of liquid carry-over in the system. Second, the system can be set up with a predefined separator level or dP for which liquid carry over will occur. In the event of "liquid carry over detection", the system will automatically increase the velocity in the multiphase line of the system to improve the quality of separation. It is important to note that liquid carry-over in the gas leg of conventional test separator operation is something that is usually not monitored and is largely ignored. To a lesser extent gas carry-under in the liquid is also frequently missed.

3.3 Operator Interface

The operator interface for the system is a Graphical User Interface (GUI) running on a Windows 95/NT platform. One GUI can be connected to several systems. The GUI communicates with the system using Modbus RTU protocol and allows the operator to configure and calibrate the system. The GUI has a powerful built-in trending function of all measurement data, and the data can also be stored in a database. Typical tuning parameters such as response time, control gain and liquid carry over threshold for the coriolis excitation voltage and separator level limits can be configured from the GUI. Figure 4 shows a picture of a typical Graphical User Interface (GUI) display.

4. Field Experience at Prudhoe Bay

The MFI High Gas System was commissioned at the end of October 1998, and there have been no operational problems after commissioning.

The control algorithm of the system was able to stabilize the flow within a few minutes as shown in figure 5. The system was operating very reliably and no fault conditions have been observed during operation. Both the coriolis tube excitation voltage and separator level proved to be reliable measurements of any liquid carry over. The coriolis excitation voltage was normally between 2.5 – 2.7 volts. Even for a small amount of liquid carry-over, the excitation voltage instantly increased by several volts. For excess amounts of liquid carry-over (> 1%), the coriolis excitation voltage was saturated at 14.5 volts. The control algorithm is robust enough to correct for any "liquid carry-over" events within seconds from detection by the coriolis excitation voltage. During normal operation, there is no liquid level in the separator as measured by the differential pressure across the separator. For the conditions at Prudhoe-Bay, liquid carry over was detected by the differential pressure measurement with approximately 10 inches of liquid level in the separator. Consequently, any liquid carry-over could reliably be detected by measuring the differential pressure across the separator. The MFI High Gas System was also operating reliably at severe slugging conditions as shown in figure 6.

The well in figure 6 was slugging at a rate of approx. two slugs pr. hour. The system was able to control the valves in order to obtain the desired conditions of the system. This graph also demonstrates one of the great advantages of such a system compared to a conventional test separator. Whereas the measurements from a test separator would be averaged out for several hours filtering out any real time data, the MFI High Gas System gives valuable information of the dynamic behavior of the well. For this particular well, the liquid and gas slugs are in phase indicating a lift gas problem as opposed to just a high GOR. Hence, by optimizing the lift gas rate based on the real-time measurement from the MFI High Gas System, the production rate from the well could be increased. Also the real-time data can be helpful in diagnosing sub-surface equipment or reservoir problems. The first three months of operation as shown in figure 7 reflect results consistent with expected well performance and metering repeatability.

5. Acknowledgments

The authors are indebted to Jim Abel the ARCO Alaska, Inc. Project Manager for support in applying this technology. Also, we would like to thank Stuart Parks for his efforts in coordinating the design, construction and start up of these systems. The views in this paper are those of its authors and do not necessarily reflect the views of the Prudhoe Bay Co-Owners.
Appendix – Tables and Figures

Appendix – Figures

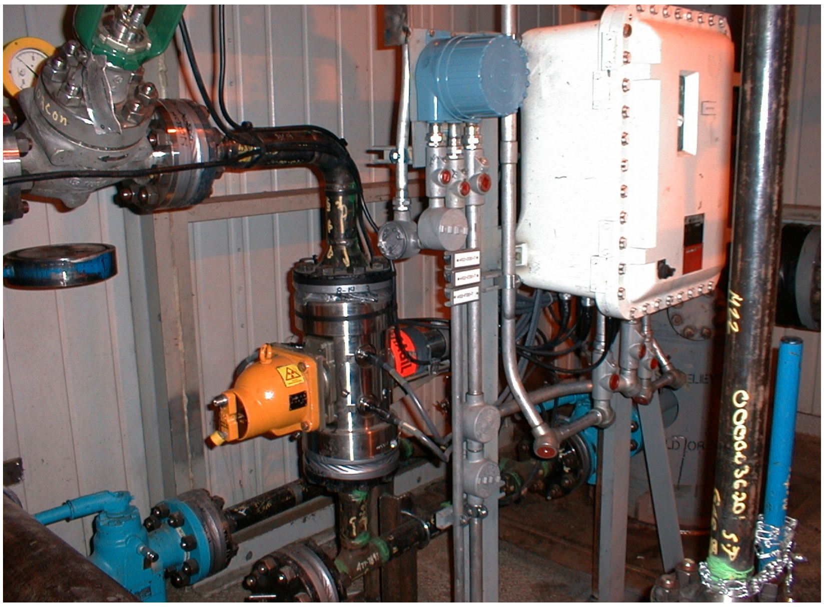

Fig. 1 - 2" MFI Multiphase Meter. The sensor is a compact, straight spool piece with no moving parts and no pressure drop. A two inch, 1500 lb. sensor with ANSI flanges is less than 450mm (18 inches) long. All measurements and calculations are done in the electronics box.

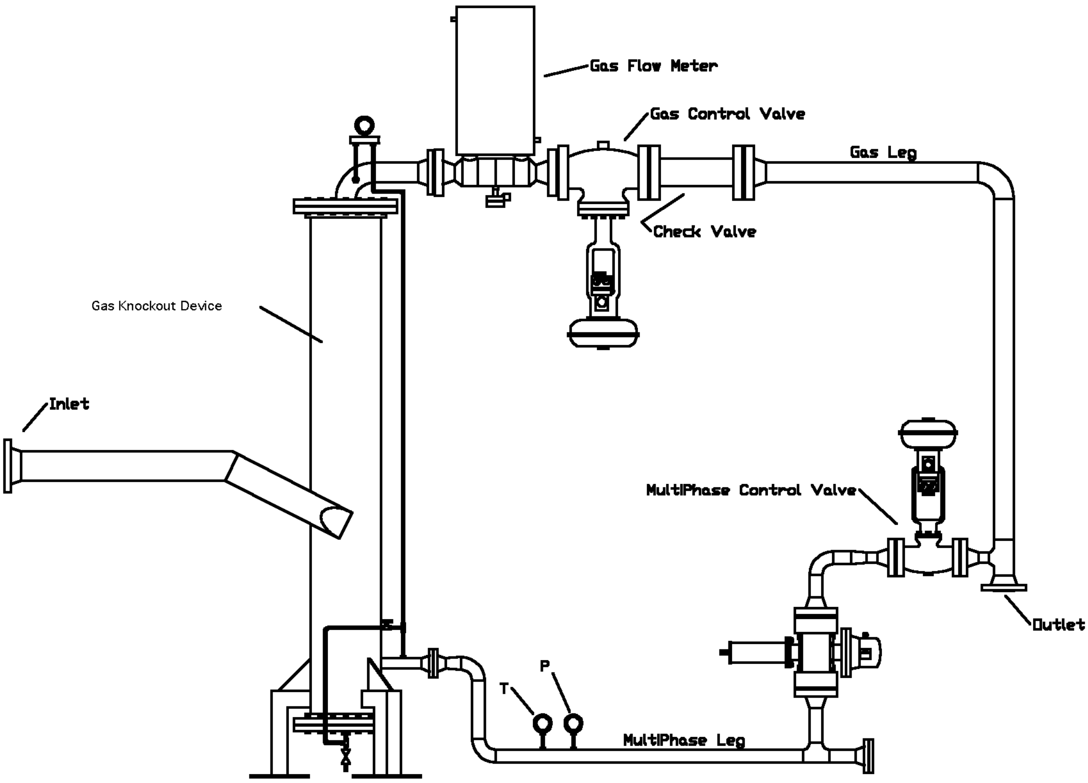

Fig 2. - MFI High Gas System. This system consists of a partial separation separator with downstream instrumentation containing a MFI multiphase flow meter and a coriolis based gas flow meter. The separator is used to widen the operating envelope of the multiphase meter and increase the accuracy of the measurements at conditions with wells having high GORs. The control of the separator, data acquisition and final calculations are done by the MFI Multiphase meter.

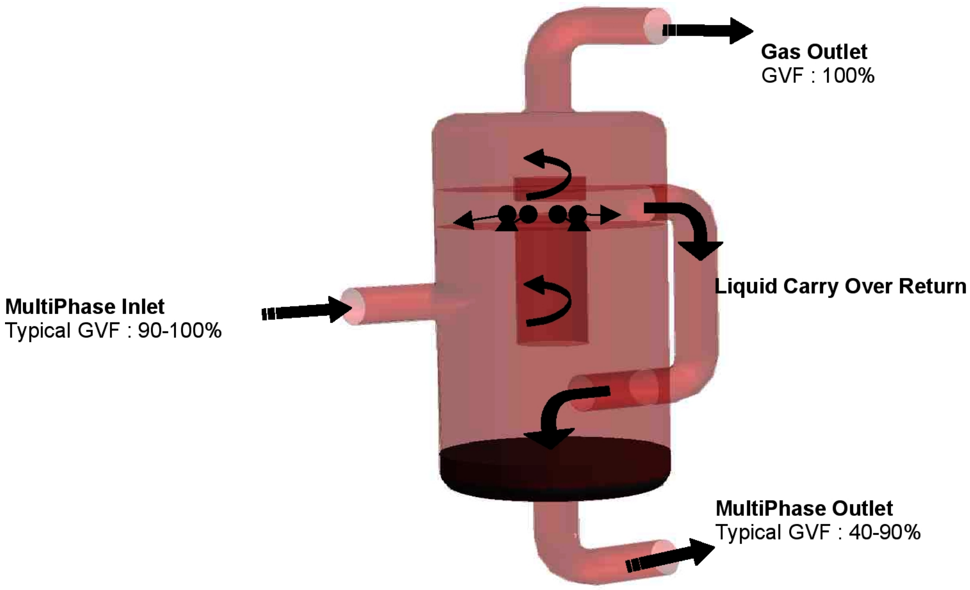

Fig 3. - The separator is a two-stage cyclone with an inner and outer gravity spin. Most of the liquid is separated out at the outer gravity spin defined by the total diameter of the separator. The gas with some remaining liquid is then sucked into the inner cyclone thus spinning at a higher velocity. Remaining liquid in the gas evacuates from the inner cyclone through a small opening at the end of the inner cyclone. Then, since the bottom of the separator is at a lower pressure, liquid from the second stage is sucked through the "liquid carry over" pipe section which is terminated near the low pressure area in the first stage vortex.

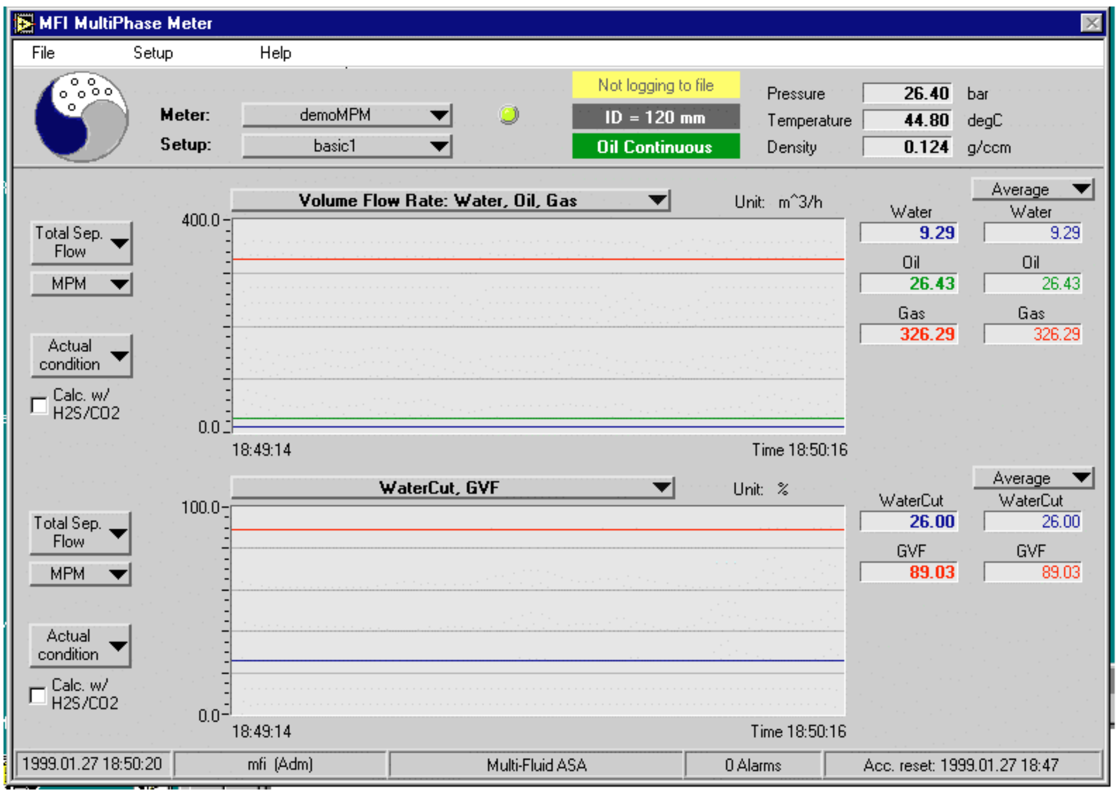

Fig. 4 - The operator interface for the system is a Graphical User Interface (GUI) running on a Windows 95/NT platform. One GUI can be connected to several systems.

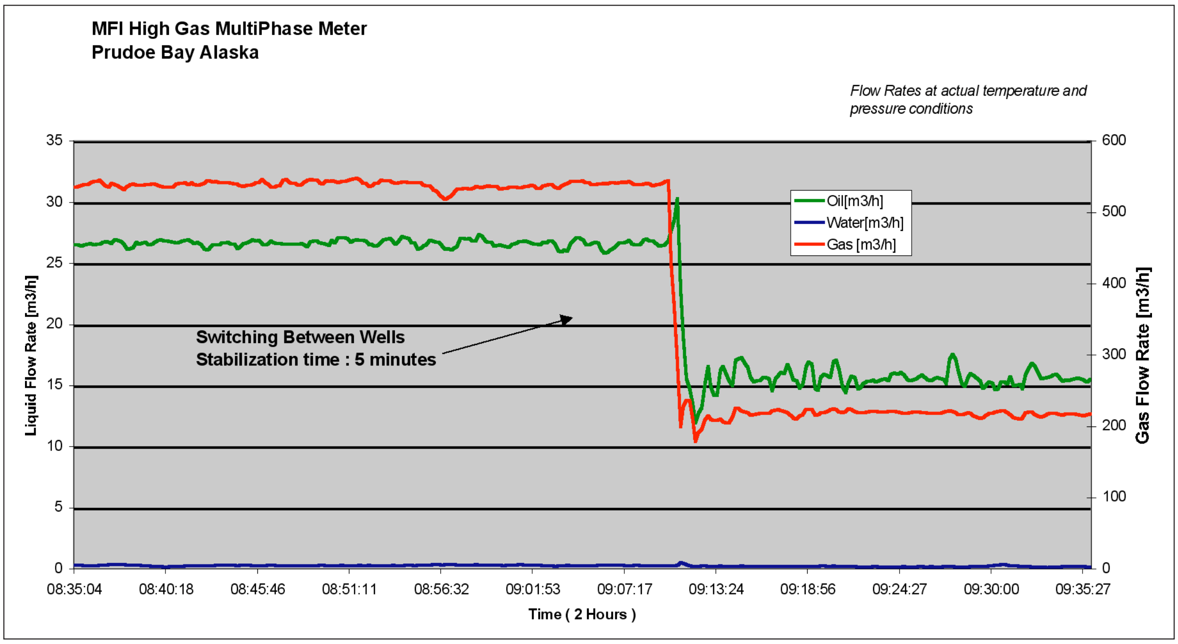

Fig 5. – The control algorithm of the system was able to stabilize the flow within a few minutes as shown in the graph.

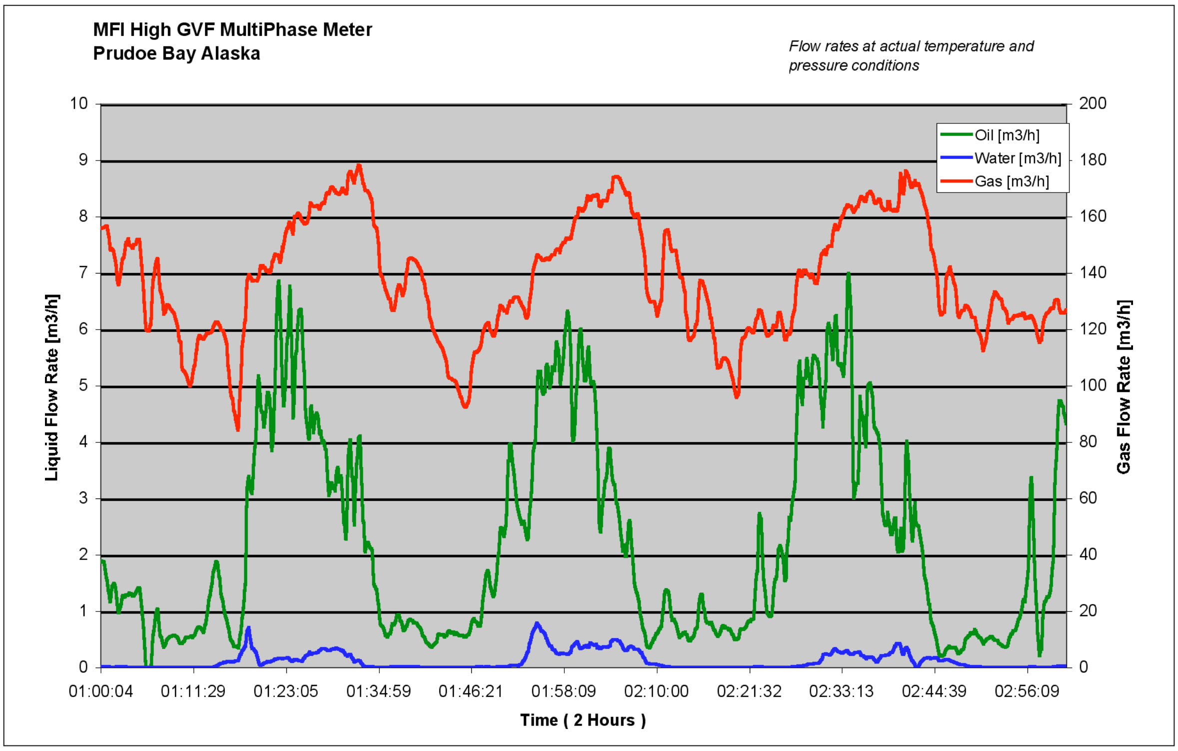

FIG. 6 – The well was slugging at a rate of approx. two slugs pr. hour as seen from the graph above. The system was able to control the valves in order to obtain the desired conditions of the system. This graph also demonstrates one of the great advantages of such a system compared towards a conventional test separator. Whereas the measurements from a test separator would be averaged out for several hours smearing out any real time data, the MFI High Gas System gives valuable information of the behavior of the well. For this particular well, the liquid and gas slugs are in phase indicating a lift gas problem. Hence, by optimizing the lift gas rate based on the real-time measurement from the MFI High Gas System, the production rate from the well could be increased. Also the real-time data can be helpful in diagnosing sub-surface equipment or reservoir problems.

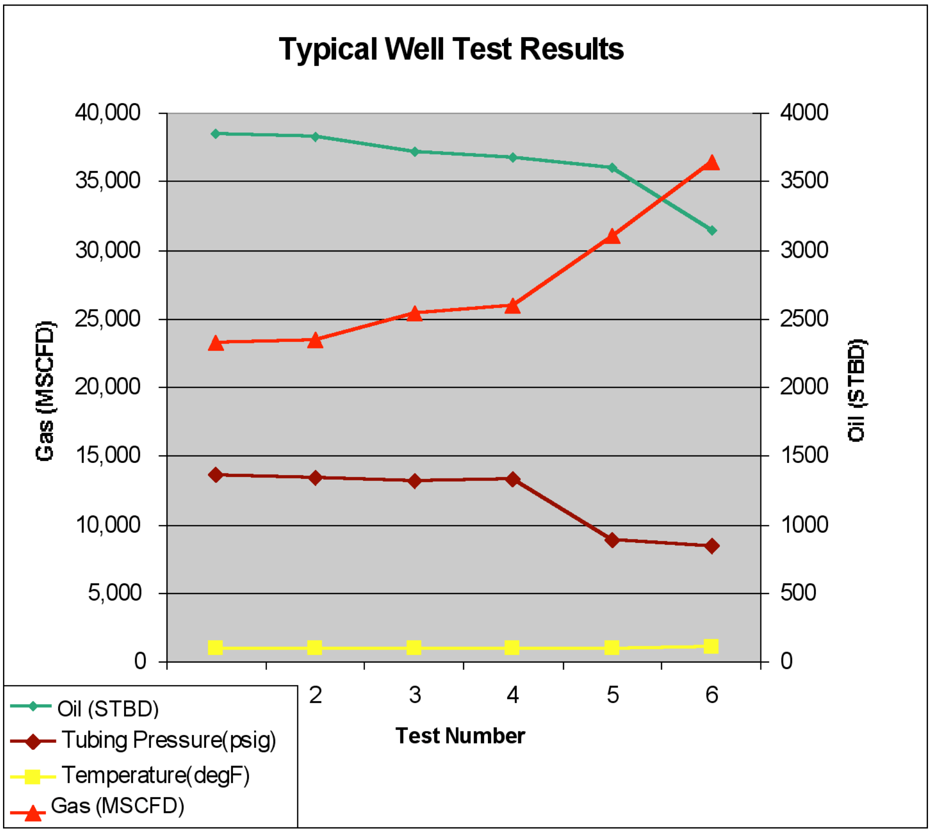

FIG. 7 – This is chart of test results between November 1, 1998 an February 1, 1999. The trend indicates that the results are repeatable and agrees with expected liquid production decline.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.