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# Multiphase Flow Meters: Experience and Assessment in PDO

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## Abstract

The use of MultiPhase Flow Meters (MPFM) in PDO has great potential economic impact on oil and gas field developments. This is the reason for the drive in PDO for using MPFM technology instead of conventional test separators. Most of the commercially available in-line MPFM's perform well at low and moderate GVF's (<80%). In order to assess the uncertainty of the MPFM's at high GVF flow regimes and high water-cut in the liquid flows, it was decided to carry out a detail accuracy tests of some of those commercially available multiphase flow meters.

Seven multiphase flow meters were proposed for the test; i.e. Schlumberger VX, Roxar, Daniel (Megra), Halliburton (FlowSys), Haimo, Axon, and Premier Instruments (GLCC).

All the seven vendors were invited to participate in the test. Roxar declined, while Axon and Premier requested to postponement of the test. The remaining four vendors accepted.the invitation for the test.

In order to evaluate the performance of these multiphase meters accurately to the live oilfield conditions, it was decided to carry out the test in a live crude facility with higher turn down ratio and known accurate reference measurements.

The test was conducted in DOD Multiphase Flow Facility located in Daqing Oilfield, Daqing City, China. This facility was conceptually designed by National Engineering Laboratory (NEL), Glasgow, UK. It was approved by China

National Measurement Institute and China National Petroleum Corporation (CNPC), the foremost authority in Measurement and Control in China.

The test was carried out over wide flow range, with oil flow rates up to 1200 $m^3$/d, a full water-cut range of 0 to 100% and a maximum gas flow rate of 28,000 $m^3$/d (actual). During the tests, the actual GVF of the multi-phase stream could be varied between 0% to 99% covering all the possible flow regimes. The behaviour of the meters were also assessed with disturbing flow condition thus simulating a slugging or surging flow from wells.

The criteria set by PDO for this test was that the meter will have to prove that it works with the following accuracy; Net Oil flow of +/-10% relative, Gas Flow of +/-10% relative and Water cut of +/-2% absolute.

The test showed that only two meters have met the above criteria. The Haimo meter showed accuracy +/-10 % relative on the net oil flow rate, water flow rate and gas flow rate and +/- 2% absolute on the water cut measurement over full range of 0 to 99% GVF. The Schlumberger meter showed accuracy +/-10 % relative on the net oil flow rate, water flow rate and gas flow rate and +/- 2% absolute on the water cut measurement over 20 to 85% GVF. Outside this GVF range, the accuracy in the water cut of the Schlumberger meter was within +/- 5% absolute. The accuracy of the other meters was found to be outside the above criteria. The results are discussed in details in this paper.

The repeatability of the reference measurements of the DOD facility was assessed. This was found to be +/-1% relative error for liquid and gas flow and +/-0.5% absolute for water cut measurements.

## Definitions

*PDO*: Petroleum Development Oman

*DOD*: Daqing Oilfield Construction in Daqing, China

*Multi-phase flow*: Both a liquid and a gaseous substance flowing simultaneously in a conduit, e.g. water and steam, oil and gas or oil, water and gas.

*MPFM*: MultiPhase Flow Meter. It is defined as a device for measuring the individual oil, water and gas flow rates in a multi-phase flow. The total package of measurement devices for composition and velocity, including possible conditioning unit, should be considered as an integral part of the meter.

*GVF*: Gas Volume Fraction. It is defined as the ratio of gas volume flow rate and the total fluid (oil, water and gas) flow rate, both volume flow rates should be converted to the same pressure and temperature. It is normally expressed as a fraction or percentage.

*WC*: Water Cut. This is defined as ratio of the volume flow rate of water and the total liquid volume flow rate, both volume flow rates should be converted to the same pressure and temperature (generally at the standard conditions). It is generally expressed in a percentage.

## 1. Introduction

During the late 80's the oil and gas industry started to realise that the availability of multi-phase flow meters could have a larger economic impact on the infrastructure of oil and gas developments. This was the reason for the development of multi-phase flow meters to be primarily driven by the oil industry. The late 80's and the early 90's saw various research programs being initiated, both in-house with the oil companies and through Joint Industry Programs (JIP's). In comparison with the developments of Coriolis and UltraSonic single phase flow meters, the development of multi-phase flow meters is far more complex, both in terms of hardware and in terms of fluid flow dynamics (Albusaidi, 1997).

Worldwide the application of Multi-Phase Flow Meters (MPFM) is growing on a large scale. They are also being applied where the oil, water and gas flow rates need to be measured close to the wellhead. They can be installed to replace the test separator, either in combination with a Multi-port Selector Valve (MSV) or with conventional manifolds. MPFMs can also be installed on individual flow lines, to replace expensive test manifolds, test lines and test separator. The latter has greater cost reductions on sub-sea applications then for onshore.

In the last ten years a substantial development has taken place, and at present a degree of maturity is emerging in applied techniques and fabrication of MPFMs by a variety of manufacturers. However a large amount of development and improvement is still required, especially in the field of improving accuracy levels over the full range of the flow rate measurement of the three phases and in terms of miniaturizing the overall foot-print of the meter.

The ultimate vision is to have a low-cost "plug & play" multi-phase meter on every single wellhead. Also in the near future, translating the surface multi-phase metering technology into concepts that are suitable for the downhole applications is the obvious next step. Although downhole multi-phase flow conditions are generally more favourable than the surface conditions (downhole is often lower in GVF), the challenges are in the design for high temperature and high pressure conditions, and also ensuring high reliability of the equipment and maintaining a small size.

## 2. Description of DOD Facility

The DOD Multiphase Flow Facility is located in Daqing Oilfield, Daqing City, China. The facility was conceptually designed by *National Engineering laboratory*, Glasgow, UK and was approved by *China National Measurement Institute* and *China National Petroleum Corporation*.

The multiphase pipeline size is DN50, DN80 and DN100. The operating pressure is 200 – 500kPa. The Maximum fluid temperature is 80 degree C.

The test fluids used in DOD are as follows:

Oil phase - Crude oil from Daqing Oilfield. Water in oil is less than 0.5%.
Gas phase - Natural gas from Daqing Oilfield. Liquid in gas is less than 0.5%.
Water phase - Produced water from Daqing Oilfield. Oil in water is less than 0.5%.

Crude Properties

| Property | Unit | Value |
|---|---|---|
| Crude density | kg/m3 @ 15degree C | 862.5 |
| Dispersed water content | wt % | 0.4 |
| Viscosity | cSt at 45 degree C | 25.34 |

Water Properties

| | | |
|---|---|---|
| Density of Water | kg/m3 @ 15degree C | 1000 |
| pH of Water | pH | 7.88 |
| OIW | ppm | 167 |
| Salinity | ppm | 2192 |
| Resistivity | mS.cm-1 25 degree | 2.901 |

The capacity of the DOD facility is given below: -

Max. Liquid flow rates: 1200 m3/d
Max. Oil flow rates: 1200 m3/d
Max. Water flow rates: 1200 m3/d
Max. Gas flow rates: 28080 Sm3/d

The accuracy and repeatability of the DOD facility is given below: -

| Description | Accuracy | Remarks |
|---|---|---|
| | | |
| Oil phase: | +/- 1.0 % relative | PD meter |
| Gas phase: | +/- 1.5 % relative | Turbine meter |
| Water phase: | +/- 0.2 % relative | Electro Magnetic meter |

The range-ability of the DOD facility is given below: -

GVF: 0 - 100 %
Water cut: 0 - 100 %

## 3. Description of the Haimo MPFM

The Haimo multiphase flow meter skid consists of cross correlation meter (two single gamma sensors), venturi meter, dual gamma source sensor, gas conditioning cyclone, vortex meter and a static flow conditioner. It also includes two pressure transmitters, DP transmitter, temperature transmitter, an electric controlled control valve and a data acquisition and analysis system.

Basically, phase fractions are derived from two separate independent measurements, i.e. water cut in the liquid and gas fraction of the entire flow. Gas and liquid velocities are determined based n the cross correlation measurement and a slip relation included in the software model with an assumption that the difference between oil and water velocities could be neglected. Temperature and pressure are also measured and assumed equal in all phases. The system obtains the phase flow rates by determining the cross correlation areas occupied by each phase, and multiplying each area by the velocity of the corresponding phase.

The gas conditioning cyclone reduces the amount of gas in the mixture by separating some of the gas away from the total flow. The separated gas is measured separately using the vortex flow meter. In the case of low GVF, the venturi meter is used instead for measuring the total flow rate.

The radioactive sources are 59.5 keV from an Am-241 source and the 22 keV that is created by a silver film that is irradiated by the 59.5 keV.

## 4. Description of the Schlumberger VX MPFM

The basic concept of the VenturiX is a Venturi measurement and a dual-energy gamma ray absorption measurement over the throat of the Venturi. The meter differs in a number of aspects from the Framo multi-phase flow meter, there is no mixing conditioning unit, the radioactive source is different and the differential pressure and nucleonic data acquisition is significantly faster, i.e. in milliseconds.

The meter should be installed vertically with upward flow and just upstream this vertical section a blind tee is recommended to improve mixing. The radioactive source for topside and onshore applications is a Gd-153 source and has energy levels of 41.5 and 97.4 keV and these two attractive energy levels are used in the dual energy gamma ray absorption concept for composition measurement. Although the source is attractive from a measurement point of view (low energies give better discrimination between oil and water), the half-life of the source is relatively short (242 days). Hence, for oilfield applications a Ba-133 source is currently recommended to be used.

## 5. Description of the Halliburton FlowSys MPFM

The meter comprises a Venturi (with the standard differential pressure, pressure and temperature sensors). In the throat of the Venturi an array of permittivity and conductivity sensors are used to measure both the liquid and the gas velocities by means of cross correlation. Hence, the velocity (flow rate) measurements are not done by the Venturi; instead the Venturi is used to measure the fluid density which is an indication for the GVF. The permittivity and conductivity measurements are used to split the liquid into water and oil. The key features are that the equipment is very simple and thus the manufacturing costs can be kept very low.

## 6. Description of the Megra Daniel MPFM

The flow rates of the individual water, oil and gas phases are derived from a measurement of the bulk fluid flow through an annular Venturi. The phase fraction information is calculated from the absorption of gamma rays emitted from a radioactive source.. MEGRA utilises an Am-241 radioactive source, located in the centre of the metering stream, to provide radiation of various energy levels, i.e. 18, 21, 26 and 60 keV.

## 7. Testing Results

The flow rates of each of the oil, water and gas and the water cut (WC) measurements determined by the 4 different MPFMs were compared against the reference flow rates and WC measurements in the DOD facility. The repeatability of the MPFMs was also tested. The response of the MPFMs under continuous disturbances was also observed. The duration for each test point was 10 - 30 mins. The results are shown in the graphs below.

## 8. Conclusions

The test was carried out over wide flow range, with oil flow rates up to 1200 $m^3$/d, a full water-cut range of 0 to 100% and a maximum gas flow rate of 28,000 $m^3$/d (actual). During the tests, the actual GVF of the multi-phase stream could be varied between 0% to 99% covering all possible flow regimes. The behaviour of the meters were also assessed under disturbing flow conditions in order to simulate slugging flow conditions as per the oilfield wells.. Results are shown on the next few pages.

The criteria set by PDO for this test was that the meter will have to prove that it works with the following accuracy; Net Oil flow of +/-10% relative, Gas Flow of +/-10% relative and Water cut of +/-2% absolute.

The test showed that only two meters have met the above criteria. The Haimo meter showed accuracy +/-10 % relative on the net oil flow rate, water flow rate and gas flow rate and

+/- 2% absolute on the water cut measurement over full range of 0 to 99% GVF. The Schlumberger meter showed accuracy +/-10 % relative on the net oil flow rate, water flow rate and gas flow rate and +/- 2% absolute on the water cut measurement over 20 to 85% GVF. Outside this GVF range, the accuracy in the water cut of the Schlumberger meter was within +/- 5% absolute. The accuracy of the other meters was found to be outside the above criteria.

It should be noted that the in all the four tested MPFMs net oil flow is determined using the water cut measurement and the gross flow measurement according to the equation below.

Oil flow Rate = Gross Flow Rate * (1 – Water Cut)

The accuracy of the net oil flow will therefore be affected by the water cut . As water cut increase higher than 90%, the accuracy of the net oil will naturally be reduced (higher than 10%) as shown in the results.

The repeatability of the reference measurements of the DOD facility was assessed. This was found to be +/-1% relative error for liquid and gas flow and +/-0.5% absolute for water cut measurements.

*It needs to be emphasized that the above results and conclusions may only be true for those particular models of meters tested at that time (year 2002) and may not necessary be true for the current models available at present taking into account the fast development in the multiphase metering technology.*

**References**

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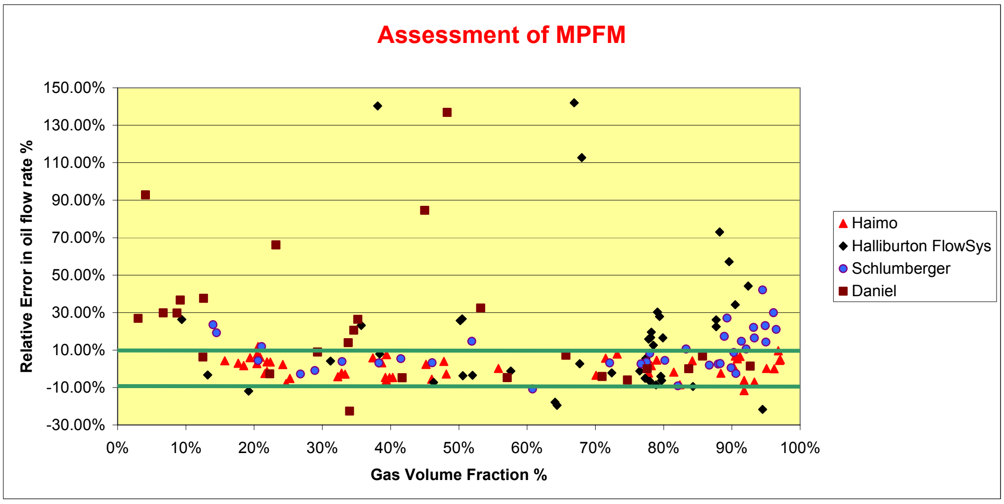
Assessment of MPFM
Relative Error in oil flow rate %
150.00%
130.00%
110.00%
90.00%
70.00%
50.00%
30.00%
10.00%
-10.00%
-30.00%
0%
10%
20%
30%
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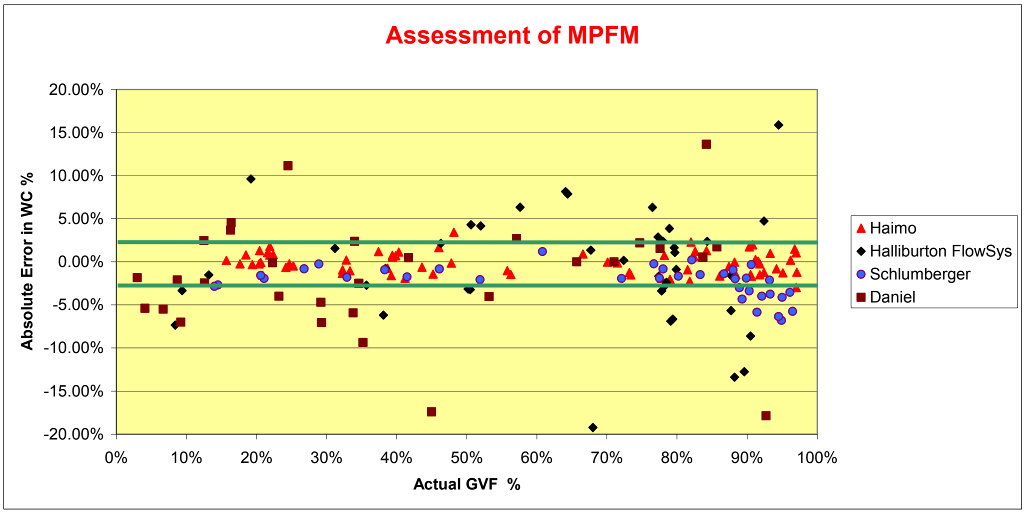
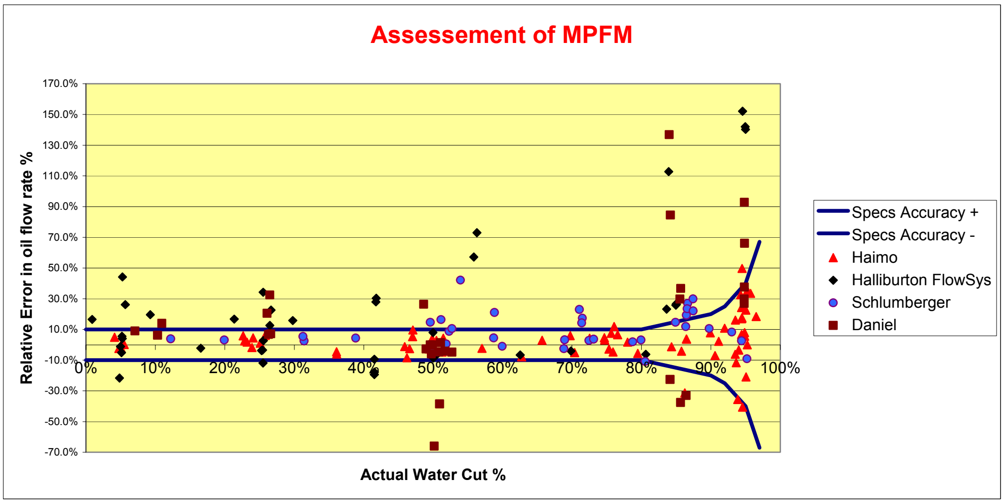
60%
70%
80%
90%
100%
Gas Volume Fraction %
Haimo
Halliburton FlowSys
Schlumberger
Daniel


Assessment of MPFM
Absolute Error in WC %
20.00%
15.00%
10.00%
5.00%
0.00%
-5.00%
-10.00%
-15.00%
-20.00%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Actual GVF %
Haimo
Halliburton FlowSys
Schlumberger
Daniel


Assessment of MPFM
Relative Error in oil flow rate %
170.0%
150.0%
130.0%
110.0%
90.0%
70.0%
50.0%
30.0%
10.0%
-10.0%
-30.0%
-50.0%
-70.0%
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%
Actual Water Cut %
Specs Accuracy +
Specs Accuracy -
Haimo
Halliburton FlowSys
Schlumberger
Daniel


Schlumberger VX MPFM during testing in DOD

FlowSys MPFM during testing in DOD

Megra MPFM during testing in DOD

Haimo MPFM during testing in DOD