Validation of MPFM Performance on Gas Lifted Wells

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ABSTRACT

Slip law has been a quite challenging subject in multiphase flow metering. In the second half of 2009 an extensive in-situ research and validation test was conducted on MPFM performance for the X field in Petroleum Development Oman (PDO). X field wells are gas lifted (GL) with extremely high gas volume fraction (GVF) and low operating pressure condition where gas flow velocity is much higher than liquid flow velocity. Serious slug situation of the wells was also observed. During the metering campaign a suitable slip modeling was built and applied to MPFM testing. A high performance tester (HPT) based on efficient separation was conducted as a verification unit. It has been proved that the slip modeling can improve gas flow rate measurements greatly. The validation test also shows that MPFM is an effective and accuracy testing facility to measure gas lifted wells.

1 INTRODUCTION

It has been many years since multiphase flow meter (MPFM) was introduced to gas and oil industry. The multiphase flow metering technologies and applications have developed significantly since 2000; they are selected more and more often in oil and gas projects and are used for periodic or continuous well testing instead of conventional test separator technology.

When it comes to gas lifted wells instability is a well-known challenge [1]. In many cases it is not acceptable that the well is connected to the production installation before some degree of control has been achieved. MPFM has advantage over test separator on monitoring variations in flow rates from instable wells; hence in such a situation it becomes a very useful tool to enhance well and reservoir managements (WRM).

X field is a filed with extremely high GVF (gas volume fraction) and low pressure condition. Artificial lift system for most wells is gas lifted. Since GVF of X field wells is extreme high, and pressure is low, there exists a large velocity difference between liquid flow rate and gas flow rate which is known as slip. It is the reason why gas flow rates are always underestimated. Meanwhile, the serious slug situation of the wells was observed, which increases the difficulty to obtain accurate gas measurement as well.

In second half of year 2009, a joint effort with PDO and the vendor was made to further improve measurements and eventually assess the MPFM performance on gas lifted wells. The multiphase meter vendor has designed and deployed a unit called High Performance Tester (HPT) as a validation tool for the multiphase meters. The HPT is based on high effective separation technique capable of operating at the full GVF range [2]. The onsite study and comprehensive comparison test show that the test results of MPFMs and HPT are in good agreements by introducing slip modelling to MPFMs.

This paper addresses measurement challenges in the described well conditions. It highlights MPFM gas flow measurements improvements due to slip law application and the use of HPT as a validation tool to assess the MPFM performance.

2 VALIDATION TOOL - HPT

2.1 Metering Principle

As shown in Fig 1 the operation principle of the HPT is simple to understand. The multiphase flow enters a vertical separator to separate gas from liquid and through two horizontal separators gas is further separated. HPT is equipped with a mist extractor to drop any remaining droplets of liquid in the gas. The separation is controlled via level control scheme ensuring no liquid carry over or gas carry under. Then gas flow rate is measured by vortex meter in the gas leg, liquid flow rate and Water Liquid Ratio (WLR) are measured by Coriolis mass meter simultaneously in the liquid leg. HPT was delivered to PDO in 2007. It has been proven to be an accurate and stable tool for both verification and mobile well testing purpose.

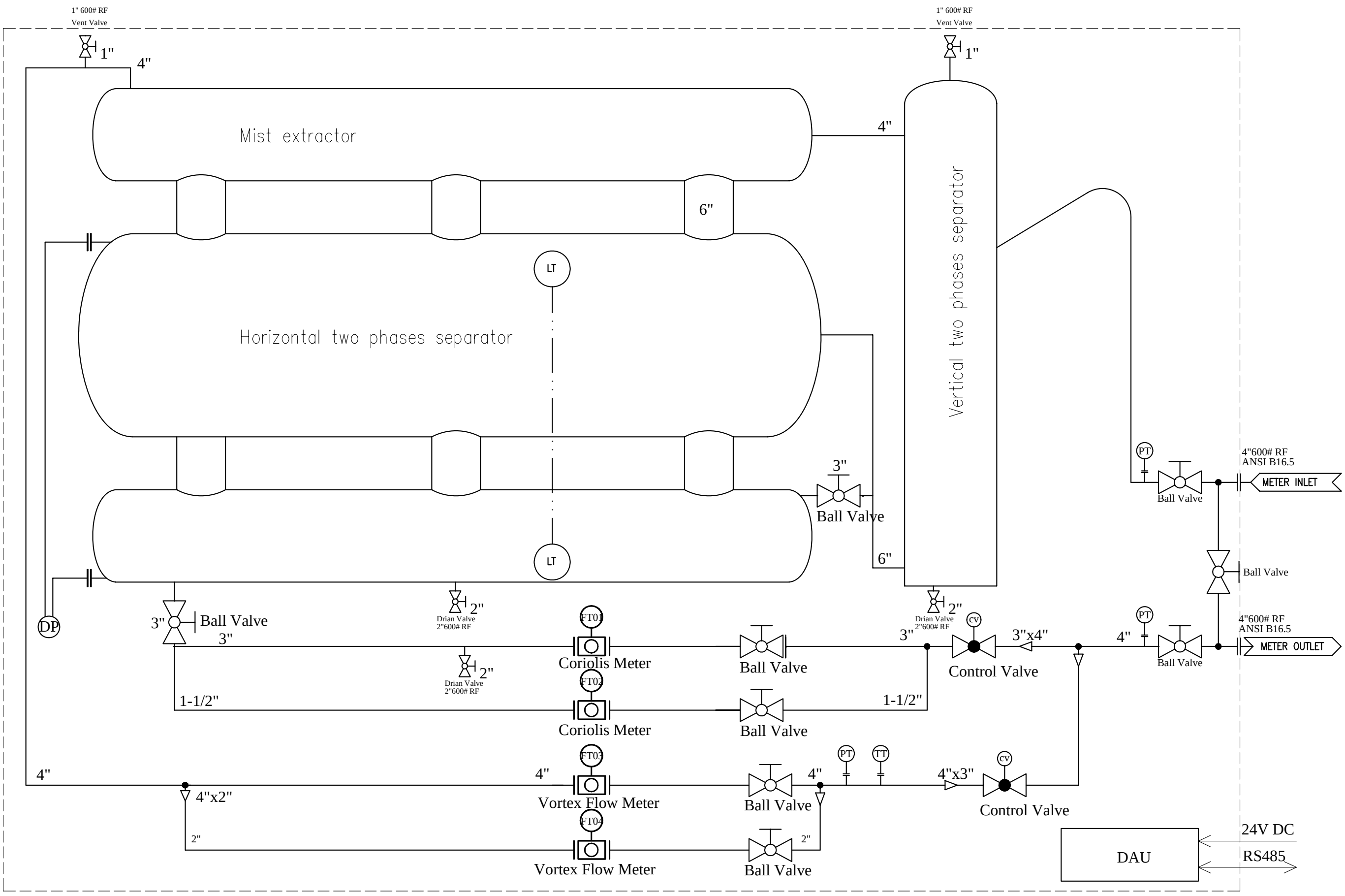

Fig 1 - P&ID of HPT

2.2 Performance Specification

The HPT has the following performance specification:

- Design Pressure: ANSI 600#
- Liquid Flow rate: 20 – 2000 m3/d
- Gas Flow rate: 0 – 25,000 am3/d
- GVF: 0 – 100%
- Water Cut: 0 – 100%
- Liquid Uncertainty: +/-5% (relative)
- Gas Uncertainty: +/-5-10% (relative)
- Water cut uncertainty: +/-1-2% (absolute)

3 MPFM SOLUTION BRIEF

The validated MPFM consists of a venturi flow meter, a single gamma sensor and a dual gamma sensor for phase fraction measurement, and a static flow conditioner as an in-line liquid sampler. It also includes pressure and temperature transmitters for obtaining the metering-condition on-line. The data acquisition and analysis system is also integrated which can offer on-line, real time multiphase flow data analysis and display.

As indicated in Fig 2, the tested stream flow into the meter through the inlet, it runs through the single-gamma detector and venturi flow meter, where the GVF and total flow rate Qv are measured. The flow then travels to the flow conditioner, where the representative liquid sample is taken and goes to the dual-gamma detector where the WLR is measured accurately with reduced gas content in the liquid sample.

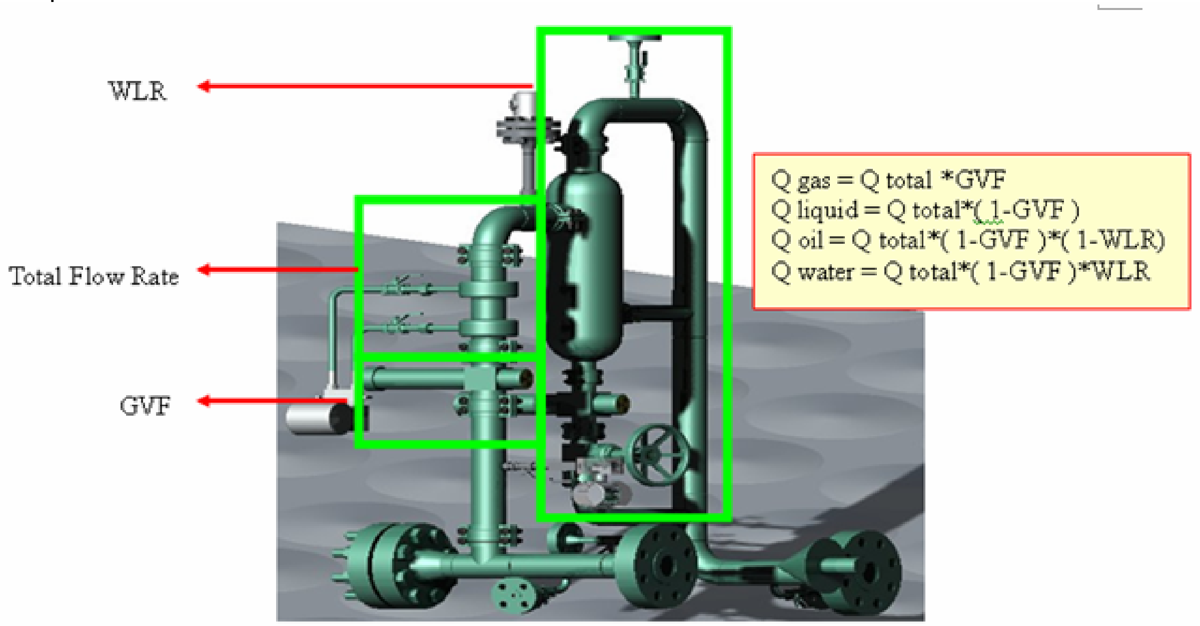

Fig 2 - Scheme for Multiphase Flow Metering Solution

Without separating individual phases MPFM giving accuracy test results is on the assumption that each phase has same or close velocity. It is well known that under high GVF and low operating pressure well condition gas flows much faster than liquid. So the only way to guarantee the gas measurement is to introduce the slip law to multiphase metering as shown in Fig 3.

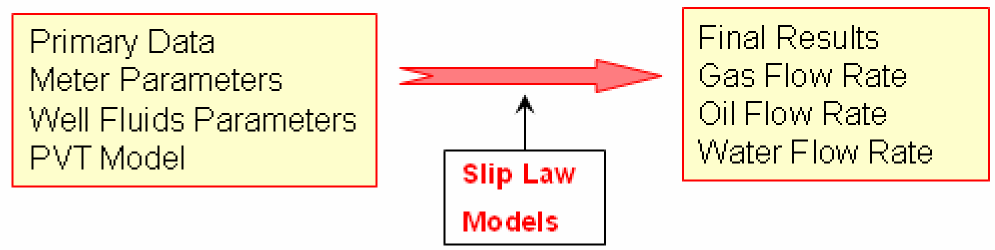

Fig 3 – Slip law modelling application

4 X FIELD INFORMATION AND VALIDATION TEST SETUP

4.1 Field Basic Information

It can be noticed from table 1 that in X field the water/oil densities vary from well to well. Before calibration the wells need to be grouped according to fluid components. As there is a large number of wells in this field, it is a tough job to calibrate all the wells. The applicable grouping means is based on same density from same reservoir, and it works always in field. And more than 10 groups were made by this way to cover all wells in the field. At the stage of samples taking for calibration, samples for some wells could not be obtained because they are dominated by gas and meantime the sample points are at the directions of 12 o'clock. How to obtain other wells densities and how to guarantee the WC test accuracy will be discussed afterwards.

X field also has a wide range of gas and liquid flow rates. WCs for some wells are up to 99%. Operating pressure is very low between 4.5 ~ 7 Bar and GVFs for almost all gas lifted wells are higher than 90%. All these well conditions indicate a severe slip difference issue during MPFM testing.

Well Numbers	76 wells
Well Type	Gas Lifted(71) ESP(5)
Gas Flow Rate(Sm3/d)	7,000～ 18,000
Liquid Flow Rate(Sm3/d)	27~650
WC(%)	40%~99%
Gas Volume Fraction（%）	30%~98%
GOR (Sm3/Sm3)	200~1,000
Temperature(Degree)	20～ 60
Operating Pressure (kPa)	450~ 700
Water Density（kg/cm3）	1,060~1,160
Oil Density（kg/cm3）	845~881

Table 1 – Well information of X field

4.2 Typical Flow Pattern of X Field

In X field 71 out of 76 wells are gas lifted. Flows of most wells are fluctuating and surging dramatically all the time. Figs 4~7 illustrate a few representative cases.

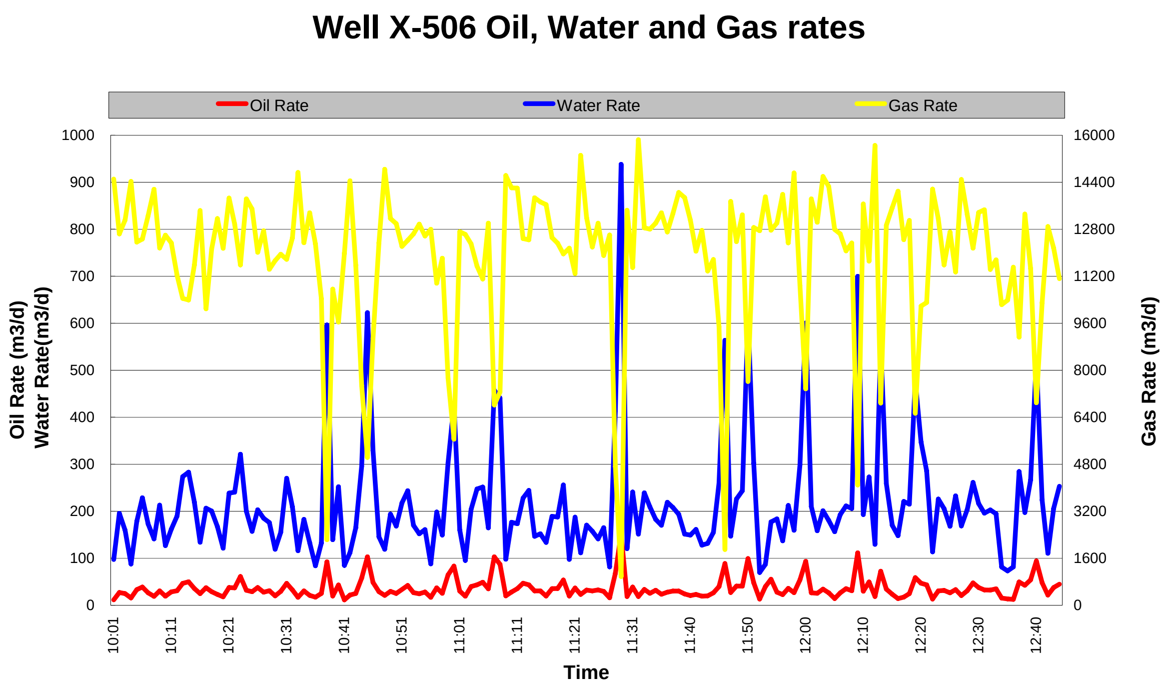

Fig 4 - Well X-506 Oil, Water and Gas Flow

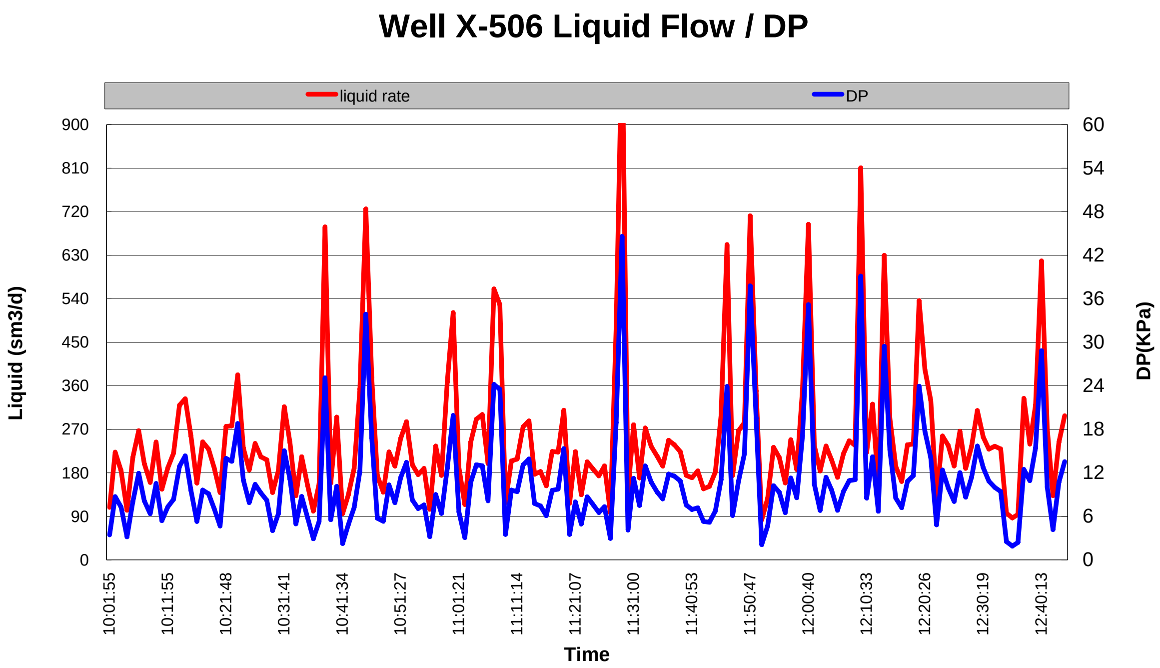

Fig 5 - Well X-506 Liquid Flow Vs DP

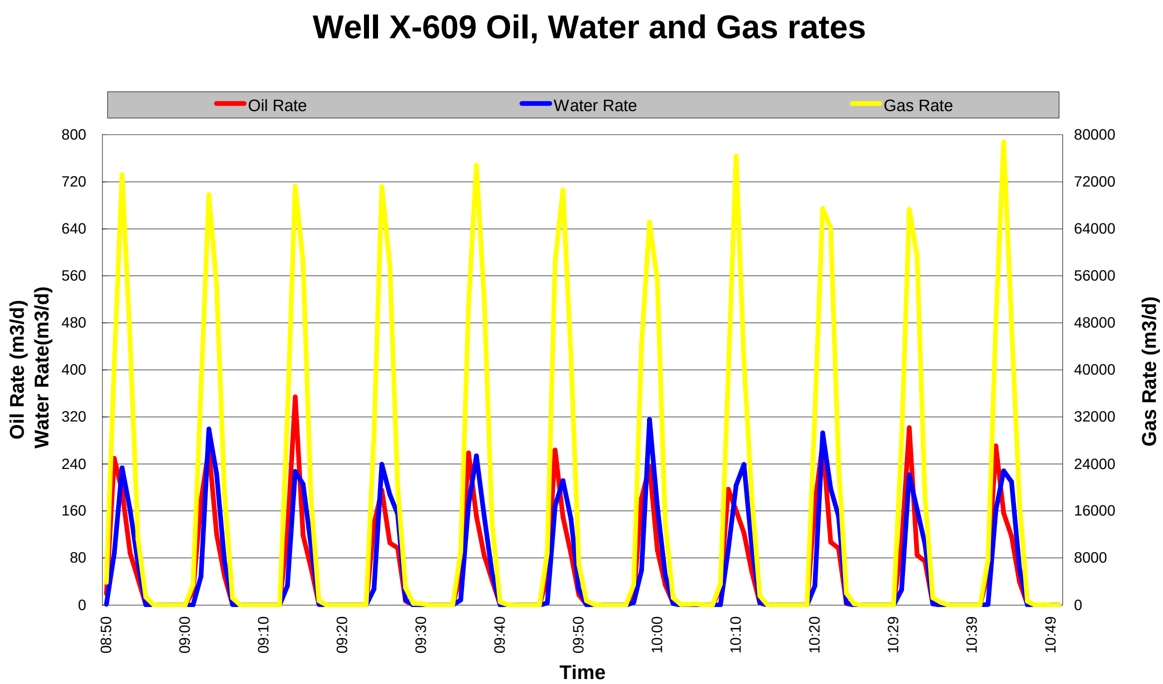

Fig 6 - Well X-609 Oil, Water and Gas Flow

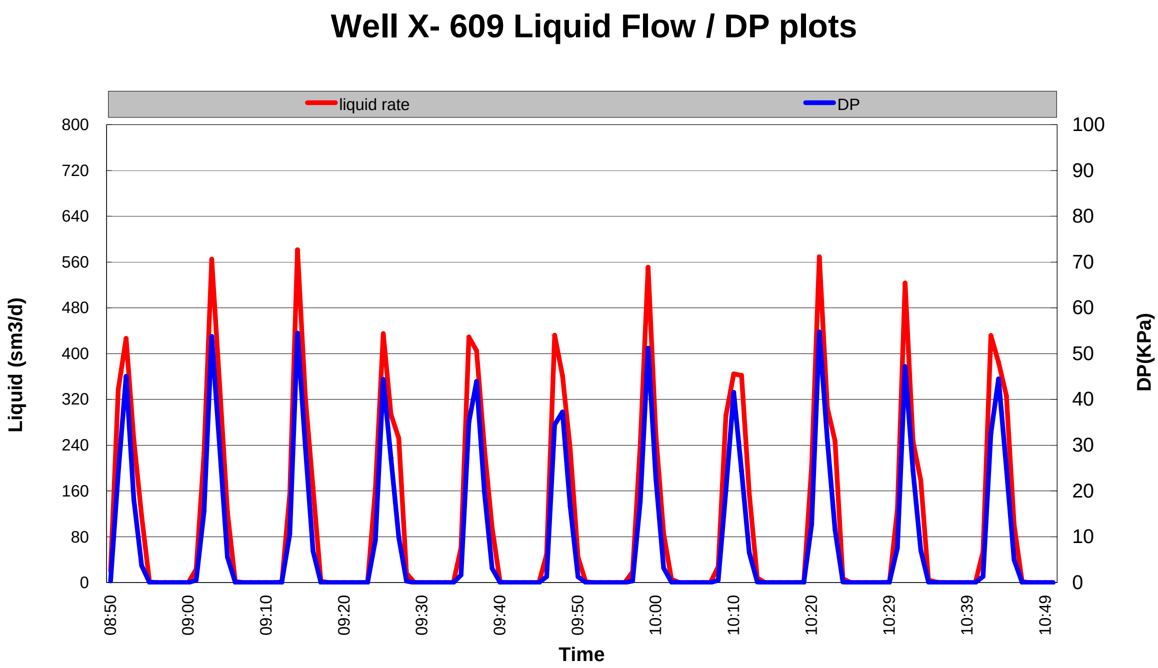

Fig 7 - Well X-609 Liquid Flow and DP

4.3 Validation Test Setup for HPT and MPFM

Fig 8 - Validation test for MPFM with HPT

Two identical validated MPFM-1 and MPFM-2 were connected to MSV valves in X field. The tested wells were controlled by the MSV valves. There are bypass valves between two meters, the wells designated to be tested by one meter can be diverted to the other meter in case the designated meter is not available. As shown in Fig 8 HPT is connected to the downstream of one MPFM as measurement reference and a third party meter can be connected downstream of the other MPFM for any purpose such as metering or verification. HPT and the third party meter can be exchanged per requirements.

5 KEY IMPACTS ON MPFM PERFORMANCE

5.1 Slip Law Modelling

Some potential aspects impact the performance of MPFM. First of all, slip law should be highlighted.

In multiphase flow metering, slip is a phenomena that exists when the phases have different velocities at a cross section of conduit. At low pressure and high GVF conditions the different phases can have different velocities as shown in Fig 9. Regarding wells of X field water and oil are mixed quite well the velocity difference between them can be ignored. But gas phase flows much faster than liquid under the same well conditions which leads to gas flow rate under reading. Slip ratio is a means of quantitatively expressing slip as the phase velocity ratio between the phases. Here, it generally means the velocity ratio between gas phase and liquid phase, that is,

$$Sr = Vgas / Vliquid$$

Sr is a complex affected by flow rates, GVF level, operating pressure level, fluids properties and geometry etc. Various models exist.
Before HPT was put in use for verification test, a lab obtained slip law was applied to the test results offline. And a great improvement for gas measurements had been achieved. After HPT test with MPFM at the same time for one month, a practical site slip law was obtained to be embedded in the software.

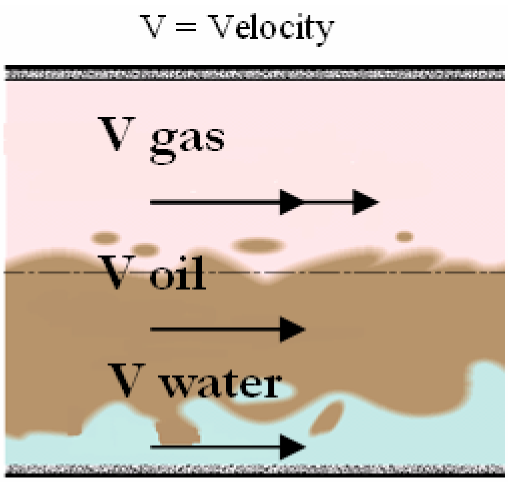

Fig 9 - Phase Velocity at a cross section of conduit

5.2 WLR Measurements

5.2.1 Flow Conditioner

It is known that the accuracy of WLR measurement depends on the GVF level when the WLR is measured by the dual-gamma detector (Funnel effect as shown in Fig 10). The unique technology of flow conditioner acts as a liquid sampling-taking tool and provides representative liquid samples with far less gas content for dual gamma sensor to measure the WLR, WLR can be measured over full range with only +/-2% absolute error. The validation tests have proved that the WLR measurements are totally independent on the GVF thanks to the innovative technology used.

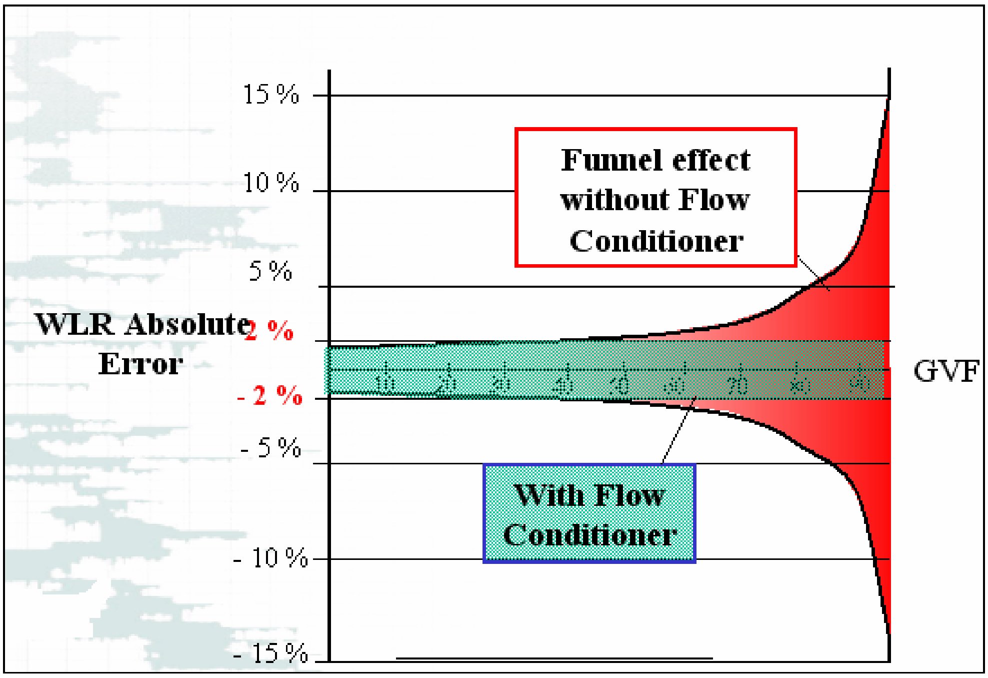

Fig 10- Funnel effect on WLR accuracy over GVF level

With the Gas hold-up lower than 60%, the WLR measurement absolute error can be controlled easily within 2%. If the Gas hold-up is higher than 60%, the WLR measurement uncertainty will increase sharply. Under the tested field, where the gas content is dominant (GVF>90%), the Flow conditioner is a must for achieving WLR accuracy within +/-2% absolute error.

5.2.2 Water Mass Attenuation

As oil/water densities for only some of the wells were analyzed and calibrated before MPFM testing because samples for some wells were not obtained, for other wells fresh samples would be taken during testing from MPFM and sent to PDO appointed chemistry lab for analysis. Once the oil/water density is available, it is supposed to find its group density. But unfortunately some wells can not be found its corresponding group of water density. Even the closest density is applied; it still causes bigger WC measurement error in some cases. Dismantle the gamma sensor to recalibrate is a solution but such activity is ineffective and not practical. Dual gamma sensor online calibration is not suitable here because water can not separate thoroughly from oil in even one day.

In order to approach high accuracy WC measurement with high efficiency, other solution has to be established. It is known that GAS HOLD-UP and WLR come from single and dual gamma sensors respectively which are functions of oil/water mass attenuation. There is a basic idea that oil mass attenuation doesn't change as much as water mass attenuation with different densities.

Water mass attenuation predominates WC measurement at high WC level. If you pay attention to water density and water mass attenuation, regular linear relationship can be obtained as shown in Fig 11 and 12. Once the relationship is available, the correct calibration parameters will be procured by this correlation instead of carrying out the physical calibration. Actually as single gamma ray has the same energy as high energy of dual gamma, in brief only high/low energy water mass attenuation Vs water density is illustrated. Fig 13 shows some successful cases for WC measurement by using this linear relationship.

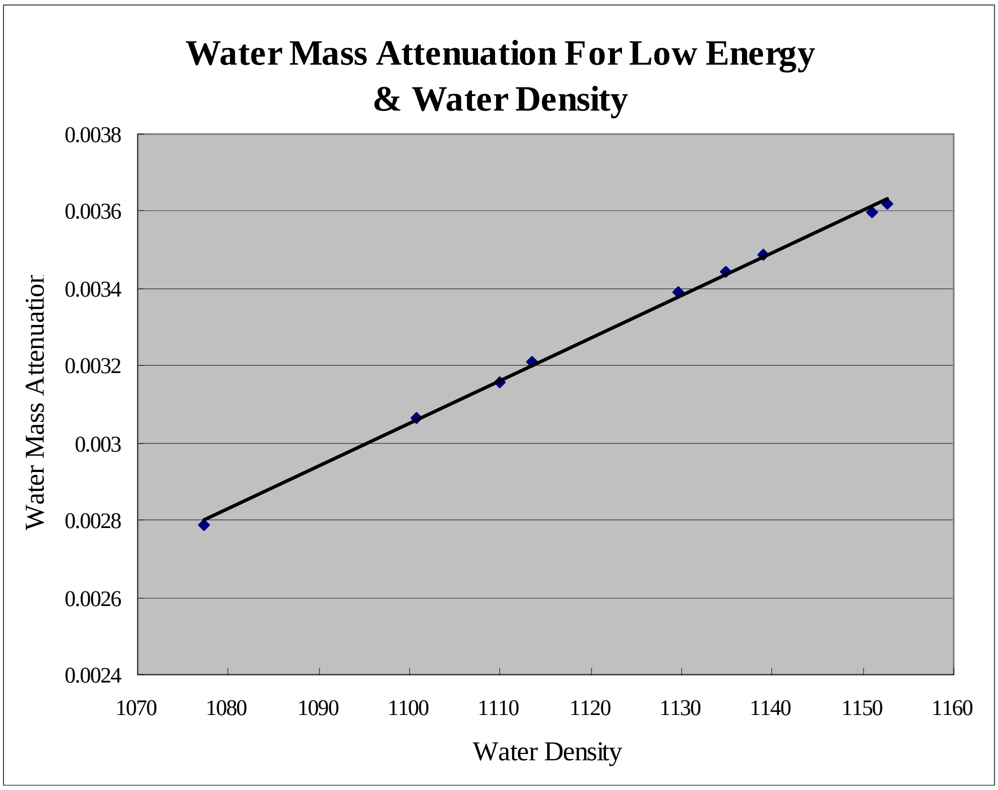

Fig 11 - Linear relationship between water density and water mass attenuation for high energy

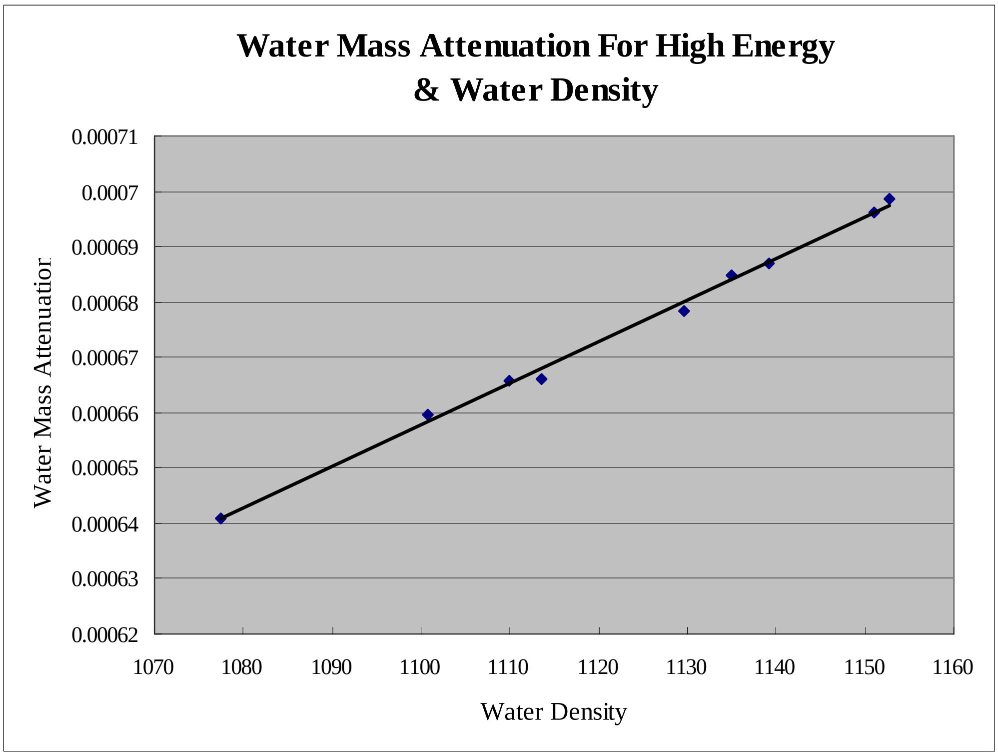

Fig 12 - Linear relationship between water density and water mass attenuation for low energy

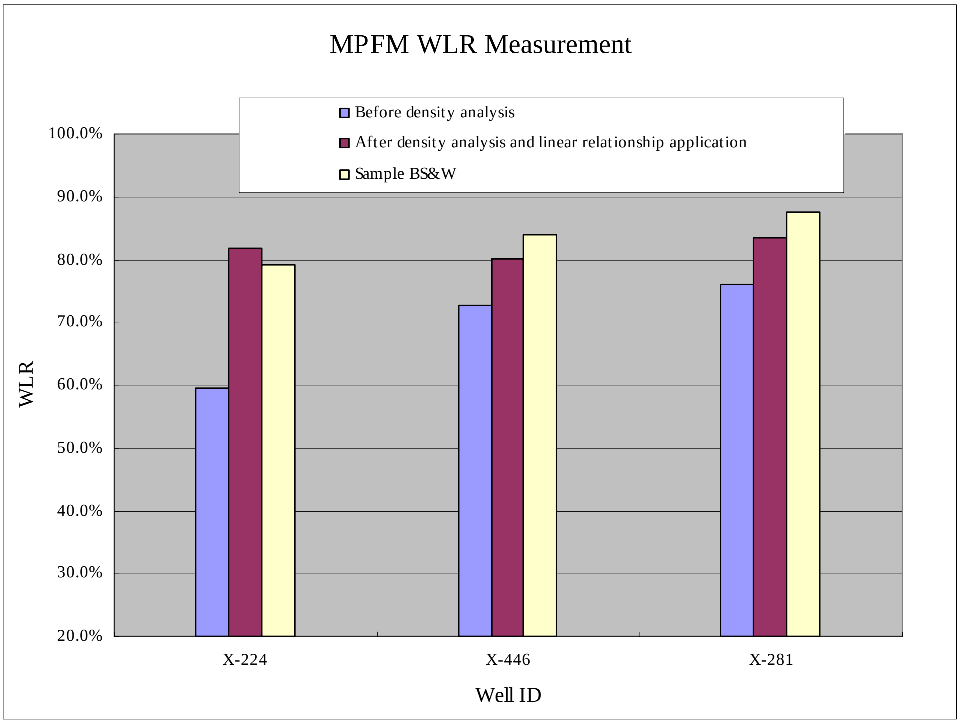

Fig 13 - Cases for WC measurement before and after water mass attenuation linear relationship application

6 VALIDATION TEST RESULTS

After all solutions done to X Field MPFMs, a practical site Sr formula has been achieved which has the same format as empirical one obtained in the lab. The slight difference is change of coefficients. After application of this gas flow modeling it is seen that the measurement performance of MPFMs is greatly improved. And MPFM tests are matched much closer to HPT.

6.1 Overall Comparison between HPT and MPFMs

Table 2 – Overall comparison between HPT and MPFMs

MPFM Overall Test Results						HPT Overall Test Results				
Liquid (sm3/d)	Net Oil (Sm3/d)	Produced Water (Sm3/d)	Gas Flow (sm3/d)	WC	Gas Flow (sm3/d) with lab slip law model	Gross Liquid (Sm3/d)	Net Oil (Sm3/d)	Produced Water (Sm3/d)	Gas Rate (Sm3/d)	WC
9649.1	2183.6	7465.5	665140	77.4%	674413	9844.7	2429.7	7415.0	653424	75.3%

From table 2 it is easy to calculate that the oil ratio is 0.899 and gas ratio is 1.018 for on-site practical slip modelling and it is 1.032 for lab modelling.

6.2 Cross plot

Fig 14~16 are cross plots for gross, gas flow rates and WC respectively. As highlighted in section 5.2.1 the unique in-line liquid sampler makes much less gas into the dual gamma sensor to guarantee WC measurement accuracy at full GVF range. Fig 17 illustrates MPFM WC deviation Vs GVF level.

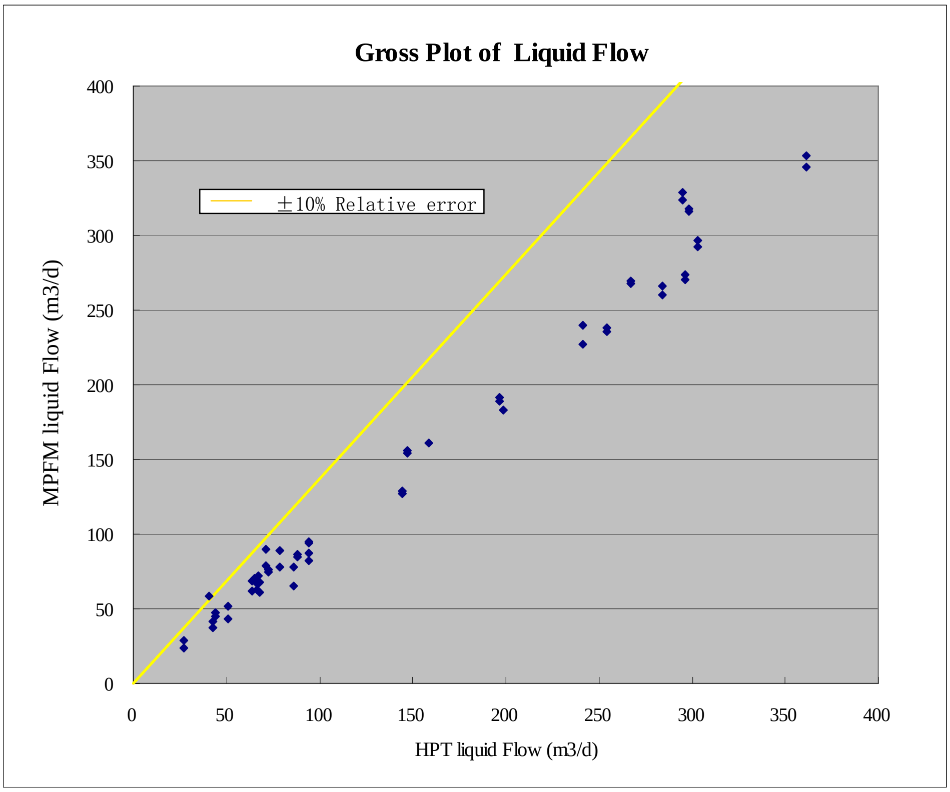

Fig 14 – Gross cross plot

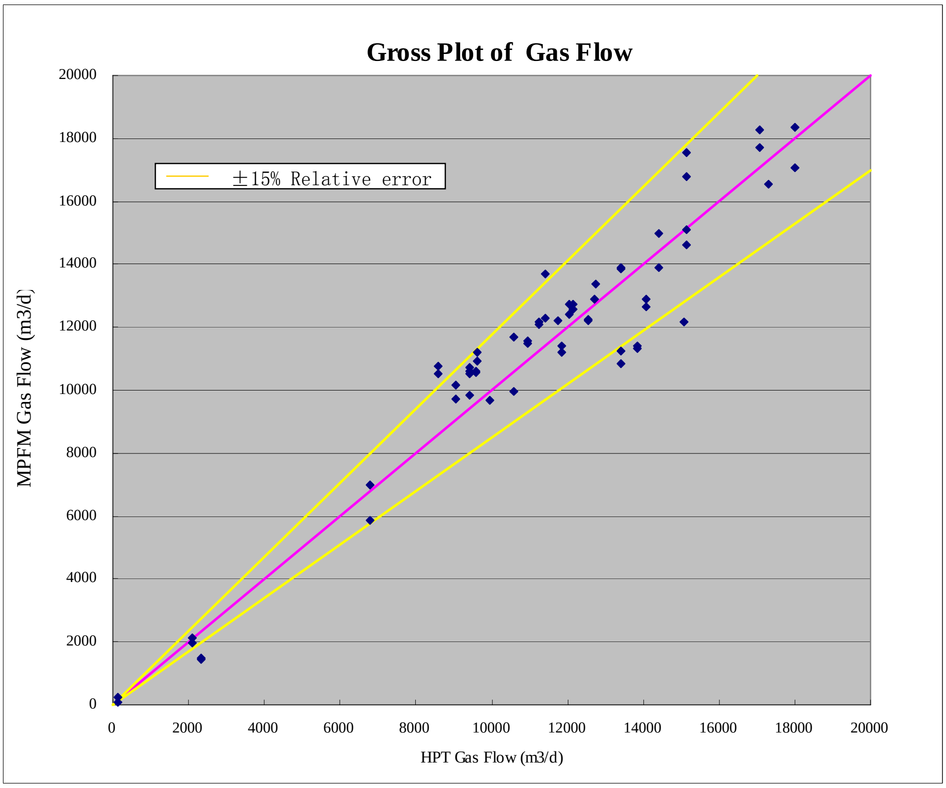

Fig 15 - Gas Flow Rate Cross Plot

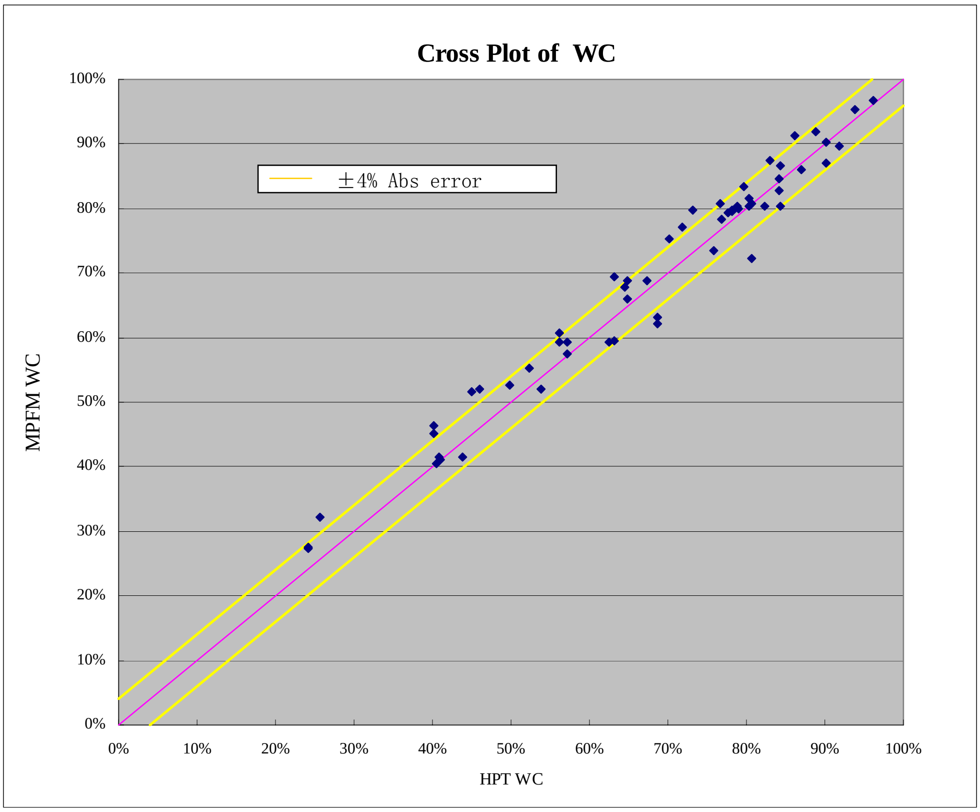

Fig 16 - WC Cross Plot

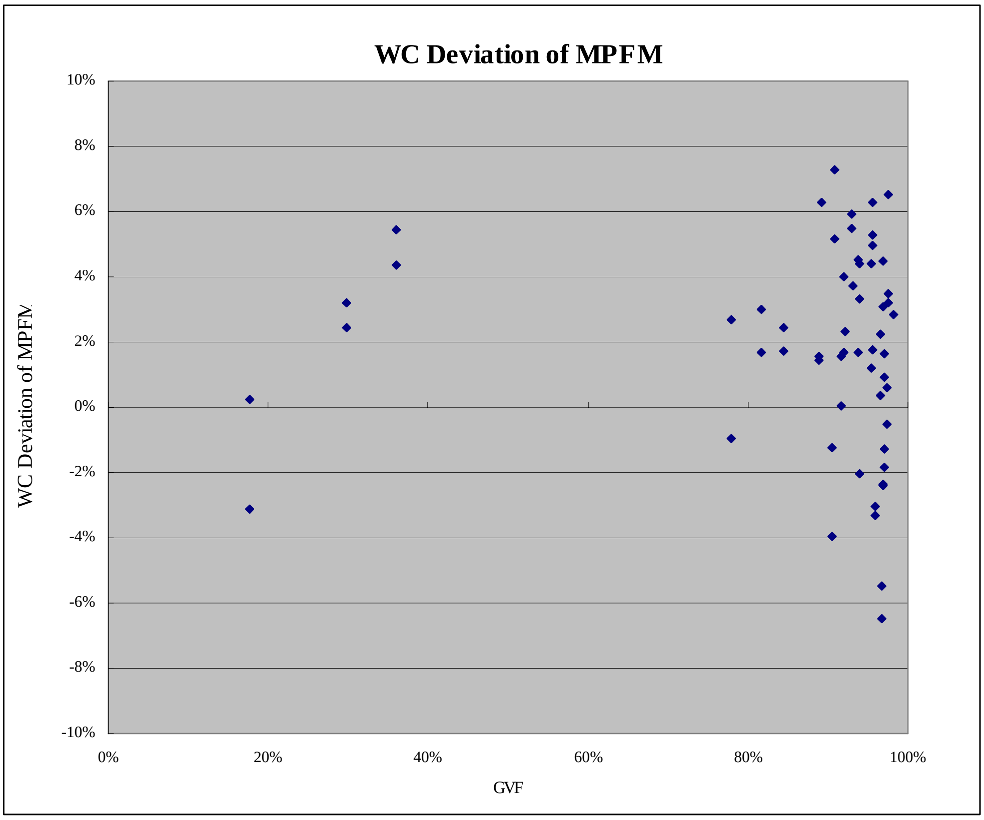

Fig 17 WC deviation of MPFM Vs GVF

6.3 Histogram

In order to demonstrate a full overview of the validation results, some histograms for gross, gas flow and WC are shown in Fig 18-20 respectively.

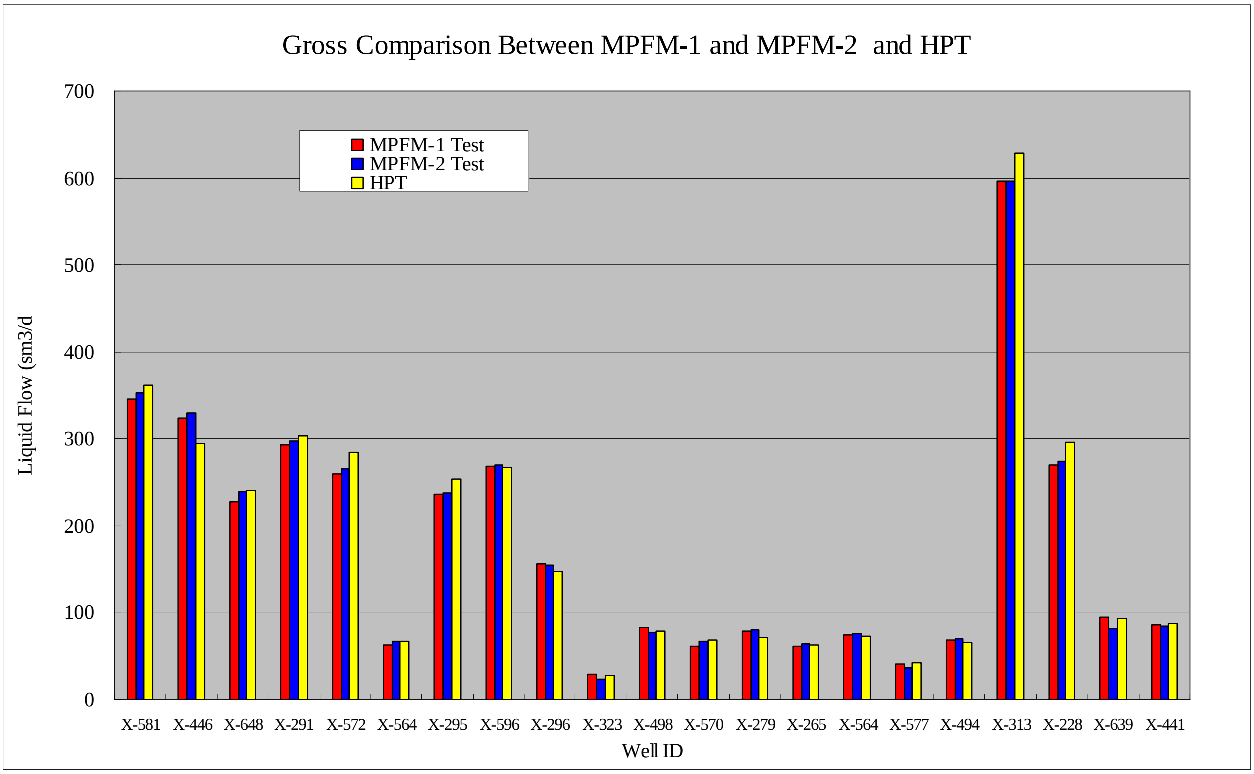

Fig 18 - Gross Comparison between MPFM-1 and MPFM-2 and HPT

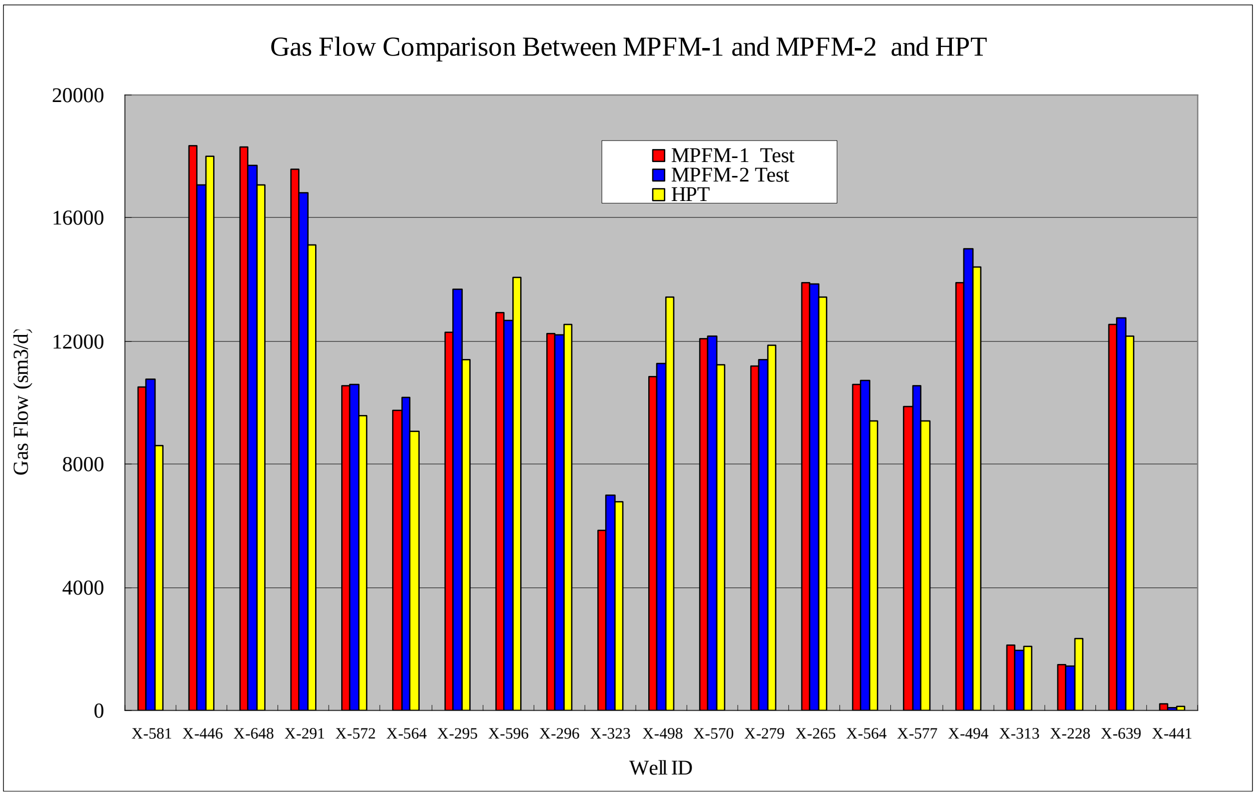

Fig 19 - Gas Flow Rate Comparison between MPFM-1 and MPFM-2 and HPT

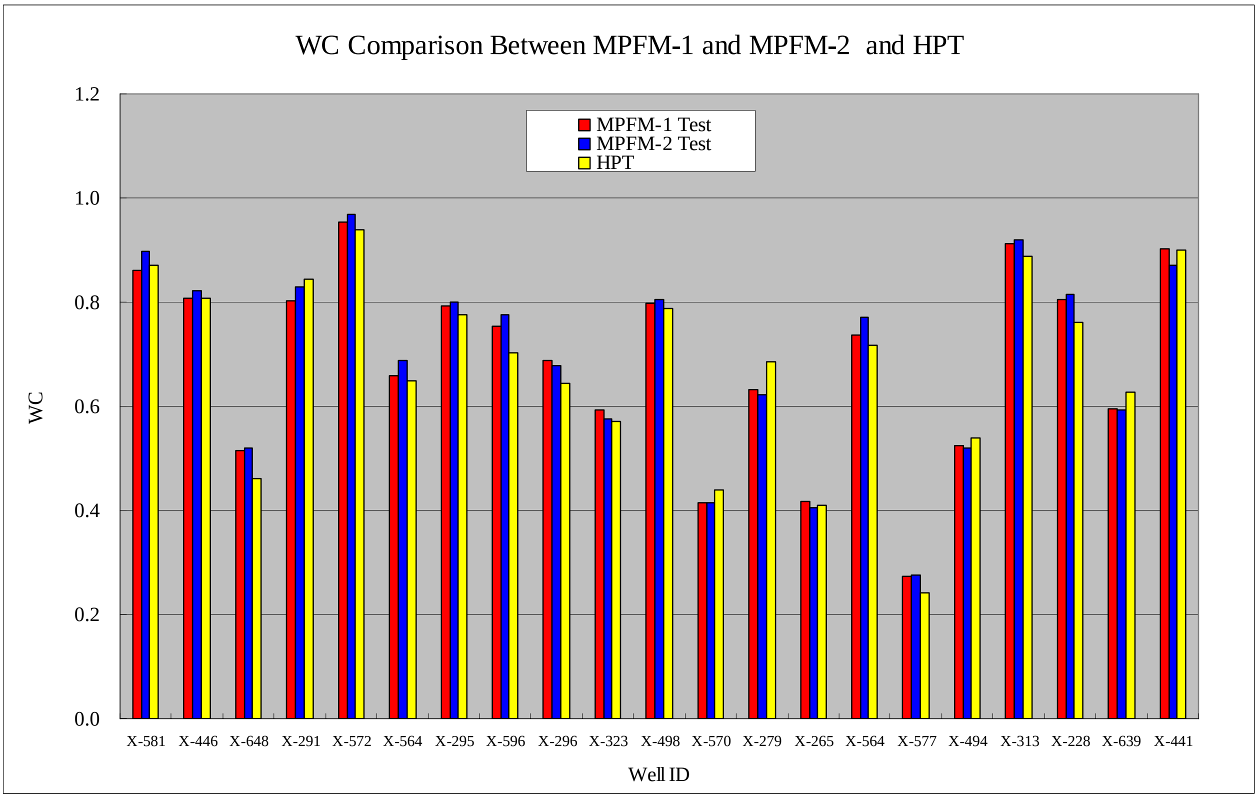

Fig 20 - WC Comparison between MPFM-1 and MPFM-2 and HPT

7 CONCLUSIONS

We describe here a rare comprehensive on-site study of slug flow regime at high GVF and low operating pressure wells. Haimo is grateful to have a chance to carry out a profound research in X field and finally achieved the target to significantly improve MPFM gas flow rate measurement quality.

The slip ratio of gas and liquid phase at high GVF low pressure flow situation is very large which is the key reason for gas flow under reading. Lab empirical flow modelling is applicable for site use to some extent. Haimo has built site suitable flow modelling for the X field project and it is believed that the same can be used to other similar field like PDO south.

Wells grouping and water mass attenuation play a very important role for WC measurements in X field. The proper use of water mass attenuation not only improves the WC test performance but also gets rid of the trouble of recalibration.

The good collaboration between different parties and the multiphase meters vendor, together with vendor initiative in deploying the HPT as a validation tool have enabled identifying key contributors to the WRM. Although a good reference in the field is often difficult to find, the HPT has delivered reliable data and increased end user confidence in the field potential determination.

Since the flows of X field gas lift wells are slugging and sometimes produce different flows at day and night, the comparison between MPFM and HPT or any third party test unit is strictly suggested to be done only when all work simultaneously and in series.

The validation proves that MPFMs is an effective and accuracy testing facility to test gas lifted wells, furthermore it also can respond to the slug flow pattern of gas lifted wells in real time which can not be achieved by a test separator.

8 NOTATIONS

Notation has been used in the paper as follows:

MPFM	Multiphase Flow Meter
PDO	Petroleum Development Oman
GL	Gas Lifted
GVF	Gas Volume Fraction
HPT	High Performance Tester
WRM	Well and Reservoir Management
WLR	Water Liquid Ratio
Sr	Slip Ratio
WC	Water Cut

9 REFERENCES

[1] Gudmundsson J.S., et al, “Pressure Pulse Analysis of Flow in Tubing and Casing of Gas Lift Wells”, ASME/API Gas Lift Workshop, February 5-6, 2002, Houston,Texas

[2] Abdullah Al-Obaidani, Salim Al-Sibani. Petroleum Development Oman (PDO) experience in well Testing at High GVF and High Pressure conditions. 8th South East Asia Hydrocarbon Flow Measurement Workshop 4th – 6th March 2009