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MPFM Response and Validation in Heavy Oil Wells

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ABSTRACT

Heavy oil is very common in oil industry and emulsions are associated issues. There is no denying that MPFM (Multiphase Flow Meter) has an obvious advantage in handling emulsions over conventional test separator. Being involved in multiphase metering for more than 15 years, Haimo has developed an innovative heavy oil MPFM based on robust and proven technology - a combination of Venturi and gamma meters.

Two validation tests were carried out on Haimo MPFM performance for offshore X field in CNOOC (China National Offshore Oil Corporation) in February 2009 and March 2010 respectively. The X field is typically heavy oil conditions with oil API going down to 12. A high performance tester (HPT) based on efficient separation was conducted as a verification unit.

High performance of MPFM in heavy oil has been proven by two comprehensive validations. Oil RF (Reconciliation factor) of X field is between 0.9~1.1 since MPFM commissioned. The objective of this paper is to provide an accuracy MPFM to measure heavy oil and emulsions and it is of interest to any operator or oil company who is looking for solution to enhance recovery and production optimization of heavy oil wells.

1 INTRODUCTION

End users of oil and gas industry are selecting more and more often MPFM technologies instead of conventional test separator technology for periodic or continual well testing. A fundamental barrier with heavy oil application is that oil and water fail to separate by gravity in a conventional separator. High viscosities encountered in heavy oil cold production add challenges and complications further in the separator control. Another related phenomenon is that any gas bubbles entrained in a viscous emulsion can not flow freely and stay trapped in a gaseous state. This can potentially lead to a large overestimation of the liquid volumetric flow rate.

The operation of in-line MPFM is able to sidestep most of these problems as no fluid separation is required and therefore has the benefit of being compact and cost-effective. There are currently few MPFM available on the market capable of handling viscous fluids in heavy oil production. Since the market moves towards heavy oil business oil industry needs multiphase meter to work under viscous conditions.

An overview of Haimo technology comes first in this paper. In particular it specifically describes how MPFM is responding and working in heavy oil applications. There is an introduction of master meter – HPT in this paper as well. The paper addresses the in-situ validation test and comparison results are shared. In addition since MPFM was conducted for heavy oil well testing achieved RF of oil flow rate is presented. Finally conclusions were given at the end of the paper.

2 HAIMO TECHNOLOGY

The validated Haimo MPFM is an in-line meter characterized by the measurement of individual phase fractions together with phase velocities directly in the multiphase flow line. The flow rate of each phase is determined by the phase fraction multiplied by the total flow rate taking into account the velocity difference between gas and liquid phase.

2.1 Venturi

A Venturi is selected for total flow rate measurement and it has been used for decades by the oil industry, including in heavy oil applications. The device is, in fact, so popular that all major multiphase manufacturers use it. The viscosity and Renolds number dependence with discharge coefficient is considered in the software.

2.2 Flow Conditioner

The Haimo MPFM also consists of the unique design, Flow Conditioner that works as an inline liquid sampler, knocking out some gas from multiphase to guarantee the WLR (water in liquid ratio) accuracy. The liquid is well mixed and representative liquid is obtained before the flow pass through Dual Gamma Sensor (WC Meter). The MPFM also has a sample point in the main pipe which can be used to assess the WC uncertainty.

It is known that the accuracy of WLR measurement depends on the GVF (Gas Void Fraction) level when the WLR is measured by the dual-gamma detector (Funnel effect as shown in Fig 1). If the GVF is higher than 60%, the WLR measurement uncertainty will increase sharply. 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.

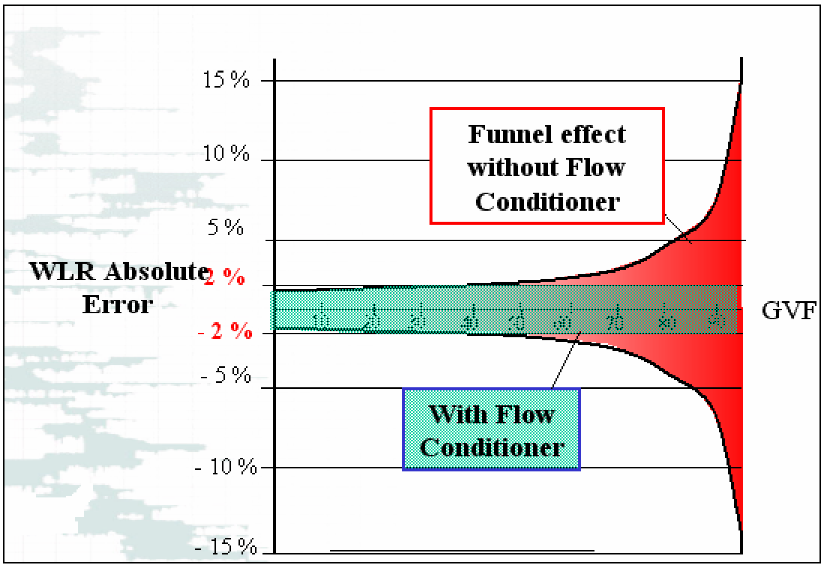

Fig 1- Funnel effect on WLR accuracy over GVF level

2.3 Gamma Ray System

The phase fraction measurement is based on gamma ray interaction with atoms constituting the oil, water and gas flowing through the pipe. This interaction along a gamma ray beam, takes place at a scale from 10^{-12} to 10^{-15} m. It means gamma rays are capable of seeing phenomena at this level of scale and therefore will not depend on the phase distribution at macroscopic scale. From very simple gamma ray absorption equations one energy of source is able to decide two phases and dual energy system can decide three phases. Haimo uses source Am241 for phase fraction measurement which has lower radiation energy level, activity than others. And it is very safe after it is put into source housing and prevented from leaking by the lead cabinet in MPFM.

Heavy emulsion does not effect or impact Haimo phase fraction measurement performance which is determined by the fundamental measuring principle of Gamma ray technology. Practically emulsion is a favourite pattern for the phase fraction measuring with Gamma ray technology.

The gamma system comprises a radioactive source emitting well collimated gamma beam towards a scintillation detector located on the opposite of the pipe (shown in Fig2).

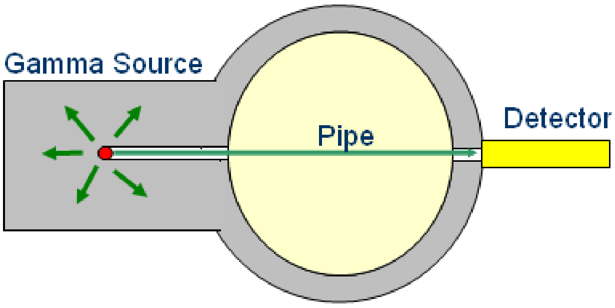

Fig 2 Gamma system

The physical relation of gamma ray absorption is well known as equation (1):

$$-\frac{1}{d} Ln \frac{N_x}{N_O} = \sum_{i=1}^{n} \alpha_i \mu_i \tag{1}$$

Where:

N_x = count rate from the gamma detector after absorption
N_o = "empty pipe" or vacuum count rate
d = gamma path length
αi = phase fraction of composition i
μi = linear attenuation of composition i

Haimo MPFM applies one energy to differentiate gas and liquid phase, namely to get the GVF and two energy to measure WLR. Formula (2) is basic absorption equation in three phase flow.

$$-\frac{1}{d} Ln \frac{N_X}{N_O} = \alpha_{gas} \cdot \mu_{gas} + \alpha_{oil} \cdot \mu_{oil} + \alpha_{water} \cdot \mu_{water} \tag{2}$$

3 MODELS DEALING WITH HEAVY OIL APPLICATIONS

Venturi flow meters are usually designed to work for high Reynolds number flows where the related correction can be applied easily shown in equation (3).

$$Q_V = KCEd^2 \sqrt{\frac{\Delta P}{\rho_{mix}}} \tag{3}$$

Where

Qv---Volume flow rate @ line condition, am3/h;
K --- Unit coefficient
C --- Discharge coefficient, related to the range of Reynolds number/viscosity
E --- Advanced velocity coefficient
d --- Inner diameter of the throttling element, mm;
ρ mix ---Mixed density of the fluid @ line condition,
△ P ---Dynamic Differential pressure, Pa;

Cold production of heavy oil always means high viscosity and associated low Reynolds number. It is a must to do modelling on the C factor of Venturi when it is applied to low Reynolds number flows.
In-line mixed viscosity is decided by every single phase viscosity and flow conditions such as temperature, WLR, GVF, emulsion and so on. Prior to obtain mixture viscosity we have to get crude oil

viscosity which can be measured by rotational viscometer (shown in fig 4) with high accuracy. Fig 5 shows the trend between viscosity and temperature of a typical well from X field.

Fig 3 Rotational viscometer

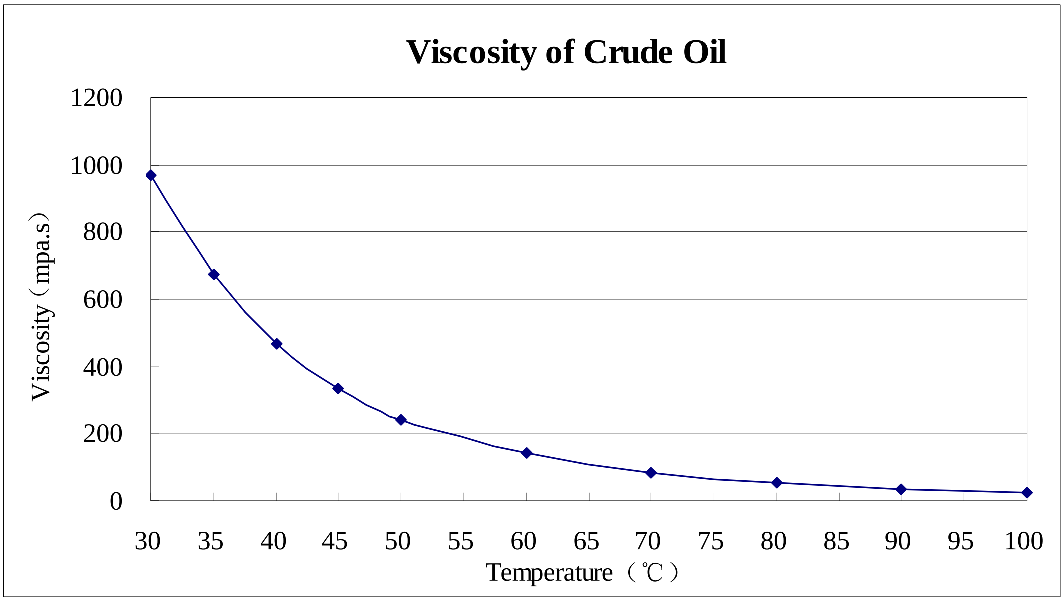

Fig 4 Viscosity changes with temperature (Well X-16)

By some equations and correlations on-line mixture viscosity is obtained. Combining with relationship between C factor and Reynolds number (shown in figure 5) the total flow rate and associated variables are able to be calculated by software.

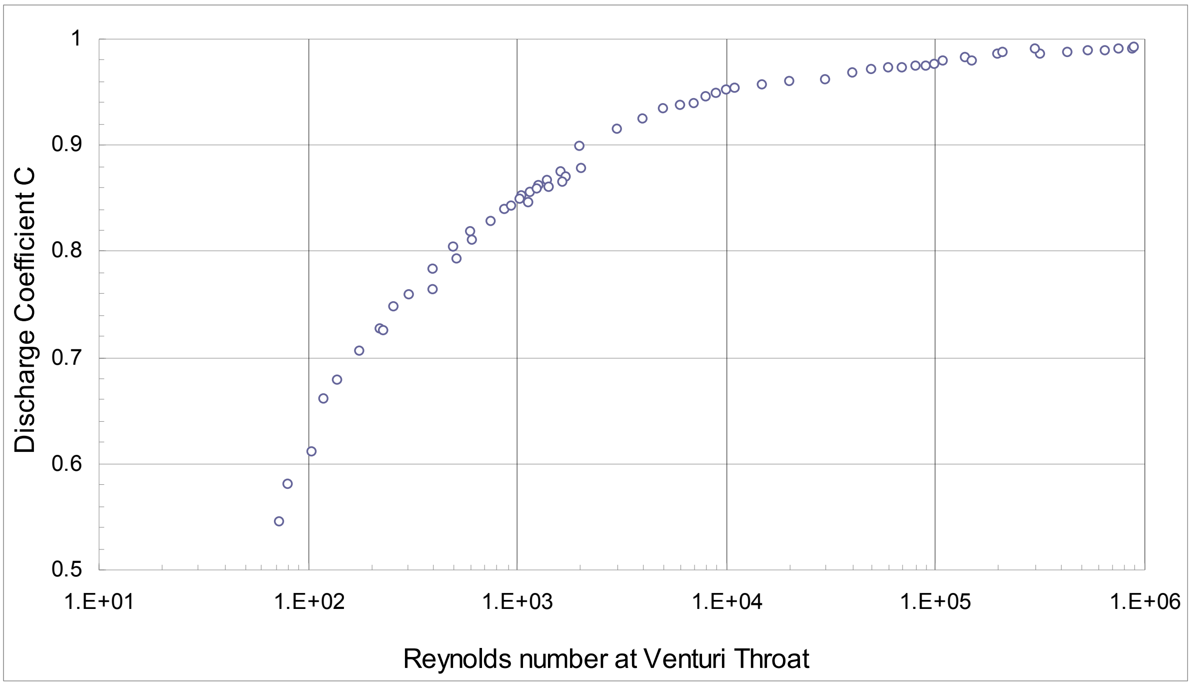

Fig 5 How discharge coefficient changes with Reynolds number

4 MPFM FIELD VALIDATION

4.1 Validation Tool-HPT

Metering Principle

As shown in Fig 6 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 has been launched and delivered to field for testing since 2007. It has been proven to be an accurate and stable tool for both verification and mobile well testing purpose.

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: +/-10% (relative)
* Water Cut Uncertainty: +/-2% (absolute)

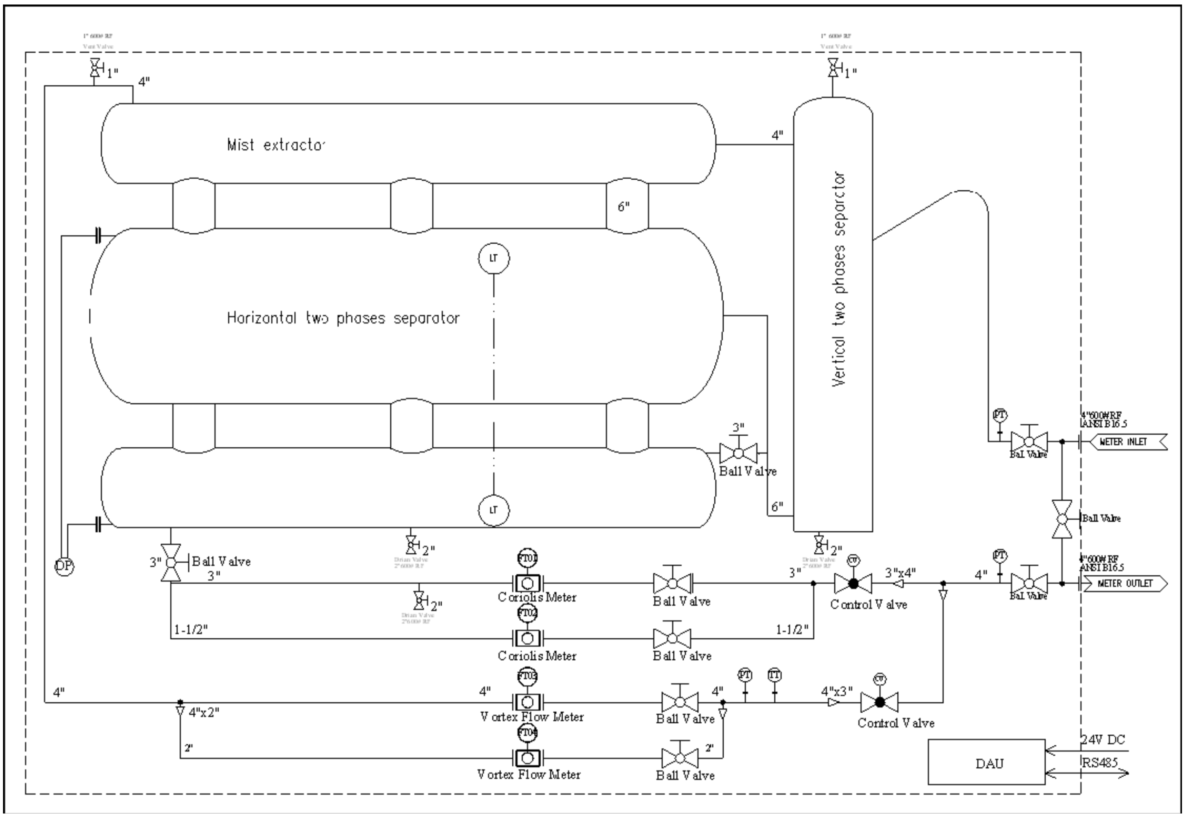

Fig 6 - P&ID of HPT

4.2 Basic Well Information of X Field

There are more than 120 wells distributed on six offshore platforms in X field. 24 wells from three platforms were selected for verification testing. Table 1 shows basic well information of X field. Densities of the picked 24 wells are illustrated by fig 7 where the oil gravity varies from 0.935 to 0.985. it can be noticed from table 1 and fig 7 that X field is a typical cold production heavy oil field.

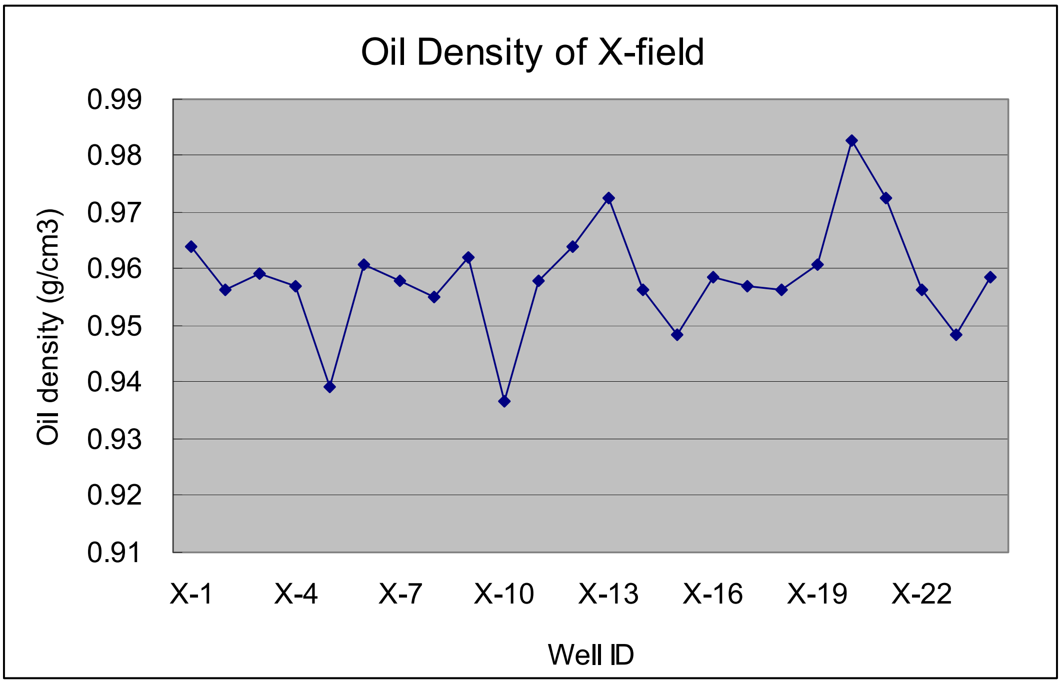

Fig 7 Oil density of X field

Well Numbers	More than 120 wells
Well Type	ESP
Liquid Flow Rate(Sm3/d)	20~1300
WC(%)	0%~100%
Gas Volume Fraction（%）	0%~60%
Temperature(Degree C.)	20～ 60
Operating Pressure (kPa)	800~ 15,000
Oil Density（g/cm3）	0.93~0.99

Table 1– Well information of X field

4.3 Validation Test Setup for HPT and MPFM

Six identical MPFMs were allocated at six platforms in X field. Three were chosen for verification test that was carried out in February 2009 session for X-A platform and March 2010 session for X-C and X-D platforms. HPT was installed downstream of MPFM as shown in Fig 8. The height between MPFM and HPT is around 15 meters. Fig 9 shows MPFM and HPT on-site setup.

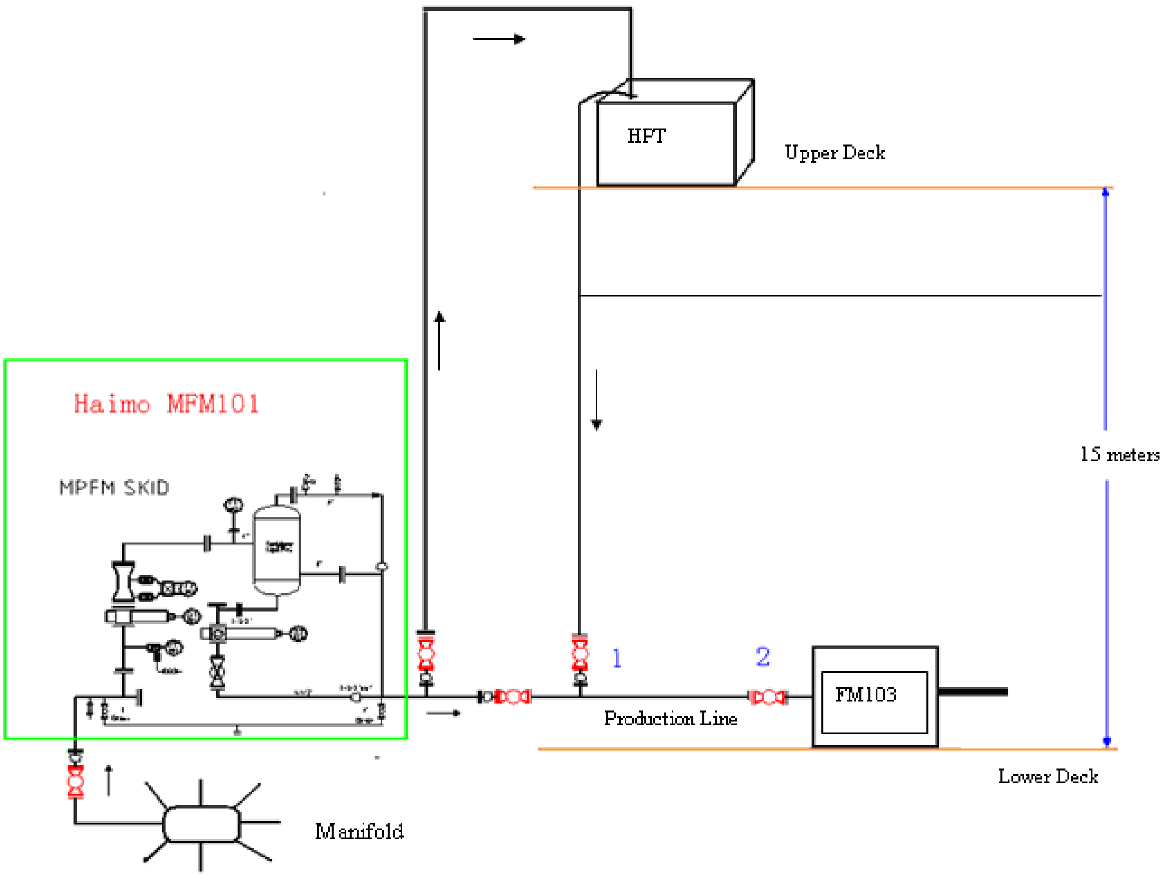

Fig 8 Layout of HPT and MPFM in X field

Fig 9 - Validation test for MPFM (left) with HPT (right)

5 VALIDATION TEST RESULTS

The validation test results is given in followings. Fig 10~fig 13 illustrate the comparison between HPT and MPFM by single well. In order to demonstrate a full overview of the validation results the compared overall readings are presented in table 2. Since the produced gas for most wells is very less and gas flow was outside lower limit of HPT gas leg, the comparison for gas flow rate is excluded in this paper.

5.1 Verification of February 2009 session

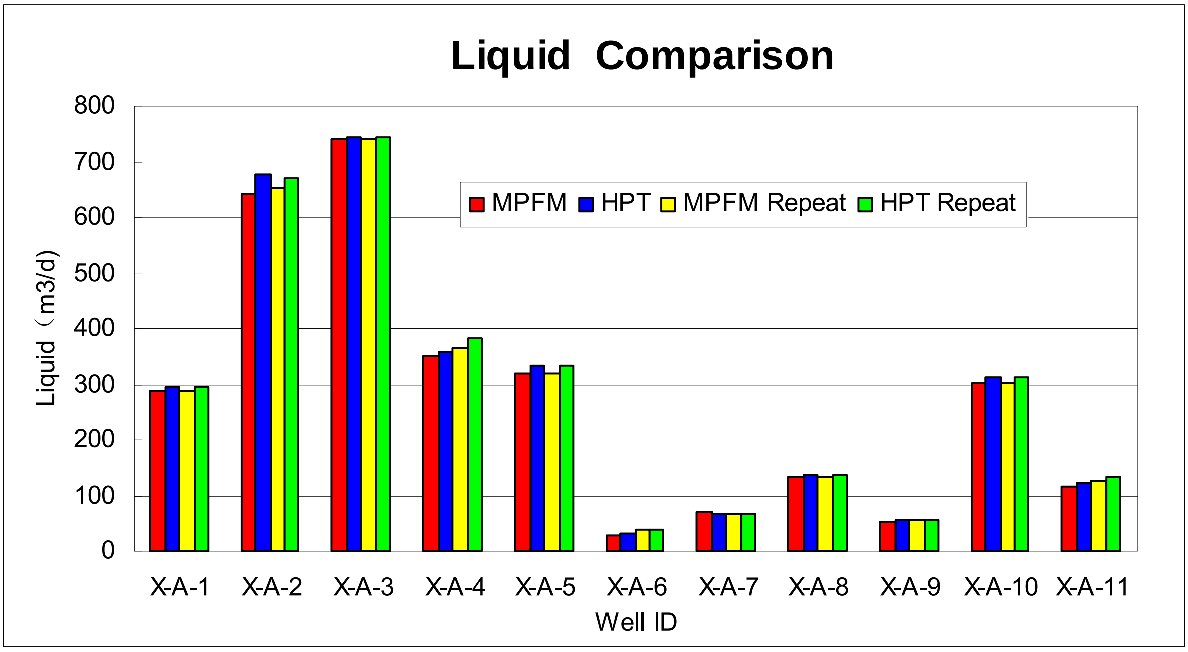

Fig 10 Liquid Comparison at X-A platform

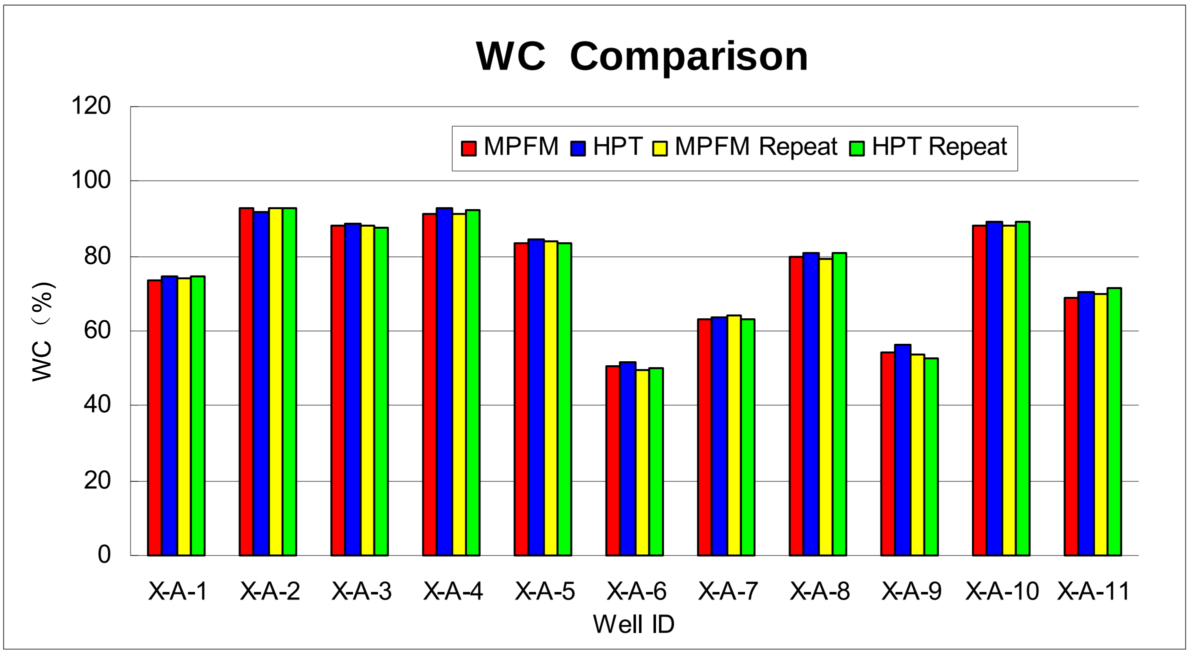

Fig 11 WC Comparison at X-A platform

It is clear that from fig 10 and fig 11 during verification test at X-A platform MPFM testing results have a good agreement with HPT. And both facility have a good repeatability.

5.2 Verification of March 2010 session

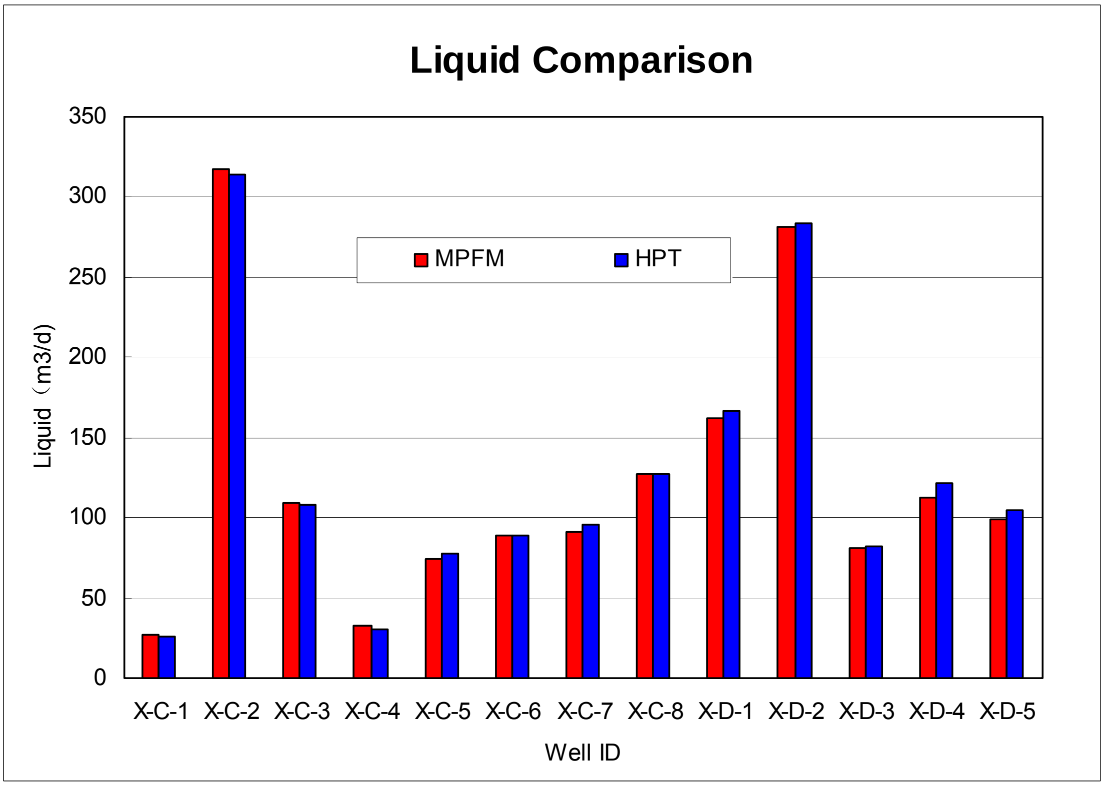

Fig 12 Liquid Comparison at X-C/D platform

Fig 12 and fig 13 illustrate verification test results in March 2020 at X-C and X-D platform. Compared with HPT, MPFMs show high performance in liquid flow rate and WC measurements.

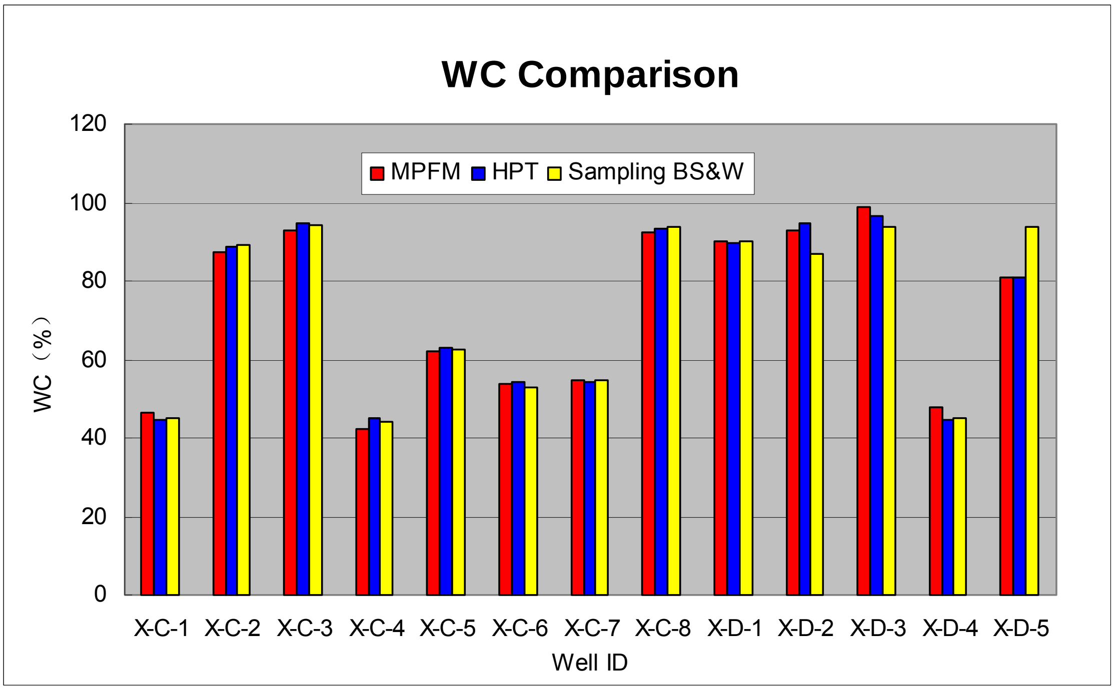

Fig 13 WC Comparison at X-C/D platform

5.3 Overall Results Comparison

Platform	MPFM				HPT			
	liquid (Sm3/d)	Oil (Sm3/d)	Water(Sm3/d)	WC	liquid (Sm3/d)	Oil (Sm3/d)	Water(Sm3/d)	WC
X-A	3037	450	2587	85.2%	3129	453	2676	85.5%
X-C	869	203	666	76.6%	867	191	676	78.0%
X-D	736	115	621	84.4%	758	122	636	83.9%
Total	**4642**	**768**	3874	83.5%	**4754**	**766**	3988	83.9%

Table 2 Overall Results Comparison

From table 2, by eliminating random error of single wells overall oil flow rates of MPFM and HPT are much closer to each other.

6 OIL RF OF X FIELD

Followed by the individual well validation test, the MPFM performance is undergoing a long-term monitoring since end of 2009 when all six MPFMs were put into use.

Since there is no reference in the field to cross-check the performance of the MPFM after the validation test, the export flow meter is being used as a validation tool. The oil rate ratio between the export flow meter and the sum reading of the MPFMs is defined here as RF. The monthly oil RF of X field is recorded in Figure 14 from Jan 2010 to Feb 2011. It can be seen that all the RF values are above 0.9 and below 1.1, which is within the criteria.

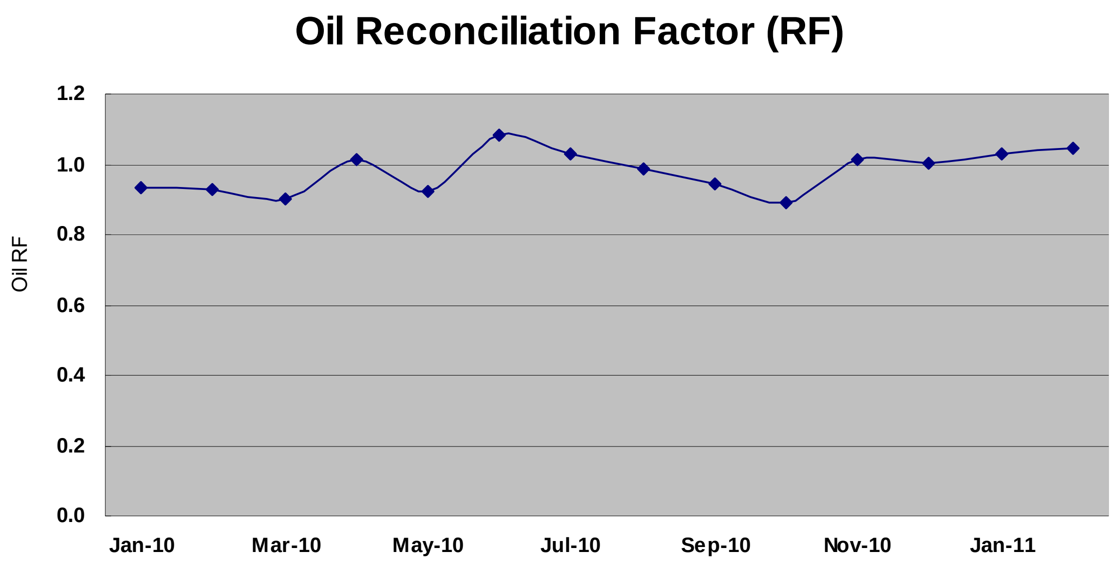

Fig 14- Oil RF since MPFM commissioned

7 CONCLUSIONS

This paper describes a comprehensive on-site verification test on heavy oil wells and addresses how MPFM responds under this well condition.

No doubt, we can conclude from working mechanism that MPFM has a remarkable advantage over conventional test separator in handling emulsion of heavy oil wells. Viscosity plays an important role to get accurate Reynolds numbers. Haimo applies rotational viscometer to get crude oil viscosity and thus to obtain the exponential correlation between the viscosity and the temperature that can be embedded in the software for further calculations. The verification test of two sessions proves that MPFMs are good at dealing with heavy oil wells. The API of in-situ X field is down to 12, but technically Haimo MPFM is believed to be able to handle any heavy oil conditions with even lower oil API by having figured out a complete solution to high viscosity and low Reynolds number issues.

Since commissioning of Haimo six meters in X field, long-term oil RF varying between 0.9~1.1 has enhanced the meters' performance of stable repeatability and the ender user's confidence.

8 NOTATIONS

Notation has been used in the paper as follows:

MPFM	Multiphase Flow Meter
CNOOC	China National Offshore Oil Corporation
GVF	Gas Void Fraction
HPT	High Performance Tester
WLR	Water Liquid Ratio
RF	Reconciliation Factor
WC	Water Cut
BS&W	Basic sediment & water