Petroleum Development Oman (PDO) experience in Well Testing at High GVF and High Pressure Conditions

Abdullah Al-Obaidani, Petroleum Development Oman, LLC.
Salim Al-Sibani, Petroleum Development Oman, LLC.

1 INTRODUCTION

Continuous and accurate well testing data is one of the challenging aspects in well testing at high GVF and high pressure applications in Petroleum Development Oman. PDO has many promising fields where wells generally are at high GVFs and relatively high pressures. The need of reliable well testing data is becoming more important to realise improvements since the company is actively moving towards well & reservoir management (WRM).

A metering project which was initiated in 2003 suggested installing different types of well testing equipment. After completion of this project in 2006, PDO realised improvements in well testing data and hydrocarbon reconciliation. However, fields with high GVFs achieved relatively less improvement and several attempts to improve the hydrocarbon reconciliation were carried out.

A joint effort with the multiphase meter vendor to further improve measurements and hence field reconciliation has taken place in early 2008 where PDO has expressed more emphasis in achieving better reconciliation factors for particular fields. This effort has resulted in a significant improvement in hydrocarbon reconciliation and hence enabled better WRM.

This paper addresses PDO's experience and measurement challenges in the joint effort in testing wells at the described conditions. It highlights different tools used and the specific improvements made. This includes using multiphase flow meters and mobile separators. In addition, this paper also highlights the methods used to back allocate hydrocarbon to the wells. Furthermore, it highlights the importance of accurate parameters to be configured in this equipment to deliver quality well testing data.

The oil field discussed in this paper will be refer to as Field-A.

2 DEFINITION OF PROCESS CONDITIONS AND RECONCILIATION STRUCTURE

It is first necessary to define the terminology used in this paper and process conditions referred to.

2.1 Process Conditions

The process conditions described in this paper are for well testing at pressures more than 30 Bar and Gas Volume Fractions (GVFs) more than 95%.

2.2 Hydrocarbon Reconciliation Structure

The reconciliation structure determines the method used to reconcile hydrocarbon to individual well on volumes of each phase (oil water and gas). The reconciliation structure of crude oil involves the fiscal metering and crude oil export nodes in the Main Oil Line (MOL) and all sub-nodes producing crude oil to the MOL. The volume balance between the reconciled crude oil to the MOL node and the total crude oil from wells is referred to as the Reconciliation Factor (RF) of that node or the field. For water and gas reconciliation, the same concept is implemented using the appropriate reference export nodes.

3 OVERVIEW OF HYDROCABON RECONCILIATION STRUCTURE

To illustrate the hydrocarbon reconciliation structure of Field-A, figure 1 shows an overview of the production streams of Field-A and other fields in the same producing node to the MOL.

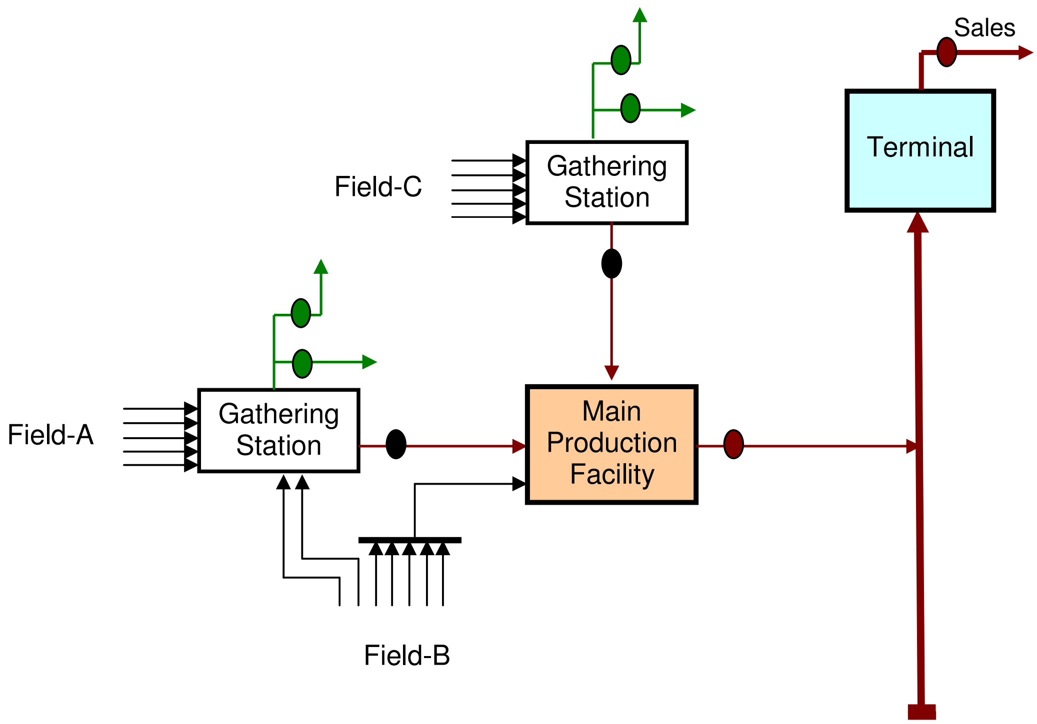

Figure 1 – Schematic Illustration of Field-A Oil Reconciliation Structure

3.1 Reconciliation Structure for Oil

Net oil is reconciled back to wells using the following structure.

- The net oil production to MOL from this node as a total monthly exported volume is first reconciled using the sales fiscal measurement.
- The stock difference in the main production station between beginning and end of the month is determined.
- The potential of all wells during the month is determined from well testing.
- Wells' deferment during the month is determined.

The reconciliation structure takes into account all wells producing to the main production station from other fields as well. Then the Reconciliation Factor (RF) for a particular node is calculated as follows.

$$RF = \frac{\text{Reconciled Production}}{\sum \text{Well Potential} - \sum \text{Deferment}} \quad (1)$$

This RF is then multiplied by the well oil production determined from well testing to arrive into the reconciled oil production for a particular well.

3.2 Water and Gas Reconciliation Structure

Water and Gas reconciliation structure does not differ in concept from the oil reconciliation structure. However, these methods use intermediate measurement points rather than fiscal measurement point as these generally do not exist for process water and process gas (ie. water injection, water disposal, produced gas, injected gas, flared gas, fuel gas, exported gas, etc.).

4 IMPROVING RECONCILIATION FACTOR

This node has suffered for many years of relatively low oil reconciliation factor (between 0.6 and 0.7). Many efforts were made in test separator upgrades, improving water cut measurement, improving export measurement to MOL and in improving well testing in general by deploying multiphase flow meters in specific fields (eg. Field-A). These have resulted in improving the RF to above 0.8 by end of 2007.

As this node involves more than one field contributing at different oil volumes to this node's production, it was necessary to focus on where additional improvement can be made without installing new hardware.

A joint effort between PDO and the multiphase meter vendor was carried out to find possible improvements in determining wells potentials from the multiphase meter and come up with a tool to ensure reliability of data. Further technical details results and finding is detailed in Section 6 of this document.

4.1 Oil Shrinkage

Field-A produces around 20% of the total oil production in this node. The crude oil from Field-A is light crude with base density (at 15 deg.C) between 750 and 800 Kg/m3 for most of the wells in Field-A. This field has mainly no water cut apart from only few wells. The well tests obtained from multiphase flow meters at the testing pressure of ~ 30 Bar were not corrected for phase change of liquid to gas and hence oil shrinkage.

4.2 Gas Density

Gas samples were taken, analysed and differences found compared to the densities configured in the multiphase meters. At high pressure and high GVF, the total mass flow rate is sensitive to errors in gas density.

4.3 Gas Shrinkage and Solution GOR

As lighter components of liquid hydrocarbon change phase to vapour when pressure is reduced to atmospheric, correct solution GOR require to be configured to add this vapour volume to the final gas at stock tank condition.

4.4 Data Validation Tool

As there is no reference in the field to cross-check the performance of the multiphase meters, the export flow meter from the gathering station was used as a validation tool for liquid measurement performance and the bulk separator gas out flow meter as a validation tool for gas measurement. Although it is known that it is often difficult to find a good reference at the field, the best available reference may be used as a check tool only. The export flow meter or the bulk separator gas flow meter, if accurate, may only indicate that the field potential is determined accurately but does not indicate if wells' potential is also determined accurately as one well may be over measured and the other well is under measured.

5 HIGH PRODUCTION TESTER (HPT)

In the joint effort to improve well potential determination and to validate the improvement, the multiphase meter vendor has designed and deployed a unit called High Production Tester (HPT) as a validation tool for their multiphase meters. The HPT is based on two phase separation capable of operating at the full GVF range.

5.1 Operating Principle

The operating principle of the HPT is simple to understand where the multiphase flow enters a vertical separator to separate gas from liquid and then through 2 horizontal separators gas is further separated. The 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. The HPT has two coriolis meters to measure liquid to achieve higher rangability and gas is measured by vortex meters. The water cut is determined from the coriolis meter and there is a provision for automatic garb sampler. Figure 2 shows HPT PI&D.

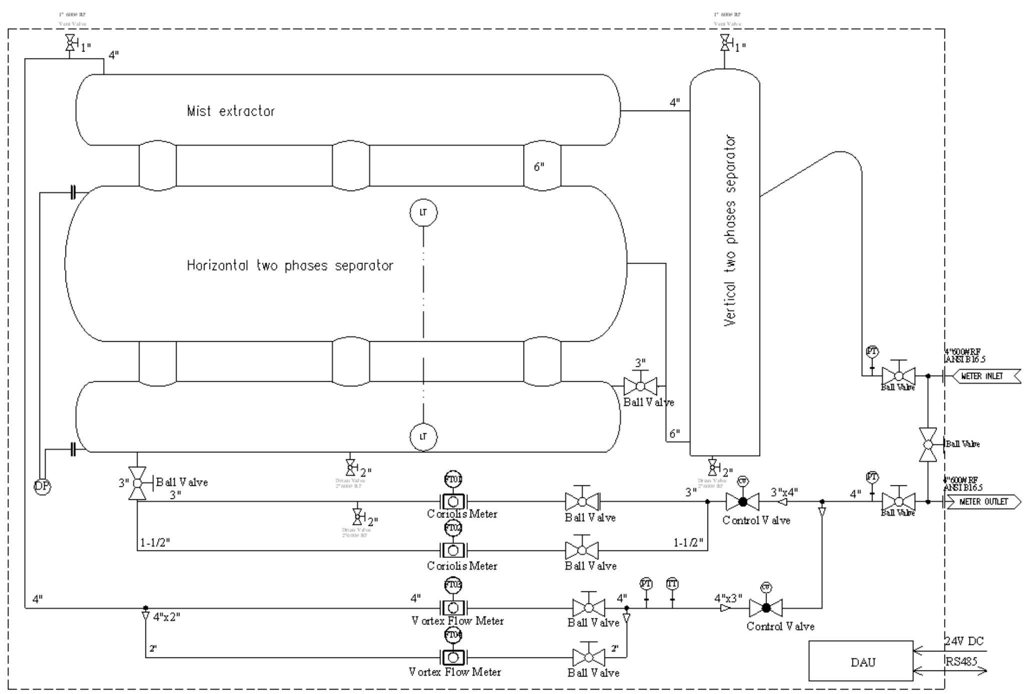

Figure 2 – P&ID of the High Production Tester (HPT)

5.2 Performance Specification

The HPT has the following performance specification which has qualified it to be used by the vendor as a validation tool for individual well testing accuracy.

Design Pressure:	ANSI 600#
Liquid flow rate:	20 – 2000 m3/d
Gas flow rate:	0 – 25,000 am3/d
GVF:	0 – 100%

Water cut range: 0 – 100%
Liquid Uncertainty: < +/-5% (relative)
Gas Uncertainty: +/-5 – 10% (relative)
Water cut uncertainty: +/-1~2% (absolute)

5.3 Operating Envelope

The HPT has wide operating envelope covering all wells in Field-A in addition to other wells in other fields. Figure 3 shows the operating envelope of the HPT.

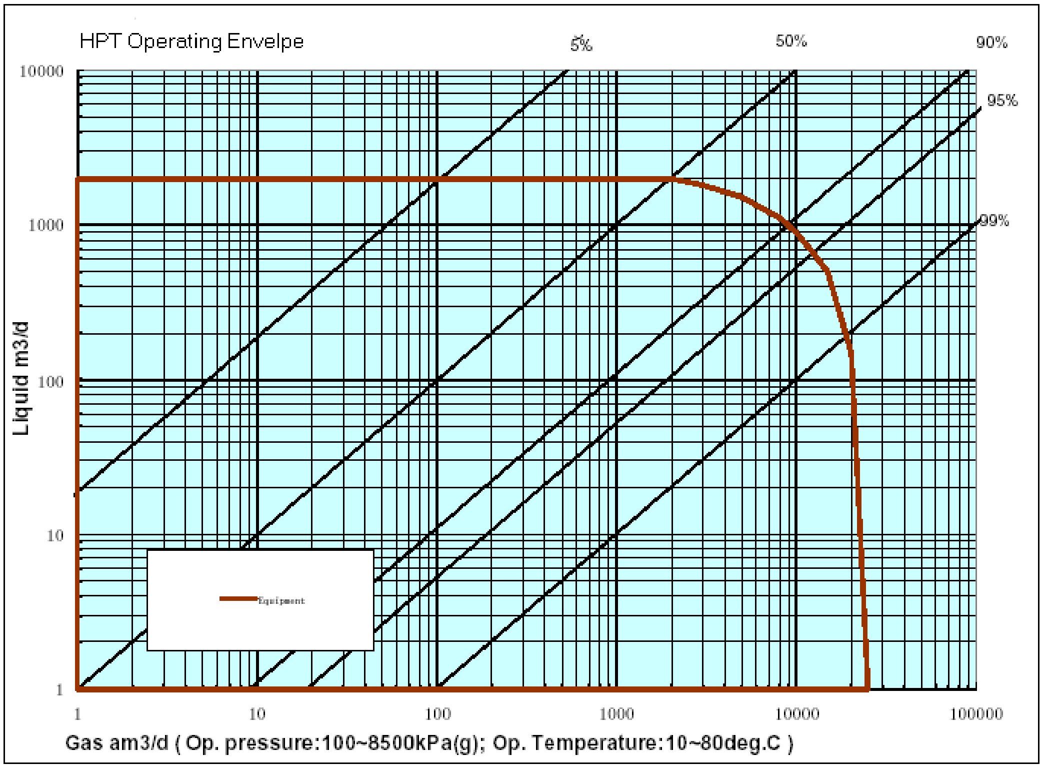

Figure 3 – HPT Operating Envelope

The unit was tested at the manufacture's test loop with transformer oil, tap water and air and performed within +/5% relative for liquid and gas and +/-1~2% absolute for water cut (WLR).

6 DATA ANALYSIS

The improvement campaign in Field-A has addressed many potential aspects that may impact the final well test data. These include fluid properties, shrinkage determination, model enhancement and validation methodology.

6.1 Field-A Wells

Field-A consists of number of wells for which 17 wells are currently on stream. The oil production from these wells vary from 20 to 200 m3/d. The water cut generally is less than 5% on average. Gas production varies from well to well. Most wells produce gas at a rate of 100,000 to 250,000 Sm3/d. The GVF is generally high at 98%. Table 1 shows typical well test data for Field-A wells before the improvement campaign.

Table 1 – Typical Well Test Data for Field-A

Well	Liquid (m3/d)	Oil (m3/d)	Water (m3/d)	Gas (m3/d)	WLR %	GVF %	Press (MPa)	Temp C
A-1	103	103	0	205,621	0.2	98.5	3.24	31
A-2	73	73	0	84,755	0.1	97.4	3.18	31
A-3	26	26	0	6,721	0.0	80.2	3.17	30
A-4	268	268	0	114,074	0.0	93.3	3.20	29
A-5	138	83	55	226,710	40.0	98.1	3.26	29
A-6	37	37	0	555	0.1	35.7	3.18	26
A-7	219	185	34	8,911	15.6	24.0	3.28	28
A-8	79	79	0	140,686	0.2	98.3	3.19	29
A-9	51	51	0	100,294	0.9	98.8	3.19	22
A-10	23	22	0	106,046	0.4	99.4	3.19	46
A-11	86	84	2	130,675	2.3	98.0	3.19	27
A-12	134	133	0	351,061	0.1	98.8	3.31	41
A-13	79	78	1	90,511	1.7	97.3	3.18	24
A-14	92	91	0	175,604	0.2	98.4	3.20	28
A-15	57	57	0	105,486	0.5	98.4	3.17	33
A-16	96	95	1	183,882	1.0	98.4	3.21	27
Total	1,561	1,466	96	2,031,592	6.1			

6.2 Field-A Densities

Oil density of Field-A wells vary from well to another. Most of these wells have oil with densities (at 15 deg.C) between 750 and 820 Kg/m3. Table 2 shows the distribution of densities per well.

Table 2 – Field-A Densities

Well	Oil Density Kg/m3	Water Density Kg/m3	Gas S.G (Air=1)
A-1	786	N/A	0.652
A-2	818	N/A	
A-3	815	N/A	
A-4	822	N/A	0.668
A-5	788	1159	
A-6	813	N/A	
A-7	809	1157	
A-8	786	N/A	
A-9	747	N/A	
A-10	772	N/A	
A-11	786	N/A	
A-12	778	N/A	
A-13	792	1149	0.643
A-14	798	N/A	
A-15	802	N/A	0.675
A-16	770		0.686

The initial configured gas S.G was 0.831 for all wells. The updated gas sample results for most of the wells were 20% less on average. Updating these densities has resulted in measurement shift of liquid and gas flow rates. Figures 4 and 5 shows the improvements made referenced to the HPT for the two multiphase meters deployed in Field-A.

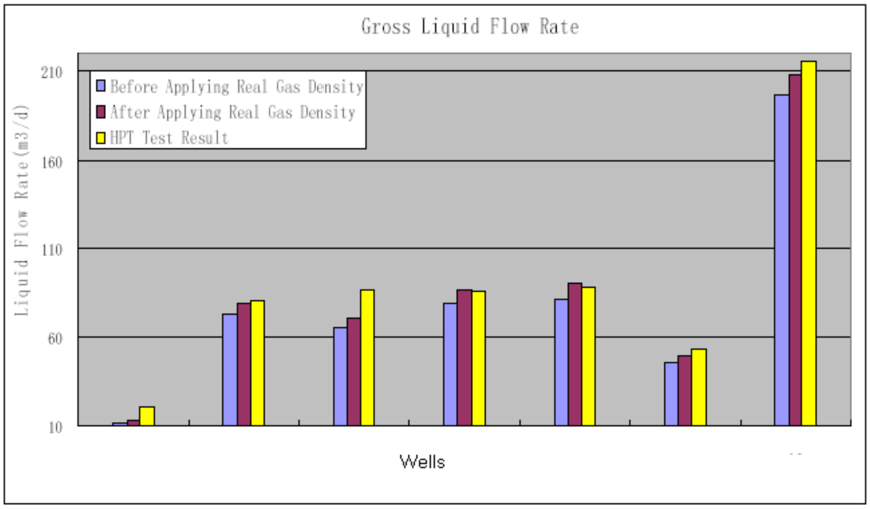

Figure 4 – Gross liquid comparison

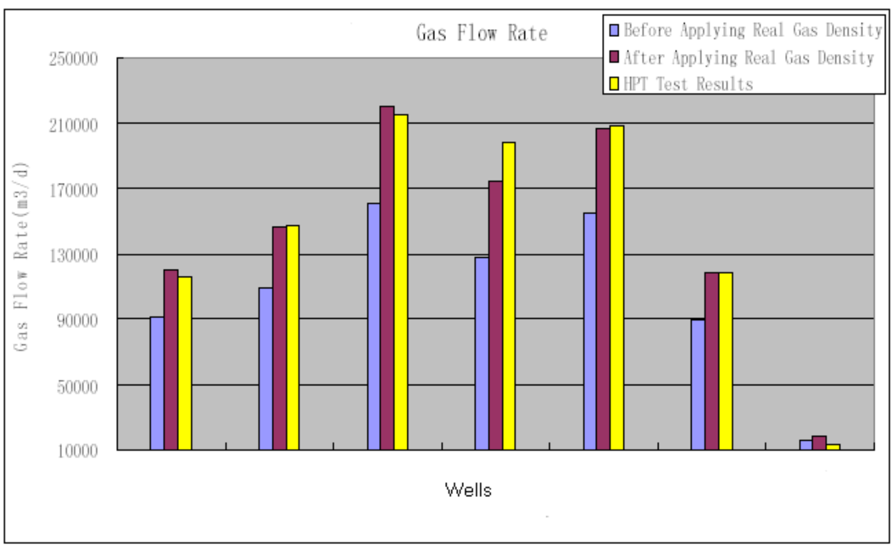

Figure 5 – Gas measurement comparison

6.3 Data Comparison Using HPT

The 16 different wells were gone under several validations using the HPT after updating the densities. Table 3 shows the comparison results of well tests between the HPT and the multiphase flow meters.

Table 3 – Data comparison between the HPT and the MPFMs

Well	HPT			MPFM			Diff. %		
	Liquid	Gas	WLR	Liquid	Gas	WLR	Liquid	Gas	WLR

A-1	94.9	189,531	0.1	82.2	211,116	0.0	-13.4	11.4	-0.1
A-1R1	103.3	205,621	0.2	100.0	208,634	0.0	-3.1	1.5	-0.2
A-1R2	96.5	200,025	0.0	4817.0					
A-2	75.8	83,779	0.8	81.1	79,550	1.1	6.9	-5.0	0.3
A-2R1	73.5	84,755	0.1	77.1	81,781	0.5	4.9	-3.5	0.4
A-4	268.2	114,074	0.0	251.8	111,966	0.0	-6.1	-1.8	0.0
A-4R1	240.6	113,542	0.0	4817.0					
A-5	138.1	226,710	40.0	136.3	232,334	42.0	-1.3	2.5	2.0
A-5R1	144.9	223,543	40.0	4817.0					
A-7	218.7	8,911	15.6	227.1	8,971	14.9	3.8	0.7	-0.7
A-7R1	242.6	11,554	12.5	4817.0					
A-8	79.4	140,686	0.4	77.6	135,887	0.0	-2.2	-3.4	-0.4
A-8R1	84.1	138,197	0.5	4817.0					
A-9	51.3	100,294	0.8	50.1	109,615	0.0	-2.3	9.3	-0.8
A-11	86.3	130,675	2.3	88.5	140,375	0.0	2.5	7.4	-2.3
A-11R1	75.0	138,783	0.0	4818.0					
A-12	140.7	343,065	0.0	4818.0					
A-12R1	127.5	348,850	0.2	120.4	383,406	0.3	-5.6	9.9	0.2
A-13	84.4	71,639	0.0	4818.0					
A-13R1	67.8	74,221	3.2	68.2	67,078	0.6	0.7	-9.6	-2.6
A-14	96.3	188,592	0.0	4818.0					
A-14R1	104.8	202,252	0.0	4818.0					
A-14R2	92.3	190,913	0.3	72.6	188,126	0.9	-21.4	-1.5	0.6
A-14R3	105.6	196,530	0.2	115.0	210,575	0.1	8.9	7.1	-0.1
A-14R4	91.7	175,604	0.2	98.1	167,258	0.0	7.0	-4.8	-0.2
A-15	57.3	105,486	0.5	56.7	115,122	0.0	-1.2	9.1	-0.5
A-15R1	67.9	84,625	0.0	4818.0					
A-15R2	75.0	97,713	0.0	4818.0					
A-16	101.4	192,312	0.5	98.3	214,544	0.0	-3.0	11.6	-0.5
A-16R1	77.9	217,820	0.0	4818.0					
A-16R2	95.9	183,882	1.0	102.8	198,594	0.0	7.3	8.0	-1.0
A-16R3	103.1	184,320	0.0	4818.0					

6.3.1 Cross Plots

The requirement of well testing accuracy is +/-10% for the three phases. Figures 6, 7 and 8 displays the cross plots for liquid, gas and WLR for Field-A wells tested by the multiphase meters against the HPT. Most of the well tests fall inside the required accuracy bands.

Figure 6 – Cross plot of gross liquid

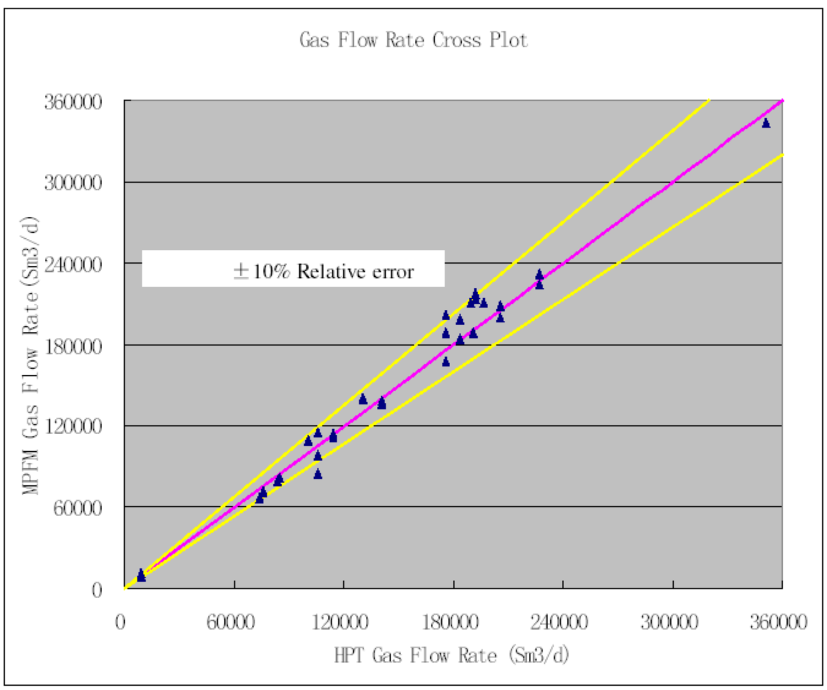

Figure 7 – Cross plot of Gas

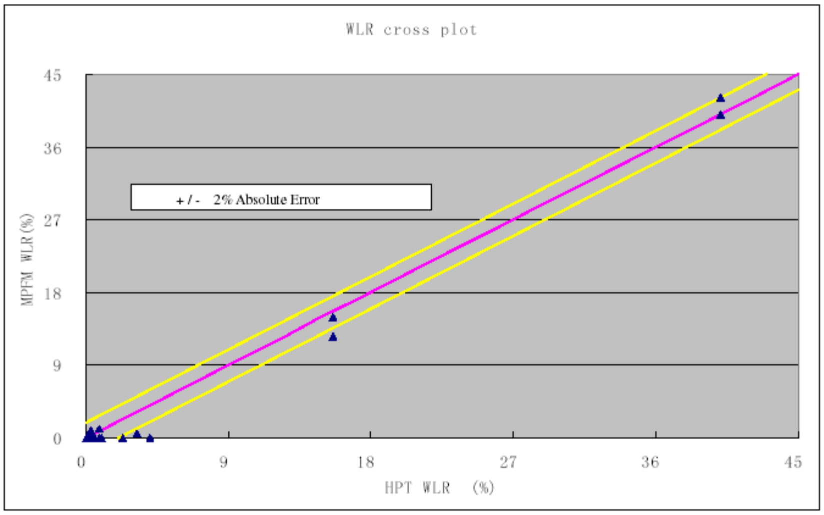

Figure 8 – Cross plot of WLR

6.4 Data Comparison Against Export Flow Meter

Prior to starting the improvement campaign in Field-A, the net oil volume imbalance between the export flow meter and the sum of Field-A oil potential from well testing by the multiphase flow meters was in the magnitude of -36% indicating an over-measurement of net oil in the well testing and contributing to low RF of this node. With the update of densities and carrying out specific enhancement activities, the imbalance was reduced to +5%. However, the node reconciliation factor for oil did not show the anticipated improvement although the well testing data and oil export data were within 5%. Section 7 of this paper will address why this was the case.

7 PVT DATA AND STOCK TANK CONDITION

It is well known that hydrocarbons change phases with the change of pressure and temperature. Filed-A wells are tested at 30 Bar and crude is degassed in bulk separator at the gathering station at similar pressure and then exported to the main production station of this node. The final product is then separated at lower pressures and transported to atmospheric tank before final export to MOL. The light component of hydrocarbon in liquid phase at the testing pressure would have changed phase to vapour at the production station shrinking the volume of the oil and expanding the volume of the gas in comparison to the measurement of oil and gas in the well testing equipment.

Determining the magnitude of this effect requires a thorough understanding of the PVT data of the hydrocarbon and the process operation. A single stage flush of the hydrocarbon may not be applicable were multi-stage separation exist. Generally more liquid hydrocarbons are recovered compared to single flush. Process simulation of specific plants may determine more representative shrinkage factors is correct PVT data is used.

7.1 PVT Input

The multiphase meters were initially provided with PVT data, shrinkage factors and solution GOR values at different pressures and temperatures to cater for the shrinkage due to PVT changes. These have been reviewed and updated resulting in additional shrinkage in the oil. The new parameters were re-configured in the multiphase flow meters and the export meter.

Table 4 lists these parameters and the updated values.

Table 4 – Typical PVT Values for Field-A

Pressure KPa	Shrinkage Factor	Z Factor	Solution GOR m3/m3
3,365.9	0.834	0.956	30
3,365.9	0.779	0.939	48

With implementing the updates parameters, this node RF has improved further. More initiatives were conducted at other fields in this node and total effort has brought the RF of this node to above 0.9 since August 2008. Figure 9 shows the oil RF trend for this node since 2005.

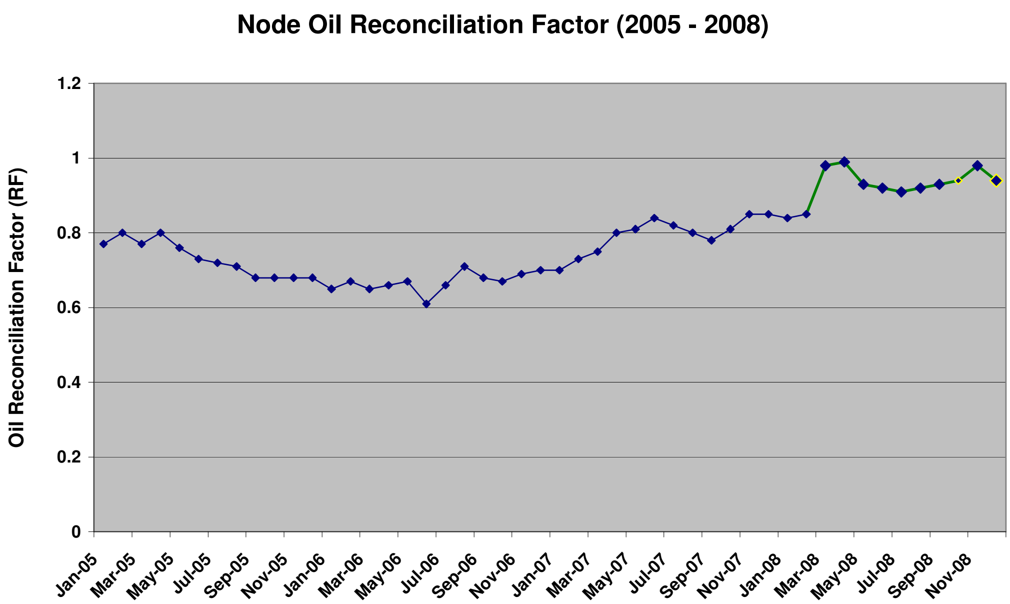

Figure 9 – Node Oil Reconciliation Factor (2005 – 2008)

8 GAS BALANCE

Gas requires similar attention to get it RF within desirable range of better than 0.9. Although gas reconciliation is relatively more complex to do due to non fiscal measurement availability as a reference for reconciled volumes, methods using gas out from the facility (gas lift, gas injection, gas export, fuel gas, etc.) has proven adequate. In case of Field-A, the measurement comparison between the HPT and the MPFMs met the requirement for both liquid and gas. A second check is to compare the sum of gas from well testing with the bulk separator gas out meter or the total injected gas volume. Due to many uncertainties in gas measurement of these different flow meters and the fact that shrinkages are applied to some of the meters but not others (for gas measurement), it was relatively more difficult to conclude a representative picture of the real gas reconciliation. However, the current available data after improvement campaign indicates a -14% imbalance between the sum of gas measured by the multiphase meters and the bulk separator gas out meter. In addition, the comparison with HPT has shown that the gas is within 5%. The HPT compares within 9% of the bulk separator gas out measurement.

9 CONCLOSION

Well testing at high pressure and high GVF conditions gives additional challenges to measurements and hydrocarbon reconciliation structure. Correct data of fluid properties and PVT are essential for devices sensitive to these parameters. In addition, specific parameters accuracy is very important at high GVF and high pressure conditions. Although this paper has covered Field-A only, there are many other similar fields in PDO where well testing is carried out at 90 Bar and more than 90% GVF.

The good collaboration between different disciplines and the multiphase meters vendor, together with vendor's initiative in deploying the HPT as a validation tool have enabled identifying key contributors to the low RF in this node. Although a good reference in the field is often difficult to find, the HPT has delivered good repeatability and increased end user confidence in the field potential determination.

This example has demonstrated that a simple parameter wrongly configured or an inaccurate parameter is configured may result in mis-measurement affecting multiple measurement. As the technology is advancing, end udders would always want technologies which are less sensitive to input parameters.

10 ABBREVIATIONS

GOR	Gas Oil Ratio
GVF	Gas Volume Fraction
HPT	High Production Tester
MOL	Main Oil Line
MPFM	Multiphase Flow Meter
P&ID	Piping & Instrumentation Diagram
PDO	Petroleum Development Oman
RF	Reconciliation Factor
S.G	Specific Gravity
WLR	Water Liquid Ratio
WRM	Well and Reservoir Management