SPE 103713

# Validation of a 16" Bulk meter for Allocation metering

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This paper was prepared for presentation at the 2006 Abu Dhabi International Petroleum Exhibition and Conference held in Abu Dhabi, U.A.E., 5–8 November 2006.



## Abstract

The use of Coriolis based mass flow meters and turbine meters is well known in the oil industry for measurement of bulk fluids (two and three phase) exported from their central processing facilities. Large flow rates and the presences of gas in the flow affect the measurement accuracy and performance of these meters.

A typical solution for the same is to use a large sized three phase multiphase meter as done by PDO in its Amal field. This is one of the first deployments of its kind anywhere in the industry. PDO is pleased to jointly present here with its vendor, Haimo, the results of a verification process that has been carried out on one of its large size multiphase meters capable of handling between 15,000 m3/day to 57,000 m3/day (approx. 90,000 bpd to 340,000 bpd) with a GVF from 0 to 50% **(Fig. 3)**

The results have produced some impressive comparisons. The presentation shall result in communicating the following to the end users:

(a) Application of Bulk Meter for export flow measurement and allocation metering.

(b) Another way of verifying the individual well test meters against an export reference, especially where there are no references available in form of test separators, meter provers or the like.

This paper is a summary of methodology used and the results obtained. It is only a factual representation of the data obtained with some additional analysis as carried out by PDO and its vendor.

## Introduction

Accurate metering of 3-phase well streams is important in onshore / offshore production measurement technology. These measurements are used for well monitoring, reservoir management, production allocation, and to evaluate the need for well work over or simulations. Multiphase meters are light in weight and small in size, and can be deployed in remote onshore areas or at offshore locations. They are unique tools and are being seen by many engineers as key components in reducing the capital and operational costs of oil and gas production facilities.

The development of these meters has been targeted essentially at improving well testing. Well Testing refers to measurement of production rates of the wells. Flow rates of each of the three phases are related to well-head parameters (such as choke size and position, well-head flowing pressure and downstream pressure). Changing any of these parameters will affect the production rates. The production from each well is integrated over a flowing period to give the total production from each well and hence from the field. Oil companies are deploying multiphase meters to bring large benefits, reducing the costs of facilities and allowing operators and reservoir engineers to optimize production.

In 2004, PDO commissioned a 16" multiphase meter for Amal, referred to as a "Bulk Meter" to monitor the phase flow rates of export fluids from a field of numerous wells. As part of its drive to deploy more such meters in the field, a joint verification / validation exercise was done recently by PDO and the vendor.

## Definitions

**PDO** – Petroleum Development Oman

**MFM** – Multiphase Flow Meter

**GVF** – Gas Volume fraction

This is defined as the gas volume flow rate, relative to the multiphase volume flow rate, at the pressure and temperature prevailing in that section. The GVF is normally expressed as a fraction or percentage

**WC** – Water Cut

This is defined as the water volume flow rate, relative to the total liquid volume flow rate (oil and water), both converted to volumes at standard pressure and temperature. The WC is normally expressed as a percentage.

**Measuring / Operating Envelope**

The area in the two-phase flow map and the composition map in which the MPFM performs according to its design specifications.

## Amal Field Description

The Amal field has around 106 wells connected to several MSVs (Multi-port Selector Valves). From these MSVs, test and bulk lines are combined to one 16" gross header which goes directly to NRPS (Nimr Production Station). Each MSV is equipped with Coriolis meters and NOCs (Net Oil Computer) which are used as well testing facilities. At times, the mobile MFM from well test contractor is used for well testing in case if the existing Coriolis well test is not reliable. The calibration of these meters is normally done on annual basis or when there are suspicions on the meter reading. All Coriolis meters were calibrated last year (2004) and will be re-calibrated again in October 2005. The individual testing is not done on a continuous or daily basis per well due to testing facility limitations and the data values for any well are recorded as constant till it is tested again.

## MFM Measurement Principles

Basically, phase fractions are derived from two independent measurements, water cut in the liquid and gas fraction of the entire flow, coupled with the continuity equation that requires the sum of oil, water and gas phase fractions to equal unity. The phase fractions and flow rates are calculated based on the following measurements:

a. Total flow rate of the multiphase fluids (TFR) is measured by the Classical Venturi.
b. Single gamma sensor measures the gas-liquid phase fraction (GVF).
c. The water cut (WC) is measured by a dual gamma sensor.
d. Pressure and temperature transmitters are mounted in appropriate locations in the skid for correction of measured values to standard conditions.
e. The gas flow rate is calculated as a product of TFR x GVF, and is corrected for pressure and temperature for representation in standard conditions
f. The gross liquid flow rate (GFR) is calculated as a product of TFR x (1-GVF).
g. The water flow rate is calculated as a product of GFR x WC and the Oil flow rate is a product of GFR x (1-WC)

## Uncertainties for Amal MFM

| | |
|---|---|
| Liquid flow rate | ± 10% relative |
| Gas flow rate | ± 10% relative |
| Water Cut | ± 2% absolute |
| Gas Volume Fraction | ± 1% absolute |

All at 90% confidence level.

## Amal Bulk MFM Description

The simple and proven MFM configuration utilizes the combination of gamma ray absorption and venturi schematically shown in attached P&ID **(Fig. 2).**

The meter consists of a venturi on the liquid leg with a single gamma meter. One dual gamma meter constitutes the water cut measurement section, independent of the liquid and gas measurement section. Measurement of the gas and liquid streams is carried out upstream of the full range water cut meter. A microprocessor based electronics unit Data Acquisition Unit (DAU) installed in the junction box (Eexd enclosure) is mounted on the skid to collect, process and archive signal and data from all the field instruments and sensors, and to carry out the flow metering calculations. The unit has two RS485 serial ports, one of which is connected with MFM PC for data transmission. Another serial port is standby for the calibration of the sensors in the field. The MFM PC is used for meter calibration, configuration and troubleshooting in the field.

**1. Single Gamma Meter.**

Gas Liquid phase fraction is measured by the Single Gamma meter.

**2. Dual gamma meter**

The dual gamma meter consists of a dual energy (241 Am + Ag) gamma source and a NaI (T1) scintillation detector. The dual energy gamma source produces 59.5 keV and 22 keV energy levels respectively. The detector receives two different kinds of energy levels when the gamma ray passes through the multiphase flow. The dual energy gamma ray meter is used to accurately measure the water cut.

**3. Venturi meter**

The total flow rate is measured by means of the venturi meter.

**4. Flow computer (MFM DAU ) — the data acquisition and analysis unit**

The data acquisition and analysis unit, enclosed in the ex-proof junction box, not only collects and handles all of the signals from the sensors and transmitters, but calculates the flow rate, water cut, GVF, pressure and temperature as well. Then it passes the data to the industrial computer at the control room via RS 485 serial port using MODBUS ASCII protocol.

**5. Master computer ( MFM PC )**

The MFM PC, loaded with dedicated software, communicates with the MFM DAU via RS- 485 serial ports. If necessary, MPFM PC may receive the data from different fields of up to 8 data acquisition and analysis units. It can display and print the process data, can edit and open the various user menus, record the history data of process variable, output and print reports / alarms, do the software configuration, calibration and remote communication.

## Test Procedure

The verification of the bulk meter was carried out by comparing the measurements from the "MFM Bulk Meter" against the "total measurement from the individual tests of wells connected to the MFM". The individual well test is carried out by either Coriolis meter or mobile MFM.

Additionally, in-situ sampling was carried out over 7 days (in 3 rounds of 2-3 days each) and at different times of the day to validate the instantaneous results of this bulk meter with regards to water cut at different times of the day. The exact time of sampling was noted and then these samples were analyzed by PDO at their Nimr field laboratory. Once results were provided by PDO, these were crosschecked against the meter reading at that same date and time.

The test data for comparison was taken from the phase flow figures of the MFM against the values as entered for the well tests in PDO EPROMs over a period of 4$^{th}$ June – 11$^{th}$ September, 2005. The data for the water cut comparison was taken over the period of 14$^{th}$ June - 4$^{th}$ July, 2005.

## Results and Analysis

The attached graphs describe the differences between the bulk MFM reading and total average well testing. These differences are calculated by adding individual well tests in each day and comparing it with the MFM reading on that specific day. The equation used is as follows

*Diff in % = (A-B)/C……………………………….…..A1*

Where A: Average MFM daily reading in m3/d
B: Total average well test from EPROM in m3/d
C: Average MFM daily reading in m3/d

These differences are considered to be random and for that reason the average differences were calculated based on the following equation

*Average difference % = D/E…………………………A2*

Where D: Sum of the individual difference
E: Total number of test points

## Gross Measurement

The attached graph **(Fig.4)** shows the gross % difference. In average, the difference is around (- 4.1%) - this means that the total well test figures are higher by 4.1% than the MFM reading. This is expected due to the fact that MFM uncertainty in gross measurement is specified at $\pm$10% relative.

The dip shown in the graph at the beginning of August is attributed to the fact that the bulk meter was testing continuously throughout the period unlike the individual well testing Coriolis meter. This could be due to trips of some individual wells in the interim period between two successive well tests by Coriolis meter.

## Water Cut Measurement

To confirm the MFM water cut readings, a comparison using sampling and laboratory analysis was conducted on different days at different timings in the day i.e. morning and afternoon. Samples were collected from a location close to the MFM water cut meter where homogeneous flow was assured. Water Cut samples were analyzed and compared with the water cut of the MFM minutes reading. The attached graph (Fig. 5) shows the difference between the MFM water cut reading and the lab samples water cut reading. The overall average difference % is 0.97% which is well within MFM water cut uncertainty ($\pm$ 2% absolute).

## Net Oil Measurement

The attached graph (Fig. 6) shows the net oil flow % difference. On average, the difference is around (- 17.7%) which mean that the total well test figures are higher by 17.7% than the MFM reading. This is expected since gas exists in some wells. Gas will tend to lower the density of liquid and the Coriolis meter will read more oil. The other factor of this high difference is the high water cut in some wells. It is well known that Coriolis water cut uncertainty is low at high water cuts which will be reflected in the net oil measurement. Typical graph presenting net oil uncertainties versus water cut is attached as Fig. 7.

## Water Measurement

The attached graph (Fig. 8) shows the water flow % difference. On average, the difference is around (-2.0%) which mean that the total well test figures are higher by 2.0% than the MFM reading. This is well within the +10% relative design accuracy of the bulk meter.

## Gas Measurement

The difference in gas measurement could not be compared due to the fact that Coriolis meter can not be used in gas measurement. Most of the 106 wells don't produce gas; however, some of them produce gas which varies from 0.5% GVF to 25% GVF. This has been confirmed by using the mobile well test MFM. Individual well gas reporting is actually done using the GOR (Gas Oil Ratio) estimated for each well. This will have high uncertainty due to the fact that GOR changes with time. This is proved by comparing the bulk MFM reading with the reported gas data and the average difference found to be (-338.8%) which mean that the total well test figures are higher by 338.8% than the MFM reading. The case is the same with the daily differences as shown in the attached graph **(Fig. 9)**

## Conclusions

The following can be concluded from this study:

1. Water cut readings spot samples as collected at the meter and analyzed at PDO Nimr lab show very good correlation with what the bulk meter indicated at the same time the spot sample was taken, validating the $\pm$2% absolute or better design accuracy of the bulk meter.
2. Keeping in mind the stated single phase accuracies of the bulk meter at $\pm$10% relative, gross readings also show good comparison.
3. Net Oil readings are acceptable taking into consideration the effect of gas in the Coriolis meter reading and high BS&W in some wells.
4. However, Gas readings do not show good correlation. This is due to the fact that reported gas figures from individual wells are calculated based on the GOR since Coriolis meter can not measure gas.

The result shows that Bulk MFM can give fairly good result if it is designed properly and used in the correct applications. Special attention needs to be given to the GVF% expected. This bulk MFM meter can measure up to 50% GVF.

Another important point concerning net oil measurement is related to the water cut. It should not be expected to achieve high accuracy in net oil measurement when using this type of meter since it's water cut uncertainty is $\pm$ 2% absolute (refer Fig. 7).

It is also important to consider the size of such meter as it could be a limitation when it comes to higher line size i.e. bigger than 24".

## Acknowledgments

This trial would not have been successful without the active co-operation and assistance of various departments at PDO and the vendor. Some of them include:

- PDO Marmul field team who provided day to day coordination and support.
- Marmul Production Chemistry Lab
- Real Time architecture group (PI & Shurooq), especially Mr. Parwez Akhtar, who assisted in collecting and compiling the MFM data in Shurooq.
- Haimo Oman field team who collected the samples and the MFM minutes data.

**Table 1. List of Amal field wells and estimated gross**

| Well # | Gross (M3/d) |
|---|---|
| ABJ001L | 19.78 |
| ABJ001S | 5.05 |
| ABJ006L | 26 |
| ABJ006S | 54 |
| ABJ007 | 91 |
| ABJ008 | 72.9 |
| ABJ011 | 77.5 |
| ABJ013 | 30 |
| ABJ014S | 3 |
| ABJ017 | 190 |
| ABJ018 | 50.44 |
| ABJ019L | 10.73 |
| ABJ021 | 11 |
| ABJ022 | 37 |
| ABJ023 | 14.5 |
| ABJ025 | 1006 |
| ABJ026 | 574.44 |
| ABJ027 | 985 |
| ABJ029 | 111 |
| ABJ030 | 66.57 |
| ABJ031 | 1099.88 |
| ABJ032 | 992 |
| ABJ033 | 151.9 |
| ABJ034 | 73 |
| ABJ035 | 126.74 |
| ABJ036 | 106.3 |
| ABJ037 | 422.6 |
| AL005 | 239.19 |
| AL011 | 106.29 |
| AL013 | 159 |
| AL014 | 47.94 |
| AL016 | 89.85 |
| AL017 | 244.98 |
| AL019 | 112.18 |
| AL020 | 8.43 |
| AL021 | 306.9 |
| AL022 | 236.26 |
| AL023 | 166.76 |
| AL024 | 139.28 |
| AL025 | 165 |
| AL027 | 97.48 |
| AL028 | 173.03 |
| AL030 | 227.8 |
| AL031 | 135.36 |
| AL032 | 194.47 |
| AL036 | 205 |
| AL037 | 130.01 |
| AL038 | 139.46 |
| AL039 | 90.74 |
| AL044 | 216.97 |
| AL045 | 1159 |
| AL046 | 984.96 |
| AL047 | 1099.12 |

| Well # | Gross (M3/d) |
|---|---|
| AL048 | 801.73 |
| AL049 | 211 |
| AL051 | 54 |
| AL052 | 965.74 |
| AL053 | 542.38 |
| AL054 | 225.19 |
| AL055 | 132.18 |
| AL056 | 99.95 |
| AL057 | 942.72 |
| AL058 | 148.41 |
| AL059 | 252.96 |
| AL060 | 80 |
| AL061 | 168.9 |
| AL062 | 95.66 |
| AL063 | 121 |
| AL064 | 200.1 |
| AL065 | 692.95 |
| AL066 | 26.95 |
| AL067 | 317.16 |
| AL071 | 1186.44 |
| AL072 | 382.01 |
| AL073 | 1566.83 |
| AL074 | 140.7 |
| AL075 | 879.14 |
| AL076 | 1217.18 |
| AL077 | 137.2 |
| AL078 | 273.16 |
| AL079 | 124.8 |
| AL080 | 246 |
| AL081 | 226.32 |
| AL083 | 80.58 |
| AL084 | 415.79 |
| AL085 | 441.29 |
| AL086 | 11.45 |
| AL087 | 353.88 |
| AL088 | 293.82 |
| AL090 | 363.35 |
| AL091 | 373 |
| AL092 | 208 |
| AL093 | 79.91 |
| AL094 | 30.48 |
| ALS001L | 94 |
| ALS001S | 87.95 |
| ALS005 | 53.66 |
| ALS007L | 92 |
| ALS008 | 70.24 |
| ALS009 | 102.92 |
| ALS010 | 31 |
| ISN001 | 45 |
| ISN002 | 41.96 |
| ISN008 | 67.28 |
| SQR001 | 33.85 |
| WHA001 | 17 |

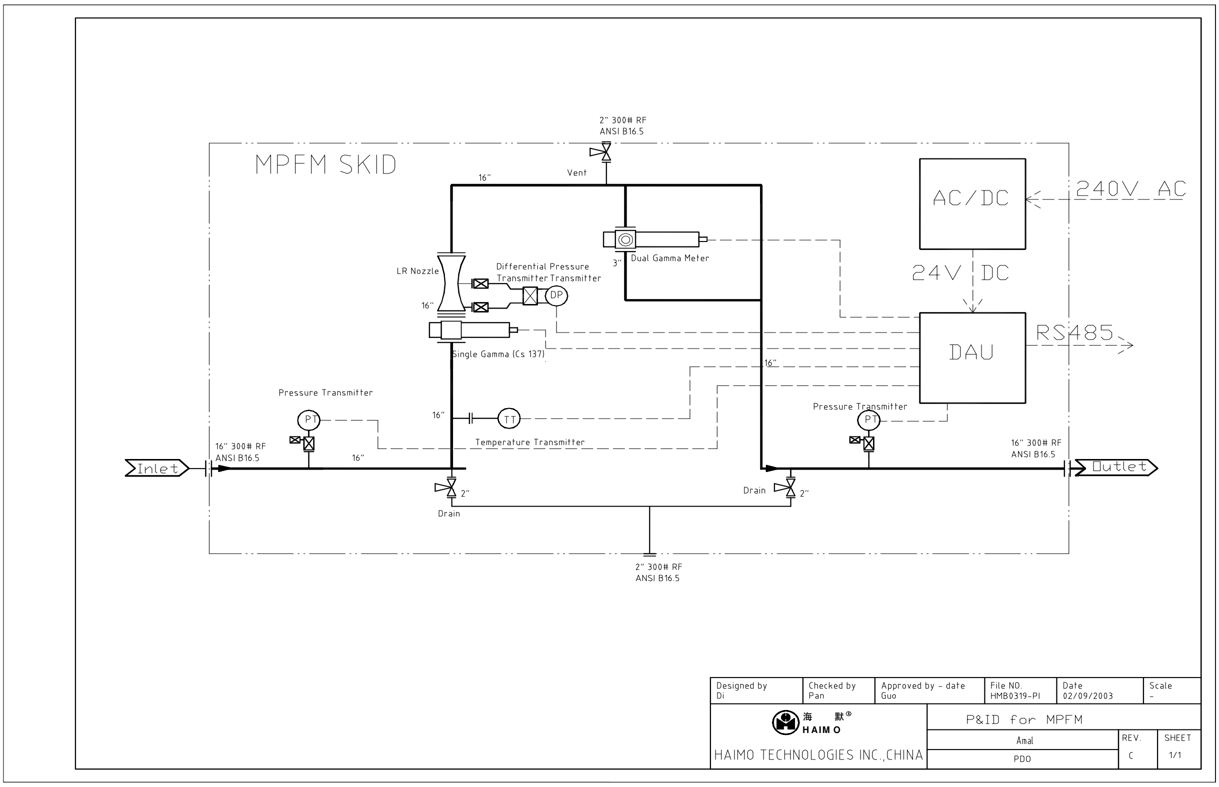
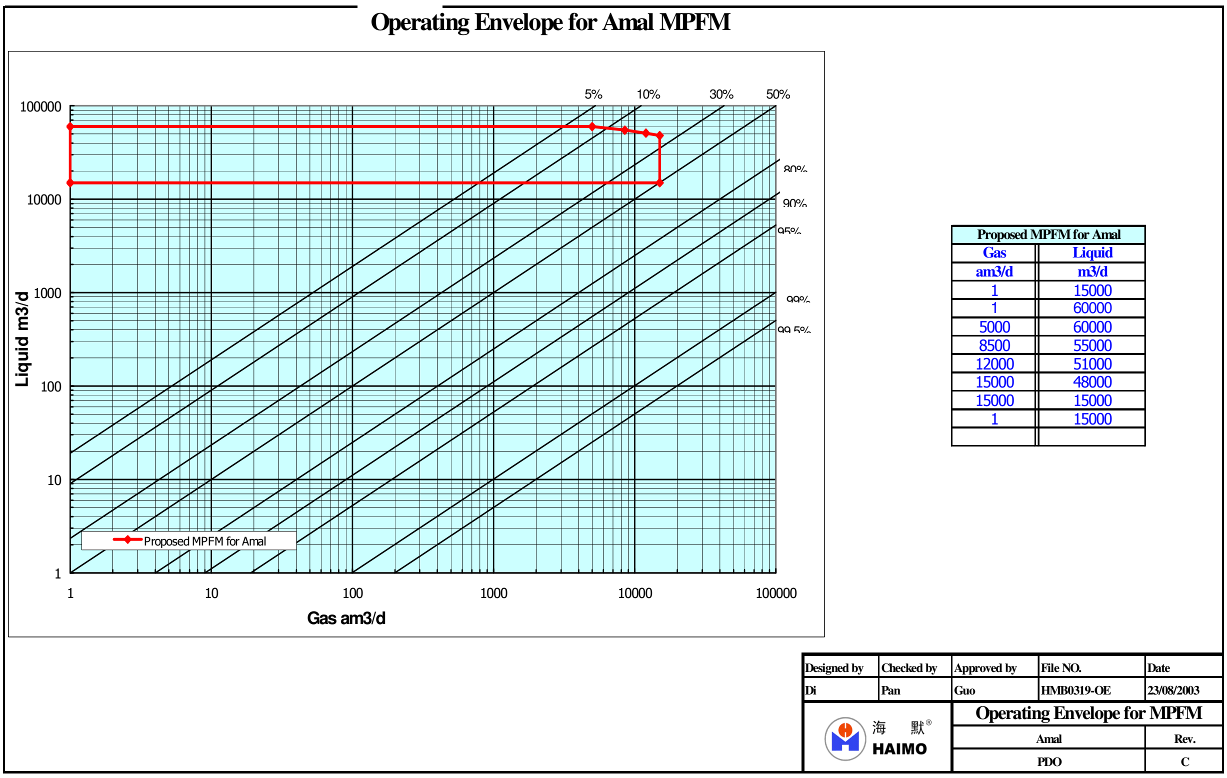



Fig. 2: P&ID of Bulk MFM skid




| Proposed MPFM for Amal | |
|---|---|
| Gas am3/d | Liquid m3/d |
| 1 | 15000 |
| 1 | 60000 |
| 5000 | 60000 |
| 8500 | 55000 |
| 12000 | 51000 |
| 15000 | 48000 |
| 15000 | 15000 |
| 1 | 15000 |

Fig. 3: Operating Envelope of Bulk MFM

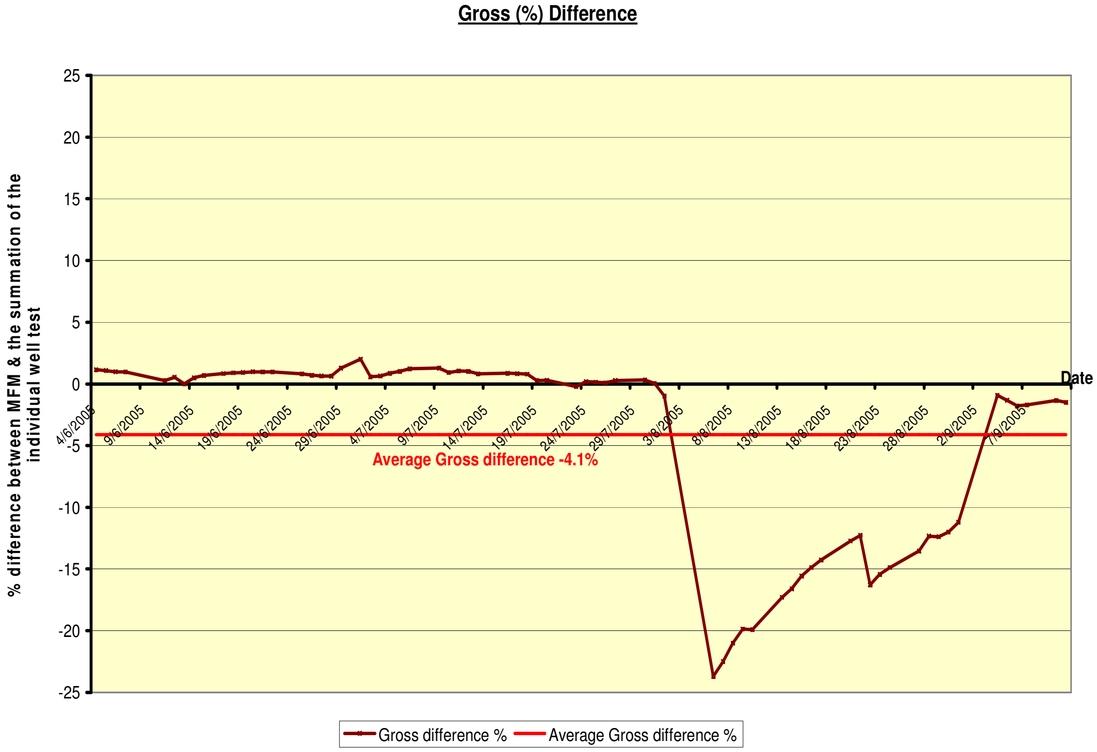



Fig. 4: Gross (%) Difference

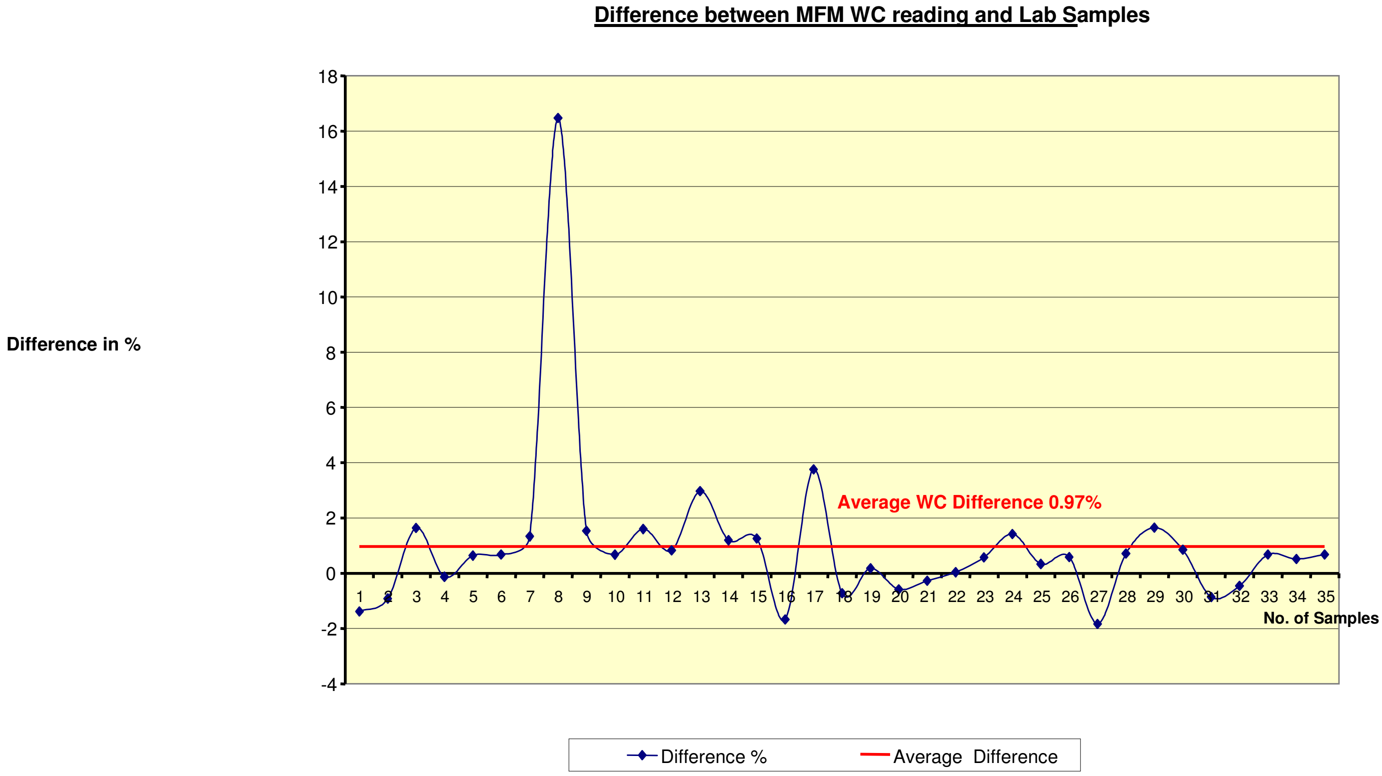



Fig. 5: Water cut (%) Difference

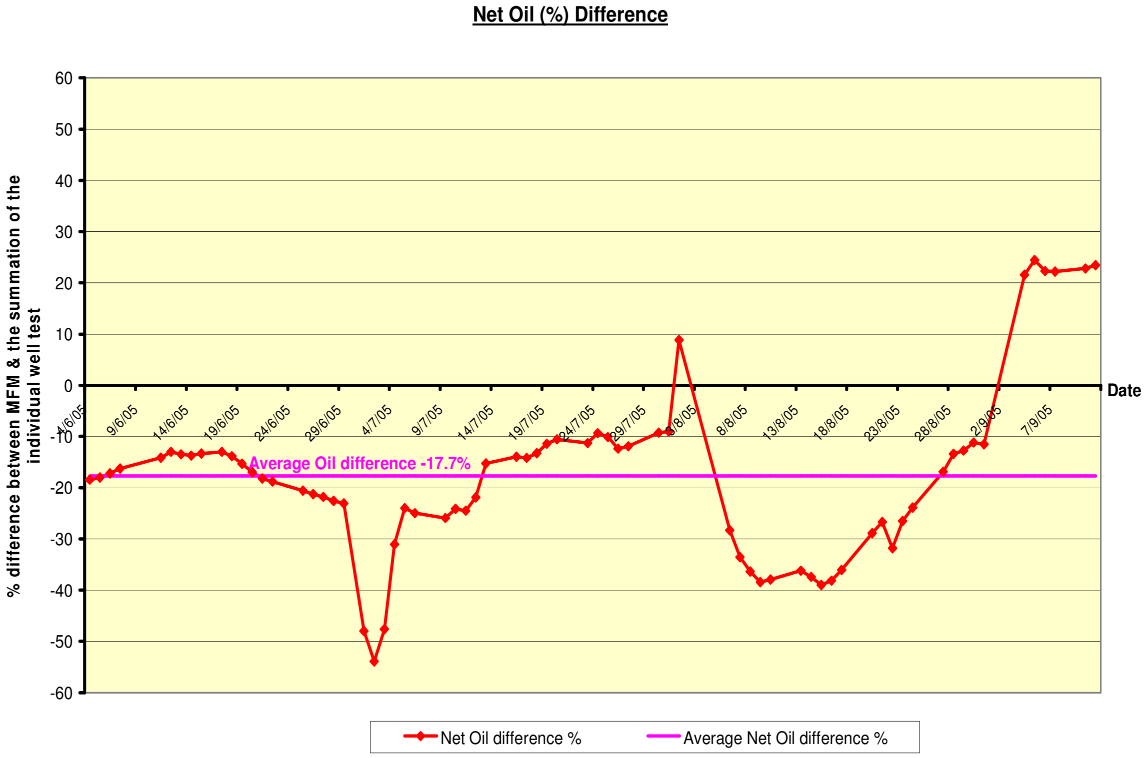



**Fig. 6: Net Oil (%) Difference**

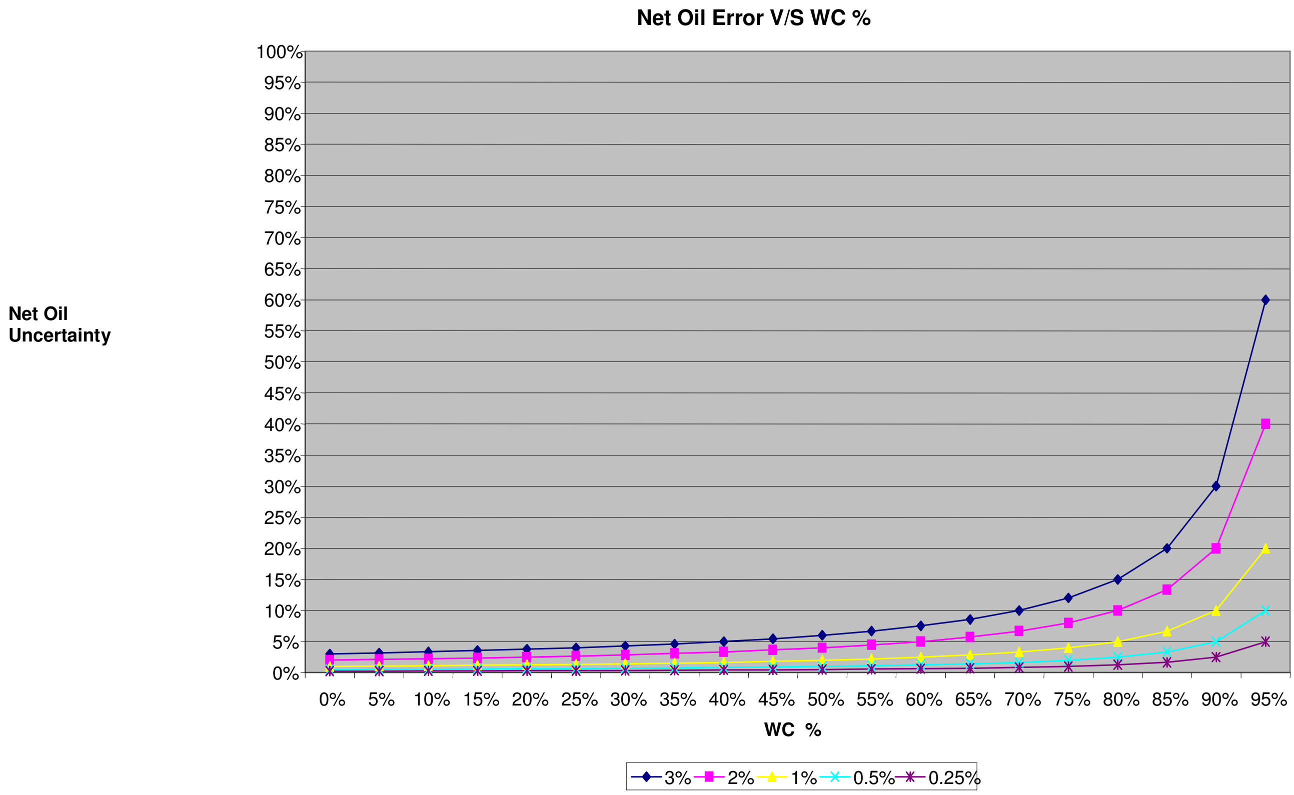



**Fig. 7: Net Oil Uncertainty graph v/s Water Cut**

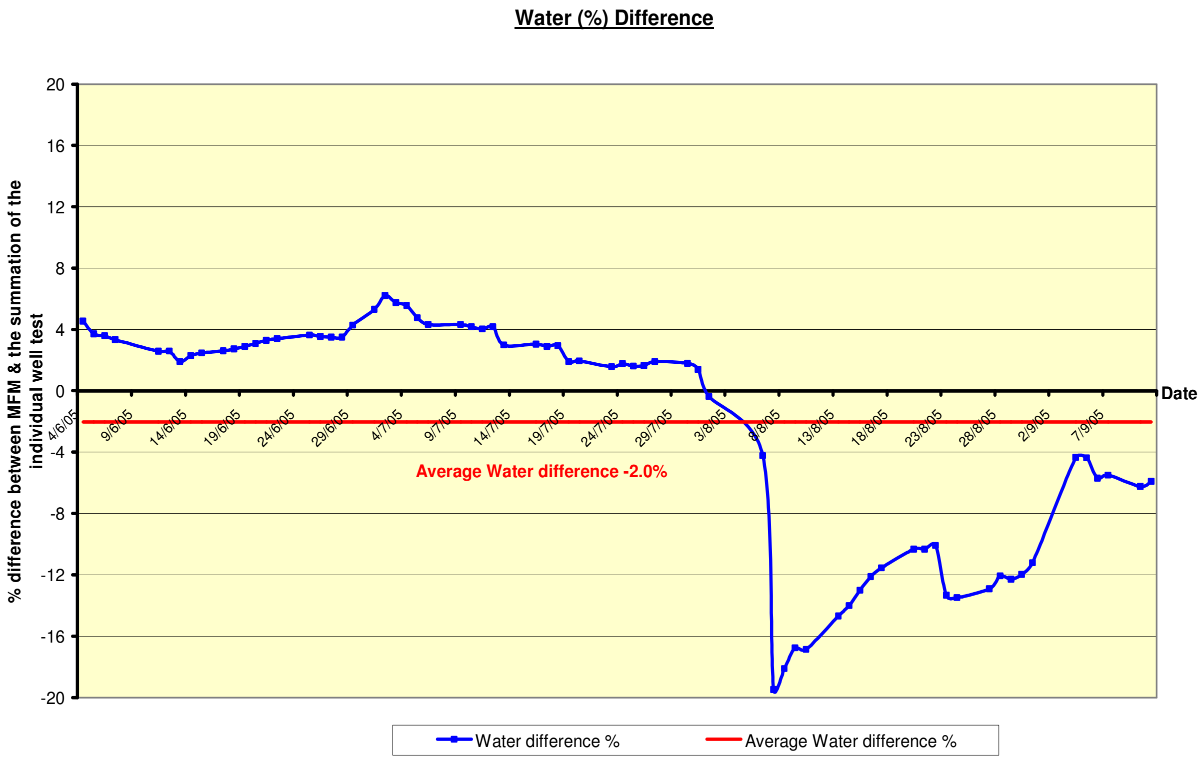



**Fig. 8 Water (%) Difference**

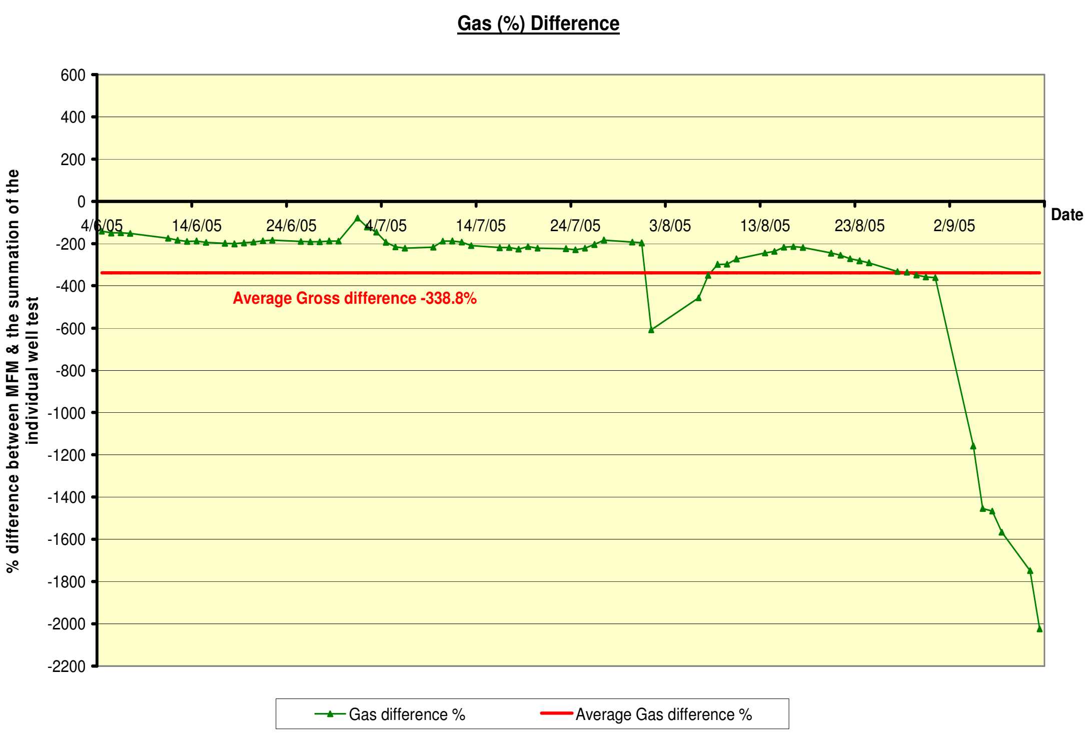



**Fig. 9: Gas (%) Difference**


**Fig. 10: Bulk MFM at Amal field**