NORTH SEA FIELD TEST OF A MULTIPHASE FLOWMETER

Andreas Hatlo, Flow Technology, Kongsberg Offshore a.s. (KOS)
Sven Sørensen, Production Programming, Mærsk Olie & Gas a.s. (MOG)

1. SUMMARY

The KOS MCF 350 Multiphase Flow meter has been tested in the Danish part of the North Sea at the Dan F platform in co-operation with Mærsk Oil & Gas. Test results are showing some promising results for further use of the KOS MCF 350 Multiphase meter for offshore application. However, some performance limitations with regards to flow regimes and watercuts were seen as expected.
A prediction of the actual multiphase flow regimes on the test site is important to avoid installation of the multiphase meter in applications outside the operational range of the meter. In addition, identification of the flow regime for the well stream on test is of major importance. Both requirements was met for the KOS MCF 350 meter for the Dan F test.
The test separator used for reference measurement was equipped with conventional metering equipment. The accuracy of the reference measurement was not verified, but the expected accuracy is given. The influence of the reference measurement accuracy on the deviation between the KOS MCF 350 measurement and the test separator is discussed.

2. INTRODUCTION

Development of the MCF Multiphase Flow meter
Kongsberg Offshore a.s (KOS) has in co-operation with Shell Research (KSEPL) and A/S Norske Shell developed the KOS MCF 350 Multiphase Flow meter. The development of the MCF Multiphase Flow meter technology started in 1991 and the first commercial KOS MCF 350 meter was available in 1993 after extensive laboratory and field testing.
Further development of the MCF technology is ongoing (October 1994), and a new version of the MCF Multiphase Flow meter, the KOS MCF 351, will be commercially available early 1995.
The aim for the development of the MCF technology is to establish a MCF meter in the market which will meet the requirements from the users regarding range of flow rates, flow regimes and different watercuts. (For more detailed information see ref. /1/).

The field test at Dan F was initiated by MOG and KOS in co-operation to verify the performance of the KOS MCF 350 Multiphase Flow meter in an offshore environment. The aim of the test was for MOG to evaluate the operability of the MCF 350 Multiphase Flow meter and to evaluate the possibilities of using this type of meter for testing of wells on satellite platforms. Hence the operational range of the meter is limited to the slug flow regime some effort was put into determining the flow regime for each single well prior to the test.

The test was initially planned for a period of three months. During this period more wells producing within the operational range of the MCF 350 meter were identified. It was therefore decided to extend the test period for another three months.
Detailed investigations regarding the use of MCF 350 on another satellite platform is ongoing.

Previous onshore field tests

Test site	Country	Company	Test period
Marmul	Oman	PDO	Sept. - Oct. 1992
Marmule / Ramlat Rawl	Oman	PDO	Feb. - Mar. 1993
Rabi	Gabon	Shell Gabon	Mar. - April 1993
Ramlat Rawl	Oman	PDO	March 1993 - (ongoing)
Lekhwair	Oman	PDO	Dec. 1993 - (ongoing)

Table 1 Overview of previous onshore field tests, KOS MCF 350 Multiphase Flow meter.

For further details see ref. /2/ which describes test results and findings for tests performed in Gabon and Oman.

The meter has been tested in well flows with high wax content and sand production and for a wide range of well flow behaviour, fluid properties and environmental conditions
These different process conditions, within the operational range of the KOS MCF 350 meter, has not been a limitation for the performance of the MCF meter or the quality of the measurements. For extreme wax production KOS can recommend steam cleaning of pipe unit, injection of wax inhibitor or pre-heating of the multiphase flow to avoid wax deposition.
The MCF has consequently proven to be a reliable equipment for onshore field conditions performing within the specification for the meter.

3. PREDICTION AND IDENTIFICATION OF FLOW REGIMES

The need of flow regime prediction and identification.
The actual flow regimes of the well stream routed through the multiphase meter must be predicted prior to the installation of the meter. This must be done to avoid installations of multiphase meters for production rates outside the operational range of the meter. The time used at the actual field application can then be more effectively used testing wells within the operational range of the meter.

The operational range of the KOS MCF 350 Multiphase Flow meter is limited to slugging flow. The prediction of the flow regime prior to the installation is therefore important. In addition the identification of the flow regime of the actual well just before test start was essential for the field test at Dan F. Through this routine wells which had changed production out of the operational range of the meter was identified and excluded from the MCF 350 test programme.

General description of multiphase flow regimes

Multiphase flow is divided into different flow regimes dependant on its physical and visual characteristics. Both for vertical and horizontal two and three phase flow the different flow regimes are defined based on the combination of liquid and gas flow rates, often given as superficial velocity. Fluid properties, such as gas and liquid viscosity, gas and liquid densities, effects from pressure gradients, pipe inclination and pipe diameters will also have influence on the boundaries between the different regimes.

General flow regime maps for horizontal and vertical flow, Figure 1 and Figure 2, indicate the differences between the flow patterns for the two different situations.

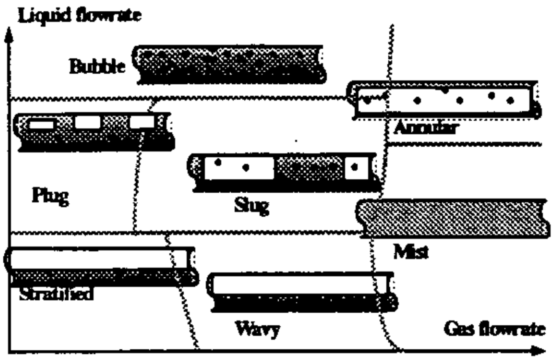


Figure 1 Flow regime map horizontal flow.

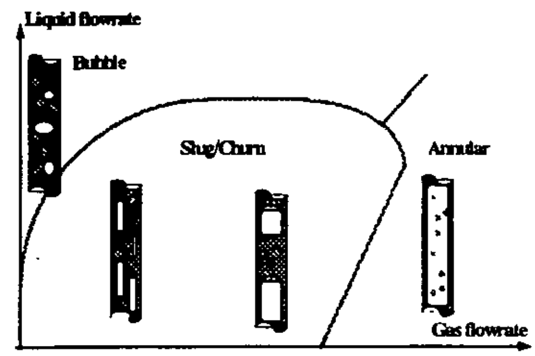


Figure 2 Flow regime map vertical flow.

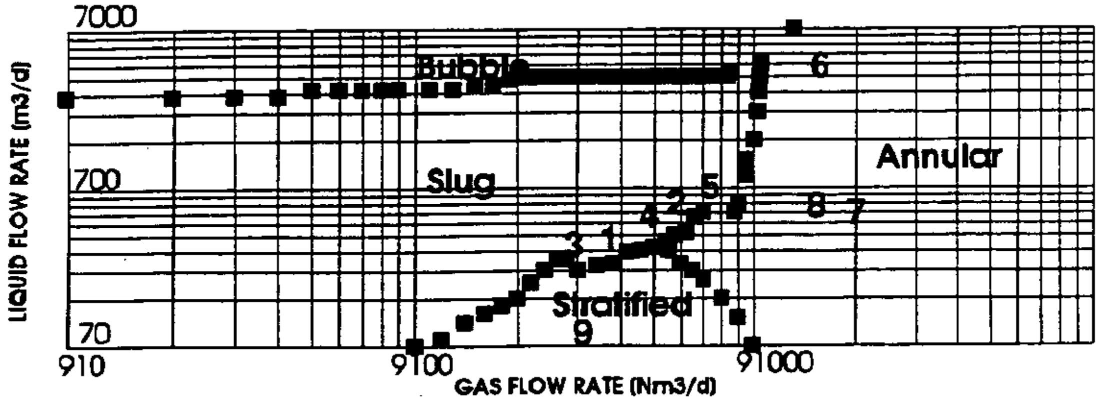
The measuring principle of the MCF 350 Multiphase Flow meter requires a slugging flow and the meter must be installed in a horizontal section. The MCF 350 meter is only depended on slug flow as such, and does <u>not</u> set any requirements to the slugs through the meter.
This paper will therefore discuss only the horizontal flow regimes with special attention on the horizontal slug flow regime.

Regime prediction and identification at Dan F

Prior to the installation of the MCF 350 Multiphase flow meter at Dan F a detailed investigation of the actual volume flow was done based on the well test data available. Through this exercise a number of wells were found to be within the operational range of the MCF 350 meter. Some wells, with either high gas production or low oil production or a combination of both, were predicted to produce outside the operational range of the MCF 350 meter.

To perform an evaluation of the flow regime for the different well production effects from fluid properties, pipe inclination and pipe diameter must be taken into account. For this purpose a software based flow regime prediction tool was used. This is a useful tool in order to successfully modelling of the changed regime borders caused by the actual fluid properties, flow conditions, etc.

The predicted flow regime map with the different well production rates based on available welltest information from Dan F is shown in Figure 3.



Identification of well predictions			
Slug flow regime		Other flow regimes	
1	Well 1	6	Well 6
2	Well 2	7	Well 7
3	Well 3	8	Well 8
4	Well 4	9	Well 9
5	Well 5		

Figure 3. Flow regime map for Dan F wells

Through the ongoing development project of the MCF multiphase metering technology with Norske Shell and Shell Research (KSEPL) the flow regime prediction was performed by Shell Research on their Shell developed Regime Prediction Tool.
Similar flow regime prediction was done on a software tool being developed at Kongsberg Offshore a.s. The KOS Flow Regime Prediction Tool is based on correlation and theoretical models from open literature. The two prediction tools gave matching results.

4. PROCESS CONDITIONS AT Dan F

Due to a number of reasons the wells on Dan F are tested on different choke settings. Consequently the production rates from the wells also changed.
Initial predictions of flow regimes indicated for some wells production in the boarder area of the operational range of the MCF. These wells were therefore closely monitored and the flow regime was identified to be either within or outside the operational range.

The fluid characteristics for the Dan field:

- Density of the oil: 850 to 885 kg/m3 at 15degC
- Density of the gas: (natural gas)
- Viscosity of the oil: 8 cP at 30°C (down to 2 cP can occur)
- Viscosity of the gas: (natural gas)
- Density of production water: 1020 - 1030 m3/kg at about 30°C
- Salinity: from 2% to 3%
- Pressure: about 13 bar (test separator pressure)
- Temperature: 15 to 60 degC

Surging well.
For the Dan F wells with heavy surging the production rates varied from production within the operational range to production outside the operational range of the MCF. This effected the total accuracy of the specific well measurement as further discussed in chapter 6.

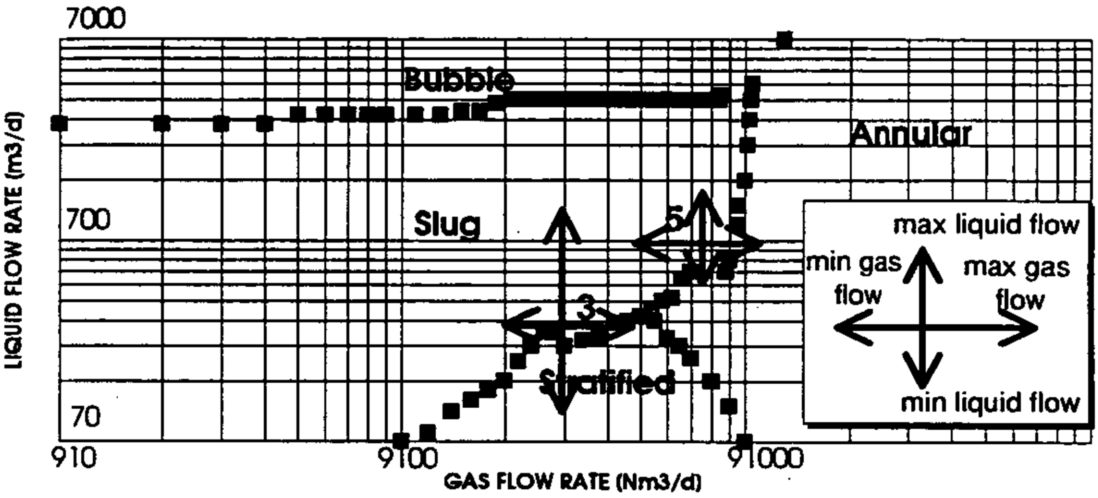


Figure 4 Example of flow variation in surging well production.

Sand production.
All wells at Dan F produced larger or smaller amounts of sand. The sand production gave erosion on the intrusive sensor plates of the KOS MCF 350 meter. During the six month period a wear of 0.5 to 1.0 millimetres was found on the upstream edge of the on the PCB sensor plate. Such erosion does not effect the quality of the measurements as the sensor is designed with upstream edges to withstand moderate sand production for upto three years.

Due to a production failure in the moulding process of the sensor used at the Dan F field the core of the sensor elements was directly exposed to process flow. The smaller sand erosion of the upstream edge led to an opening between the outer and inner PCB layers on the sensor element. This unexpected malfunction was indicated by a shift in the measurements and the sensor was replaced immediately.

A development programme for alternative sensor materials is now being finalised at Kongsberg Offshore a.s. The new sensor is designed to withstand sand erosion as well as high pressure and temperature.

Wax deposition.

Some of the wells gave wax deposition due to low temperature at the MCF 350 installation point upstream the test separator (for mechanical installation see chapter 5, Figure 5). The sensor elements were therefore manually cleaned regularly. An increasing wax layer on the sensor plate gave a shift in the calibration value. However, such wax deposition is easily detected by inspection of capacitance signal from the sensor, and did therefore not influence the quality of the well tests performed.

As an alternative to the manual cleaning procedure of the sensor plates used for the DanF test capacitance signals for a gas filled pipe can be inspected through the MCF 350 system. Any consistent shift in the measured values compared to corresponding gas calibration values will indicate a wax deposition on the sensor plates.

(More detailed description of different methods to avoid wax deposition or remove such wax layer on the sensor plates are shown in ref. /2/).

5. Dan F TEST INSTALLATION

The MCF was installed at the test separator deck on the Dan F platform.
An overview of the test installation is shown in Figure 5.

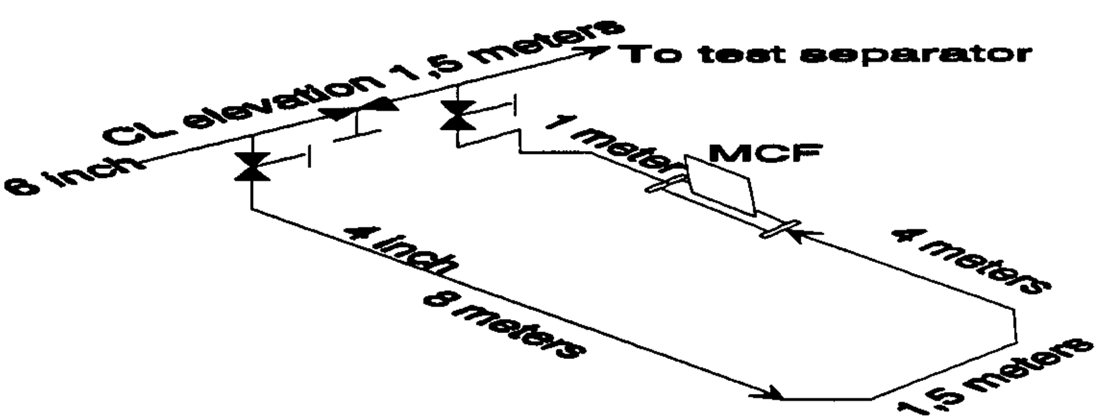


Figure 5. Mechanical layout of test installation.

The MCF system tested at Dan F consisted of:

- KOS MCF 350 Field Unit, 4 inch
- KOS MCF 350 Signal Conditioning Unit
- KOS MCF 350 Control System

The KOS MCF 350 Field Unit was installed upstream of the test separator in a purpose made bypass loop. The well flow from the test header was then either routed through the KOS MCF 350 meter and to the test separator or directly into the test separator.

The KOS MCF 350 Field Unit was connected to the KOS MCF 350 Signal Conditioning Unit in the Central Control Room through a purpose made cable. The cable length from Signal Conditioning Unit to Field Unit was 100 meters.

Test separator instrumentation.

The test separator instrumentation was as listed below.

- The oil metering system for the test separator consisted of:
  1 off 1 inch turbine meter, Hydril.
  1 off 2 inch turbine meter, Hydril.
  1 off 3 inch turbine meter, Hydril.

- The gas metering system for the test separator consisted of:
  Standard Daniel Junior Orifice fitting with manual replacement of orifice plate.

- The water metering system for the test separator consisted of:
  1 off 1 inch Electromagnetic flow meter, Krone.
  1 off 3 inch Electromagnetic flow meter, Krone.

The size of the used reference meters on the gas, oil and water leg was chosen and optimised dependent on the actual flow. Only one meter was used for oil and one for water at the time.

All instrumentation on the test separator has for this test period (December 1993 to May 1994) been subject to ordinary maintenance such as re-calibration of pressure transmitters and replacing of turbine meters. Action was taken to increase level stability of the test separator. The level indicators were opened to drain to give a very low circulation of crude to prevent wax, sand and others to block the level transmitters.

Repeatability tests on the reference measurements using wells with stable production was performed. From these tests it was concluded that the repeatability of the reference measurement was varying through the whole test period.

Accuracy figures for the reference measurements could not be directly derived from these tests. However, results from these tests and judgement done by metering specialists in Mærsk Oil & Gas the accuracy of the reference measurement was expected to be:

± 5 - 7 % for oil volume flow rate
± 10 - 15 % for gas volume flow rate
± 8 - 10 % absolute for Watercut

6. TEST RESULTS

Test results for well production within the operational range of the meter are shown in Figure 6 a) and 6 b) with the corresponding reference measurements at the test separator.
A number of measurements from 5 different wells are presented from test period, November 1993 to May 1994.
There were 38 wells available at Dan F for this test period. An overview of the number of wells tested and welltests performed is given in table 2.

	Test separator	KOS MCF 350
no. of wells tested	30	5
tot. no. of welltests performed	124	22

Table 2 Overview of Dan F wells tested and welltests performed from Nov. '93 to May. '94.

This discussion will highlight the performance of the KOS MCF 350 Multiphase Flow meter based on wells tested in the test period.
The accuracy specification for the **KOS MCF 350**:

± 10 % for liquid volume flow rate
± 10 % for gas volume flow rate
± 3 % absolute for Watercut

To evaluate the quality of the MCF readings its important to take in to consideration the expected accuracy of the reference measurements as given in chapter 5 above.

In Figure 6 a) and 6 b) the readings for the five different wells are shown as the test separator measurement on the abscissa axe and the corresponding MCF measurement on the ordinate axe.
The specified accuracy of the MCF 350 multiphase flow meter of ± 10 % of the flowrate for liquid (oil and water) and gas is shown graphically. In addition the different wells with surging production are marked. The behaviour of these wells are described further in chapter 4.

A full verification of the specified accuracy of the KOS MCF 350 meter was not possible. Such verification can only be done based on special designed reference measurement system with the required stability and repeatability.

The acceptance of the actual deviations between the MCF 350 measurement and the test separator must therefore be based on the specified accuracy of the MCF 350 combined with the expected accuracy of the test separator as independent measurements.
Deviation larger than the specified ± 10 % on the liquid and gas flow has therefore been closely examined and accepted.

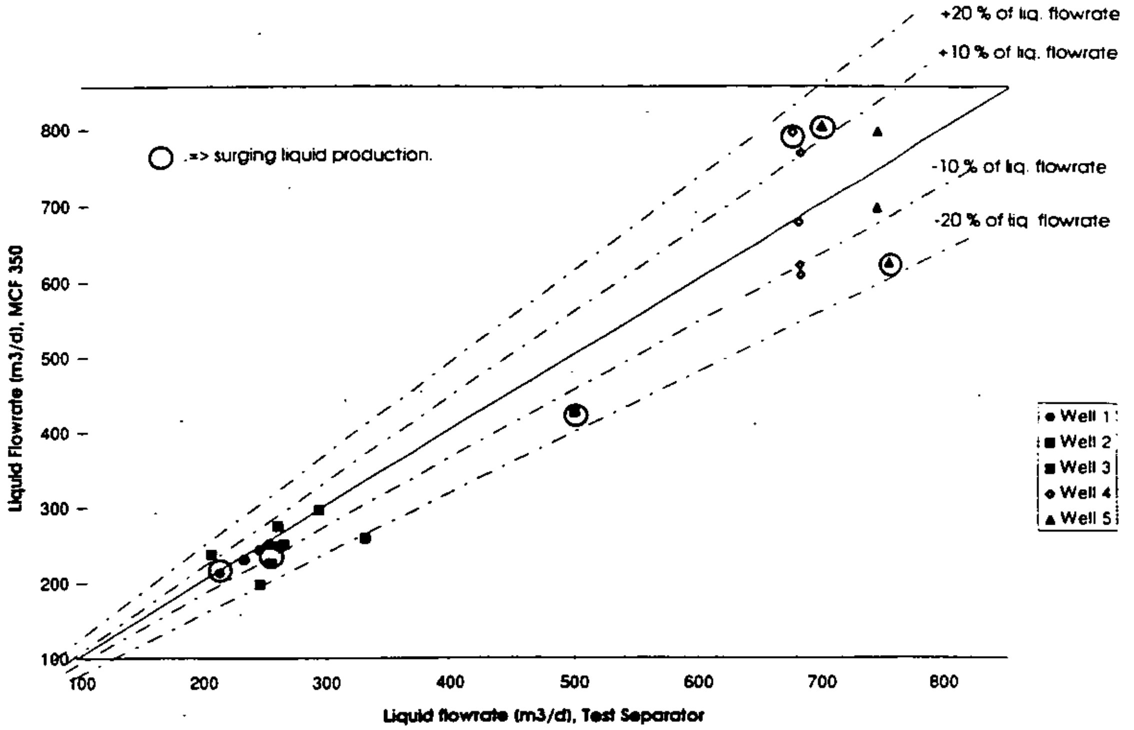


Figure 6 a) Test results for liquid flowrate.

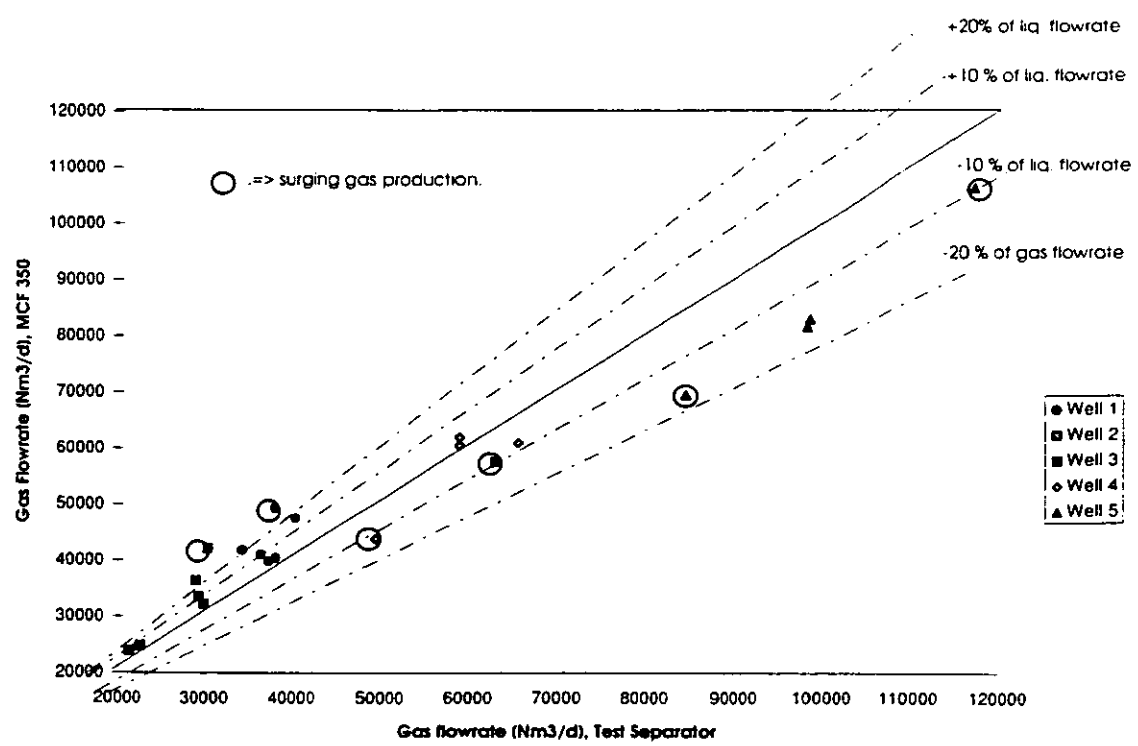


Figure 6 b) Test results for gas flowrate

The larger deviations shown in Figure 6 a) and 6 b) are mainly caused by surging well behaviour. Surging well production gave larger deviations as the well partly produced in flow regimes outside the operational range specified for the MCF.
The other test results are acceptable based on combination of the specified accuracy of the MCF 350 and the expected accuracy of the reference measurements.
As shown, repeated measurements on identical production has for the majority of the wells was not possible due to a number of reasons.

The Dan F wells tested produced from 10 % to 40 % water in the total liquid. The MCF 350 meter measured in average a lower watercut with a 10% absolute deviation relative to the test separator. The systematic underreading was small for the lowest watercuts and increasing with increasing water content in the produced total liquid (watercut).
The recorded systematic underreading is thought to be an effect of both overreading on water flows at the separator and a systematic underreading by the MCF 350. The underreading by the MCF 350 has been examined closely and found to be minor and caused by high gas volume fraction. This is a subject for optimisation for later tests in similar flow conditions with high gas volume fraction (GVF). A possible solution for this phenomena has been found.

Generally a stable deviation was found for the MCF and the test separator for the different wells at a stable production level. Changed production rates gave a shift in the deviation reflecting the accuracy for the different flow rates both for the MCF and the reference measurements.

7. Acknowledgement

This paper has only been possible to realise through a close and open co-operation between the Production Programming group in Mærsk Oil and Gas and Kongsberg Offshore a.s. Further we will like to acknowledge the staff at the Dan F installation for all practical help and for the flexibility shown during the active test periods at their installation.
We would also like to acknowledge the assistance and advises given by David Brown at Shell Research KSEPL prior to the performance of the tests.

8. References:

/1/ D. Brown, J.J.den Boer and G. Washington: "A multi-capacitor multiphase flow meter for slugging flow", The North Sea Flow Measurement Workshop, October 1992.

/2/ D. Brown: "Field experience with the multi-capacitor multiphase flow meter", The North Sea Flow Measurement Workshop, October 1993

/3/ C.J.M. Wolff: " The required operating envelope of multiphase flowmeters for oil production measurement", The North Sea Flow Measurement Workshop, October 1993.