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North Sea
FLOW
Measurement Workshop
1995

Paper 15:

THE KOS MCF 351 MULTIPHASE METER FIELD EXPERIENCE AND TEST RESULTS

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Norwegian Society of Chartered Engineers
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THE KOS MCF 351 MULTIPHASE FLOW METER - FIELD EXPERIENCE AND TEST RESULTS.

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SUMMARY

The KOS MCF 351 multiphase flow meter has been tested at four different locations for applications onshore and offshore. The variety of flow conditions have covered the operational range of the KOS MCF 351 meter. The meter have also been tested with flowrates outside the operational range.
Good results for liquid and gas flow rates and watercuts have been obtained over a large range of liquid and gas flowrates. Testpoints outside the operational range have demonstrated the KOS MCF 351 meter's capability and potentials for extending it's operational range. Generaly good repeatability is demonstrated for comparable flowrates.

Reliable installation in explosive (Ex) zone on an unmanned offshore rig with the MCF charged by solar power has been demonstrated. In addition operation in extreame ambient conditions with high temperature, high humidity and tropic storms have been problem free.
All results from the different tests are shown and disused on general basis. Variations in test results for comparable flow rates and diverging test results are discussed in detail.
All tests have demonstrated the flexibility, easy installation and reliability of the KOS MCF 351 multiphase flow meter. The KOS MCF 351 meter is a commercial available product launched in the market on a broad basis for all types of applications.

INTRODUCTION

Kongsberg Offshore a.s (KOS) has in co-operation with Shell Research (KSEPL) and A/S Norske Shell developed the KOS MCF 351 Multiphase Flow meter, ref. /1/. The development of the MCF Multiphase Flow meter technology started in 1991 and the first commercial KOS MCF 350 meter for oil external (oil continuos) flow was available in 1993 after extensive laboratory and field testing, ref. /2/.

The KOS MCF 351 multiphase flow meter is now a commercial product. This meter is designed for the full range of watercuts from 0 to 100% in the slug flow regime.
Further development of the MCF technology is ongoing and the target performance for the next generation MCF meter is an operational envelope covering bubble, plug and annular flow upto a given maximum GVF limit in addition to slug flow. The stratified and wavy regime will be measured by use of a slug generator, ref. /3/.

All four tests reported in this paper were executed in 1995 on the KOS MCF 351 meter. Three of the tests were real life field applications. Whereas the last was in a controlled environment at a laboratory using fluids from a oil field close to the facility.
The KOS MCF 351 meter has in addition been tested by Statoil, Saga Petroleum a.s. and Norsk Hydro a.s. (SSH consortium) in Hydro's multiphase flow laboratory in Porsgrunn, Norway. No testpoints on the KOS MCF 351 meter are reported from the test due to process conditions outside the operational range of the KOS MCF 351 meter.

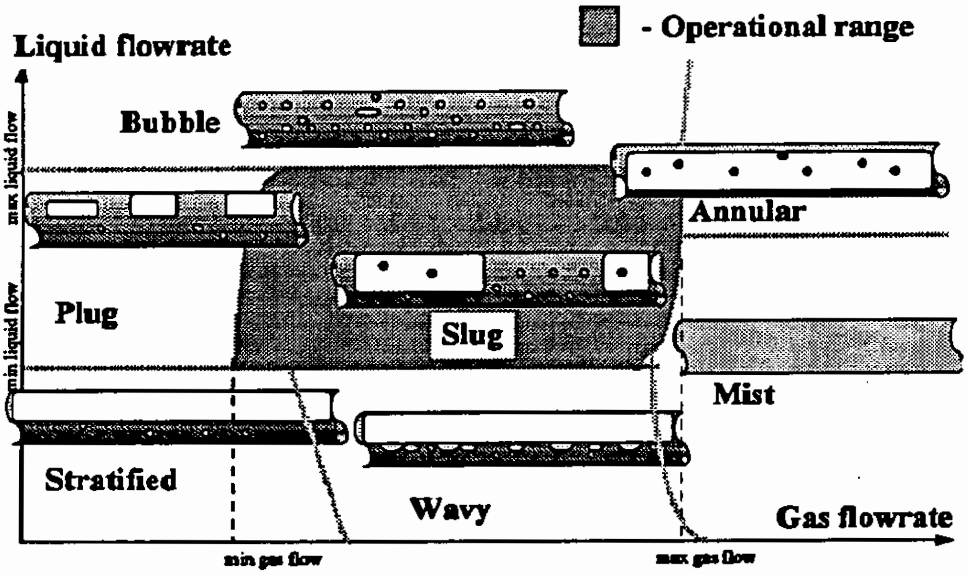

Figure 1 Operational range of the KOS MCF 351 multiphase flow meter

	3 inch meter		4 inch meter	
	Liquid m^3/h	Gas m^3/h	Liquid m^3/h	Gas m^3/h
Min flow	5	25	9	44
Full scale	50	215	88	380

Table 1 Minimum and Full scale flow specified for the KOS MCF 351 Mutliphase flow meter.

TEST LOCATIONS

The KOS MCF 351 Multiphase Flow Meter has been extensively tested at several locations under a variety of different process conditions, installation set-ups, onshore, offshore, at manifold, in flowline etc.
Specialities for the different installations will be described later.

Test site	Country	Company	Test period	Application
Rabi	Gabon	Shell Gabon	January-February	Onshore test
Tembungo B	Malaysia	Petronas Carigali	April-May & Aug.-Oct.	Offshore install.
Humble	USA	Texaco	April	Laboratory test
Luna Modular	Mexico	Pemex	July & August	Onshore test

Table 2 KOS MCF 351 Multiphase Flow meter installations 1995.

The installations at the different locations are according to requirements for the KOS MCF 351 meter; slugging flow and four meter upstream pipe with inner diameter corresponding to the size of the meter.

The different installations are motivated by a genuine need for multiphase flow measurements in the field. The installations include remote sites with solar powering where other alternative methods for well testing is either economically or technically unfavourable. The compact design, non-nuclear safe operation with low power consumption and flexible communication options makes the KOS MCF technology a favourable choice for these installations.
Although the world main market for multiphase metering is onshore, a number of offshore applications have an absolute need for this cost economical alternative for flow measurement. The technology base and the compact design of the KOS MCF 351 are favourable for the meter. Easy and safe installation combined with the flexibility offered on communication interface to the meter are big advantages for a multiphase meter for field use both onshore and offshore.

TEST SET-UP AND RESULTS

All different installations are presented separately. Individual experience from the different tests is presented. The results for all tests are listed in addition to Figure 3, 4, 5, 6 and 7, where the KOS MCF 351 liquid and gas flow measured are plotted against reference measurements.

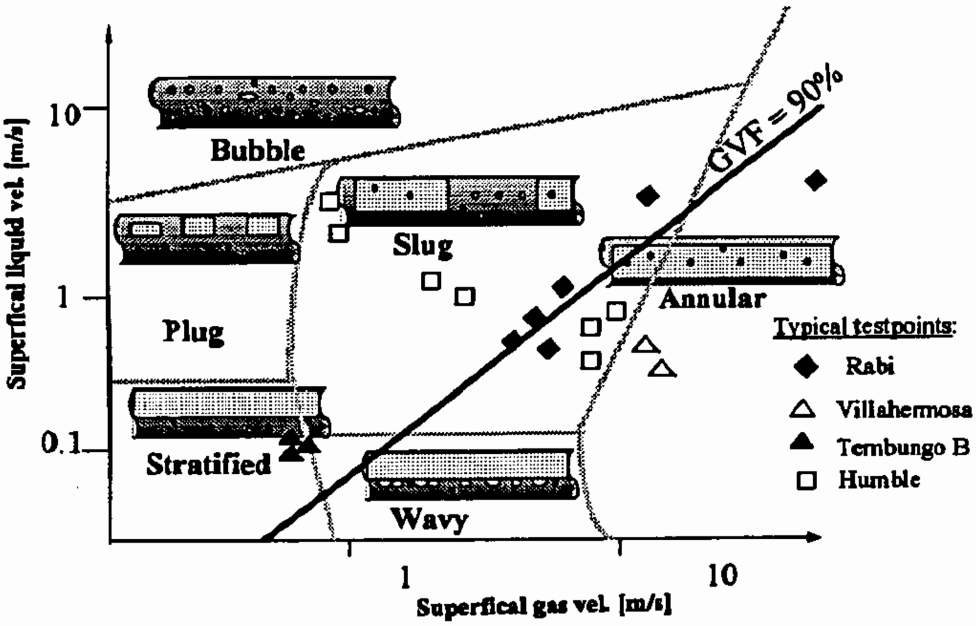

Figure 2 Typical flow conditions for different installations.

Average deviations and standard deviations for the different tests are calculated as percentage deviations related to full scale specified for the meter size (3 or 4 inch, see Table 1). This to better compare these numbers to the specified maximum and minimum deviation shown on Figure 3, 4, 5 and 6. Watercuts are given as absolute deviations both in the listing below and in Figure 7.
Note that all deviations and results presented include both errors in the KOS MCF 351 and in the reference measurements. For type of meter and excepted accuracy of the reference measurement see Table 7.

Rabi

This was the first field test of the KOS MCF 351 meter. A test at the same location of the KOS MCF 350 in 1993 is described in ref. /2/.
A 4 inch KOS MCF 351 meter was tested from week 3 to 7 1995 on 16 different wellflows with a total of 29 tests reported. This includes tests both in the loop on test manifold and in the flowline. One well was producing in water external emulsion (water continuos, ~76 % watercut). Test pressure was 5 bar(g).
In addition to the reference measurement (see Table 7) a liquid test tank was used to interpret the oil volume flowrate and percentage of water in the liquid.

The flowlines for the different wells tested are from 200 meters up to 2500 meters from wellhead to manifold. The terrain effect from the pipeline path had, for a majority of the well flows, an impact on the natural slugging flow. Longer more liquid filled slugs were formed.

For most well tests the multiphase flow was routed through an upstream test heater. Neither the heater nor the heat (increased liquid and gas temperature) had any effect on the flow and consequently no impact on the measurement. This leads to the conclusion that slugging flow is very robust to any upstream disturbances.
With the MCF meter installed in the flowline good results were obtained on gross liquid flow agreeing with tests in the manifold loop. (Note, only one well tested with KOS MCF 351 in productionline. One of the 29 test reported). The well tested with the MCF in the flowline produced with liquid slugs upto 200 meters length! The ten meters upstream 4 inch pipeline was therefore not enough to stabilise the slug velocity. An acceleration of the slugs were observed giving an underreading of gas velocity and concequently an underreading the gas volume flow of 10%.
The functionality of the electronics exposed to high ambient and fluid temperature in addition to repeating rainstorms was not effected.
Wax coating of the MCF was expected to be a problem. Even after flowing through different combinations of wellflows with high wax content for over 48 hours no wax coating was observed on the MCF sensorplates. For further discussion on wax coating see ref. /2/.

Results:
All results are show in Figure 3, 5 and 7, and they will be discussed later.
Average deviations between KOS MCF 351 and reference measurement are shown below. The spread in the results are given as standard deviations.

	Average deviation	STD
Liquid volume flow	-0,6 %	7 %
Gas volume flow	-0,7 %	10 %
Watercut	-1 %	12 %

Table 3 Test results at Rabi.

<u>Luna Modular</u>
One KOS MCF 351 is installed at the onshore Luna field (Luna Modular) in Tabasco, Mexico. The meter is installed in a flow loop giving access to 12 wells connected to a test manifold and separator, stock tank and orifice run. The flow line length are typical from 600 to 1400 meters, and diameters mainly 6 inch and 8 inch.

The flow regime occurring in this installation is annular due to high pressure (80 barg) giving higher actual gas density. The meter was reconfigured for annular flow by performing velocity measurements in the liquid film on the pipewall and in the gas core in the middle of the pipe.

Results:
Given the annular flow regime for which the meter originally was not designed for, it was still able to measure close to the rated accuracy for a number of the wells.

	Average deviation	STD
Liquid volume flow	-0,8 %	7,6 %
Gas volume flow	-3 % (*)	5 % (*)
Watercut	2,4%	7,8%

(*) Deviation for the one well test far outside the operational range is not used for this calculations.

Table 4 Test results at Luna Modular.

Tembungo B
The Tembungo B is an offshore production rig. Special requirement to the equipment was therefore evident. The KOS MCF 351 needed to be solar-powered. The solar-power cells with battery pack and all necessary equipment has been installed in Ex zone and was supplied by KOS.
The MCF has been installed in a purpose made pipesection on a manifold arrangement. All wells on the platform were connected to this manifold.
Reference measurements on liquid was done about 3500 meters downstream, on another offshore rig, Tembungo A (on the production from Tembungo B as a total). The test separator at Tembungo A was equipped as listed in Table 7.
All testing was done sequential by deferment. The reference testing on the well tested through the KOS MCF 351 meter was done directly after the KOS MCF test. This was done by closing in that specific well and measure the reduced total production. The accuracy on the gas outlet on the testseparator was not such that the relative small reduction in total gas flow could be detected with an acceptable accuracy. No gas reference measurements are therefore reported from the tests at Tembungo B.

The gross liquid production from the different wells are relatively low, from 14 m^3/d to 140 m^3/d. For the Tembungo B process conditions the wells with no exceptions were producing in stratified flow.
Motivated by this, a slug generator (ref. /3/) was installed directly upstream the KOS MCF 351 meter. This gave slug flow for all wells with exception of two extreme low producers. These wells are now closed in.
Four different wells were tested with liquid reference measurement only. A total of 32 well tests are reported.

Results:
All results are show in Figure 4, 6 and 7.
Average deviations between KOS MCF 351 and reference measurement are shown below. The spread in the results are given as standard deviations.

	Average deviation	STD
Liquid volume flow	-0,7 %	1,5%
Gas volume flow	- (*)	- (*)
Watercut	0 % (**)	0 % (**)

(*) No gas reference measurements reported.
(**) All wells had 0% watecut.

Table 5 Test results at Tembungo B.

In addition to the result shown in Table 5 comparison were done on total flow:

- Liquid flow average underreading of ; 10.3%.
- Gas flow average overeading of ; 10,7%

This total is based on flow from 11 wells. All these wells were tested through the KOS MCF 351 meter without single point reference (deferment testing on the separator).

Humble

The Joint Industry Program (JIP) "PERFORMANCE EVALUATION OF THE NEPTUNIA AND L4H PUMPS AND MULTIPHASE METERS" was formed to establish and report performance on a number of multiphase meters including the meter manufactured by Kongsberg Offshore a.s (KOS).

The KOS MCF 351 was tested at Texaco's Humble Flow Facility for a variety of crude oil, water and methane gas flow rates. A variety of different testpoints were tested based on the KOS MCF 351 specification. Tests were conducted with nominal total volumetric flow rates of 54-183 m^3/h (8150 - 27600 bbl/d), gas fractions of 50-95%, watercuts of 0-40%, all in slug flow.

Liquid flows above and below the specified range were also tested. These testpoint are formally outside the operational range, but are integrated in the results presented below and in Figure 4, 6 and 7.

Results:

The results show, ref./4/, that the KOS MCF 351 meter generally measured the total liquid rates within the specified +/-5% of liquid full scale. The gas rates were typically low at low gas volume fractions (i.e. 50%) and within specifications at higher gas volume fractions. The specified uncertainty in the gas flow rate is also +/-5% of gas full scale. The measured watercuts were typically within range or low, the specified accuracy is +/-3% absolute. Several tests were run outside the specified operating range, and the results of these tests were about as good as those from within the operating range.

	Average deviation	STD
Liquid volume flow	+5 %	9 %
Gas volume flow	-5 %	7 %
Watercut	-3 %	3 %

Table 6 Test results at Humble.

Discussion of test results

The test results for the four different tests are in general very good over a large range of flow conditions. These tests had flow conditions and watercuts covering the operational range of the KOS MCF meter, the slug flow regime. In addition lower flow rates in stratified flow regime and higher flow rates in annular flow regime have been successfully tested with good accuracy.
All test point are shown in Figure 3 to Figure 7. For all figures the measured flowrate or watercut on the KOS MCF 351 is compared to the reference measurement. The accuracy specification for the KOS MCF 351, which is +/- 5% of full scale (full scale 3 and 4 inch meter, see Table 1) for liquid and gas and +/- 3% absolute for watercut, is shown on these figures. The testresults are splitted between 3 inch and 4 inch figures to better compare the testresults with the specification for the KOS MCF 351 meter.

The liquid testresults on Figure 3 and Figure 4 are covering liquid flow rates with a turndown of about 1:15. A majority of the testpoints are well within the specified +/- 5% of liquid full scale. The very stable and regular slug flow conditions at the **Rabi** field gave liquid readings within the specification for 28 of the 29 test points reported. The one point of maximum flow was just above the specified maximum deviation reflecting a testpoint with high liquid flow and gas flow rate.

The production at **Luna Modular** gave, as described above, annular flow conditions. The flow rates as such are not extreme compared to the other wellflows tested. These different testresults are easily comparable in Figure 3 and Figure 5 for liquid and gas respectively. The pressure at **Luna** is however about 80 bar(g) giving an increased actual gas density which is narrowing the slug flow regime. In-house simulations and experience from the **Luna** field show that slug flow will not occur above a Gas Volume Fraction (GVF) of about 78%. One testpoint from **Luna** with reference liquid flow at about 18 m^3/h, see Figure 3, and corresponding reference gas flow at about 450 m^3/h, see Figure 5, is far below the specified accuracy. This specific testpoint is for a well producing far into the annular flow regime with GVF at 96%. For this flow condition the gas core of the flow is almost without liquid droplets. The crosscorrelation of gas velocities in the gas core is therefor suffering from lack of correlations in the gas flow. The dominant velocity profile in the liquid and gas could therefor not be established.

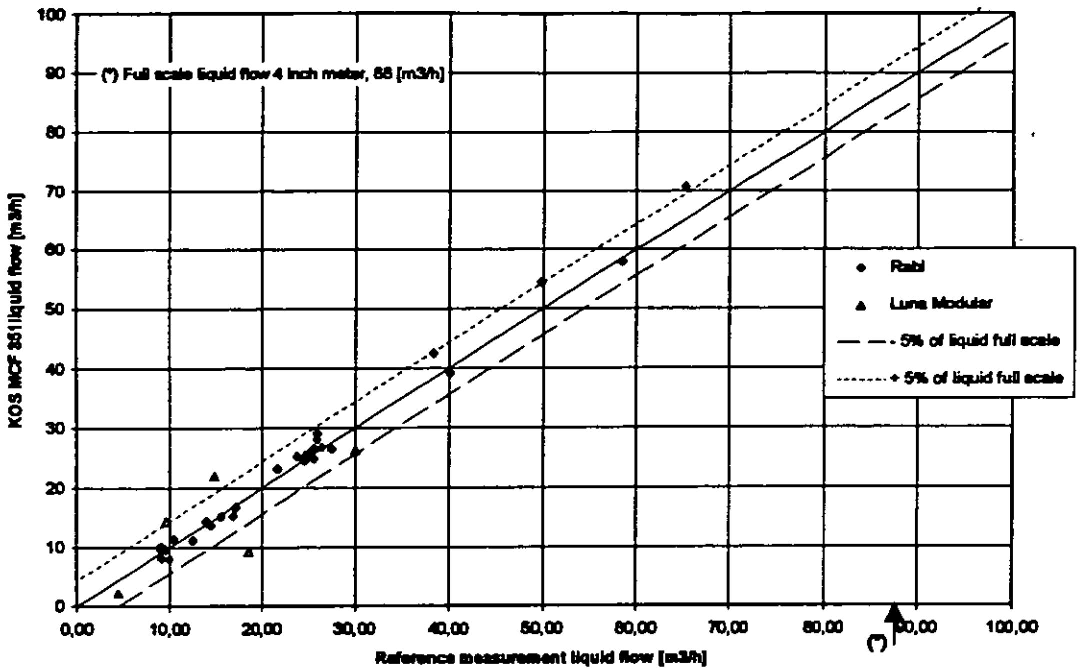

Figure 3 Test results liquid flow for 4 inch meters, Rabi and Luna Modular

For the **Tembungo B** test a slug generator was used to shift the stratified well flows into the slug flow regime. Low liquid producers down to 0,5 m^3/h , see Figure 4, was successfully tested with very good accuracy. These testpoints are comparable with corresponding testpoints for **Humble** and **Luna**. A difference is however seen in the results between **Tembungo B** and **Humble** test for low liquid production. In general the **Humble** testpoints shows an overeading for these low liquid productions. This is understood by two important factors:

1) Large gas entertainment in liquid phase
2) Testing of the KOS MCF 351 for low liquid range and below low liquid range.

Testing at **Humble** for low liquid flows are all combined with high GVF upto 95% giving large gas entertainment in the liquid phase. Measurement of this unexpected large gas entertainment was for the **Humble** test not sufficient and causing this overeading. A verification of this effect is also seen on measured watercut in Figure 8. Underreading for 10% watercut, as an example, is increasing with increasing gas entertainment, higher GVFs. As the watercut and gas entertainment measurement is interconnected in the KOS MCF 351 both the liquid flow overrreading and the watercut underreading is caused by the gas entertainment. The same effect is seen on the **Humble** data for 30% and 40% watercut.

Low liquid flows at **Humble** are below or close to minimum flow specified for the KOS MCF 351 meter. From in-house simulations and extensive field and laboratory experience such overreading is to some extent expected for the Humble flow condition and fluid properties. The **Rabi** and **Luna** testpoints for low liquid flows below 10 m^3/h demonstrate the KOS MCF 351 meter capability to measure these low flowrates with acceptable accuracy. Remember that liquid flow of 10 m^3/h in a 4 inch meter is directly comparable to 5 m^3/h liquid flow in a 3 inch meter.

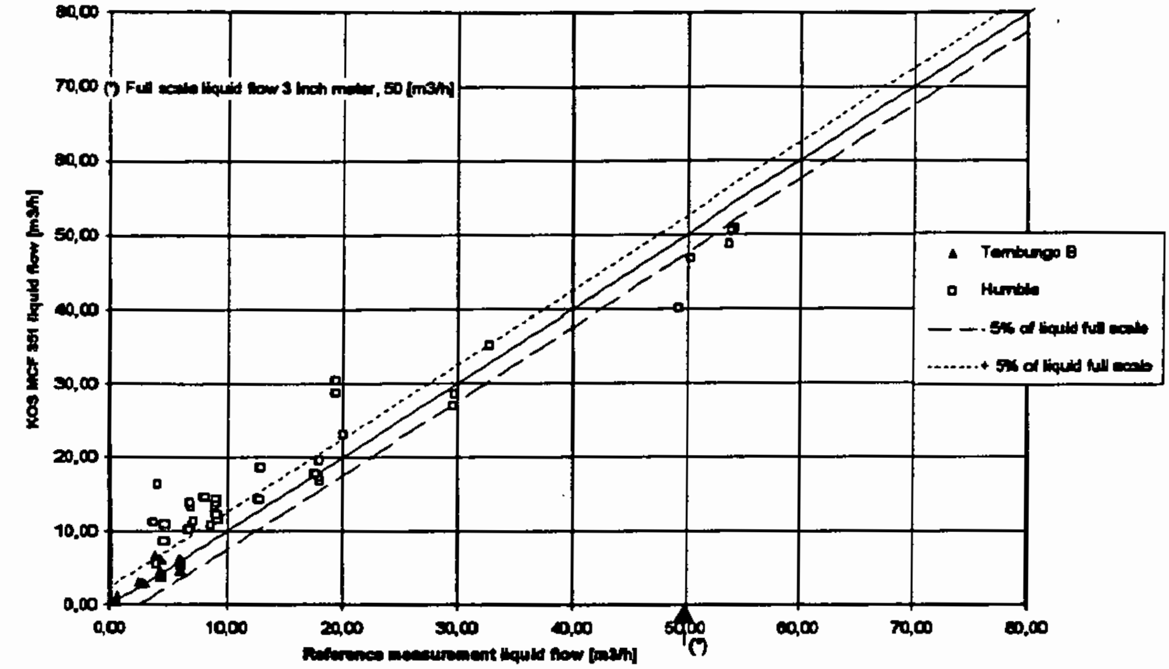

Figure 4 Test results liquid flow for 3 inch meters, Tembungo B and Humble

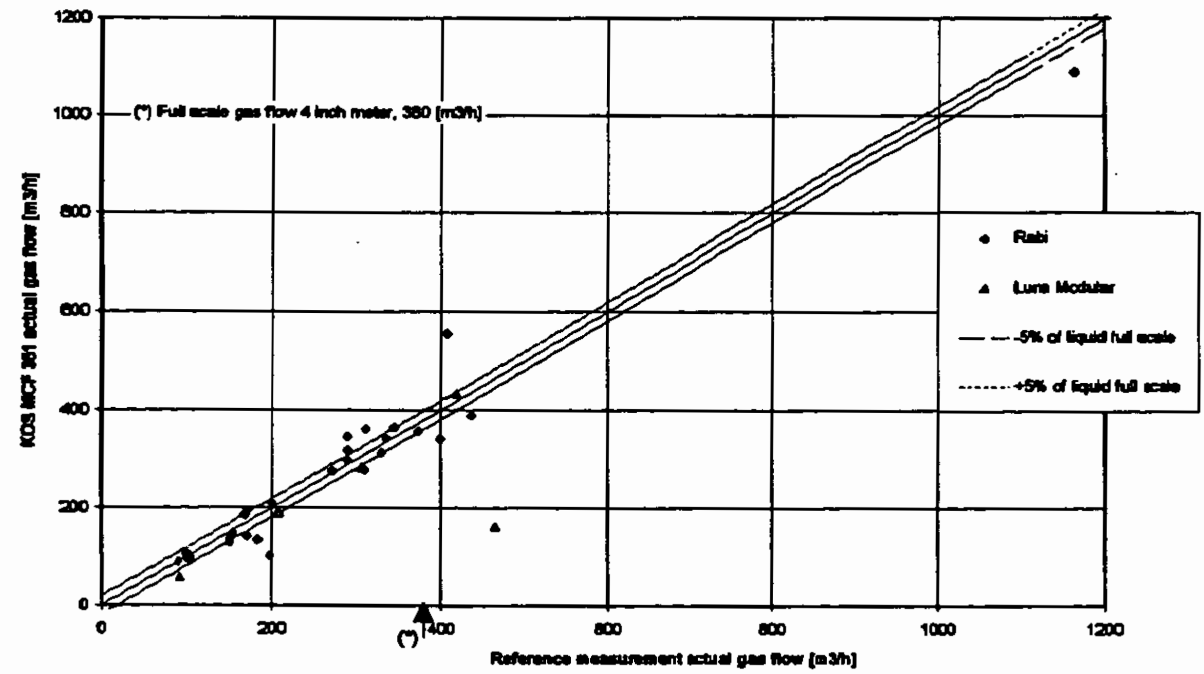

Figure 5 Test results gas flow for 4 inch meters, Rabi and Luna Modular

Underreading of liquid flow from **Humble**, see Figure 4, for higher liquid flows <u>above maximum</u> flow specified are for well flows with GVF at 50% and 70%. Measurement in this type of flow regimes, plug and bubble, is under development for use in later versions of the KOS MCF meter. For lower gas flow rates shown in Figure 6 an underreading is seen for the **Humble** data. The same tendency is seen for **Rabi** and **Luna** testpoints for lower gas flow rates. The larger deviations for the **Humble** data is due to the higher gas entrainment in the liquid phase and gas entrainment correction as discussed above.
The scatter on the **Rabi** gas flow accuracy shown in Figure 5 is mainly addressed to the combination of reference accuracy (see Table 7) suffering form surging well production giving large variations in testseparator pressure and consequently pressure drop over the orifice.
One extreme test point from Rabi is shown in Figure 5 on about 1100 m^3/h. Due to terrain effects the the well flow had a slugging behaviour giving valid measurement by the KOS MCF 351 meter.

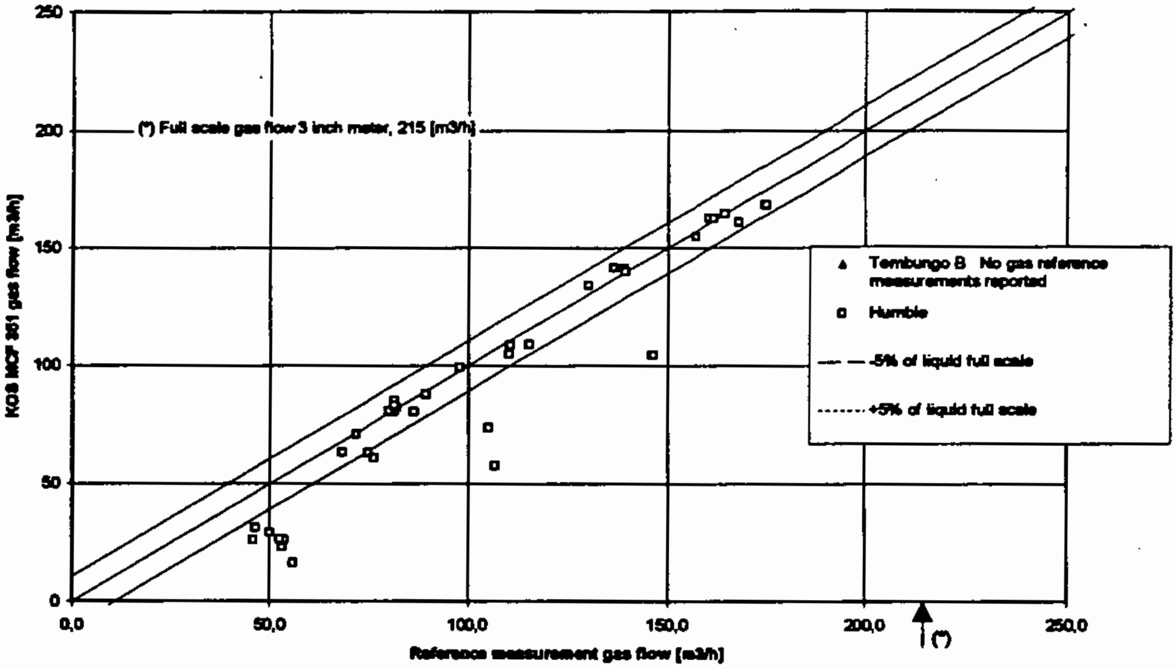

Figure 6 Test results gas flow for 3 inch meters, Tembungo B and Humble

Watercut in percentage is shown for all four tests in Figure 7. As discussed above the underreading of watercut for the **Humble** test is caused by large gas entertainment in the liquid phase. The **Rabi** watercut measurement is covering a large range from 0% to 76%. Maximum watercut at 76% is in water external emulsion (water continuos). The deviations is for 27 of the 29 testpoint within the specified accuracy.
The watercut at **Luna** is low and within specification with exception of one testpoint which on the KOS MCF gave 13,8% watercut and no water was detected in the reference stock tank. No repeated test was reported for this well and any errors in the KOS MCF 351 or uncertainty in the quality of the manual 'dip stick' stock tank testing has not been verified.

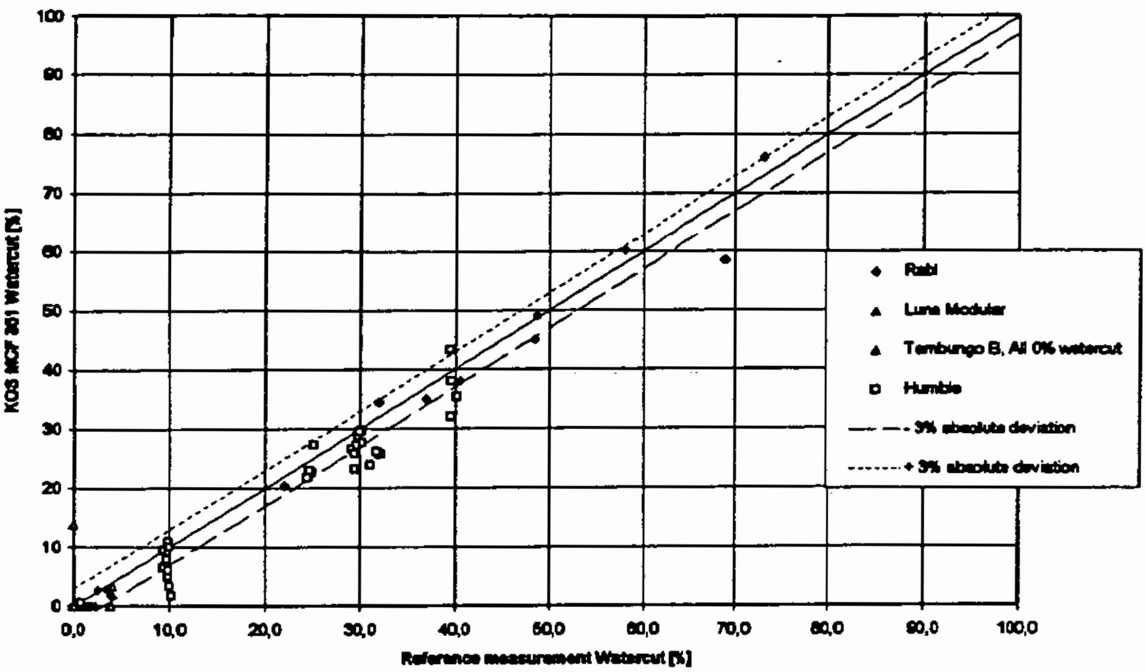

Figure 7 Test results for watercut, KOS MCF 351.

CONCLUSION

The KOS MCF 351 multiphase flow meter has through the reported field tests proven to be a reliable well test equipment. Good accuracy is shown over a large range of liquid and gas flowrates with a variety of watercuts. In addition excellent repeatability is demonstrated for repeated tests on one well and for different comparable wellsflows.

Further the KOS MCF 351 Multiphase flow meter has demonstrated it's potentials for reliable measurement outside the present specified operational range. Measurements on wells with low production in the stratified flow regime was successfully demonstrated at Tembungo B, Malaysia. The higher flow rates in annular flow regime, which is rather extreme for the KOS MCF 351, was demonstrated at the Luna field in Mexico.

The KOS MCF 351 meter is a field proven commercial product for the world market suitable for installation onshore or offshore. The KOS MCF 351 has flexibility for easy integration in any application.

Acknowledgement

This paper has been based on a number of people concentrating and focusing on the KOS MCF 351 meter performance in different corners off the world. This enthusiasm, the commitments established and hard work invested by the different operation organisation can not be appreciated enough.
In addition to the positive involvement from the management in Shell Gabon, Texaco Humble, Pemex and Petronas Carigali a special acknowledgement is hereby addressed to the different operational staffs. This acknowledgement is given for their positive co-operation and assistance during commissioning, start-up and testing.

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/ 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/ R.M. Pols and V.A. Olemans "Liquid slug generator for separated gas/liquid flow in pipes", Multiphase '95, Cannes, June 1995

/4/ Texaco EPTD "Performance Evaluation of Kongsberg Multiphase Meter", JIP report July, 1995

Rabi	Meter type	Expected accuracy
Liquid leg	EXAC coriolis meter	+/- 5%
Gas outlet	Daniel orifice fitting	+/- 15%
Tembungo B		
Liquid leg	Smith PD meter (Custody transfer)	+/- 1%
Gas outlet	Daniel orifice fitting	+/- 10-20%
Humble		
Oil leg	Smith PD oil leg, Micro Motion	+/-1%
Water leg	Coriolis meter	+/- 1%
Gas outlet	Daniel orifice fitting, Stork ultrasonic	+/-1,5%
Luna Modular		
Liquid leg	Stock tank and sampling	+/-5%
Gas outlet	Daniel Orifice fitting	+/-15%

Table 7 REFERENCE MEASUREMENT.

Rabi	Density	Viscosity
OIL	sg 0,854 / API 34.1 at 153C	11 cP at 40°C, 6 cSt at 60°C
GAS	NA (natural gas)	NA (natural gas)
Production WATER	sg 1,19 at 40°C	-
Tembungo B		
OIL	sg 0,843	2,66 cP at 25°C
GAS	NA (natural gas)	NA (natural gas)
Production WATER	1,15	-
Humble		
OIL	MW 264, sg 0,9093 at 60°F API 23,96	36,3 cP at 1000 psi / 80°F
GAS	Methane MW 16,06	NA (natural gas)
Production WATER	Brine	-
Luna Modular		
OIL	sg 0,808, API 42,95	2,1 cP at 39°C
GAS	0,67 kg/m^3	-
Production WATER	60550 ppm salinity	-

Table 8 FLUID PROPERTIES.