Paper 23

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Joe J. S. Shen,
ChevronTexaco Exploration & Production Technology Co, USA
S. J. Vierkandt and K. A. Ogden, Tengizchevroil, Kazakhstan

21st International North Sea Flow Measurement Workshop, Tønsberg, Norway, October 2003

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J. J. S. Shen, ChevronTexaco E&P Technology Company, Houston, USA
S. J. Vierkandt, Tengizchevroil, Atyrau, Kazakhstan
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ABSTRACT

This paper presents two years of operating experience and field evaluation of a 3” Roxar (MFI model) multiphase meter used for continuous production testing in a highly sour field environment where the hydrogen sulfide concentration in the production gas exceeds 10 mole percent. The MFI meter was installed and commissioned in February 2001 at a well site in Tengiz Field, Kazakhstan. The multiphase meter’s performance was evaluated by comparing measured flow rates with a three-phase test separator located at a meter station approximately one kilometer downstream of the well site. The oil and gas flow rates from the MFI multiphase meter were found to be in reasonable agreement with the test separator flow rates measured by vortex meters. The water cut measurement error was somewhat higher than Roxar’s multiphase meter’s accuracy specification. Since the water production in Tengiz is very low, the water cut measurement became an indicator of the reliability of the MFI meter. During the last meter repair in November of 2002, the ceramic sleeves inside the microwave sensor were found to be broken and surrounded by a layer of iron sulfide scale. The water cut measurement returned to the baseline value after the broken sleeves were replaced. In conclusion, two years of well testing experience at Tengiz Field suggested that the MFI multiphase meter’s oil and gas flow rate measurements agreed reasonably well with test separator results when it is functioning properly. Its poor reliability in water cut measurement was probably caused by gradual degradation of the ceramic sleeves inside the water cut sensor which might be exacerbated to some extent by the formation of iron sulfide scale in the sour field environment.

INTRODUCTION

This paper presents the field testing and operation of a multiphase flow meter at Tengiz and Korolev Fields in Kazakhstan. Both fields, located on the northeastern edge of the Caspian Sea in western Kazakhstan, are operated by Tengizchevroil (TCO). At three miles (5 km) deep, the Tengiz reservoir, with up to nine billion barrels of recoverable oil, is the deepest producing oil field in the world.[1] Its daily production of 285,000 barrels is characterized by light oil (43-45 API gravity) and sour gas with high H_2S concentration. Figure 1 is a map showing some of ChevronTexaco’s interests in the Caspian Sea region.[1]

Figure 1. Area map of the Caspian Sea region in western Kazakhstan.

The traditional way of conducting well testing at Tengiz Field is by three-phase test separators located at various meter stations. The field SCADA system diverts a well from a manifold to an insulated test separator for testing that usually lasts 24 hours or more. The oil, gas and water flow rates from the test separator are measured by 2” vortex meters which are located inside a meter shed next to the separator. Individual well production rates are controlled using the field SCADA system via a remotely operated adjustable choke.

During the development planning of the Korolev Field, which is a new field adjacent to Tengiz, TCO decided to adopt multiphase metering technology to measure well production rates rather than installing traditional 3-phase test separator. Prior to installing the selected multiphase meters at Korolev Field, an evaluation program of several meters, both the in-line type and compact-separation type, was conducted at Tengiz Field in 2001. This paper describes the experience of an in-line type multiphase meter that was first tested at a well site in the Tengiz Field in early 2001 and was later moved to a meter station in Korolev Field starting in early 2002.

A 3” multiphase meter manufactured by Roxar in Stavanger, Norway, (the MFI model referred to as the “MFI meter” in this paper to avoid confusion with the Fluenta model) was one of the multiphase meters that was tested at Tengiz Field. Very briefly, this multiphase meter consists of the following measurement components: gamma ray densitometry for gas fraction determination, cross correlation of microwave signals for fluid velocity determination, resonance microwave frequency for water liquid ratio (water cut) determination, and a venturi meter for another flow rate determination. Further technical details of the MFI multiphase meter are available from the manufacturer[2] and not elaborated upon here.

Field operation of MFI and other brands of multiphase meters have been widely reported in the literature over the last ten years or so (e.g. Ref. 3-6 for MFI meter operations and Ref. 7-8 for multiphase meters in general); however, very few field conditions are as sour as those encountered in the Tengiz and Korolev Fields. Selected fluid properties at a typical wellhead condition as calculated by a PVT package are listed in Table 1. It is seen that the H_2S concentration in the production gas may be 10% or higher which might have impacted the multiphase meter performance as described later in this paper.

TABLE 1. Properties of Tengiz Fluid at 102 Bar and 77 C

	Liquid	**Vapor**
Density (gm/ml)	0.6585	0.1011
Z factor	0.4520	0.8228
Viscosity (cp)	0.3001	0.0168
Molecular Weight	84.95	23.74
N_2 (mole %)		1.515
CO_2 (mole %)		3.779
H_2S (mole %)		10.787
CH_4 (mole %)		66.907

METER PERFORMANCE DURING COMMISSIONING PERIOD

The MFI multiphase meter skid was installed in a by-pass loop at the well site of Tengiz Well-A in February 2001 for a six-month evaluation. The meter was insulated and heat traced for the harsh winter condition. Prior to flow-through, a Roxar factory engineer performed necessary empty pipe calibration for the gamma ray densitometer and entered fluid densities at applicable operating pressure and temperature ranges into the meter for mass flow calculations. The meter was started up smoothly on February 19 by gradually opening the double isolation valves of the by-pass loop to divert the production through the meter skid.

In the first week following flow-through, the well's choke opening was decreased from fully open to 25% open. The average pressure, temperature, flow rates, water cut, and gas fraction are shown in Table 2. Also shown in the table is the uncertainty range for the flow rate of each phase. Those uncertainty values in parenthesis were calculated based on the MFI accuracy specifications at 90% confidence level for the metering condition. Basically, the accuracy of MFI's oil and gas flow rate measurements was calculated to be approximately ±6.8% and ±10.5% of reading, respectively. The error range for the net water was very high simply because the measured water cut was approximately the same magnitude of the water cut measurement uncertainty.

Table 2. Average Measurements of MFI Multiphase Meter

Date	Choke Open	Pressure	Temp.	Oil Rate (m3/h)	Gas Rate (m3/h)	Water Rate (m3/h)	Water Cut (%)	Gas Fraction (%)
22/02/01	99%	103.1	77.3	55.2 ± 3.7 (6.8%)	107.2 ± 11.2 (10.5%)	2.3 ± 1.7 (75%)	4.0	65.1
23/02/01	99%	103.2	77.6	54.3 ± 3.7 (±6.8%)	107.3 ± 11.2 (±10.5%)	2.3 ± 1.7 (±73%)	4.1	65.4
25/01/01	60%, 40%	102.1	77.4	54.3 ± 3.7 (±6.8%)	103.7 ± 10.9 (±10.5%)	1.9 ± 1.7 (±88%)	3.4	64.8
26/02/01	40%	101.5	77.0	53.3 ± 3.5 (±6.8%)	101.1 ± 10.4 (±10.5%)	1.8 ± 1.6 (±94%)	3.2	65.1
27/02/01	25%	98.4.5	75.3	48.6 ± 3.3 (±6.7%)	91.8 ± 9.6 (±10.5%)	1.3 ± 1.5 (±116%)	2.6	64.8

AVERAGE DEVIATIONS FROM TEST SEPARATOR MEASUREMENTS

The MFI multiphase meter measurements averaged over a certain time period were compared with the average test separator results over the same period. Using the test separator as the standard, the MFI meter deviations are shown in Table 3.

Table 3. Deviations between MFI Meter and Test Separator Measurements

Date	Choke Open	Test Sep Pressure	Test Sep Temp.	Oil Rate	Gas Rate	Water Rate	Water Cut	Gas Fraction
22/02/01	99%	87.7	71.5	3.8%	3.9%	27%	0.7%	-0.1%
23/02/01	99%	87.9	71.9	2.6%	4.1%	29%	0.8%	0.1%
25/01/01	60%, 40%	87.6	71.9	7.0%	3.3%	-21%	-1.2%	-0.4%
26/02/01	40%	87.7	71.0	7.7%	3.5%	-28%	-1.6%	-0.5%
27/02/01	25%	86.9	69.1	11.8%	4.5%	-52%	-3.1%	-0.8%

As an example, trend plots of one-minute data collected for various parameters (pressure, temperature, oil and gas flow rates, GVF and water cut) with Well-A flowing at 99% choke opening on 22/02/2001 are shown in Figures 2-7. The trends in pressure and temperature data are well matched between the MFI meter and test separator. The step-change appearance in the test separator data was simply due to the data updating threshold in the SCADA system. The MFI meter's gas flow rate deviations were quite consistent at about 3-5% higher than the vortex meter measurement at the test separator. The MFI meter's oil flow rate was generally within or close to its uncertainty specification of 7%. The larger deviation at 25% choke opening in Table 3 was also observed in later testing in March 2002 where the well had a longer time to stabilize after a choke setting change than during the commissioning period. It was speculated that the test separator performance might be suspect as there was a correspondingly higher water flow rate at the test separator (e.g. it could be explained by the possibility of oil being dumped out the water leg).

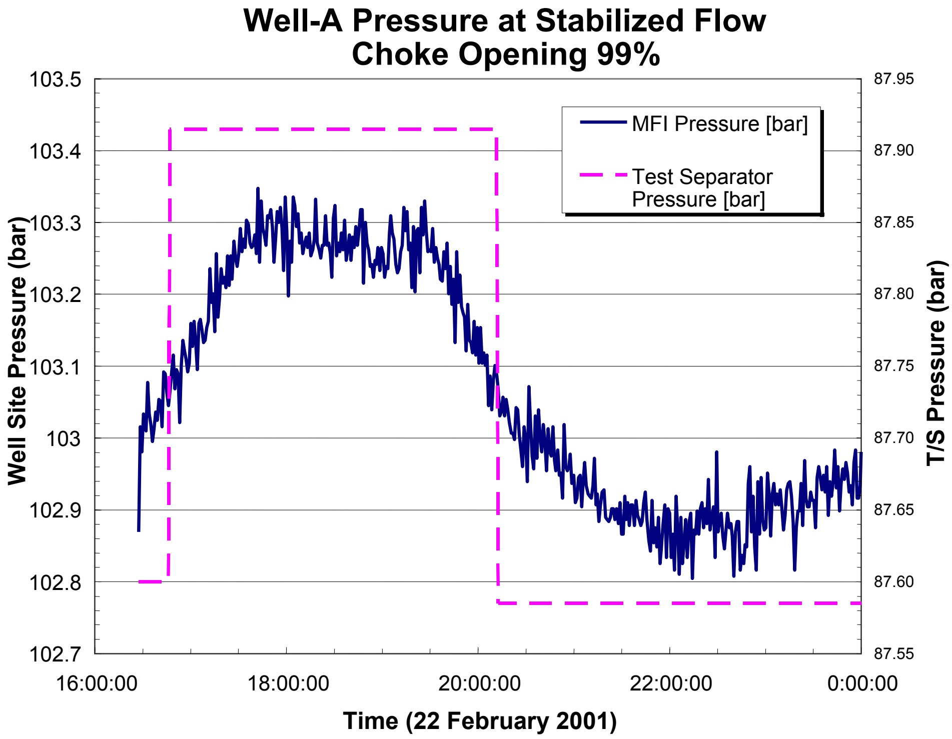

Figure 2. Comparison of pressure measurements by MFI and test separator on 22-02-01.

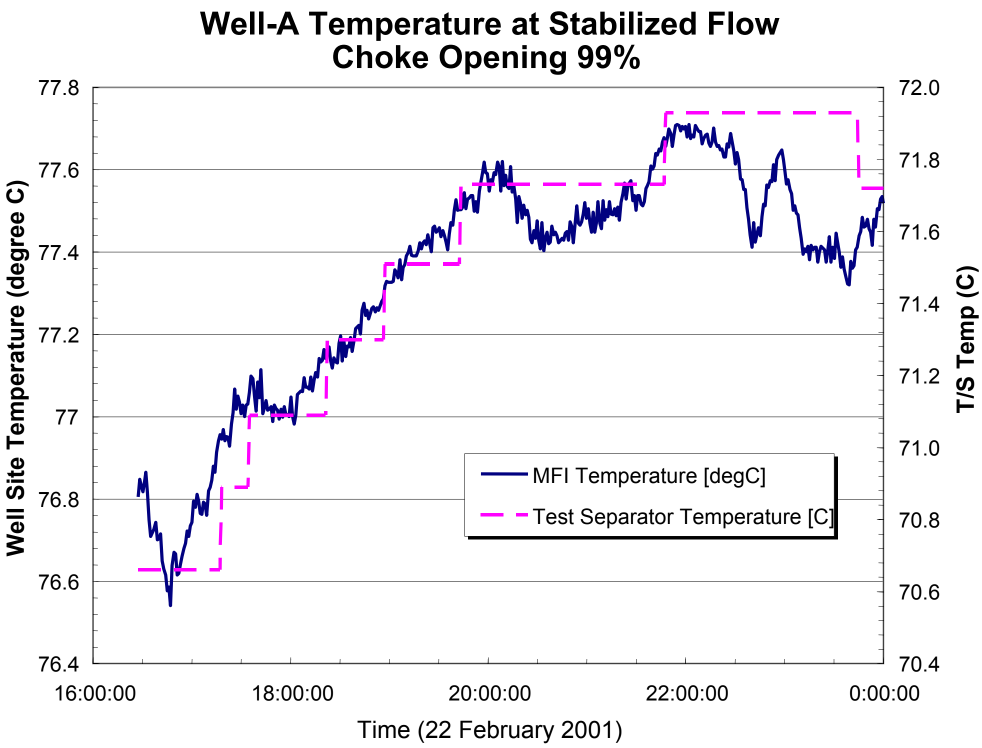

Figure 3. Comparison of temperature measurements by MFI and test separator on 22-02-2001.

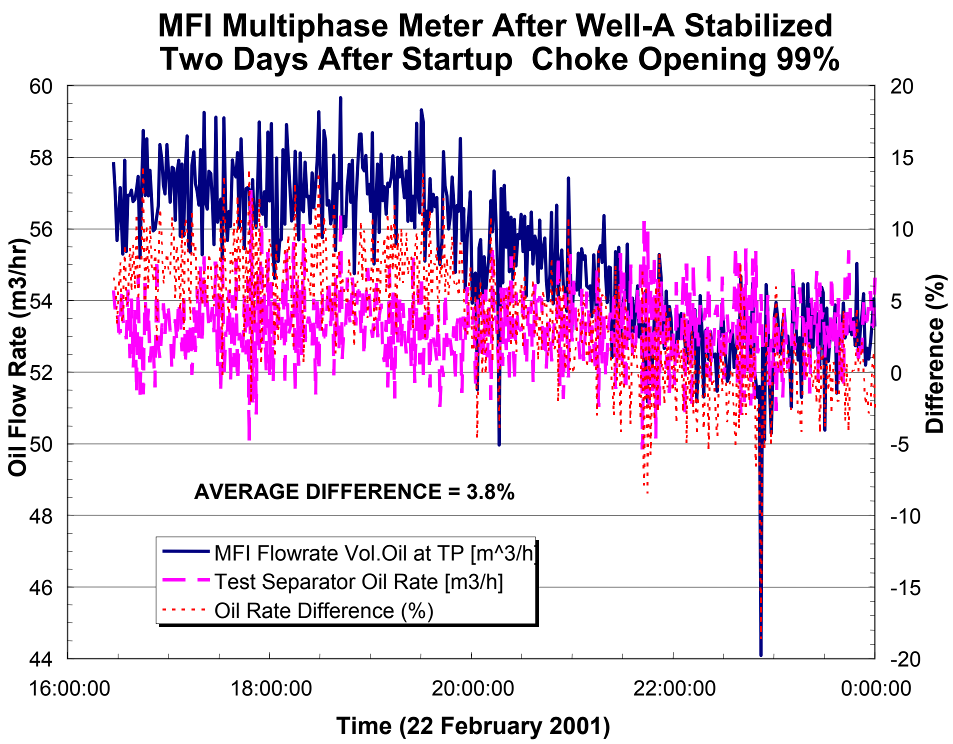

Figure 4. Comparison of oil flow rates by MFI and test separator on 22-02-2001.

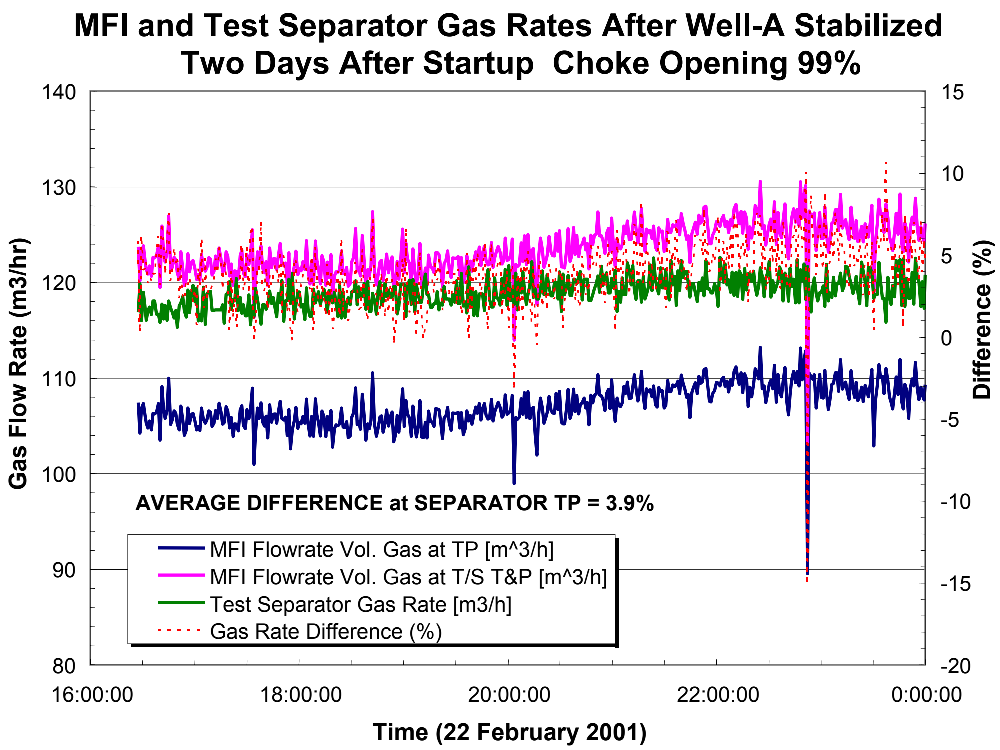

Figure 5. Comparison of gas flow rates by MFI and test separator on 22-02-2001.

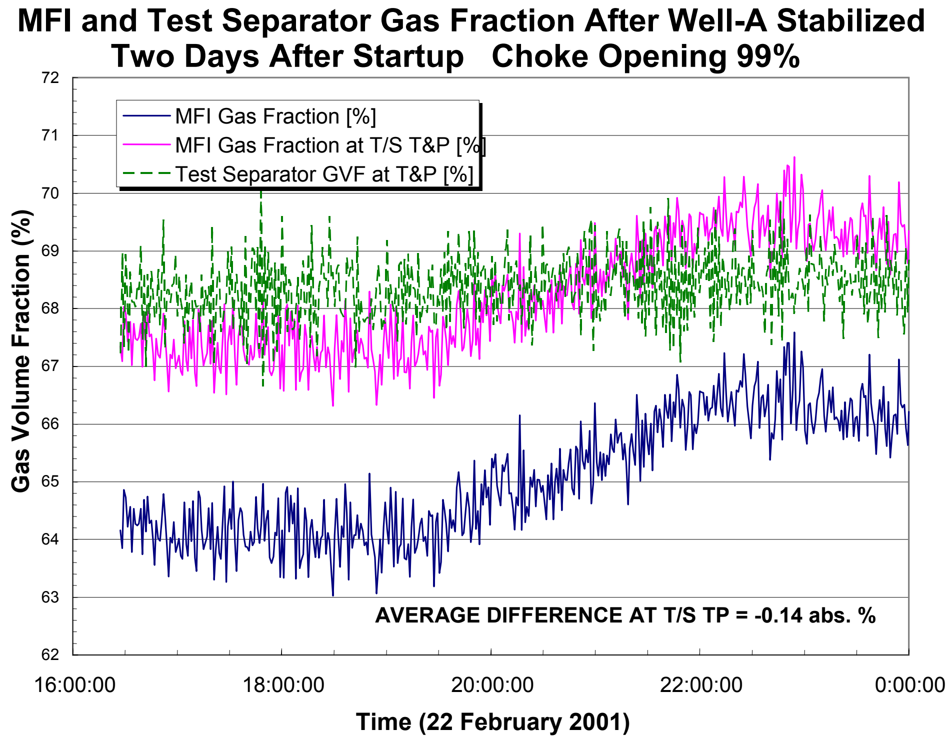

Figure 6. Comparison of gas volume fraction measurements by MFI and test separator on 22-02-2001.

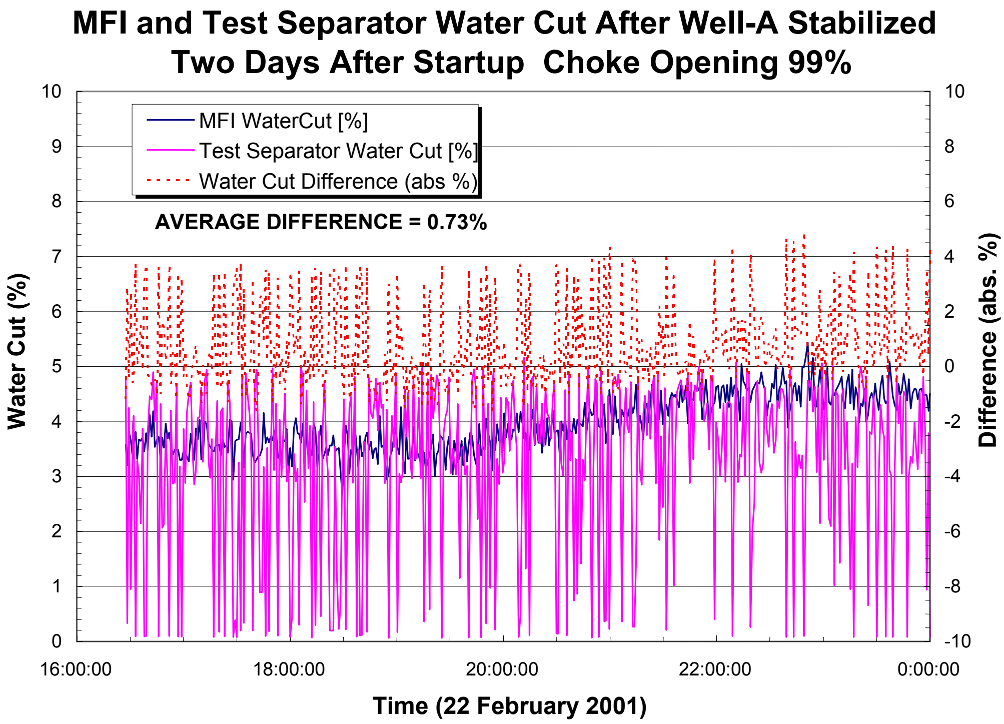

Figure 7. Comparison of water cut measurements by MFI and test separator on 22-02-2001.

The test separator, located approximately one kilometer away from Well-A, operated at a lower pressure and temperature than that at the wellhead. The oil volume could be expected to shrink a little while additional gas volume would evolve with decreasing pressure. After attempting to account for this PVT effect of the crude, the updated deviations of average oil and gas flow rates are shown in Figures 8 and 9, respectively. The oil flow rate deviation narrowed from about +4% to be very close to the test separator result while the gas flow rate deviation widened from about +4% to +8% which was still within the meter's uncertainty specification.

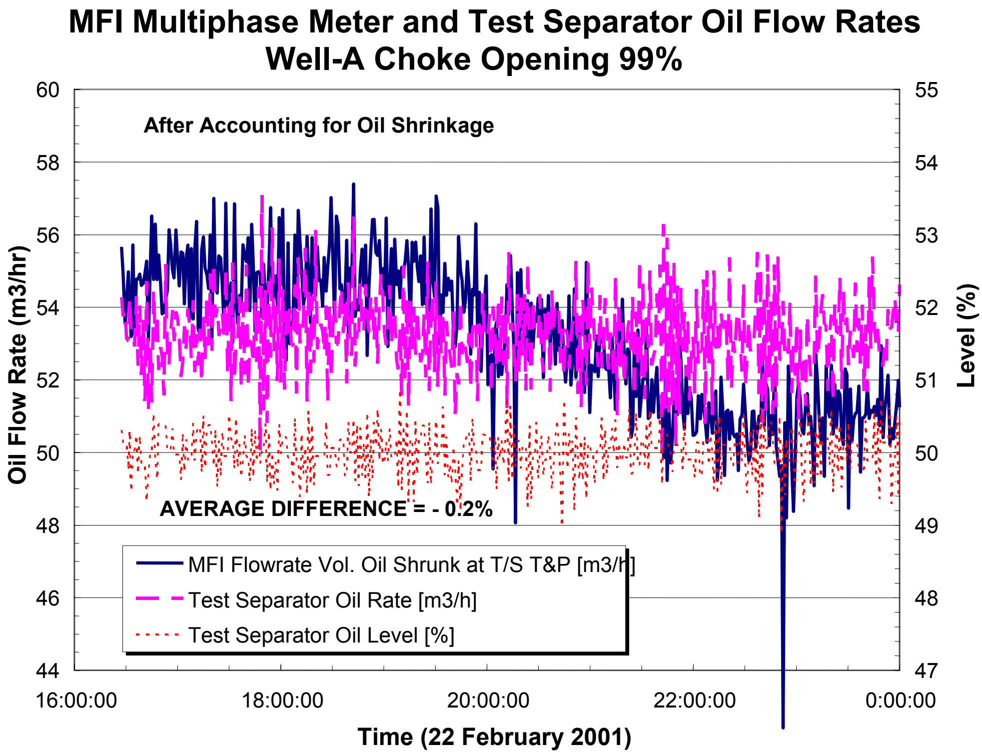

Figure 8. Comparison of oil flow rates by MFI and test separator on 22-02-2001 after accounting for oil shrinkage.

PROBLEMATIC WATER CUT MEASUREMENT

The water cut measured by the MFI multiphase meter for Well-A averaged about 3.5%, which is quite close to the test separator result (see Figure 7). However, the water flow rates measured by both the MFI multiphase meter and the test separator were expected to be in error because there is negligible water in Tengiz production. Due to the high H_2S condition at Tengiz, catching a liquid sample to check for water was not a routine operation as in other oil fields. Although the water content of Well-A production was not verified by sampling, a water cut level of much lower than 1% is expected for most wells.

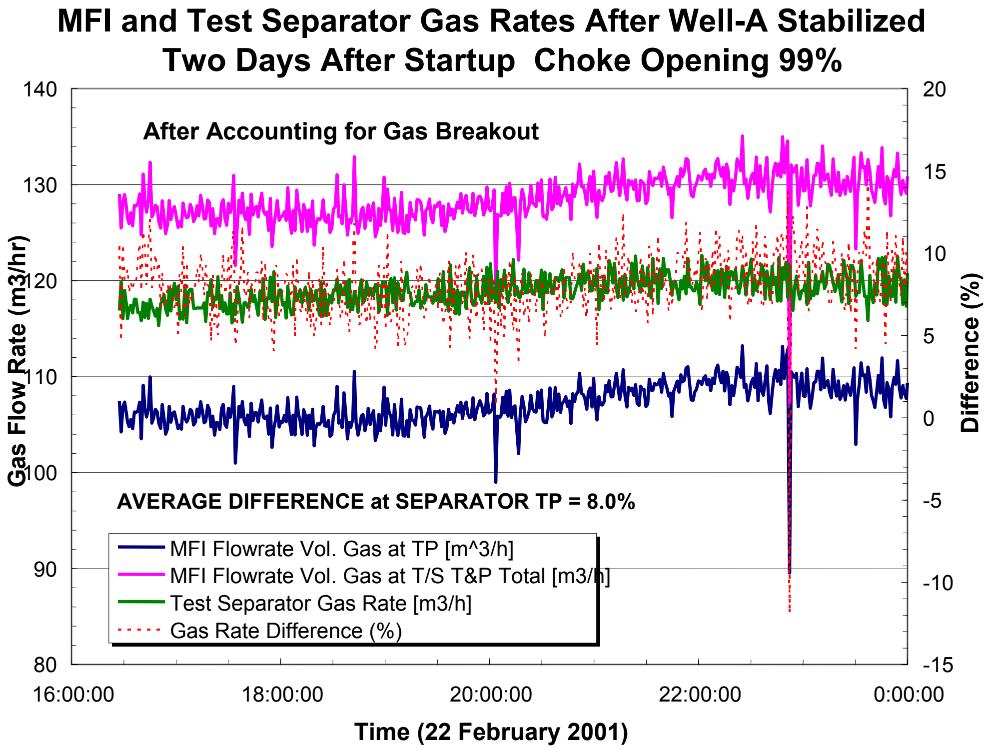

Figure 9. Comparison of gas flow rates by MFI and test separator on 22-02-2001 after accounting for gas breakout.

Thus the average water cut of 3% to 4% (slightly higher than the MFI meter's 3% accuracy specification for the operating condition) was taken to be a bias in the meter's water cut measurement. In fact, as long as the water production characteristics did not change (i.e. close to zero water cut), the water cut measurement could be used as a diagnostic tool for the health of the MFI multiphase meter. If the measured water cut drifted away from the 3.5% level, the accuracy and validity of the meter's measurements would become questionable. For example, the measured water cut began to shoot up to 100% occasionally in April of 2001. Roxar subsequently determined the gamma ray densitometer to be the problem, and the water cut returned to the baseline value after replacing the bad densitometer in June 2001.

In September 2001, after completing the field trial in Tengiz, the MFI meter was moved to the meter station in the nearby Korolev Field. During the meter commissioning at Korolev the baseline water cut reading was once again measured at approximately 3.5%. Soon after the meter was placed into continuous service unstable and high water cut measurements, with spikes up to 60%, were recorded for both Well-B and Well-C as shown in Figures 10 and 11. During a site visit by a Roxar technician it was determined that faulty microwave modules were the cause of the erroneous water cut measurements. Following the replacement of the modules the water cut readings were reduced to between 3%-6%, however the water cuts did not return to the stable baseline values of 3.5%.

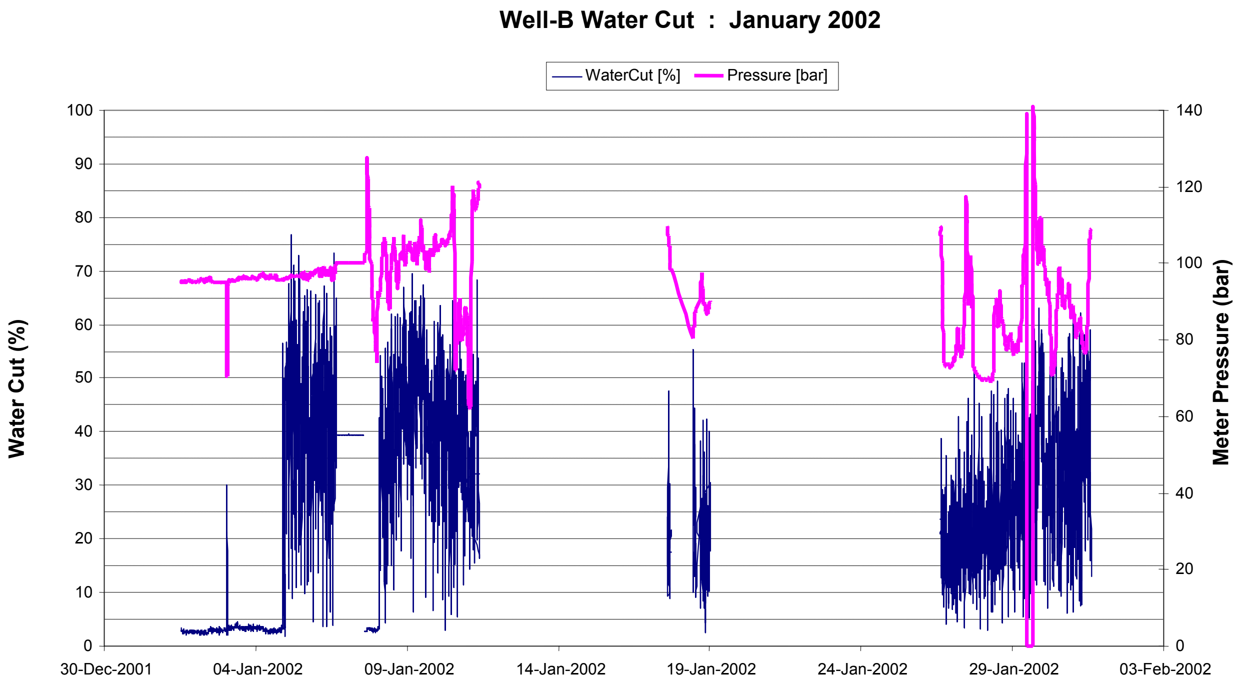

Figure 10. Well-B water cut measured by MFI meter in January 2002.

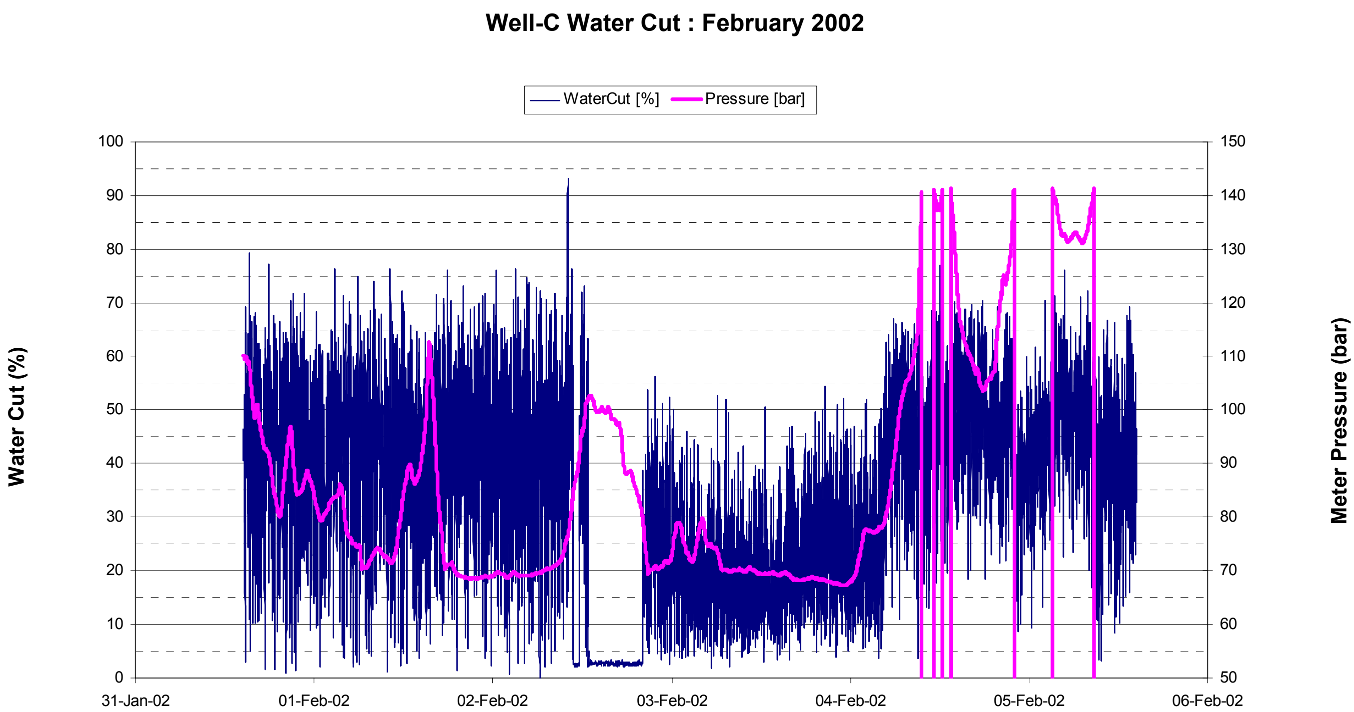

Figure 11. Well-C water cut measured by MFI meter in February 2002.

Additional service visits in June and September 2002 attempted to address the slightly higher water cut readings. Again microwave modules were replaced and additional troubleshooting steps were taken, however the water cut readings remained high. As shown in Figures 12 and 13, the measured water cut still averaged about 8% for Well-C and about 6% for Well-B, respectively, in well testing results obtained in October 2002.

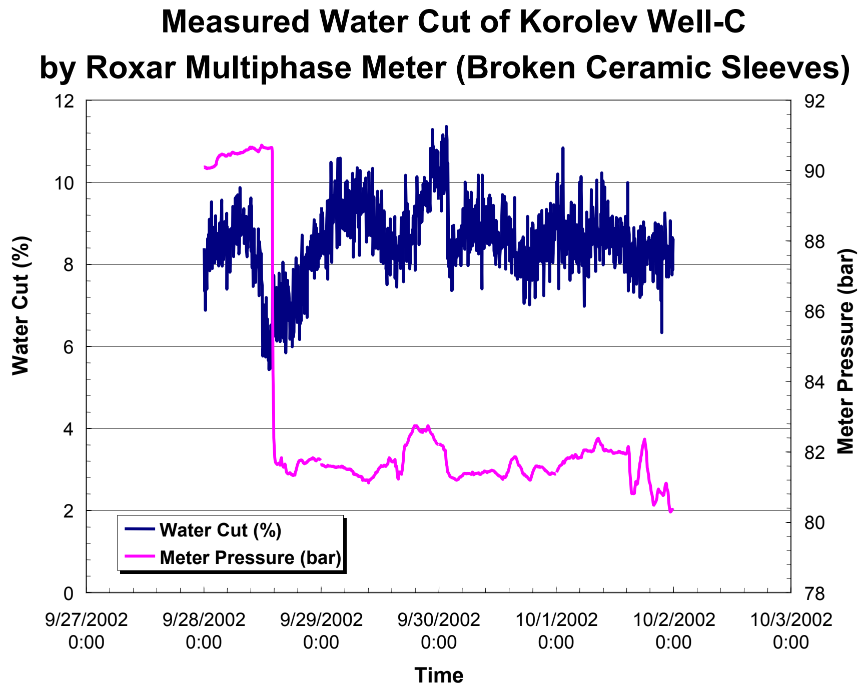

Figure 12. Well-C water cut measured by MFI meter in October 2002, before November repair.

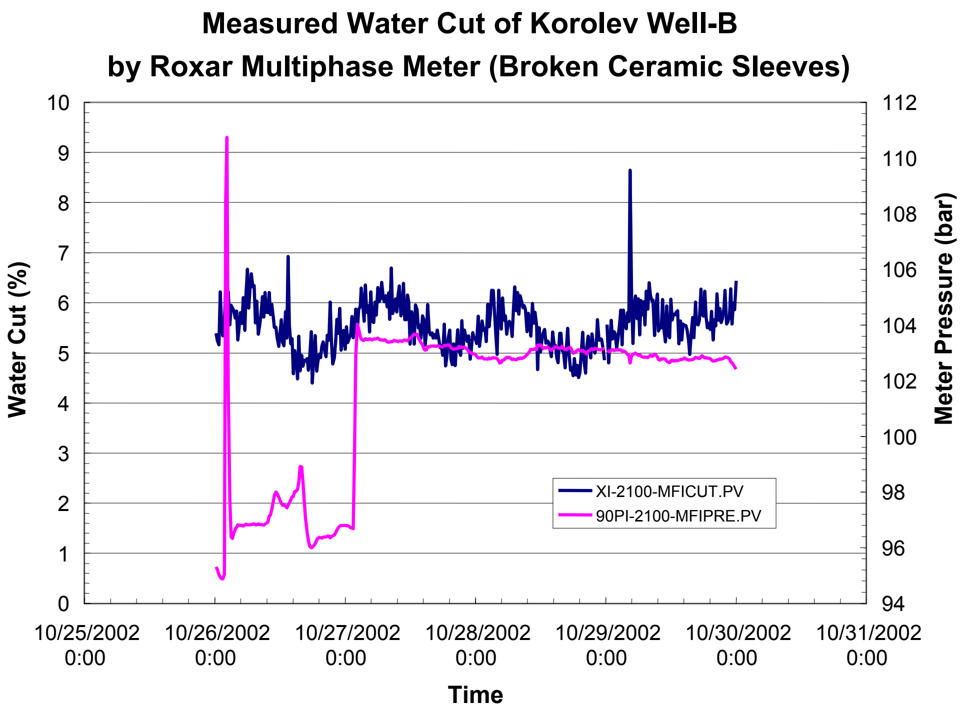

Figure 13. Well-B water cut measured by MFI meter in October 2002, before November repair.

LAST REPAIR IN NOVEMBER 2002

Based on the water cut data trend and service records, Roxar suspected that the ceramic sleeves at both ends of the sensor might be broken so that the microwave technique became less reliable. The Roxar engineer brought new sleeves to Tengiz in November 2002 and the MFI water cut sensor was dissembled from the meter skid for repair. The ceramic sleeves at both ends of the spool were found to be disintegrated. A layer of black solid deposit was seen to surround remnants of the sleeve as shown in Figure 14.

Figure 14. An inside view of MFI meter before repair in late 2002.

After replacing the broken ceramic sleeves with new stainless steel sleeves, satisfactory well testing results by the MFI meter were obtained. The average water cut for both Well-C and Well-B returned to the 3.5% baseline value as shown in Figures 15 and 16.

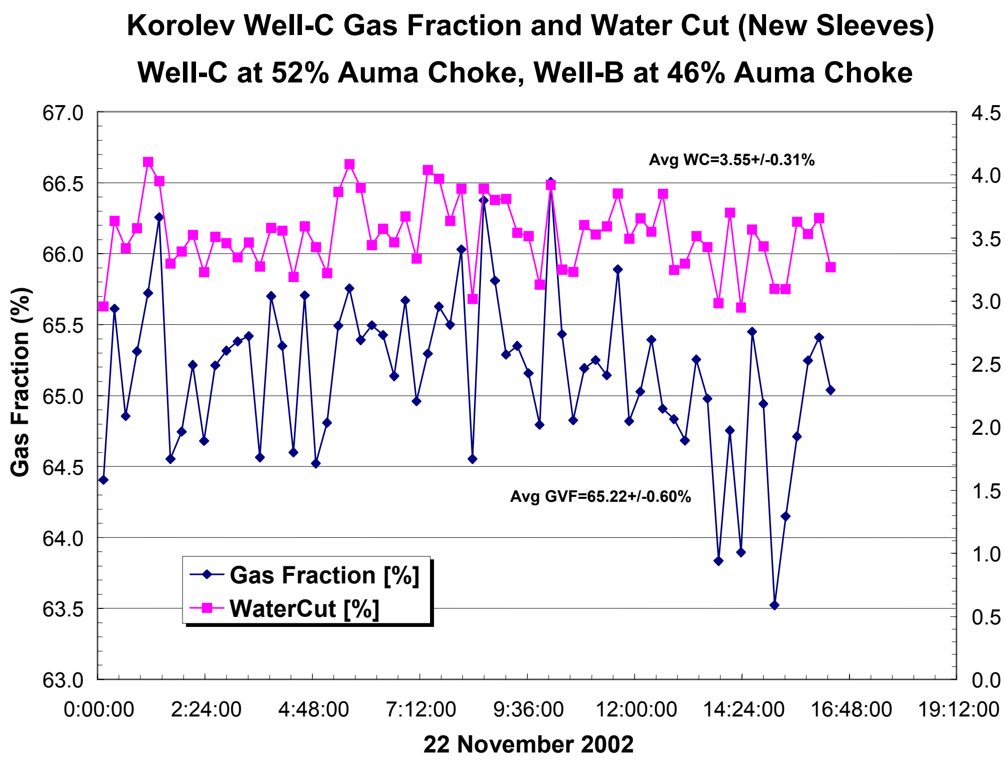

Figure 15. Well-C GVF and WLR measured by MFI meter after repair in November 2002.

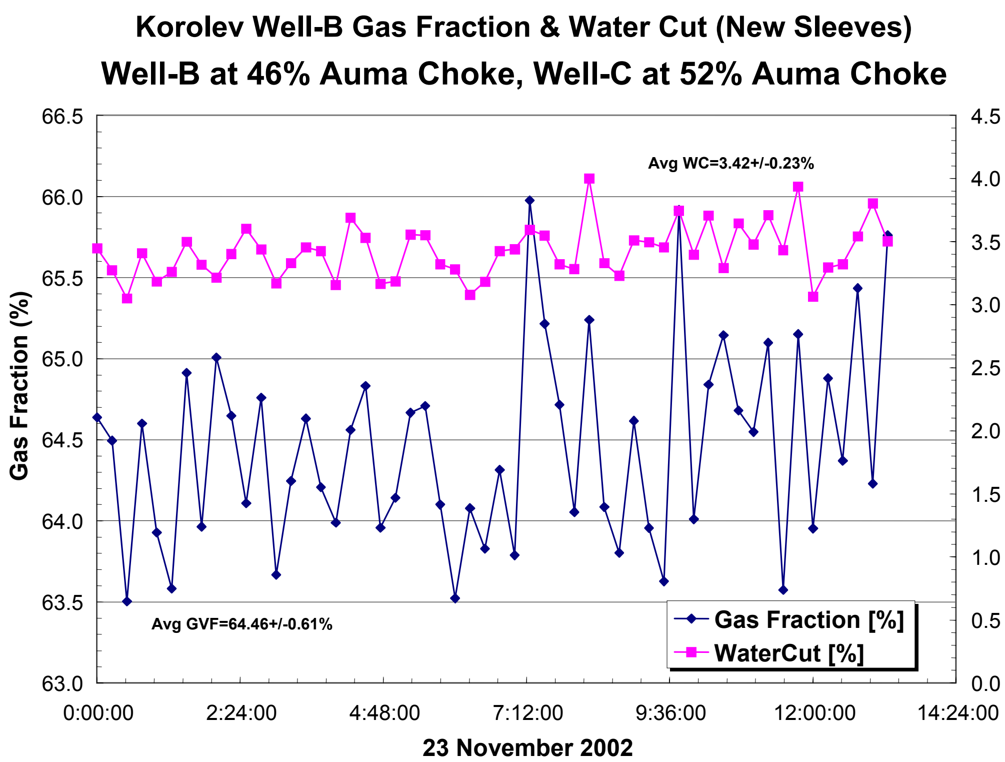

Figure 16. Well-B GVF and WLR measured by MFI meter after repair in November 2002.

A sample of the solid deposit was analyzed by the ChevronTexaco lab in Houston. According to the lab analysis, the sample was suspected to be Iron Sulfide FeS_2 (or polymorphs there of) as it was magnetic and because of the presence of high H_2S concentration in the crude. Based on these assumptions, it was decided to quantify the concentration of iron and sulfur in the sample. Also a qualitative elemental analysis was performed to identify other major elements contributing to the sample without regard to concentration. Two methods were employed: LIBS (Laser Induced Plasma Spectroscopy) for iron, and XRF (X-Ray Fluorescence) for sulfur. It was determined at the 95% confidence level that the sample is:

$38\%_{WT/WT}$ +/- $13\%_{WT/WT}$ Elemental Iron
$48\%_{WT/WT}$ +/- $19\%_{WT/WT}$ Elemental Sulfur

The iron and sulfur sum by molecular formula to account for 82% of the sample as Iron Sulfide FeS_2. Figure 17 is the qualitative output of the LIBS analysis, and Figure 18 is the qualitative output of the XRF analysis. Additional elements were identified by techniques as follows in decreasing order: Iron > Barium > Calcium > Magnesium by LIBS and Sulfur > Iron > Zinc > Silicon by XRF.

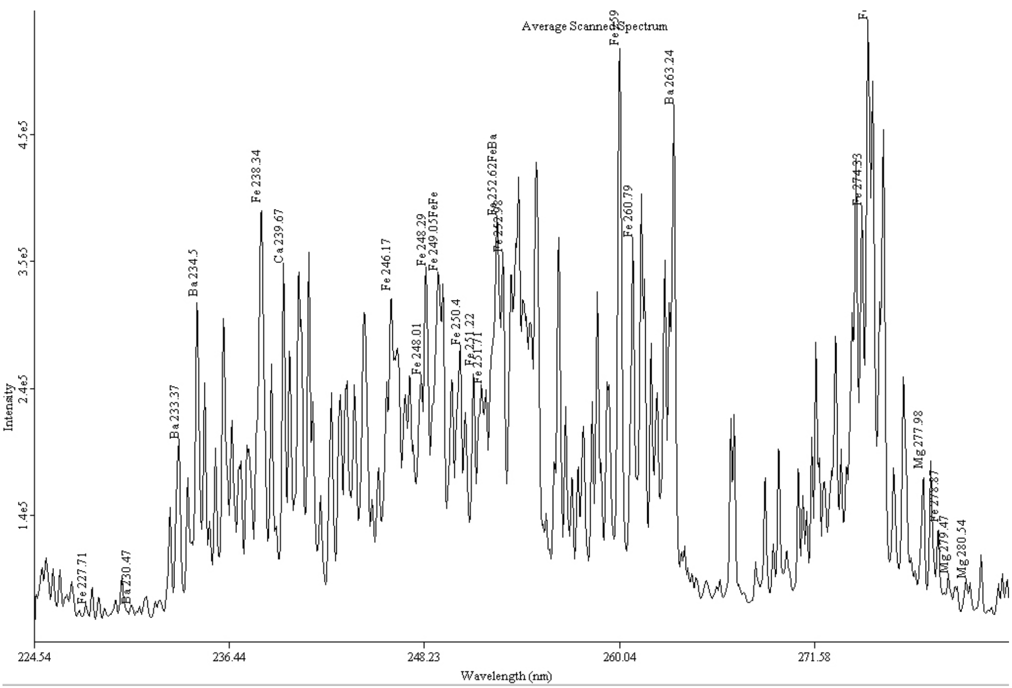

Figure 17. Laser induced plasma spectroscopy analysis of solid deposit inside the MFI meter.

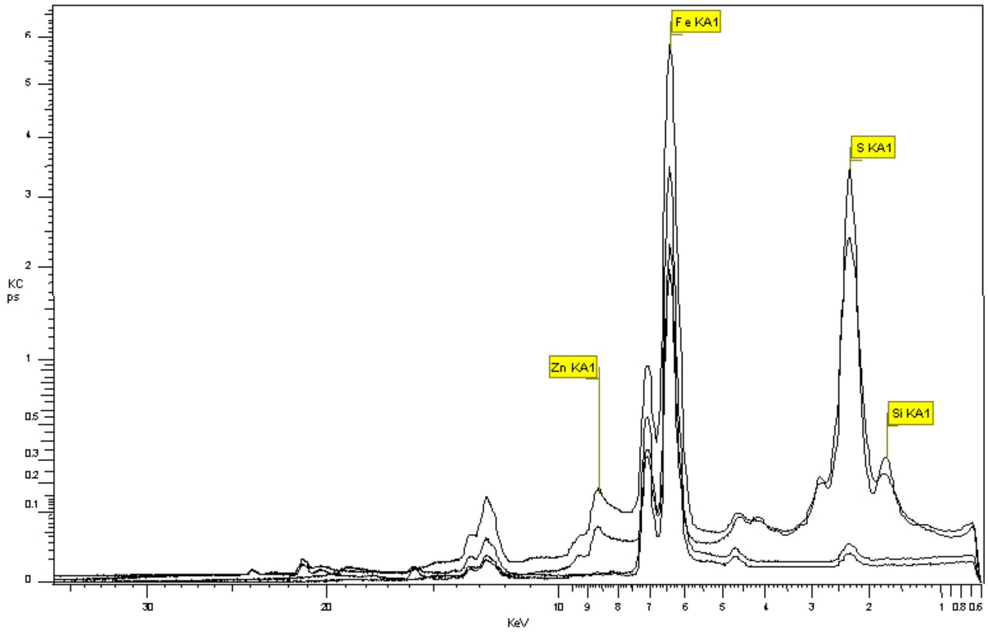

Figure 18. X-ray fluorescence analysis of solid deposit inside the MFI meter.

Other software improvements to the meter were also performed in the November 2002 service call, including outputting flow rates determined by both cross correlation and venturi methods to the SCADA system (only one set of flow rates were output by the meter prior to this upgrade). It may be of interest to note the 3% average difference between the two flow rate methods is comparable to the average of approximately 2% obtained by manual spot checking the two flow rates during the original commissioning in February 2001.

CONCLUSIONS

1. The MFI multiphase meter was started up smoothly without difficulty in the Tengiz field trial. The flow rates measured by the multiphase meter were generally within its accuracy specifications of ±6.8% for oil and ±10.5% for gas when using the downstream test separator results as the reference.

2. The water cut measurements by both the MFI multiphase meter and the 2" vortex meter at the test separator were in the 2%-4% range which was known to be in error for Tengiz production. The average 3.5% water cut was taken as a baseline bias and served as a useful diagnostic tool to gauge the health of the multiphase meter measurements in operation.

3. The MFI multiphase meter has had several on-site service calls which were alerted by invalid water cut measurements since the startup. The recurring water cut problem was probably caused by gradual degradation of the ceramic sleeves inside the sensor which might be exacerbated by an iron sulfide deposit formed in the sour field environment. The meter's water cut measurement returned to its baseline level after replacing the ceramic sleeves with stainless steel sleeves.

4. The two methods (cross-correlation and venturi) employed by the MFI multiphase meter provided comparable flow rate determinations. The average difference was in the 2%-3% range when the meter was operating properly.

5. The evaluation and operational experience over the last two years demonstrated that the multiphase metering technology can be used with acceptable well testing results in a highly sour field environment.

6. Should future service calls be required to address measurement issues, one item to investigate will be the presence of scale buildup in the meter.

REFERENCES

1. Johnson, M., "Kazakhstan. The Next Generation," *CVX The ChevronTexaco Global Magazine*, Vol. 2, No. 3, pp. 3-11 (2003).

2. Roxar Flow Measurement AS, Bergen and Stavanger, Norway.

3. Arnstein, W. and R. Haddeland, "Field Experience of the MFI Multiphase Meter," presented at Flow Measurement '99, Abu Dhabi, 28 April 1999.

4. Cellos, H. and A. Wee, "Multiphase Flow Measurement System of High-GOR Applications," presented at 17th North Sea Flow Measurement Workshop, Oslo, Norway, 25-28 October 1999.

5. Moestue, H. and A. Wee, "Operational Experience of a Multiphase Meter on Norsk Hydro's Brage Platform," presented at 16th North Sea Flow Measurement Workshop, Perthshire, Scotland, 26-29 October 1998.

6. Klemp, S., H. Berensten, and B. L. Pedersen, "Asgard and Gullfaks Satellites Field Developments. Efficient Integration of Multiphase Meters," presented at 15th North Sea Flow Measurement Workshop, Norway, 1997.

7. Falcone, G., G. F. Hewitt, C. Alimonti, and B. Harrison, "Multiphase Flow Metering: Current Trends and Future Developments," SPE 71474, presented at 2001 SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, 30 September-3 October 2001.

8. Al-Taweel, A. and S. G. Barlow, "Field Testing of Multiphase Meters," SPE 56583, presented at 1999 SPE Annual Technical Conference and Exhibition, Houston, Texas, 3-6 October 1999.

ACKNOWLEDGEMENT

The authors wish to thank Tengizchevroil colleagues involved in this field trial. They also thank TCO management and the joint venture partners for permission to publish this work.