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Paper 6.3

Neftemer - A Versatile and Cost Effective Multiphase Meter

Vladimir Kratirov and Andrew Jamieson
Neftemer Ltd

Hoi Yeung and Stephen Blaney
Cranfield University

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Stephen Blaney and Hoi Yeung, Cranfield University

1 INTRODUCTION

Western international oil companies began development of multiphase meters in the late 1970s. The story of the development can be traced in the papers presented over the years at North Sea Flow Measurement Workshops and other conferences and seminars. The development process was based on the use of multiphase test loops built at manufacturers' facilities, oil companies' laboratories or at research companies facilities. What drove the development was the expectation that if relatively low cost multiphase meters could be developed which could be installed on individual wells, they would dramatically reduce the costs of field development and provide the essential information to manage oilfields efficiently and cost effectively. That expectation has been partially realised. A clear indicator of this is that increasingly it is acknowledged that the performance of multiphase meters is better than the performance of the test separators they have replaced. About 1600 multiphase meters have been deployed by oil companies in the west, and project teams routinely consider their deployment. However, they are still very expensive, and in many applications they are used as a replacement for a test separator for testing multiple wells.

Our story concerns the parallel development of a multiphase meter in Russia, for different applications to those in the West and taking a different approach. This development has had significant difficulties to contend with: - the break-up of the former Soviet Union, the subsequent transformation of the government research institutes, the collapse of many Russian manufacturing companies, not to forget several financial crises and collapses of the oil price. However, there was sufficient evidence that Neftemer was based on sound principles, and there was sufficient interest by Russian oil companies to use the equipment. Currently some 200 meters are deployed, almost all on thermally stimulated wells producing heavy oil.

This paper tells the story of the development of Neftemer since the late 1970s. It describes the testing and verification in oilfields, the uses of Neftemer for improving the production from wells, and the different applications where it is deployed. In Russia there are no multiphase test loops. All testing had to be done in the field, with simple, practical, yet accurate methods. This significantly different approach has given us difficulties in making comparisons with Western multiphase meters, but has also raised challenging questions on the validity of the Western approach to the testing and verification of multiphase meters. We plan to market Neftemer in the West and have worked with staff of Cranfield University to test the meter in their recently installed multiphase test facilities. We considered that it was essential to perform similar tests to those performed on Western multiphase meters to get a sound basis for comparison. We discuss the tests at Cranfield and issues that have arisen during the testing. We also discuss recent field tests of Neftemer, and where Neftemer fits in the current multiphase metering market.

2 REVIEW OF THE DEVELOPMENT OF NEFTEMER

2.1 Development from late 70s to end of Soviet period

In the late 1970s Russian (state) oil companies requested the central body which co-ordinated industrial research in the former Soviet Union for possible solutions for measuring unseparated flow in oil well flow lines, particularly heavy viscous oils. This request was circulated to the research institutes. Vladimir Kratirov was working at the Institute for Cybernetics for Space Research in St Petersburg, which specialised in measurements based on gamma radiation. He was working on the related problem of metering two-phase water-steam flows in nuclear reactors, and had come up with the idea of monitoring the density fluctuations with gamma radiation, and relating these fluctuations to the flowrates of the steam and water phases. He realised that he had a potential solution for the Russian oil industry requirements.

In 1978 the oil company Belarusneft sponsored research on this approach with the aim of developing a low-cost non-intrusive multiphase meter. Over the next few years much time was spent in the field gathering data on wells, evaluating different ways of deploying gamma-ray sources and detectors, and establishing the principles for the design of an instrument, its calibration and verification. Vladimir Kratirov's original expertise was in the use of radiation based sensors, not flow metering. To ensure that these ideas made sense in flow metering terms, he involved one of the leading Russian flow metering experts, Professor P. Kremlevsky as an external consultant. He also involved experts on statistical signal processing.

In western multiphase meters the phase flowrates have traditionally been given in volumes at line conditions, following the practice of separator measurement both in operations and at multiphase test facilities. V. Kratirov decided to measure the liquid flow in mass units, partly because the gamma ray absorption meter is a mass related device, largely because the heavy oil/water mixtures cannot readily be metered using volume meters (indeed, this was the main reason for starting the non-intrusive metering project in the first place), but also because it was relatively straightforward to divert the (low pressure) flow from an oil well into a tank mounted on a commercial weigh bridge. This meant that there was a practical and highly accurate way to gather field data for establishing the fluid models and algorithms to be used. The fluctuating absorption signal from the oil well could be recorded during the test period. The fluid model and the algorithm would calculate the total liquid mass, which could be compared with the mass total from the weighbridge. The parameters in the fluid model and the algorithms could then be adjusted to give the best overall fit to the data gathered.

Further testing was sponsored by Belarusneft, with the result that in 1988, after ten years of research and development, the 'Pulsar' flow meter was designed. It comprised a specially designed gamma-ray absorption meter and software running on a special computer for processing density fluctuations of the multiphase flow. Before the 'Pulsar' meter could be deployed, it had to be approved by the State Measurement Authorities. This meant that a state metrologist had to agree the comparison method using the tank on the weigh bridge, and the performance criteria. He had to oversee the actual testing and report the results. Approval was given in 1988, and in 1989 ten commercial prototypes were ordered for testing in three oil companies, Belarusneft (Belorussia), Komitermneft (Russia), and Komsomolskneft (Kazakhstan). These tests showed that there was a major requirement to extend the liquid mass flow rate measurement to lower values for low production wells, and that it would be essential to measure the watercut in the liquid.

2.2 Development 1991 – 1998

In 1991, V. Kratirov set up the company Complex Resource to develop an improved meter, which eventually would become 'Neftemer'. At this time, the early 1990s, the former Soviet Union was breaking up and the next few years were very difficult. The company manufacturing the 'Pulsar' meter went out of business, funds for R&D were virtually non-existent, and for Complex Resource it was a struggle for survival. Effectively, V. Kratirov had to start from scratch again.

However, by 1995 a new prototype was designed for the revised technical requirements, focussing on wells with

- flowrates from 5 - 300 tons/day (approx. 30 - 1800 bbl/day)
- very high watercuts
- thermally stimulated, with variable modes of injecting the steam

The new protype was tested by Lukoil at Lasyogan, Tyumen Region in August 1995 and April 1996. The results are given in section 5.2.

On the basis of the 1995/96 test results, Complex-Resource obtained a contract for the design and development of a yet more advanced version of Neftemer. In 1997, an experimental version was tested in commercial operation. The target accuracy was ±5% relative accuracy in liquid mass flow rate, but this was achieved for only 30% of the points. This was considered unacceptable. After further work on the signal processing ±5% relative accuracy was achieved for about 70% of the points. On the basis of this commercial exercise, the complete set of documentation for the working design of Neftemer was begun. In 1997 certification for the improved Neftemer was achieved.

Detailed tests were made at Langepas in 1998 on air-water flows and on very high watercut oil well flows, and are reported in section 5.2. These tests showed that the shortcomings of the earlier versions had been removed. The instrument could be used as a flow rate indicator, and it could now be submitted to the testing necessary to gain approval to be included in the State Register of Measuring Equipment.

2.3 Development 1998 to 2006

Further operational tests of Neftemer were carried out in 2001 at Usinsk, in the Komi Republic. These tests are reported in section 5.2. By the end of 2005, some 50 Neftemers had been installed and commissioned at Usinsk, on heavy oil, thermally stimulated wells. These were installed as multiple assemblies, with up to 10 detectors mounted on individual vertical flowlines grouped round a common source with 10 windows. This is a very cost effective solution for new installations, but is less attractive for retrofitting. About 150 more were installed and commissioned. As well as metering, these Neftemers have detected operational problems with wells, enhancing their operational value. In 2006, a test was conducted at an oil gathering and separation station which had accurate oil and water metering. The three incoming multiphase pipelines from the fields feeding into the gathering station were fitted with Neftemers. The data from the formal part of this test were not available for this paper, but the data from the preliminary period are discussed in section 5.3.

2.4 Development of Neftemer for use outside Russia

About 1996 first contacts were made with western companies. V. Kratirov presented a paper at the 1997 Norflow seminar in Aberdeen organised by the Institute of Measurement and Control. The people who were to make up the future Neftemer Ltd met at this time, but although interest was shown in Neftemer, most of the western oil companies had cut their research and development budgets severely, and there were no means of setting up an evaluation programme. In 2003 the same people met to investigate the possibilities of developing Neftemer for markets outside Russia. They decided to use the recently installed multiphase test facilities at Cranfield University. Tests began in February 2005, and are discussed further in section 6. Currently work is ongoing to obtain appropriate electrical safety certification for the detector unit and to obtain appropriate approvals for the radioactive source holder. The initial target market is for applications similar to those where Neftemer has been successfully installed in Russia, namely heavy oil, thermally stimulated wells. Single Neftemers will be marketed, as these can be readily retrofitted to existing installations.

3 OPERATING PRINCIPLES

Neftemer comprises two elements: a gamma source housed in a holder unit and a gamma detection unit. As shown in Figure 1, these units are mounted diametrically opposite each other on a vertical pipe section containing a vertically upward multiphase flow.

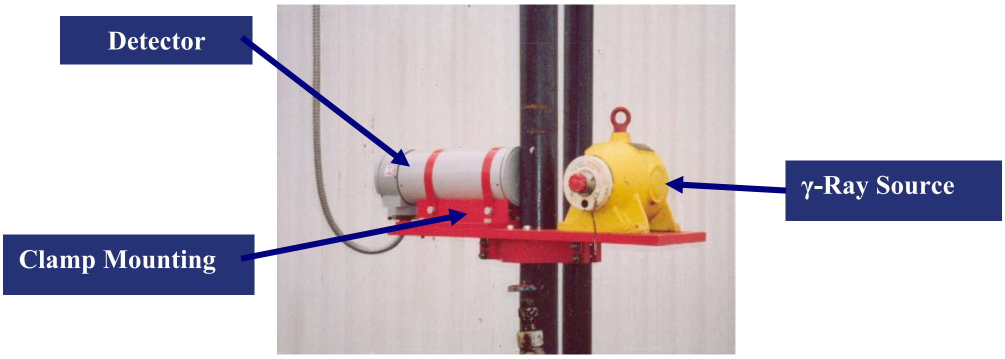

Figure 1 – Neftemer MPFM

The detection unit was specially designed for Neftemer. It uses a sodium iodide crystal with a photomultiplier for the gamma ray detection. Key to Neftemer operation is the fast scan rate for the detector, 250 Hz. The gamma source is the radioisotope caesium-137. The gamma-ray source emits a narrow gamma-ray beam directed along the pipe's cross-sectional diameter towards the sodium iodide crystal in the detector unit. A typical Caesium spectrum measured at the detector after passing through the pipe and multiphase fluid is shown in Figure 2. This spectrum contains the main intense 661 kev peak, but also contains a broad spectrum of less intense, lower energy gamma radiation. Accordingly, Neftemer is inherently a multi-energy multiphase meter

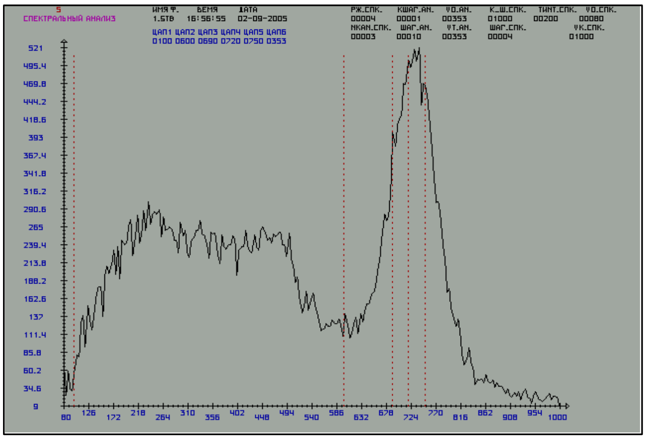

Figure 2 – Caesium-137 Spectrum

Neftemer depends on fluctuations in the density of the multiphase fluid. The density of multiphase fluid is inferred by the raw gamma count monitored by the Neftemer metering system in its operating mode, Figure 3.

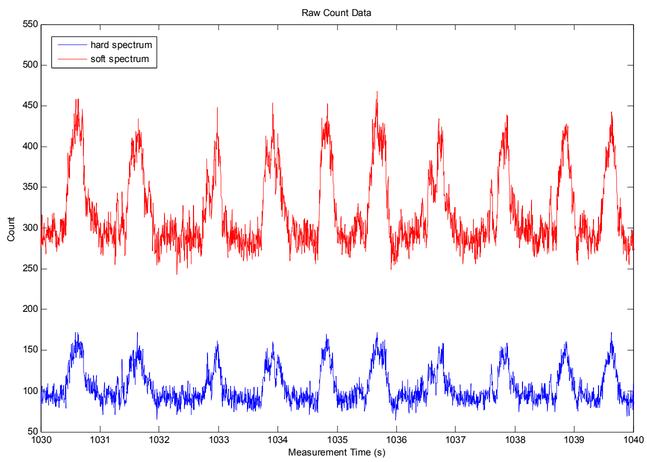

Figure 3 – Example of Raw Count Signal

The meter infers values for the liquid mass flow rate, gas volume flow rate and the water-cut present in a pipeline across which the attenuation occurs. The meter is mounted on a vertical section of pipeline, so axial symmetry in the flow is assumed. The calculation cyle runs every two seconds, so effectively the fluid is chopped up into 2-second sections.

We consider density fluctuations in the pipe during the passage of free gas bubbles in liquid through the measurement section. The passage of an individual bubble of free gas through the pipe section gives an increase in the gamma count as a result of the decrease in absorbing matter along the path of the gamma beam. The count fluctuation pulse amplitude is dictated by the physical size of the bubble while its width is a function of both the bubble size and the fluid velocity. By analysing the multiphase mixture density fluctuations it is possible to determine the velocities for bubbles of different sizes. It is well known that gas bubbles below a critical size will not exhibit phase slip and are effectively entrained in the liquid phase. Thus, the analysis of the motion of liquid entrained bubbles facilitates liquid phase velocity determination. Determination of the average velocity of all gas bubbles yields the gas phase velocity.

In practice, and especially with the heavy oil, high watercut, low gas wells where Neftemers are installed, about half of the time there are no fluctuations. During the periods when there are fluctuations, the challenge is obtain liquid and gas velocities. From the research and development programme over the last 25 years, spectral patterns have been identified for gas and liquid whose frequency of appearance is strongly related to the gas and liquid velocities. The high scan rate, 250 Hz, allows velocities to be determined over a wide range. The next step is to determine the fractions of oil, water and gas across the pipe section for each scan. The single phase absorptions are input to the system during meter calibration. The phase fractions are determined using

- First, the overall gamma density
- Second, the standard dual energy equations, taking the absorptions at two pre-defined energy levels in the detected spectra
- Third, the overall shape of the detected spectrum, which is related to the oil, water and gas fractions.

From the liquid and gas velocities and the oil, water and gas fractions, the oil, water and gas flowrates can readily be determined. It is evident that this method required a detailed mathematical analysis and requires sophisticated statistical processing to generate accurate measurements. In practice, simplifications have to be made to allow Neftemer to operate in real time, and tuning is required for a new application.

4 OPERATING ENVELOPE

The current operating envelope of the Neftemer multiphase flow meter is depicted in Figure 4.

The meter operating envelope is displayed with the delivery envelope for the catenary riser test section of the Cranfield University multiphase test facility. The plot has been annotated with well flow data from field installations in Russian and the laboratory test data from work undertaken at Cranfield University

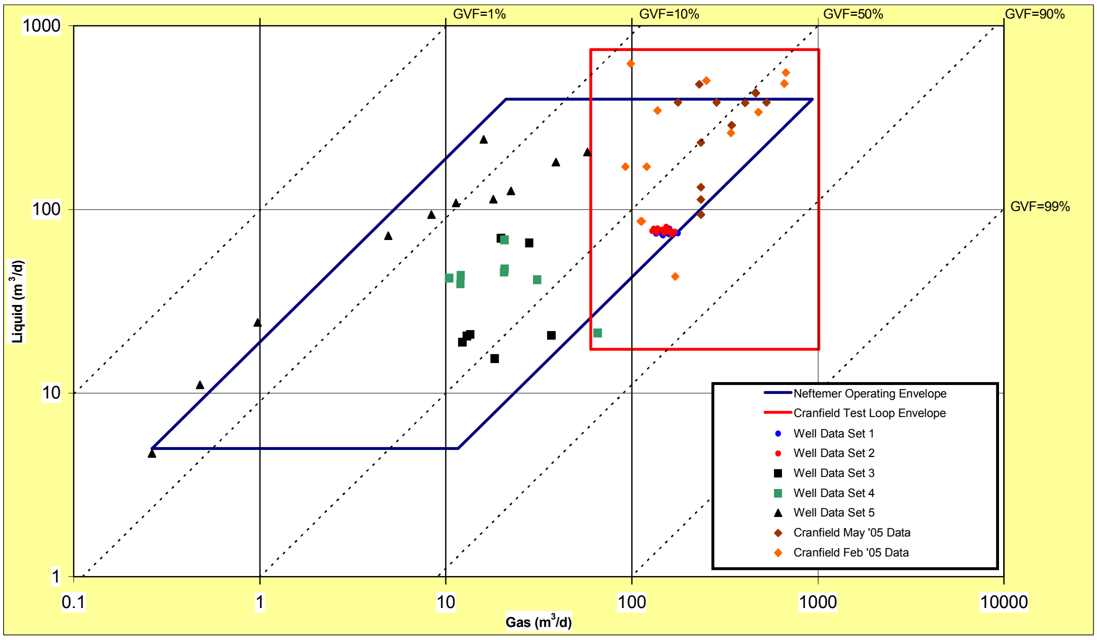

Figure 4 – Neftemer Operating Envelope

5 FIELD TESTING OF NEFTEMER

Neftemer has been subjected to various field tests since its installation in Russian oil fields in order to determine its suitability as a production optimisation tool through accurate multiphase flow rate determination. Thus far, all field trials have been undertaken in Russia on operational wells employing artificial-lift techniques (electrical submersible pumps, sucker rod pumps and screw pumps). Test well characteristics have been varied with water cuts ranging between 28 and 100%, and liquid mass flow rates between 8 and 200 tonne/day. The results from the earlier campaigns in 1995/96, 1998 and 2001 are grouped together. Very recent tests in 2006 are described separately.

5.1 Test Procedure

The Neftemer multiphase meter was tested in the field for the earlier campaigns as follows:

1. The Neftemer instrument was installed on the inlet pipeline of the test line to a separator mounted on a strain-gauge weighbridge.
2. Flow from the test well was diverted to the separator.
3. Well production was gauged by the Neftemer instrument on the inlet. Simultaneously, 'actual' well production was measured by monitoring the mass of the contents of the separator located on the strain-gauge weighbridge.
4. Surfactants were added to the well products.
5. The wells were shut-off from the test line.
6. Gas phase was vented to the atmosphere.
7. The liquid products were kept under atmospheric pressure for 24 hours.
8. Location of the air-oil and oil-water interfaces was determined using an Agar ID-210 Interface Concentration Detection System. (Note: only done for 1995/96 tests.)
9. Volumes of liquid and water were then determined from the level to volume calibration of the separator and converted to mass using the densities of the oil and water.
10. The volume water cut could then be determined and converted to mass watercut
11. Liquid mass and mass water cut measurement errors were determined

NB There are no reference figures for the gas production. The Russian oil companies were not concerned with the gas production from the test wells.

5.2 Results of earlier campaigns

The results issued for three different Neftemer field testing campaigns in 1995/96, 1998 and 2001 are presented below.

Table 1 – LUKOil-Langepasneftegaz Field Trials (Potochnoye Field 1995/1996)

Well	Measurement		Liquid Mass Flow Rate (t/d)			Water Cut				
	No.	Date	Neftemer	Ref. meter	Error (%)	Neftemer	Agar ID201	Sample	Error (%)	
									Agar	Sample
325	1	Aug-95	193	192	0	0.971	0.96	-	1	-
	2	Sep-96	176	180	-2	0.941	-	0.95	-	-1
	3	Sep-96	210	210.1	0	0.92	-	0.95	-	-3
683	1	Aug-95	156	153	2	0.946	0.963	-	-2	-
	2	Sep-96	136	126	8	0.844	-	0.9	-	-6
	3	Sep-96	134	136	-2	0.834	-	0.9	-	-7
864	1	Aug-95	163	173	-6	1.007	0.956	-	5	5
	2	Sep-96	168	177	5	0.895	-	0.95	-	-6
	3	Sep-96	148	168	-13.5	0.891	-	0.925	-	-4
1689	1	Sep-96	8.86	8.6	3	0.901		0.932		3
	2	Sep-96	8.86	8.6	3	0.9	-	0.932	-	-3
1800	1	Aug-95	66	67	-1	0.288	0.287	-	0	-
	2	Sep-96	19.9	20.4	-2	0.967	-	0.98	-	-1
1801	1	Aug-95	-	37	-	0.998	1	-	0	-
	2	Sep-96	24.9	24	4	1	-	1	-	0
1803	1	Aug-95	115	108	6	0.969	0.96	-	1	-
	2	Sep-96	97.1	100.8	-4	0.977	-	1	-	2

In these tests the watercut measurements were also tested. The relative errors in liquid mass flow rate were generally less than 10%, and the watercut errors less than 7%.

Table 2 – LUKOil-Langepasneftegaz Field Trials (Potochnoye Field 1998)

Wells	Reference Measurement	Neftemer Measurement			Error (%)
	Liquid Mass Flow Rate (t/d)	Liquid Mass Flow Rate (t/d)	Water Cut (%)	GVF (%)	Liquid Mass Flow
1689	4.2	4.7	97.5	5.6	11.9
s2_1	11.9	11.1	98.3	4.3	-6.7
s4_2	23.7	24.3	98.3	4	2.5
1176	76.2	72.2	97.8	6.8	-5.2
s5_2	96.5	94	97.4	8.9	-2.6
s5_1	101	108.8	96.9	10.4	7.7
683	120	113.9	94.9	15.8	-5.1
s1_1	125	126.5	94.4	17.7	1.2
s3_1	187	181.7	94.5	21.5	-2.8
s6_1	211.6	206	93.2	28	-2.6
s7_1	227	241.8	98.7	6.6	6.5

The relative errors in mass flow rate were generally well below 10%. No watercut tests were performed.

Table 3 – Nobel Oil Field Trials (Usinsk 2001)

Well	Date	Artificial lift	Reference Measurements		Neftemer Measurements			Liquid Flow Error	
			Water Cut (%)	Liquid Mass Flow (t/d)	Q_{gas} (m^3/d)	Water Cut (%)	Liquid Mass Flow (t/d)	Absolute	Relative
4571	27.11.01	Screw Pump	67	77.7	28.11	58.2	65.85	-11.85	-15%
4571	30.11.01	Screw Pump	67	78.7	19.77	58.3	69.96	-8.74	-11%
6108	21.11.01	Rod Pump	73	44.7	20.71	86.2	47.52	2.82	6%
6108	27.11.01	Rod Pump	73	46.4	10.42	82.7	42.46	-3.94	-8%
6108	30.11.01	Rod Pump	73	47.1	20.57	82.2	45.65	-1.45	-3%
6109	26.11.01	Rod Pump	55	40.7	31.02	81.6	41.49	0.79	2%
6109	28.11.01	Rod Pump	55	-	65.41	51.6	21.3	-	-
7167	24.11.01	Rod Pump	44	75.9	12	80.8	39.57	-36.33	-48%
7167	26.11.01	Rod Pump	44	74.9	20.7	73.9	68.47	-6.43	-9%
7167	26.11.01	Rod Pump	44	75.2	12.04	75	44	-31.2	-41%
7168	24.11.01	Screw Pump	59	21.5	12.98	83.5	20.58	-0.92	-4%
7168	30.11.01	Screw Pump	59	20.6	12.25	80.7	18.94	-1.66	-8%
8290	22.11.01	Screw Pump	77	20.1	13.56	81.3	20.92	0.82	4%
8290	29.11.01	Screw Pump	77	20.5	36.83	78.2	20.67	0.17	1%
8290	01.12.01	Screw Pump	77	-	18.3	78.3	15.45	-	-
7168 & 8990	25.11.01	-	59,77	36.7	15.41	77.8	37.39	0.69	2%
7169 & 8990	29.11.01	-	96,77	37.5	32.34	75.5	23.49	-14.01	-37%
7170 & 8990	01.12.01	-	68,77	37.5	32.45	76.4	31.51	-5.99	-16%
7168, 8290 & 6109	01.12.01	-	59,77,55	40.9	17.89	67.5	49.88	8.98	22%

In these tests there were a large number of wells, or combinations of wells where the relative errors in mass flow rate were very large. This reflected the more difficult fluid conditions, and the fact that when wells are combined, their combined flow is not necessarily the same as the sum of their independent flowrates.

5.3 Testing of Neftemer 2006

These tests were carried out by a different operator. As discussed earlier, the current version of Neftemer was developed to meter heavy viscous oils, released from the reservoir by steam injection. For these wells conventional well testing techniques do not work – oil of 4700 cS viscosity cannot be metered using turbine or PD meters. It was strongly recommended that a testing system based on a separator on a weigh bridge should be built, similar to that used in the 1995/96 tests. This has been designed, but not yet ordered. A number of the Neftemers installed were indicating that well conditions were different to those expected by operational staff, but there was no way of easily confirming the Neftemer indications. Consequently, there was great interest in trying to find an alternative way of checking the performance of Neftemer in the field in the short term.

In the area there are also fields producing light oil (density about 820 kg/m3). These are operated in a conventional manner and so far Neftemers have not been installed on these. The fluids from the wells of each of these fields are commingled and the field production then taken by multiphase pipeline to a common processing station where the oil, water and gas is separated. At one station, oil from three fields was processed. Accurate metering was available for the oil (Smith's Positive Displacement meters) and for the water (Halliburton turbine meters). The gas was not metered accurately. Some is flared, some is used for utility purposes on site, and some goes into the local area gas distribution network. This station was chosen for a comparative test of Neftemer against the station metering.

Single Neftemers were installed In a similar manner to that illustrated in Figure 1 on vertical sections of the incoming multiphase pipelines, one 325 mm diameter (12” nominal) and two 219 mm diameter (8” nominal). As it happened, the 325 mm pipeline carried more than 99% of the total production. The plan for the test was to set up the instruments, seal the instruments and collect data for a month. The oil company would commission an independent analysis of the results. Data from the formal part of the test has so far not been released as the meetings to discuss the results have had to be postponed. We do have data from the preliminary part of the test over an 11 day period from 6 to 17 July 2006. The analysis that follows obviously represents work in progress.

Table 4 – Production measured by Neftemer on incoming pipelines

	Production for time of operation					Production for 24 hours				
Date	Mass of Liquid Tonnes	Mass of Water Tonnes	Mass of Oil Tonnes	Volume of gas m^3	No. of 2-hour intervals	Mass of Liquid Tonnes	Mass of Water Tonnes	Mass of Oil Tonnes	Volume of gas m^3	WC Neftemer %
Neftemer A on 325 mm diameter pipeline										
06/07/06	4227.3	2927.0	1300.4	4941.0	11	4611.6	3193.0	1418.6	5390.1	69
07/07/06	3884.8	2744.4	1140.4	4337.1	10	4661.8	3293.3	1368.5	5204.5	71
08/07/06	3967.5	2839.1	1128.4	4295.3	10	4761.0	3406.9	1354.1	5154.3	72
09/07/06	791.8	569.3	222.5	847.5	2	4750.9	3415.9	1334.9	5085.0	72
10/07/06	1208.2	872.9	335.3	1278.3	3	4832.9	3491.6	1341.3	5113.1	72
11/07/06	4514.3	3321.0	1193.3	4507.2	11	4924.7	3622.9	1301.8	4916.9	74
12/07/06	4421.4	3194.7	1226.7	4674.8	11	4823.3	3485.1	1338.2	5099.8	72
14/07/06	3622.3	2622.3	999.9	3809.8	9	4829.7	3496.4	1333.3	5079.7	72
15/07/06	4504.1	3311.5	1192.7	4508.2	11	4913.6	3612.5	1301.1	4918.1	74
16/07/06	4682.1	3315.6	1366.5	5202.7	12	4682.1	3315.6	1366.5	5202.7	71
17/07/06	4676.3	3305.9	1370.5	5216.4	12	4676.3	3305.9	1370.5	5216.4	71
Neftemer B on 219 mm diameter pipeline										
06/07/06	0.4	0.3	0.1	0.6	1	4.8	3.6	1.2	7.2	75
07/07/06	4.3	3.2	1.1	6.4	11	4.7	3.5	1.2	6.9	74
08/07/06	2.3	1.7	0.6	3.4	6	4.6	3.5	1.2	6.8	75
09/07/06	0.8	0.6	0.2	1.1	2	4.6	3.4	1.1	6.7	74
10/07/06	5.6	4.2	1.4	8.2	12	5.6	4.2	1.4	8.2	75
11/07/06	5.6	4.2	1.4	8.2	12	5.6	4.2	1.4	8.2	75
12/07/06	5.2	3.9	1.3	7.5	11	5.6	4.2	1.4	8.2	75
14/07/06	4.3	3.2	1.1	6.2	9	5.7	4.2	1.4	8.2	75
15/07/06	3.3	2.5	0.8	4.8	7	5.6	4.2	1.4	8.2	75
16/07/06	5.6	4.2	1.4	8.1	12	5.6	4.2	1.4	8.1	75
17/07/06	5.6	4.2	1.4	8.1	12	5.6	4.2	1.4	8.1	75
Neftemer C on 219 mm diameter pipeline										
06/07/06	28.9	28.3	0.7	3.7	12	28.9	28.3	0.7	3.7	98
07/07/06	29.3	28.6	0.7	3.8	12	29.3	28.6	0.7	3.8	98
08/07/06	30.7	30.0	0.7	4.1	12	30.7	30.0	0.7	4.1	98
09/07/06	5.2	5.1	0.1	0.7	2	31.1	30.4	0.7	4.2	98
10/07/06	26.0	25.4	0.6	3.5	10	31.2	30.5	0.7	4.2	98
11/07/06	28.6	27.9	0.7	3.8	11	31.2	30.4	0.7	4.2	98
12/07/06	25.8	25.2	0.6	3.5	10	31.0	30.3	0.7	4.2	98
14/07/06	19.8	19.3	0.5	2.6	8	29.6	29.0	0.7	3.9	98
15/07/06	24.6	24.0	0.6	3.2	10	29.5	28.8	0.7	3.9	98
16/07/06	26.8	26.2	0.6	3.5	11	29.3	28.6	0.7	3.9	98
17/07/06	26.8	26.2	0.6	3.5	11	29.2	28.6	0.7	3.8	98

Table 4 gives the production data for the three pipelines. In the metering reporting system, oil, water and gas totals are displayed in 2-hourly increments and 24- hour totals. The Neftemers were configured accordingly. During this period when installation and commissioning work was going on, the Neftemer record is not continuous. However, production from the fields was very steady during this period, confirmed by operator observations at the wells. For days when a complete record was not available, the average flow rate over the number of complete 2-hour increments has been converted to a 24-hour total for comparison with the 24-hour totals for the separated oil and water metering figures.

Table 5 – Comparison of Neftemer totals with Gathering Station Metering totals

	Total production - Neftemer				Total production - Metering system			
Date	Mass of Liquid Tonnes	Mass of Water Tonnes	Mass of Oil Tonnes	Mass WC %	Mass of Liquid Tonnes	Mass of Water Tonnes	Mass of Oil Tonnes	Mass WC %
06/07/06	4645.4	3224.9	1420.4	69.4	4641.7	3296.9	1344.8	71.0
07/07/06	4695.8	3325.4	1370.4	70.8	4753.3	3454.4	1298.9	72.7
08/07/06	4796.4	3440.4	1356.0	71.7	4763.7	3487.8	1275.9	73.2
09/07/06	4786.6	3449.7	1336.8	72.1	4831.2	3477.4	1353.8	72.0
10/07/06	4869.8	3526.3	1343.5	72.4	4807.5	3447.1	1360.4	71.7
11/07/06	4961.5	3657.6	1303.9	73.7	4863.2	3493.0	1370.2	71.8
12/07/06	4860.0	3519.6	1340.4	72.4	4911.1	3536.8	1374.3	72.0
14/07/06	4865.0	3529.6	1335.4	72.6	4842.4	3426.3	1416.1	70.8
15/07/06	4948.7	3645.5	1303.2	73.7	4866.3	3434.6	1431.7	70.6
16/07/06	4716.9	3348.4	1368.5	71.0	4787.4	3468.0	1319.4	72.4
17/07/06	4711.1	3338.6	1372.5	70.9	4728.6	3434.6	1294.0	72.6

Table 5 gives the liquid, water and oil production figures from all Neftemers and from the station metering system on a daily basis for the 11 day test period. This table also gives the Mass Watercut figures (the ratio of mass of water to mass of liquid).

Table 6 – Observed errors in Neftemer relative to Gathering Station

	Error (only for 325 mm pipeline)				Error (all 3 pipelines)			
Date	Relative error mass liquid, %	Relative error mass water, %	Relative error mass oil, %		Relative error mass liquid, %	Relative error mass water, %	Relative error mass oil, %	Abs. error Mass Watercut %
06/07/06	-0.6	-3.2	5.5		0.1	-2.2	5.6	-1.6
07/07/06	-1.9	-4.7	5.4		-1.2	-3.7	5.5	-1.9
08/07/06	-0.1	-2.3	6.1		0.7	-1.4	6.3	-1.5
09/07/06	-1.7	-1.8	-1.4		-0.9	-0.8	-1.3	0.1
10/07/06	0.5	1.3	-1.4		1.3	2.3	-1.2	0.7
11/07/06	1.3	3.7	-5.0		2.0	4.7	-4.8	1.9
12/07/06	-1.8	-1.5	-2.6		-1.0	-0.5	-2.5	0.4
14/07/06	-0.3	2.0	-5.9		0.5	3.0	-5.7	1.8
15/07/06	1.0	5.2	-9.1		1.7	6.1	-9.0	3.1
16/07/06	-2.2	-4.4	3.6		-1.5	-3.4	3.7	-1.5
17/07/06	-1.1	-3.7	5.9		-0.4	-2.8	6.1	-1.8
Average	-0.63	-0.84	0.10		0.11	0.12	0.25	-0.02
2 x Std. Dev.	2.43	6.76	10.90		2.44	6.79	10.90	3.49

Table 6 gives the errors in Neftemer assuming no error in the station metering. This is reasonable for this analysis provided the station metering is at least a factor of three more accurate than the Neftemers. Several sets of errors are shown.

- The relative errors in oil and water daily totals for the sum of all three Neftemers
- The relative errors in oil and water daily totals ignoring the two smaller pipelines which contribute together less than 1% of the production during the test period
- The absolute error in watercut for the daily liquid production
- The average values of the above for the 11 day test period
- 2 x Standard Deviation of the above daily error figures have been calculated to indicate the uncertainty at 95% confidence level

Figure 5 give plots over the test period of the liquid, water and oil data for the station metering system, all three Neftemers and for Pipeline 325 alone.

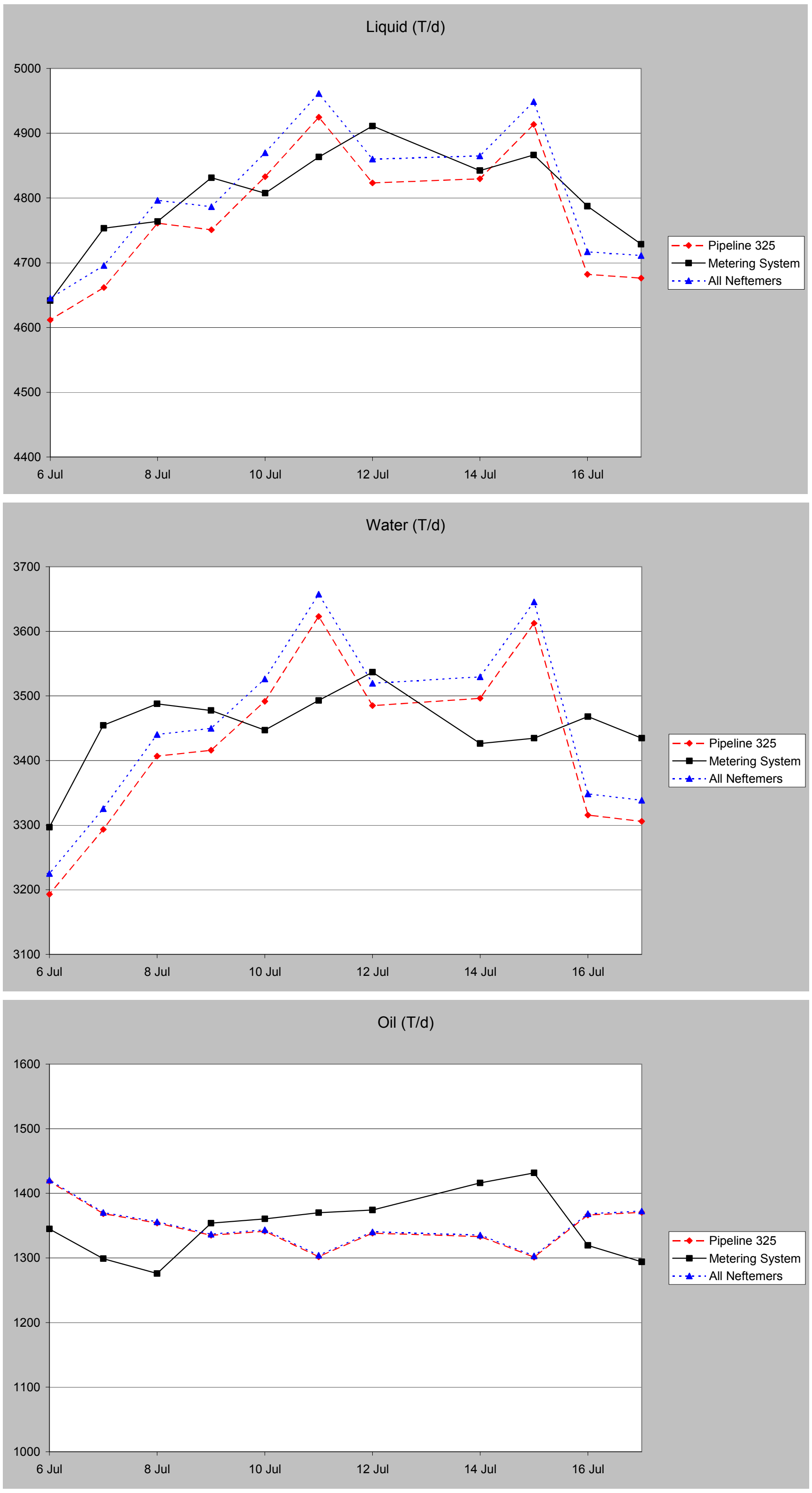

Figure 5 – Liquid, water and oil data for Neftemer and Gathering Station Metering

We make the following observations:

- The average errors in the daily production figures for liquid, water and oil (0.11%, 0.12%, 0.25% respectively) indicate that the systematic errors from the calibration and setting up procedures were small and that the larger daily variations were mostly random.

- The average errors for the daily liquid and water figures for pipeline 325 only (-0.63% and -0.84% reflect a systematic error introduced because the contribution from the two smaller pipelines was about 95% water. This is also a confirmation of Neftemer's ability to see small changes in multiphase flows.

- The liquid production was steady during the test period, varying by less than 6% on a daily basis. As a result one can consider this test as 11 repeat measurements of the same multiphase flow. The values for 2 x Standard Deviation of the measurements for liquid, water, oil and mass watercut (2.4%, 6.8%, 10.9%, 3.5% respectively) give an indication of the uncertainties at that liquid production rate and watercut. The paper by Slijkerman et al (Oil companies' needs in multiphase flow metering, NSFMW 1995) gave target accuracies for liquid measurement of 10% relative for well testing and 5% relative for allocation, and a target accuracy for (volume) watercut of 2% for all applications. From this test Neftemer has performed well regarding the measurement of liquid, but improvements in the watercut measurement are required.

- Although the liquid production varied by only some 6% during the test period, the Neftemers clearly tracked this variation in production accurately. This is further confirmation that in this test the uncertainty of Neftemer was significantly less than the variation in the liquid production. For the water and the oil the indicated uncertainty (6.8%, 10.9% respectively) was only slightly less than the variation in the water an oil production (7.3% and 12.2% respectively), and one cannot expect clear tracking of the variation in water and oil production.

- The Neftemers on the 219 mm diameter pipelines were being asked to measure very low flow rates, corresponding to superficial liquid velocities of about 2 mm/s and 10 mm/s. The superficial velocity in the 325 mm line was about 700 mm/s, 350 and 70 times greater by comparison. This test did not allow the accuracy at these low flow rates to be estimated, but it is evident from the plot of liquid production that the Neftemers on the smaller pipelines are giving reasonable data. The key to the good performance in liquid measurement is the fast scan rate, 250 Hz, for acquiring the gamma ray spectra.

6 LABORATORY TESTING OF NEFTEMER

In February 2005, two Neftemer multiphase flow meters were installed on Cranfield University's multiphase flow facility. The facility is capable of providing a wide variety of flow regimes, similar to those found in oil and gas industry at flow rates and in pipe sizes comparable with industrial practice. The facility has a maximum operating pressure of 25 barg and the test fluids comprise air, tap water (treated with biocide) and BP-7269 lubricating oil (ρ = 815 kg/m^3, μ = 4 cS). The flow loop can deliver up to 140 m^3/h of oil and/or water, and 4000 Sm^3/h of air. The two meters were installed in series, at the top of the riser, at right angles to each other, Figure 6. They were installed close together to allow direct comparison of their performance.

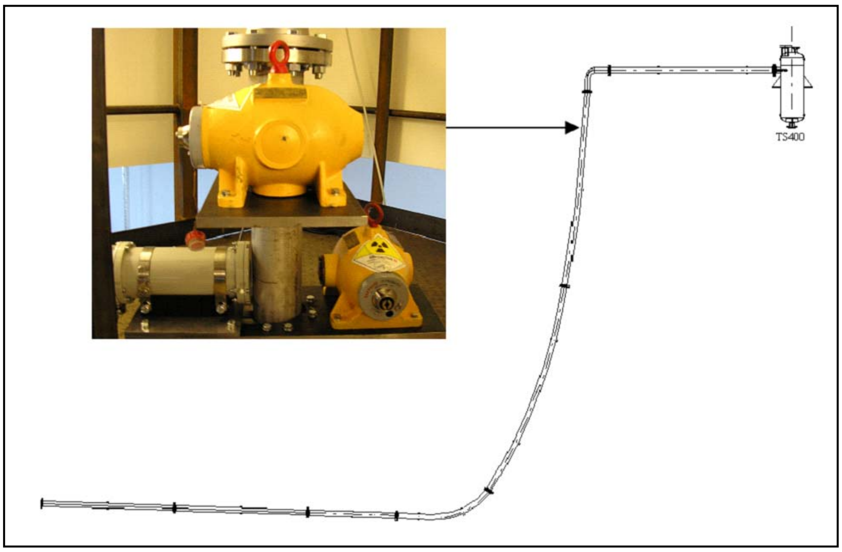

Figure 6 – Neftemer Units Installed at the Top of the Riser

The test programme was based on that for Multiflow 2 in order to allow straightforward comparison of performance with other multiphase meters in the market. It comprised a relatively small subset of the Multiflow 2 test matrix and is given in Table 7.

Table 7 – Test Matrix

Liquid Flow Rate (kg/s)	GVF (%)						
	15	30	35	40	55	60	80
0.5							x[3]
1						x[3]	
2			x[2]	x[2]			
3					x[1]		
4		x[6]				x[3]	
5.5			x[4]		x[5]	x[4]	
6							
7	x[4]						

Notes:
1 -Test point to be made at 35% water-cut.
2 -Test point to be made at 40% water-cut.
3 -Test point to be made at 50% water-cut.
4 -Test point to be made at 55% water-cut.
5 -Test point to be made at 60% water-cut.
6 -Test point to be made at 80% water-cut.

The considerable differences in the conditions of the laboratory test facility and the field conditions in which Neftemer has been set up to operate are summarised in Table 8.

Table 8 – Difference between Laboratory and Field Conditions

Conditions in Test Loop	Conditions in Field
Pipe work: 304 Stainless Steel (Schedule 40)	Pipe work: Carbon Steel (range of thicknesses)
Oil is lubricating oil	Oil ranges from heavy to medium
Water is tap water	Water is saline formation water
Gas is air	Gas is natural gas

6.1 Results

The results of the phase 1 preliminary tests were encouraging in terms of meter performance.

Figure 7 plots the results for the total liquid flow rate measurement. 92% of readings were within the specified target accuracy of ±10%, relative to test facility, with 75% as close as ±5%.

Figure 8 plots the results for the gas flow rate measurement. These met the specified target accuracy of ±10%, relative to the test facility, for 75% of Neftemer's readings. 58% of readings were within ±5%

Figure 9 plots the results for the water-cut measurements. It was observed that 58% of readings were within ±5% absolute error. However, there was a large spread of errors during tests with no apparent trend in these inaccuracies

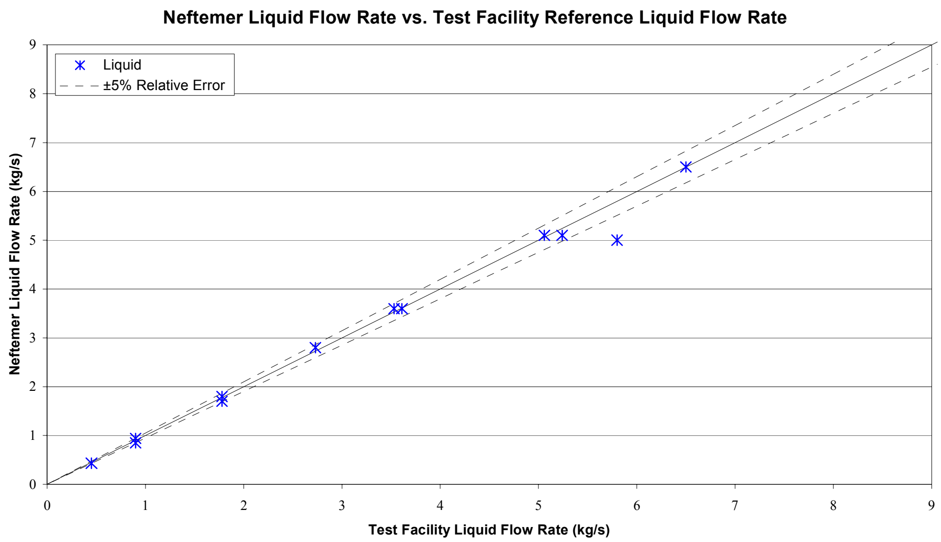

Figure 7 – Neftemer Liquid Flow Rate vs. Test Facility Reference Liquid Flow Rate

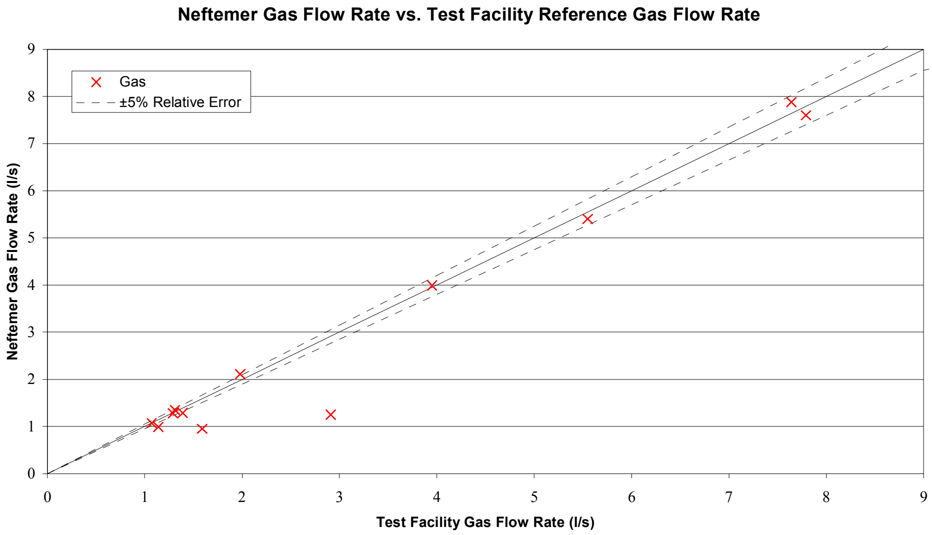

Figure 8 – Neftemer Gas Flow Rate vs. Test Facility Reference Gas Flow Rate

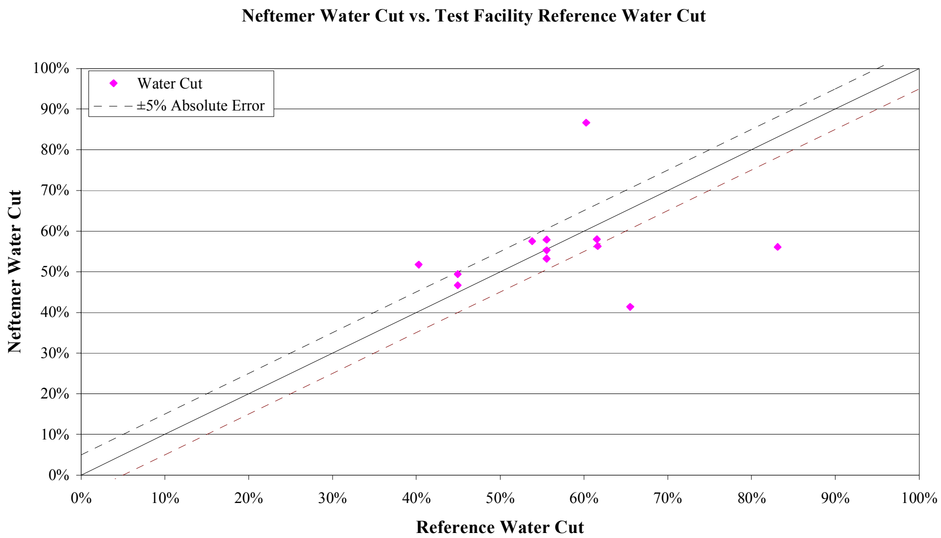

Figure 9 – Neftemer Water Cut vs. Test Facility Reference Water Cut

6.2 Further tests

Neftemer is designed to measure the slowly changing flow rates of producing wells. If the production rate changes abruptly, it requires some time to build up the statistics from the new flow pattern before it can give accurate measurements. This means that comparison of Neftemer with a Western style test loop can be very time consuming. On the Cranfield test loop, at least 30 minutes were required for each test point. It can be difficult to maintain stable conditions in test loops for long periods, particularly at high flow rates.

In May 2005, further tests were made, but we have not yet been able to make sense of the data. This has partly been due to the large amount of installation and commissioning work in Russia, and partly due to difficulties in reprocessing the test data. Operation of the test loop was checked, and the two Neftemers were tracking each other. For us, the clear warning was that there is still much to be understood in how Neftemer and the test loop interact, and that it would be wise to apply Neftemer initially on applications that are similar to those where it has been shown to work in Russia.

7 CONCLUSIONS

Neftemer has been developed over more than 25 years for lower production, artificially lifted, land based wells, which represent most of the oil wells in the world. It has been demonstrated that the non-intrusive measurement principles can work for a wide range of crude oils, in particular very heavy, high viscosity oils, and for a wide range of flow line sizes.

Field calibration methods based on a separator on a weighbridge are a practical method for testing multiphase meters on low pressure production systems. These should be considered for Western applications.

The difficulties of testing Neftemer on a Western style test loop challenge the underlying thinking behind the use of these test loops. It is clear that they have a very important, indeed essential role in understanding multiphase flows. However, they do not, and perhaps cannot, accurately reproduce the conditions in flowing wells. There is a great need to find out how to combine field testing methods and laboratory testing methods.

The results of the testing at Cranfield gave warning to be careful when tackling new applications. Neftemer, as a non-intrusive, easily installed meter, can be used as a diagnostic device to assess wells before deciding on a permanent installation.

There is a perception that multiphase metering is a “mature” technology. The market penetration of about 0.2% (say 2000 meters for about 1 million oil wells worldwide) strongly suggests otherwise. We believe that multiphase metering is just beginning to make its impact felt, and that a diverse range of multiphase meters will be required. Neftemer is a versatile and cost-effective addition to that range of multiphase meters.