18th NORTH SEA FLOW MEASUREMENT WORKSHOP 2000

MULTIPHASE FLOW RATE IDENTIFICATION BY PATTERN RECOGNITION AT SHELL AUK ALPHA PLATFORM

Dr Haluk Toral, PSL
Dr Shiqian Cai, PSL
Dr Ersin Akartuna, PSL

1 INTRODUCTION

Multi-phase flow metering methodology developed by PSL is founded on the premise that there is a relationship between the time, frequency and amplitude domain properties of the turbulent hydrodynamic signals sampled at a high frequency and the average “engineering quantities”. In specific laboratory and industrial implementations of the methodology, it has been shown that there is non-linear relationship between the turbulent pressure signals and the average flow rates of the total liquid and gas phases and the turbulent impedance signal and the composition of the liquid phase (as water/oil). The relationships can be mathematically modeled by neural nets or template matching pattern recognition systems. It has also been established that models are conditioned by “field effects” such as pipeline, fluid composition, temperature and pressure. In theory, the field effects can be compensated by means of a large scale database of hydrodynamic signals and the field parameters. The method and the resulting flow meter named Expert System for Multiphase Metering (ESMER) was described in detail in a number of publications [1], [2], [3], [4], [5], [6], [7], [8], [9].

The paper describes the results of a special project carried out by Petroleum Software Limited on behalf of Shell Expro Limited on the Shell Auk Alpha Platform. This platform does not have a test separator, so well testing necessarily means significant deferment of oil production. The project aimed to monitor liquid and gas flow rates from a number of wells on the platform by analysis of the characteristics of pressure and impedance sensor signals, and thus demonstrated that ESMER could be used for well testing. The sensors were mounted on a full bore pipe the same diameter as the process line (no obstruction to flow and no differential device). The spool was previously used on another production line from July 1997 to July 1999 when the system was re-installed downstream of the low pressure production manifold with the objective to measure flow rates from a number of wells. These exhibited a variety of operating conditions and enhanced recovery procedures. Oil flow rate was of most important to the operators, and it was possible to calibrate in situ for this parameter against the oil flowrate measurement by a vortex meter in the outlet of the free water knock out (FWKO) vessel. This meter was carefully set-up for the well tests that in effect used the FWKO vessel as a limited-capability test separator. The operators’ performance targets were:

- Oil flow rate accuracy against platform meter of better than 15%
- BS&W accuracy against platform lab analysis of better than 25%
- Gas Flow rate accuracy - some thing believably close to estimated GOR
- Oil trend responds correctly to change in flow rate in both directions.

Due to the cost of well tests it was requested that this performance should be achieved after 2 calibrations (well tests) per well.

One of the exciting aspects of the project was that it was managed entirely from base through internet without necessitating any off-shore visits by PSL. The data presented in this paper was obtained entirely by the platform staff. The platform staff ran the tests and the ESMER system independently and transmitted data to PSL at intervals. PSL analyzed the data at base and returned to the platform the calibration models (neural nets) through internet. The platform staff would then install the neural nets on the ESMER PC and the measurements would continue. A data interface was also developed to view the measurements in real time at the beach.

2 HARDWARE

The spool comprised a non-intrusive horizontal four inch diameter pipe which was mounted with two Druck differential pressure sensors (axial and radial tappings), a Druck absolute pressure sensor, a capacitance sensor and an impedance sensor made by Meridian (now Milltronics). The distinctive characteristics of the sensors are that they all give a frequency response of 100Hz or more. The signals were carried into the control room with a 4-20 mA circuit, passed through Zener barriers and sampled digitally by means of a PC at the rate of 800 Hz for a sampling period of 40.96 s.

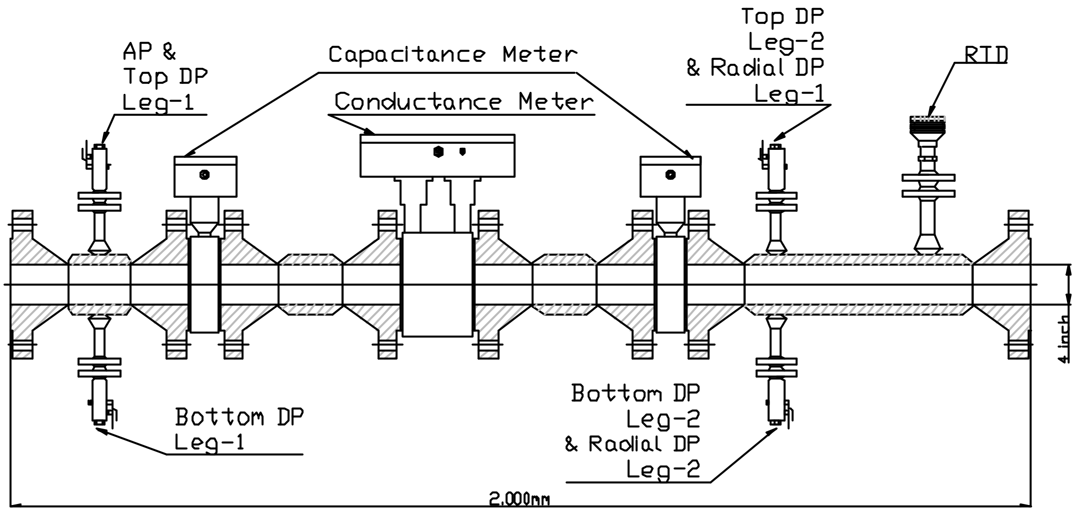

Fig. 1 - Hardware Schematic

3 SOFTWARE

The software system consists of two parts. The metering software (running on a PC in the control room) is named the *Client System*. This system contains a neural net, which is capable of identifying turbulent patterns and the flow rates of individual phases, which are related to these patterns. Another software system, maintained at base is named *the Server System*. The Server System comprises a "universal" data base of turbulence "fingerprints" and signal processing algorithms which are used to train the neural nets (which eventually run on the *Client System)*. The Client System shares a common input / output standard with the Server System to enable exchange of data. At intervals chosen by the operator, field data can be transmitted to the Server for re-tuning the calibration. The new calibration can then be downloaded to the Client System through Internet.

Two other features of the Client System worth noting are its capability to handle multiple wells and its real time interface with the onshore mainframe. It was intended that the operations production technologist and production programmer based onshore would make use of the real time data to optimise the oil production in conjunction with offshore staff.

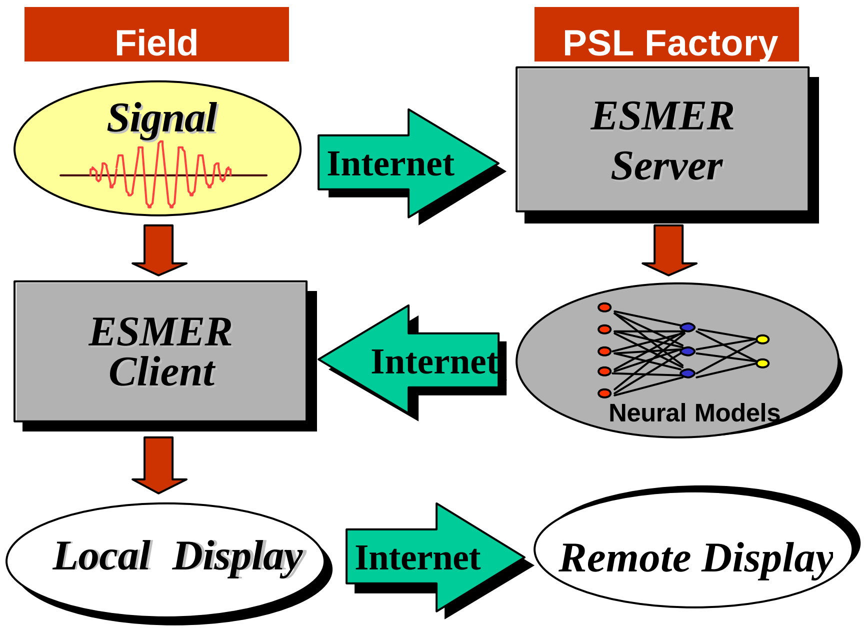

Fig. 2 - Data Flow between the Field and the Base

4 INSTALLATION

The system was installed horizontally on a by-pass between the low pressure manifold and the low pressure FWKO vessel as shown on the diagram below. A total of ten wells were connected to the low pressure manifold designated as AA01 to AA11 (missing out AA09).

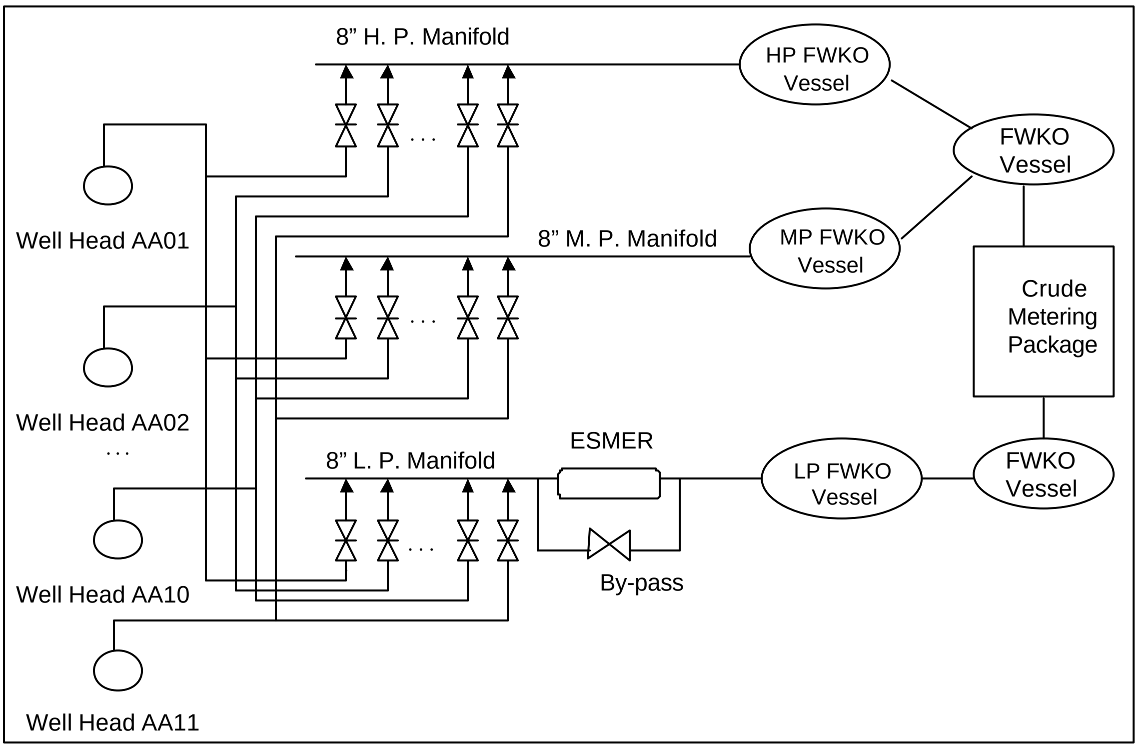

Fig. 3 - Process Line Diagram

5 CALIBRATION REQUIREMENT

In the present context calibration means establishing the relationship between the characteristics of the high frequency samples drawn from the process line by ESMER and the reference measurements (well tests) made by the operators. Ideally the well tests should cover a wide range of conditions and should involve all the wells. The performance of the system will improve with repeated well tests covering as wide a stretch of the normal operating envelope as possible. (The operators stipulated that the performance target should be reached after two tests per well). A technical point that needs particular attention is that sampling and recording of reference measurements must be done synchronously. The full calibration cycle consisted of three stages:

1. At the platform: Run well tests where the oil flow rate is measured by a vortex meter in the outlet of the FWKO vessel, the water composition is measured by BS&W and GOR was estimated. The test data (Reference Log) is transmitted by e-mail to PSL together with data sampled by the ESMER system.

2. At PSL: The new calibration (neural net model) is derived from the latest well test results. The model is back tested against previous well test data and then transmitted to the platform by e-mail.

3. At the platform: The new calibration is installed on the ESMER PC.

The above exercise was repeated for different wells as each well had a different flow characteristic.

6 OPERATING ENVELOPE OF THE WELLS

The production rate of the wells is shown on the diagram below. These show the normal producing characteristics of the wells. Production was enhanced at times by gas lifting or water injection and resulted in considerable variation of the operating characteristics.

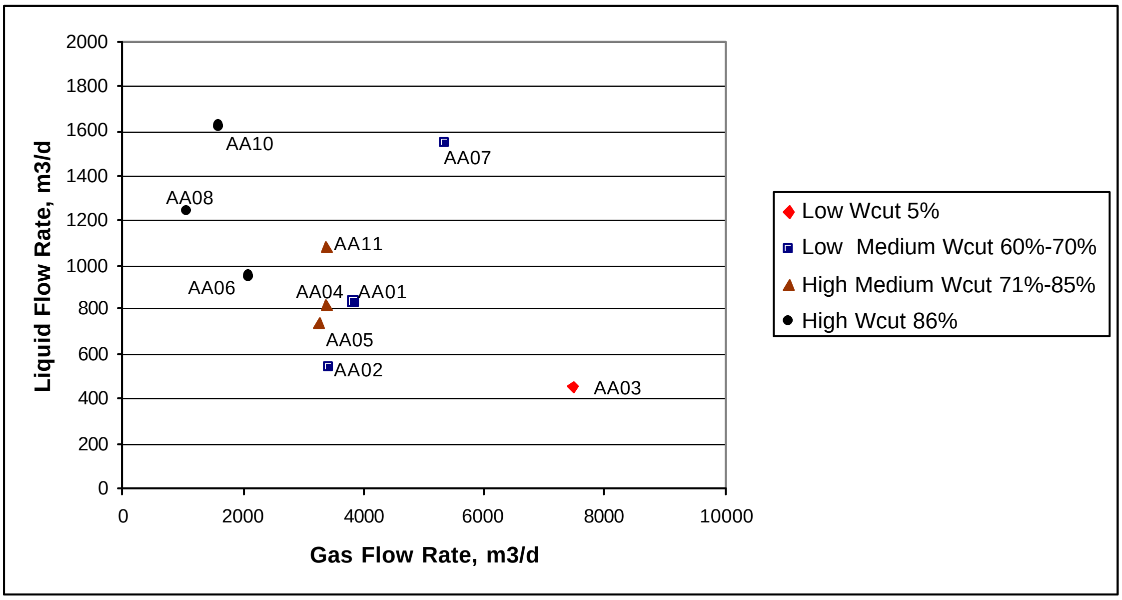

Fig. 4 - Operation Envelope of Wells

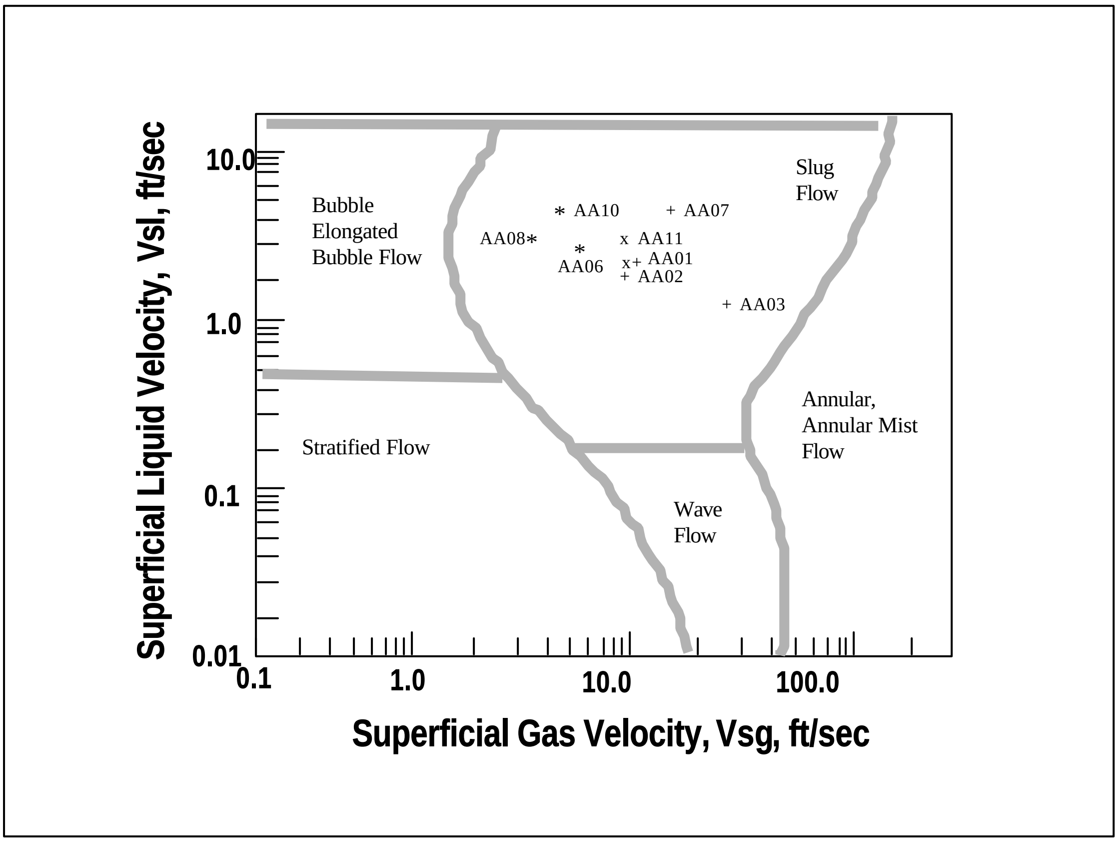

Fig. 5 - Flow Regime of Wells

The expected liquid and gas flow rate for each well was converted into superficial velocity coordinates to identify the flow regimes (within the horizontal ESMER spool). It is seen that all the wells are producing in the slug flow regime but some wells are positioned on the opposite extremes of the slug flow regime. For instance well A08 borders on the bubbly flow whereas well A03 is close to the annular flow regime.

7 WELL TESTS

Well tests used in this study are listed on the following table. This is a sub-set of the full range of tests carried out during the course of the project. At interim stages calibrations were released to the operators based on the results of some tests which were eliminated subsequently on account of their quality. Thus, some of the on-line measurements carried out by the operators during live use were made with calibrations which were less than perfect.

The quantities measured directly were the oil flow rate from the WFKO vessel and the water composition from BS&W. The total liquid rate was determined from: OilRate/(1-WaterCut/100) and the gas flow rate was determined from the estimated GOR of 31. The last column on the table indicates whether the by-pass line around ESMER was left open or closed during the test. Normally, it was required that the by-pass should be kept closed so that the reference measurements can be related to the ESMER data samples in the neural net training exercise but in some tests the by-pass was left open accidentally. The data for such tests became useful later for verifying that the neural net was trending the reduction of flow rates (flow split round the by-pass) correctly.

Table 1 - Well Tests for Calibration of the ESMER System

	Well No.	MPM	MPM	% Well	Tot Oil	Liquid	Gas Flow	Well Test	Well Test	By-Pass
		Press Bar	Temp, C	BS&W	m3/day	m3/day	m3/day	Date	Time	Status
1	AA01	0.9	83.9	58	365.3	870	5898	8-Aug-99	11:00-15:00	Open
2	AA01	2.3	86.3	60.8	327	834	3833	19-Dec-99	14:00-18:00	Close
3	AA02	1.1	83.4	68.5	211	670	3722	1-Sep-99	13:00-18:00	Open
4	AA02	1.1	81.1	65	188.8	539	3427	26-Nov-99	12:00-15:00	Close
5	AA03	1.1	58	4	434.88	453	7485	13-Feb-00	14:00-18:00	Close
6	AA04	0.7	81	70	265	883	5940	1-Aug-99	08:00-12:00	Open
7	AA04	0.7	81.5	73	243.6	902	5476	7-Aug-99	08:00-12:00	Open
8	AA04	1.5	81.4	78	221.6	1007	3381	26-Nov-99	08:00-11:00	Close
9	AA04	1.5	83.6	72	229	818	3391	19-Dec-99	08:00-13:00	Close
10	AA05	0.5	81.2	82	133.1	739	3277	7-Aug-99	14:00-18:00	Open
11	AA06	1.2	85	86	161.33	1195	2731	30-Aug-99	12:00-18:00	Open
12	AA06	1.8	85.8	84	152	950	2097	21-Nov-99	11:00-1400	Close
13	AA07	1.3	73	25	444	592	6968	28-Aug-99	13:00-18:00	Open
14	AA07	3.5	87	57	495.3	1165	4743	6-Sep-99	09:00-11:00	Close
15	AA07	2.9	86	61	484.8	1243	4642	6-Sep-99	14:00-16:00	Close
16	AA07	2.9	85.7	63	508.8	1375	4973	25-Nov-99	11:30-14:30	Close
17	AA07	3	86.5	64	555.6	1543	5348	18-Dec-99	08:00-12:00	Close
18	AA08	2.1	93.2	93.3	83.2	1242	1058	20-Nov-99	13:30-16:30	Close
19	AA10	2.1	91.7	92	129.6	1620	1602	25-Nov-99	15:30-18:30	Close
20	AA11	2.1	89	83	256.6	1509	3717	26-Aug-99	09:00-15:00	Open
21	AA11	2.4	90	85	154.2	1063	2651	5-Sep-99	17:00-21:00	Close
22	AA11	2.7	88.7	83	200	1176	3035	20-Nov-99	09:00-12:00	Close
23	AA11	2.5	88.9	80.6	210	1082	3392	18-Dec-99	13:00-17:00	Close

8 CALIBRATION DETAIL

The wells exhibited different production characteristics. Some wells were in the water injection mode and produced more water than oil. Some wells were in natural production mode and produced more oil than water with water cut around only 5%. Some wells produced more gas with a higher GOR ratio. Wells were firstly grouped into three different pools according to their production characteristics.

Table 2 - Well Pools

Pool	Description	Wells in the Pool
A	General	AA01, AA02, AA04, AA05, AA06, AA07, AA08, AA10
B	High GOR	AA11
C	Oil Continuous	AA03

Two neural net models were trained for each pool. One of these was used for identifying the liquid and gas flow rates and the other the water cut.

Stochastic features derived from the absolute pressure (AP), bottom differential pressure (BDP), top differential pressure (TDP) and radial differential pressure (RDP) sensors were used to train the flow rate models.

The data sets used to train the two neural net models consisted partly of data gathered at the NEL laboratory and partly of the present well test data.

Table 3 - Well tests used in training model in Pool A

Well No.	LP Man	MPM	MPM	% Well	Tot Oil	Liquid	Gas Flow	Well Test	Well Test
	Press Bar	Press Bar	Temp C	BS&W	M3/Day	M3/Day	M3/Day	Date	Time
AA02	1.9	1.1	81.1	65	188.8	539	3427	26-Nov-99	12:00-15:00
AA04	2.6	1.5	81.4	78	221.6	1007	3381	26-Nov-99	08:00-11:00
AA04	2.6	1.5	83.6	72	229	818	3391	19-Dec-99	08:00-13:00
AA06	2.7	1.8	85.8	84	152	950	2097	21-Nov-99	11:00-1400
AA07	4.6	2.9	85.7	63	508.8	1375	4973	25-Nov-99	11:30-14:30
AA07	4.6	3.0	86.5	64	555.6	1543	5348	18-Dec-99	08:00-12:00
AA08	3.1	2.1	93.2	93.3	83.2	1242	1058	20-Nov-99	13:30-16:30
AA10	3.6	2.1	91.7	92	129.6	1620	1602	25-Nov-99	15:30-18:30

Table 4 - Well separator test was used in training model in Pool B

Well No.	LP Man	MPM	MPM	% Well	Tot Oil	Liquid	Gas Flow	Well Test	Well Test
	Press Bar	Press Bar	Temp C	BS&W	M3/Day	M3/Day	M3/Day	Date	Time
AA11	4.1	2.7	88.7	83	200	1176	3035	20-Nov-99	09:00-12:00
AA11	3.9	2.5	88.9	80.6	210	1082	3392	18-Dec-99	13:00-17:00

Table 5 - Well separator test was used in training model in Pool C

Well No.	LP Man	MPM	MPM	% Well	Tot Oil	Liquid	Gas Flow	Well Test	Well Test
	Press Bar	Press Bar	Temp C	BS&W	M3/Day	M3/Day	M3/Day	Date	Time
AA03	1.9	1.1	58	4	434.88	453	7485	13-Feb-00	14:00-18:00

The structure of the flow rate neural model is 16 features in the input layer, 8 neurones in the hidden layer and 2 neurones in the output layer. The structure of water cut neural model is 16 features in the input layer, 8 neurones in the hidden layer and 1 neurone in the output layer.

9 TESTING

Two types of tests were performed to evaluate the performance of the system. First type of test involved training the models with some well test data and testing against others (not included in the training). The other type of test was to see the trending in the predictions. That is, for example, when all evidence pointed to the fact that the flow should be lower or higher did ESMER trend as expected.

9.1 AA01

Pool A model (excludes AA01 well tests) was used for testing against the well test of AA01 on 19.12.99. The model agrees with the reference measurements very well as shown on the following table. However it should be acknowledged that this level of accuracy is exceptional and no claim is made here that it represents a norm which is reproducible (with this particular system and calibration environment).

Table 6 - Pool A Test Results of AA01 on 19.12.99

Date	Meter measurement				Separator Ref.				Error			
	Oil	Liq.	Gas	Wc	Oil	Liq	Gas	Bs&W	Oil	Liq.	Gas	Wc
	M^3/d	M^3/d	M^3/d	%	M^3/d	M^3/d	M^3/d	%	%	%	%	%
19/12/99	329.2	851.9	3975	61.2	327	834	3833	60.8	0.7	2.1	3.7	0.4

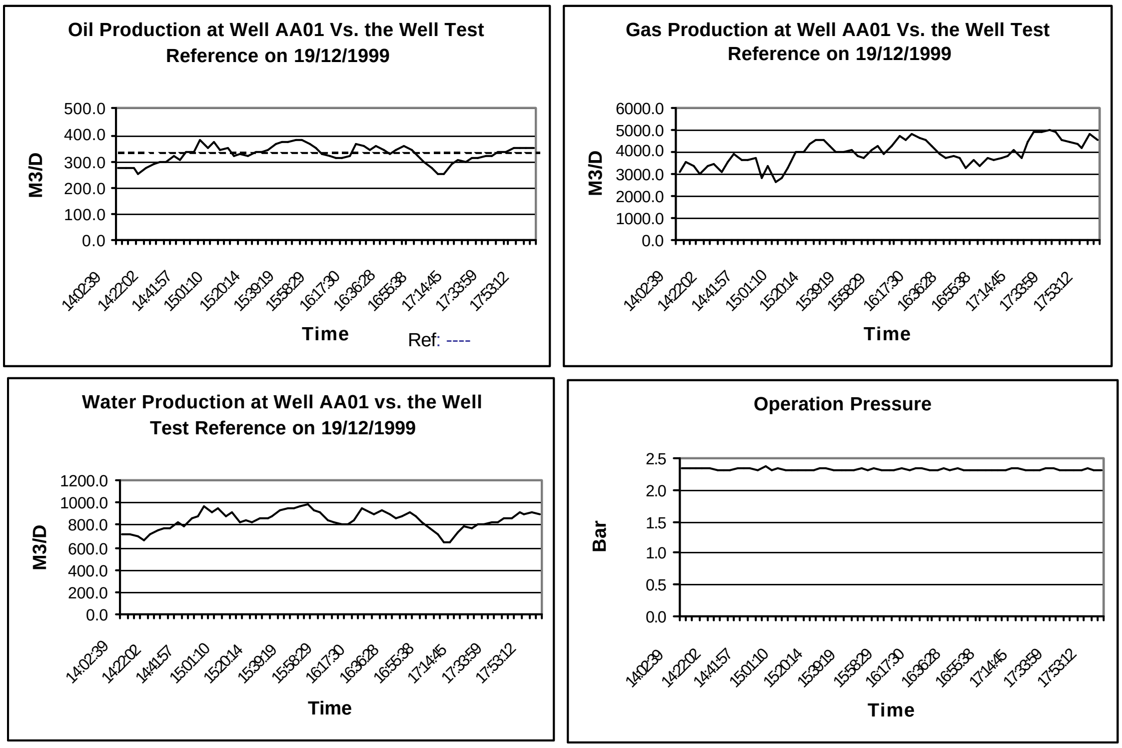

Fig. 6 - AA01 Test Results

9.2 AA04

Pool A model was tested against well test of AA04 on 19.12.99 (excluded from the training pool). As shown on the next table the back test result is not satisfactory. We believe that this was caused by the inconsistency in the liquid reference measurement (derived from the oil flow rate and Bs&W). For example, in November the liquid rate was 1007 m3/d with the mean value and the standard deviation of bottom differential pressure transmitters at 28 and 62 mbar; the mean and standard deviation of top differential pressure transmitters at 31 and 55 mbar. In December the liquid rate was 818 m3/d with the same measurements standing at 28,71 mbar (bottom) and 35,69 mbar (top). That is, the dp measured by ESMER sensors increased slightly with “decreasing” flow rate. This throws doubt on the reference measurement.

Table 7 - Pool A Test Results of AA04 on 19.12.99

Date	Meter measurement				Separator Ref.				Error			
	Oil	Liq.	Gas	Wc	Oil	Liq	Gas	Bs&W	Oil	Liq.	Gas	Wc
	M^3/d	M^3/d	M^3/d	%	M^3/d	M^3/d	M^3/d	%	%	%	%	%
19/12/99	342.8	1220	2225	71.7	229	818	3391	72	49	49	-34	0.3

9.3 AA11

Pool B model (NEL data plus well test of 20.11.99) was tested against well test of AA11 on 18.12.99 (excluded from the training pool). The following table shows that the oil flow rate and liquid flow rate were predicted within the required accuracy level

Table 8 - Pool B Test Results of AA11 on 18.12.99

Date	Meter measurement				Separator Ref.				Error			
	Oil	Liq.	Gas	Wc	Oil	Liq	Gas	Bs&W	Oil	Liq.	Gas	Wc
	M^3/d	M^3/d	M^3/d	%	M^3/d	M^3/d	M^3/d	%	%	%	%	%
18/12/99	195.5	1152	5182	82.2	210	1082	3392	80.6	-6.9	6.5	52.7	1.6

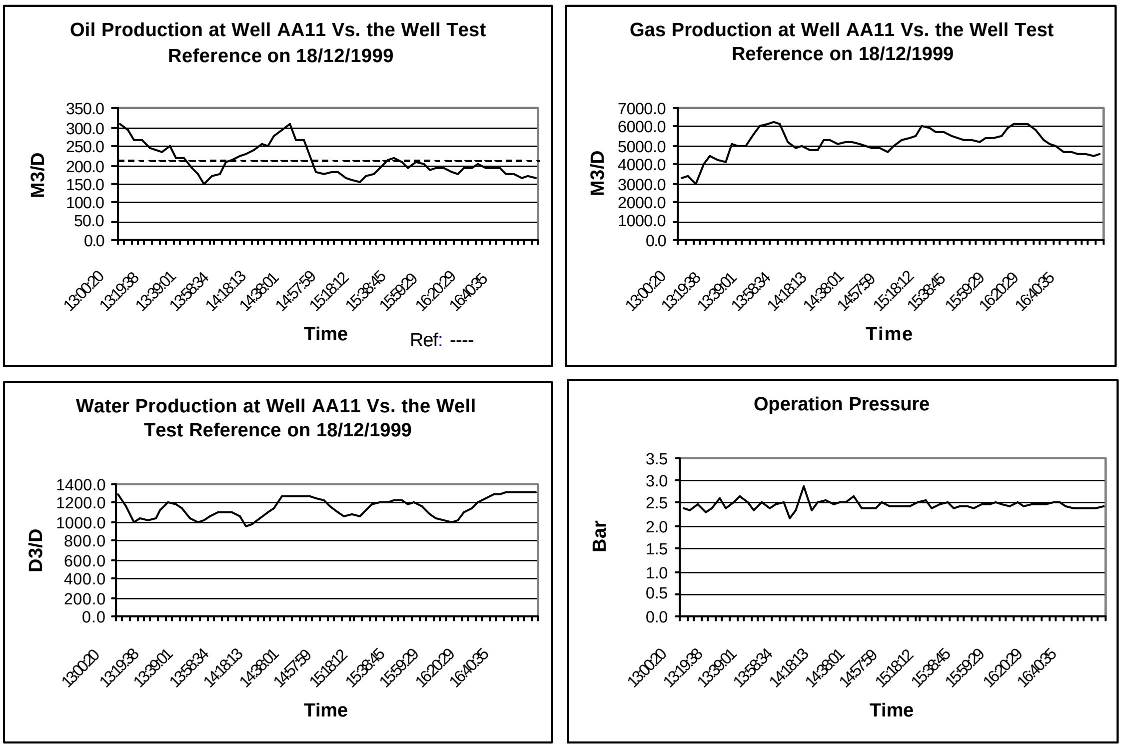

Fig. 8 - AA11 Test Results

9.4 AA07

Well test data of 18/12/99 for A07 was used to train the model. The model was then used to back test against earlier well tests for well AA07. The test results can be summarised as follows

Table 9 - Test Results of AA07

		ESMER				Separator				Error			
Date	**Time**	**Oil**	**Liq.**	**Gas**	**Wc**	**Oil**	**Liq.**	**Gas**	**Bs&W**	**Oil**	**Liq.**	**Gas**	**Wc**
		M3/D	**M3/D**	**M3/D**	**%**	**M3/D**	**M3/D**	**M3/D**	**%**	**%**	**%**	**%**	**%**
25/11/1999	11:30-14:30	510	1395	6548	62	509	1375	4973	63	0.2	1.5	31.7	-1
06/09/1999	9:00 - 11:00	583	1442	6267	59	495	1165	4743	57	17.7	23.8	32.1	2
06/09/1999	14:00-16:00	487	1203	7795	59	485	1243	4642	61	0.5	-3.2	67.9	-2

From the above table, it can be seen that total liquid flow rates and oil flow rates were matched quite well with the separator tests for November and for the afternoon of 6th of September but not for the morning of 6th September. The gas measurement was also not satisfactory but it should be noted that the reference measurement is also based on estimation.

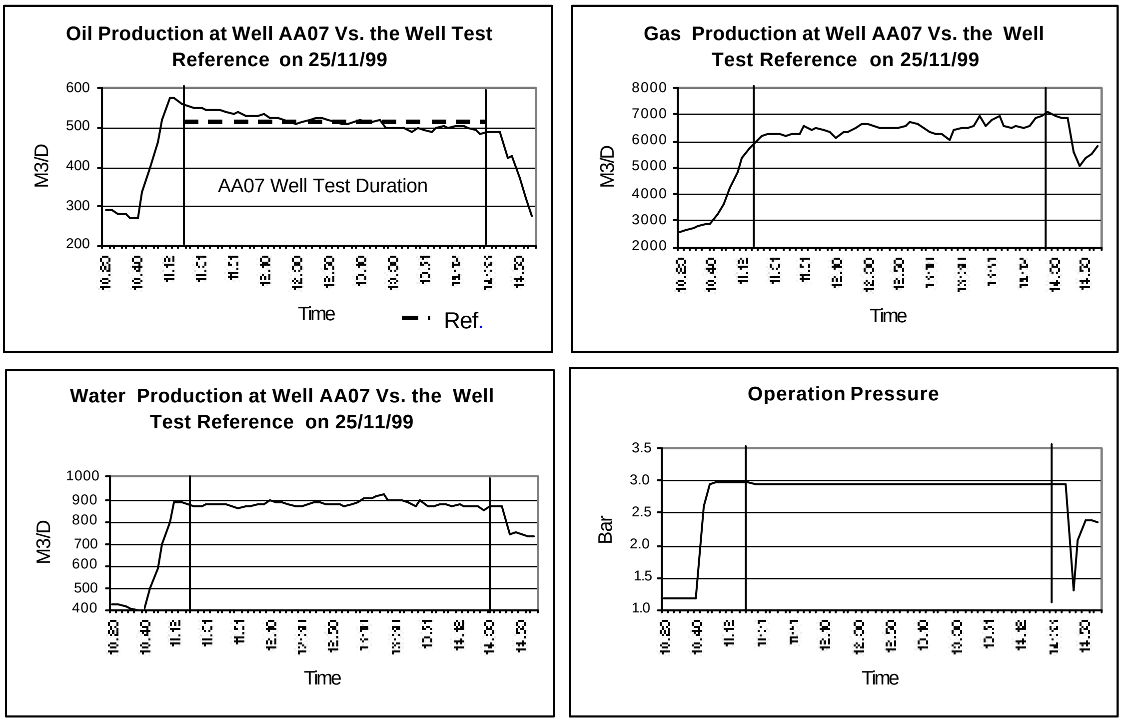

Fig. 9 - AA07 Test Results 25/11/99

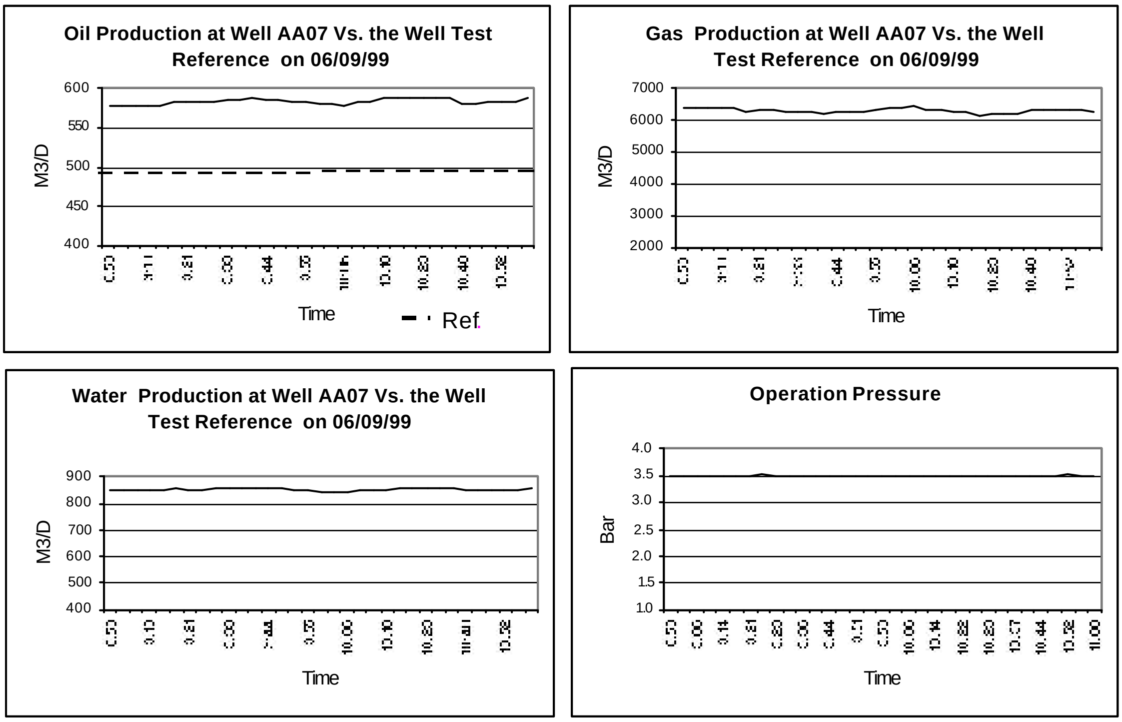

Fig. 10 - AA07 Test Results Morning of 06/09/99

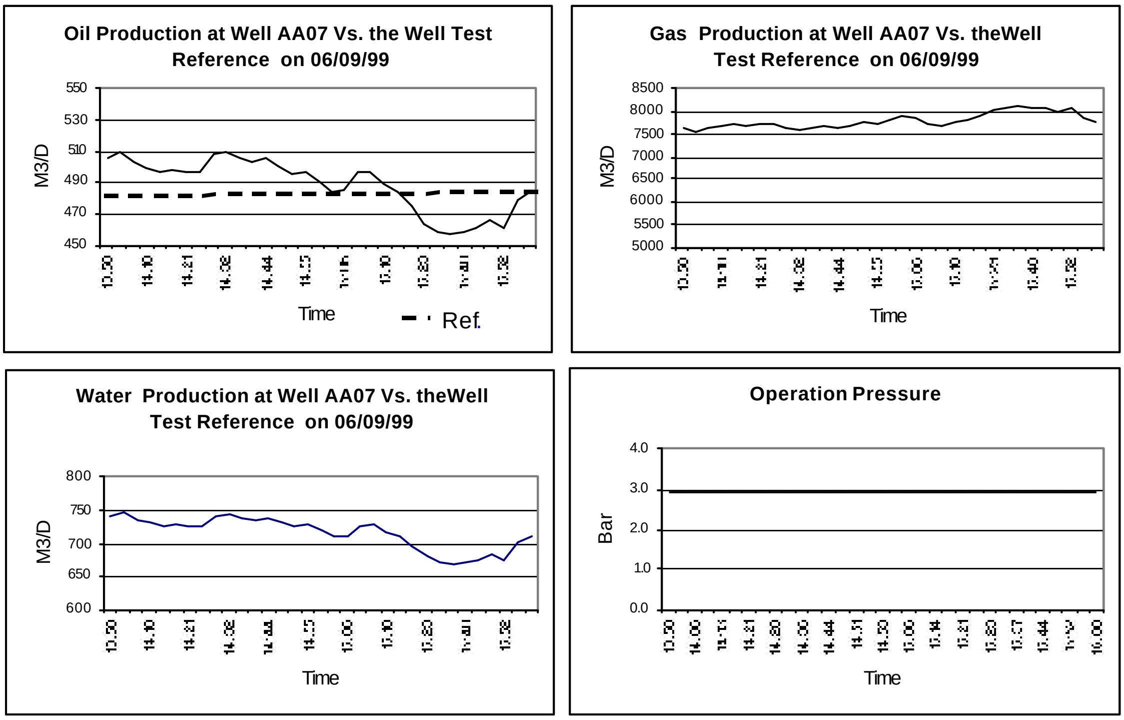

Fig.11 - AA07 Test Results Afternoon of 06/09/99

9.5 Trending

One of the tests, which could be carried out with relative ease in order to demonstrate whether the ESMER system was trending correctly, was the manipulation of the by-pass line. During normal production the by-pass was left open. On closing the by-pass (under constant conditions), the flow rate through ESMER would be expected to go up (to be approximately doubled). The following graph illustrates the result of one such test. The step on the graph results from operators closing and then reopening the bypass. As expected the liquid and gas flow rates indicated by ESMER went up but the water composition remained constant during the time the by-pass was closed.

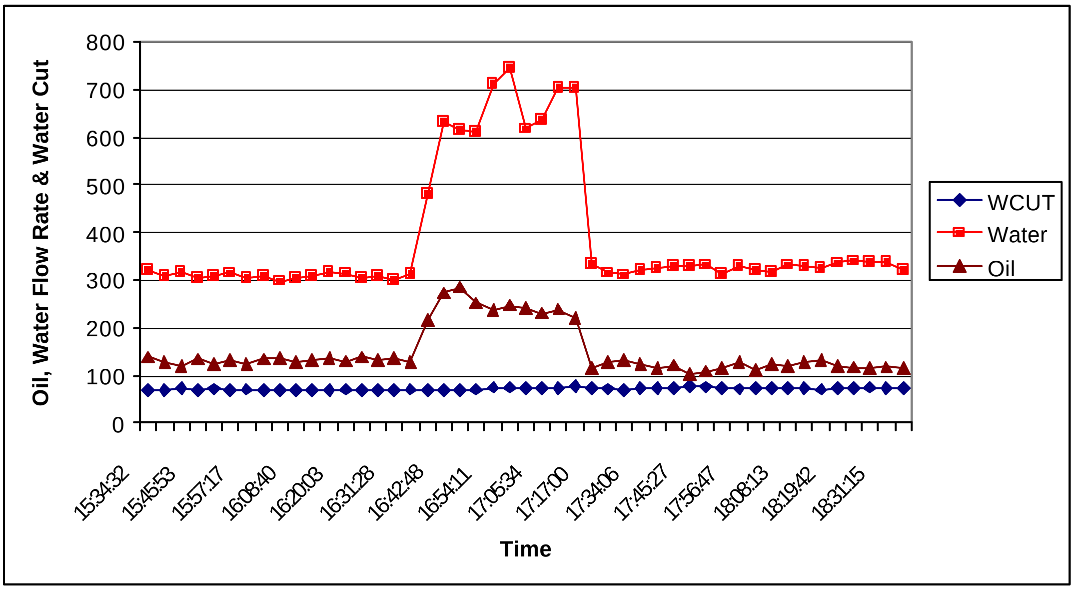

Fig.12 – ESMER Measurement for Well AA04 on 08/09/99

10 PRODUCTION HISTORY

The following graphs show highlights from the production history recorded by ESMER between November 1999 and February 2000. The graphs show ESMER responding to various events during this time such as production from different wells, production from one well under different enhanced recovery operations (water injection and gas lift were tried at different times), shut down and start ups.

10.1 November 1999

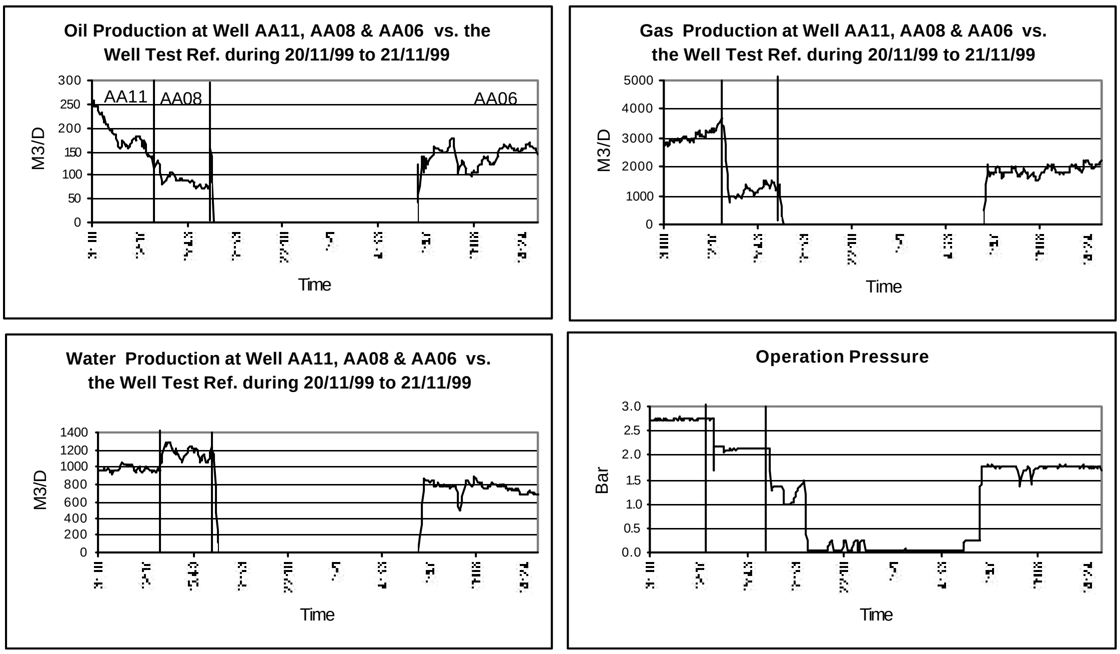

Fig.13 - 20th – 21st November 1999

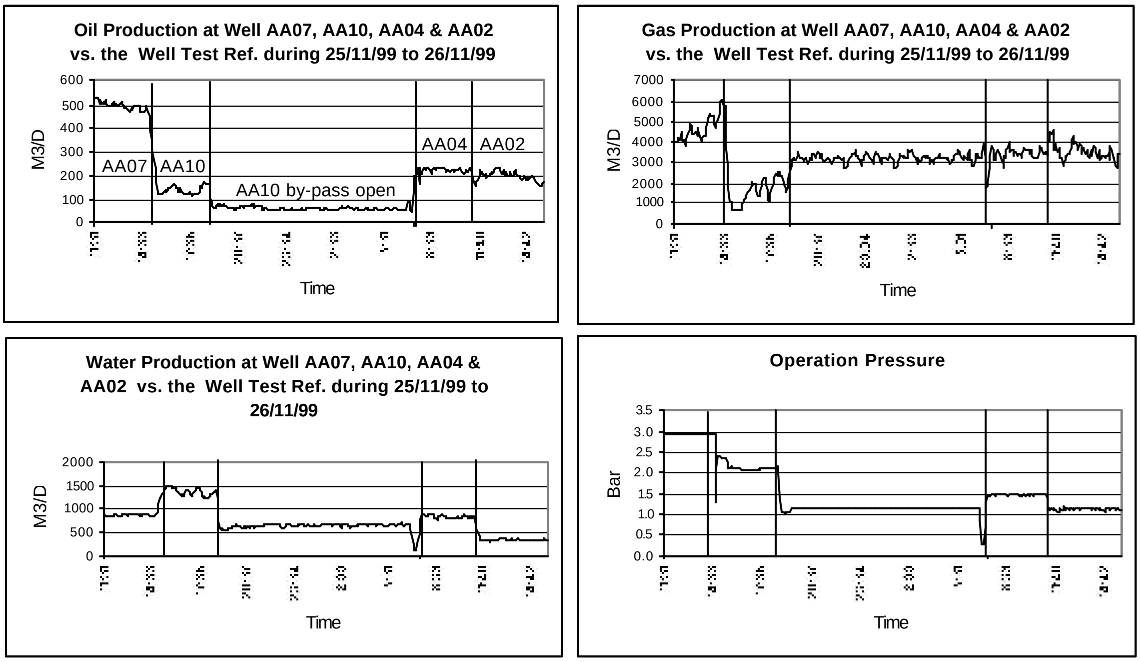

Fig.14 - 25th – 26th November 1999

10.2 December 1999

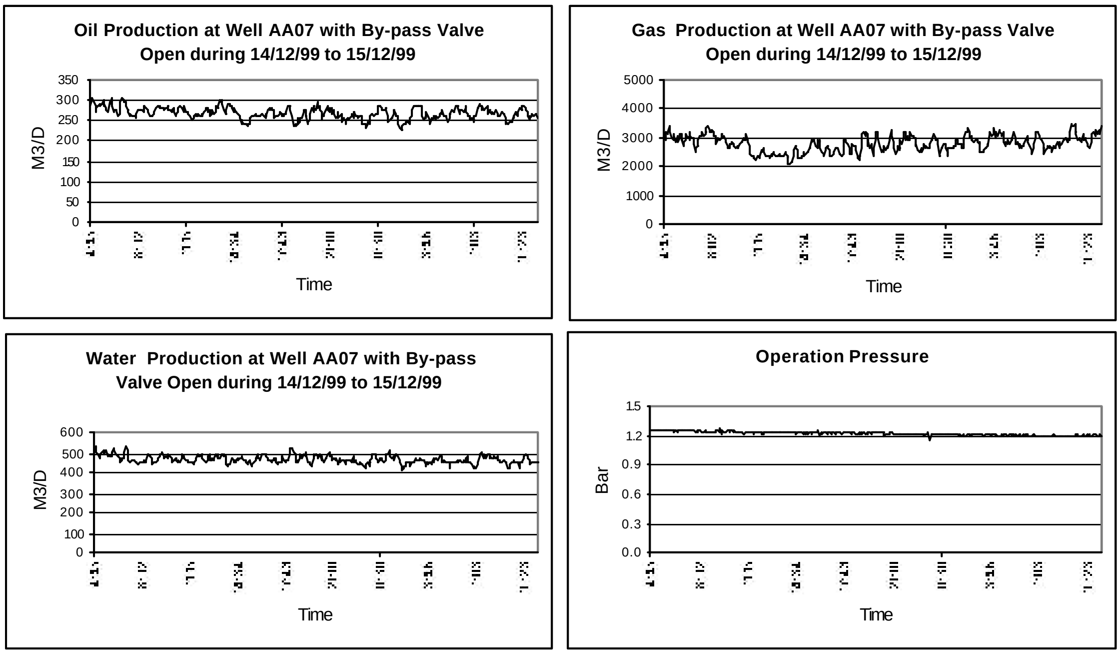

Fig. 15 - 14th – 15th December 1999

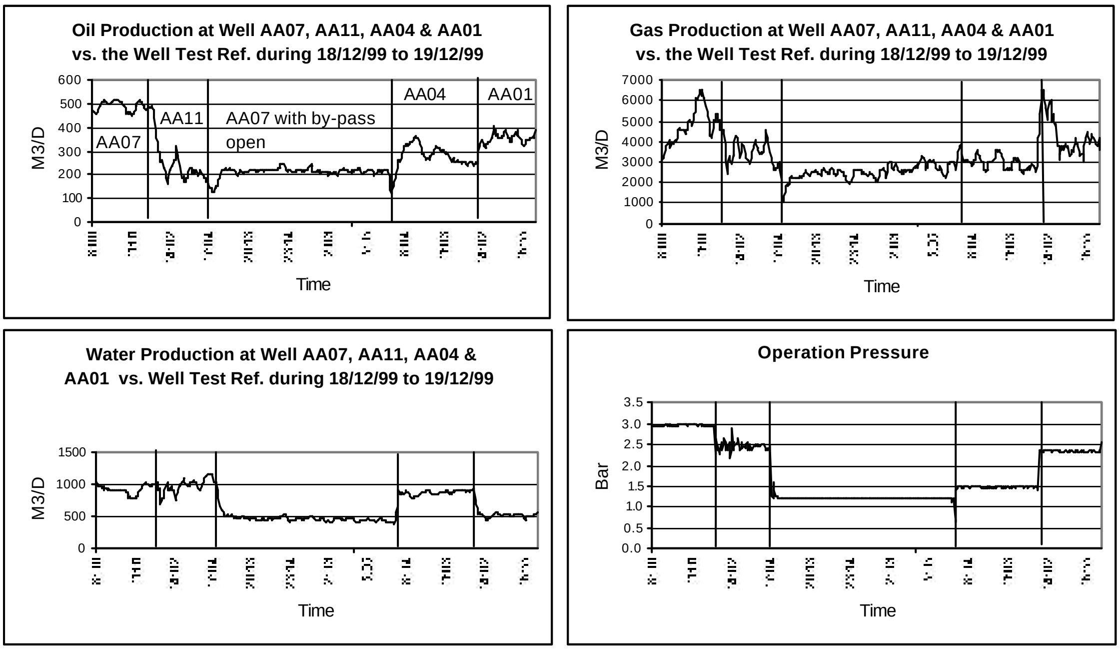

Fig. 16 - 18th – 19th December 1999

10.3 January 2000

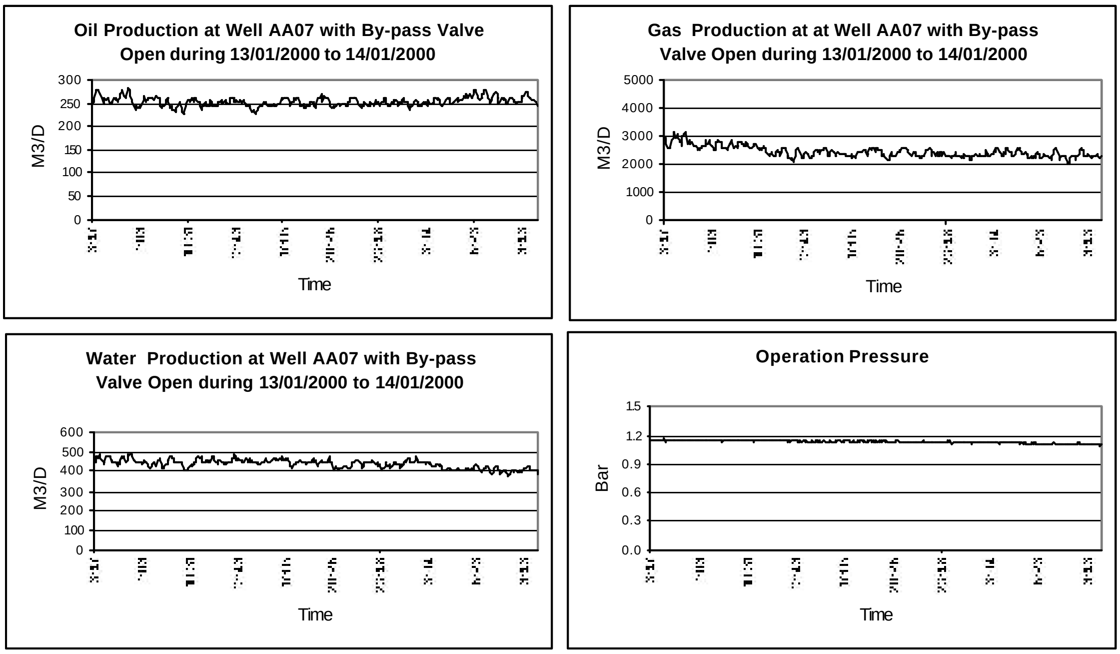

Fig. 17 - 13th – 14th January 2000

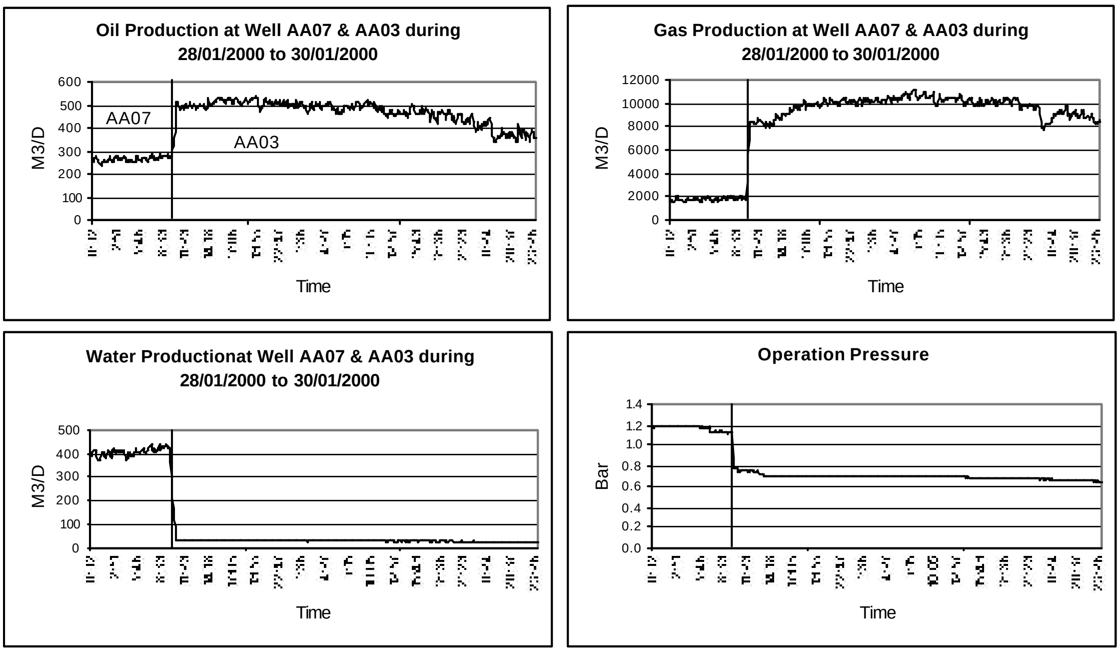

Fig. 18 - 28th – 30th January 2000

10.4 February 2000

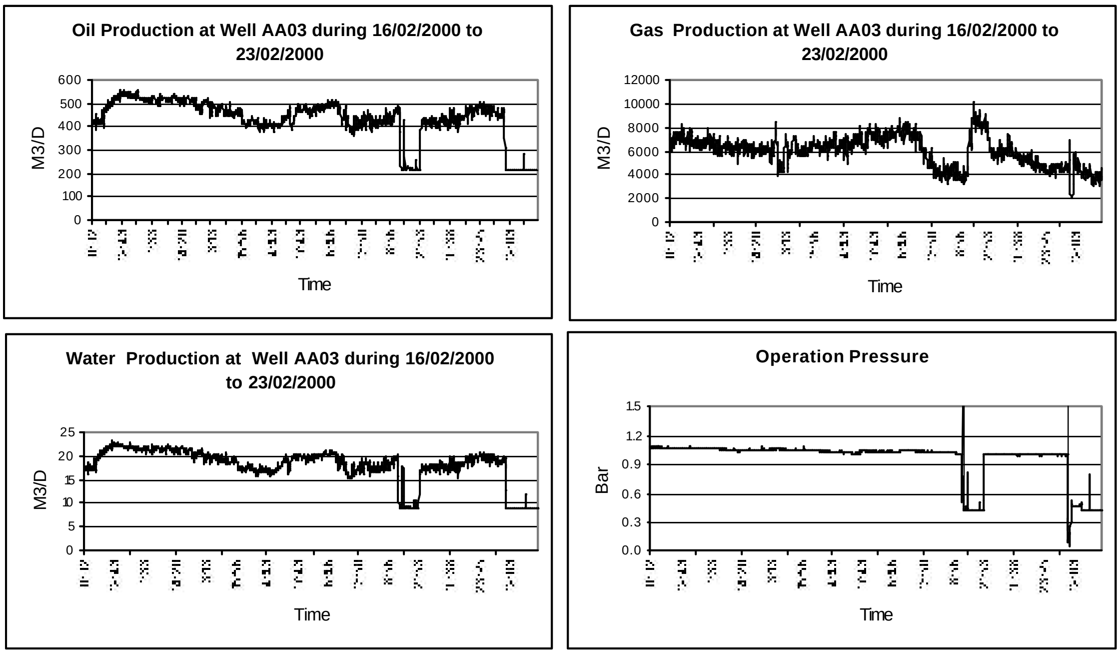

Fig. 19 - 16th – 23rd February 2000

11 CONCLUSIONS

The project showed that it is possible to obtain a trend indication about the flow rates of liquid and gas phases by pattern recognition of signals emitted by differential and absolute pressure sensors. Similarly water cut trends can be identified by the analysis of capacitance and impedance signals. The sensors were installed on a full-bore pipe. Such a system has to be calibrated in-situ against well test reference data. The accuracy of the system will improve with the availability of more data.

The project demonstrated the feasibility of running tests remotely through internet even though the tests required the gathering and transmission of massive data sets.

There are two directions in which the concept and the technology demonstrated in this paper can move from this point:

1. An on-line multiphase trend indication system, which works with resident sensors (as in the present study). The software architecture should be further advanced to enable auto calibration of this system in-situ with minimal operator attention.
2. A multiphase flow meter, which can be factory calibrated. This requires a dedicated spool containing a flow conditioner, which enables the turbulence patterns to be decoupled from in-situ effects.
3. The present experience has shown that the latter solution is required to meet the performance objectives of the operators.

12 REFERENCES

[1] DARWICH, T. A statistical method for two phase flow metering, Ph.D. thesis, Imperial College of Science Technology and Medicine, Universitiy of London, 1989.

[2] DARWICH, T., TORAL, H., and ARCHER, J. A stochastic study of horizontal two-phase flow, SPE paper 19511, 1989.

[3] DARWICH, T., TORAL, H., and ARCHER, J. A software technique for flowrate measurement in horizontal two-phase flow, SPE Production Engineering, 1991, 265-270.

[4] CAI, S., TORAL, H., and QIU, J. Flow regime identification by a self organizing neural network, International Conference on Artificial Neural Networks, 1993, Amsterdam, 13-16.

[5] CAI, S., and TORAL, H. Flow rate measurement in air-water horizontal pipeline by neural networks, Proc. Int. Joint Conf. On Neural Networks, 1993, Vol. 2, Nagoya, Japan, 25-29 October, 2013-2016.

[6] AKARTUNA, S. E. Identification of phase flow rates in oil-gas-water flow from turbulent capacitance and pressure signals, Ph.D. thesis, Imperial College of Science Technology and Medicine, University of London, 1994.

[7] TORAL, H., BEGG, N., and ARCHER, J. Multi-phase flow metering by software, Int. Conf. On Basic Principles and Industrial Applications of Multiphase Flow, London, 1990.

[8] BEG, N., and TORAL, H Off-situ calibration of a two-phase pattern recognition flow meter, 1993, Int. J. Multiphase Flow, 19, 999-1012.

[9] CAI, S. An artificial neural network method for three phase flow measurement, Ph.D. Thesis, Imperial College of Science Technology and Medicine, University of London, 1995.

13 ACKNOWLEDGEMENTS

Our thanks are due to the personnel on the Shell Auk Alpha platform and on-shore for their encouragement and support in executing this project. Thanks are particularly due to Andy Jamieson and Ted Cottrell for reviewing and commenting on the paper and to Peter Roebuck for his work on the platform in running the reference tests and the ESMER system.