North Sea FLOW Measurement Workshop

Paper 1.3

Infrared Water Cut Meter for Cost Effective Individual Monitoring of Complex Wells

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1 INTRODUCTION

The success of field management depends on the accuracy and availability of well performance data. Continuous monitoring provides information so that corrective action can be taken in a timely manner to better manage expensive well assets by maintaining well potential, managing water conformance and increasing the well life. Accurate water-cut monitoring can significantly reduce the dead well number by providing the data to timely implement corrective action.

Methods for measuring water-cut values range from conventional hand sampling to cutting edge technology. Saudi Aramco's traditional well testing practices, utilizing a test trap at a GOSP, limit the information available, due to the infrequent test trap availability on a per well basis, usually exceeding one month or more. Test trap data also has inherent error built in, due to averaging and human error. What is needed is real-time, in-line and accurate water-cut monitoring.

When considering technologies for monitoring water-cut, factors such as accuracy, data transfer rate and cost play major roles. This paper presents how an infrared meter provides an accurate and cost effective means to monitor water-cut in complex wells. The infrared monitoring device is an in-line real-time monitoring system that provides accurate water-cut even, in very challenging flow conditions. A pilot test of the infrared water-cut meter was successfully conducted in a major oil field in Saudi Arabia. Results from this test will be included in the paper.

2 BACKGROUND

Near infra-red spectroscopy is a well-known technique for chemical analysis and has been successfully applied to measurement of small quantities of water in a variety of media such as paper, methanol, tobacco, etc. The technology was further developed to exploit the very characteristic attenuation of infra-red light by water as a means to measure the water-cut in mixtures of oil and water. Saudi Aramco initiated a trial test to evaluate the real-time water-cut monitoring using infrared water-cut meter. The test started in March 2006 and was successfully completed in January 2007. The trial test was conducted in two wells, referred to here as Well-408 and Well-458.

The infrared water-cut meter was used for the first time by Saudi Aramco for this specific application. The trial test was intended to verify the reliability of using infrared water-cut meters to provide cost effective means of monitoring expensive horizontal wells. This real-time water-cut monitoring should enable remedial actions to taken in a timely manner and, therefore, prevent potential loss on horizontal wells that is attributed to uncontrolled water-cut increase.

The trial test also intended to verify the practicality of using the infrared water-cut meter in areas that lack communication infrastructure. On the two wells tested, GSM technology was used to transmit well data to engineers' office computers.

Drilling wells with long horizontal section in many fields is a standard practice. Drilling complex wells with multi-laterals is at an increasing trend. The cost of these wells is very high opposed to conventional wells. The expenditure of such wells cannot be recovered if changes in water-cut go unnoticed, due to shortage of data, and eventually cause these wells to load up and die.

The only method that Saudi Aramco uses currently to acquire such data is through periodic well testing. This is a traditional well testing technique that utilises a test trap at the Gas Oil Separation Plant (GOSP). This technique limits the information availability as such tests are periodic on a per well basis. The interval between well tests normally exceeds one month. This has increased the feasibility of real-time water-cut monitoring systems should they provide data with the required frequency and precision. Choosing the right application for real-time water-cut monitoring depends on how much data is required and how accurate it needs to be. For the evaluation purposes, measurement accuracy, data transfer capabilities and cost effectiveness played a major role.

There are various methods to measure the water-cut in a producing well. Methods for measuring water-cut values range from conventional hand sampling to real-time high-end technology measurement. By facilitating means for continuous water-cut monitoring, we ensure that the required information is available to take corrective action in a timely manner to better manage expensive well assets by maintaining well potential, managing water-cut conformance and increasing the well life.

A real-time water-cut monitoring trial test was initiated in the Saudi Aramco Idea Management System. A multi-disciplined team was formed to evaluate and test the idea where applicable.

During the test, no major problems were encountered. The minimum water-cut measurement during the test was 5% and the maximum reached 42%. The meter was tested on oil wells with GOR of ±550 Scf/STB. The post test inspection of water-cut meters components indicated no corrosion at any of the water-cut meter components.

3 INFRARED WATER-CUT METER TRIAL TEST

3.1 Infrared Water-Cut Meter Description

The infrared water-cut measurement is based on near-infrared absorption spectroscopy. As shown in Figure 1, the dependence of absorption of near-infrared light on wavelength varies with the composition. At several key wavelengths, infrared light absorption is dependent on the behaviour of carbon-hydrogen and oxygen-hydrogen bonds in the molecules. Water contains O-H bonds and hydrocarbons do not, therefore, allowing infrared absorption to distinguish water from organic molecules. Furthermore, the characteristic wavelength associated with bending of the H-O-H bond in water is different from the wavelength associated with O-H bond stretch, so there exists the potential for water to be distinguished from other molecules, such as methanol, containing O-H bonds.

The infrared water-cut meter extends the performance of an older generation meter, which used a single wavelength, to allow more accurate measurements at lower water-cut, by simultaneously measuring multiple wavelengths that include both the water and oil absorbent peaks. Scattering effects caused by emulsions, sand or gas bubbles are expected to have the same effect at all wavelengths and as such can be eliminated.

Furthermore, changing salinity should have no effect on the measurement, since the water absorption is based on the water molecule itself, not what is dissolved in the water.

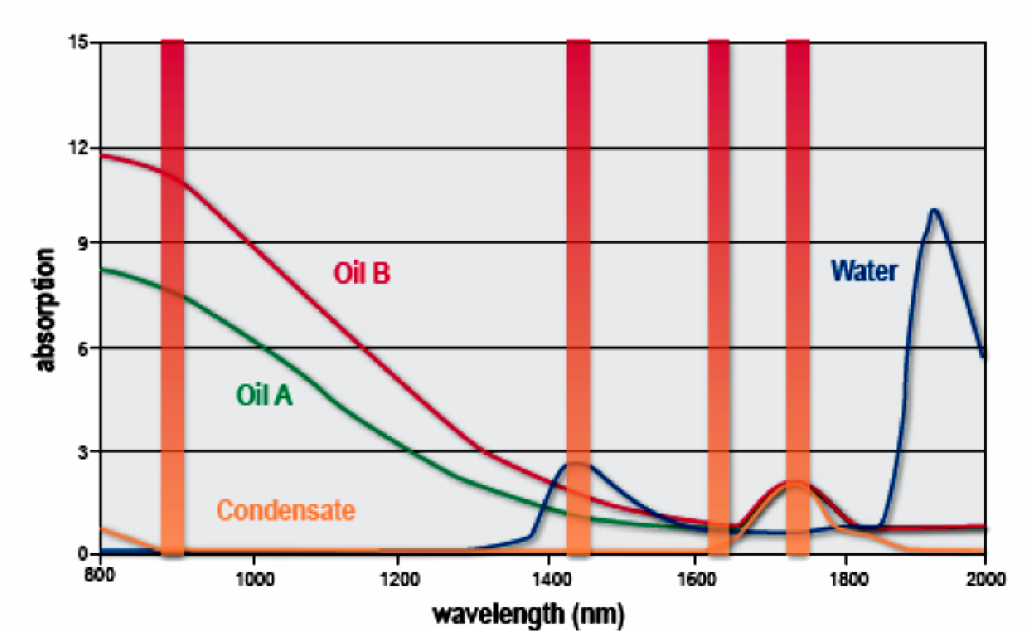

Figure-1: Near Infrared Absorption Spectrum

The internal design of the meter is shown in Figure 2. The meter consists of a probe which is inserted into the flow, either through a 1–inch NPT flowline tap or using a 1½–inch flanged connection and an electronics module mounted directly onto the probe. The only external connections required are for power (10 to 30 V DC @ 8 W) and output signal (4-20 mA analogue or RS-485 MODBUS outputs).

Figure-2: Infrared Meter Cross-Section

The main measurement section within the insertion probe has a small gap, with an infrared source on one side and detector consisting of a fibre optic bundle on the other. Between the optical source and detector and the process fluids are sapphire windows for their optical and mechanical properties, including abrasion resistance.

3.2 Well Selection

This trial test was conducted in a major oil field in the Eastern Province of Saudi Arabia. The field contains two oil bearing reservoirs. The produced crude is classified as Arabian Light Crude, 34^{O} API. The selection of the two wells (408 & 458) was based on several factors. The GOR in the field plays a major role in the selection criteria. The selected area had a moderate GOR of ±550. The wells were selected as they have low to moderate water-cut ranging from 12% to 30%. Finally, the candidate wells were selected due to location with a GSM signal available. The field where the trial test was conducted did not have established communication infra-structure field wide. Using data enabled SIM cards and utilizing the existing GSM coverage allowed for data transfer from the well to the GOSP using this data transfer option for the first time in Saudi Arabia.

3.3 Trial Test Preparation

The infrared meter installed in Well-458 was calibrated by flowing single phase oil and single phase water through the meters prior to starting the test. Manual intervention was required during the test to double check the configuration. However, the meter installed on Well-408 was installed without the benefit of any reference water-cut readings. This was done to test the performance of the meter without using baseline test

Figure-3 and Figure-4 illustrate the site configuration for the infrared meter installation. The insertion style design (as illustrated in Figure-3) reduces the installation cost and saves time if performed correctly. The electronics are mounted directly to the measurement probe so the only field wiring required is for the power and output signal cables.

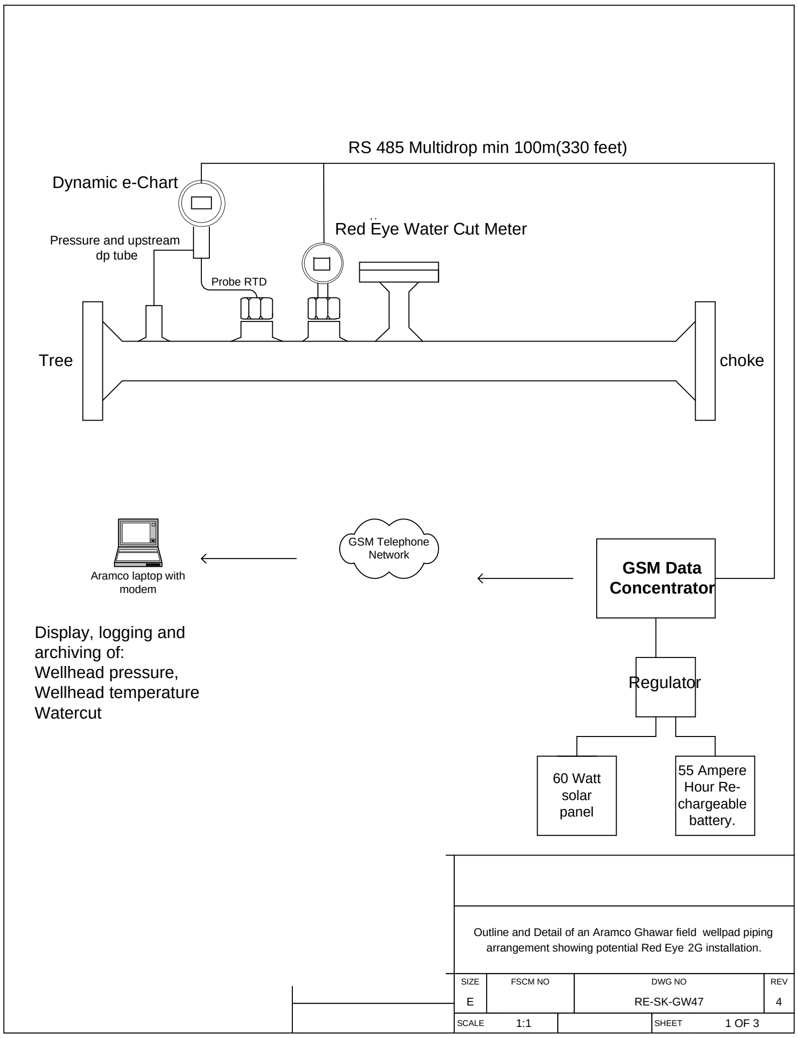

Figure-3: Infrared Site Installation

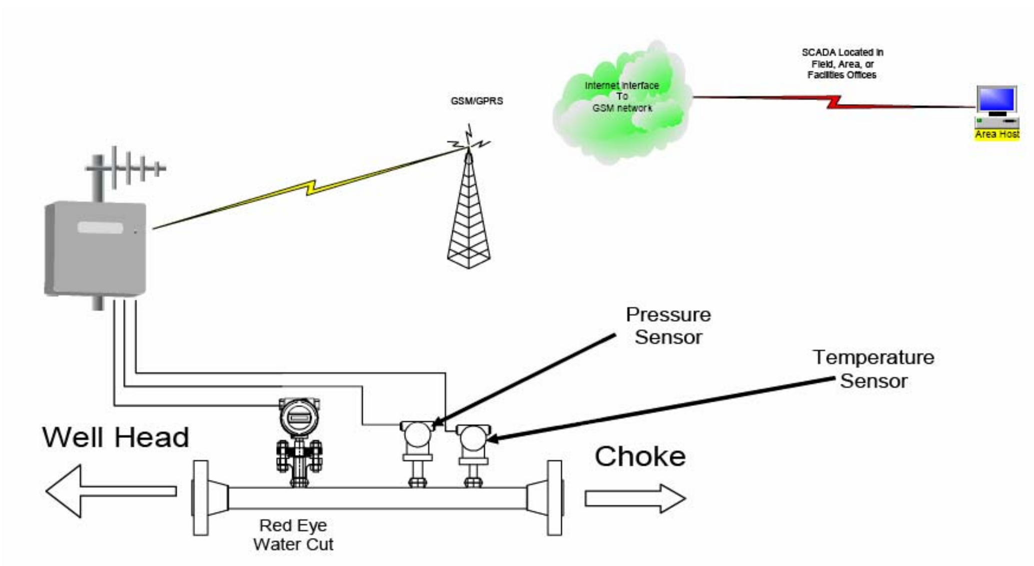

Figure-4: Infrared General Configuration

The data is gathered and collected in the RTU (Figure-5) before the system flushes itself and start saving the data for the next interval. The data can be downloaded manually every two to three months.

Figure-5: Infrared RTU

Moreover, the system has the capability to send the data as illustrated in the previous mentioned attachments. Data enabled GSM-SIM cards were used in this test to securely transmit the data from the well location sites to a receiving laptop in the engineering offices. Refer to Figure-6 and Figure-7 for the office interface.

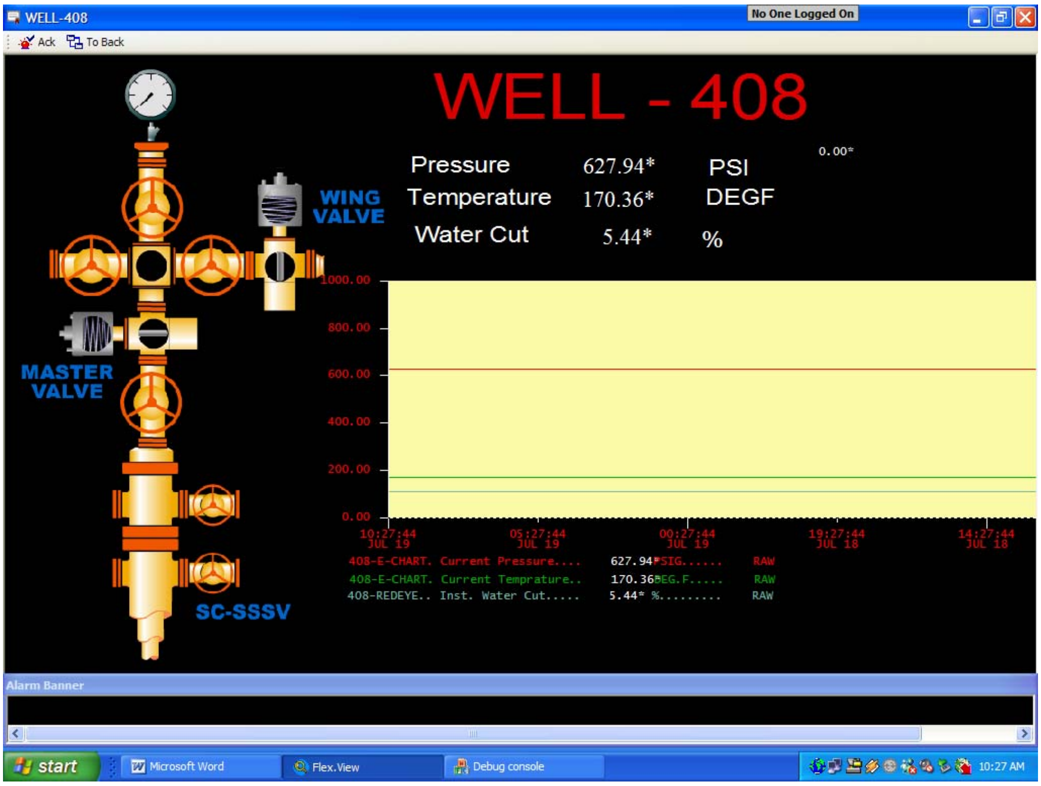

Figure-6: Well 408 Data Format Interface

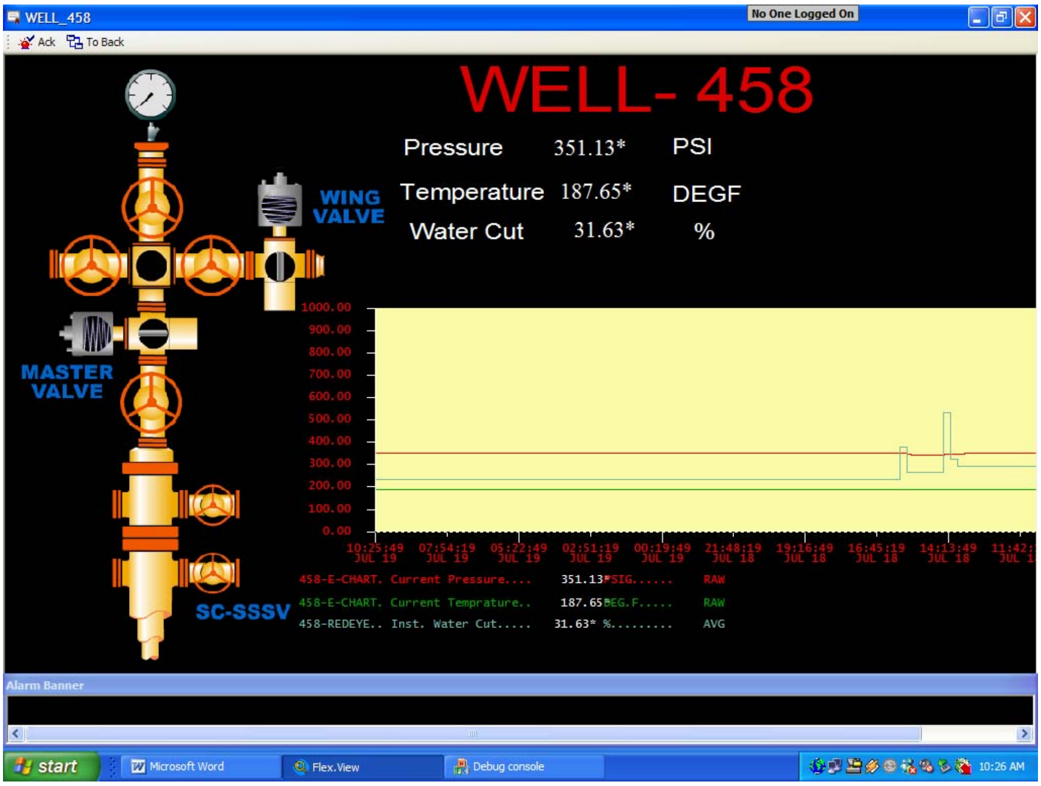

Figure-7: Well-458 Data Format Interface

3.4 Power & Communication

After the six month of trial test period, ending in November 2006, both infrared units experienced occasional loss of the water-cut signal. When the default configuration state is active, the actual readings and outputs from the meter unit are forced to zero even though the meter may be in an otherwise perfect working order. The internal data log showed the infrared units always dropped to 0% or came back to actual readings around 6 and 9AM in the morning.

If the battery runs low, the equipment will eventually shut off. Normally this is not a problem since once there is sufficient solar power the meter will start up and reload its configuration file then it will continue reading and reporting water-cut. However, if that start up is not "clean" as can happen with battery systems, the meter can experience an error with the configuration readings and go into the fault mode. This will stay active until another "clean" power cycle is experienced.

Starting in November, the days became shorter and the occasional rain resulted in the supplied solar power to drop below the minimum acceptable voltage. This would normally happen in the early morning, as can be seen in Figure-19. When the battery voltage climbs up to an acceptable level the system turns on. The added load on the battery typically results in a sag in voltage from the battery. This can trigger an on-off-on cycle as the solar power is coming back on line and this can, in some circumstances, cause the meter to experience the fault.

After consulting and studying the issue with the vendor, three remedies were brought forward to resolve the issue:

1. One option was to increase the solar panel/battery capacity and avoid the low power conditions.

2. The second option involved the use of a low voltage cut off with dead-band and this could be as a short term correction. With this approach, the unit will still turn off when

supply power drops below a set limit but the dead-band voltage between shut off and power up will eliminate the saggy/weak start up condition.

3. The third option was to provide electrical power to run system.

The meter also needed a modification for the firmware to check for valid configuration file at each start up. The vendor established the necessary modification and reconfigured the meters. In addition to the low cut off voltage modification, the vendor modified the system to track the input and output voltages provided to the system. Later, tracking the voltages shows that Well-408 battery is damaged due to excessive operation below 11.5V DC. The battery was changed and the performance is being tracked.

Although GSM has been used for the purpose of this trial test, it is recommended to use other communication alternatives in the future. The other possible options are summarized in the following table:

Table 1: Wireless Communications Options

Method	Advantages	Disadvantages
UHF Radio	– One time cost. – Easy to install. – Adequate bandwidth for application. – Long coverage.	– Authorization difficulty. – Not secure.
Spread Spectrum Radio (2.4GHZ Serial Data	– Easy to install – Adequate bandwidth – Possibility of storing and forwarding the data.	– Non licensed radio frequency may be difficult to import. – Remote diagnostics may not be possible. – Limited distance at restricted effective radiated power, typically 1 watt max. – Not secure.
Spread Spectrum Radio 2.4 GHZ Ethernet	– Easy to install. – Higher bandwidth. – Enable remote diagnostics. – Possibility of storing and forwarding the data. – Secure.	– Non licensed radio frequency may be difficult to import. – Limited distance at restricted effective radiated power.

Other alternatives include copper wire, fiber optics, satellite communication (V-Sat) and other types of Spread Spectrum Radio such as WiMAX. Copper wire communication is limited by the distance, and boosters may be required every four kilometres although boosters are not recommended. Although the fibber optics speed is unlimited, it requires huge construction and implementation cost. WiMAX is the best choice among these alternative, in terms of reliability and coverage. Out of the previous alternatives WiFi may be the quickest and cheapest alternative, if approved.

The recommendation is to work with the IT/Communication to determine other communication alternatives, to ensure reliable data communication for real-time water-cut and wellhead data monitoring in future.

4 TEST RESULTS

4.1 Infrared Water-Cut Meter and Test Trap Data Comparison

During the test, the choke setting was changed twice on both wells (408 & 458) to ensure that water-cut meter readings changed in conjunction with changes in choke settings. Additionally, the wells were scheduled to be tested through the test trap on a monthly basis to check the water-cut readings. The first test was conducted in April 2006 and the second was conducted in September 2006. Figures- 8, -9 and -10 show the test conducted in April 2006 and Figures-11, -12 and -13 shows the test conducted in September, 2006 along with the comparison of the tests.

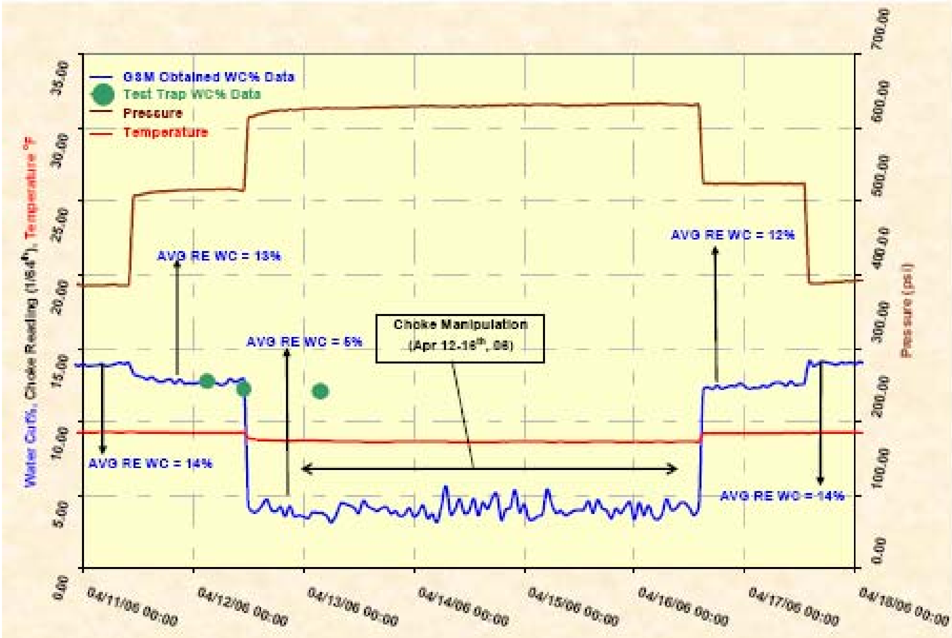

Figure-8: Well-408 April 2006 Test Data and Results

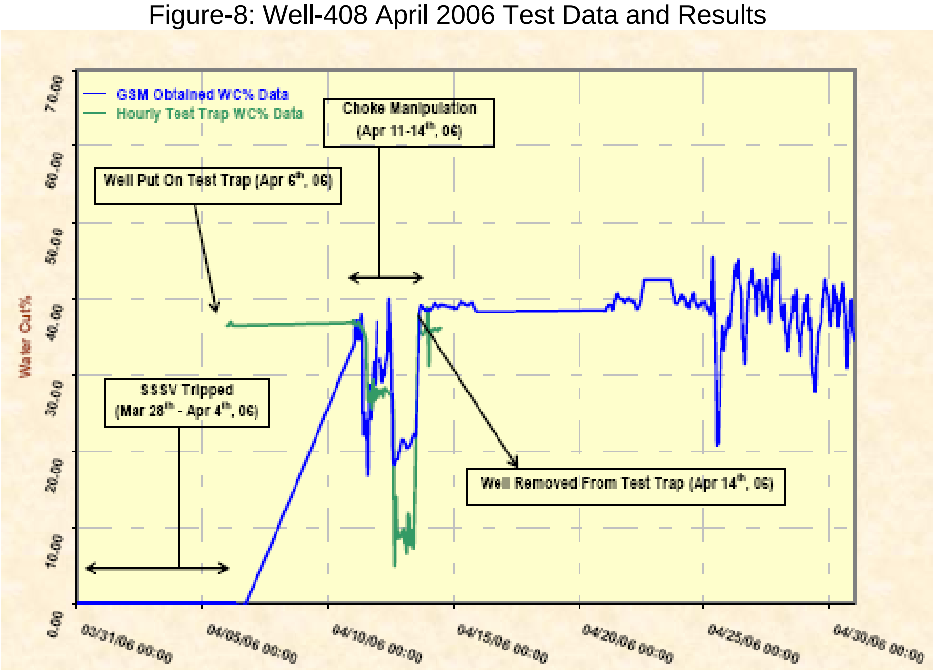

Figure-9: Well-458 April 2006 Test Data

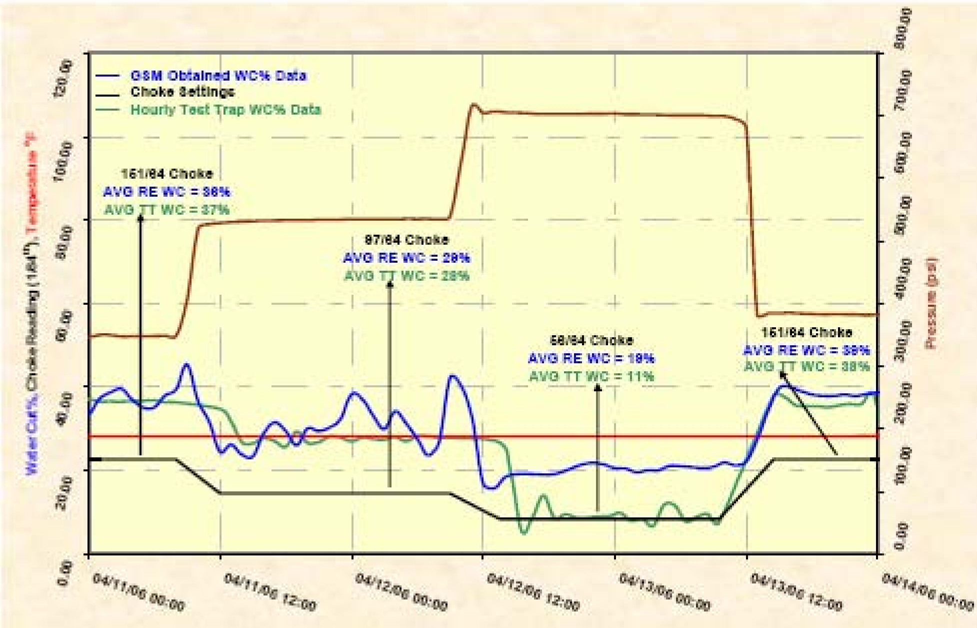

Figure-10: Well-458 April 2006 Test Results

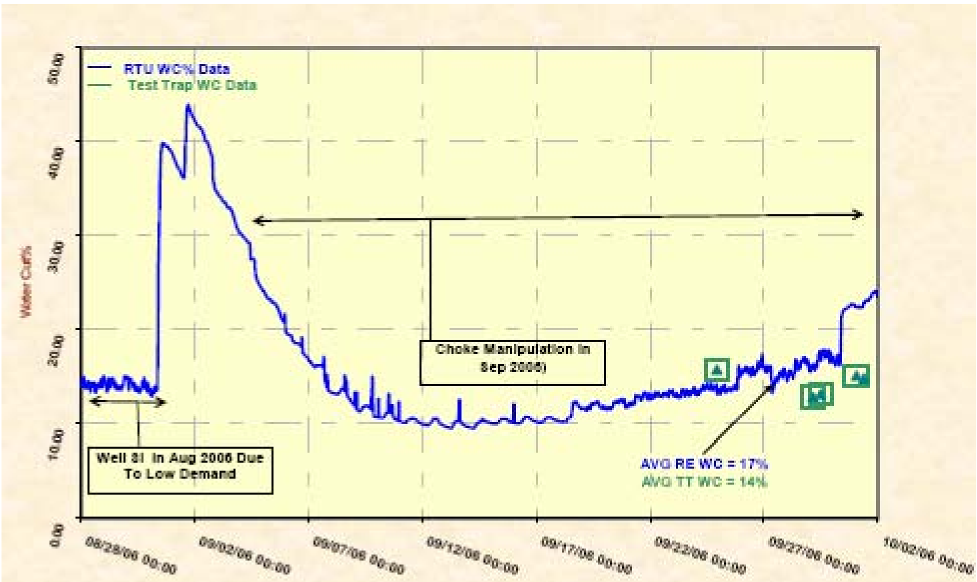

Figure-11: Well-408 September 2006 Test Data & Results

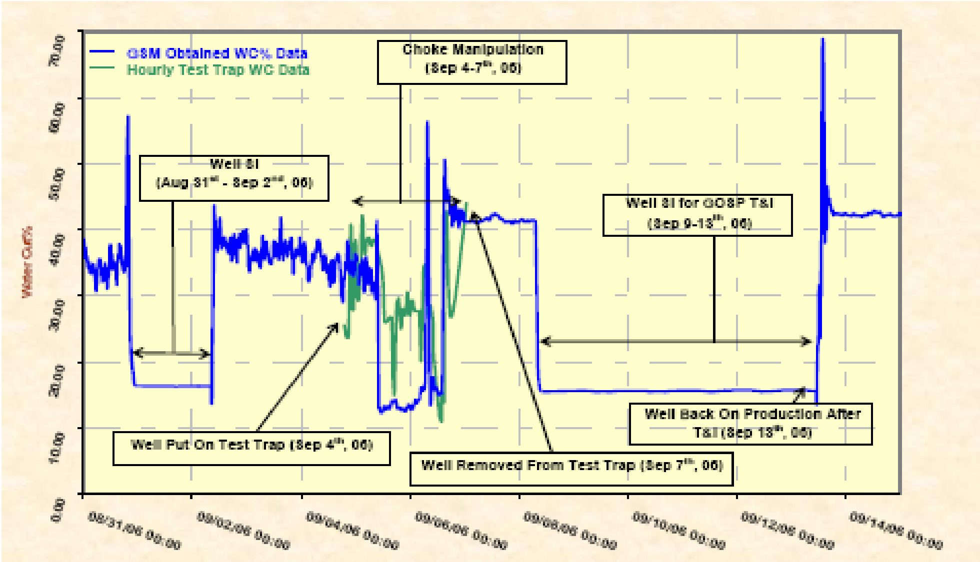

Figure-12: Well-458 September 2006 Test Data

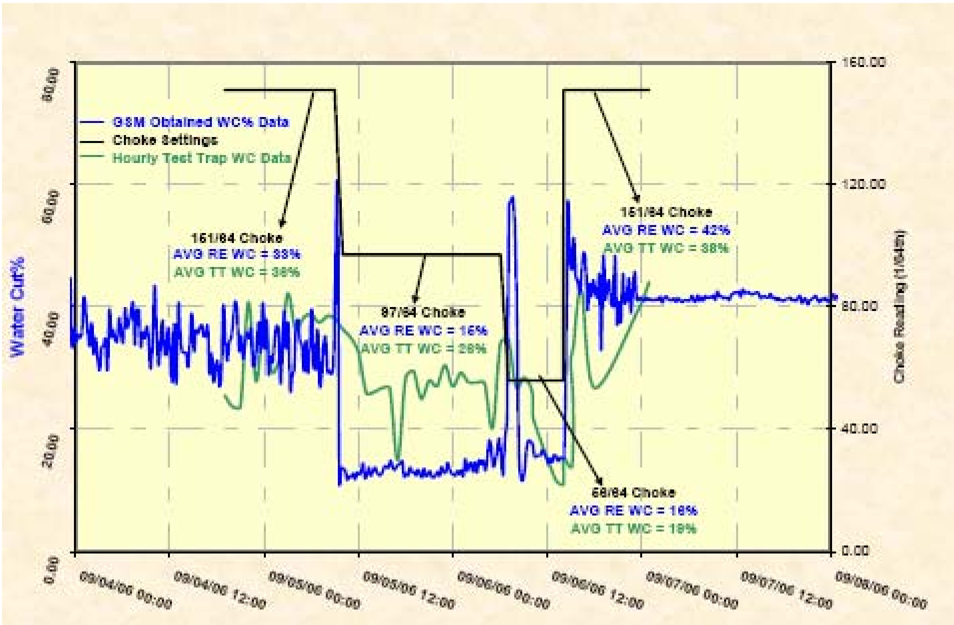

Figure-13: Well-458 September 2006 Test Results

Figure-11 illustrates the Red Eye 2G and the Pressure-Temperature transmitter. Well-408 has a water-cut of about 15-20% while Well-458 has a water-cut between 35-40%. Figures-15 and -16 show the data gathered through the test from Well-408 and Well-458. The figures show the quality of the data as well as the pressure and temperature behaviour. The figures also indicate that the meter is showing a reasonable qualitative data match for both wells.

Figure-14: Infrared Meter and P-T Transmitter

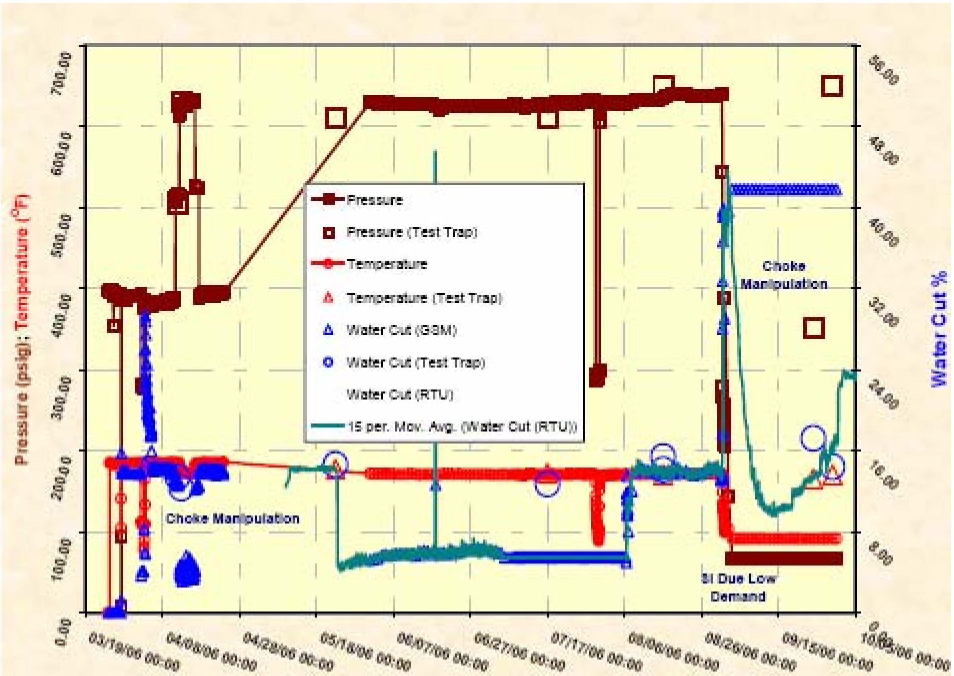

Figure-15: Well-408 General Test View Data

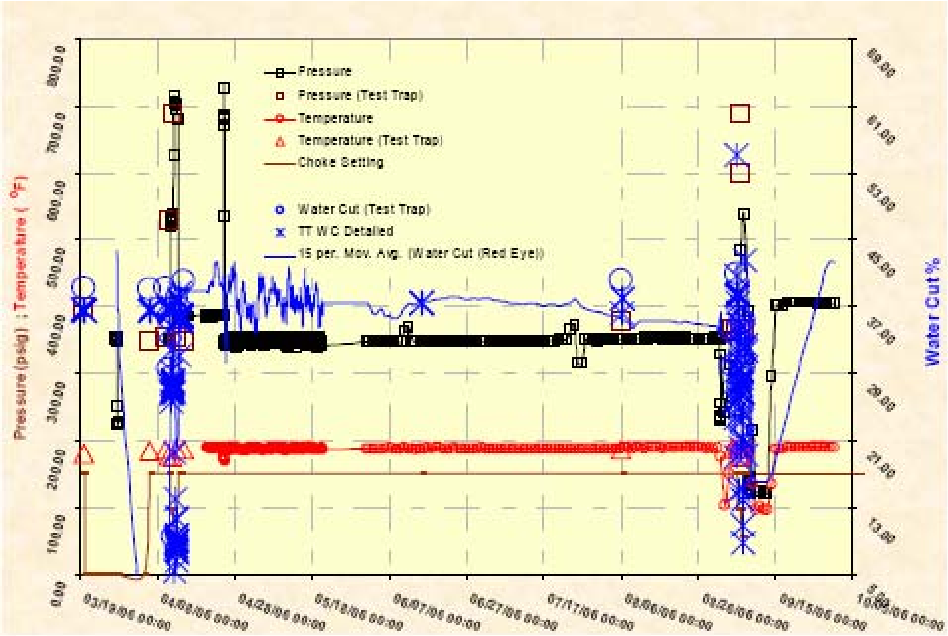

Figure-16: Well-458 General Test View Data

The data obtained from the RTU loggers shows acceptable water-cut tracking excluding the data lapses due to the problems encountered during the test. Initially, the meter was recording the instantaneous values for the water-cut but that was changed at a later stage and the meter was then reconfigured to show the average water-cut through a 10 second time interval. This was done in May of 2006 and the impact on the recorded water cut is clear. In the fourth quarter of 2006, the infrared meter began to experience power related problems as described in section 3.4.

In May 2007, the infrared meters on both wells were removed for corrosion inspection. No corrosion was observed on the meters. Figure-17 and -18 shows the internal probe of the meter installed in Well-408 and Well-458.


Figure-17: Probe (Inner Rod) For Well-408 Infrared Meter


Figure-18: Probe (Inner Rod) For Well-458 Infrared Meter

4.2 Results Validation and Verification

The trial test data was sent to Reservoir Engineering Department (RMD) to ensure the validity and the usability for better reservoir management. RMD validated the measurement quality of the meter, after cross checking it with the test trap data and advised on implementing the concept in the field where applicable. The meter will be useful to assist with the process of monitoring the water arrival on frontline wells and to take remedial action in a timely manner.

4.3 System Reliability and Technical Support

The overall test proved system reliability for qualitative measurement. As a new system, however, some issues were encountered during the test as shown in Figure-19. During the installation, the meter installed at Well-408 was found to have a faulty NIR source. A replacement meter was received and installed, configured and put into service. The meter was, however, installed and configured without the benefit of any reference water-cut readings for the previously mentioned reason.

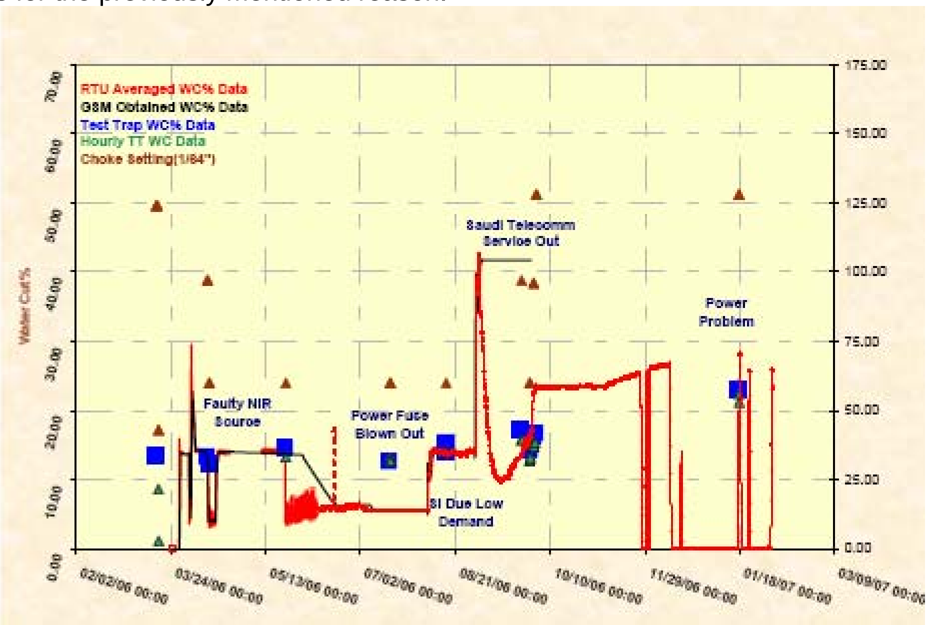

Figure-19: Problems Encountered In Well-408 Test

In June 2006, the reading in the office for Well-408 went flat again. This time the water-cut meter power fuse was blown. The vendor was consulted and the investigation revealed that the supply power from the solar panel system may have temporarily dropped below 9V DC, which would result in an increased current draw. A 12V to 24V converter was installed on both wells to resolve the problem.

In October 2006, the infrared meter data could no longer be gathered and obtained in the office. The data enabled GSM-SIM cards service was disconnected from the Saudi Telecomm Company after six months. Since then, data has been downloaded in the field.

A field visit was arranged in December 2006 and it was found that both meters were no longer displaying water-cut readings and reporting default-configuration errors. Troubleshooting the issue was started for further diagnoses and the vendor was consulted and confirmed that the meter will force a zero (0) water-cut reading if the default-configuration flag is active. The preliminary analysis was done under the assumption of possible firmware bug, but it was found after further diagnosis that the problem was caused due to a low power start-up issue.

4.4 Additional Findings

The infrared meter proved its qualitative measurement to detect the change in the well status. The previous mentioned figures demonstrate this issue clearly. Furthermore, Figure-12 shows an incident occurred in Well-458 when the SCSSSV tripped and the well was shut-in. If the well behaviour change had not been seen by the infrared data, the well would have remained shut in until field service arranged a visit to the well site. This would have resulted in production loss depending on the time of the visit.

5 CONCLUSIONS & RECOMMENDATIONS

The trial test showed that the increase and the decrease in water-cut trends measured by infrared water-cut meter were consistent with the choke changes and the test trap data. The infrared measurement provided accurate measurement on the selected wells with minimum water-cut measurement of 5% and a maximum of 42% during the test. The water-cut meter provided a qualitative means to monitor water-cut trends. Real-time monitoring provides continuous monitoring of well production behavior and status.

The test highlighted that water-cut meter installation is effective only with real-time monitoring capabilities. Without real-time monitoring, true benefits of decision making for remedial action can not be taken in a timely manner.

Communication wise, the first time use of the GSM-SIM card to transmit water-cut data, pressure, and temperature was successful and could be utilized in future as a temporary data transfer option. On the power side, no major problems were encountered, however, data interruption was noticed due to solar power dropping below minimum acceptable voltage during winter time (November-December).

Based on test results, it is recommended to use infrared water-cut meters to monitor water-cut trends on critical wells. The water-cut meter performed satisfactorily on wells with GOR of ± 550 Scf/STB. It is also recommended to consider usage of infrared water-cut meter downstream of 2-phase separator to aid in determining the water-cut in the liquid leg. Finally, it is recommended to liaise with IT/Communication to determine best communication alternatives to ensure reliable data communication for real-time monitoring on a field wide basis.

References

[1] Paper presented at the North Sea Flow Measurement Workshop, a workshop arranged by NFOGM & TUV-NEL

Note that this reference was not part of the original paper, but has been added subsequently to make the paper searchable in Google Scholar.