Successful Field Evaluation of the Efficiency of a Gas Gravity Drainage Process by Applying Recent Developments in Sponge Coring Technique in a Major Oil Field

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ABSTRACT

This paper describes the application and integration of new technologies and recent developments in Sponge coring and presents the methodology used to carry out successfully the various phases of well designed Sponge coring project, including the coring phase, the on-site measurements and the full evaluation of the Sponge core samples. A field case is presented where a Sponge coring project was accomplished to obtain accurate fluids distribution and evaluate the gas gravity drainage efficiency in one of the Arab D sub-reservoirs of a major oil field offshore Abu Dhabi.

A Sponge coring technology team was created to optimize the methodology used during Sponge coring and minimize the uncertainties which persisted on some of the previous operations. The effectiveness of the technique is discussed, in comparison with open hole logs and SCAL data.

Realistic petrophysical parameters were obtained from non-invaded, native-state core samples. The effective oil saturation obtained from the Sponge core analysis results showed that the gravity segregation mechanism has been very active and efficient to recover the oil in the reservoir.

1. INTRODUCTION

The use of Advanced Reservoir Management techniques right from the start of field development and exploitation provides information that is vitally important for engineering and controlling future EOR processes. It is fundamental to obtain data representative of in-situ reservoir rock properties. The time and money spent to provide the high quality information needed, after all, is certainly cheaper than an EOP project failure.

The selection of efficient techniques for determining ROS is based on the formation and wellbore conditions of the well to be tested. There are a variety of reasons why computation of oil or water saturation from logs is sometimes extremely difficult. Formation parameters (porosity, cementation factor, saturation exponent, etc.) influence the accuracy of logs for ROS determination.

Data from cores represent the only direct measurements of reservoir rock properties. All other information and data are indirect evaluations of these properties. The best starting point is a truly representative core sample.

To evaluate the gas gravity drainage efficiency in one of the Arab D sub-reservoirs, some logging techniques were previously investigated and tested to have access to the effective value of the residual oil saturation after gas displacement. RFT and TDT logging techniques showed some evidence for gas influx into the area with corresponding flushing of the oil originally present before production started, but the TDT results could not be regarded as reliable due to the numerous assumptions required to carry out the interpretation.

The in-situ measurements from openhole logs indicated that a gas effect made it impossible to accurately quantify the residual oil saturation. The uncertainty of the results was unacceptable for ROS to implement any future additional development plans.

Sponge coring projects conducted recently proved convenient, economic and reliable and provided invaluable information to answer one of the main questions before considering any EOR project in the field: "How much oil still remains in the reservoir, where is the residual oil, and how much of it could be recovered ?"

The Sponge coring technique was applied to evaluate the efficiency of the gas gravity drainage and provide reliable fluids saturation distribution. A team of reservoir evaluation, Sponge coring specialists supervised all the phases of the operation, and provided the synergy needed to design and fulfil this successful project. The interpretation and evaluation of the results called for the joint effort of all team members.

2. SPONGE CORING TECHNOLOGY

Barrel Design - Overview :

The Sponge coring technique uses a sponge-sleeve modification to a conventional core barrel. The sponge sleeve is made of oil-wet (or water-wet) polyurethane material, with a 70-80% interconnected porosity and 2 Darcy air permeability (Fig. 1). From the operational point of view, the Sponge core barrel is handled similarly to the standard core barrel. During the coring operation, the core enters and fits tightly inside the sponge liners. As the core is brought to the surface, hydrostatic pressure drops and gas comes out of solution inside the core, expelling oil out of the core. Experience has shown that trapping of the oil by the liners is efficient, with no oil loss during retrieval to surface. The oil bleeding from the core is collected in the sponge and reconstituted back into the core porosity to correct the oil saturation for bleeding. The amount of oil in the core and sponge is converted to in-situ conditions by applying the current oil formation volume factor. Pore volume in the core is adjusted for compaction using the stress correction factor.

Technology Team - Pilot Objectives :

To obtain exceptional core quality, and provide accurate reservoir data, a Sponge coring technology team was formed to review and process a large number of previous Sponge operations and analysis, with a fundamental objective to optimize the existing methodology used and augment the effectiveness of the technique. This multi-disciplinary team consisted of specialists in reservoir evaluation coring, reservoir engineering, core analysis, and geology. Additional expertise was sought as required (mud engineering, mud tracers & tracer analysis, etc.).

Extensive review of the existing techniques are made, with emphasis on the following main targets :

1. The performance of the Sponge material under various coring conditions.
2. The capability of the oil-wetness and high storage capacity of current sponge material to trap the oil expelled from the core at different oil saturation levels.
3. The effectiveness of the technique in formations with various petrophysical properties, including large variations in permeability and porosity, different GOR ratios, and the presence of free gas.
4. The efficiency of the advanced, low invasion coreheads in the various applications, and the effect of ROP on the amount of mud filtrate invasion.
5. The accuracy of determination of mud filtrate invasion and its effect on the estimation of oil flushing during the coring process.
6. Surface handling of the Sponge core liners and the performance characteristics of the preservation methods for Sponge cores and plug samples.

Sponge Liner

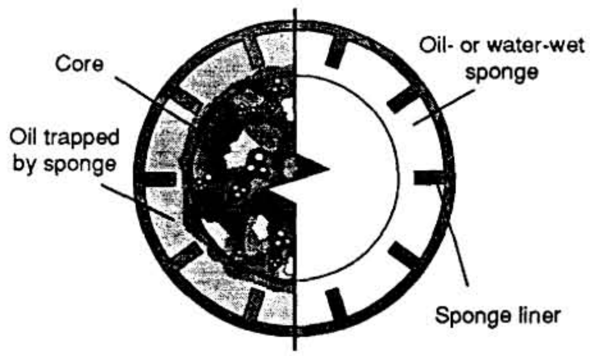

Figure 1 - Sponge Liner

Sponge Material :

The Sponge material was verified to be chemically inert and stable under most coring conditions, with operations performed at depths greater than 18,000 ft and bottom hole temperatures exceeding 165°C.

Oil Retention :

Applications conducted in "virgin" oil-bearing zones, with So levels exceeding 80%, were examined and confirmed the lab tests where efficient retention of the oil by the sponge was evident, particularly when tight fit of the core inside the sponge liners is observed which secures good capillary contact between the core and sponge.

Invasion & Oil Flushing :

Any invasion may compromise fluid saturation analysis carried out on the core. Therefore, the use of proven low invasion coring technology is critical to the success of Sponge technique. It is assumed that filtrate invasion must take place for any oil to be flushed. Situations can exist, however, where filtrate invasion can take place with no oil flushing. Careful evaluation of the amount of invasion and flushing mechanism is imperative to assess and compensate, when necessary, for any mud filtrate invasion and oil flushing during the coring process. This type of analysis requires good knowledge and expertise in core analysis for reservoir engineering.

The evaluation of several mud tracing techniques indicated that isotopic tracers were superior to chemical tracers, and much more accurate. This evaluation was based on the fact that effective use of chemical tracers always required extensive investigations to ensure compatibility with the application.

The tracers must :

- not occur naturally in formation fluids,
- be compatible with formation rock and fluids
- be detectable at low concentrations, from small volumes,
- not degrade with time or under coring conditions.

The natural presence of Deuterium Oxide (D_2O) in consistent concentrations of 145-155 ppm in nature has been proven through many field tests. Deuterium Oxide represented the best selection for water-based mud tracing programs, as one of the most stable, non-radioactive tracers available which can be analyzed in the laboratory to an accuracy of ± 0.5 ppm.

Sophisticated mud tracing programs, using Deuterium Oxide tracer and on-site plug sampling & trimming techniques, were therefore integrated with Sponge technology, associated to a relevant analysis program which is carried out on both whole core and on-site plug samples. The on-site plug sampling technique (Fig. 2) provides inner (normally represent natives-state sample) and outer core plugs drilled from freshly recovered Sponge core samples at the rig-site.

To enhance the quality of information obtained from the technique, a low invasion plug taking & trimming device was especially developed and field tested to ensure that plugs can be cut at the wellsite with no invasion or flushing of core fluids. The design of the new equipment allows the use of different cooling methods, ranging from air, air-brine mist or neutral oil, with the option to employ liquid nitrogen cooling.

Effect of Petrophysical Properties :

Accurate quantification of invasion was accomplished using the reliable invasion profiles obtained. Analysis of the invasion profiles from several recent Sponge coring projects showed zero to minimal mud filtrate invasion. The examined applications covered limestone and dolomites which exhibited different nature (fractured, vuggy), and interbedded sandstone and shale, with zones of permeability varying from a few md to several hundred md, and porosity in the range of 5-35%.

On-Site Plug Sampling

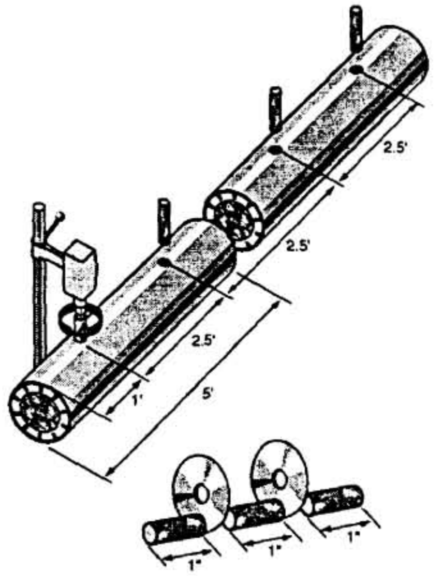

Figure 2 - Plug Sampling

Results also indicated that at low residual oil saturation (<10%), and even when GOR is extremely low, notable volumes of oil expulsion from the core was experienced due to gas expansion typically occurring while pulling the core out of hole.

Effect of ROP :

Evaluation of the coring parameters in the examined applications showed that the effectiveness of the advanced coreheads used was consistent, not relying mainly upon achieving low invasion by increasing the ROP. Even at highly changing penetration rates, ranging from 6-120 ft/hr, none to minimal invasion was observed.

Low Invasion Technology :

Elimination of the mud invasion that can take place during the coring process is the major influencing factor in the success of low invasion coring. Once a low invasion core sample is inside the inner tube, then any further seepage mud filtrate invasion can be considered insignificant because :

1. The protective filter cake formed on the core acts as impervious barrier.
2. The core, during pulling out of hole, is continuously in a state of gas expansion, giving rise to higher pressures inside the core which prevents seepage mud losses.

The advanced coreheads tested performed the main low invasion functions of permitting the protective filter cake on the core to remain intact as the core passes through the core bit throat, significantly reducing the differential pressure on the core, with further reduction in the exposure time of the core to the mud by increasing the rate of penetration during coring. A significant aspect of the design is that the significant increase in ROP is achieved hydraulically, independent of the number of cutters on the bit.

Low Invasion Technology

The unique design features (Fig. 3) which provided the low invasion capability of the used coreheads were :

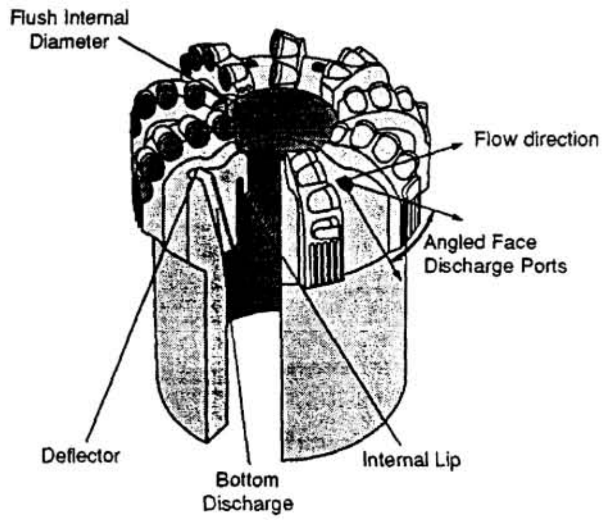

Figure 3 - Low-Invasion Corehead

- Flush internal diameter (ID)
- Internal lip
- Angled face discharge ports

Recent development was focused on optimizing the flow distribution, and influence of port positioning, flow rate, port section, flow repartition (between the bottom discharges and inner space), and port diameter.

The Flush Internal Diameter permits the protective filter cake on the core to remain intact as the core passes through the core bit throat (Fig. 3).

The Internal Lip on the pilot shoe overlaps with an internal lip on the core bit, creating a labyrinth-type seal between the shoe and the core bit which eliminates direct flow impinging upon the core and reduces the differential between the mud and the core. The optimization work resulted in flow repartition of 99% through bottom discharges and 1% through the inner space (Fig. 3).

The Face Discharge Ports are angled from the inside of the core bit to the outer diameter and direct the flow of drilling fluid away from the core. The curvature of the flow port, in combination with the profile of the core bit body, creates the unique hydraulic characteristics, with a suction that removes the drilled cuttings from the face of the bit. With the sealing effect of the internal lip, they carry almost all the fluid flow. The reduction of the mud pressure around the core lowers the tendency for invasion (Fig. 3).

Surface Handling & Preservation :

To further minimize the core's exposure to the atmosphere and speed up the retrieval operation, a disposable aluminium inner tube is used and easily cut to retrieve the liners for immediate preservation. This also eliminates the water leakage problems previously experienced while pumping the liners out of the inner tube. The recent development of the Sponge barrel allows quick and easy conversion of a standard core barrel into a Sponge barrel, making it possible to utilize standard inner tubes.

In applications for oil saturation determination, filling of the PVC tubes with brine resulted in significant imbibition between the in-filling brine and the core. This phenomenon did not however affect the oil saturation results. To minimize the imbibition, and effectively preserve the reservoir characteristics, a high performance preservation package was used, comprising sleeves made of the field proven Plastic / Aluminium laminate. The Sponge liners are put into the "Air Tight Sealed" PVC tubes after evacuating the air out of the sleeves.

To maintain the plug samples in the best condition during "hot-shot" transport to the laboratory, the plugs are initially wrapped in non reactive film, then put into envelopes made of the same Plastic / Aluminium laminate. Final storage inside cool boxes ensures maintaining low temperature to prevent evaporation and drying out.

The newly implemented preservation package proves very resistant to chemical alteration and degradation, and provides impermeable barrier to water vapor and gases, maintaining the fluids content of the core and preventing changes in properties such as the wettability of the core.

Diffusion and Imbibition

If any mud filtrate invasion takes place (typically in the outest part of the core), then, during transportation of the core, diffusion of the mud filtrate will occur within the core. This will result in mixing of original brine and mud filtrate across the core sample. Therefore, the on-site plug sampling & trimming technique is applied to isolate the water in individually preserved core plugs, which, when using low invasion coring, provides center plugs with representative water saturation.

To quantify the amount of Imbibition taking place between the Sponge pre-saturation fluid and core brine, the methodology was enhanced by using a different tracer to trace the Sponge pre-saturation fluid. Tracer analysis is then carried out on the core extracted water. Comparing the results with tracer background level in formation brine and Sponge pre-saturation fluid, it was possible to assess the amount of Imbibition.

3. APPROACH

The control of the different processes in all the phases of a Sponge coring project is critical to the success of the technique. Previous experience indicated that less than desirable outcome has resulted in most cases due to poor improper application of any one procedure. The importance of conducting all operations in the right fashion cannot be underestimated.

Careful evaluation of numerous Sponge coring jobs indicated that even if all aspects of technology remained consistent, not having full control on all the phases of a Sponge coring project would have diverse impacts on the results.

The new approach ensured excellent team work which, together with effective communication, were key factors to the success of recent Sponge jobs. The work is managed in a manner that ensures the joint effort of all team members is optimized to provide the synergy needed to design and fulfil successful Sponge coring projects, from planning and field operation to interpretation and evaluation of the results.

4. FIELD CASE

The Sponge coring technique was applied to one of the Arab D sub-reservoirs of a large offshore Abu Dhabi field, in an area where gas-cap gas was expanded into the oil rim, in order to evaluate the gas gravity drainage efficiency.

The reservoir has been produced during its initial development stage under unbalanced replacement condition which created an expansion of the gas-cap gas noticeable by early gas breakthrough in some up-dip producers (Fig. 4).

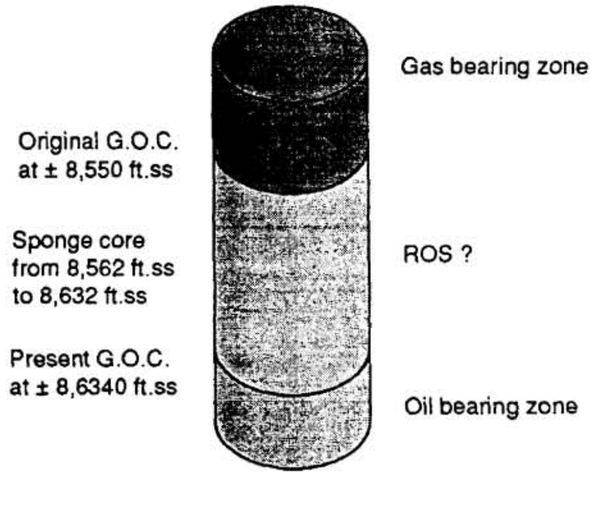

Figure 4 - Arab Sub-Reservoir - Fluids Distribution (after Gas Gravity Drainage)

Successful field evaluation was of prime importance to understand the current reservoir mechanism, and define possible EOR target projects, which is essential in the evaluation and implementation of any development plan for the reservoir.

The excellent planning, including discussion and preparation in advance of the program corresponding to each phase of the operation with the relevant operating and contractor personnel, and the attitude of top management towards reservoir engineering problems, were key factors in the success of Sponge coring projects.

4.1. Reservoirs characteristics

This reservoir has been produced for more than 30 years and is mainly composed of limestone with dolomite occurrences and anhydritic barriers.

The porosity is generally high with values of 10% to 25%. The permeability ranges from a few md to several hundred md (Fig. 5,6). The initial gas-oil and oil-water contacts were defined at 8,550 ft.ss and 9,200 ft.ss respectively.

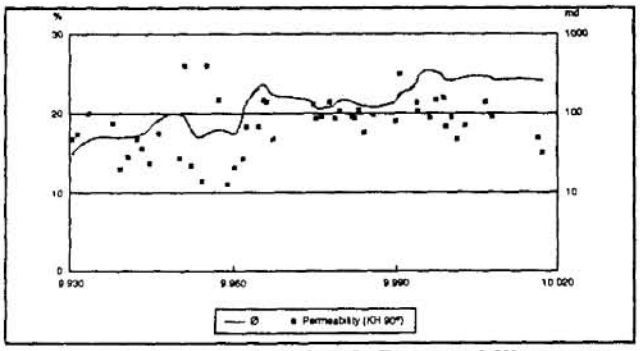

Figure 5 - Porosity & Permeability Whole Core

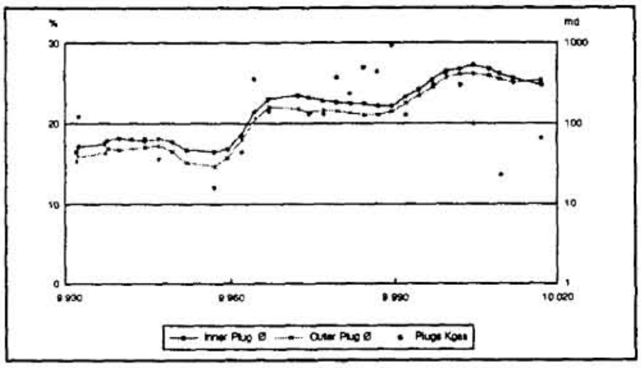

Figure 6 - Porosity & Permeability Plug Samples

4.2. Planning and implementation

The planning phase of the Arab D Sponge coring started early enough to ensure that the decisions made at this stage were based on careful assessment and complete understanding of the application, together with the end of the data to be obtained and contractor personnel. The design of the project ensured that the capabilities of Sponge coring would match the expectations of the end users. This is critical to the success of such projects.

An upper area producer, located in the expected area, was selected and proposed to conduct field measurements using the Sponge coring technique, as a secondary objective for the well. The initial reservoir oil of the Arab D sub-reservoir was expected to be gas flooded by the expansion of the gas-cap gas as this location (Fig. 4).

A Sponge coring project was initiated and the design of all the phases discussed with the coring specialists and all parties involved, including:

End users: Reservoir Engineer, Geologist, Petrophysicist
Drilling department
Mud Engineering
Core analysis company

An assessment was made of the well conditions, formation characteristics, and mud properties to determine compatibility with Sponge Coring.

Pre-coring meetings involving all parties were conducted to discuss the procedures of all the stages and achieve agreement that the job could be performed as planned without adversely affecting other aspects of the well.

The non-damaging, polymer coring fluid planned for the application provided the desirable parameters for Sponge coring, with sized $CaCl_2$ salt used to give the required mud density. With a mud density of 10.0 ppg, dictated by the formation pressure gradient through the open hole, a differential pressure of approximately 500 psi prevailed during coring.

The optimized methodology used can be summarized in 6 main points:

1. Use of advanced coreheads to achieve low invasion of the core as well as high recovery efficiency.
2. Use of highly oil-wet Sponge liners to trap the expelled oil from the core due to gas expansion.
3. Trace the mud using sophisticated tracing technology.
4. Implement the on-site plugging sampling technique, associated to mud tracing analysis to provide accurate information on the invasion profile of the core.
5. Centrifuge the inner plug samples to estimate any mobile fluids present in the reservoir rock.
6. Analysis of oil saturation of whole core, plug and sponge samples associated with their rock characteristics.

A total of 90 ft of Sponge core was cut below the Original Gas Oil Contact in three runs, 30 ft each, from 9,948 ft to 10,038 ft BRT (log depth), corresponding to 8,562 ft to 8,632 ft.ss (Fig. 4), using two types of advanced design coreheads, size $8^1/_2$ x 3 $^1/_4$", with different cutting structure.

The first run used a Thermal Stable Diamond corehead, while a Polycrystalline Diamond Compact corehead completed the other 2 runs. ROP averaged 20 ft/hr, with excellent recovery and efficiency of 100% (Fig. 7,8). Both coreheads were in excellent condition (as new) after the runs.

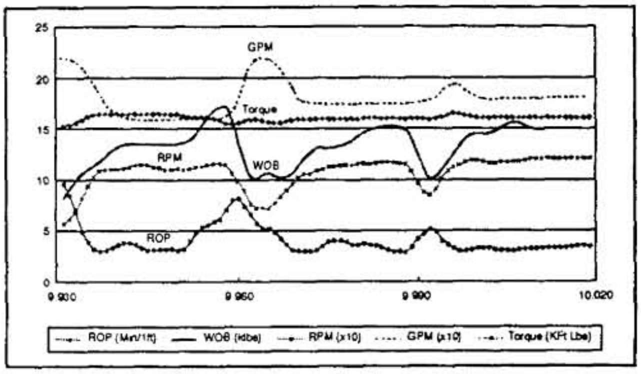

Figure 7 - Coring Parameters

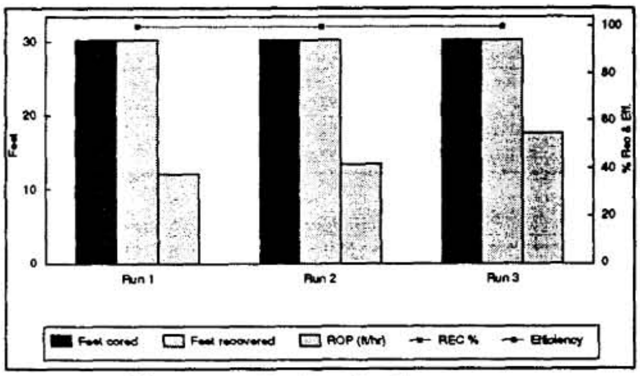

Figure 8 - Coring Performance
100% Recovery & Efficiency

The deuterium oxide tracer was mixed in the mud system, maintaining consistent concentration of ±275 ppm that was sufficiently higher than the background level, which has been measured at ± 150 ppm for the Arab D sub-reservoir, for good analytical data. The higher levels of D_2O used in the past resulted in dilution of the samples prior to measurement, adding unnecessary work and wasted resources.

Before coring, the inner tube containing the Sponge liners was filled with actual formation brine as the pre-saturation fluid. This process involves sealing the inner tube at both ends and evacuating the air inside to create a vacuum. If any air is left in the inner tube, the Sponge will be compressed by the hydrostatic pressure in the well allowing the drilling fluid to enter the inner tube and contaminate the Sponge. When coring was completed, the barrel was tripped out of the hole, and the Sponge core liners retrieved, and immediately stored inside the PVC tubes. The plug sampling & trimming technique was carried out, before final preservation of the plug samples and whole core.

The establish a reliable invasion profile, and determine the Mobile State of core fluid, on-site plugging sampling and trimming was implemented to complement the mud tracing technique, associated to a relevant analysis program which was carried out on both whole core and on-site plug samples. A highly accurate invasion profile was established after the interpretation of the Deuterium Oxide tracer analysis results.

4.3 Results

Tracer Analysis Results

Thirty plugs were collected on-site and trimmed in three pieces, two outer and one inner piece, to evaluate the mud filtrate invasion of the core. Water was extracted from inner and outer plugs as well as from 18 md samples using Dean-Stark analysis technique. These water samples were analyzed for deuterium oxide.

A representative sample of reservoir formation water and analytical grade toluene used during the water extraction process were also analysed.

From the plotted results (Fig. 9), the following conclusions were drawn:

- A consistent D_2O level of ±275 ppm was maintained in the mud system, ranging between 257-291 ppm.
- There is almost no difference between the tracer concentration content in the inner and outer plugs. The tracer concentration level in the plugs is comparable to the prevailing formation water level (± 153 ppm). None to minimal mud filtrate invasion took place during the sponge coring process.
- The oil saturation measurements are consequently not affected by mud filtrate invasion.

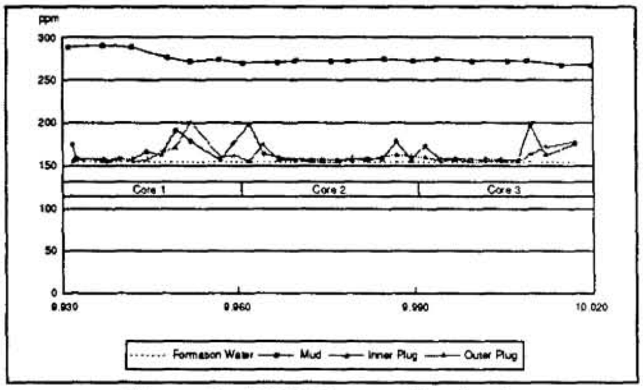

Figure 9 - D2O Tracer Analysis

Water Saturation Results

Seventeen preserved inner plug samples were centrifuged prior to Dean-Stark analysis in order to estimate any mobile fluids present in the reservoir rock. At the 3 different capillary pressures, (i.e. 17,30 & 60 psi), applied to simulate 3 different heights above the Gas-Oil Contact, no Oil was produced during the centrifuge test; however, a certain amount of water was produced and measured (Fig. 10).

It is important to note that a capillary pressure of 17 psi is equivalent to the expected variation of the gas oil contact level, i.e. 100 ft at reservoir condition, the oil and gas gradient being equal to 0.28 and 0.11 psi/ft, respectively.

The produced water from centrifuge tests, together with extracted water from Dean-Stark tests, was used to calculate the initial water saturation for inner plugs and the capillary pressure trend for each plug.

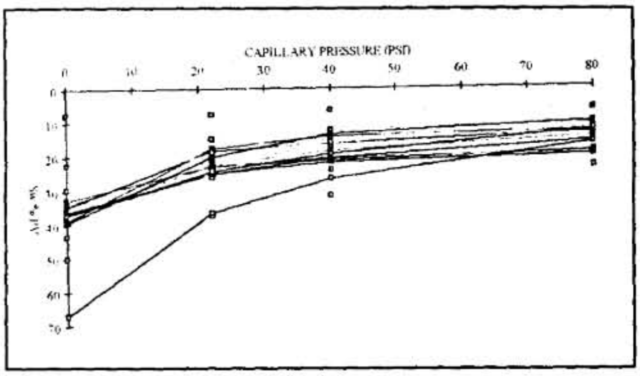

Figure 10 - Capillary Pressure Curves

Water was also extracted by Dean-Stark technique from 54 whole core samples to evaluate the water saturation profile and compare with the plug saturation data.

The results were averaged per geological unit, clearly indicating the following points:

- Some mobile water was present in the core at the time the core arrived on the rig floor and plugs were cut.
- The water saturation of the inner plugs was however, lower than the water saturation of the outer plugs and of the whole core samples.

The gas saturation, initially present in the reservoir core at the time of coring, seems to have been partially replaced by water due to imbibition mechanism between the sponge, initially saturated with formation brine, and the core associated with a good contact between sponge and core in the corebarrel. This phenomenon does not however affect the oil saturation results.

Subsequent application employed pre-saturation fluid tracing program and Imbibition study, and resulted in successfully quantifying the amount of water imbibition to enhance the quality of water saturation data as well. On-site plug samples showed zero to minimal amounts of imbibed water.

Oil Saturation Results

The volume of oil, extracted during the cleaning process undertaken at the end of the Dean-Stark test, was collected and recorded for all whole cores and Sponge samples as well as inner and outer plug samples to determine the oil saturation in surface and in-situ condition.

The oil saturation data derived from inner and outer plugs (Fig. 11) only show a very slight discrepancy and are in agreement with the results of the tracer analysis showing none or minimal invasion of the core by the mud filtrate.

No oil was produced during spinning at the 3 different Capillary Pressures applied to simulate 3 different heights above the Gas-Oil contact, which suggests that no mobile oil is present.

The results of the analysis of the Sponge indicate that the amount of oil recovered in the Sponge is minimal with an oil saturation usually less than 0.5% PV and in few exceptions between 1.5-2.5% PV. These results confirmed the plug centrifuge analysis results which indicate that no mobile oil was present in the cored zone under such capillary pressure.

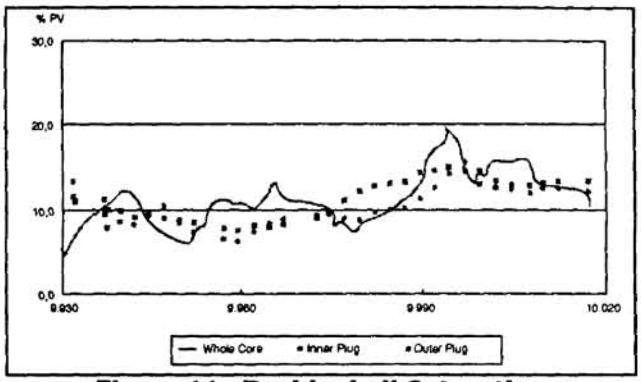

Figure 11 - Residual oil Saturation (Reservoir Condition)

The global saturation, determined from whole core analysis after adding the oil volume collected into the sponge, shows the same trend of the plug samples (Fig. 11). Their results are however more accurate than plug samples due to the amount of fluid present in the core sample during these test.s Results from whole core samples should be preferred to those of plug samples.

Oil saturation data (in-situ condition) were averaged for each geological unit corresponding to the core description (Table 1). The oil saturation, remaining in the Arab D middle layer, is in the range of 5.5 to 16.7% PV, with an average of 11% PV, however no effective trend can be found with the depth or with the rock characteristics.

4.4 Data Integration

To evaluate the gas gravity drainage efficiency in the Arab D sub-reservoir, some logging techniques were investigated and tested to have access to the effective value of the residual oil saturation after gas displacement.

RFT Data

The interpretation of the pressure measurements, carried out with the RFT tool, shows that, at the coring depth location, the continuous phase is the gas phase with a gas gradient of 0.11 psi/ft. No differential depletion is observed between the different sub-zones of the Arab D sub-reservoir and the gas oil contact is accordingly moved from an original level of ± 8,550 ft.ss to the current level of ± 8,634 ft.ss due to the expansion of the gas-cap gas (84 ft down dip).

SCAL Data

The Sorg obtained from SCAL analysis, carried out on several samples covering the different Arab D units, ranged between 38-60% P V, averaging 42% P V (Table 1). These results are related to 2 main points:

1. Only Viscous forces were applied during laboratory measurement, at ambient condition. Reservoir performance, where gas-gravity drainage is the major force, is not simulated in the lab.

2. The rock samples are not in native-state, and therefore not representative of reservoir properties (Fluids Distribution, Saturation, Saturation History, and Wettability). The samples (oil-wet carbonate rock) were cleaned during the Dean-Stark extraction process.

Residual Oil Saturation Comparison

(SCAL : Viscous Forces, Refined Oil-Brine, & Ambient Condition)

Unit Number	SCAL Data Sorg	Sponge Core Sorg
1	0.40	9.0
2	38.0-44.0	15.2
3	38.0-42.0	16.7
4	40.0-45.0	8.4
5	38.0-40.0	12.8
6	35.0-48.0	11.0
7	40.0-60.0	8.4
8	42.0-45.0	10.5
9	40.0-43.0	5.5

Table 1

Comparison to Open Hole Log Results

The objective of this comparison is to confirm the reliability of the Sponge core results and/or to evaluate the capability of logs to determine the residual oil saturation in such conditions.

Core Depth Matching

Porosity correlation, using core porosity data and CPI porosity data, has been established to calibrate the depth data and indicated a discrepancy of 18 ft. Eighteen feet have to be added to the measured and reported core depth to be identical to the logging depth in ft.BRT (Log Depth = Core Depth + 18 ft).

Open Hole Logs

The results of the ELAN analysis of the open hole log data are presented on Fig. 12. The density and neutron logs after environmental correction are plotted on track 2 and the crossover has been shaded to highlight the gas effect.

Track 3 shows the standard ELAN saturations but, in addition, the gas effect is represented in porosity units, after correcting for the presence of dolomite, between the density and neutron logs. The zero gas effect is indicated by the first of the vertical grid lines, the majority of the formation is consequently gas affected but with the tendency to a greater gas effect towards the base of the interval shown on Fig. 12 where the porosity is higher. The core residual oil saturation data from whole core and plugs samples are also represented on this track 3, the scale is such that the second vertical grid line indicates zero residual oil saturation. It is apparent that there is a slight trend towards lower residual oil saturations at shallower depth as might be expected based on the greater time for drainage to occur and also because of the greater height above the current Gas Oil Contact.

Track 4 shows the lithology and porosity as calculated by ELAN but also as measured during the previously described core analysis without any correction for overburden pressure but after core depth matching.

Evaluation

Using the previous plots, the gas effect is clearly noticeable on these logs and it is possible that its magnitude is related to the residual oil saturation. No useful correlation is apparent when cross plotting the residual saturation from core data against the dolomite corrected gas effect (Fig. 12). This is not surprising since the gas effect is strongly dependent on the degree and duration of the invasion which is generally unpredictable. It is not possible, in particular, to quantify the slumping of filtrate away from the wellbore after the mud cake has built up. This phenomenon is particularly important in gas bearing formation, which is the case here, because of the high mobility of the gas. Hydrocarbon saturations are clearly defined by open hole logs, however it is impossible to have access to the residual oil saturation after gas displacement or to differentiate quantitatively the oil and gas phases.

It is possible that the MSFL tool could indirectly measure this residual oil saturation since any oil saturation might be expected to increase the total residual hydrocarbon saturation on the assumption that the residual gas saturation is not affected by the presence or absence of residual oil. Unfortunately slumping is still a problem and can lead to anomalously high MSFL readings, particularly in the more porous formations where the gas is more mobile. Indeed this effect is apparent on Fig. 12 where the greatest apparent residual saturations are seen in the higher porosity bed towards the base of the interval shown in the figure. It is much more likely that filtrate slumping has occurred in this bed than that is really has a higher residual gas saturation than the poorer porosity beds above it.

5. CONCLUSIONS

1. A Sponge coring project was successfully accomplished, implementing a new optimized methodology, to evaluate the gas gravity drainage efficiency in a major oil field. The effective oil saturation results showed that the gravity segregation mechanism has been very active and efficient to recover the oil in the reservoir.

2. The excellent planning, including discussion and preparation in advance of the program corresponding to each phase of the operation with the relevant operating and contractor personnel is a key factor in the success of Sponge coring projects.

3. Realistic petrophysical parameters were obtained from non-invaded, native-state core samples.

4. Centrifuge Analysis was carried out on the inner plug samples. No oil was produced during spinning which suggested that no mobile oil is present.

5. The use of latest technology, field proven low-invasion core heads resulted in none to minimal mud filtrate invasion during the coring process.

6. Special on-site plugging sampling and trimming equipment was developed and successfully used to cut on-site plugs, without invading or flushing the core.

7. Sophisticated mud tracing technology was implemented, using Deuterium Oxide tracer, and provided accurate invasion profiles.

8. Recent optimization of the sponge coring methodology, in oil-wet Sponge applications, allowed the quantification of water imbibition to provide accurate water saturation and complete fluids distribution profile. This was achieved by tracing the sponge pre-saturation brine.

9. Oil typically expelled from the core while pulling out of hole was completely trapped by strongly oil-wet sponge material used.

10. A comparison has been made with in-situ measurements from open hole logs and indicated that a gas effect can be observed on log, which was also in agreement with Sponge core results, but it is so far impossible to accurately quantify the residual oil saturation from logs, due most likely to slumping of the filtrate away from the wellbore because of the high mobility of the gas phase.

NOMENCLATURE

EOR	=	Enhanced Oil Recovery
ROS	=	Residual Oil Saturation
GOR	=	Gas Oil Ratio
ROP	=	Rate Of Penetration
So	=	Oil Saturation
Sorg	=	Residual Oil Saturation due to Gas Flooding
Sorg*	=	Residual Oil Saturation due to Gas Gravity Expansion

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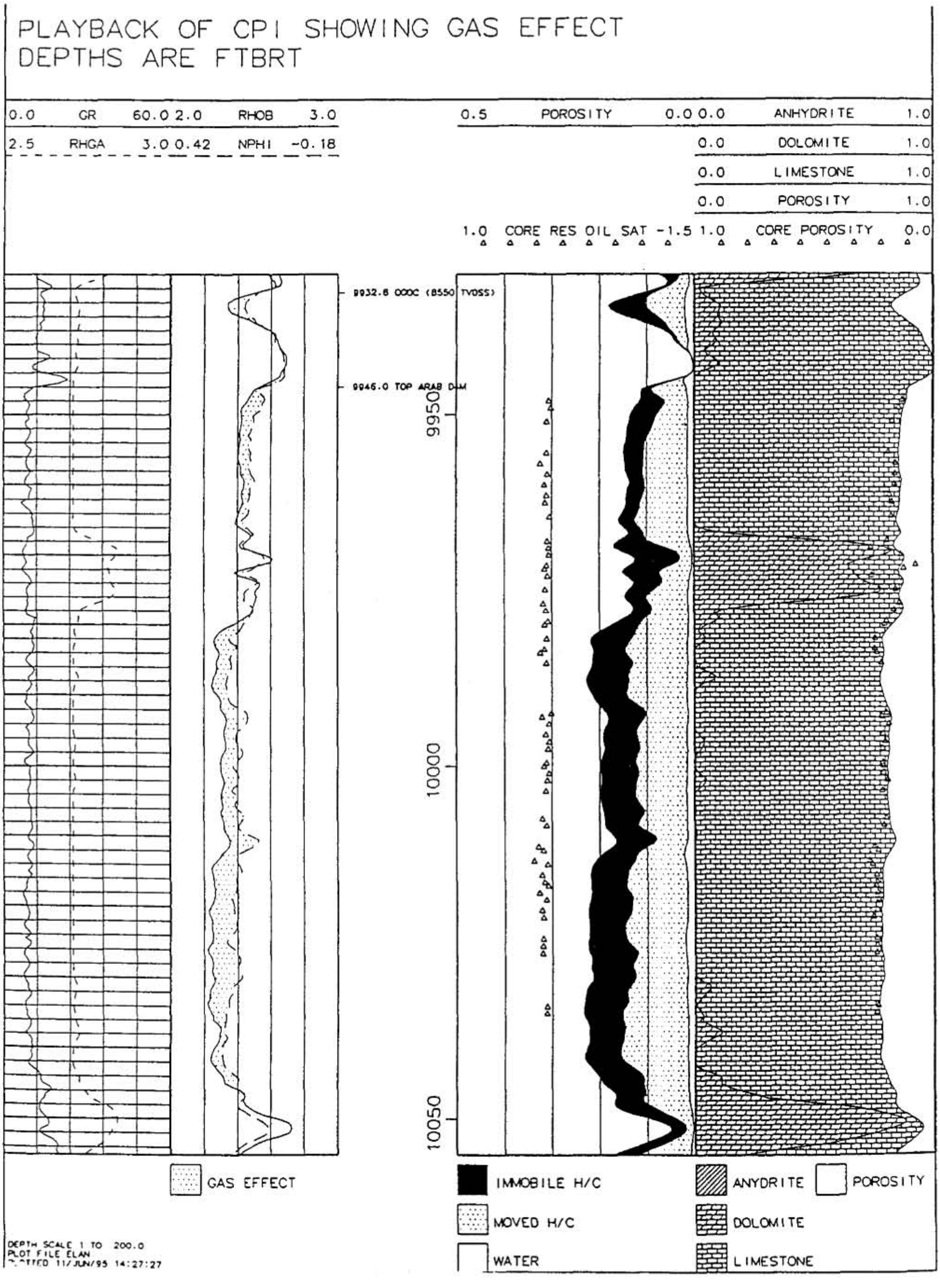
PLAYBACK OF CPI SHOWING GAS EFFECT
DEPTHS ARE FTBRT
0.0 GR 60.0
2.0 RHOB 3.0
2.5 RHGA 3.0
0.42 NPHI -0.18
0.5 POROSITY 0.0
0.0 ANHYDRITE 1.0
0.0 DOLOMITE 1.0
0.0 LIMESTONE 1.0
0.0 POROSITY 1.0
1.0 CORE RES OIL SAT -1.5
1.0 CORE POROSITY 0.0
9946.0 TOP ARAB D-M
9950
10000
10050
GAS EFFECT
IMMOBILE H/C
MOVED H/C
WATER
ANYDRITE
POROSITY
DOLOMITE
LIMESTONE
DEPTH SCALE 1 TO 200.0
PLOT FILE ELAN

Figure 12