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GAS SATURATION MONITORING IN HETEROGENEOUS RESERVOIR USING TDT MODELING TECHNIQUE

Hamada, G.M* and Dahab, A. A.*
Abdel Dayem M.M.,**
Heikel, S.***
* King Saud University, Saudi Arabia,
** Cairo University, Egypt,
***SUCO, Egypt

ABSTRACT

The Zeit Bay field reservoir units consist of sandstone and carbonates, partially overlaying a tilted block of fractured basement reservoir with a complex drive mechanism. A secondary recovery scheme of gas re-injection into the original gas cap was initiated to maintain reservoir energy and to overcome pressure decline. Hence accurate detection of gas movement is very critical. Several difficulties to monitor gas-oil contacts were encountered in a considerable number of wells. Some of these difficulties were, gas channelling behind the casing, gas coning, wellbore fluid changes, porosity and lithology changes, wellbore fluid invasion into the reservoir and the presence of formation stimulation fluid. The application of conventional methods using the response of gas indicator curves could result in a false indication of formation gas-oil contacts.

This paper discusses the approach adopted in order to determine the gas-oil contact in wells where such problems occur. A database was established including more than 70 TDT runs, open hole log and pressure data of 12 infill wells, and production performance records of all Zeit Bay wells. The approach follows the Polyachenko model of functional relationship between count rates and gas saturation. Several crossplots for the same range of porosity and connate water saturation, e.g. formation capture cross section (SIGM), total selected near detector counts (TSCN), total selected far detector counts (TSCF), the capture cross section of the borehole (SIBH), and inelastic far detector counts (INFD). Each crossplot gives a definite diagnostic shape around the depth of the formation gas-oil contact. By using these crossplots it will be possible to calculate gas saturation from a stand alone run. The model was validated by RFT and open hole log data from infill wells. Also it was successfully applied in wells which showed an ambiguity in the detected formation gas-oil contact. The field gas-oil contact in Zeit Bay was revised using the results of the model. This revision lead to an accurate definition of the oil column and to the drilling of three additional wells in the field. The open hole log results of these wells verified the gas-oil contact determined by the model.

INTRODUCTION

The Zeit Bay field has a NW-SE trending structure comprising of clastic and carbonate rocks overlaying a tilted block of granitic basement. The field was discovered in 1981, about 40 development wells were actively depleting the reservoir; and 25 of these wells are still active producers. The reservoir in Zeit Bay field is in complete hydraulic communication (Heikel et al 1997).

Production from Zeit Bay field commenced in 1984, and reached around 200 MMSTB in 1996. The average field GOR started to increase by the end of 1987. The primary recovery mechanism is a solution gas drive supported by gas cap expansion, gravity drainage, aquifer support and gas injection optimized to a level of more than 70% of total gas production (El Hamalawy et al, 1993).

The gas movement in Zeit Bay field is affected by a large number of factors: cumulative production, well location, formation dipping, fracture direction and the degree of communication between producing and gas injection wells. These factors made the determination of the GOC a very difficult task without running cased hole logs and taking reliable data from these logs. Unfortunately the TDT-P log run in the most of high GOR wells in the Zeit Bay field gave an apparent response of the GOC the shut in pass shown in Figure 1 which is deeper than that of the flowing pass shown in Figure 2.

So the results from these TDT-P runs became inconclusive for the reservoir monitoring. These inconclusive results of the logging records are due to the effect of the following factors on the TDT-P measurements:

1. Gas channelling behind the casing due to bad cement, and borehole fluid changes.
2. Gas conning.
3. Porosity and lithology changes
4. The presence of formation stimulation fluid.
5. The borehole fluid invasion into the reservoir.

These operational and environmental complications created certain limitations on the GOC consistency to reservoir performance. The objective of this work is to develop a functional relationship between the TDT-P records matching together as a crossplot model. This approach would be able to distinguish between those undesired changes in GOC and the GOC change attributed to reservoir performance behaviour.

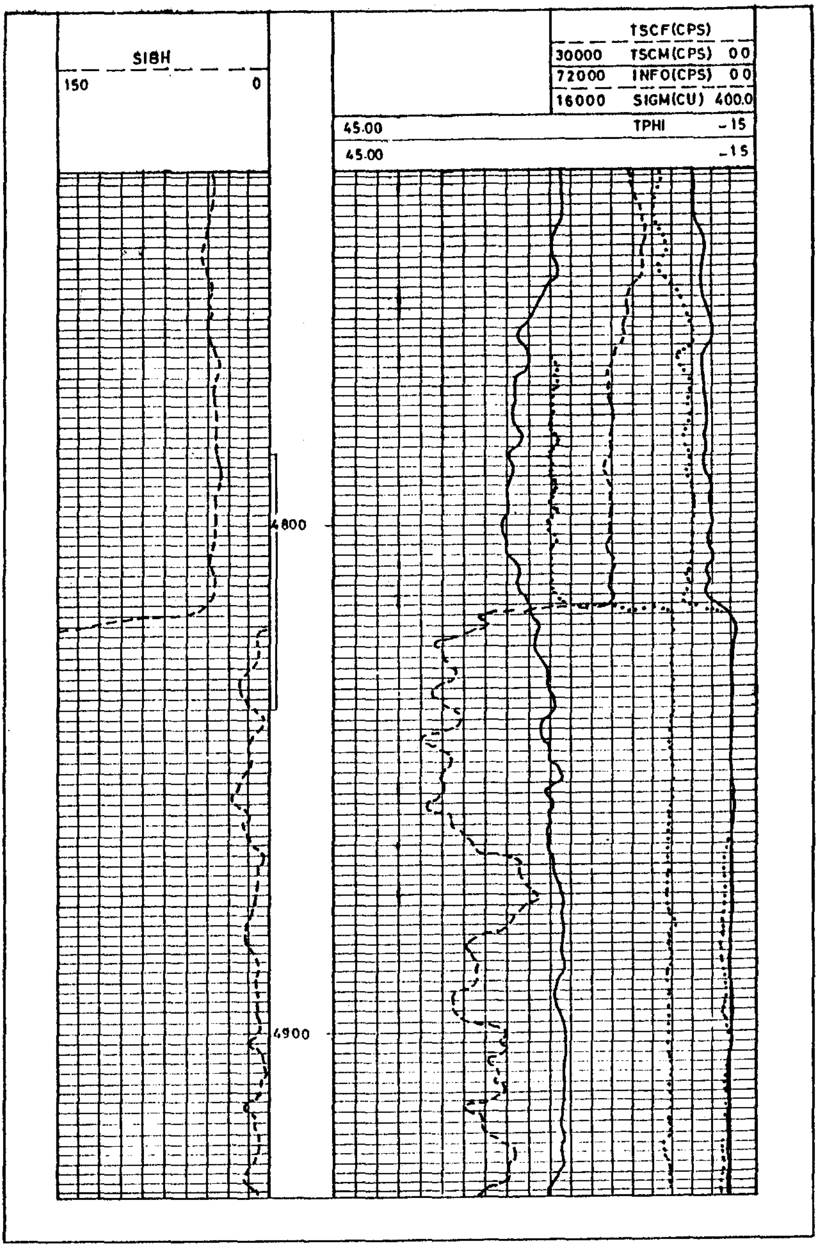

Fig. 1 TDT record (Shut-in pass, 1992) in well 8

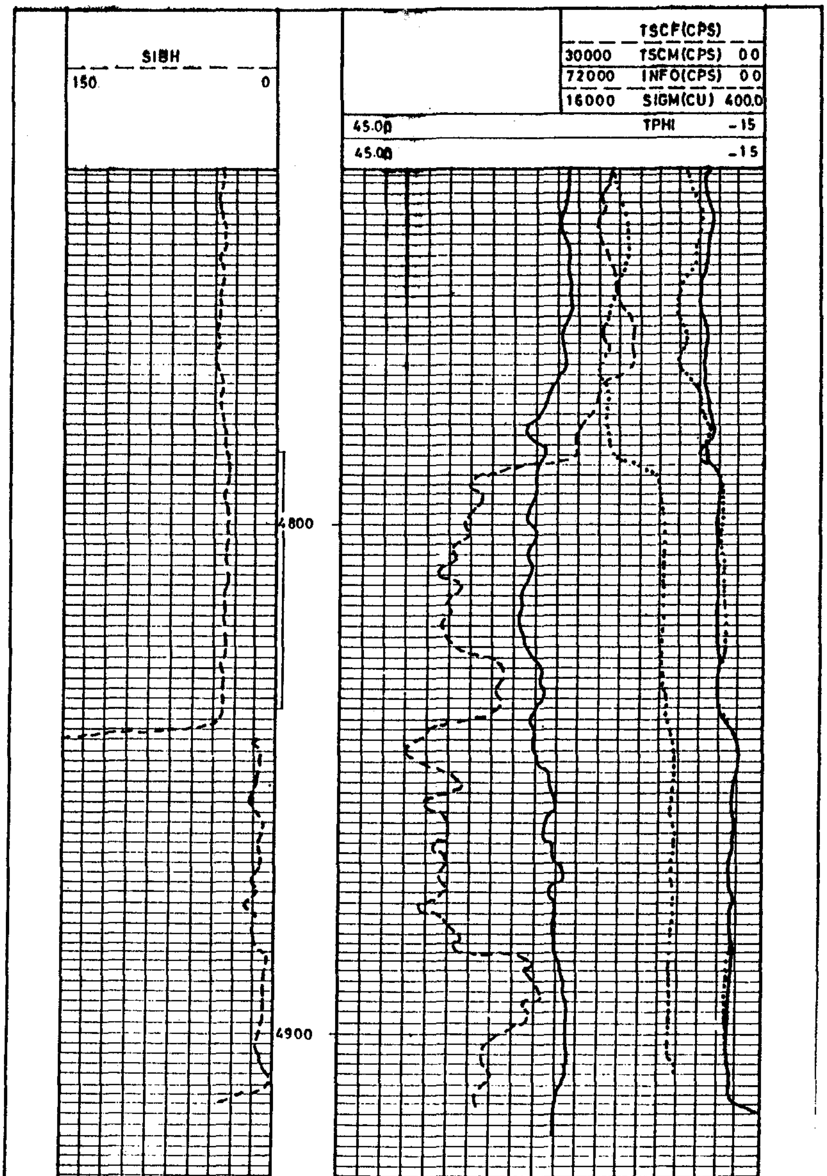

Fig. 2 TDT record (Flow-in pass, 1992) in well 8

Gas Saturation Monitoring

This model is based on the data base constructed for each well in the field including: well performance, original GOC, the raw data from both open hole logs and TDT-P covering the whole reservoir section (Smith et al, 1988, Bonnine, 1991, Schlumberger, 1991, Fitz and Ganapathy, 1993; Keikel et al, 1997).

GAS SATURATION DETECTION MODEL

Data from about 70 TDT runs in the Zeit Bay field were utilised with the assistance of the open hole log results to outline the behaviour of the near and far rate counts in the oil and gas zones. This behaviour is represented by a set of crossplots for the same range of porosity and connate water saturation and for the same lithology. This model was consistent with the result of the behaviour of the count rates for the near and far detectors based on the Polyachenko analytical model (Pennebaker, 1980, Hart and Pohler, 1989, Dunn et al, 1994 ; Hamada and Al Awad, 1998). These crossplots can differentiate between the response of the gas in the formation and gas in the borehole. All data of TDT were plotted in a linear scale to produce the developed model, which is composed from the cross plots: TSCF-TSCN, SIGM - TSCN, SIGM - INFD and, SIGM - SIBH.

The results from gas saturation model were applied in the Zeit Bay field. Each model crossplot had a definite shape for the cases: borehole gas stage, formation gas saturation changes, and formation fully saturated by gas.

Borehole Fluid Change

As the borehole fluid is water and/or oil and there is no gas in the formation there is no considerable change in both near and far counts, so it is properly scaled on a log. This phenomenon is represented by the interval **(A.B)** on crossplots, shown in Figure 3 (a-d).

When the borehole fluid changes to gas, both near and far counts increase abruptly which is presented by interval (B-C) on the crossplots. A straight line in the TSCF-TSCN crossplot with a slope represents this phenomenon less than unity, as the increase in the near count is greater than that in the far count. This is represented by a line nearly horizontal on both SIGM-TSCN and SIGM-INFD crossplots as the SIGM value is not affected by the borehole fluid change, however both TSCN and INFD counts increase abruptly due gas development in the formation. Also it is represented by a straight line on the SIGM-SIBH but in reverse direction as SIBH decreases steeply.

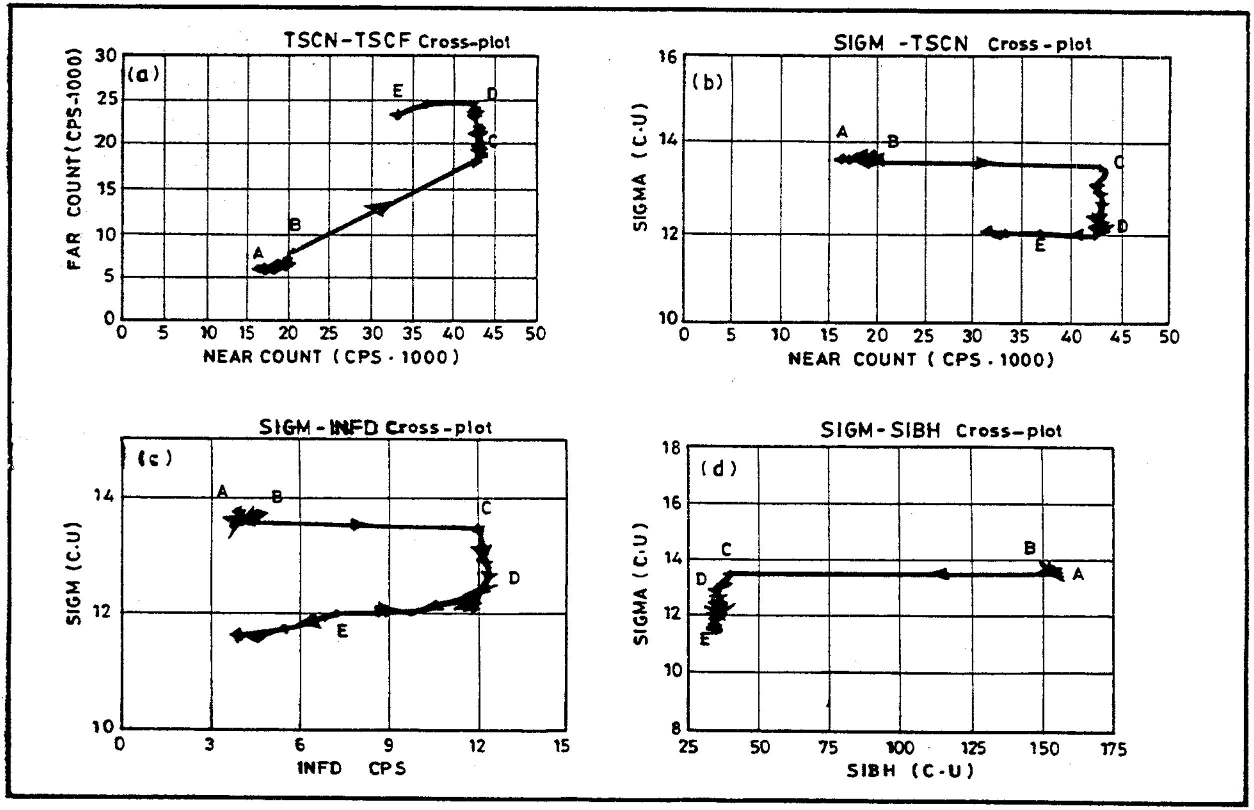

Fig. 3 Developed TDT model to detect changes in gas saturation.

Formation Gas Saturation

The effect of the formation gas saturation on the different crossplots are represented by the interval (C-.D) of TSCF-TSCN crossplot (Figure 3a) shows that as the gas saturation increase the near count rates stay without significant changes, however, the far counts increase so the curve moves upward. While SIGM-TSCN crossplot (Figure 3b) shows a decrease in SIGM value so the curve moves downward. But SIGM-INFD crossplot (Figure 3c) illustrates that the INFD values stay at its higher values without a significant change so the curve moves downward. SIGM-SIBH crossplot (Figure 3d) shows that the SIBH is not affected by the change in the formation fluid so the curve moves downward.

Formation Fully Saturated With Gas

The TDT-P was run in a gassed out zone in a considerable number of wells in Zeit Bay field. The response of the TDT-P records is represented by the interval (D-E) on different crossplots, Figure 3.

- TSCF-TSCN crossplot shows that the near and far count rates decrease so the curve bends to backward, at a certain point representing the depth of GOC.

- SIGM-TSCN crossplot indicates that the SIGM value showed a slight decrease so the curve bends backwards at a point representing the depth of GOC.

- SIGM-INFD crossplot indicates that there is a significant decreases in the INFD values, so the curve bends backward at a point representing the depth of GOC.

- SIGM-SIBH crossplot shows that the SIBH is not affected by this phenomenon so there is no change in the curve.

Effect of Acid on the Model

Acid treatments are used to improve the permeability of rock around the borehole in carbonate reservoirs in the Zeit Bay field. The response of the TDT-P in acidified interval gives high SIGM values. Also TSCF and TSCN slightly increase, as it is porosity and lithology dependant. The INFD and SIBH values are independent of this phenomenon. The ΔΣacid calculated by comparing before and after acid treatment logging runs (Crowith et al, 1990).

$$\Delta\Sigma acid = \Sigma log - \Sigma base \qquad (1)$$

where.

$\Delta\Sigma acid$ increase in the SIGM value due to acid effect.
Σlog the SIGM values logged after acid.
$\Sigma base$ the SIGM values logged before acid.

The effect of acid treatment on the SIGM value should be subtracted to use it on the model as following:

$$SIGM = \Sigma monitor - \Sigma base \qquad (2)$$

Where:
$\Sigma monitor$ is SIGM of the interpreted log.

In the case of absence of a base run, the openhole logs were used with the value of the capture cross-section of the matrix Σm to construct a base run "synthetic base run". The following equation is used:

$$\Sigma syn = \Sigma_m * (1-\phi_{oh} - V_{SH}) + \Sigma_{SH} * V_{SH} + \phi_{oh} [\Sigma w * S_{woh} + \Sigma h * (1 - Sw_{oh})] \qquad (3)$$

Where:
Σsyn : The estimated values of SIGM.
Σ_m : Matrix sigma estimated
ϕ_{oh} :Formation porosity from open hole logs.
V_{SH} : Volume of the shale per unit volume.
Σ_{SH}, Σw, Σh : Capture cross sections of shale, water, hydrocarbon respectively.

The Σm is estimated from the SIGM-PHIOH cross plot. Figure 4 illustrates this crossplot for the case of sandstone formation. It has been plotted for a set of data that correspond to a zone where S_{woh} is about 10%. Using the field data, the intersection of the straight line with the SIGMA axis gives $\Sigma_m = 6.7$ c.u.

EFFECT OF LITHOLOGY AND POROSITY CHANGES ON THE MODEL

Figure 5 shows the behaviour of TSCF-TSCN cross plot in both sandstone and carbonate reservoir having the same porosity. This figure showed that the tool response in gas carbonate reservoir, which defined by the points cluster around the symbol "B" has the same responses as that of oil sand defined by the points cluster around the symbol "C". These cluster phenomena forced us to well define lithology before using this model. On the other hand Figure 6 shows the behaviour of the same cross plot for different porosity (15 and 30) p.u. in carbonate reservoir.

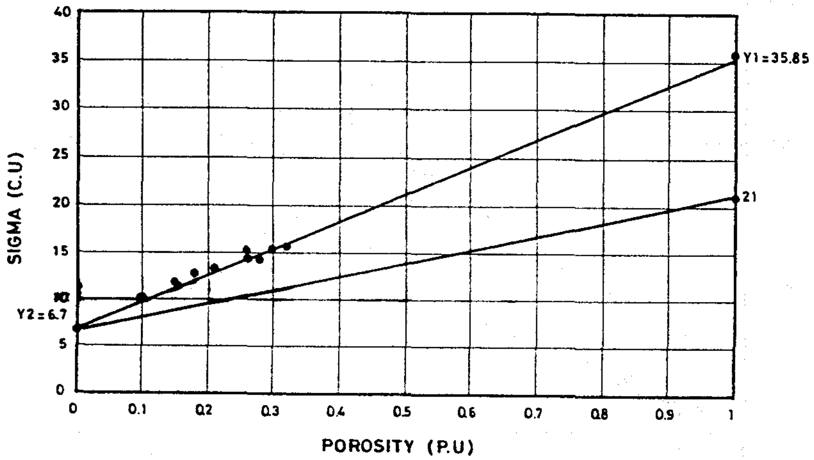

Fig. 4 Example for SIGMA-PHI crossplot in sandstone formation.

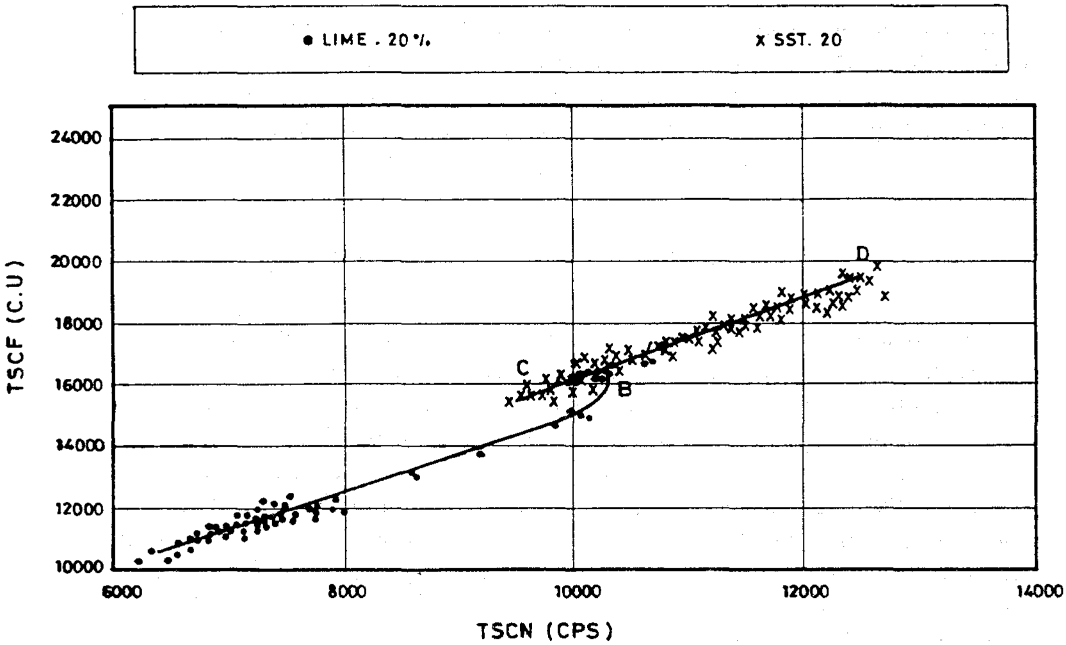

Fig. 5 TDT record for sandstone and limestone sections having porosity about 20%.

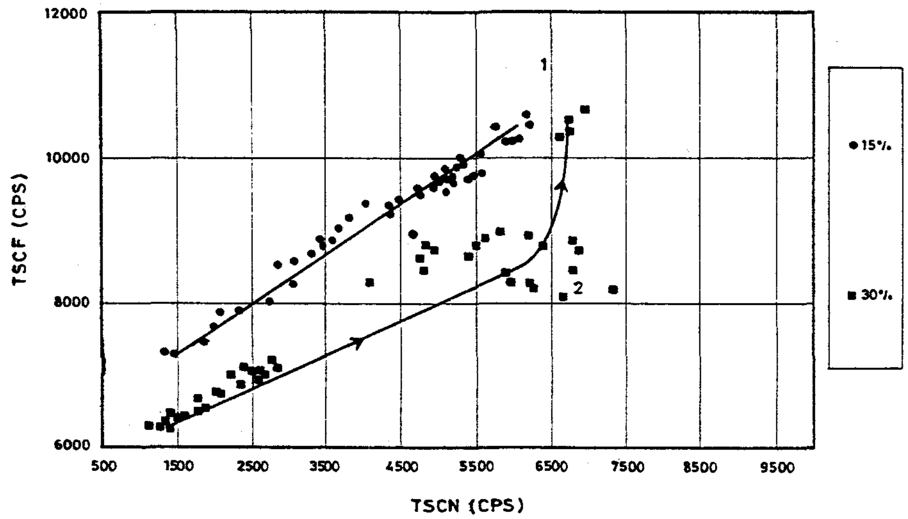

Fig. 6 Effect of porosity on TDT response in limestone formation.

It is clear that there is insignificant change in the values of both TSCF, and TSCN counts in the high range of porosity (25, 30) p.u. For low porosity zones (average 15 p.u.) the reading of the TSCF higher than that of the high porosity which may give a false indication of a gas zone, if these phenomenon is not considered in the interpretation.

EFFECT OF GAS CONING ON THE MODEL

Gas conning is well known phenomenon in some reservoirs especially those having a primary gas cap. To overcome this problem several shut-in and flowing passes should be performed. The gas conning phenomenon was detected in some wells by comparing the SIGM values in both shut-in and flowing passes. (Figure 7) showed the SIGM values recorded in both shut-in and flowing passes SIGM94S, and SIGM94F represented by dotted and solid lines in the 2-nd track respectively. There is an apparent similarity of both readings below the depth of 5530 ftMD as the two curve reflect the oil readings, and above the depth of 5030 ftMD which reflects the gas reading, this depth represents GOC. The reading of SIGM94F is lower than that of SIGM94S through the interval between these two depths which is due to gas conning. Using the reading of the shut-in pass gave a good result to detect the GOC, using the gas saturation charts.

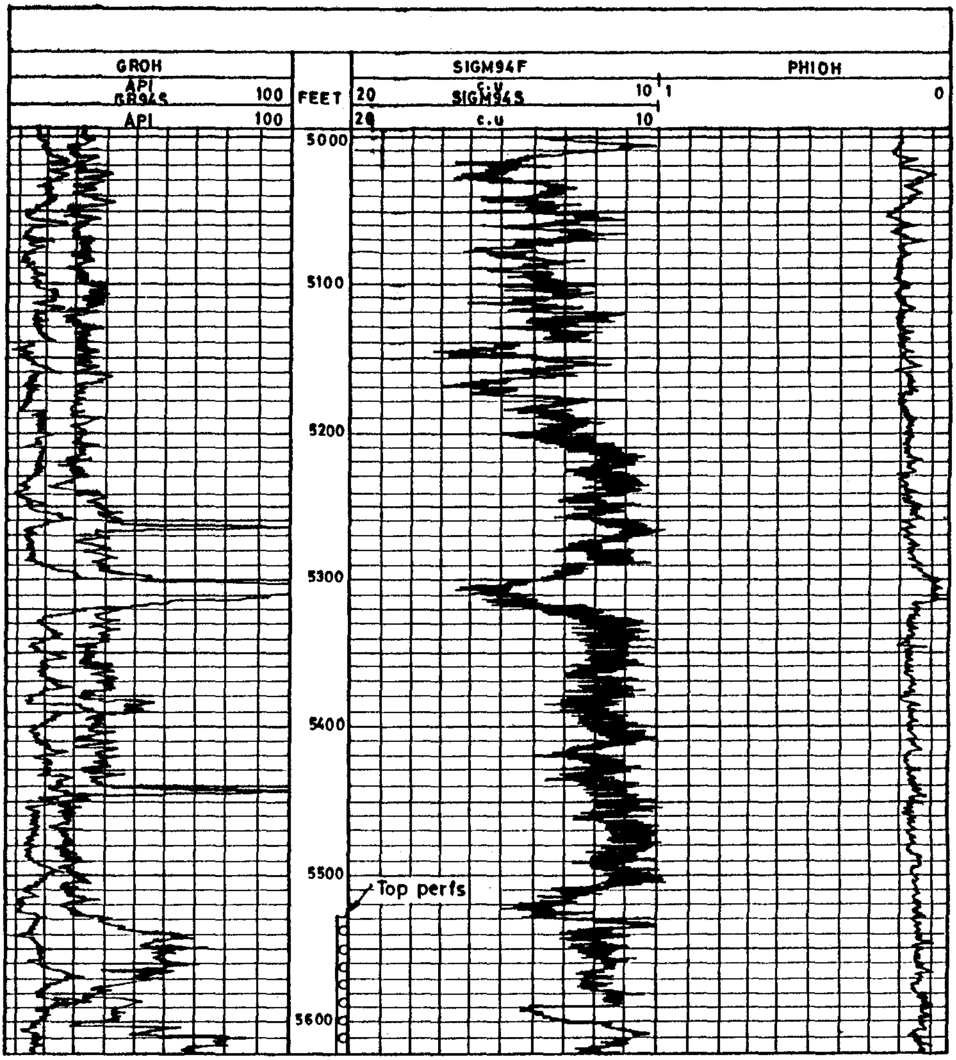

Fig. 7 TDT and GR surveys (shut-in and flow-in, 1994) in high angle well.

GAS SATURATION MONITORING IN ZEIT BAY FIELD

Two TDT-P runs in this well in 1992 and 1994, gave the response of GOC in the shut-in pass lower than that in the flowing pass as shown in Figures 1,2. Based on the well performance and TDT reading; the GOC was considered as that from the flowing pass at depth 4786 ftMD (-4552 ftTVDss).

Matching the results of the gas saturation model with the data of TDT-P run in 1994. Figure 8 monitors the behavior of the TSCF-TSCN crossplot detecting GOC at a depth of 4623 ftMD, (4320 ftTVDss) in well 8. The developed gas saturation model used to interpret the GOC in 18 wells of the Zeit bay field. These GOC detected was plotted per each well on Zeit Bay well location map.

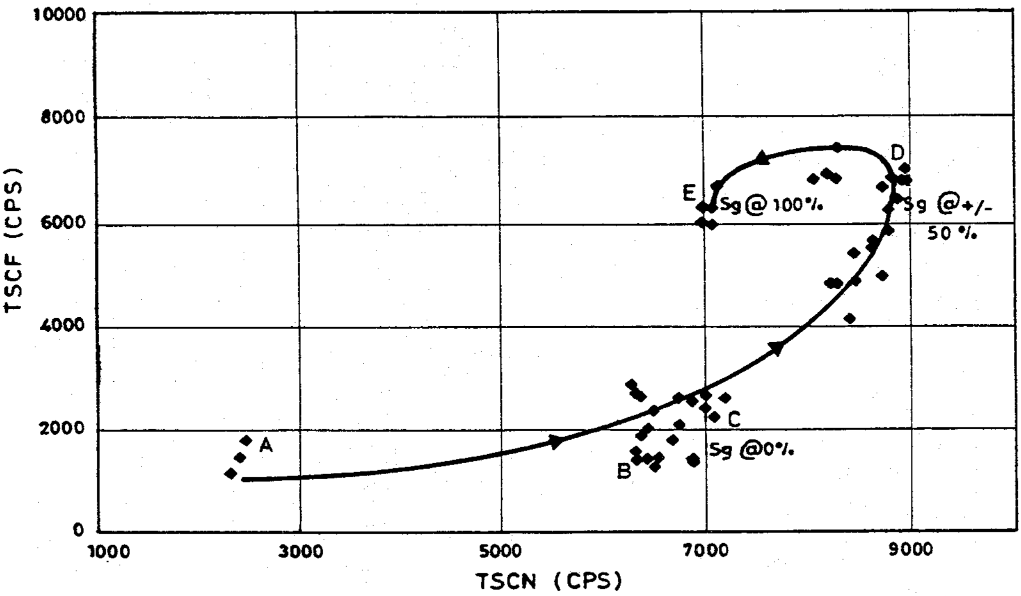

Fig. 8 TSCF-TSCN crossplot in well 8

Attempt to track the iso-gas level map to construct the iso-gas level contour map, Figure 9. Three new infill wells were drilled in the western flank of the Zeit Bay field. The average proposed GOC for each infill wells was estimated based on the location of the proposed drainage area on the iso-gas level contour map, Figure 9. The openhole logs results performed in these wells had verified the proposed gas oil contact.

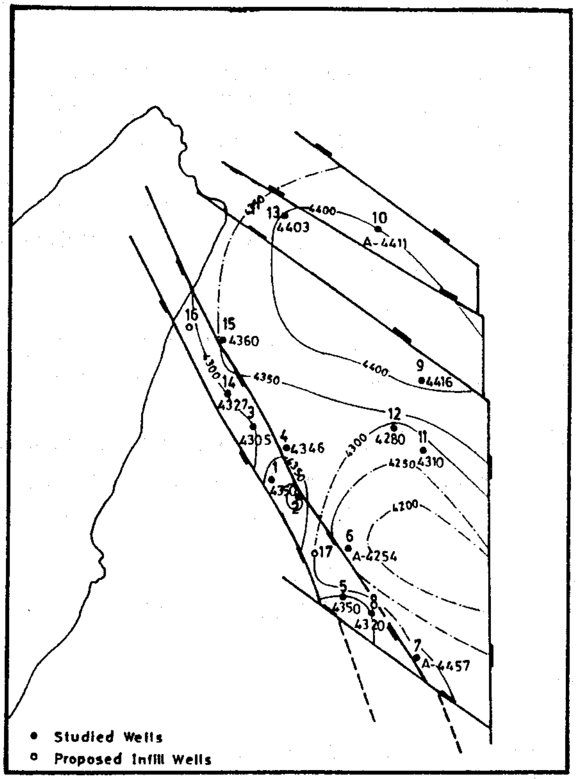

Fig. 9 New gas oil contact contour map for Zeit Bay field.

CONCLUSIONS

Based on the behavior of the TDT-P measurements in Zeit Bay Field we arrived to the following conclusions.

1. Construction of a gas saturation detection model is the best method used for gas detection in similar heterogeneous reservoirs, which should be consistent with many empirical observations of the TDT-P count rates for the near and far detectors.

2. The model has given the remedy to the cases at which the conventional methods failed, such that the borehole filled with gas.

3. As the gas saturation increase, both far and near count rate increase. The far counts increase at a slightly high rate, however there is an abrupt

increase in the "INFD" counts, and the SIGM values decrease.

4. As the borehole fluid changes from water and/or oil to gas there is an abrupt increase in both the TSCF, TSCN, and INFD count rate. However SIBH decreases and there is no change in SIGM values.

5. The presence of the acid fluid in the carbonate reservoir is considered by a fluid saturation calculation as a watered out interval. Using the synthetic TDT-P base log solved this problem.

6. The wells where GOC is suffering from gas conning problem, the SIGM flowing increases to become similar to SIGM shut-in period.

7. New and updated gas level map has been produced for Zeit Bay field based on the developed model. The importance of this map is that it reflects the actual aerial configuration of gas movement in the field.

NOMENCLATURE

GOC	Gas oil contact
GOR	Gas oil ratio
TDT-P	Thermal decay time log tool-P
TSCN	Total selected count near detector
TSCF	Total selected count far detector
SIGM	Capture crossection corrected to borehole
SIBH	Capture crossection of the borehole fluid
INFD	Inelastic count far detector
Σ_{log}	Recorded formation capture crossection
Σ_{base}	Capture cross section for base run
$\Sigma_{monitor}$	Capture cross section for monitor run
Σ_{ma}	Matrix capture cross section
$\Sigma_o, \Sigma_w, \Sigma_g$	Capture cross section for oil, water and gas
Σ_{syn}	Synthetic capture cross section
Σ_{acid}	Capture cross section due to acid
ϕ	Formation porosity
s.u.	Saturation unit
p.u.	Porosity unit
V_{sh}	Shale volume

S_{woh} Porosity volume occupied by water

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