PETROPHYSICAL ANALYSIS OF NUKHUL FORMATION IN OCTOBER OIL FIELD, NORTHERN GULF OF SUEZ, EGYPT.

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التحليل البتروفيزيائي لتكوين نخل بحقل أكتوبر ، شمال خليج السويس–مصر

الخلاصة. تهدف هذه الدراسة إلى حساب الخواص البتروفيزيائية لتكوين النخل فى شمال حقل أكتوبر بخليج السويس وذلك عن طريق تحليل التسجيلات الكهربائية لستة آبار بمنطقة الدراسة. وقد تم تمثيل البارامترات البتروفيزيائية المحسوبة رأسيا لتوضيح تغير التركيب الليثولوجى والمسامية والمحتوى الهيدروكربونى والمحتوى المائى لتكوين النخل فى شمال حقل أكتوبر بخليج السويس. وخلصت هذه الدراسة إلى أن التركيب الليثولوجى لتكوين النخل عبارة عن الكربونات والحجر الرملى والطفلة.

ABSTRACT. *The present work is denoted to give a comprehensive petrophysical analysis for the Lower Miocene Nukhul Formation in October oil field, Northern Gulf of Suez, Egypt. The coordination between the formation evaluation of well-logs and the subsurface geology of the study area was achieved to estimate the different petrophysical parameters and hydrocarbon potentialities of Nukhul Formation through six wells (OCT-F1 , OCT-F2, OCT-D4, OCT-D1, OCT-D3A and OCT-D5A,). The available log data includes the Vsh tools (Gamma Ray and Self-Potential logs), Resistivity tools (shallow and deep devices), Porosity tools (Sonic, Density and Neutron logs) and caliper log. The volume of shale obtained from gamma ray method gives reliable results. The lithology and porosity identifications have been applied using different methods and techniques. The mineralogical components have been determined from crossplotting different types of porosity. The estimated perophysical parameters are represented vertically through lithosaturation-crossplots to illustrate the vertical variation of the lithology, porosity and fluid contents of the studied formation.*

INTRODUCTION

The lower part of the Nukhul Formation represents one of the most important reservoirs especially in October oil field. The main Miocene reservoir came from conglomerates and sandstones of alluvial to shallow marine environments (*Hassouba, et al., 1994*).

The Nukhul sandstone is well developed in the Gulf of Suez, but is locally absent, particularly in places that remained structurally high or emergent until later times. The Nukhul Formation thins towards the margins of the Gulf of Suez and reaches its maximum thickness in the central offshore area. It represents about 11.5% of production potential and produces oil from the Rudeis, Sidri, Shoab Ali, GS 173, Zeit Bay, Hilal, Ashrafi, Gemsa SE, and Darag fields and oil and gas from Hareed field. The sandstone is conglomeratic in parts and yields porosities ranging between 17 and 25%. The Nukhul carbonates of reefal origin produce oil from three fields (Al Ayun, Kareem, and Zeit Bay). The average porosity of these carbonates is 16%. The net pay thickness of the Nukhul reservoirs in these fields ranges from 20 to 60 m, (Alsharhan, 2003). Thickness of the Nukhul Formation is extremely variable and it is characterized by a lateral variation in thickness and facies as a result of the earlier Oligocene-Miocene tectonics. The Nukhul deposits are most commonly conglomerates, sandstone and limestones. The non-marine to shallow, restricted marine facies of the Nukhul are poorly dated, Nukhul Formation is rich in Oysters, pectens, Osteracods and benthonic foraminifera assemblages generally assigned to the Aquitanian-lower Burdigalin (El-Heiny, 1982; Youssef, 1986).

The Nukhul sediments directly overlie Middle Eocene to Jurassic sediments, where the Nukhul Formation was deposited on the low areas and substantially high areas. In the study area, (Fig. 1), the thickness of Nukhul Formation in the investigated wells is found to be (354 ft) in OCT-F1 well, (425 ft) in OCT-F 2 well, (388 ft) in OCT-D4 well, (292ft) in OCT-D1well, (577 ft) in OCT-D3A well and (438 ft) in OCT-D5A well. Saoudi and Khalil, (1984), divided the Nukhul Formation into different facies, the Ghara facies, the Gharamul facies, and the October facies. Nukhul sediments are well developed at areas close to wadies entrance and clastics source on the low flanks of the tilted fault blocks, while non-deposition and / or erosion processes prevailed at the crest of the structurally high areas. The startigraphic column of October area, (Fig.2), consists of a thick clastic section overlaying the basement rocks and underlies a thick evaporite section. The clastic section extends throughout the geologic time from Carboniferous to middle Miocene (Kareem Formation). The evaporite section is an excellent cap rock.

DATA AND APPLIED METHODS.

The available data obtained for interpretation are well-log data including composite logs, sonic logs, density, neutron, gamma ray, caliper and deep and shallow resistivity logs. The well-log analysis has been carried out to determine shale content, matrix lithology, porosity, water and fluid saturation. Correction of log data due to the effect of the borehole, lithology, mud weight and formation temperatures, takes place before determining the different petrophysical parameters.

Shale analysis is the first step in well log interpretation. It includes two important processes; calculation of shale volume and identification of its different parameters. The shale parameters, GR_{Sh} (shaly bed), the resistivity of shale bed (Rt_{Sh}), sonic transit time (ΔT_{Sh}), density of shale(ρ_{bSh}) and the neutron reading of shale (ΦN_{sh})), are determined by using frequency crossplots, (Schlumberger, 1970). Table (1) shows the selected shale parameters derived from such plots.

Several methods are used to estimate the shale volume from gamma ray, neutron and electric logs (Poupon and Gymard, 1970, Dresser Atlas, 1982 and Schlumberger, 1987).

Porosity (total and effective) was determined for clean and shaly zones from porosity tools (sonic, density and neutron logs) using the equations of, Dresser Atals, (1979), and Schlumberger, (1987).

The neutron compensated, formation density and sonic logs are directly influenced by the matrix composition. By using two or three porosity log readings, it is possible to determine the porosity and calculate the amount and type of each lithologic component; sandstone, limestone and dolomite (Schlumberger, 1970 and Dresser Atlas, 1982)

Moreover, fluid saturation was determined for Nukhul Formation in the studied area. This fluid is distinguished into water or hydrocarbons. Water saturation can be estimated by using Poupan and Leveaux equations (1971). The hydrocarbon saturation determined by using simple equations can be distinguished into residual and movable hydrocarbons.

Shale volume.

The volume of shale is important because it largely influences the porosity and the fluid saturation determination. In the present study, the volume of shale has been estimated using single curve shale indicators, (Gamma Ray, Spontaneous potential, Neutron and

Resistivity methods), and double-curve shale indicators, (Neutron-Density, Neutron-Sonic and Sonic-Density methods), Schlumberger, (1970).

Figure (3), illustrates the calculated values of shale using single-curve methods versus depth. The majority of Vsh values obtained from gamma ray logs are less than those detected from the other logs, the minimum values of Vsh are the closest values to the true ones (Schlumberger, 1974 and Helander, 1981). Therefore, the values obtained from the gamma-ray logs are most representative to clay value in the study interval and are used in the present calculations except in zones of high radioactivity where we use the Vsh determined from neutron log.

Mineral Identification.

The matrix analysis using the crossplots gives a good idea about actual matrix composition in the studied intervals although some confusion may be present due to probable shale, gas and/or secondary porosity effects. Such analysis has been applied on the Nukhul Formation using, neutron-density (ϕ_N-ρ_b), neutron-sonic (ϕ_N-Δt), M-N and MID crossplots.

The ϕ_N-ρ_b crossplot of the Nukhul Formation in the October-D1 well, (Fig. 4a) shows that, some of the data points are located between the sandstone-limestone lines and some others are located between the limestone-dolomite lines; the presence of heavy minerals displaces a lot of the data points downwards. The ϕ_N-Δt crossplot (Fig. 4b) reveals that the litholigy is represented by sandstone, limestone and dolomite.

The M-N plot of the October-D1 well (Fig. 5a) illustrates that the matrix materials of the studied interval is mainly composed of siliceous (quartz) and lime (carbonate) minerals. The MID plot, (Fig. 5b) shows that the most of the data points are concentrated around the quartz and calcite points. A few points are found around the dolomite point. This is with a remarkable effect of the gas that displaces the plotted data to the north eastern part of the plot.

Lithosaturation crossplots.

The Nukhul reservoir rocks are evaluated through studying the vertical distribution of the well logging deduced petrophysical parameters (table 2), based on the results of well log analysis (analog). The analog consists of two tracks, one of them is responsible for fluid analysis and the other is for the formation analysis. This evaluation of reservoir potential can be used as a reliable basis to make the decision to either complete or abandon the well. It is also useful to isolate zones for possible future testing.

1- Litho saturation crossplot of OCT-F1 well.

The litho saturation crossplot of Nukhul Formation (Fig. 6) shows that, this section can be classified into two distinguished intervals where, the upper part, from depth 9340 ft to 9528 ft shows the prevalence of carbonate over sandstone and shale. Shale is the minor percentage in this part which reaches its maximum at depth intervals 9460 ft-9466 ft. In the lower part, which lies below depth 9528 ft, shale is high with decreasing amount of carbonate and sandstone to depth 9672 ft. The average effective porosity of this formation Φe is 12.7% and total porosity is 16.4%. The hydrocarbons are found in appreciable amounts in high porosity intervals, which are mostly represented by high carbonate and sandstone percentage.

2- Litho saturation crossplot of OCT-F2 well.

In this well, the litho-saturation crossplot of Nukhul Formation (Fig.7) shows that, the formation consists of carbonate, sandstone and shale. The shale values in some intervals (10438-10454 ft), (10494-10554 ft), (10636-10642 ft), (10706-10718 ft) and (10790-10794 ft) reaches 100% giving 0% effective porosity at depth 10730 ft, 10734, and 10808 ft. The effective porosity Φe is ranging from 1% to 13% in most zones of the formation except in zones of clean lithology where it reaches 33%. The percentage of the residual hydrocarbons are considerable compared to the percentage of the movable hydrocarbons which is absent in most of the studied horizons. The hydrocarbons and reservoir conditions are found in appreciable amounts in high porosity intervals, which are mostly represented by high limestone and sandstone percentage.

3- Litho saturation crossplot of OCT-D4 well.

In this well, Nukhul Formation (Fig. 8) consists of carbonate, sandstone and shale. The lithology of the upper part is carbonate and sandstone with high value of shale which increases to reach its maximum values at depths 9884 ft, 9900 ft, 10042 ft and 10050 ft. In the lower part below depth 10092 ft, the main lithology is carbonate and sandstone. Shale is observed in very small amounts. The porosity in the upper part ranges from 0.10% to 27%, and 5% to 15% in the lower part of the formation. The average value of effective porosity Φe is 8.2% and the average value of total porosity is 10.8%. Track (2) shows that Sw and S_{hm} values are more than Shr in the porous intervals of the upper part. S_{hr} is higher than Sw and S_{hm} value in the lower part of the formation where gas saturation is shown in this part, therefore, the possibility of reservoir conditions may be considered in this formation. Generally, the hydrocarbons are found in appreciable amounts in high porosity intervals, which are mostly represented by high sandstone and carbonate percentage.

4- Litho-saturation crossplot of OCT-D1 well.

The litho-saturation crossplot of Nukhul Formation (Fig. 9) in this well reveals that, the Nukhul Formation composed mainly of carbonate, sandstone and shale (Track 1). Shale content is high and prevails over the other components where it reaches its maximum value at depth 9452-9460 ft, 9466-9500 ft, 9504ft, 9574-9612 ft, and at 9722ft to the bottom of the formation and reaches to minimum value at depth interval 9612-9716 ft. The formation can be divided into two parts, the upper part from the top to depth 9620 ft at which the formation consists mainly of carbonate, sandstone and shale, with high porosity and hydrocarbon saturation at depth 9458-9466 ft and 9478-9620 ft. The lower part of the formation consists mainly of carbonate and sandstone with minor amount of shale except at depth 9722 ft to the bottom, where shale prevails over carbonate and sandstone. Porosity of this part is generally moderate to high where it ranges from 12 % to 43%. The hydrocarbons are found in appreciable amounts in high porosity intervals, which are mostly represented by high carbonate and sandstone percentage. Generally, porosity of this zone is about 17% and Φ_e reaches to 11.4%. The formation may be considered as good reservoir especially in the parts which have high porosity.

5- Litho saturation crossplot of OCT-D3A well.

In this well, The Nukhul litho-saturation crossplot (Fig. 10) illustrates that, the formation consists mainly of carbonate and sandstone with shale. The formation can be divided into two parts, the upper part, from the top to depth 10396 ft where the carbonates form the major matrix constituent as the carbonates prevail over sandstone. Shale constitutes a minor part of the lithology at depth 10396 ft and it reaches its high value at depth interval 10396-10562 ft where it reaches100% giving 0% effective porosity at depth 10492 ft,10516 ft,10526 ft and 10538 ft with decreasing value of carbonate and sandstone. In the lower part, which lies below depth 10562 ft, shale is low with increasing percent of carbonate and sandstone, but below depth 10790 ft, shale form the major part of the lithology where it reaches100% giving 0% effective porosity at depth 10784 ft and 10794 ft with minor occurrence of sandstone and carbonate. The average effective porosity value of this formation Φe is 10.96 %. Total porosity ranges from 0.4 % to 38% in the upper part and from 6% to 16 % in the lower part, Track (2) reveals that the water saturation Sw and movable hydrocarbons S_{hm} are higher than S_{hr} in the upper part of the formation, while Sw and S_{hm} are lower than S_{hr} in the lower part of the formation. The formation has good reservoir possibility especially at the intervals of the upper part of the formation which have high porosity values and hydrocarbons are observed.

6- Litho saturation crossplot of OCT--D5A well.

In this well, Nukhul Formation (Fig. 11) consists mainly of carbonate with sandstone and shale. Shale prevails over the matrix in some zone at depth 11908 ft-11974 ft and 12202 ft-12308 ft and this is accompanied by decreasing the volumes of carbonate and sandstone. The shale values in some intervals as at depth 12244 ft and 12278ft, reaches 100% giving 0% effective porosity but it is few or rare allover the section from depth 12298 ft to the end of formation. The average effective porosity Φe is 8% and it ranges from 2% to 30% in the upper part at depths (11989ft-11914 ft) ,(11966-11988 ft), (12134-12166 ft), (12170-12194 ft) and (12198-12200 ft), and from 2%-24% in the lower part at depth 12300 ft to the end of the formation. These porosities belong to the sandstone and limestone fractions. The average value of total porosity is 11.4%. S_{hm} is low in porous zones of the upper most and the lower most parts of the formation. S_{hm} reaches its maximum value at the middle part of the formation with minor occurrence of gas especially at the lower zone of the formation. The formation has good conditions for reservoir possibility.

Isoparametric maps.

The calculated petrophysical parameters were represented horizontally to show their horizontal distribution. Shale volume distribution map, Fig. (12), reveals that shale increases at the east direction, sandstone distribution map, Fig. (13), illustrates increasing values toward the central parts of the study area. Carbonate distribution map, Fig. (14), shows that the volume of carbonates increases to the eastern portion of the study area.

The iso-porosity map of the formation, Fig. (15), shows that the effective porosity increases toward the east direction. The average water saturation map, Fig. (16) show an increasing water saturation towards the east direction of the map and decreasing towards the west direction.

The depositional environment of the minerals forming Nukhul Formation is studied by constructing sand/shale ratio map, Fig. (17), which reflects shallow marine to fluvio-marine environment in the central part of the study area and deep marine in the other parts of the studied area.

CONCLUSIONS.

The results of applying the previously mentioned methods to determine the different petrophysical parameters for Nukhul Formation in the study area, show that the formation, in most of the investigated wells is consisted mainly of limestone interbeded with thin beds of marl, limestone, shale, and sandstone at the top of the formation, and conglomerate, consisted of chert, sand, and quartz at the base of the formation. In OCT-D5A well, Nukhul Formation consisted mainly of sandstone interbeded with limestone and shale at the top and conglomerate at the base, while in OCT-F1 well; Nukhul Formation is consisted of limestone, sandstone and shale interbeded with calcareous shale. In OCT-F2 well, Nukhul Formation consisted of sandstone interbeded with shaly limestone and thin beds of limestone and shale at the top, and shaly limestone interbeded by shale beds at the base of the formation.

Based on the petrophysical analysis, the Nukhul Formation in the studied wells can be considered as a good reservoir rock where it consists mainly of carbonates, sandstones and shale, the average total porosity is ranging from 16% to 25% and the average effective porosity ranges from 8% to19.8%. The maximum average water saturation is about 67% in OCT-F1-well while the maximum hydrocarbon saturation is about 62.7% in OCT-D3A-well. It is found that the residual hydrocarbons have the highest value at OCT-D1, OCT-F1 and OCT-F2 wells. While movable hydrocarbons have highest values in OCT-D3A, OCT-D4 and OCT-D5A wells.

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