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Fracture, VUG and Intercrystalline Porosity and Permeability Analysis from Well Logs of LIRTIM Oil Field, Iraq

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Abstract-- Carbonate reservoir unarguably contributes over 50% of presently produced crude oil in the world today especially from the middle-eastern part of the world with appreciable amount of reserve estimate yet unexplored. Deposition, sedimentation, diagenesis and other geological features of carbonate rocks has been studied leading their classification into: mudstone, wackestone, packstone, grainstone, boundstone and crystalline carbonate rocks. These are all characterised by various features such as fractures and vugs which influences its petro-physical behaviour.

The study of the main features of carbonate reservoir using Archie's cementation exponent "m" is an acceptable method of verifying the geological features in the reservoir which actually contribute to rock fluid properties and other production attributes of the reservoir. This was verified for some reservoir using well log values for Lirtim oil field in Iraq. The dominating geological features of the field were verified from a graphical representation of the different data from field reservoir.

The reservoirs used as case studies in the research were also classified into different carbonate rocks using a graphical plot of their permeability against porosity values. This result gives a clue of the textural and grain size characteristics as well as the effective pore sizes of the reservoir. This method of analysis makes it easier to evaluate the post diagenetic strength of the reservoir rocks and fluid hosting capability in view of recovering hydrocarbon in the area.

Index Term-- carbonate, reservoir, petro-physical, diagenesis, fractures, vugs, porosity, permeability

1.0 INTRODUCTION

Recent studies on the behaviour and features of hydrocarbon reservoir are aimed at defining the path for future development and production to maximise profit. According to Ahmed (2010), the difference in behaviour of a hydrocarbon mixture combined with the physical properties of reservoir rocks can determine the ease with which reservoir fluid are transmitted or retained. Classification of oil and gas reservoir has been done broadly into those with parameters relating to composition of their hydrocarbon mixture, those with peculiar initial reservoir pressure and temperature and others with desirable surface production conditions.

Satter, et al., (2007) explained that the initial pressure and temperature of a reservoir and the composition of its hydrocarbon system determines the reservoir or petroleum type ranging from black oil, volatile oil, dry gas and condensate reservoirs. Pedersen and Christensen (2007) also explained that reservoir fluid types can be grouped based on the location of the mixture-critical temperature relative to the reservoir temperature as shown in figure 1

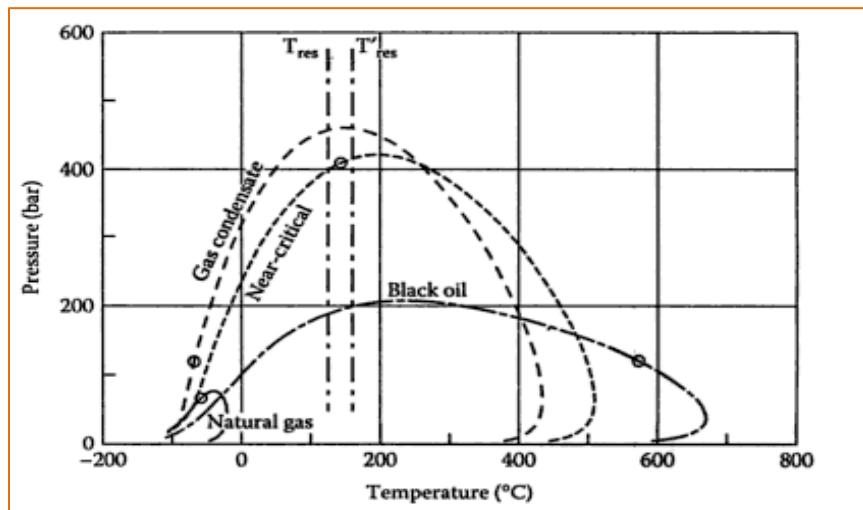


Fig. 1. Phase Envelope for various types of reservoir fluid (Pedersen and Christensen 2007)

The study of reservoir rocks is vital in visualising the behaviour of reservoir fluids. According to Hyne (2001), reservoir rocks are rocks that have the ability to accumulate, store and transmit fluids. Two (2) properties of great significance in reservoir study are porosity and permeability. Porosity is the ratio of voids in a rock to the total volume of rock and reflects the fluid storage capacity of a rock thereby making it a reservoir. The porosity or percentage pore volume of reservoir rocks can be measured from well cuttings, core samples from drilling or wireline well logs. Typical generally admissible porosity values for an oil reservoir range from between 10% and 25%, with porosity values of above 25% desirable (Hyne, 2001).

Permeability on the other hand explains how connected reservoir pores, vugs or fractures are structured and variably determines the ease of flow of fluids through the rocks. They are measured in Darcy or millidarcy. Permeability and porosity of a rock are interrelated as higher porosity implies higher permeability (Rotimi, et al., 2014). In addition, the grain size of a rock also determines the pore throat (narrow connections) that can exist in the reservoir rock thereby controlling the permeability rate. Coarse grained rocks such as carbonates and sandstones have bigger pore throats, thus they are highly permeable while rocks with lesser grain size as shale have smaller pore throats with little or no permeability (Hyne, 2001).

Halliburton, (2001) explained that porosity and permeability properties of reservoir rocks are predisposed by the depositional pore-geometries of the reservoir sediments and the post-depositional diagenetic changes that take place during the early stages of the reservoir formation. This led to classification of porosity into primary and secondary porosity. Primary porosity represents the total pore spaces present in the sediment during deposition or created during sedimentation. It is usually a function of the amount of space between rock forming grains while secondary porosity resulting from recrystallization, fracturing and groundwater dissolution; essentially from post-depositional changes. Furthermore, the interconnected pore volume available for fluid flow is termed effective porosity, while total porosity is the total void space in a rock and matrix whether connected or otherwise.

According to Majid and Veizer (2007), the spatial relationship between the lithologic facies of Lirtim carbonate reservoir suggest that carbonate deposition proceeded in alternating carbonate ramp and carbonate rimmed shelf settings. They also explained that porosity in Lirtim oil field is mainly associated with the packstone, grainstone and nummulites facies in the deposition as well as the bio-clasts sediments of the reservoir. Porosity is both primary (inter-granular and intra-skeletal) and secondary (dissolution of vugs and fractures). This porosity behaviour of Lirtim oil field will however form the area of focus for the analysis of this study.

2.0 GEOLOGY OF STUDY AREA

Oil reservoirs of the Middle East and North Africa contain 70% of the world's known oil reserves and approximately 50% of the world's natural gas reserves. These are mostly

contained in reservoirs with carbonate sediment origin which may be fractured or tight reservoirs (Edgell, 1997). It is believed that Lirtim oil field has about 610 m oil column mostly in reef, fore reef and these reefs contain foraminifera, calcareous shoal reef limestone algae and corals (Verma, et al., 2004). The northern Lirtim oil field is one of the giant carbonate reservoir oil fields of the world discovered in 1927 with an estimated 8.7 billion barrel of remaining reserves. The oil field according to Gong and Gerken (2003) is located in North of Iraq and it was formed during the Oligocene (Figure 2). Banks (2012) further clarified that the Lirtim Oil field alone sums 25 billion barrels of proven and probable recoverable oil. The oil field is believed to be a source of information on the structural geology studies of carbonate lithologies ranging from: carbonate reservoir rocks, carbonate source rocks and carbonate cap rocks.

Structurally, the oil field is characterised by a twisted anticline which is about 105km long and 3 – 5km wide. It is oriented in the NW – SE direction with five different terminations or domes, known as Zab, Khurmala, Avanah, Baba and Tarjii domes (Rpsgroup, 2012). Its primary trap is anticlinal in nature as shown in figure 3 and the oil field has a depth of 0.85 km or 2,788.85 ft. (Gong and Gerken, 2003). The crude oil contains API of 35⁰ and 1.97% sulphur content. These values have however declined sharply in the year preceding the war to API of between 32⁰ – 35⁰ and sulphur content has risen to 2%.

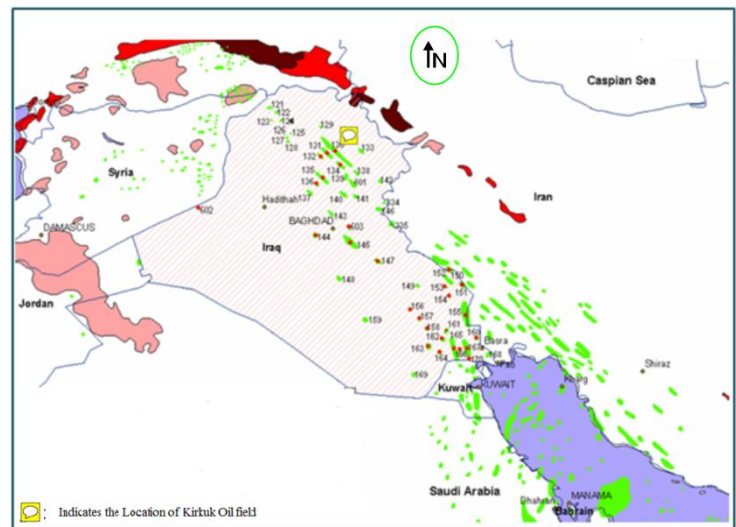


Fig. 2. The giant field of Iraq with Lirtim oil field in the northern portion (after Gong and Gerken, 2003)

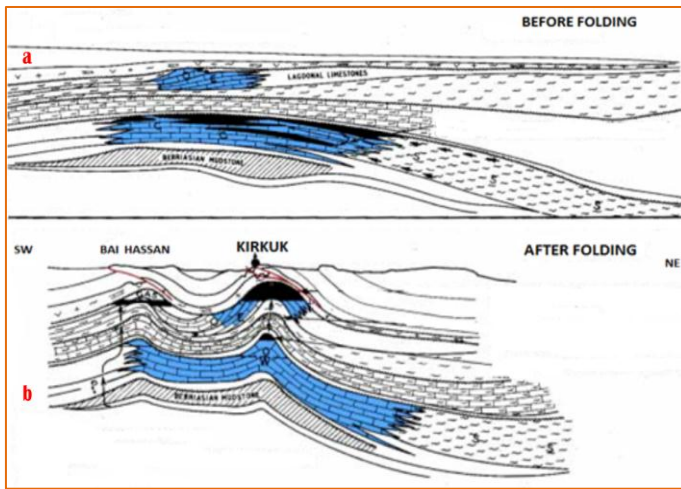


Fig. 3. Anticline formation of Lirtim oil field as a result of folding (modified from Gong and Gerken, 2003)

3.0 METHODOLOGY

The method of study was basically based on well log (Petro-physical) data from Lirtim oil field in Northern Iraq. Porosity, permeability, formation resistivity and connate water resistivity values for ten different wells were obtained from well logging of Lirtim oil well.

Using Archie’s relation (equation 1), resistivity factor, cementation exponent and pore radius for each well were derived and tabulated in Table 1 and Table 2 (Archie, 1942; 1947; 1950; 1952). Line and scattered point’s graphs were generated for the Cementation exponent and the textural properties of the carbonate reservoirs from both oil fields were inferred from permeability – porosity plot. Figure 3 is a scattered plot generated for data of tables 1 and 2.

Cementation factor ‘m’ is derived by taking the gradient of the scattered log plot of resistivity factor against porosity (figure 2) as shown in equation 4.

$$F = \frac{a}{\phi^m}$$

$$= \frac{R_o}{R_w}$$

Thus:

$$m = \frac{\text{Log}(\frac{1}{\phi})}{\text{Log} F}$$

Where F is formation resistivity, ϕ is porosity, m is cementation exponent, R_o is Formation resistivity, R_w is connate water resistivity

Also, the effective radius of the pores in wells from Archie’s equation was derived from equation 3:

$$R = \sqrt{\frac{K}{126.7\phi^m}}$$

Where R is effective pore radius (microns), K is measured permeability, m is cementation exponent.

$$\text{Gradient (m)} = \frac{\text{Initial Log (F)} - \text{final Log (F)}}{\text{Initial porosity } (\phi) - \text{final porosity } (\phi)}$$

Solving equation 4 by obtaining values from Table 2 (highlighted wells 2 and 9) gives a cementation factor of ‘2’. This is in agreement with literature inferences.

Table I
Petrophysical data well logs of Lirtim oil field

Wells	Porosity fractions (Φ)	in Porosity(Φ) in %	in Permeability (md)	Ro	Rw
1	0.163	16.3	2.38	2.068	0.055
2	0.194	19.4	12.92	1.463	0.055
3	0.198	19.8	16.07	1.403	0.055
4	0.161	16.1	2.13	2.123	0.055
5	0.176	17.6	4.83	1.774	0.055
6	0.176	17.6	5.1	1.774	0.055
7	0.161	16.1	2.13	2.123	0.055
8	0.151	15.1	2.02	2.412	0.055
9	0.17	17	2.38	1.903	0.055
10	0.14	14	1.62	2.806	0.055

Table II
Formation resistivity and log transform values of petrophysical data in Table I

Wells	Formation Resistivity (F)	Log (F) = (Log Ro/Rw)	Log (Φ)	Pore Radius (Micron)	Φ ^m
1	37.594	1.575	-0.788	0.84	0.0266
2	26.596	1.425	-0.712	1.647	0.0376
3	25.51	1.407	-0.703	1.799	0.0392
4	38.61	1.587	-0.793	0.806	0.0259
5	32.258	1.509	-0.754	1.109	0.031
6	32.258	1.509	-0.754	1.139	0.031
7	38.61	1.587	-0.793	0.806	0.0259
8	43.859	1.642	-0.821	0.836	0.0228
9	34.602	1.539	-0.769	0.806	0.0289
10	51.02	1.708	-0.854	0.808	0.0196

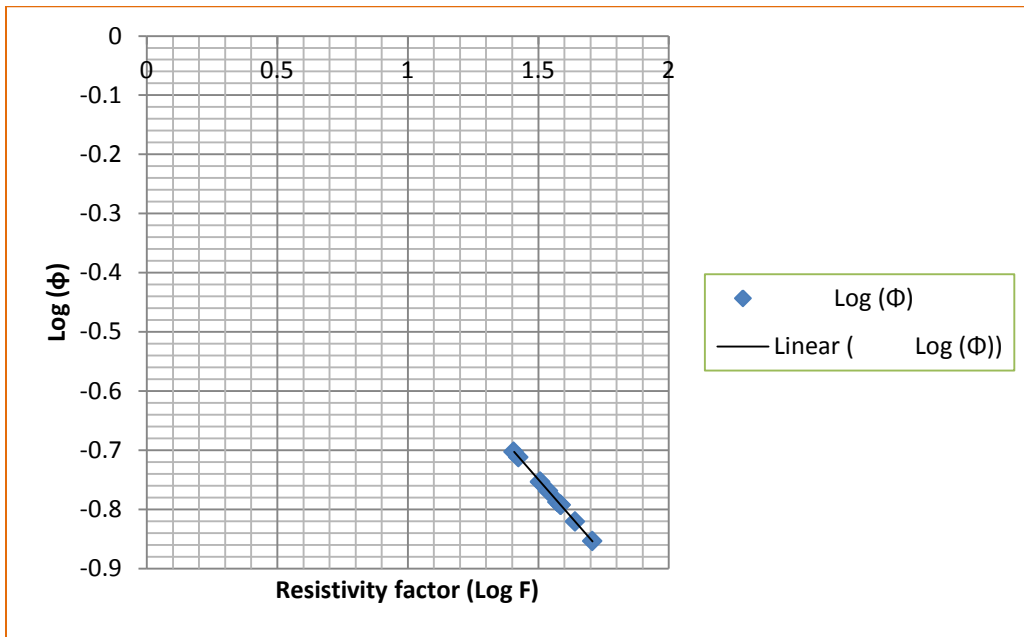


Fig. 4. Log - Log graph of Resistivity factor against porosity for Lirtim oil field

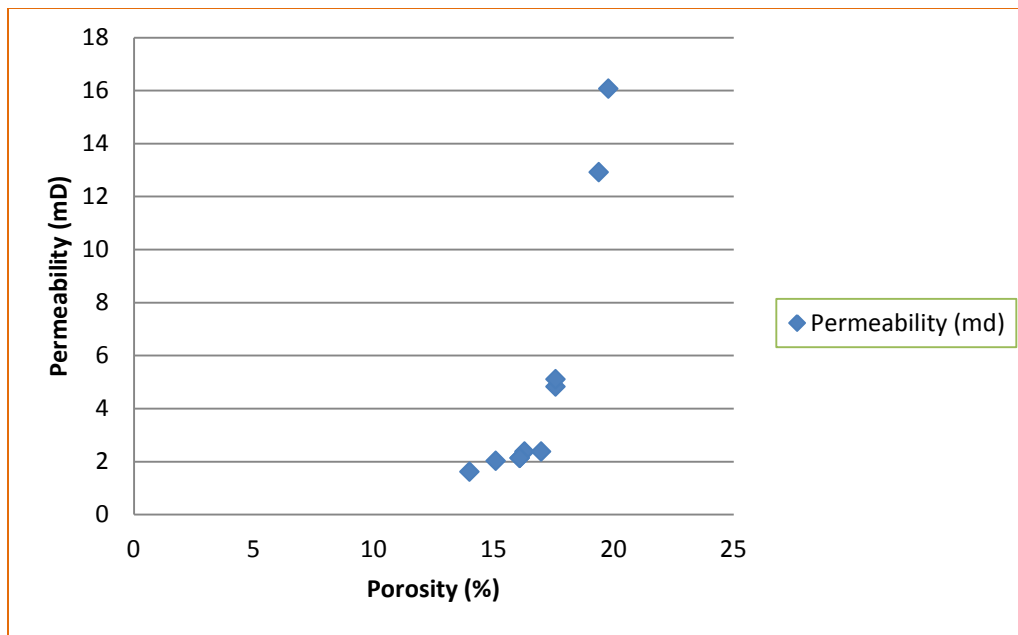


Fig. 5. Permeability against porosity curve to explain the Textural properties and classification of Lirtim Oil field carbonate reservoir

4.1 Results and Interpretations

4.1.1 Features of Carbonate Reservoir Rocks

Carbonate reservoirs are characterised with geologic features such as fractures, vugs and unique inter-crystalline structure which all contribute immensely to their secondary porosity. It is however important to be aware of the particular features contributing to the porosity of a producing carbonate reservoir so as to be able to predict, evaluate and possibly enhance the reservoir production. Though these features of carbonate reservoir provide only a small amount of the total hydrocarbon pore space, they still enhance the reservoir to produce at economic rate. The cementation exponent 'm' also called lithologic exponent is a major factor in determining the calculation of hydrocarbon or water saturation in heterogeneous carbonate reservoirs. This was done using resistivity and petro-physical data.

It can be deduced from the analysis that bulk of the natural fractures that were generated during the depositional and diagenetic stage of the reservoir has undergone some form of

geological changes such as leaching, dolomitization, re-crystallization and cementation which may all be due to drilling, production and oil recovery activities over time since inception of exploration in Lirtim oil field. The gradient value (equation 4) which implies the cementation exponent of "2" simply connotes an inter-crystalline enhanced porosity according to Archie's porosity classification from Archie's (1952) and using Pickett plot shown in Figure 6. Average values of rock properties for each well (1-10) presented in Tables 1 and 2 are sampled and values from wells 2 and 9 was used to compute the gradient (cementation factor) using equation 4.

It was inferred as a result of the analysis that the study area will further undergo diagenetic process during further production over the years. The methods adopted for oil recovery purposes would further result in leaching and dissolution of the inter-crystalline pores leading to vuggy-solution porosity which are usually more complex than either intergranular – intercrystalline or fracture porosity system.

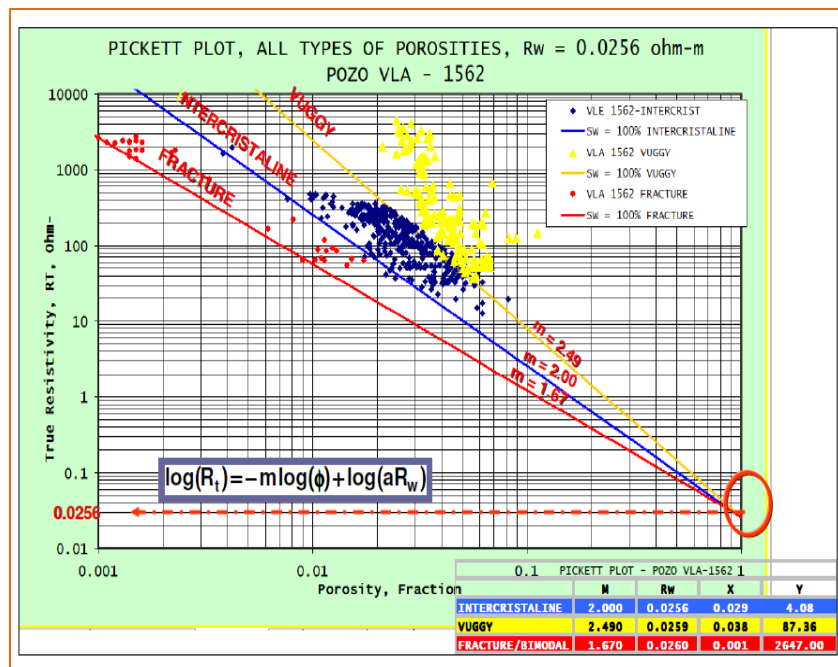


Fig. 6. Pickett plot for Validating Cementation exponent “m” (Rodolfo et al., 2012)

Classifying the carbonate rocks of Lirtim oil field according to the Dunham classification plot (Figure 7) using effective porosity values derived from their permeability data suggests packstone lime, mudstone and some moldic grainstones. This is inferred on the plot on figure 5 thus confirming the textural properties and grain size of the study area.

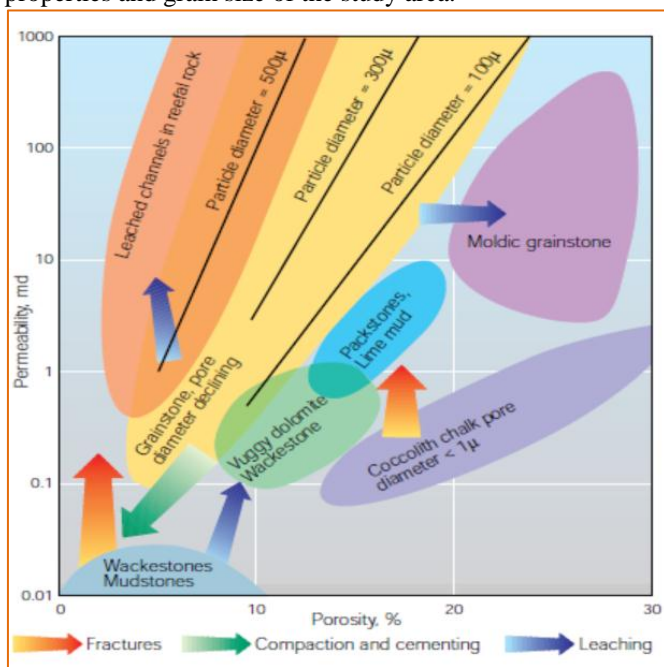


Fig. 7. Dunham carbonate classification Using Permeability – Porosity Curve (Akbar, et al., 1995)

The analysis from figure 5 shows that about 80% of the observed lithofacies in wells of Lirtim oil field are packstones with some traces of mud, clay and fine silt size carbonates which therefore explains a gradual change in the original

grainstones and packstone structure of the reservoir at the time of deposition as earlier explained by Majid and Veizer (2007). Other wells observed however indicate moldic grainstones which is a sharp deviation from the original depositional facies of the reservoir and therefore verifies the dissolution of a pre-existing constituents of the Lirtim carbonates through the various drilling and production activities over the years.

4.1.2 Economic implications of Diagenetic changes of carbonate formation studied

The variability and heterogeneity features of carbonate reservoir from pore to reservoir scale create a significant problem covering data acquisition, petro-physical evaluation and consequently reservoir description (Bust, et al., 2011). They further explained that the variation in properties of carbonate facies and their pore character often control the distributions of net pay, porosity and hydrocarbon saturation. Generally, carbonate reservoir quality is governed by pore character unlike in sandstone reservoir where variations in mineralogy, grain-size distribution and sorting, texture and degree of indurations governs the reservoir quality (Rotimi, et al., 2010). From the above stated, it is imperative that diagenetic activities such as compaction, cementation, dolomitization, dissolution and leaching which have a significant effect on the pore structure are minimized by using efficient drilling and production techniques. However, it is important to note that diagenetic activities such as dissolution and leaching could either enhance or decrease the connectivity or permeability of the pores in a carbonate reservoir. Drilling activities such as the effect of drilling bits, reactions from the combination of drilling fluids with reservoir fluids and well completion activities could also destroy the natural micro-pores of a carbonate reservoir, dissolve the inherent fractures in the reservoir and hence reduce the connectivity of the pores or further destroy the inter-crystalline structure.

All these will reduce the flow rate in the reservoir and consequently decrease the performance and production rate of the well. Lirtim oil field is presently undergoing some form of petro-physical changes as a result of dissolution and leaching of the natural fractures that were originally formed with the reservoir at deposition. This will consequently reduce the pore connectivity, flow rate of the hydrocarbon fluids and the production in barrels per day of the oil field.

5.1 Conclusions

Fractures and vugs usually contribute to the secondary porosity of carbonate reservoirs thus creating a dual or sometimes triple porosity model for carbonate rocks in addition to the primary porosity derived from the matrix structure of the rock. Carbonate reservoir generally are either fractures or non-fractured (tight) during sedimentation, further diagenetic activities after sedimentation results in the formation of some of these micro-pore features. The cementation exponent “m” of a carbonate reservoir as well as data obtained from wireline logs are usually been used with Archie’s equation to distinguish these features. This study has however further shown that these features changes from the natural fractures to complex vugs overtime as the reservoir ages and the production years increases. It is therefore necessary that production engineers adopt production and recovery techniques that will preserve the natural fractures that were formed during deposition and sedimentation period of the reservoir. Furthermore, it could assist the production engineer to understand why there might be sharp changes in the production or flow rate at varying periods of time in the life of a reservoir and guides on the appropriate reservoir enhancement methods that would help to preserve such features in carbonate reservoirs.

The use of discreet fracture network (DFN) flow simulator should be encouraged in fracture studies of carbonate reservoir. It portrays fractures and their connectivity differently from other methods. Each conductive fracture are modelled explicitly as one or more 1D, 2D or 3D element and their physical properties such as transmissivity or storage and geometrical properties such as size, elongation and orientation can be analysed using DFN. A model of this kind combines deterministic fractures (those directly imaged through seismic or intersected in wells) and stochastic fractures i.e. the small scale fractures that may not be detected through seismic analysis, yet they may be important for reservoir performance.

ACKNOWLEDGEMENTS

The authors are grateful to North Oil Company (NOC) for the release of data and permission to publish.

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