Computation of cementation factor and saturation exponent for selected oil fields in southern Iraq

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Abstract

This study aims to calculate cementation factor and water saturation exponent for four different lithological formations from different oil fields in south of Iraq and compare the results with typical values of these reservoir parameters. The formations that being selected for this study are: Yamama Formation in West Quran (WQ-60 well), Zubair Formation in south Rumaila (Ru-64 well), Nahr Umr Formation in Luhais oil field (Lu-5 well), and Mishrif Formation in Tuba oil field (Tu-4 well). The cementation factor for clastic formations (Zubair and Nuhr Umr) was calculated via Wyllie (1949) and He (2005) empirical equations. It is found that the value of this parameter is estimated to be 1.1 and 1.90 m for the Zubair formation using Wyllie equation and is equal to 2.4 and 1.6 m for Nahr Umr Formation according to the He equation. For the carbonate formations (Yamama and Mishrif), the cementation factor was estimated using Borai (1987) and Focke and Munn (1987) equations. This parameter was equal to 1.3 for both formations according to Focke and Munn (1978) and estimated to be 1.95 and 1.98 for Yamama and Mishrif formations according to equation developed by the Borai. The calculated saturation exponent was 2.5, 2, 2.21 and 0.5 in Zubair, Nahr Umr, Mishrif, and Yamama formations, respectively. The new calculated values were then applied in the Archi equation to estimate water saturation. The obtained results were compared with that calculated in laboratory (from core). Results showed that Wyille equation is better than the He equation. The final result confirmed that Wyllie equation is more accurate than He equation for calculating cementation factor in sandstone, while Borai equation was more accurate than Focke and Munn equations for the cementation factor in limestone rocks.

حساب معامل السمنتة واس التشبع لحقول نفطية مختارة في جنوب العراق

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الخلاصة

تم في هذه الدراسة حساب معامل السمنتة واس التشبع لاربعة تكاوين ذات صخارية مختلفة في حقول مختلفة من جنوب العراق. تضمنت هذه التكاوين تكوين اليمامة الكاربوناتي في حقل غرب القرنة (well WQ-60) وتكوين الزبير الرملي في حقل الرميلة الجنوبي (well Ru-64) و تكوين نهر عمر الرملي في حقل اللحيس (well Lu-5) وتكوين مشرف الجيري في حقل الطوبة (well Tu-4). حسب معامل السمنتة للتكاوين الرملية هما الزبير ونهر عمر حسب معادلتي (Wyllie,1949) و(2005) He فوجد ان قيمة معامل السمنتة (m) مساوية الى 1.1 و 1.9 حسب معادلة Wyllie لتكويني الزبير ونهر عمر على التوالي، ومساوية الى 2.4 و1.6 حسب معادلة He لتكويني الزبير ونهر عمر على التوالي. اما بالنسبة الى التكاوين ذات الصخارية الجيرية هما تكويني اليمامة ومشرف فحسبت m لهما حسب معادلتي (Borai,1987) و (Focke and Munn , 1987)، فوجدت قيمة معامل السمنتة (m) مساوية الى 1.3 حسب معادلة Focke and Munn , 1987 للتكوينين، ووجدت مساوية الى 1.95 و1.98 حسب معادلة Borai,1987 لتكويني اليمامة والمشرف على التوالي. وحسب اس التشبع (a) فوجدت قيمته مساوية الى 2.5 و 2 و2.21 و 0.5 في تكاوين الزبير ونهر عمر ومشرف واليمامة على التوالي. ثم طبقت القيم الجديدة في معادلة ارجي لحساب التشبع المائي ورسمت النتائج الجديدة مع النتائج المحسوبة فوجدت ان معادلة Wyllie افضل من معادلة He لحساب قيم m في الصخور الرملية. بينما كانت معادلة Borai افضل من معادلة Focke and Munn لحساب m في الصخور الجيرية.

1. Introduction

Reservoir water saturation (S_w) is an important factor for studying petroleum reservoir. Calculation of S_w is an essential step for computing oil saturation and in place oil accumulation. The simplest way for calculating S_w is Archie formula, which is defined mathematically as:

$$S_w = \left(\frac{aR_w}{\phi^m R_t} \right)^{\frac{1}{n}} \qquad \text{.......................(1)}$$

where, S_w is water saturation, ϕ is porosity (fraction), R_w is formation water resistivity, R_t is true resistivity of the formation, a is tortuosity factor, m is cementation factor, and n is saturation exponent. m is a measure of the degree of cementation and consolidation of the rock. As the degree of consolidation increase, the value of the cementation factor increase too [1]. The m in Archie's equation plays an important role in the calculation of hydrocarbon and water saturation, which are indispensable parameters in the exploration of oil reservoir [2, 3, 4]. The poor estimates of the *m* can cause errors in the calculation of the S_w when using Archie's equation and may lead to discrepancies between log interpretation and production test results [5]. In petrophysics routine evaluation, Archie's parameters are held constants with default saturation exponent equals to 2 [4]. In fact, *n* varies considerably from the default value of 2 in strongly water wet reservoir rocks to more than 20 in strongly oil wet reservoir rocks [6]. In addition, there are different factors affect on the *m* parameter such as shape of the grain, geometry of the pore system, grain size, tortuosity, grain size distribution, porosity, influence of pore geometry and wettability.

In this study, Archie's parameters were computed using different formula and compare with those calculated with default values.

2. Geological setting and stratigraphy

The study area includes Four Formations in Four oil fields: Yamama Formation in West Qurna (well WQ-60), Zubair Formation in South Rumaila (well Ru-64), Nahr Umr Formation in Luhais oil field (well Lu-5) and Mishrif Formation in Tuba (well Tu-4) oil fields as shown in (Fig. 1). They are located south part of Iraq. According to the tectonic zones of Iraq, the study area is located within the Mesopotamian basin, in Zubair subzone according to the tectonic subdivision. The southern Rumaila third largest gathering in the world after oil fields in Kuwait (Burgan) and Ghawar in Saudi Arabia, this field was discovered in 1953. The field is located in the southern and southeastern Iraq, 50 km south-west of the city of Basrah, total area is about 520 km. The West Qurna is one of Iraq's largest oil fields, located north of Rumaila field, west of Basra approximately 70 km NW of Basra city. Tuba oilfield is located in Basrah, approximately 40 km SW of Basrah city. Its coordinates are 30°28'60" N and 47°4'60" E. Luhais oil fields is located in southern part of Iraq, 120km west of Basrah, 60km Southwest of North Rumaila oil.

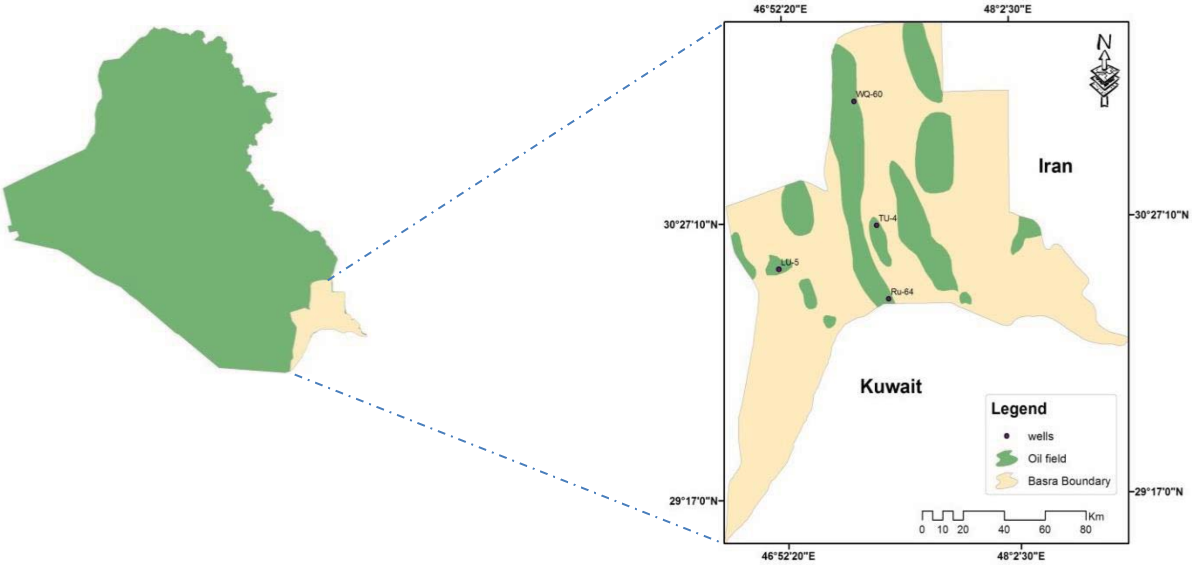

Fig. (1) The study area

The Yamama Formation in South Iraq comprises outer shelf argillaceous limestones and oolitic, pelloidal, pelletal and pseudo-oolitic shoal limestones [7]. Al – Siddiki (1978) [8] has divided the Yammam Formation to five rocks units with different petrophysical properties, three of this units are reservoir (YA,YB,YC) separated by two units rocks (CI, CII) . The Yamama formation is of Berriasian- Valanginian age [9]. The formation is usually conformably overlain by the Ratawi Formation, towards the west cover the Salman zone, where the Yamama and Ratawi formations are absent, the Zubair Formation unconformably overlies Jurassic rocks [10].The Zubair Formation is the most important formation of the Lower Cretaceous cycle in Iraq [11]. The formation comprises 380-400 m of alternating shale, siltstone and sandstone [7]. Owen and Nasser (1958) [12] divided the Zubair Formation into five members: Upper shale Member, Upper sand Member, Middle shale Member, Lower sand member and Lower shale member. The Zubair Formation is assumed to represent a prograding delta originating from the Arabian shield [13, 14]. The age of the formation as determined based on fossils is Hauterivian till early Aptian [9]. While palynomrphs evidence extended this formation up to earliest Albian age [15].

The average thickness of this formation is 425 m. The contacts of Zubair Formation are mostly gradational and conformable. The underlying formation is the Ratawi Formation which consists of dark, slightly pyretic shales interbedded with pseudo -Oolitic detrital limestone [9], and this is overlain by Shuaiba Formation which consists of dolometic limestone.The Nahr – Umr Formation is composed of sandstone and shale. It is defined by Glynn Jones in 1948 in [9] from the Nahr – Umr structure in south Iraq. It is up to 360 m thick in the south parts of the Salman and Mesopotamian zones [7]. At its type section in the Nahr – Umr field, it comprises black shales interbedded with medium to fine grained sandstone containing lignite, amber and pyrite [12]. The Nahr – Umr Formation is interpreted to be an alluvial to lower coastal plain to deltaic deposit with shallow – marine and aeolian influences [16, 17]. At Buzurgan, the formation includes glauconitic and bitumeinous sandstone and abmer [18].

Average TVD thickness of Nahr – Umr Formation is 260 m, Nahr Umr Formation is an oil reservoir in some fields. The upper contact of the Nahr Umr Formation with the overlying Mauddud Formation is conformable and gradational, and is placed at the base of the limestone of the Mauddud Limestone Formation and the top of the black shale of the Nahr Umr Formation [19]. The lower contact of the Nahr Umr Formation at the type section is with the Shuaiba Limestone Formation, where a disconformity was established on regional evidence [20]. The Mishrif Formation represents a heterogeneous formation originally described as organic detrital limestone, with beds of algal, rudist, and coral-reef limestone, capped by limonitic fresh water limestone [9].

Mishrif Formation is divided into two main reservoir units: upper Misherif and lower Misherif Separated by unit of shale. The Cenomanian-early Turonian is the Mishrif Formation age. The formation thins towards the West and NorthWest, while its thickness in the Rumaila and Zubair fields reach 270 m, in the Nahr Umr and Majnoon fields along the Iraq-lran border is of about 435 m, and in the Abu Amud field between Kut and Amara reach to 380 m [7]. The formation was deposited as rudist shoals and patch reefs over growing subtle structural highs developing in an otherwise relatively deeper shelf on which open marine sediments of the Rumaila Formation were deposited [7], The underlying Rumaila Formation consists predominantly of chalky and marly limestones. A conformable and gradational-junction with the Mishrif Formation are dark grey and greenish shales, alternating with grey, fine-grained marly limestones of the Khasib Formation [9].

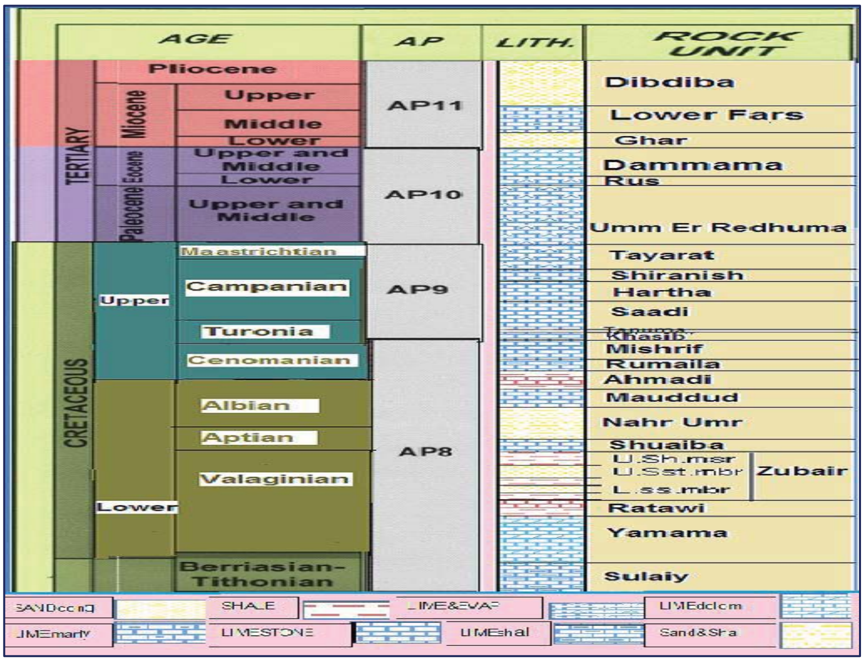

Fig. (2) Stratigraphy in southern Iraq (Zb-49 well).

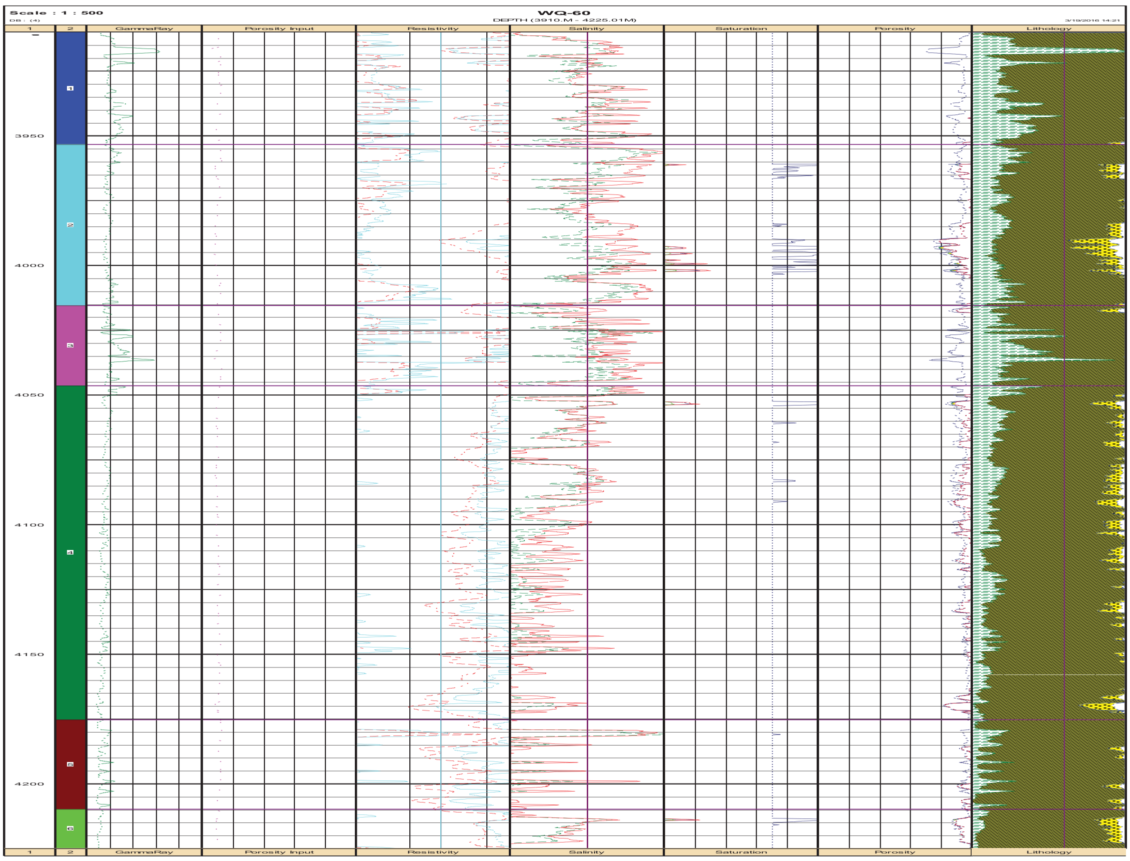

Fig (3) The zonation of Yamama formation in WQ-60.

3. Methodology:

In this study, a set of equations were used to calculate the values of cementation factor and saturation exponent according to the type of rock, they are listed below along with their authors.

- Formula for clean Sand stone $m = \frac{\ln(\emptyset/a^{0.5})}{ln\emptyset}$ (Wyllie, 1949) [21] and He (2005)[22] Adopted in the calculation of m on the value of index $\sqrt{k/\emptyset}$ as following:
- $m=2.36e^{-0.02\emptyset}$ for $\sqrt{k/\emptyset}$ ≥ 0.92
- $m=0.03\emptyset + 1.38$ for $\sqrt{k/\emptyset}$ < 0.92.
- Formula for carbonate m= 2.2-0.035/(Ø+0.042) (Borai, 1987) [23]
- Formula to calculated the cementation factor, m, in limestone and for different permeability values: (Focke and Munn, 1987) [24]

m=1.2+0.1286Ø For K< 0.1 md

m=1.4+ 0.0857Ø For K=0.1 to 1 md

m=1.2+0.0829Ø For K= 1-100 md

m=1.22+0.034Ø For K > 100 md.

The saturation exponent (n) is calculated by plot the water saturation (Sw) and the resistivity index ($I_{R=}$ $R_t/R_\circ$). This plot is usually yield a straight line with a slope equal to n. The calculated cementation factor and saturation exponent are used to calculate water saturation and the results were compared with that calculated using default values.

4. Results and discussion

When applying the equations for calculating a and m according to the rock type, the results confirmed that a is equal to 2.5 in the Zubair formation, while it is equal to 2.21 in the Nahr Umar Formation, and 0.5 and 2 in the Mishrif and Yamama formations, respectively, Figure (4) and Table (1 ,2,3 and 4). Equations of Wyllie and He were used to calculate the m coefficient of sandstone formations, Zubair and Nahr Umar. The new values of m & a were used to calculate water saturation, and the new results plotted with calculated water saturation values using default values. The correlation factor between the values of water saturation calculated by He equation and the calculated water saturation using laboratory-calculated are 0.78 and 0.85 for the Zubair and Nahr Umar formations, respectively Figure (5).

The coefficient of correlation between the values of water saturation using *m* that calculated by Wyllie equation and the laboratory-calculated water saturation are 0.93 and 0.89 for Zubair and Nahr Umar formations. Respectively, Figure (5). Based on the above results it is clear that the Wyllie equation for calculating the *m* coefficient of sandstone formations is better than the He equation, Figure (6).

The Borai and Fock equations were used to calculate the *m* coefficient of carbonate formations, the Yamama and Mishrif formations, and the new values of *m* & *a* were used instead of the default in Archi equation to calculate water saturation. The new results were plotted with calculated water saturation values. Results show that values of coefficient of correlation between the values of water saturation using *m* calculated by Borai equation and the calculated water saturation equal to 0.94 and 0.44 for the Mishrif and Yamama formations respectively, Figure (5).

The coefficient of correlation between the values of water saturation using *m* calculated by Fock equation and the calculated water saturation are 0.78 and 0.21 for the Mishrif and Yamama formations respectively, Figure (5). Based on the results above, it is clear that the Borai equation for calculating the coefficient of *m* for carbonate formations is better than the Fock equation, Figure (6).

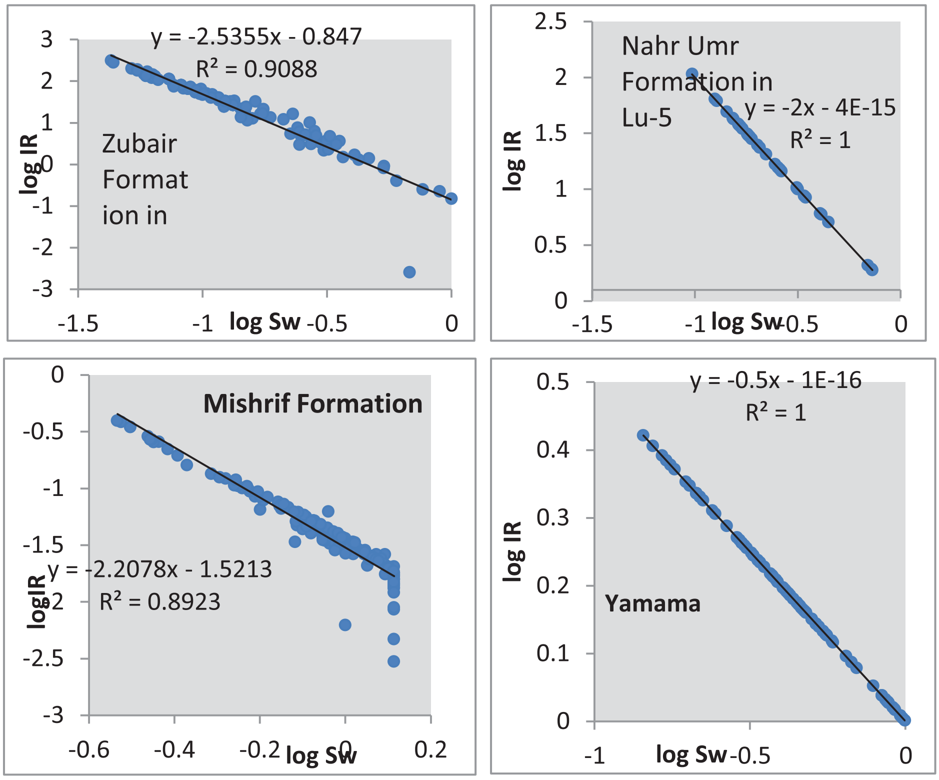

Fig. (4) Water saturation (Sw) Vs. the resistivity index IR for study area.

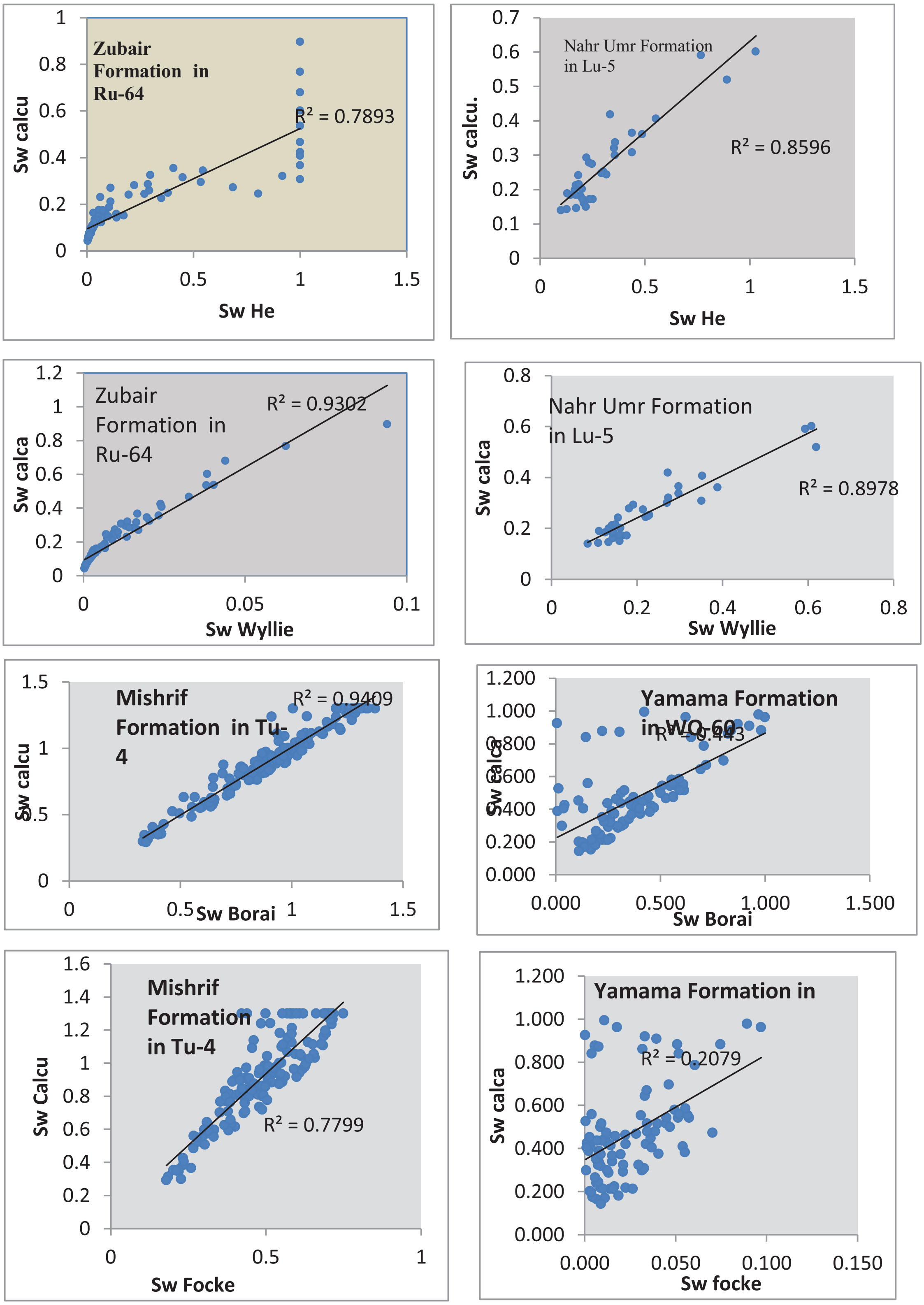

Fig. (5) Water saturation (Sw) using new values of a and mVs. water saturation calca.

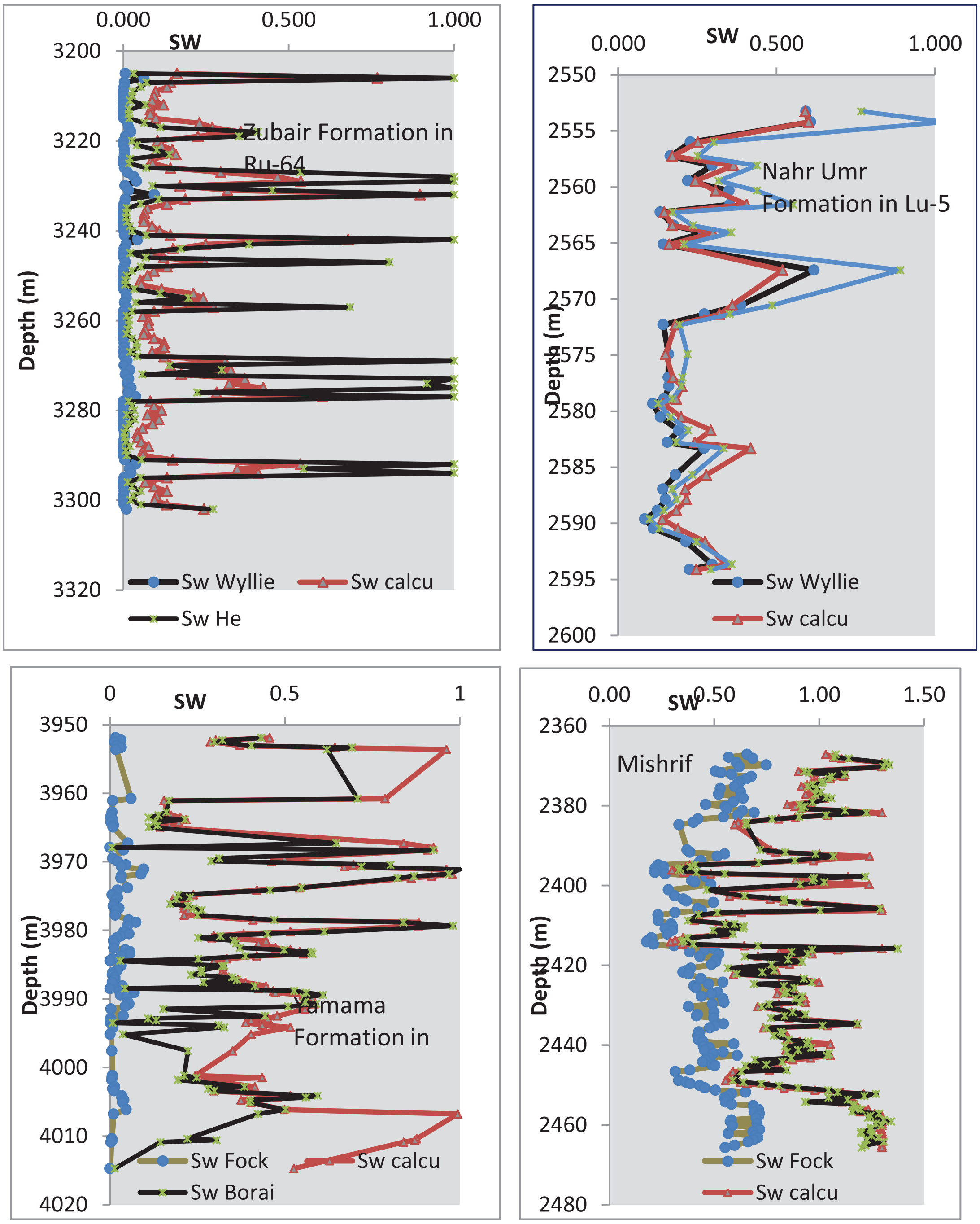

Fig. (6) Water saturation (Sw) vs. depth

Conclusions

1) The Wyllie equation for calculating the *m* coefficient of sandstone formations is better than the He equation.
2) The Borai equation for calculating the coefficient of *m* for carbonate formations is better than the Fock equation.
3) The calculated values of *a and m* by empirical equations should be used instead of the default values in the calculation of water saturation.

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Nomenclature

Ro	resistivity of fully water-saturated rock (Ω.m)
Rt	resistivity of the partly water-saturated rock (Ω.m)
Rw	resistivity of water (Ω.m)
F	formation factor
Ir	Resistivity index
ϕ	Porosity
m	cementation factor
Sw	water saturation
n	saturation exponent.
K	Permeability (md)

Appendix

Table(1) Results of Zubair Formation in Ru-64

Porosity	Permeability (md)	Value of m calculated according to		Value of water saturation according to			IR
		Wyllie (1949)	He (2005)	sw he	Sw calculated	sw wyllie	
0.158	105	1.169193	2.353	0.032	0.163	0.007	32.313
0.188	354	1.053978	2.351	1.000	0.768	0.063	0.249
0.197	463	1.049757	2.351	0.070	0.143	0.004	21.127
0.199	498	1.087831	2.351	0.053	0.133	0.003	26.709
0.224	556	1.092984	2.349	0.029	0.097	0.002	49.411
0.243	1268	1.092984	2.349	0.027	0.094	0.002	53.418
0.244	1760	1.092984	2.349	0.021	0.087	0.001	65.889
0.255	1573	1.098137	2.348	0.067	0.122	0.002	24.164
0.046	1.5	1.077583	2.358	0.017	0.082	0.001	79.813
0.122	5.3	1.103371	2.354	0.017	0.082	0.001	79.813
0.2	391	1.103371	2.351	0.019	0.099	0.002	64.794
0.221	1154	1.119482	2.350	0.064	0.230	0.013	16.156
0.186	443	1.169193	2.351	0.112	0.270	0.017	10.063
0.167	205	1.139187	2.352	0.407	0.355	0.023	3.582
0.199	441	1.090449	2.351	0.350	0.226	0.007	5.387
0.223	916	1.066387	2.349	0.027	0.104	0.002	49.883
0.162	232	1.103371	2.352	0.041	0.116	0.003	34.721
0.15	351	1.092984	2.353	0.101	0.149	0.004	16.311
0.17	35	1.077583	2.352	0.139	0.159	0.004	12.602
0.196	66	1.072112	2.351	0.021	0.087	0.001	65.889
0.19	636	1.098137	2.351	0.018	0.089	0.002	71.184
0.161	237	1.108606	2.352	0.070	0.143	0.004	21.391
0.113	1.2	1.08809	2.355	0.536	0.295	0.013	3.417
0.189	795	1.069335	2.351	1.000	0.466	0.033	1.367
0.218	1164	1.069335	2.350	1.000	0.536	0.040	0.899
0.247	2058	1.06431	2.348	0.089	0.171	0.006	16.025
0.234	1585	1.092984	2.349	0.450	0.315	0.016	3.625
0.196	661	1.077583	2.351	1.000	0.897	0.094	0.221
0.231	1295	1.053904	2.349	0.106	0.187	0.007	13.354
0.229	1125	1.092984	2.349	0.053	0.133	0.003	26.709
0.206	497	1.092984	2.350	0.011	0.073	0.001	111.490
0.217	335	1.113969	2.350	0.010	0.064	0.001	129.696
0.018	40.2	1.103371	2.359	0.009	0.063	0.001	142.606
0.108	27	1.108659	2.355	0.012	0.063	0.001	119.921

Table (2) Nahr Umer Formation in Lu-5

Porosity	Permeability (md)	Value of m calculated according to		Value of water saturation according to			IR
		Wyllie (1949)	He (2005)	sw he	Sw calculated	sw wyllie	
4.500	0.200	1.054	1.515	0.768	0.591	0.594	2.085
19.400	7.000	1.027	1.962	1.029	0.602	0.608	1.922
18.500	355.000	1.028	1.630	0.302	0.252	0.229	14.444
20.100	8.000	1.027	1.983	0.252	0.172	0.165	28.037
14.600	2.000	1.030	1.818	0.439	0.365	0.297	8.412
14.800	2.500	1.030	1.824	0.317	0.244	0.220	15.659
22.900	629.000	1.026	1.493	0.439	0.308	0.351	6.065
17.900	3.800	1.028	1.917	0.553	0.406	0.353	5.922
18.800	213.000	1.028	1.620	0.173	0.146	0.134	43.040
16.400	20.000	1.029	1.700	0.236	0.172	0.176	24.757
19.000	123.000	1.028	1.614	0.357	0.300	0.270	10.268
16.900	4.700	1.029	1.887	0.208	0.162	0.143	37.410
16.200	50.000	1.029	1.707	0.892	0.519	0.619	1.886
4.500	3.100	1.054	1.515	0.487	0.361	0.388	5.057
20.700	265.000	1.027	1.560	0.353	0.321	0.273	10.008
15.700	90.000	1.030	1.724	0.194	0.181	0.143	37.494
13.000	4.800	1.032	1.770	0.219	0.150	0.159	30.381
19.800	462.000	1.027	1.588	0.203	0.173	0.159	30.423
22.300	375.000	1.026	1.511	0.200	0.202	0.161	29.351

Table (3) Mishrif Formation of Tu-4

Porosity	Permeability (md)	Value of m calculated according to			Value of water saturation according to			IR
		Focke and Munn , 1987	Borai ,1987	Masoud, 2008	Focke and Munn , 1987	Borai,1987	Sw calcu.	
21.4	0.48	1.42	2.06	4.23	0.6575	1.081	1.03	2.98
14.6	1.3	1.21	2.01	4.85	0.5693	1.073	1.07	2.63
19.2	0.46	1.42	2.05	4.39	0.6843	1.141	1.11	3.22
17.8	6.9	1.21	2.04	4.51	0.6086	1.316	1.30	3.30
20.6	0.91	1.42	2.06	4.28	0.7494	1.336	1.30	3.68
16.9	1	1.21	2.03	4.59	0.6203	1.307	1.30	3.00
16	1	1.21	2.03	4.69	0.5069	0.93	0.90	2.41
10.7	0.08	1.21	1.97	5.52	0.5329	0.953	0.98	2.51
14.5	0.08	1.22	2.01	4.87	0.5833	1.124	1.13	2.74
10	0.26	1.41	1.95	5.69	0.6782	1.062	1.12	3.15
13.2	0.24	1.41	2.00	5.05	0.6548	1.049	1.06	3.04
19.2	0.21	1.42	2.05	4.39	0.6256	1.017	0.98	2.91
20.9	0.74	1.42	2.06	4.26	0.6187	1.013	0.96	2.87
16.9	0.38	1.41	2.03	4.59	0.6087	0.972	0.94	2.82
16.8	0.38	1.41	2.03	4.60	0.5993	0.948	0.92	2.72
16.2	1	1.21	2.03	4.66	0.5302	0.987	0.96	2.42
16.5	0.26	1.41	2.03	4.63	0.6267	1.009	0.98	2.88
19.7	10	1.22	2.05	4.35	0.5225	0.982	0.94	2.42
19.1	0.91	1.42	2.05	4.39	0.6289	1.035	0.99	2.94

Table (4) Results of Yamama Formation in WQ-60

Porosity	Permeability (md)	Value of m calculated according to			Value of water saturation according to			IR
		Focke and Munn , 1987	Borai ,1987	Masoud ,2008	Focke and Munn , 1987	Borai, 1987	Sw calcu.	
0.122	0.04	1.22	1.99	5.22	0.017	0.432	0.457	1.48
0.148	0.22	1.41	2.02	4.83	0.032	0.322	0.303	1.82
0.142	5.5	1.21	2.01	4.91	0.013	0.298	0.287	1.87
0.155	1	1.21	2.02	4.74	0.020	0.405	0.372	1.64
0.152	2.2	1.21	2.02	4.78	0.033	0.693	0.644	1.25
0.08	0.04	1.21	1.91	6.33	0.018	0.621	0.963	1.02
0.114	10	1.41	1.98	5.37	0.061	0.708	0.787	1.13
0.158	3	1.21	2.03	4.71	0.008	0.169	0.154	2.55
0.129	3.3	1.21	2.00	5.10	0.007	0.162	0.165	2.46
0.098	2.5	1.21	1.95	5.74	0.004	0.139	0.176	2.39
0.07	1.6	1.21	1.89	6.79	0.003	0.111	0.202	2.22
0.13	10	1.21	2.00	5.08	0.009	0.215	0.218	2.14
0.081	0.07	1.21	1.92	6.29	0.004	0.129	0.197	2.25
0.1	0.32	1.41	1.95	5.69	0.011	0.137	0.170	2.42
0.096	0.19	1.41	1.95	5.80	0.009	0.112	0.144	2.64
0.095	0.15	1.41	1.94	5.82	0.052	0.647	0.840	1.09
0.0076	0.03	1.20	1.49	-32.93	0.000	0.007	0.926	1.04
0.137	4.7	1.21	2.00	4.98	0.040	0.926	0.910	1.05
0.078	8.5	1.21	1.91	6.41	0.009	0.313	0.500	1.41
0.078	0.15	1.41	1.91	6.41	0.022	0.290	0.463	1.47
0.178	6.6	1.21	2.04	4.51	0.046	0.802	0.697	1.20
0.151	4.6	1.21	2.02	4.79	0.034	0.719	0.670	1.22
0.142	0.28	1.41	2.01	4.91	0.097	1.000	0.963	1.02