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Effect of Porosity Type Upon Archie's Parameters of Carbonate Reservoir

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تأثير نوع المسامية على مُعامل التشبّع في معادلة Archie

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تعتبر معادلةArchie المعادلة المستخدمة لحساب معامل التشبع المائي n, m تساوي 2.

تم إجراء تجارب معملية لحساب معامل التشبع ومعامل الإلتحام لمكامن جيرية مختلفة المسامية وذات مجال واسع بحوض سرت بليبيا. تم تجميع عدد عشرة عينات لبيّة من عدة طبقات جيرية ذات مسامية متباينة ومن مواقع متباعدة، كما تم قياس مقاومة التيار الكهربائي بواسطة اللوح المسامي. أثبت نتائج التجارب أن قيمة n تتغير ويمكن أن تكون أقل أو تساوي 2 بينما قيمة n يمكن أن تصل إلى 2.78 واستنتج أن قيم m و n تعتمد على مسامية الصخور. كما أن علاقة التشبع المائي مع مقاومة الصخور للتيار الكهربائي تتفق تماماً مع معادلة Archie بإستثناء الصخور المسامية التي وجد أن قيمة n تصل بها إلى 2.78.

توصى هذه الدراسة بإجراء قياسات لتحديد قيمة m و n لعدة عينات صخرية من كل طبقة تتغير فيها المسامية بدلاً من إستخدام قيم ثابتة لكامل التكوين الجيولوجي.

Abstract: *Water saturation determinations from resistivity logs are based on Archie's equation; $Sw = (\phi^{-m} Rw/Rt)^{1/n}$. The cementation factor m, and saturation exponent n play an important role in Sw calculation. In carbonate formations m = n = 2 is usually used. However, m values between 1.88 and 2.5 have been measured, and also n was found to be between 2.11 and 2.78 for a Libyan carbonate reservoir. Incorrect m and n would lead to large inaccuracies in the calculated hydrocarbon/water saturation.*

An experimental study was carried out to measure m and n for carbonate samples with a wide range of porosity and permeability. Ten samples were collected from a formation having vuggy and interparticle porosity types. The resistivity measurements were performed using the porous plate method, with four-electrodes system. Reservoir fluids are simulated using a brine and oil of the formation of interest. As a result of this study, it has been found that the Archie's parameters are functions of pore structures. Samples, mainly with interparticle or intercrystalline porosity, shows m-value to be less than or equal to 2, while vuggy samples generate high values of m. The resistivity/saturation correlation is well fitted by Archie's law except for vuggy samples, where n was found to be as high as 2.78. As a consequence, it is recommended that in order to evaluate cementation factors and saturation exponent for carbonates, representative numbers of samples from each zone or interval porosity type should be used rather than an average of m and n of the whole formation.

INTRODUCTION

Carbonate formation may have several types of porosity which includes interparticle, vuggy,

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moldic and fracture porosity as classified by Choquette and Pray[1] and discussed by Rieke *et al.*[12]. Many investigators studied the Archie parameters[3] of carbonate formation with focus on the influence of porosity type[4,5,6]. However, as a result of these studies, many other approaches were derived such as the empirical approach (Shell formula[7], Borai correlation[8]). Although these approaches were successful in many cases but do not take in account the fact that the Archie parameters (m and n) may vary in the same way as porosity and lithology[9]. A case study is presented in this article to contribute somehow to the carbonate formation evaluation.

EXPERIMENT

The formation resistivity factor and resistivity index were measured in the laboratory at ambient conditions for $1^1/_2$" diameter for ten carbonate samples. Their physical properties are shown in Table 1.

Table 1. Core plugs properties

Sample No.	ϕ(%)	K(mD) (gm/cc)	G.D
1	20.34	2.37	2.84
2	12.43	3.3	2.84
3	16.2	31	2.86
4	27.92	158	2.86
5	10.84	0.25	2.84
6	37.36	145	2.85
7	11.12	1.46	2.84
8	26.33	3.58	2.84
9	31.21	6.94	2.85
10	13.25	10.3	2.84

These plugs have been collected from a Libyan reservoir in the Sirt Basin. The samples were cleaned in hot solvents, dried and then mounted into the core holder. All samples were saturated with brine (80,000 ppm). The resistivity measurements were performed using the 4-wire method which has the advantage of eliminating end effects. The resistivity of the saturated samples (Ro) and brine resistivity (Rw) were measured on consecutive days until the results were stabilized. The resistivity index measurements were carried out using the porous plate method, in order to compare it with continuous injection technique results. In this method, the resistivity measurements and desaturation process takes place separately. The samples were desaturated simultaneously by placing them on a porous place in a pressure cell, and gas pressure was applied. The gas (nitrogen) enters the samples from all directions except from the end face. The gas pressure was maintained until no more brine was produced. After capillary equilibrium was reached, the gas was then released and the samples removed from the pressure cell and weight measurements were taken as well as resistivity readings. The procedure was repeated for several pressures in the range of 0.5 psi to 180 psi. The desaturated process for each sample typically took 4-5 days to complete. Finally, m was calculated (m = -logRo/Rw/log ϕ) as well as n being (n = - logRt/Ro/log Sw).

RESULTS AND DISCUSSION

Figure 1 shows the relation of log F versus log ϕ for all samples. Table 2 represents m and n values of all samples.

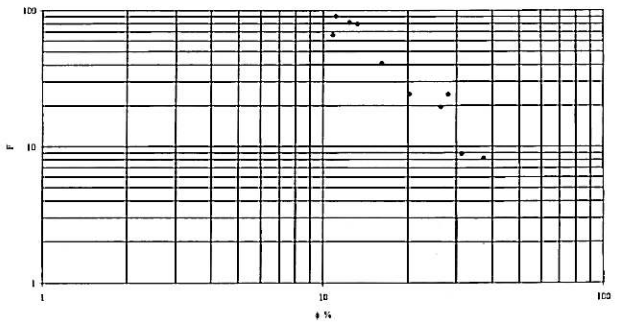

Fig. 1. Formation factor *vs.* porosity

Table 2. m and n values for all samples

Sample No.	m value	n value
1	2.01	2.31
2	2.11	2.46
3	2.05	2.11
4	2.5	2.78
5	1.86	2.14
6	2.14	2.48
7	2.06	2.26
8	2.23	2.34
9	1.88	2.51
10	2.17	2.46

Archie's equation obtained for this reservoir by averaging m an n values was $Sw = (\phi^{-2.1} Rw/Rt)^{1/2.39}$. This cementation factor values were close to each other and m ranged from 1.88 to 2.5. However, higher m values were found in vuggy samples such as samples 4 and 9 and m values were around 2 for interparticle type porosity (samples 1, 3 and 7). The saturation exponent values were between 2.11 and 2.78. It is observed that high n values were found associated with vuggy samples such as samples 4, 9 and 10. Lower n values were generated for interparticle porosity type samples (sample 3 and 5). These findings suggest that the assumption of m=n=2 for carbonates is inaccurate because m and n depend on a type of porosity which exists in a zone or formation. This assumption is valid for a reservoir with only interparticle or intercrystalline porosity type. The error in water saturation determination could reach even 20% and a decision to consider a zone or formation is dry or productive would be in great risk. Table 3 shows Sw values calculated and error in it; when m, and n assumed to be constant and when they are variable.

Table 3. Sw calculations at different m and n

Sample No.	m=n=2	m, n variable	ΔSw%
1	24.58	29.9	5
2	51.36	63.86	12.5
3	30.86	34.26	3.4
4	22.86	43.51	20.65
5	58.9	52.72	6.18
6	13.38	20.88	7.5
7	57.41	64.87	7.46
8	24.24	33.96	9.72
9	20.45	19.07	1.4
10	37.74	52	14

CONCLUSION

In carbonate reservoir evaluation, the Archie's parameters has a wide variation depending on the pore structure (porosity type). It is concluded that the vuggy samples generate higher m and n than the interparticle porosity type samples. It is recommended that samples representing each porosity type should be used rather than an average of m and n of the whole formation.

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