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Electric Power Fractal Dimension for Characterizing Shajara Reservoirs of the Permo-Carboniferous Shajara Formation, Saudi Arabia

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Abstract

The quality and assessment of a reservoir can be documented in details by the application of electric power. This research aims to calculate fractal dimension from the relationship among electric power, maximum electric power and wetting phase saturation and to confirm it by the fractal dimension derived from the relationship among capillary pressure and wetting phase saturation. In this research, porosity was measured on real collected sandstone samples and permeability was calculated theoretically from capillary pressure profile measured by mercury intrusion techniques. Two equations for calculating the fractal dimensions have been employed. The first one describes the functional relationship between wetting phase saturation, electric power, maximum electric power and fractal dimension. The second equation implies to the wetting phase saturation as a function of capillary pressure and the fractal dimension. Two procedures for obtaining the fractal dimension have been utilized. The first procedure was done by plotting the logarithm of the ratio between electric power and maximum electric power versus logarithm wetting phase saturation. The slope of the first procedure is positive = 3- Df (fractal dimension). The second procedure for obtaining the fractal dimension was concluded by plotting logarithm of capillary pressure versus the logarithm of wetting phase saturation. The slope of the second procedure is negative = Df -3. On the basis of the obtained results of the fabricated stratigraphic column and the attained values of the fractal dimension, the sandstones of the Shajara reservoirs of the Shajara Formation were divided here into three units. These Units from bottom to top are: Lower Shajara Electric Power Fractal dimension Unit, Middle Shajara Electric Power Fractal Dimension Unit, and Upper Shajara Electric power Fractal Dimension Unit.

1. Keywords

Capillary pressure fractal dimension; Electric power fractal dimension Shajara Formation; Shajara Reservoirs

2. Introduction

The wetting phase saturation can be described as function of capillary pressure and fractal dimension was demonstrated by **[1]**. The Purcell model was found to be the best fit to the experimental data of the wetting phase relative permeability for the cases as long as the measured capillary pressure curve had the same residual saturation as the relative permeability curve was described by **[2]**. A theoretical model to correlate capillary pressure and resistivity index based on the fractal scaling theory was reported by **[3]**. The fractal dimension resulting from longer transverse NMR relaxation times and lower capillary pressure reflects the volume dimension of larger pores was described by **[4]**. The fractal dimension derived from the short NMR relaxation times is similar to the fractal dimension of the internal surface was described by **[4].** The fractal dimensions can be used to represent the complexity degree and heterogeneity of pore structure, and the coexistence of dissolution pores and large intergranular pores of Donghetang sandstones contributes to a heterogeneous pore throat distribution and a high value of fractal dimension was reported by **[5]**.The relationship among capillary pressure (PC), nuclear magnetic transverse relaxation time (T2) and resistivity index (I) was studied by **[6]**.An increase of bubble pressure fractal dimension and pressure head fractal dimension and decreasing pore size distribution index and fitting parameters m * n due to possibility of having interconnected channels was confirmed by **[7]**. An increase of fractal dimension with increasing arithmetic, geometric relaxation time of induced polarization, permeability and grain size was investigated by **[8-10]**.An increase of seismo electric and resistivity fractal dimensions with increasing permeability and grain size was described by **[11,12]**.

3. Material and Method

Samples were collected from the surface type section of the Shajara reservoirs of the Permo-carboniferous Shajara formation at latitude 26° 52′ 17.4″, longitude 43 ° 36′ 18″. Porosity was measured and permeability was derived from the measured capillary pressure data.

The electric power can be scaled as

$$\mathbf{Sw} = \left[\frac{\mathbf{P}}{\mathbf{Pmax}}\right]^{[\mathbf{3-Df}]} \qquad \mathbf{1}$$

Where Sw the water saturation, P the electric power in watt, Pmax the maximum electric power in watt, and Df the fractal dimension.

Equation 1 can be proofed from

$$\mathbf{J} = \boldsymbol{\sigma} * \mathbf{E} \qquad \mathbf{2}$$

Where J the electric current density in ampere /square meter, σ the electric conductivity in Siemens / meter. and E the electric field volt / meter.

But the electric conductivity σ can be scaled as

$$\boldsymbol{\sigma} = \left[\frac{\mathbf{2} * \boldsymbol{\Sigma}}{\mathbf{r}}\right] \qquad \mathbf{3}$$

Where Σ the surface conductance in Siemens, and r the grain radius in meter. Whereas the electric field E can be scaled as

$$\mathbf{E} = \left[\frac{\mathbf{V}}{\mathbf{L}}\right] \qquad \mathbf{4}$$

Where V the electric potential in volt, and L the distance in meter. Insert Equation 3 and Equation 4 into Equation 2

$$\mathbf{J} = \left[\frac{\mathbf{2} * \boldsymbol{\Sigma} * \mathbf{V}}{\mathbf{r} * \mathbf{L}}\right] \qquad \mathbf{5}$$

The electric potential V can be scaled as

$$\mathbf{V} = \left[\frac{\mathbf{U}}{\mathbf{Q}}\right] \qquad \mathbf{6}$$

Where U the electric potential energy in Joule, and Q the electric charge in Coulomb. Insert equation 6 into Equation 5

$$\mathbf{J} = \left[\frac{\mathbf{2} * \boldsymbol{\Sigma} * \mathbf{U}}{\mathbf{r} * \mathbf{L} * \mathbf{Q}}\right] \qquad \mathbf{7}$$

The electric potential energy U can be scaled as

$$\mathbf{U} = \mathbf{P} * \mathbf{t} \qquad \mathbf{8}$$

Where P the electric power in watt and t the time in second.

Insert equation 8 into Equation 7

$$\mathbf{J} = \left[\frac{\mathbf{2 * \Sigma * P * t}}{\mathbf{r * L * Q}}\right] \quad \mathbf{9}$$

Equation 9 after rearrange of grain radius r will become

$$\mathbf{r} = \left[\frac{\mathbf{2 * \Sigma * P * t}}{\mathbf{J * L * Q}}\right] \quad \mathbf{10}$$

The maximum grain radiusrmax can be scaled as

$$\mathbf{rmax} = \left[\frac{\mathbf{2 * \Sigma * Pmax * t}}{\mathbf{J * L * Q}}\right] \quad \mathbf{11}$$

Divide Equation 10 by Equation 11

$$\left[\frac{\mathbf{r}}{\mathbf{rmax}}\right] = \left[\frac{\frac{\mathbf{2 * \Sigma * P * t}}{\mathbf{J * L * Q}}}{\frac{\mathbf{2 * \Sigma * Pmax * t}}{\mathbf{J * L * Q}}}\right] \quad \mathbf{12}$$

Equation 12 after simplification will become

$$\left[\frac{\mathbf{r}}{\mathbf{rmax}}\right] = \left[\frac{\mathbf{P}}{\boldsymbol{Pmax}}\right] \quad \mathbf{13}$$

Take the logarithm of Equation 13

$$\mathbf{log}\left[\frac{\mathbf{r}}{\mathbf{rmax}}\right] = \mathbf{log}\left[\frac{\mathbf{P}}{\mathbf{Pmax}}\right] \quad \mathbf{14}$$

$$\mathbf{But, log}\left[\frac{\mathbf{r}}{\mathbf{rmax}}\right] = \frac{\mathbf{log\,Sw}}{\mathbf{[3 - Df]}} \quad \mathbf{15}$$

Insert equation 15 into Equation 14

$$\frac{\mathbf{log\,Sw}}{\mathbf{[3 - Df]}} = \mathbf{log}\left[\frac{\mathbf{P}}{\mathbf{Pmax}}\right] \quad \mathbf{16}$$

Equation 16 after log removal will become

$$\mathbf{Sw} = \left[\frac{\mathbf{P}}{\mathbf{Pmax}}\right]^{[\mathbf{3-Df}]} \quad \mathbf{17}$$

Equation 17 the proof of equation 1 which relates the water saturation Sw, the electric power P, the maximum electric power Pmax , and the fractal dimension Df.

The capillary pressure can be scaled as

$$\mathbf{log\,Sw = (Df - 3) * log\,Pc + constant} \quad \mathbf{18}$$

Where Sw the water saturation, Pc the capillary pressure and Df the fractal dimension.

4. Result and Discussion

Based on field observation the Shajara Reservoirs of the Permo-Carboniferous Shajara Formation were divided into three units as described in Figure 1.These units from bottom to top are: Lower Shajara Reservoir, Middle Shajara reservoir, and Upper Shajara Reservoir. Their acquired results of the electric power fractal dimension and capillary pressure fractal dimension are displayed in Table 1. Based on the attained results it was found that the electric power fractal dimension is equal to the capillary pressure fractal dimension. The maximum value of the fractal dimension was found to be 2.7872 assigned to sample SJ13 from the Upper Shajara Reservoir as verify in **Table1**. Whereas the minimum value 2.4379 of the fractal dimension was reported from sample SJ3 from the Lower Shajara reservoir as displayed in Table1. The electric power fractal dimension and capillary pressure fractal dimension were observed to increase with increasing permeability as proofed in **Table1** owing to the possibility of having interconnected channels.

The Lower Shajara reservoir was denoted by six sandstone samples **(Figure 1)**, four of which labeled as SJ1, SJ2, SJ3 and SJ4 as confirmed in Table 1 were selected for capillary pressure measurement. Their positive slopes of the first procedure and negative slopes of the second procedure are delineated in **(Table 1)**.Their electric power fractal dimension and capillary pressure fractal dimension values are proofed in Table 1. As we proceed from sample SJ2 to SJ3 a pronounced reduction in permeability due to compaction was reported from

1955 md to 56 md which reflects decrease in electric power fractal dimension and capillary pressure fractal dimension from 2.7748 to 2.4379 as specified in **Table 1**. Again, an increase in grain size and permeability was recorded from sample SJ4 whose electric power fractal dimension and capillary pressure fractal dimension was found to be 2.6843 as described in **(Table 1**).

In contrast, the Middle Shajara reservoir which is separated from the Lower Shajara reservoir by an unconformity surface as shown in **(Figure 1**). It was designated by four samples **(Figure. 1)**, three of which named as SJ7, SJ8, and SJ9 as illustrated in **Table 1** were picked for capillary pressure measurement. Their positive slopes of the first procedure and negative slopes of the second procedure are shown in **Table 1**. Their electric power fractal dimensions and capillary pressure fractal dimensions show similarities as delineated in Table 1.Their fractal dimensions are higher than those of samples SJ3 and SJ4 from the Lower Shajara Reservoir due to an increase in their permeability as explained in **(Table 1)**.

Formation	Reservoir	Sample	Φ %	k (md)	Positive slope of the first procedure Slope=3-Df	Negative slope of the second procedure Slope=Df-3	Electric power fractal dimension	Capillary pressure fractal dimension
Permo-Carboniferous Shajara Formation	Upper Shajara Reservoir	SJ13	25	973	0.2128	-0.2128	2.7872	2.7872
		SJ12	28	1440	0.2141	-0.2141	2.7859	2.7859
		SJ11	36	1197	0.2414	-0.2414	2.7586	2.7586
	Middle Shajara Reservoir	SJ9	31	1394	0.2214	-0.2214	2.7786	2.7786
		SJ8	32	1344	0.2248	-0.2248	2.7752	2.7752
		SJ7	35	1472	0.2317	-0.2317	2.7683	2.7683
	Lower Shajara Reservoir	SJ4	30	176	0.3157	-0.3157	2.6843	2.6843
		SJ3	34	56	0.5621	-0.5621	2.4379	2.4379
		SJ2	35	1955	0.2252	-0.2252	2.7748	2.7748
		SJ1	29	1680	0.2141	-0.2141	2.7859	2.7859

Table 1: Petro physical model showing the three Shajara Reservoir Units with their corresponding values of electric power fractal dimension and capillary pressure fractal dimension.

On the other hand, the Upper Shajara reservoir is separated from the Middle Shajara reservoir by yellow green mudstone as revealed in Figure 1. It is defined by three samples so called SJ11, SJ12, SJ13 as explained in Table 1.Their positive slopes of the first procedure and negative slopes of the second procedure are displayed in Table 1.Moreover, their electric power fractal dimension and capillary pressure fractal dimension are also higher than those of sample SJ3 and SJ4 from the Lower Shajara Reservoir due to an increase in their permeability as clarified in **(Table 1).**

Overall a plot of electric power fractal dimension versus capillary pressure fractal dimension as shown in Figure 2 reveals three permeable zones of varying Petrophysical properties. Such variation in fractal dimension can account for heterogeneity which is a key parameter in reservoir quality assessment. This heterogeneity was also revealed by plotting positive slope of the first procedure versus negative slope of the second procedure as described in **(Figure 3).**

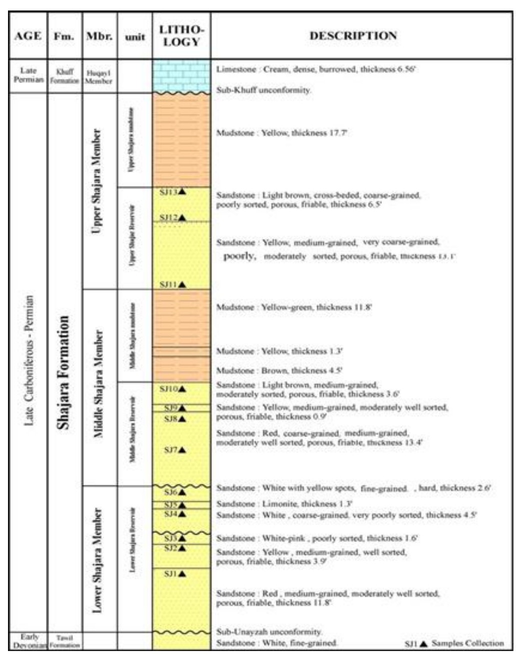

Figure 1: Surface type section of the Shajara reservoirs of the Permo-Carboniferous Shajara

Formation at latitude 26° 52' 17.4", longitude 43° 36' 18".

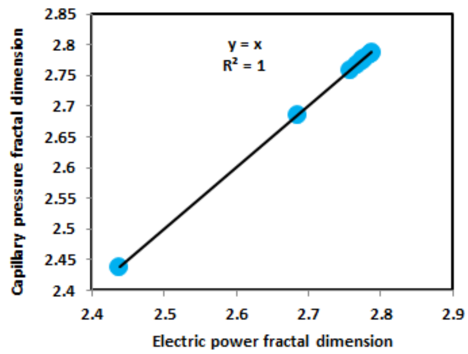

Figure 2: Electric power fractal dimension versus capillary pressure fractal dimension.

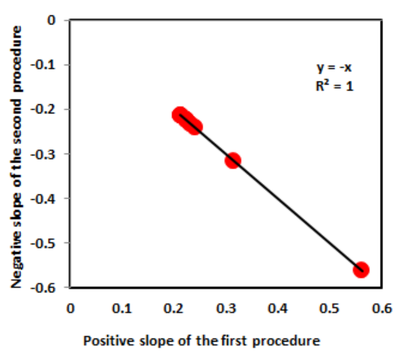

Figure 3: Positive slope of the first procedure versus negative slope of the second procedure.

5. Conclusion

- The sandstones of the Shajara Reservoirs of the Permo-Carboniferous Shajara Formation were divided here into three units based on electric power fractal dimension.
- The Units from bottom to top are: Lower Shajara Electric Power Fractal dimension Unit, Middle Shajara Electric Power Fractal Dimension Unit, and Upper Shajara Electric power Fractal Dimension Unit.
- These units were also proved by capillary pressure fractal dimension.
- The fractal dimension was found to increase with increasing grain size and permeability.

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