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On Similarity of Seismo Diffusion Coefficient and Pressure Head 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 seismo diffusion coefficient. This research aims to calculate fractal dimension from the relationship among seismo diffusion coefficient, maximum seismo diffusion coefficient and wetting phase saturation and to approve it by the fractal dimension derived from the relationship among inverse pressure head * pressure head and wetting phase saturation. Two equations for calculating the fractal dimensions have been employed. The first one describes the functional relationship between wetting phase saturation, seismo diffusion coefficient, and maximum seismo diffusion coefficient and fractal dimension. The second equation implies to the wetting phase saturation as a function of pressure head 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 seismo diffusion coefficient and maximum seismo diffusion coefficient versus logarithm wetting phase saturation. The slope of the first procedure = 3- Df (fractal dimension). The second procedure for obtaining the fractal dimension was determined by plotting the logarithm (inverse of pressure head and pressure head)versus the logarithm of wetting phase saturation. The slope of the second procedure = 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.

Keywords: *Shajara Reservoirs; Shajara Formation; Seismo diffusion coefficient fractal dimension; Pressure head fractal dimension, Permeability*

Introduction

Seismo electric effects related to electro kinetic potential, dielectric permitivity, pressure gradient, fluid viscosity, and electric conductivty was first reported by [1]. Capillary pressure follows the scaling law at low wetting phase saturation was reported by [2]. Seismo electric phenomenon by considering electro kinetic coupling coefficient as a function of effective charge density, permeability, fluid viscosity and electric conductivity was reported by [3]. The magnitude of seismo electric current depends on porosity, pore size, zeta potential of the pore surfaces, and elastic properties of the matrix was investigated by [4]. The tangent of the ratio of converted electic field to pressure is approximately in inverse proportion to permeability was studied by [5]. Permeability inversion from seismoelectric log at low frequency was studied by [6]. They reported that, the tangent of the ratio among electric excitation intensity and pressure field is a function of porosity, fluid viscosity, frequency, tortuosity and fluid density and Dracy permeability. A decrease of seismo electric frequencies with increasing water content was reported by [7]. An increase of seismo electric transfer function with increasing water saturation was studied by [8]. An increase of dynamic seismo electric transfer function with decreasing fluid conductivity was described by [9]. The amplitude of seismo electric signal increases with increasing permeability which means that the seismo electric effects are directly related to the permeability and can be used to study the permeability of the reservoir was illustrated by [10]. Seismo electric coupling is frequency dependent and decreases expontialy when frequency increases was demonstrated by [11]. An increase of permeability with increasing seismo magnetic moment and seismo diffusion coefficiernt fractal dimension was reported by [12,13]. An increase of, molar enthalpy, work, electro kinetic, bubble pressure and pressure head fractal dimensions with permeability increasing and grain size was described by [14-17].

Materials and Methods

Sandstone samples were collected from the surface type section of the Permo-Carboniferous Shajara Formation, latitude 26° 52' 17.4", longitude 43° 36' 18". (Figure1). Porosity was measured on collected samples using mercury intrusion Porosimetry and permeability was derived from capillary pressure data. The purpose of this paper is to obtain seismo diffusion coefficient fractal dimension and to confirm it by pressure head fractal dimension. The fractal dimension of the first procedure is determined from the positive slope of the plot of logarithm of the ratio of seismo diffusion coefficient to maximum seismo diffusion coefficient log ($SDC^{1/4}/SDC^{1/4}_{max}$) versus log wetting phase saturation (logSw). Whereas the fractal dimension of the second procedure is determined from the negative slope of the plot of logarithm of log (inverse of pressure head α * pressure head h, log (α* h) versus logarithm of wetting phase saturation (log Sw).

The Seismo diffusion coefficient can be scaled as

$$Sw = \left[\frac{SDC^{\frac{1}{4}}}{SDC^{\frac{1}{4}}_{max}}\right]^{[3-Df]} \qquad 1$$

Where Sw the water saturation, SDC the seismo diffusion coefficient in square meter / second, SDC_{max} the maximum seismo diffusion coefficient in square meter / second

Equation 1 can be proofed from

$$SDC = \left[\frac{A}{t}\right] \qquad 2$$

Where SDC the seismo diffusion coefficient in square meter / second, A the area in square meter, t the time in second

The area can be scaled as

$$A = \left[\frac{Q}{V}\right] \qquad 3$$

Where A the area in square meter, Q the flow rate in cubic meter / second, and V the velocity in meter / second

Insert equation 3 into equation 2

$$SDC = \left[\frac{Q}{t*V}\right] \qquad 4$$

The flow rate can be scaled as

$$Q = \left[\frac{3.14*r^4*\Delta p}{8*\eta*L}\right] \qquad 5$$

Where Q the flow rate in cubic meter / second, r the pore radius in meter, Δp the differential pressure in pascal, η the fluid viscosity in pascal* second, and L the capillary length in meter

Insert equation 5 into equation 4

$$SDC = \left[\frac{3.14*r^4*\Delta p}{t*V*8*\eta*L}\right] \qquad 6$$

The maximum pore radius can be scaled as

$$SDC_{max} = \left[\frac{3.14*r^4_{max}*\Delta p}{t*V*8*\eta*L}\right] \qquad 7$$

Divide equation 6 by equation 7

$$\left[\frac{SDC}{SDC_{max}}\right] = \left[\frac{\left[\frac{3.14*r^4*\Delta p}{t*V*8*\eta*L}\right]}{\left[\frac{3.14*r^4_{max}*\Delta p}{t*V*8*\eta*L}\right]}\right] \qquad 8$$

Equation 8 after simplification will become

$$\left[\frac{SDC}{SDC_{max}}\right] = \left[\frac{r^4}{r^4_{max}}\right] \qquad 9$$

Take the fourth root of equation 9

$$\sqrt[4]{\left[\frac{SDC}{SDC_{max}}\right]} = \sqrt[4]{\left[\frac{r^4}{r^4_{max}}\right]} \qquad 10$$

Equation 10 after simplification will become

$$\left[\frac{SDC^{\frac{1}{4}}}{SDC^{\frac{1}{4}}_{max}}\right] = \left[\frac{r}{r_{max}}\right] \qquad 11$$

Take the logarithm of equation 11

$$\log\left[\frac{SDC^{\frac{1}{4}}}{SDC^{\frac{1}{4}}_{max}}\right] = \log\left[\frac{r}{r_{max}}\right] \qquad 12$$

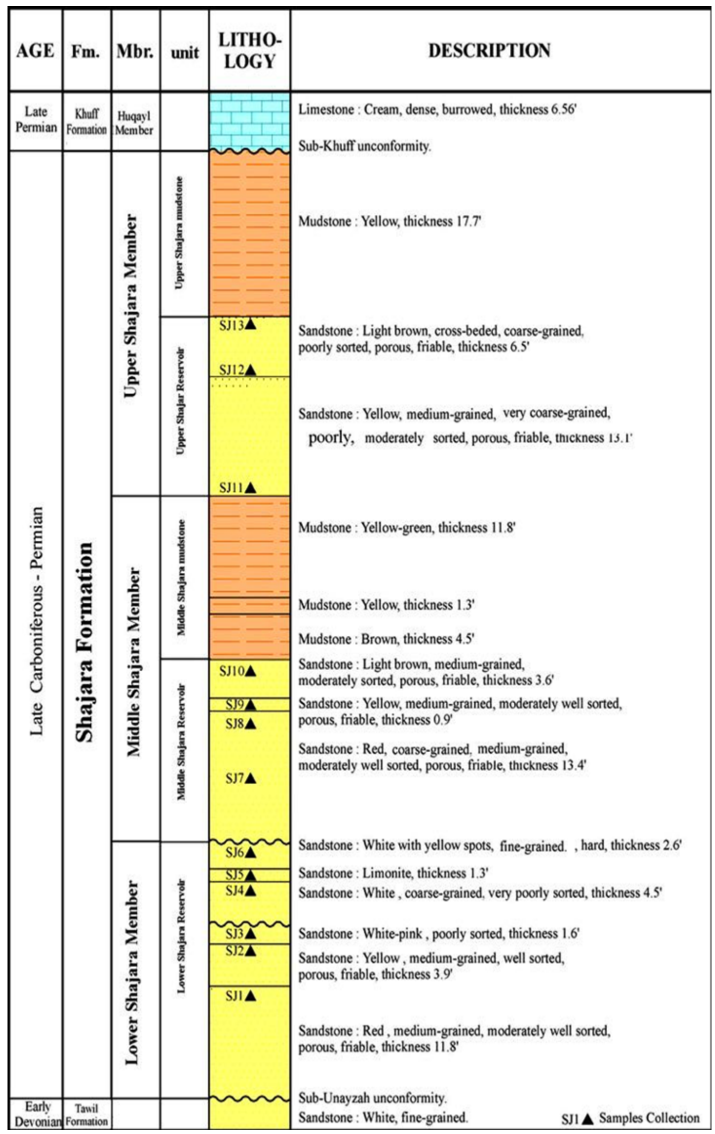

Figure 1: Surface type section of the Shajara Reservoirs of the Permo-Carboniferous Shajara Formation at latitude 26° 52' 17.4" longitude 43° 36' 18".

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Table 1: Petrophysical model showing the three Shajara Reservoir Units with their corresponding values of seismo diffusion coefficient fractal dimension and pressure headfractal dimension.

Formation	Reservoir	Sample	Porosity %	k (md)	Positive slope of the first procedure Slope=3-Df	Negative slope of the second procedure Slope=Df-3	Seismo diffusion coefficient fractal dimension	Pressure head 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

But;

$$\log\left[\frac{r}{r_{\max}}\right]=\frac{\log \mathrm{Sw}}{[3-\mathrm{Df}]} \qquad 13$$

Insert equation 13 into equation 12

$$\frac{\log \mathrm{Sw}}{[3-\mathrm{Df}]}=\log\left[\frac{\mathrm{SDC}^{\frac{1}{4}}}{\mathrm{SDC}_{\max}^{\frac{1}{4}}}\right] \qquad 14$$

Equation 14 after log removal will become

$$\mathrm{Sw}=\left[\frac{\mathrm{SDC}^{\frac{1}{4}}}{\mathrm{SDC}_{\max}^{\frac{1}{4}}}\right]^{[3-\mathrm{Df}]} \qquad 15$$

Equation the 15 proof of equation 1 which relates the water saturation, seismo diffusion coefficient, maximum seismo diffusion coefficient, and the fractal dimension.

The pressure head can be scaled as

$$\mathrm{LogSw}=[3-\mathrm{Df}]*\log(\alpha*h)+\mathrm{Constant} \qquad 16$$

Where Sw the water saturation, α inverse of pressure head, h the pressure head and Df the fractal dimension.

Results and Discussion

Based on field observation the Shajara Reservoirs of the Permo-Carboniferous Shajara Formation were divided here 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 attained results of the seismo diffusion coefficient fractal dimension and pressure head fractal dimension are shown in **Table 1.** Based on the achieved results it was found that the seismo diffusion coefficient fractal dimension is equal to the pressure head fractal dimension. The maximum value of the fractal dimension was found to be 2.7872 allocated to sample SJ13 from the Upper Shajara Reservoir as verified in Table 1. Whereas the minimum value of the fractal dimension 2.4379 was reported from sample SJ3 from the Lower Shajara reservoir as shown in Table1. The Seismo diffusion coefficient fractal dimension and pressure head fractal dimension were detected to increase with increasing permeability as proofed in Table1 owing to the possibility of having interconnected channels.

The Lower Shajara reservoir was symbolized by six sandstone samples (Figure 1), four of which label as SJ1, SJ2, SJ3 and SJ4 were carefully chosen for capillary pressure measurement as proven in Table 1. Their positive slopes of the first procedure log of the Seismo diffusion coefficient to maximum Seismo diffusion coefficient versus log wetting phase saturation (Sw) and negative slopes of the second procedure log (inverse of pressure head α*pressure head h) versus log wetting phase saturation (Sw) are clarified in **Figures 2-5** & Table 1. Their Seismo diffusion coefficient fractal dimension and pressure head fractal dimension values are revealed in Table 1. As we proceed from sample SJ2 to SJ3 a pronounced reduction in permeability due to compaction was described from 1955 md to 56 md which reflects decrease in Seismo diffusion coefficient fractal dimension from 2.7748 to 2.4379 as quantified in table 1. Again, an increase in grain size and permeability was proved from sample SJ4 whose seismo diffusion coefficient fractal dimension and pressure head 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 revealed in **Figure 1.** It was nominated by four samples (Figure 1), three of which named as SJ7, SJ8, and SJ9 as illuminated in Table 1 were chosen for capillary measurements as described in Table 1. Their positive slopes of the first procedure and negative slopes of the second procedure are shown in **Figures 6- 8** &Table 1. Furthermore, their Seismo diffusion coefficient fractal dimensions and pressure head fractal dimensions show similarities as defined 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.

On the other hand, the Upper Shajara reservoir was separated from the Middle Shajara reservoir by yellow green mudstone as shown 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 **Figures 9-11** & Table 1. Moreover, their seismo diffusion coefficient fractal dimension and pressure head 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 simplified in Table 1.

Overall a plot of positive slope of the first procedure versus negative slope of the second procedure as described in **Figure 12** reveals three permeable zones of varying Petrophysical properties. These reservoir zones were also confirmed by plotting seismo diffusion coefficient fractal dimension versus pressure head fractal dimension as described in **Figure 13**. Such variation in fractal dimension can account for heterogeneity which is a key parameter in reservoir quality assessment.

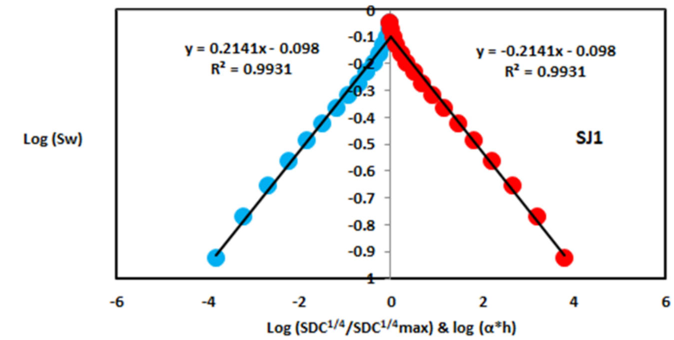

Figure 2: Log ($SDC^{1/4}/SDC^{1/4}{}_{max}$) & log ($\alpha$ * h) versus log Sw for sample SJ1.

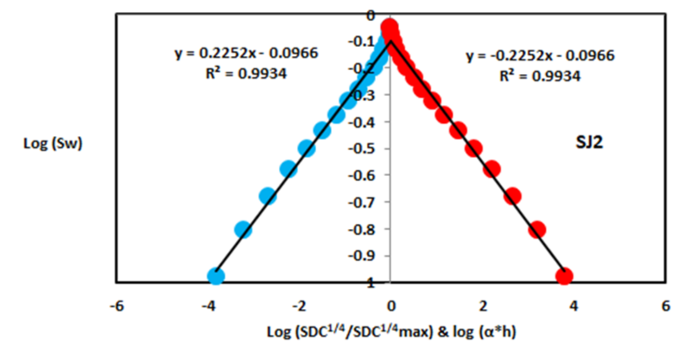

Figure 3: Log ($SDC^{1/4}/SDC^{1/4}{}_{max}$) & log ($\alpha$ * h) versus log Sw for sample SJ2.

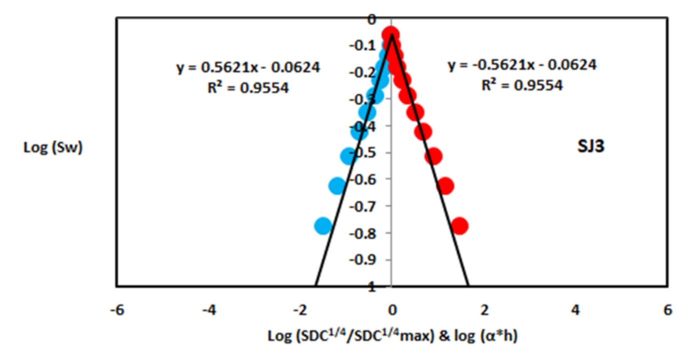

Figure 4: Log ($SDC^{1/4}/SDC^{1/4}{}_{max}$) & log ($\alpha$ * h) versus log Sw for sample SJ3.

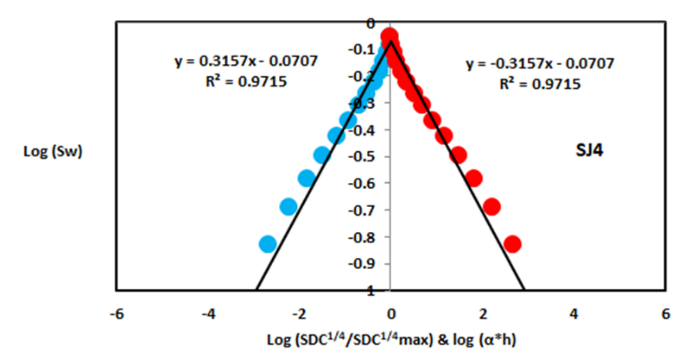

Figure 5: Log ($SDC^{1/4}/SDC^{1/4}{}_{max}$) & log ($\alpha$ * h) versus log Sw for sample SJ4.

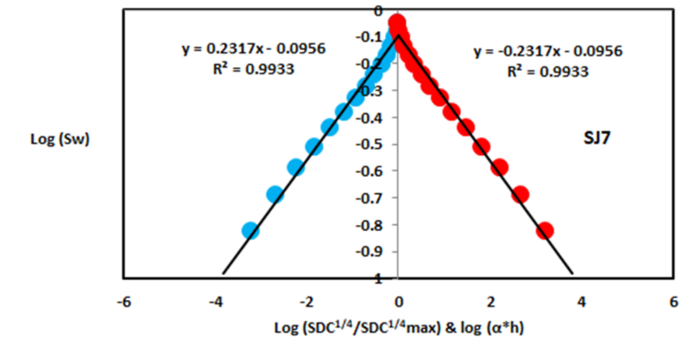

Figure 6: Log ($SDC^{1/4}/SDC^{1/4}{}_{max}$) & log ($\alpha$ * h) versus log Sw for sample SJ7.

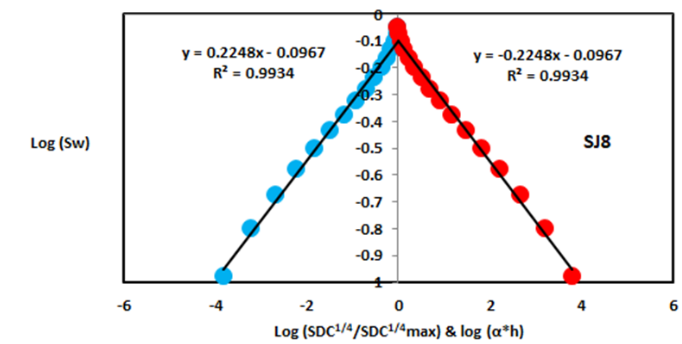

Figure 7: Log ($SDC^{1/4}/SDC^{1/4}{}_{max}$) & log ($\alpha$ * h) versus log Sw for sample SJ8.

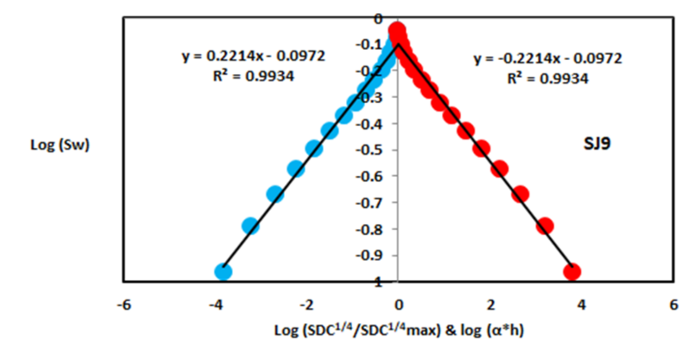

Figure 8: Log ($SDC^{1/4}/SDC^{1/4}{}_{max}$) & log ($\alpha$ * h) versus log Sw for sample SJ9.

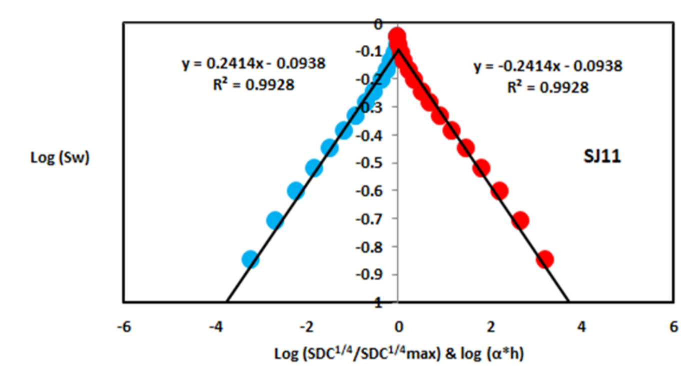

Figure 9: Log ($SDC^{1/4}/SDC^{1/4}{}_{max}$) & log ($\alpha$ * h) versus log Sw for sample SJ11.

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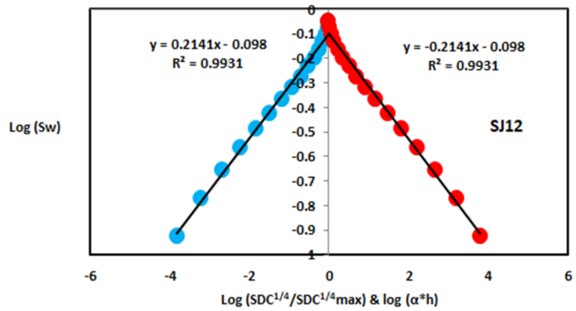

Figure 10: Log ($SDC^{1/4}/SDC^{1/4}_{max}$) & log (α * h) versus log Sw for sample SJ12.

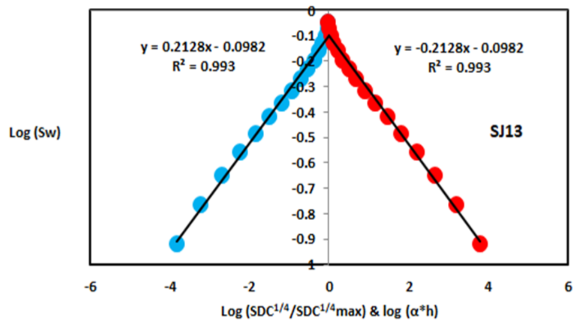

Figure 11: Log ($SDC^{1/4}/SDC^{1/4}_{max}$) & log (α * h) versus log Sw for sample SJ13.

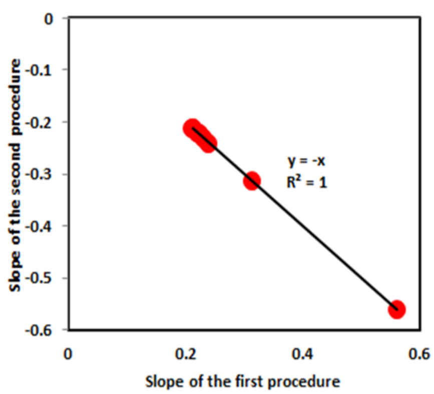

Figure 12: Slope of the first procedure versus slope of the second procedure.

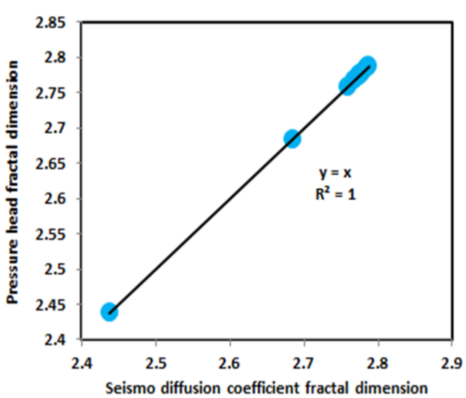

Figure 13: Seismo diffusion coefficient fractal dimension versus pressure headfractal dimension.

Conclusion

The sandstones of the Shajara Reservoirs of the permo-Carboniferous Shajara Formation were divided here into three units based on seismo diffusion coefficient fractal dimension. The Units from base to top are: Lower Shajara Seismo Diffusion Coefficient Fractal Dimension Unit, Middle Shajara Seismo Diffusion Coefficient Fractal Dimension Unit, and Upper Shajara Seismo Diffusion Coefficient Fractal Dimension Unit. These units were also proved by pressure head fractal dimension. The fractal dimension was found to increase with increasing grain size and permeability owing to possibility of having interconnected channels.

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