A Trial of Correlating Rock Permeability to Other Petrophysical Rock Properties

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ABSTRACT

Permeability of reservoir rocks is one of the most important petrophysical properties for reservoir description and simulation, but also it is not easy to be obtained during well drilling. On the other hand, other parameters such as porosity and fluid saturations are measured using various methods and techniques while and after drilling. However, measuring rock permeability and obtaining accurate values from cuttings can only be estimated using a pre-generated correlation between permeability and some other petrophysical rock properties such as porosity or liquid saturation which can be measured from cuttings.

In this paper, I tried to correlate permeability, porosity and irreducible water saturation of some core samples retrieved from an oil well using different computerised methods. Firstly, using Microsoft excel, in this method different relationships were established by plotting permeability values against a combined parameters called ‘’V1 through V5’’ which represent different parameters formed of combining core porosity and irreducible water saturation values. This method managed to show that the best obtained value for the Coefficient of Multiple Determination (R^2) was 0.9582 from correlating core permeability and parameter V4.

The other method was done by using DataFit software which gave a direct relationship between the three core parameters which are permeability, porosity and irreducible water saturation. The accuracy of the obtained correlation from this method was very high; it showed that the Coefficient of Multiple Determination (R^2) was 0.9998.

INTRODUCTION

For any oil or gas production company there is always a quick looking for answering two main questions when drilling a new well; firstly, what are the parameters which determine hydrocarbons in place (porosity, saturation), then what would be the well deliverability (which is related directly to reservoir permeability)?. For most cases, according to Egermann P. et al. (2002), well logging give reliable estimates of reservoir porosity and fluid saturations. Furthermore, these parameters can be easily measured from drill cuttings. The measurement of rock permeability, on the other hand, requires more additional work and techniques to be done on a retrieved core samples, Timur A. (1968).

In exploration drilling, cuttings and sidewall samples are retrieved continually to look for oil and to investigate reservoir quality. According to Timur, Geochemical and paleontological information are normally obtained from these small samples. Other information about mineralogical structure, grain density, and grain-size and pores morphological information can be acquired with a further work.

Opposing to core samples, which are only obtained over interesting reservoir intervals, drill cuttings are taken in all reservoir intervals including cap-rocks and source rocks. In the past, standard petrophysical measurements on cuttings were cumbersome if not impossible. But later, many investigators worked hard to get useful information from preliminary measurements of porosities and irreducible water saturations of drilling cuttings, where these petrophysical properties can easily be measured for cuttings whereas permeability estimation needs some further work to be determined for the reservoir rocks.

According to Fens T. et al. (1998), many International Exploration and Production companies have carried out their research with their aims of predicting petrophysical properties from small size samples like sidewall samples and cuttings at an early age of the well. The main drives for these researches were the increasing numbers of deep exploration prospects which face harsh circumstances such as high pressure and temperature. Due to these surroundings, it is not merely difficult but also expensive to obtain cores. As a result, it is hard to get perfect information for petrophysical and geological evaluation.

Various techniques for permeability investigation were carried out by different investigators. The most reliable method of estimating permeability from cuttings was developed by Timur A. (1968). In this method, Timur has correlated the permeability of a number of core samples retrieved from some North American fields with their porosities and irreducible water saturations. Several relationships were evaluated by Timur from analyzing the data obtained during the laboratory measurements on these plugs.

Timur put his final generalized relationship for estimating core permeability in the form of:

$$k = 0.136 * \frac{\Phi^{4.4}}{S_{wirr}^{2}}$$

Where:

k= Permeability (md), Ø= Porosity (%), and S_{wirr} = Irreducible water saturation(%).

In this paper, I am focusing on evaluating permeability of cuttings by estimating a reliable correlation between permeability, porosity and irreducible water saturation of some retrieved core samples from one well drilled in the Upper Nubian Sandstone formation in the Sirt basin, Libya. I am full of hopes to present or to start the way of presenting a good correlation which can be used for estimating permeability of cuttings from a pre-generated equation in this area.

METHODOLOGY

The plan of performing this paper was done through the following steps:

1. Collecting the required data; porosity, permeability and irreducible water saturation for nine plug samples retrieved from a well drilled in the Upper Nubian Sandstone formation in the Sirt basin, Libya.

2. Conducting data analysis using two different methods:
   - **a.** Using Microsoft Excel; various two dimensional relationships, 2D, were obtained from correlating the three reservoir petrophysical properties, k, Ø & S_{wirr}. Also, another five relationships were obtained by correlating core permeability to different parameters namely V1 through V5 which represent a combined relationship between porosity and irreducible water saturation.
   - **b.** Using DataFit software; a three dimensional relationship was obtained by correlating the three available parameters, k, Ø & S_{wirr}. The benefit of using this method is that, firstly, it can save time and, secondly, it gives a direct relationship between more than two parameters at one time.

RESULTS and DISCUSSION

<u>1. Results obtained using Microsoft Excel</u>:_ Firstly, using Microsoft excel, the obtained relationship between the permeability and porosity values when plotted on a semi-log plot as shown on figure (1) was not good enough to indicate whether the reservoir is homogeneous or not. Furthermore, it did not represent a sufficient correlation between these two parameters.

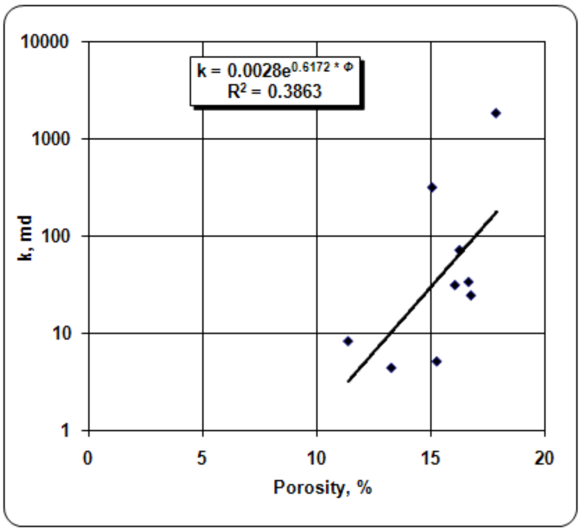

Figure (1) shows the direct relationship between permeability and porosity

On the other hand, the correlation between the reservoir permeability and the irreducible water saturation values was almost semi-linear where R^2 value was 0.9702 as shown on figure (2).

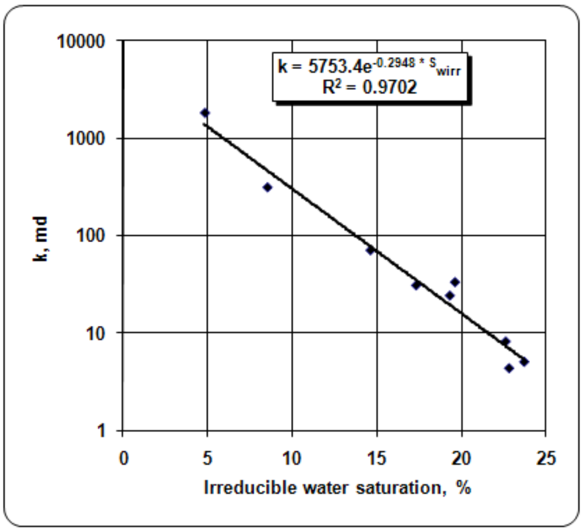

Figure (2) shows the direct relationship between permeability and irreducible water saturation

Using parameters V1 through V5 which represent the different combinations between porosity and irreducible water saturation as shown in table (1), many results and figures were obtained by plotting permeability values against these parameters. The calculated values of parameters V1 through V5 are shown in table (2) and plotted in figures (3-7). Furthermore, the regression outputs of using these parameters are summarized in table (3).

Table (1): shows an illustration of parameters V1 through V5:

Parameter	What does it refer to
V1	$\frac{\phi^6}{S_{wr}^2}$
V2	$\frac{\phi^3}{S_{wr}^2}$
V3	$\frac{\phi^3}{(1-\phi)^2 * S_{wr}^2}$
V4	$\frac{\phi}{S_{wr}^2}$
V5	$\frac{\phi^{4.4}}{S_{wr}^2}$

Table (2): shows the row data of permeability, porosity and irreducible water saturation values and the obtained values for parameters V1 through V5:

Sample	ϕ	S_{wirr}	k	V1	V2	V3	V4	V5

#	%	%	md					
1	15.1	8.50	311	164067.98	47.653	1251.211	0.209	2131.38
2	13.3	22.8	4.30	10647.316	4.526	8083.778	0.026	169.464
3	11.4	22.6	8.10	4297.4640	2.901	6996.241	0.022	87.532
4	16.8	19.3	24.0	60358.866	12.730	7075.030	0.045	661.068
5	16.3	14.6	70.2	87987.285	20.317	3943.535	0.076	1011.39
6	17.9	4.80	1812	1427695.9	248.93	462.667	0.777	14127.7
7	16.1	17.3	30.6	58191.969	13.944	5477.923	0.054	682.247
8	16.7	19.6	33.0	56465.956	12.124	7258.757	0.043	624.368
9	15.3	23.7	5.00	22837.675	6.376	9837.821	0.027	290.500

Table (3): Regression outputs of 2D analysis for estimating permeability from a combination of porosity and irreducible water saturation using equation form of ($k = a * V^b$):

Parameter	Number of Samples	Regression Coefficients		Correlation Coefficient
		a	b	R^2
V1	9	0.000211	1.109723	0.8667
V2	9	0.764141	1.435853	0.9407
V3	9	1.7E+08	-1.83857	0.9072
V4	9	3740.203	1.677431	0.9582
V5	9	0.009196	1.273098	0.9088

Where: a= the exponent factor, b= the slope.

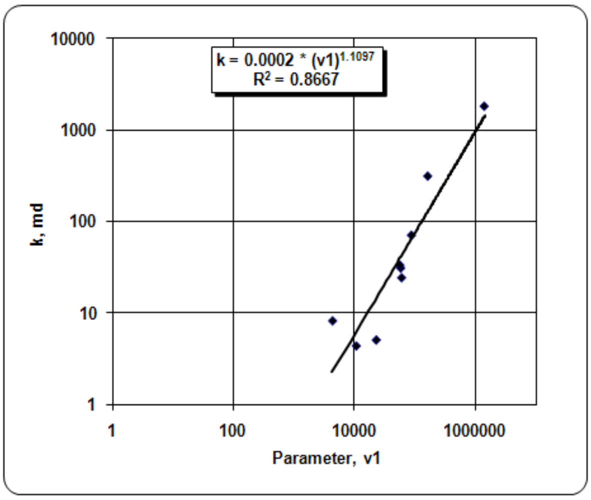

Figure (3) shows the relationship between core permeability and parameter V1

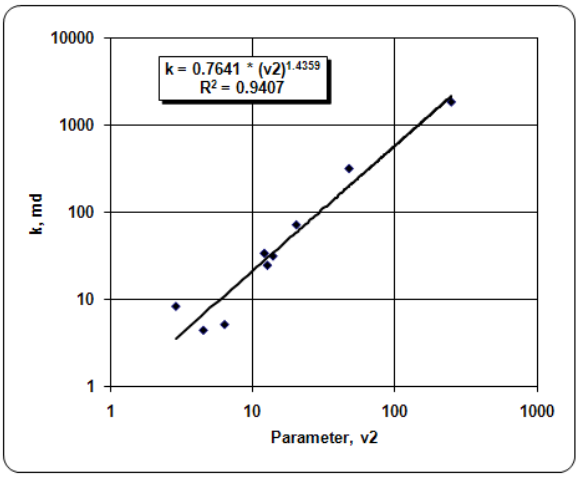

Figure (4) shows the relationship between core permeability and parameter V2

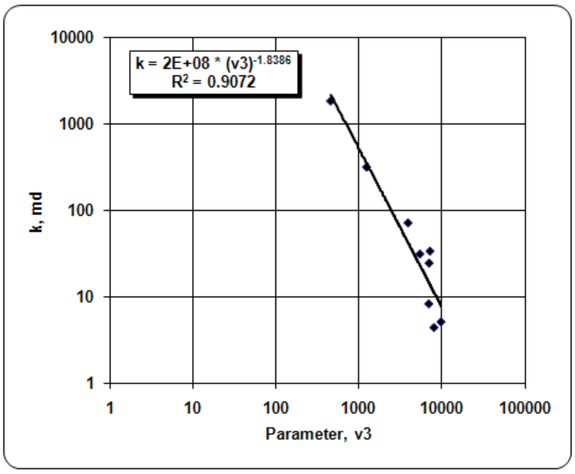

Figure (5) shows the relationship between core permeability and parameter V3

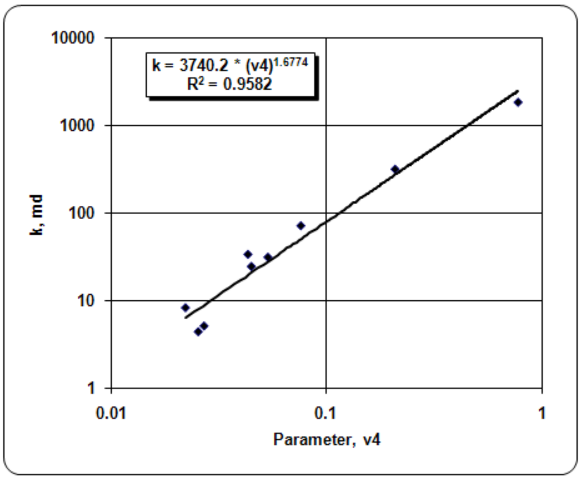

Figure (6) shows the relationship between core permeability and parameter V4

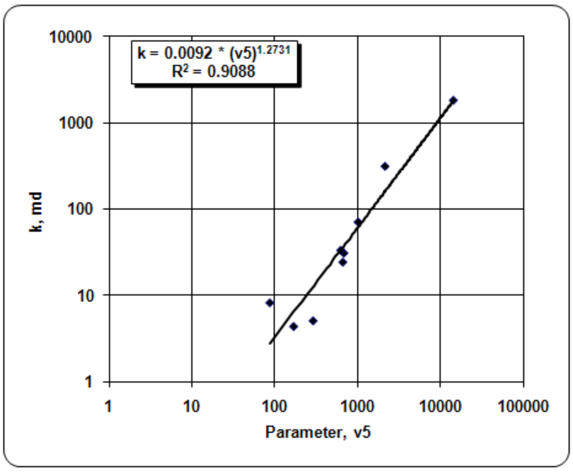

Figure (7) shows the relationship between core permeability and parameter V5

As it can be seen from these figures obtained using parameters V1 through V5, the best R^2 value was obtained using parameter V4, although other parameters such as parameter V2 gave a very good value of R^2 which is 0.9407.

2. Results obtained using DataFit software:_ A direct relationship between permeability, porosity and irreducible water saturation was generated using 3D analysis for estimating permeability through the equation:

$$k = a \times \frac{\phi^b}{S_{wirr}^{-c}}$$

where: (a, b & c) are the correlation factors.

The regression outputs are shown in table (4) and plotted in figure (8).

Table (4): shows the regression outputs of 3D analysis using DataFit:

Number of observations = 9
Number of missing observations = 0
Solver type: Nonlinear
Coefficient of Multiple Determination (R^2) = 0.9998

Variable	Value
a	11199.66
b	0.923
c	-2.858

$$k = 11199.66 \times \frac{\phi^{0.923}}{S_{wirr}^{2.858}}$$

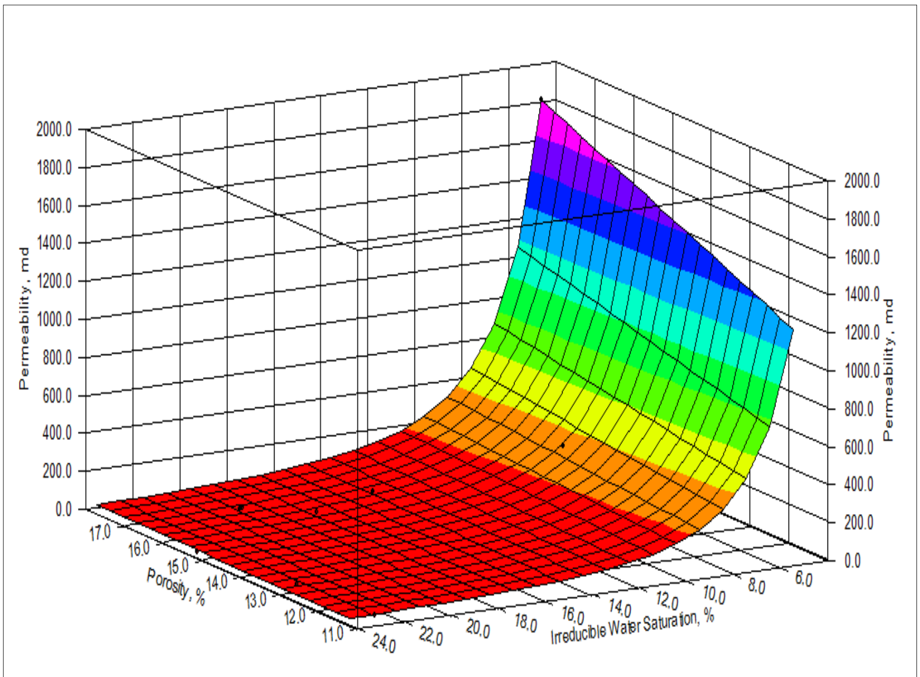

Figure (8) shows the 3D relationship obtained using DataFit software between core permeability, porosity and irreducible water saturation.

CONCLUSION

To conclude, as the Coefficient of Multiple Determination R^2 was the main indicator of the best relationship, there was a great similarity between R^2 value, 0.9582, obtained from 2D analysis by correlating core permeability to the parameter V4 and the value, 0.9998, which was obtained from the 3D analysis by correlating all of the three parameters to each other. Therefore, the final obtained equation from 3D analysis can be used for estimating the permeability of cuttings only for the well of study, although there might be some restrictions due to reservoir homogeneity because this correlation was generated for some randomly selected samples retrieved from different depth intervals of the well and these may not represent all the reservoir intervals.

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