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Permeability Estimation by Using the Modified and Conventional FZI Methods

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ABSTRACT

There many methods for estimation of permeability. In this Paper, permeability has been estimated by two methods. The conventional and modified methods are used to calculate flow zone indicator (FZI). The hydraulic flow unit (HU) was identified by FZI technique. This technique is effective in predicting the permeability in un-cored intervals/wells. HU is related with FZI and rock quality index (RQI). All available cores from 7 wells (Su -4, Su -5, Su -7, Su -8, Su -9, Su -12, and Su -14) were used to be database for HU classification. The plot of probability cumulative of FZI is used. The plot of core-derived probability FZI for both modified and conventional method which indicates 4 Hu (A, B, C and D) for Nahr Umr formation based on the four straight lines. The permeability was calculated by two methods for comparison and choosing the best. The modified FZI method gives better results because the predicted permeability by this method demonstrates a coefficient of correlation (R^2) higher than that of the conventional approach, where the value of R^2 is 0.9645 of modified FZI method while 0.892 of the conventional approach. When plotting RQI versus $\emptyset_z$ on a log-log scale, all core samples with similar *FZI* values will lie on a straight line with a unit slope. Other core samples that have different *FZI* values will lie on other parallel lines. All lines in (RQI and$\emptyset_z$) plot of modified FZI method have unit slop and more parallel than these of the conventional approach. The plot of probability cumulative of FZIm is used to determine number of hydraulic flow unit for Nahr Umr formation. The plot of core-derived probability FZI for both modified and conventional method which indicates 4 Hus for Nahr Umr formation based on the four straight lines, these four straight lines of modified FZI method was more distinguished than these of the conventional approach.

Key words: Permeability, Flow Zone Indicator, Hydraulic Flow Unit, Rock Quality Index, Coefficient of Correlation

حساب النفاذية باستخدام طريقة FZI التقليدية والمطورة

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الخلاصة

هناك العديد من الطرق لحساب النفاذية. في هذا البحث تم حساب النفاذية بطريقتين. تم استخدام الطريقة التقليدية والمطورة لحساب FZI. تم تحديد وحدات الجريان الهيدروليكي بواسطة تقنية FZI. تعد هذه التقنية من الطرق الفعالة في تحديد النفاذية في الابار التي لم تحدد نفاذيتها بواسطة قياسات اللباب. ترتبط وحدات الجريان الهيدروليكي بFZI ومؤشر نوعية الصخرة .استخدمت قاعدة البيانات المستحصلة من قياسات اللباب من سبعة ابارلتصنيف الوحدات الهايدروليكية. تم استخدام رسم الاحتمالية التراكمية لFZI . رسم الاحتمالية التراكمية ل FZI من الطريقة التقليدية والمطورة دل على وجود اربعة وحدات هيدرولية (A, B, C and D) في تكوين نهر عمر بالاعتماد على وجود اربع خوط مستقيمة. تم حساب النفاذية بطريقتين لغرض المقارنة وايجاد الافضل. الطريقة المطورة اعطت نتائج افضل لان النفاذية المحسوبة بهذه الطريقة اظهرت معامل مضاهاة اعلى مما هو عليه في الطريقة التقليدية حيث بلغت قيمته (0.9645) بينما بلغت قيمة عامل المضاهاة للنفاذية المحسوبة بالطريقة التقليدية (0.892) وكذلك عند رسم قيم RQI *مقابل* $\emptyset_z$ على مقياس لوغارتمي كل نماذج اللباب التي لها نفس قيمة *FZI* سوف تقع على خط واحد له ميل مقداره واحد وتوازي بقية الخطوط التي لها قيم *FZI* مختلفة،عند استخدام الطريقة المطورة كل هذه الخطوط كان لها ميل مقدراه واحد ومتوازية مع بعضها اكثر مما هو عليه باستخدام الطريقة التقليدية وعند استخدام رسم الاحتمالية التراكمية ل*FZI* لغرض تحديد عدد الوحدات الهيدروليكية لتكوين نهر عمر كان عدد الوحدات اكثر تمييزا باستخدام الطريقة المطورة مما هو عليه باستخدام الطريقة التقليدية والمتمثلة في عدد الخطوط المستقيمة.

الكلمات الرئيسية: النفاذية, مؤشر نطاق الجريان, وحدات الجريان الهيدروليكي, مؤشر نوعية الصخرة, معامل مضاهاة.

1. INTRODUCTION

Reservoir characterization is a very important domain of petroleum engineering. An effective management strategy can be applied only after obtaining a detailed of spatial distribution of rock properties. Among these, the most difficult to determine and predict is permeability, **Jaber,** and **Shuker, 2014.**

Permeability is one of the most important parameters to quantify in any reservoir rock. Its importance arises due to the major role it plays during the development phase of any reservoir. During any reservoir simulation study, permeability perdition is a very critical and perhaps the most challenging task. In the early stage of the industry, simple permeability–porosity transformations were generated to estimate permeability at un-cored wells. However, such simple relationships were unreliable and results were not in good agreement with field data. Hence, many models have been proposed to predict permeability by incorporating many parameters other than effective porosity, **Nooruddin,** and **Hossain, 2011.**

Rock typing by hydraulic units can be characterized as units of rock that have special permeability-porosity relationship, relative permeability curves and capillary pressure profiles. It has a lot of applications in reservoir characterization and simulation studies. Properly doing of the rock typing that results to accurate generation of initial water saturation profiles and consequently, credible reservoir simulation studies, a reliable estimation of the permeability in the uncored wells, **Davies,** and **Vessell, 1996, Shenawi, et al., 2007.**

Amaefule et al., 1993 presented for the first time the concept of flow zone indicator (FZI) and reservoir quality index (RQI) to define HU based on the **Kozeny-Carmen** model. In this regard, Amaefule's technique is recognized as a very simple, practical, and widely used established technique. This well-known method classifies rock types using the original **Kozeny-Carmen** model. The well-known form of the original **Kozeny-Carmen** model is given by:

$$K = \left(\frac{1}{f_g\, \tau S_{V_{gr}}^2}\right)\frac{\emptyset^3}{(1-\emptyset)^2} \qquad (1)$$

Where k is permeability in μm^2, f_g is the shape factor in the dimensionless unit, τ is the tortuosity in the dimensionless unit, $S_{V_{gr}}^2$ is the specific surface area of the grain in μm-1 and is the effective porosity in fraction.

The **Kozeny-Carmen** correlation was developed based on the concept of average pore throat size. Further mathematical manipulation is carried on Eq.1 that leads to the following form:

$$0.0314\sqrt{\frac{K}{\emptyset}} = \left(\frac{1}{\sqrt{f_g\,\tau}\; S_{V_{gr}}}\right)\frac{\emptyset}{(1-\emptyset)} \qquad (2)$$

From Eq.2, the reservoir quality index (*RQI*) is defined as:

$$RQI = 0.0314\sqrt{\frac{K}{\emptyset}} \qquad (3)$$

The normalized porosity($\emptyset_z$) is defined as:

$$\emptyset_z = \frac{\emptyset}{(1-\emptyset)} \qquad (4)$$

The flow zone indicator (*FZI*) is defined as:

$$FZI = \frac{RQI}{\emptyset_z} \qquad (5)$$

When plotting RQI versus $\emptyset_z$ on a log-log scale, all core samples with similar *FZI* values will lie on a straight line with a unit slope.

Other core samples that have different *FZI* values will lie on other parallel lines.

2. PROPOSED MODIFICATION TO THE KOZENY-CARMEN MODEL, NOORUDDIN, AND HOSSAIN, 201120

The proposed correlation is based on a modified **Kozeny-Carmen** model and has the advantage over the conventional approach of incorporating the tortuosity term in a more representative manner. The conventional model eliminates the inherent nonlinearity between tortuosity and porosity accordingly. The modified correlation is given by:

$$K = \left(\frac{1}{f_g\, a^2 S_{V_{gr}}^2}\right)\frac{\emptyset^{2m+1}}{(1-\emptyset)^2} \tag{6}$$

Where, a is the lithology factor and m is the cementation exponent. Rearranging and taking the square root of Eq.6 results in the following form:

$$0.0314\sqrt{\frac{K}{\emptyset}} = \left(\frac{1}{\sqrt{f_g}\, a\, S_{V_{gr}}}\right)\frac{\emptyset^{m}}{(1-\emptyset)} \tag{7}$$

The left hand side of Eq.3 is the reservoir quality index (*RQI*) where permeability (*k*) is in mD. The first part of RHS $\left(1/\sqrt{f_g}\, a\, S_{V_{gr}}\right)$ is the modified flow zone indicator (*FZIm*). Since the normalized porosity index ($\emptyset_z$) equals to ($\emptyset$ / (1-$\emptyset$)), rearrangement of Eq.7 yields:

$$RQI = FZI_m \times \emptyset_z \times \emptyset^{m-1} \tag{8}$$

Taking the logarithm of both sides of Eq.8 results in the following relationship:

$$\log(RQI) = \log(FZI_m) + \log(\emptyset_Z \times \emptyset^{m-1}) \tag{9}$$

It can be noticed that if the cementation exponent (m) equals to one, then Eq.9 becomes identical to Amaefule model. As (m) increases, the plot of RQI versus ($\emptyset_Z \times \emptyset^{m-1}$) on log-log scale gives higher slope lines. Each group of rocks having similar *FZI* will constitute a HU.

For unconsolidated sands, the exponent has been noticed near 1.3 and is believed to increase with cementation. The values of cementation exponent for consolidated sandstones are 1.8 < m < 2.0 commonly, **Archie, 1942.**

In the current study, the exponent m has been chosen to be equal 1.9.

3. PERMEABILITY PREDICTION

Hydraulic Flow Unit (HU) has been used excessively as a technique in rock typing and permeability modeling. (HU) is related with (FZI) and (RQI). This technique is effective in predicting the permeability in un-cored intervals/wells.

In this study, the hydraulic flow unit was identified by FZI technique. The conventional and modified methods are used to calculate FZI. The permeability was calculated by two methods for comparison and choosing the best.

Equations 3, 4 and 5 were used to calculate RQI, PHIZ ($\emptyset$z) and FZI. All available cores from 7 wells (Su -4, Su -5, Su -7, Su -8, Su -9, Su -12, and Su -14), **Ministry of Oil, 1976-1980,** were used to be database for HU classification. The plot of probability cumulative of FZIm is used. The plot of probability cumulative is the integral of the histogram plot that a normal distribution is represented in a straight line format. The plot of core-derived probability FZI for both modified and conventional method which indicates 4 Hus for Nahr Umr formation based on the four straight lines, respectively is shown in Figure 1.

Depending on the HU definitions obtained from the plot of cumulative probability, a log-log plot of RQI versus ($\emptyset_Z \times \emptyset^{m-1}$) was made as shown in **Fig. 2**. For modified method in this study, cementation exponent (m) is assumed to be 1.9 while it is assumed to be 1 for conventional method. The unit slop lines were drawn related to mean FZI values that intercept with the vertical line $\emptyset_Z$ =1. The clustering was significantly improved using modified HU characterization as compared with the conventional model. Samples that have similar pore throat attributes lie on the same straight line and constitute a HU, **Shenawi, 2009.**

A plot of log permeability (k) versus ($\emptyset$) as shown in **Fig. 3** demonstrates a better correlation using the modified technique as a comparison to the conventional technique for each HU. The relation between porosity and permeability for each rock type was illustrated using power law model, high correlation coefficients were obtained for all rock types, and then permeability can be estimated accurately from equation of curve for each rock type.

Permeability core versus predicted permeability for all rock type was plotted in **Fig. 4** for both the modified approach and the conventional approach. The modified FZI method gives better results because the predicted permeability by this method demonstrates a coefficient of correlation (R^2) higher than that of the conventional approach.

Core permeability and predicted permeability by the modified approach versus depth for all rock type are shown in **Fig. 5**.

CONCLUSIONS

1. FZI technique is effective in predicting the permeability in un-cored intervals/wells.
2. The modified FZI method gives better results because the predicted permeability by this method demonstrates a coefficient of correlation (R^2) higher than that of the conventional approach.
3. There are four hydraulic flow units (A, B, C and D) in Nahr Umr reservoir.

REFERENCES

- Amaefule J. O., Altunbay M., Tiab D., Kersey D., and Keelan D., “Enhanced Reservoir Description: Using Core and Log Data to identify Hydraulic (Flow) Units and Predict Permeability in Uncored Intervals/Wells,”Paper SPE 26436 presented at the Annual TechnicalConference and Exhibition, Houston, Texas, 3-6October 1993.

- Archie, G.E., "The electrical resistivity log as an aid in determining some reservoir characteristics". Petroleum Transactions of AIME, 1942. 146: 54–62. Doi: 10.2118/942054-g.
- Davies, D.K., Vessell, R.K., " Identification and Distribution of Hydraulic Flow Units in a Heterogeneous Carbonate Reservoir: North Robertson Unit, West Texas", paper SPE 35183 presented at the Permian Basin Oil and Gas Recovery Conference, Midland, Texas, 1996, 27-2.
- Jaber A. K., Shuker M. T. "Multiple Linear Regression Approach for the Permeability Calculation from Well Log: A Case Study in Nahr Umr Formation - Subba Oil Field, Iraq", International Journal of Science and Research (IJSR), June 2014.
- Ministry of Oil, Routine core analysis (RCA) for wells (Su-4, Su-5, Su-7, Su-8, Su-9, Su-12and Su-14), 1976-1980.
- Nooruddin H. A., Hossain M. E., "Modified Kozeny–Carmen correlation for enhanced hydraulic flow unit characterization", Journal of Petroleum Science and Engineering 80 (2011) 107–115.
- Shenawi, S.H., White, J.P., Elrafie, E.A., Kilany, K.A., "Permeability and Water Saturation Distribution by Lithologic Facies and Hydraulic Units: A Reservoir Simulation Case Study", Paper SPE 105273, presented at the 15th SPE Middle East Oil & Gas Show and Conference, Kingdom of Bahrain, 2007.
- Shenawi, S.H., Al-Mohammadi, H., Faqehy, M., "Development of Generalized Porosity – permeability Transforms by Hydraulic Units for Carbonate Oil Reservoirs in Saudi Arabia", paper SPE 125380, prepared for presentation at the 2009 SPE/EAGE Reservoir Characterization and Simulation Conference held in Abu Dhabi, UAE, 19-21 October 2009.

NOMENCLATURE

List of Symbols and Abbreviations

FZI	flow Zone Indicator
HU	hydraulic Flow Unit
RQI	rock Quality Index
k	permeability
$\emptyset z$	normalized Porosity
m	cementation Exponent

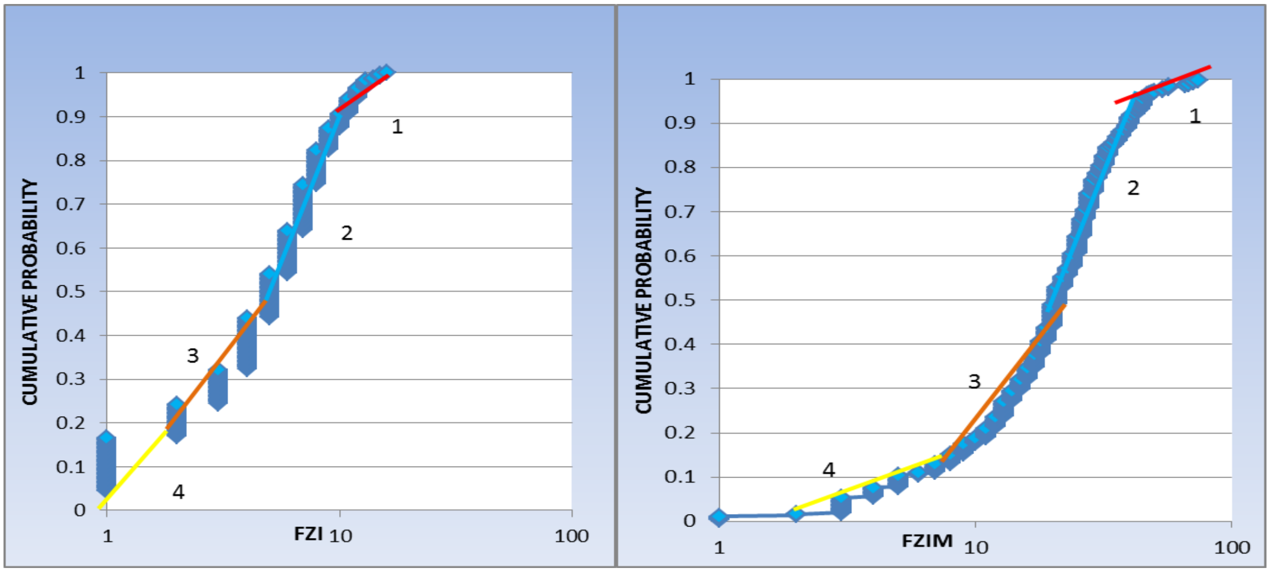

Figure 1. Plot of cumulative Probability of FZI distribution for both the modified (right) and conventional technique (left).

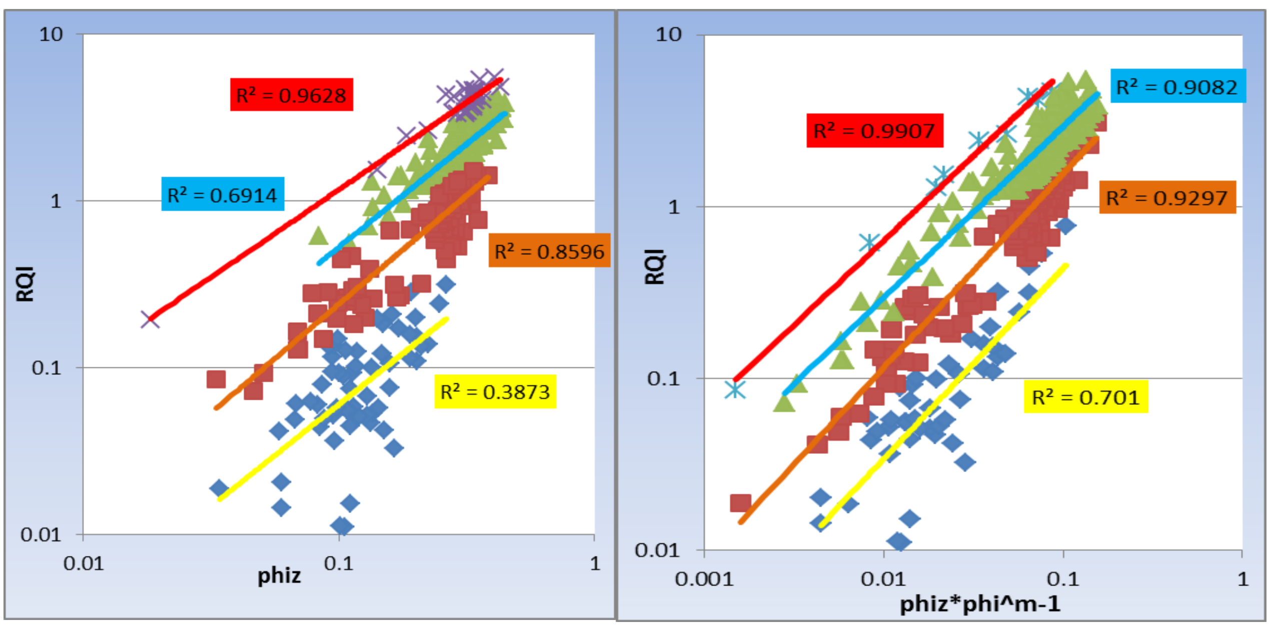

Figure 2. RQI versus PHIZ (ϕ_Z) plot for both the modified approach (right) and conventional one (left).

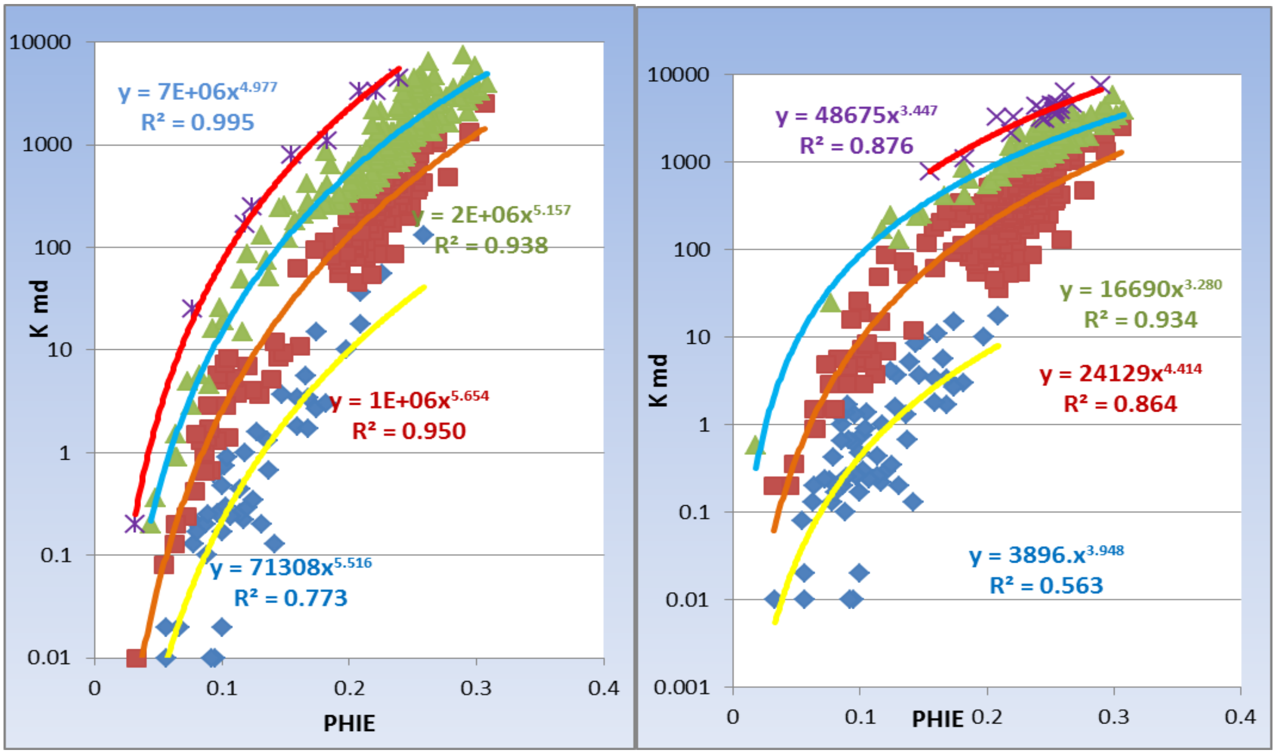

Figure 3. Log permeability (k) versus PHIE plot for both the modified approach (right) and conventional one (left).

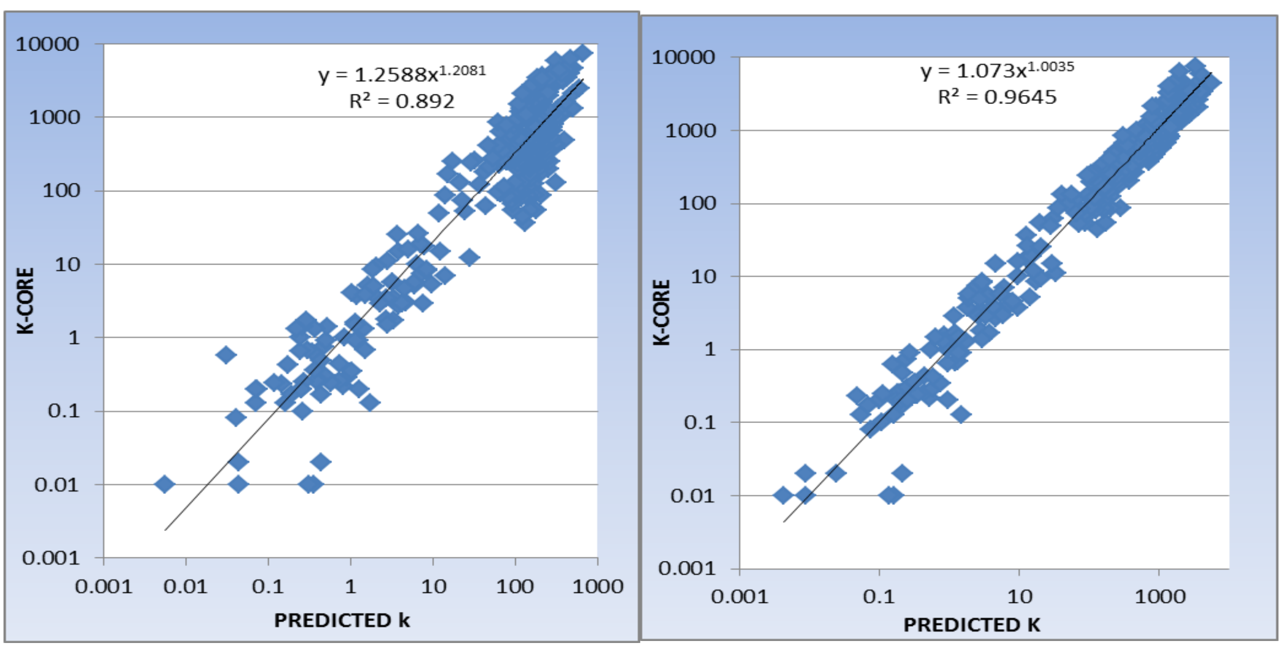

Figure 4. Core permeability versus predicted permeability plot for both the modified approach (right) and conventional one (left).

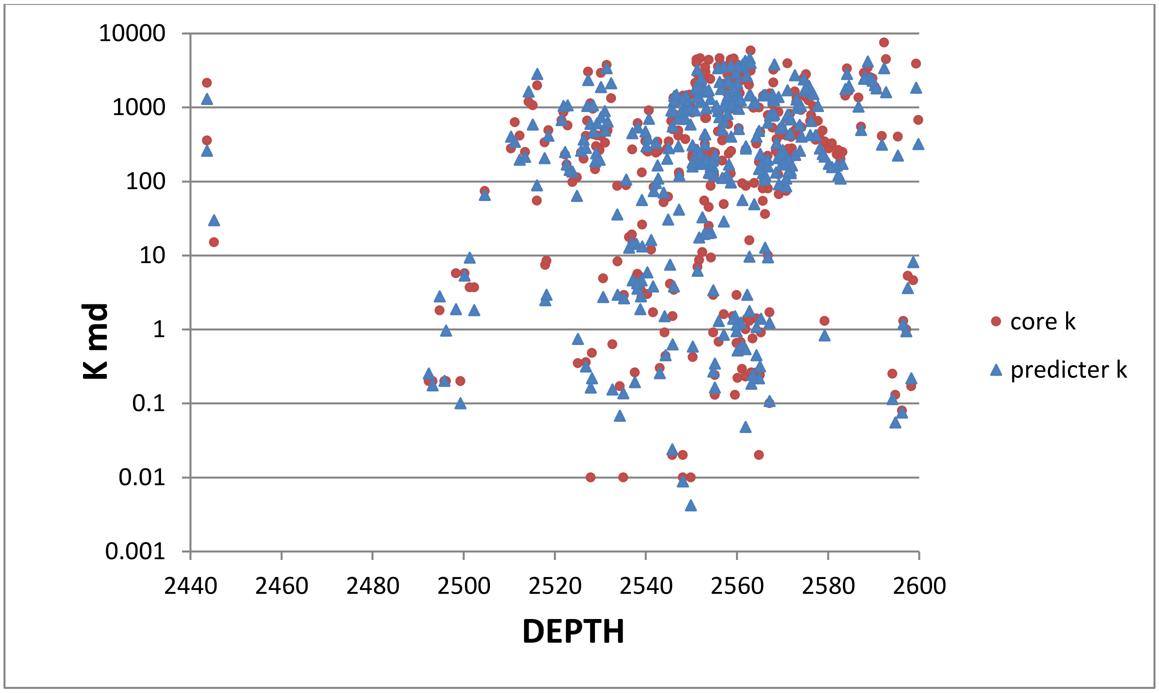

Figure 5. Core permeability and Predicted permeability by the modified approach versus depth for all rock type.