Permeability Estimation of Khasib Formation in Amara Oil Field from Well logs Data Using Multilinear Regression Technique and Empirical Models

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Abstract:

Permeability is the property that permits the passage of fluids through the interconnected pores of a rock. It is one of the most important, most spatially variable, most uncertain, and hence least predictable transport properties of porous formations. This paper represents a method to predict permeability of Khasib Formation in two wells (Am-1,Am-2) of Amara field using Multilinear regression (MLR) technique and various empirical models, such as Tixier's, Timur's and Coates and Dumanoir equations, are used to quantify permeability from well log calculations of porosity and irreducible water saturation. Measured porosity and permeability data from plugs of the available core intervals were used for validation of the predicated data from the logs. The calculated permeability values were compared with the laboratory measurements of core samples to those estimated from different empirical approaches, such as Tixier, Timur, Coates and Dumanoir models, as well as multilinear regression technique by using the statistical correlation coefficient (R2). The present study indicates that Multilinear regression (MLR) technique is the best method and the most validity to estimate permeability from well logs data.

الخلاصة:

النفاذية هي الخاصية التي تسمح بمرور السوائل خلال المسامات المتصلة للصخرة . النفاذية هي أحد أهم وأكثر المتغيرات المكانية والمجهولة , لذلك تعتبر أقل الصفات الناقلة للسوائل التي يمكن توقعها للتكاوين المثقبة . يمثل هذا البحث طريقة لأيجاد والتنبأ بنفاذية تكوين الخصيب في بئرين من ابار حقل العمارة النفطي (بئر عمارة 1وعمارة 2) وبأستخدام تقنية الانحدار الخطي المتعدد و الموديلات التجريبية (الاختبارية) مثل معادلة Timur's ومعادلة Tixier's ومعادلة Coates و Dumanoir , التي أستعملت لتحديد النفاذية من حسابات المجسات البئر ية للمسامية والتشبع المائي الغير قابل للأستخراج . أستخدمت معلومات المسامية والنفاذية المحسوبة من اللباب الصخري المتوفر لمعرفة دقة وصحة المعلومات المحسوبة من المجسات البئرية . تم مقارنة النفاذية المحسوبة مع النفاذية المقاسة مختبريا من نماذج اللباب الصخري مع تللك المقاسة من مختلف المعادلات التجريبية وتقنية الانحدار الخطي المتعدد وبأستخدام معامل الترابط الاحصائي R2 . تدل الدراسة الحالية على ان تقنية الانحدار الخطي المتعدد هي أفضل طريقة واكثرها دقة لتحديد النفاذية من معلومات المجسات البئرية.

Introduction:

Permeability is one of the most important characteristic of hydrocarbon bearing formation which reflects the ability of rocks to transmit fluids in the presence of a potential energy gradient. Understanding the spatial distribution of this property is fundamental to the successful exploitation and reservoir management. Determination of permeability of rocks is a major problem in petroleum industry because of its inherent non-linear dependency on rocks and fluid contained within them such as porosity, irreducible water saturation, shale volume, tortusity, pore connectivity and other factors associated with well conditions or formation damage. To date, there are three generally reliable ways of acquiring knowledge on rock permeability. These are: (1) direct measurement of rock sample (cores). (2) Empirical models that relate permeability to parameters calculated from well logs such as porosity and water saturation, and (3) by using artificial intelligence (AI) techniques such as artificial neural network, fuzzy inference system, and genetic algorithm. The wire-line, which is one among several well logging techniques, can provide a continuous permeability profile throughout a particular interval of a geological column [1, 2]. The aim of this article is to use multilinear regression technique to estimate a permeability of the Khasib Formation at the Amara oil field, south eastern Iraq from well logs data, as well as using empirical models, such as Timur's [3], Tixier's [4], and Coates and Dumanoir' [5] equations to predicate permeability from porosity and irreducible water saturation values.

Reservoir description:

The Amara field locates at south eastern Iraq in Missan province, on the unstable shelf at the Mesopotamian basin. The Amara oil field was first discovered from seismic surveys conducted on Missan Province in late 1970's. It is about 10 Km to the south west of Amara city [6]. The Khasib Formation is one of the important reservoirs in the Amara oil field, and it is deposited at the base of megasequence AP9 in the late Touronian- Early Campanian sequence [7]. The late Touronian- Early Campanian sequence represented by Khasib, Tanuma, Sa`ady, and Komitan Formations, There are two main facies in this sequence: middle shelf represented by Khasib, Tanuma, and Sa`ady formations, However influence of the outershelf environment is obvious with the planktonic abundance [8], and basinal depositional environment of the equivailant Komitan Formation [7]. Khasib reservoir is mainly composed of Limestone rocks from the late Cretaceous Period. According to Bellen *et al*,. (1959) [9] the lower boundary of the formation is disconformable with Mishrif Formation. The upper boundary with theTanuma Formation is gradational.

Methodology:

A total of 60 core permeability measurements from two exploration wells (Am-1 and Am-2) were attained from archive of Missan oil company (M.O.C), and were used to compare with the permeability predicated from well logs. The Didger Software Package 3.03 was used for the digitization of the used well logs data include gamma ray (GR), bulk density log (RHOB), sonic log (DT), neutron log (NPHI), and induction log (ILD). One reading per 0.25m depth is selected for recording the input data measurements, which is used in this study. Interactive Petrophysics software (IP) was used to carry out the environment corrections of well logs and to calculate permeability from well logs using multilinear regression technique and empirical models.

Multi Linear Regression Technique:

The '*Multi Linear Regression*' technique is a mathematical method that allows predicting permeability from a number of input well logs using a least squares regression routine, which will try and find the best fit to the input data. This method is based on averaging of the input well log data which is associated with the permeability core (K) in md. Gamma ray (GR) with API, density (Den) in gm/cm^3 neutron (Neut) with porosity unit (ρ.u) and sonic logs (Δt) in µsec/ft were used as input values in this model with the below equation [10]:

$$\text{Log}(k) = (-2.488-0.0073*GR- 0.619*Den + 11.128*Neut + 0.050*\Delta t) \ldots\ldots (1)$$

Through any reservoir has its environment and the measurements of the log tool affected by the reservoir conditions, it is not possible to use the above formula directly, then after some trials on the log relations, a new equation is suggested for each well under study using Interactive Petrophysics software (IP) which gives more reasonable matching with the core Measured permeability.

The suggested equations for each well are as follows:

$$(K) \text{ For } (Am\text{-}1) = 10\wedge^{(-4.7192251 + 1.918141\, RHOB + 2.3160178\, NPHI + 0.031013\, DT - 0.1137736\, GR)} \ldots\ldots (2)$$

$$(K) \text{ For } (Am\text{-}2) = 10^{\wedge (-40.154694 + 9.557456\, RHOB + 16.525712\, NPHI + 0.3259965\, DT - 0.061199\, GR)} \ldots\ldots (3)$$

The two equations above include several input data derived from log measurements. Based on their relations with permeability the equations were created: GR log refers to shale volume in the reservoir rock, which has negative (inverse) effect on the permeability and make it to act as negative (-) parameter in the equations, while all other three logs: Density, Neutron, and Sonic, which are porosity logs, and they have normal (direct proportion) relation with the permeability and act as positive (+) parameters in the equations with the labeled factor to each one

Empirical models:

In empirical modeling, the permeability is determined by measuring porosity and irreducible water saturation from well logs to predict permeability values for the un-cored sections. Several investigators attempted to grasp the complexity of the permeability function into a model with general applicability. These studies gave a better understanding of the factors controlling permeability. Moreover, they showed that it is an illusion to look for a universal relation between permeability and other variables. The major concern with the models relating permeability to specific surface area per unit grain volume (Sgv) is that, they cannot be determined directly from well logs but rather from core analysis. Therefore, the real well log derived permeability is obtained by relating specific surface area per unit grain volume (Sgv) to irreducible water saturation (Swi). Irreducible water saturation (Swi) is defined as the saturation at which a reservoir will produce hydrocarbon with little or no water. Empirical models are only valid for estimating permeability in formations at irreducible water saturation. Before calculating the permeability, we must first determine whether or not a formation is at irreducible water

Saturation, This depends upon bulk volume water values (BVW = Sw - Ø). When the bulk volume water values of a formation are constant, the zone is at irreducible water saturation [11]. Of course, this requires additional work to detect the levels of irreducible water saturation.

Morris and Bigges [12] stated, that can be done by plotting SW against the porosity on a linear scale. Then, a hyperbola is drawn for the minimum water saturation, and the levels that fall on this hyperbola, which represents the irreducible water saturation, are selected. Figures (1, 2) show the saturation vs. porosity plots on a linear scale for wells Am-1 and Am-2. A hyperbola is drawn for the minimum water saturation. A general empirical relationship proposed by Wyllie and Rose [13] relates the permeability, k, of a porous medium to its porosity, Ø, and irreducible water saturation, Swi, as

$$K = a\frac{\text{Ø}^{b}}{\text{swi}^{c}} \ldots\ldots\ldots\ldots\ldots (4)$$

Where a, b, and c are statistically determined model parameters.

Based on this general expression, various empirical relationships (5 6 and 7) have been proposed to calculate permeability from values of porosity and irreducible water saturation derived from well logs, including:

Timur: [3] $K = 62.5\frac{\text{Ø}^{6}}{\text{swi}^{2}} \ldots\ldots\ldots\ldots (5)$

Tixier.[4] $K = 8.58\frac{\text{Ø}^{4.4}}{\text{swi}^{2}} \ldots\ldots\ldots\ldots (6)$

Coates and Dumanoir. [5] $K = 10.0\frac{\text{Ø}^{4.5}}{\text{swi}^{2}} \ldots\ldots\ldots\ldots (7)$

Despite these equations widespread use, existing models used to calculate permeability from porosity and irreducible water saturation do not explicitly include the role played by rock structure, grain geometry, grain-size distribution, wettability, and spatial distribution of irreducible water in the pore space.

Laboratory studies have shown that permeability depends on a long list of parameters: porosity, pore size and shape, pore size distribution, clay content, fluid type, and water saturation – a nearly overwhelming complexity [14], [15].

Discussion and Conclusions:

The applicability and validity of permeability predicated from Multi Linear Regression Technique and Empirical models were tested using the core data of permeability for two wells under study. Figures (3, 4) show the variation of k-values with depth. As may have been noticed from the figures, acceptable correlation, reflected by the good coincidence between the k-core and k-estimated data curves is obtained. The results of permeability calculation using Multi Linear Regression Technique are shown in figures (3A and 4A). The comparison between the computed and measured core permeability values indicates that acceptable results may obtained by using this technique.

Figures (3 B, C, and D) for well Am-1 and figures (4 B, C, and D) for well Am-2 show a comparison between the measured and predicted permeability values by applying the empirical equations. These figures indicate that in general, the core and the computed permeability values are not greatly differ from each other. Accordingly, these equations were applied to the units of the Khasib Formation after the effective porosity and the irreducible water saturation have been estimated from the well logs.

The validity (degree of accuracy) of the formulated equations and Multi Linear Regression technique are investigated through their application of the core data. This is accomplished by comparing the variation of permeability with depth using permeability values from the core analysis data and those computed from the formulated equations and Multi Linear Regression Technique as shown in figures (5-8). The correlation coefficient (R^2), which ranges from (0 to 1), was used as a criterion to compare the ***k***-estimated and ***k***-core values. If the value of (R^2) is (1) there is a perfect correlation in the samples, i.e. there is no difference between the *k*-estimated and the *k*-core values. On the other extreme, if the value of (R^2) is (0) the regression equation is not helpful in predicting permeability values. The values of R^2 that range from (0.688) in Coates and Dumanoir equation to (0.795) using MLR technique indicate that the multi linear regression technique is the best method to predict permeability from well logs data which reflected acceptable correlation with the permeability measured from core data.

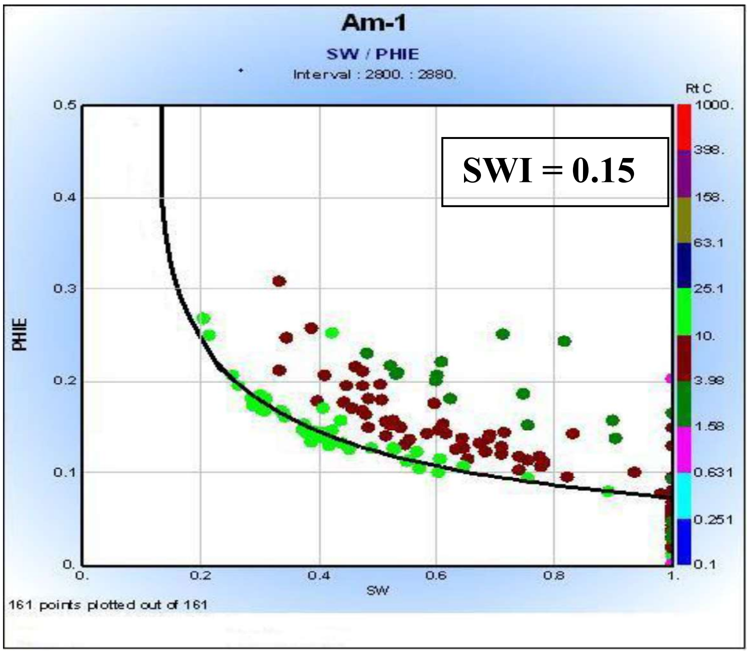

Fig. (1) Water Saturation – porosity with true resistivity log plot for Am-1 well to determine (SWI) value

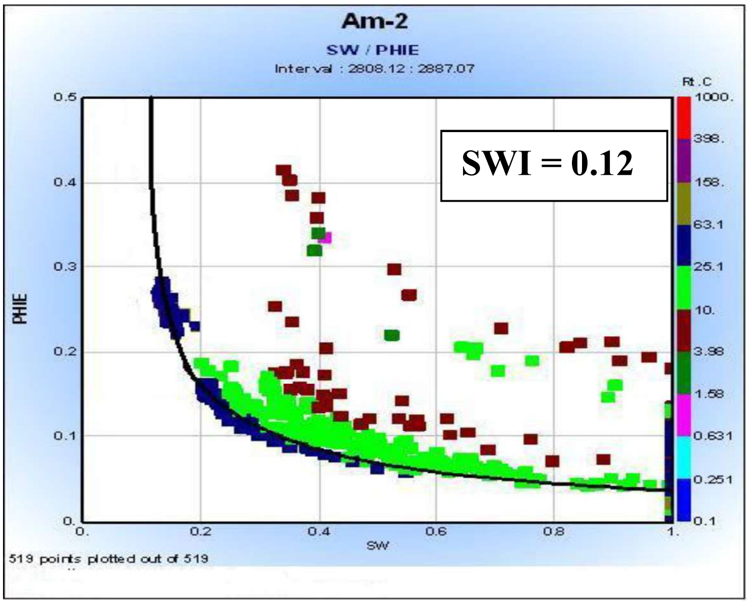

Fig. (2) Water Saturation – porosity with true resistivity log plot for Am-2 well to determine (SWI) value

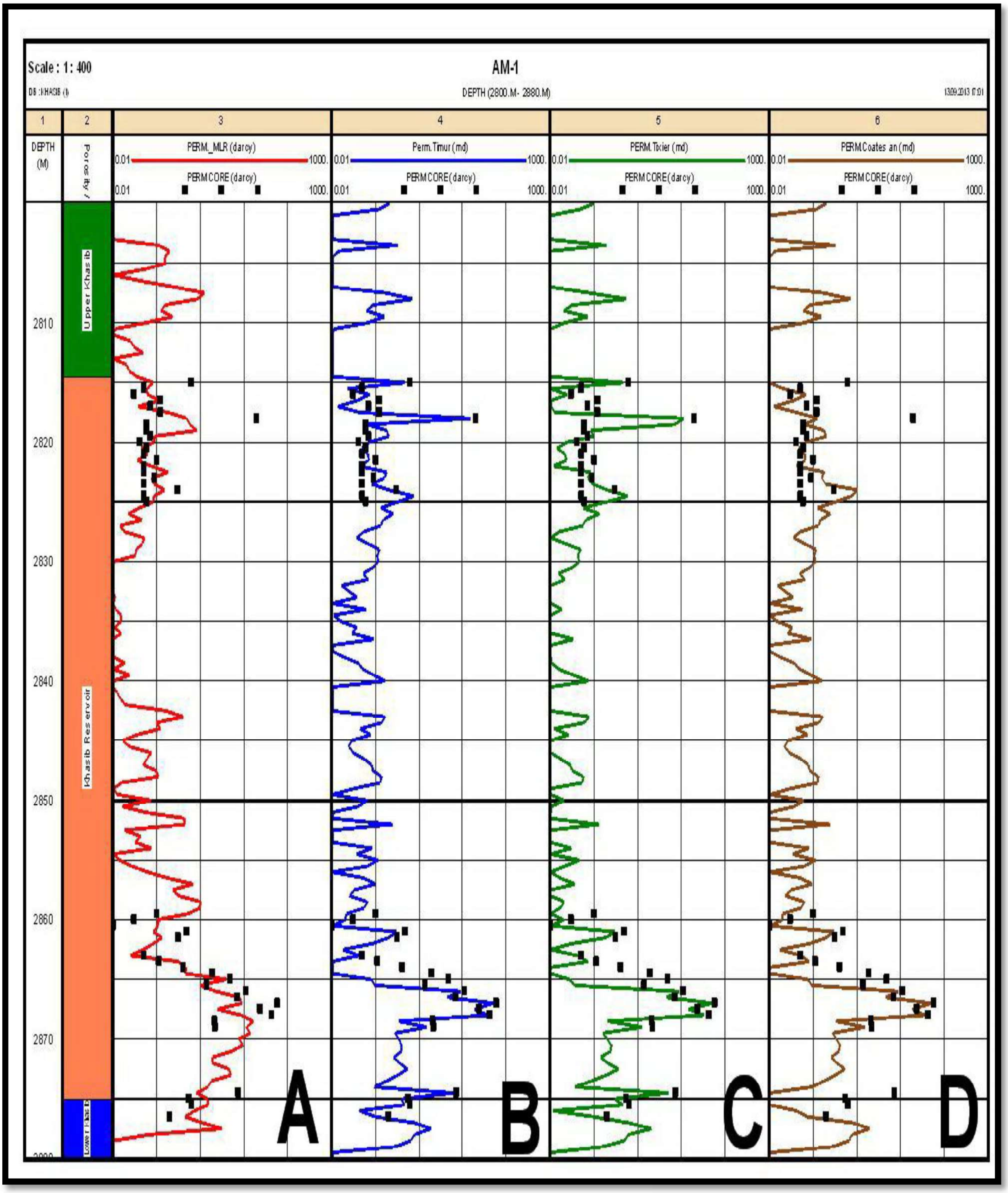

Fig. (3) Measured permeability of core samples compared to their estimated values from different empirical models and Technique for Am-1 well :(A) MLR, (B) Timur, (C) Tixier, (D) Coates and Dumanoir

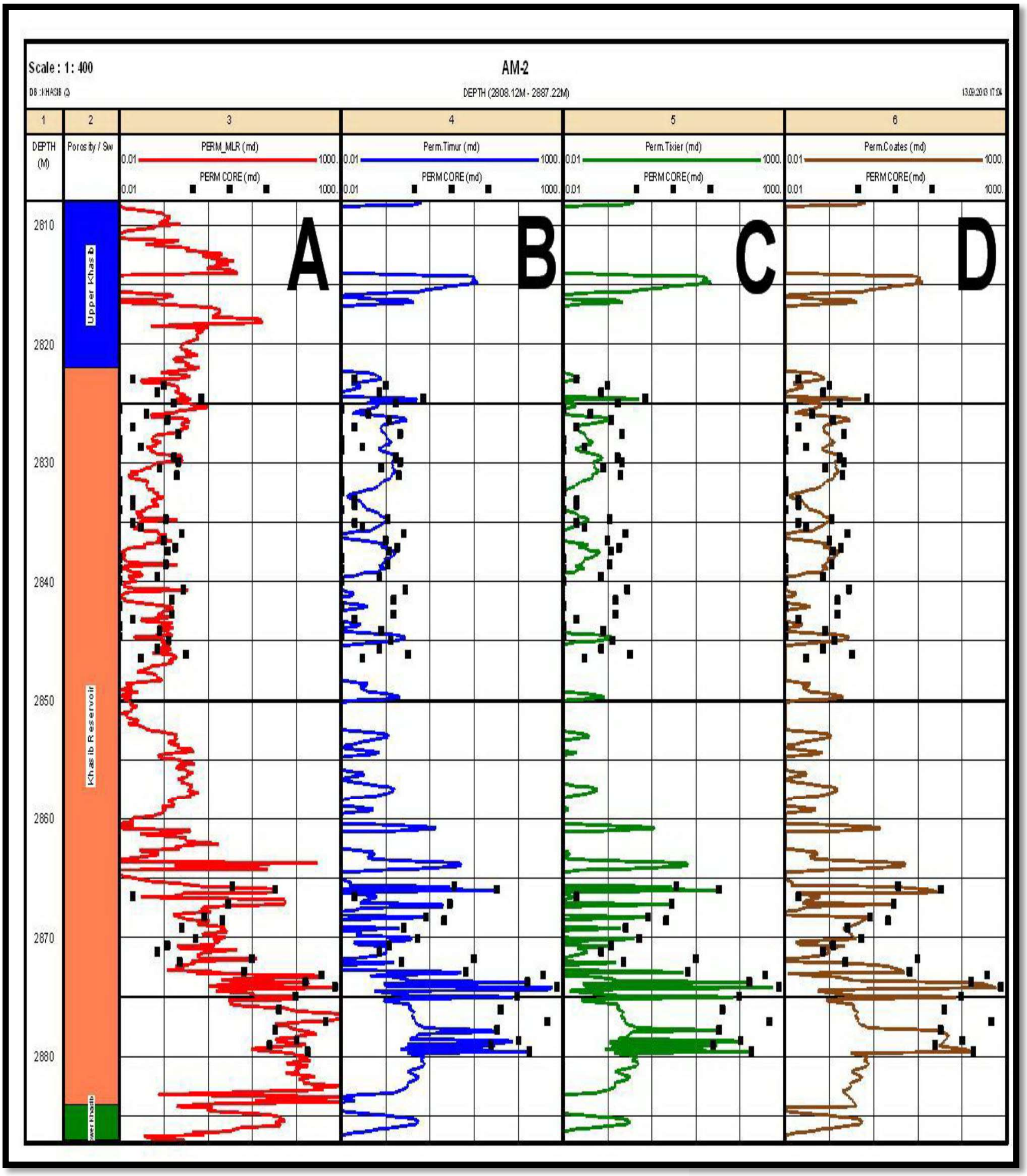

Fig. (4) Measured permeability of core samples compared to their estimated values from different empirical models and Technique for Am-2 well :(A) MLR, (B) Timur, (C) Tixier, (D) Coates and Dumanoir

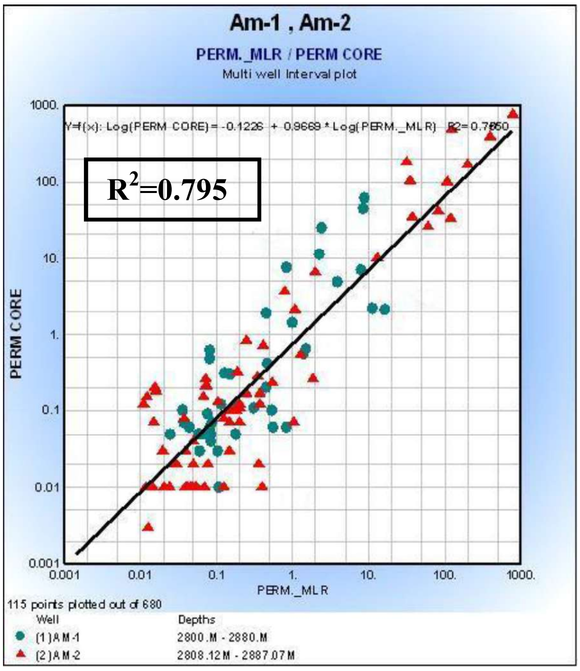

Fig. (5) Cross plot of measured vs. predicted Permeability using MLR technique

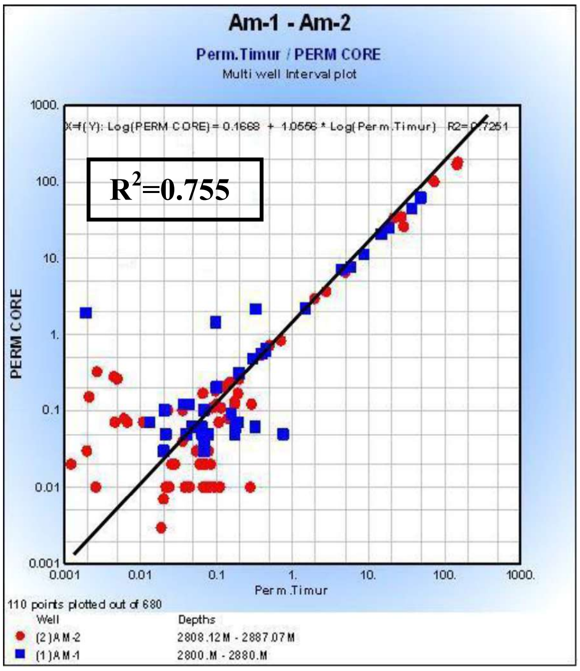

Fig. (6) Cross plot of measured vs. predicted Permeability using Timur equation

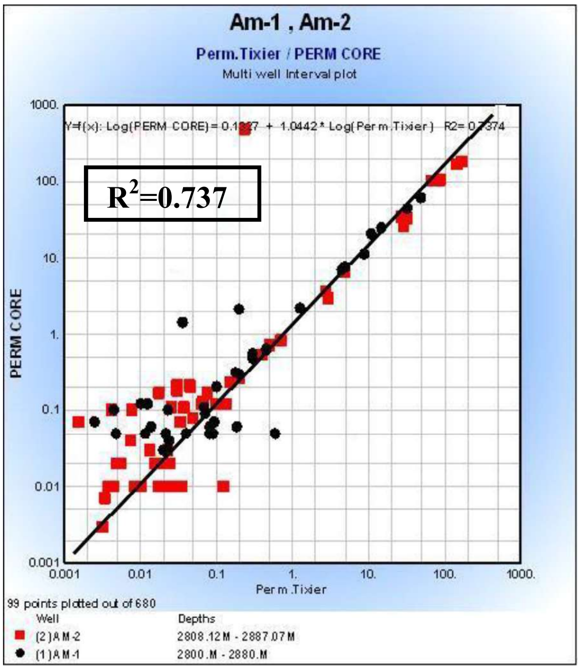

Fig. (7) Cross plot of measured vs. predicted Permeability using Tixier equation

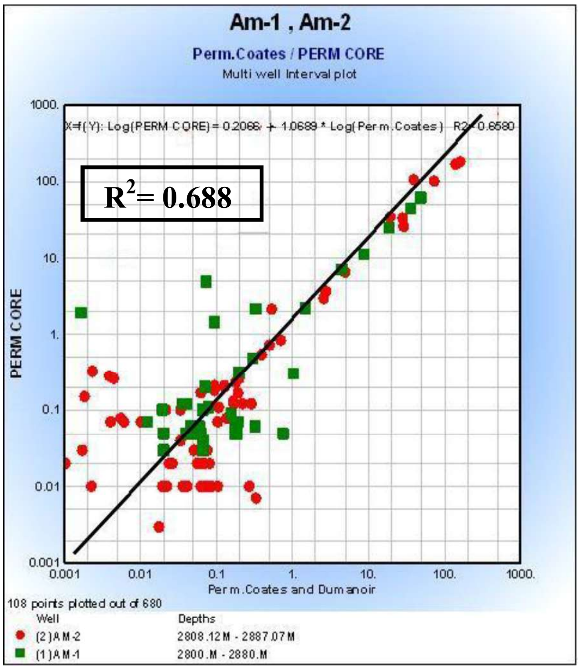

Fig. (8) Cross plot of measured vs. predicted Permeability using Coates and Dumanoir equation

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