# Permeability Prediction of Un-Cored Intervals Using FZI Method and Matrix Density Grouping Method: A Case Study of Abughirab Field/Asmari FM., Iraq

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## Abstract

Knowledge of permeability is critical for developing an effective reservoir description. Permeability data may be calculated from well tests, cores and logs. Normally, using well log data to derive estimates of permeability is the lowest cost method. This paper will focus on the evaluation of formation permeability in un-cored intervals for Abughirab field/Asmari reservoir in Iraq from core and well log data. Hydraulic flow unit (HFU) concept is strongly related to the flow zone indicator (FZI) which is a function of the reservoir quality index (RQI). Both measures are based on porosity and permeability of cores. It is assumed that samples with similar FZI values belong to the same HFU. A generated method is also used to calculate permeability in un-cored zones depending on matrix density grouping, where each group has its own permeability-porosity correlation. After applying the both methods and correlating the calculated permeability with the core permeability data it revealed that matrix density grouping is the best method to calculate permeability in un-cored zones and it is better than FZI method in this field, then the estimated permeability is distributed through the members of Asmari reservoir in Abughirab field and it is concluded that permeability in this field is generally increases toward south culmination of Abughirab field.

## Introduction

Permeability is one of the most important petrophysical parameter required for reservoir evaluation and monitoring. Reliable permeability data derived from core measurements conditioned to well test permeability is scarce for most reservoirs as there is low percentages of cored wells due to technical and economical reasons. Therefore, suitable approach to estimate the permeability values in the non-cored wells of any reservoir with an acceptable accuracy, unquestionably, deemed very necessary. Deriving permeability using log data is the approach that has been followed in the industry. This requires, however, prior effort of modeling relationships between log responses and core permeability in the cored wells [1]. In the introduction to *API code 27* it is stated that *"permeability is a property of a porous medium and is a measure of the capacity of the medium to transmit fluids"*. The measurement of permeability then is a measure of the fluid conductivity of the

particular material [2]. The permeability of a rock depends on its effective porosity; consequently, it is affected by the rock grain size, grain shape, grain size distribution (sorting), grain packing, and the degree of consolidation and cementation. The type of clay or cementing material between sand grains also affects permeability, especially where fresh water is present. Some clay, particularly smectites (bentonites) and montmorillonites swell in fresh water and have tendency to partially or completely block the pore spaces [3].

**Literature Review**

There are many methods were developed to estimate permeability based on the correlation between core porosity and permeability and sometimes water saturation. The following some of these methods:
Archie in 1942 [4] studied a correlation between permeability and formation factor and he found that there is no significant correlation between them.
Timur in 1968 investigated the relationships between permeability, porosity and residual water saturation in a three different oil fields. He tested several relations for $k$, $\varphi$, and $S_{wi}$, by statistical technique to find the standard error of estimate and correlation coefficient for each field, and then for all fields. He found the best estimation of permeability through equation (1) [5];

$$k = 0.136 \frac{\varphi^{4.4}}{S_{wi}^2} \qquad …(1)$$

Coats and Dumanoir in 1973 [6] Developed an approach to improve log derived-permeability. The permeability index was derived as a function of porosity, formation resistivity at irreducible water saturation $(R_{tirr})$, hydrocarbon density $(\rho_h)$ and rock type $(w)$. The basic relationships:

$$k^{0.5} = \frac{C}{w^4} \cdot \frac{\varphi^{2w}}{R_w/R_{tirr}} \qquad …(2)$$

Where,

$$C = 23 + 465\rho_h - 188\rho_h{}^2 \qquad …(3)$$

And,

$$w^2 = (3.75 - \varphi) + 0.5 \left(log \frac{R_w}{R_{tirr}} + 2.2\right)^2 \qquad …(4)$$

With the support of core and log studies, they adopted a common exponent, $w$, for the saturation exponent, $n$, and cementation exponent, $m$ (i.e. $m=n=w$). Equations (2, 3, and 4) are valid for clean, oil-bearing formations, with oil density equal to 0.8. When the hydrocarbon has a density appreciably different from *0.8*, the log reading of $R_{tirr}$, are multiplied, before entering equation (4), by a correction factor given by:

$$\frac{R_{tcorr}}{R_{tlog}} = 0.077 + 1.55\rho_h - 0.627\rho_h^2 \qquad …(5)$$

Gomez in1977 [7] discussed some considerations for the possible use of the parameter *(a)* and *(m)* as a formation evaluation's tool through well logs, his conclusion that computed *(a)* and *(m)* from well logs can be used for detecting permeable zones, as follow:

$$k = \frac{\varphi^m}{a} \left(\frac{\varphi}{1-\varphi}\right)^2 \frac{1}{S_{wi}^2} \qquad …(6)$$

**Study Area**
*Abughirab* oil field is located in south east of Iraq in *Missan* governorate near *Iranian* border, it has an axial length about *30 km* and its width is about *5 km* with these coordinates *(3575000-360000)* northing lines and *(71000-73500)* easting lines. It is composed of two domes northern and southern with

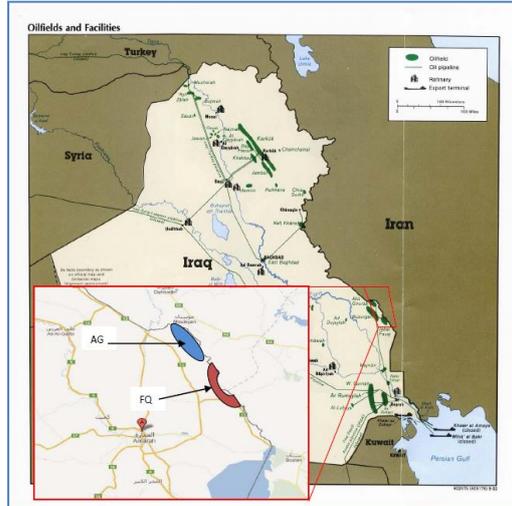a saddle zone [8], see figures (1) and (2).
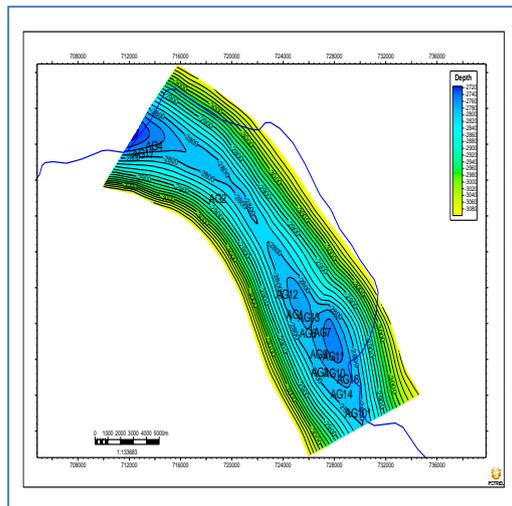


Fig. 1, location of AG field



Fig. 2, structural map of top of Jeribe-Euphrates Fm

*Asmari* formation in this field is divided to four sub formations in which they are [9]; *(1) Jeribe-Euphrates*, which it composed of mainly dolomite with some lime stone and anhydrite. *(2) Upper Kirkuk*, it is composed of mainly lime stone, dolomite and some sand stone. *(3) Buzurgan Member*, it is mainly containing sand stone with some dolomite, lime stone, and shale in the upper part. *(4) Middle-Lower Kirkuk*, it is in general composed of lime stone, dolomite, and sand stone with huge

amounts of shale see figure (3). Core data in this field is available from *10* wells and they well be used to estimate permeability through them.

## Estimating Permeability by FZI Method

Amaefule et al. in 1993 [10] Introduced the concept of flow units and the *FZI* method. They developed a technique for identifying and characterizing a formation having similar hydraulic characteristics, or flow units, based on the microscopic measurements of rock core samples. This technique is based on a modified *Kozeny-Carman* equation and the concept of mean hydraulic radius as follows;

$$k = \left(\frac{1}{K_T s_{vgr}^2}\right)\left(\frac{\varphi_e^3}{(1-\varphi_e)^2}\right) \qquad \dots(7)$$

Where,
$k$ = permeability, md.
$\varphi_e$ = effective porosity.
$S_{Vgr}$ = specific surface area per unit grain *volume.*
$\tau$ = tortuosity of the flow path.
$K_T = K_{ps}\,\tau$ = effective zoning factor.

*Amaefule et al.* also introduced the concept of Reservoir Quality Index (*RQI*), considering the pore-throat, pore and grain distribution, and other macroscopic parameters. Dividing both sides of equation (7) by porosity and taking the square root of both sides yields;

$$\sqrt{\frac{k}{\varphi_e}} = \frac{1}{s_{vgr}\sqrt{K_T}}\left(\frac{\varphi_e}{1-\varphi_e}\right) \qquad \dots(8)$$

If permeability is expressed in millidarcies and porosity as a fraction, the left hand side of equation (8) becomes:

$$RQI = 0.0314\sqrt{\frac{k}{\varphi_e}} \qquad \dots(9)$$

Where, *RQI* is expressed in micrometers or *μm (1 μm =1x10$^{-6}$m)*
The flow zone indicator is defined from equation (8) as;

$$FZI = \frac{1}{s_{vgr}\sqrt{K_T}} \qquad …(10)$$

Thus equation (8) can be written as:

$$RQI = \varphi_z FZI \qquad …(11)$$

Where, $\varphi_z$ is the ratio of pore volume to grain volume;

$$\varphi_z = \left(\frac{\varphi_e}{1-\varphi_e}\right) \qquad …(12)$$

Taking the logarithm of equation (11) on both sides yields:

$$logRQI = log\varphi_z + logFZI \qquad …(13)$$

Equation (13) yields a straight line on a log-log plot of *RQI* versus $\varphi_z$ with a unit slope. The intercept of this straight line at $\varphi_z = 1$ is the flow zone indicator. Samples with different *FZI* values will lie on other parallel lines as in figure (4). Samples that lie on the same straight line have similar pore throat characteristics and; therefore, constitute a flow unit.

Straight lines of slopes equal to unity should be expected primarily in clean sandstone formations. Slopes greater than one indicate a shaly formation.

*FZI* values are rounded for one digit. The data of Permeability vs. porosity cross plot can be classified according to the values of *FZI* where each group has a specified value of the latter, *i.e.* same pore throat and rock type features as shown in figures (5).
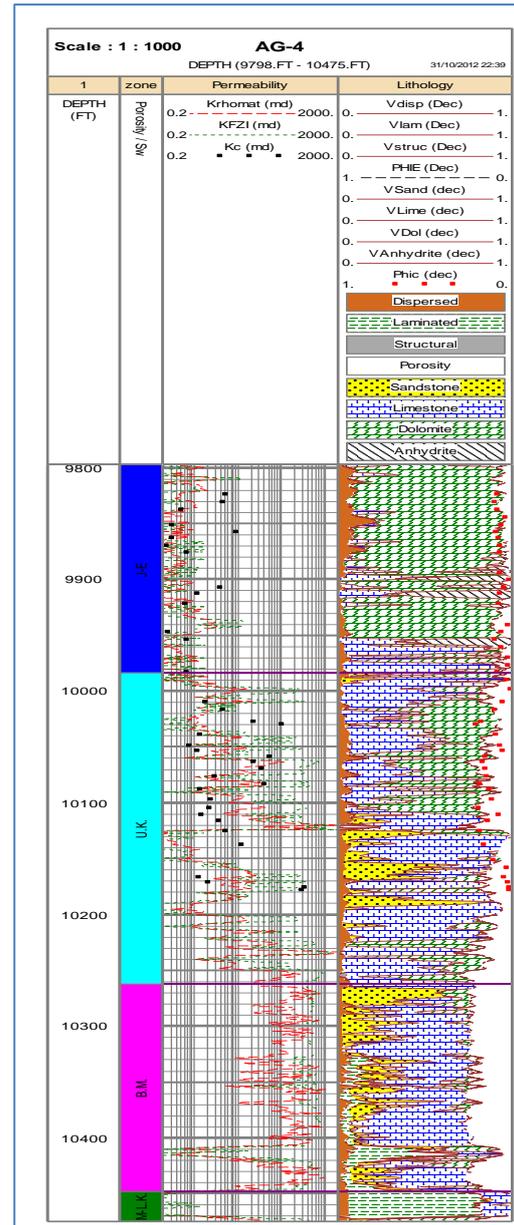


Fig. 3, Asmari Fm. members and application of FZI method and matrix density grouping method in one of AG wells
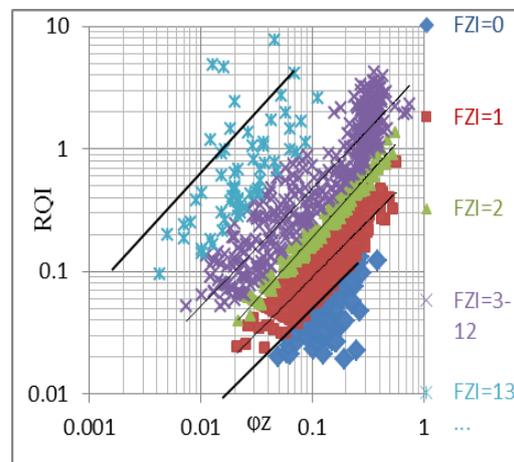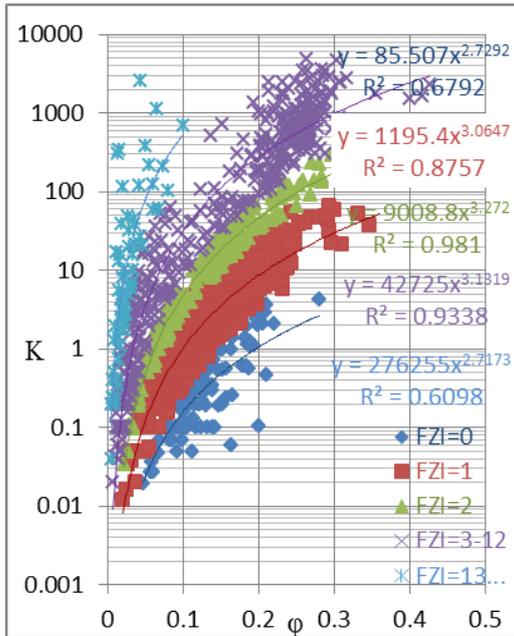


Fig. 4, RQI vs. φz in AG field

Fig. 5, k vs. φ in AG field categorized according to FZI

Each group has its own permeability-porosity relationship and it will be used to calculate permeability in the non- cored zones, this required the availability of the value of *FZI* or related features for these zones, since these features are not available in the reports, so the log porosity will be used as an indication of *FZI* as in table (1). Figure (3) represents the results that obtained from this method for one of *AG* field wells.

Table 1, k vs.φ correlations according to FZI

| Field | Permeability-porosity correlations according to FZI | | $R^2$ values |
|---|---|---|---|
| Abughirab | FZI≥13≈(φ_e≤0.03) | $k=27625\varphi^{2.717}$ | 0.61 |
| | FZI=0≈(0.03<φ_e≤0.08) | $k=85.5\varphi^{2.73}$ | 0.68 |
| | FZI=1≈(0.08<φ_e≤0.12) | $k=1195\varphi^{3.06}$ | 0.88 |
| | FZI=2≈(0.12<φ_e≤0.17) | $k=9008\varphi^{3.3}$ | 0.981 |
| | FZI=3-12≈(φ_e>0.17) | $k=42725\varphi^{3.13}$ | 0.933 |

Due to the lack of the data about facies and rock clustering so this method will not give accurate results in this field.

### $\rho_{ma}$ Grouping Method [11]

This method depends on classifying matrix density as groups, each core permeability and porosity data belong to a group will be correlated to find an equation represents that group as shown in table (2).

Table 2, k vs.φ correlations according to $\rho_{ma}$ categories

| Field | $\rho_{ma}$ categories | k vs.φ correlation | $R^2$ values |
|---|---|---|---|
| Abughirab | $\rho_{ma}<2.69$ | logk=-1.085+15.23φ | 0.78 |
| | $2.69\leq\rho_{ma}<2.73$ | logk=-1.163+12.92φ | 0.6 |
| | $2.73\leq\rho_{ma}<2.77$ | logk=-0.835+10.25φ | 0.55 |
| | $2.77\leq\rho_{ma}<2.83$ | logk=-1.322+12.5φ | 0.62 |
| | $2.83\leq\rho_{ma}<2.87$ | logk=-0.65+8.6φ | 0.4 |
| | $\rho_{ma}\geq2.87$ | logk=-0.961+11φ | 0.5 |

taking a quick look on in table (2) it is revealed that sandstone groups (sandstone, limy sand, and dolomitic sandstone) which discriminated by $\rho_{ma} < 2.69$ or a combination of the three minerals give high values of correlation factor $(R^2)$ this indicates that the porosity in these zones has a good correlation with permeability and it isn't influenced by the diagenetic processes that make the correlation non-uniform. On the other hand the

category ($2.83 \leq \rho_{ma} < 2.87$) in *AG* field has low values of $R^2$ this indicates that the correlation between permeability and porosity is not uniform in the zones with these categories. These two categories represent dolomite groups and as known this type of rock has a good properties and it is expected to show a uniform or semi uniform correlation between permeability and porosity!? But the fact that the zones with these categories are subjected to diagenetic processes that changed their properties, presence of shale or presence of anhydrite that may damage the properties of dolomite and this is clear in *J-E* formation. Figure (3) represents the results that obtained from this method for one of *AG* field wells.

Finally after correlating core permeability data with calculated permeability by each method on log-log scale it revealed that the best method is $\rho_{ma}$ *Grouping Method* which gives good results and it is having a good match between core permeability and predicted permeability, (*i.e.* highest $R^2$ value) as in figures (6) and (7) where $R^2$ for this method is *(0.74)* while for the *FZI* method is (0.47) so the former method will be adopted to calculate permeability in non-cored zones.
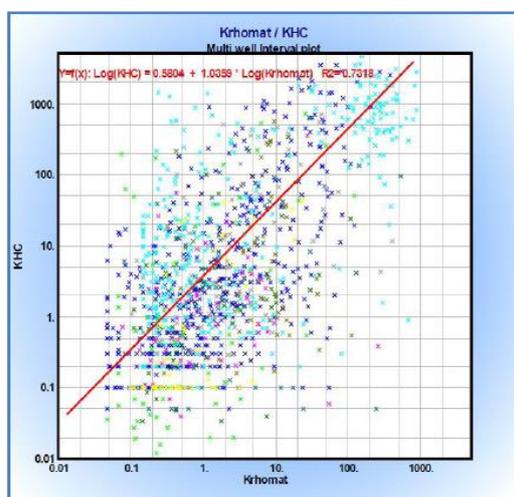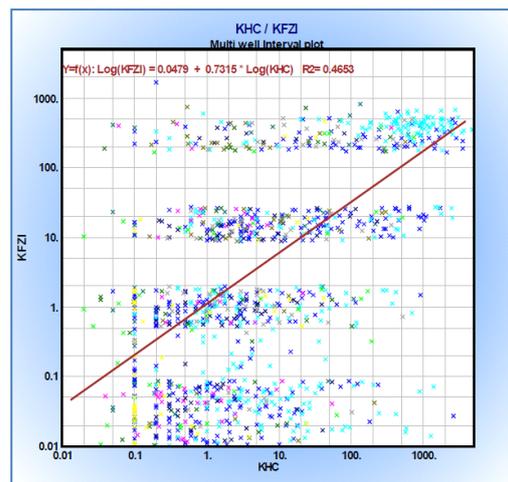


Fig. 7, k from FZI Method vs. k core for AG field.$R^2$=0.47

## Distributing Permeability in Asmari Fms. /AG field

Utilizing petrel software, *2008* the permeability can be distributed through the members of *Asmari Fm*. using the data that obtained previously. The members of *Asmari Fm*. are divided to layers to increase the accuracy of averaging, see figure (8). Gaussian simulation algorithm is used as a statistical method which fits with the amount of available data and to extrapolate the values of permeability through the formations, figures (9-12) represent this distribution. The presence of small fissures, fractures, and vugs may increase the permeability in the zones with low porosity especially in *J-E* and upper part of *U.K. Fms.*
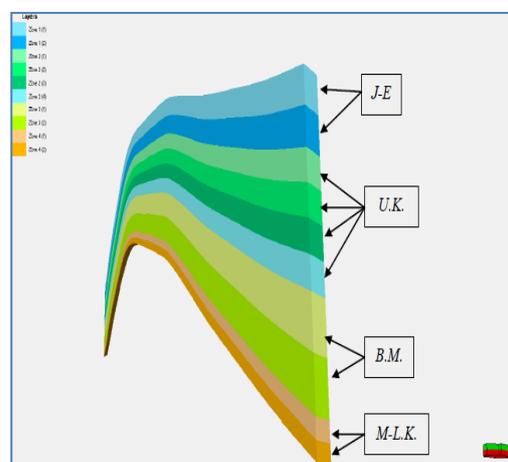


Fig. 6, k from $\rho_{ma}$ Grouping Method vs. k core for AG field.$R^2$=0.732



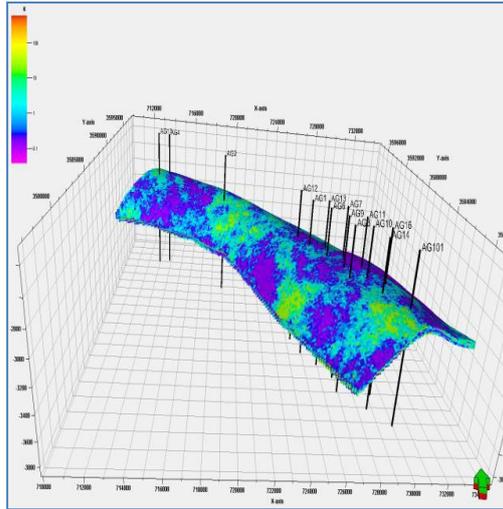Fig. 8, layers of Asmari Fms. in AG field divided by Petrel software
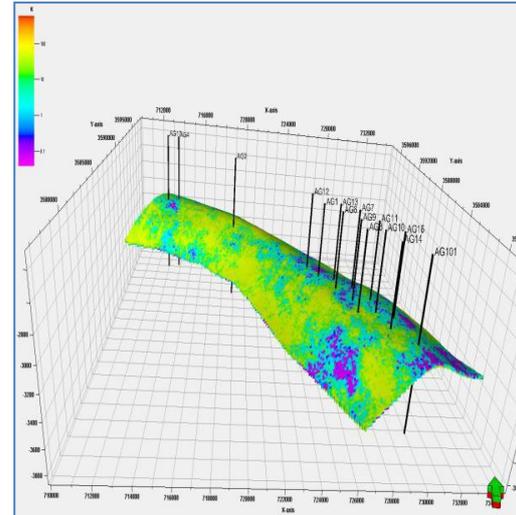
Fig. 9, k distribution in AG field/J-E Fm
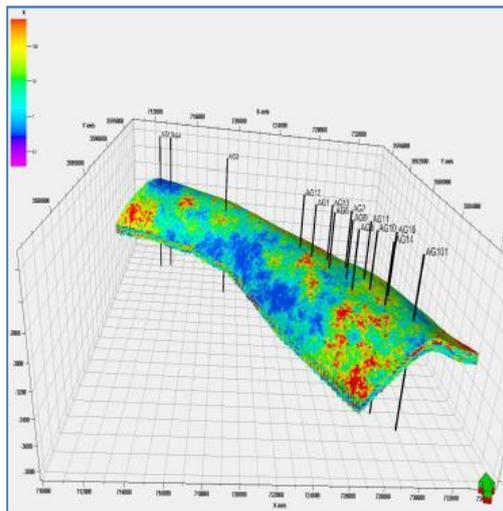


Fig. 10, k distribution in AG field/U.K. Fm



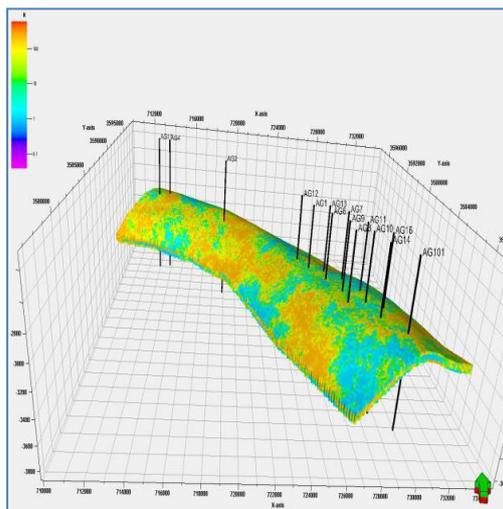Fig. 11, k distribution in AG field/B.M. Fm



Fig. 12 k distribution in AG field/M-L.K. Fm

## Conclusions

Based on the results of this study the following conclusions were obtained:

1. The complex nature of *Asmari* formation has a great effect on permeability and its correlation with porosity.

2. *FZI* method failed to give a good match between calculated permeability and core permeability because of the absence of the information about facies, pore throat, and other features that related with this method.

3. $\rho_{ma}$ *Grouping Method* gave good results and the match between permeability from this method and core permeability was good, and this method is adopted to calculate permeability in un- cored zones.

4. Permeability in general is improving toward the south of *AG* field.

5. The presence of small fissures, fractures, and vugs may increase the permeability in the zones with low porosity especially in *J-E* and upper part of *U.K. Fms.*

reservoir department/Missan Oil Company.

## Nomenclature
$a$=tortuosity factor
$AG$=Abughirab field
$B.M.$ = Buzurgan member
Fm. = Formation
$FZI$=flow zone indicator
$HFU$=hydraulic flow units
$J-E$= Jeribe-Euphrates formation
$k$=core permeability, md
$m$= porosity exponent
$M-L.K.$ = Middle-lower Kirkuk Fm.
$RQI$=resistivity quality index
$R_{tirr}$=resistivity at irreducible water zone
$R_w$=formation water resistivity
$S_{wi}$= irreducible water saturation
$U.K.$ = Upper Kirkuk Fm.
$\rho_h$= hydrocarbon density, gm/cc
$\rho_{ma}$= matrix density, gm/cc
$\tau$= tortuosity of flow path.
$\varphi_e$= effective porosity
$\varphi_z$= ratio of pore volume to matrix volume

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