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Estimation Liquid Permeability Using Air Permeability Laboratory Data

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Abstract
Permeability data has major importance work that should be handled in all reservoir simulation studies. The importance of permeability data increases in mature oil and gas fields due to its sensitivity for the requirements of some specific improved recoveries. However, the industry has a huge source of data of air permeability measurements against little number of liquid permeability values. This is due to the relatively high cost of special core analysis.

The current study suggests a correlation to convert air permeability data that are conventionally measured during laboratory core analysis into liquid permeability. This correlation introduces a feasible estimation in cases of data loose and poorly consolidated formations, or in case of the unavailability of old cores to carry out liquid permeability. Moreover, the conversion formula offers a better use of the large amount of old air permeability data obtained through routine core analysis for the further uses in reservoir and geological modeling studies.

The comparison analysis shows high accuracy and more consistent results over a wide range of permeability values for the suggested conversion formula.

Keywords: Air permeability; Liquid permeability

Introduction
Nowadays, all the reservoir studies that are based on reservoir simulation technique requires a huge source of permeability data, which is always difficult to obtain, and may not be available at all [1]. Therefore, the engineers are forced to assume values of liquid permeability data based on a limited number of core laboratory analysis.

The conversion of air permeability to liquid permeability forms a cost effective method for coring [1].

However, the routine core analysis that is usually performed through the exploratory stage of the field development provides a huge data of air permeability. This analysis may serve for estimating the liquid permeability if using higher degree of correlation. The correlative approach appears to be the best practical method of estimating liquid permeability data [2].

Ideally, those data should be obtained experimentally. Occasionally, these data are not either available or reliable; then, empirically derived correlations are used to predict the liquid rock permeabilities. However, the success of such correlations in prediction depends mainly on the range of data at which they were originally developed.

These data were divided into two groups: the first was used to cross validate the relationship established during the training process and, the second was used to test the model to evaluate their accuracy and trend stability.

The current study tries to fit the relationship between air permeability and liquid permeability for Iraqi reservoirs into a mathematical form to make use of the available air permeability data; in addition to generalize the suggested correlation for a wide range of fields.

Data Acquisition and Analysis

The developed correlation is based on 446 field data sets collected from different wells in Khasib formation of Iraqi oil fields [3], in addition to 12 data sets collected from some fields in Egypt (Nubia C, October, Ramadhan, East Tanka, Hilal, Gebel El-Ziet and Ras-Burdan) [1]. Each data set contains depth, air permeability, liquid permeability, water saturations and porosity. These Iraqi data were divided into two groups. The first one (386 sets) was used to cross-validate the relationship established during the training process and, the second group which consist of (60 sets) were used to test the correlation to evaluate their accuracy and trend stability; in addition to use the other (12) data sets of air permeability that are collected from Egyptian oil fields to conduct the evaluation of the suggested empirical correlation for more validation of generalization.

The range of collected permeability data falls between (0.004 to 409 md) for Iraqi wells which consist of (168 data points less than unity and 276 data points greater than unity) in addition to (12 data points) having liquid permeability range (7 to 3000 md) collected from the Egyptian oil fields; this wide range of the data offers high reliability of the suggested correlation.

Work Development

The work development could be achieved throughout suggesting a conversion formula that is dimensionally pass the physics, gives minimum absolute errors and obey the assumptions reservoir coring analysis; these statement can be summarize as follows.

1- Statistical Error Analysis

Statistical error analysis is performed to compare the performance and accuracy of the new model to the laboratory data. Average absolute percentage relative error, minimum and maximum absolute error, root mean square and standard deviation were used as comparison criteria.

2- Assumption

Although the volume of the cored intervals representing an infinitesimal area when compared to the reservoir itself, it is important to assume that the sample is accurately represent the formation within the drainage area of the well; i.e. the core analysis data provide a true distribution function for the permeability.

3- Conversion Formula

The suggested form of the conversion formula should first maintain the physics before the trails that could be made to find the best fitness. The physics of the conversion formula should involve the formation porosity as major dependable factor effects on both of air and liquid permeabilities.

Moreover, both sides of the suggested formula must obey the dimensional physics. However, this suggestion may provide the reliability for the proposed correlation than that is already used in the literature (Sameh M. Macary-1999) that is ignore the porosity and use only an adjustable constants between the liquid and air permeabilities to fit the conversion formula.

Therefore, the suggested formula can be written using the following form;

$$K_l = A.K_a^B.\varphi^C \qquad \ldots(1)$$

Where; K_a and K_l are the air and liquid permeabilities respectively in millidarcy (md). A, B and C are constants to fit the correlation with the actual data measurements; and φ is the core porosity. Hence, adding the parameter of porosity gives the suggested equation the reliability due its direct effect on permeability [4].

Several ways have been adapted to create the most accurate conversion formula; these ways can be categorized as follows;

1- Deal with all-data points of air permeability variation as one group.
2- Explicit the data points into some groups depending on the range of air permeability.
3- Find relation for (A, B and C) constants as function of air permeability or porosity.

It is found that the last two categories are the best ways that can be used to create the most accurate conversion formula than the first category. Therefore, the experimental air permeability data have been divided into some groups depending on their air permeability data ranges. The trail procedure of regression analysis for the collected trained data points shows that the best value of porosity power (C) which gives the minimum absolute and percentage relative errors for the predicted liquid permeability is (C = 0.09) as shown in figure 1; this value has been obtained throughout extensive trails to gather all liquid permeability data along the 45 degree slope line that is indicating the perfect agreement between the experimental and estimated liquid permeability data.

While, it is found that further fitness can be achieved which offers the highest degree of accuracy and consistency can be taken (A = 0.73) for air permeability values less than (1 md) and (A = 1.002) for air permeability values greater than (1 md). Meanwhile, the constant (B) is fixed to unity in order to fix the dimensional units of the suggested formula and to ensure its reliability for a wide range of permeability data.

Thus, equation 1 can be rewritten as follows.

$$K_l = A.K_a.\varphi^{0.09} \qquad \ldots(2)$$

Where (A = 0.73) for air permeability values less than unity, and (A = 1.002) for air permeability values greater than unity. The values of (A) gives the best corrections for the slippage and inertial effect that is most significant in low permeability cores [5].

Equation 2 represents the most accurate conversion formula to convert air permeability data to liquid permeability.

Finally, it could be stated that other trails have been made to relate (A and B) parameters to be a function of either air permeability or porosity that keeps the exact fitness between estimated and experimental data for any range of permeability. These trails show no reliable dependence for (A and B) parameters to be a function of either air permeability or porosity. Therefore, the suggested model represented by Eq. 2 can be considered the best conversion formula to estimate the liquid permeability using that of air laboratory data.

Results and Discussion

Figures 2 and 3 were obtained for air permeability data less and greater than unity respectively, illustrate scatter diagrams of the predicted versus laboratory data. These cross plots indicates the degree of agreement between the laboratory and predicted values. If the agreement is perfect, then all points should lie on the 45 degree line on the plot. These cross plots show tightest cloud of points around the 45 degree line indicating the high reliability and accuracy of the suggested conversion formula to estimate the liquid permeabilities using air permeability laboratory data.

The deviation from the 45 degree straight line did not exceed (0.5 %) between estimated and experimental data of liquid permeabilities.

Moreover, figures 4, 5, 6, 7 and 8 drawn between air and liquid permeabilities for each well individually. While, figure 9 drawn for all data points collected from all wells and shows the maximum deviation from the 45 degree straight line did not exceed (2.3 %) between estimated and experimental data of liquid permeabilities.

In order to check the validity and the accuracy of the conversion formula, the liquid permeabilities measured for the 60 core samples collected from different Iraqi wells and that of 12 core samples collected from Egyptian oil reservoirs were compared with calculated values generated by equation 2. Hence, figures 10 and 11 show the tests that have been made for samples representing wide range of permeability variation (not enter to train the model) show also the extremely high results provided by the suggested model. While, the tests performed for the samples collected from different Egyptian fields show also the acceptable results compared with that experientially obtained liquid permeability data.

These tests have also been stated in tables 1 and 2 to show the absolute and percentage relative errors for these samples. These tables show the existence of somewhat higher percentage absolute errors (5-30%) in samples No. 3, 14, 37 and 38; however, this variance occur only in some very low permeability samples; since, the absolute percentage errors occurs will also be very low and may not have a significant effect on such low permeability samples. However, figure 12 shows the clear behavior between the calculated and experimental laboratory data for all of the tested core samples.

This may assist to support the high reliability and consistency of the suggested model for estimating liquid permeability using the laboratory air permeability data.

Conclusions

The suggested conversion formula can be used to estimate the liquid core permeability using air permeability core data that is part of routine core analysis in reservoir simulation studies. This formula may give a cost effective method for coring.

References

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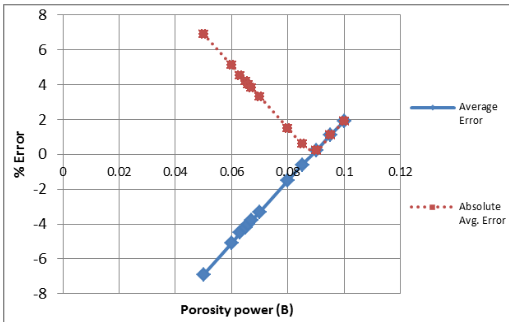

Fig. 1, Percentage Error against porosity power (B) between Estimated and experemental Liquid Permeability data

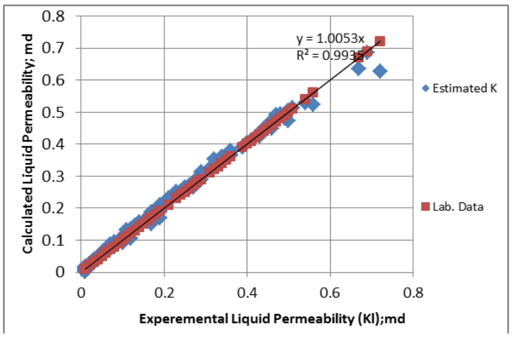

Fig. 2, Experimental versus Estimated liquid permeability (156 Samples)

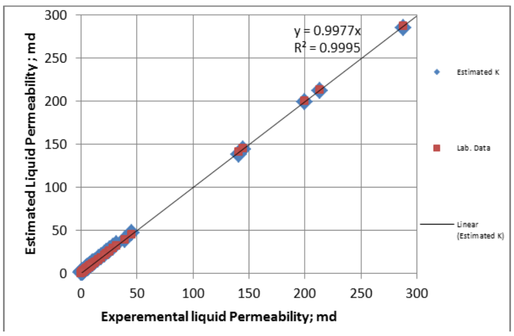

Fig. 3, Experimental versus Estimated liquid Permeability (230 data point)

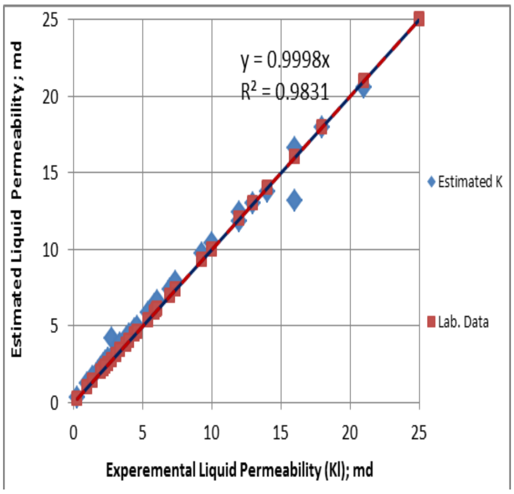

Fig. 4, Experemental versus Estimated Liquid Permeability-well AD/2, (52 points)

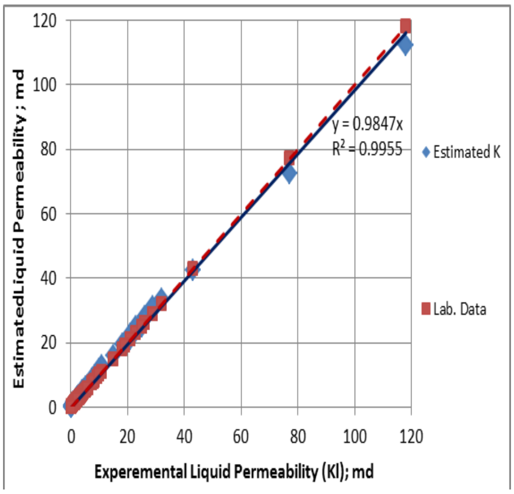

Fig. 5, Experemental versus Estimated Liquid permeability - well AD/3), (110 points)

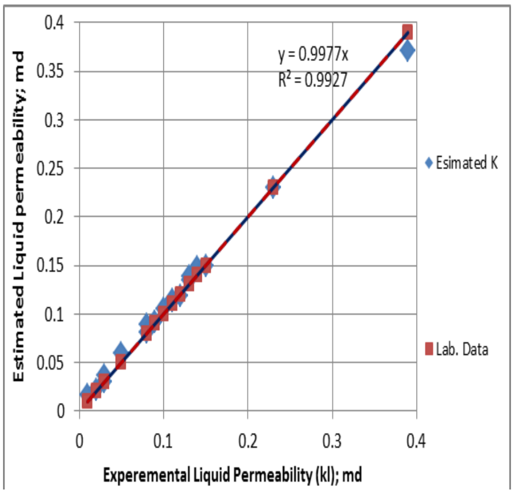

Fig. 6, Experemental versus Estimated Liquid permeability-Well AD/5, (39 points)

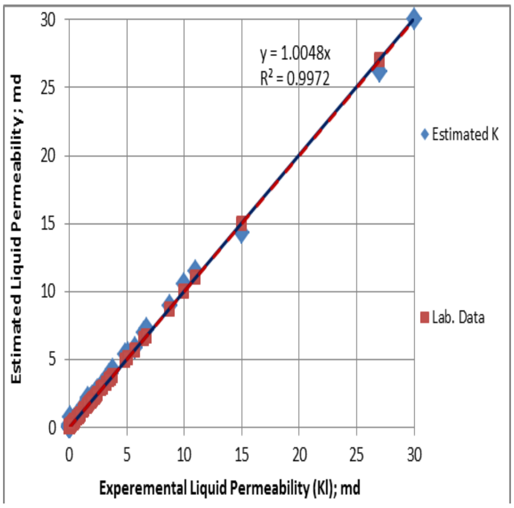

Fig. 7, Experemental versus Estimated Liquid permeability -well AD/6, (114 points)

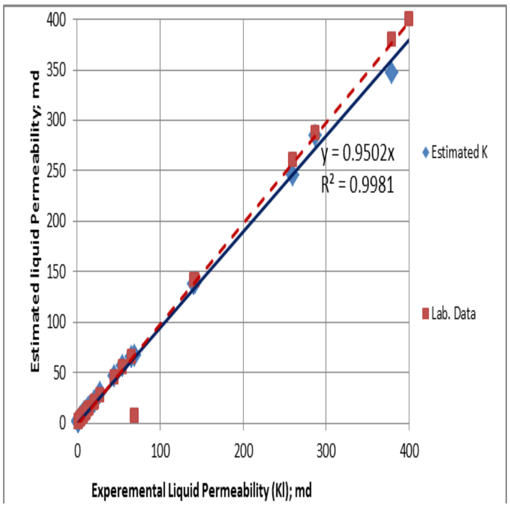

Fig. 10, Experemental versus Estimated Liquid permeability-wells AD/2,3,5,6,7; (60 points)

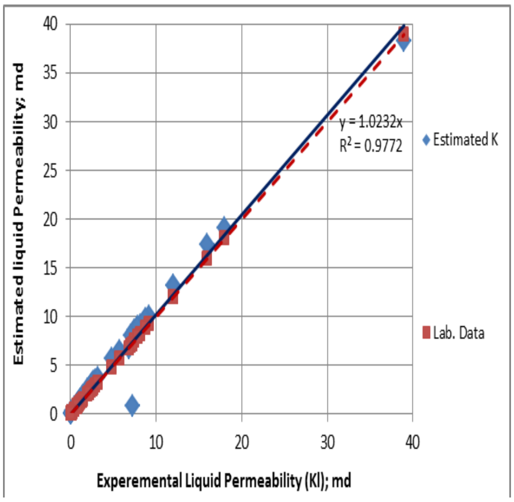

Fig. 8, Experemental versus Estimated Liquid permeability-well AD/7, (71 points)

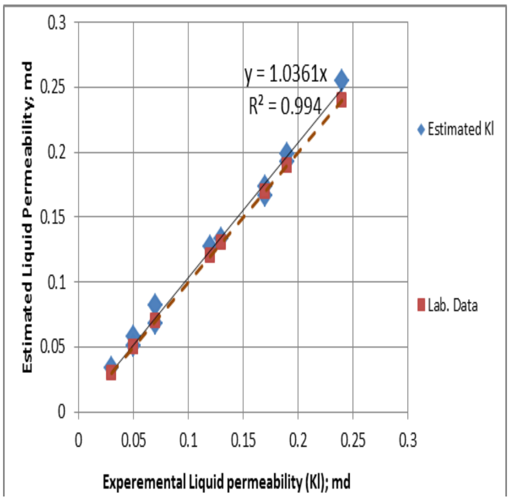

Fig. 11, Experemental versus Estimated Liquid permeability data (12 data points)

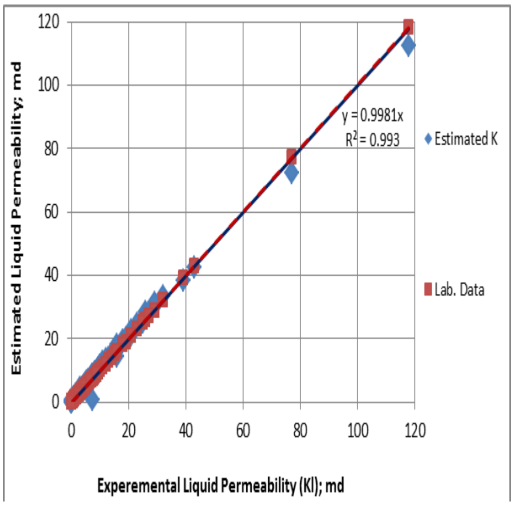

Fig. 9, Experemental versus Estimated Liquid permeability-Wells AD/2,3,5,6,7- (386 points)

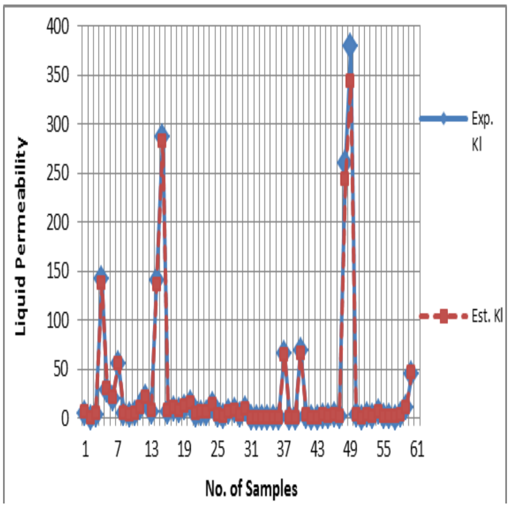

Fig. 12, The agreement between the calculated and experemental liquid permeability

Table 1, Comparison between laboratory and calculated liquid permeability data shows the percentage absolute relative errors and the absolute errors for Iraq Field

Measured. K_a md	∅	Lab. (Kl)-md;	Calculated (Kl); md	Percent Relative Error	Absolute Error
6.9	0.238	5.2	5.116554	1.630903	0.083446
5.1	0.189	3.8	3.621115	4.940042	0.178885
158	0.226	142	147.4854	3.719274	5.485386
34	0.233	28	28.36121	1.2736	0.361208
23.7	0.247	20	19.34283	3.397476	0.657168
64.2	0.2	55	55.40076	0.723382	0.400759
6	0.283	4.5	4.471943	0.627407	0.028057
4.4	0.255	3.3	3.174118	3.965881	0.125882
5.6	0.242	4.2	4.094194	2.584304	0.105806
12.8	0.184	10	9.714203	2.942051	0.285797
25	0.188	21	19.98861	5.059836	1.011391
8.4	0.209	6.5	6.247931	4.034431	0.252069
157	0.213	141	145.7032	3.227945	4.70322
317	0.271	287.5	317.5496	9.462975	30.04964
8.6	0.235	6.6	6.47597	1.91524	0.12403
11.6	0.265	9	9.030407	0.336719	0.030407
9.3	0.302	7.2	7.205144	0.071391	0.005144
13.6	0.226	11	10.56202	4.146754	0.437981
18	0.233	15	14.31538	4.78242	0.684621
4.7	0.241	3.5	3.390077	3.242486	0.109923
7	0.208	5.3	5.133682	3.239743	0.166318
6.4	0.244	4.8	4.729676	1.486861	0.070324
16.3	0.215	13	12.74923	1.966946	0.25077
4	0.226	2.9	2.834047	2.327152	0.065953
2.3	0.219	1.6	1.558907	2.636002	0.041093
8.8	0.072	6.8	5.967627	13.94814	0.832373
9.7	0.06	7.5	6.518326	15.06021	0.981674
4.4	0.269	3.3	3.189424	3.466974	0.110576
11.3	0.203	8.8	8.5715	2.665811	0.2285
75.8	0.181	66	65.63845	0.550818	0.361548
77.3	0.166	69	66.51591	3.734579	2.484089
3.10	0.145	2.2	2.074016	6.074374	0.125984
3.1	0.218	2.2	2.147819	2.429468	0.052181
2.62	0.212	1.9	1.787998	6.264114	0.112002
4.54	0.221	3.3	3.240807	1.826481	0.059193
2.53	0.198	1.8	1.711502	5.17081	0.088498
280	0.208	260.2	271.0047	3.9869	10.80469
409	0.14	379.2	392.9209	3.492037	13.72095
4.24	0.233	3.1	3.025542	2.46098	0.074458
3.8	0.102	2.8	2.496688	12.14858	0.303312
2.84	0.165	2	1.906398	4.909874	0.093602
7.92	0.23	6.1	5.915724	3.115013	0.184276
1.69	0.167	1.2	1.092309	9.859014	0.107691
1.95	0.214	1.4	1.302709	7.468387	0.097291
1.51	0.246	1	1.002091	0.208681	0.002091
3.95	0.215	2.9	2.783455	4.187064	0.116545
12.6	0.224	10.9	9.721729	12.11997	1.178271
53.1	0.21	45	45.37318	0.822466	0.373179
0.4	0.221	0.24	0.241236	0.51486	0.001236
0.31	0.235	0.19	0.184448	2.921893	0.005552
0.27	0.240	0.17	0.15933	6.276623	0.01067
0.21	0.211	0.13	0.120208	7.532528	0.009792
0.09	0.195	0.05	0.049137	1.726427	0.000863
0.13	0.201	0.07	0.071464	2.091159	0.001464
0.11	0.118	0.07	0.058581	16.31215	0.011419
0.20	0.213	0.12	0.114742	4.381836	0.005258
0.06	0.041	0.03	0.027939	6.871614	0.002061
0.31	0.171	0.19	0.179232	5.667447	0.010768
0.27	0.155	0.17	0.153136	9.919934	0.016864
0.09	0.065	0.05	0.043471	13.057	0.006529
Average Percentage Error					5.00 %

Table 2, Comparison between laboratory and calculated liquid permeability data shows the percentage absolute relative errors and the absolute errors for Egypt Field

Measured. K_a (md)	Ø	Lab. (Kl)-md;	Calculated (Kl); md	Percent Relative Error	Absolute Error
1275.9	0.189	1150.73	1100.499	4.3653	50.2334
160.00	0.185	122.714	137.6908	12.204	14.976
408.43	0.153	337.728	345.625	2.338	7.89619
48.72	0.166	34.1326	41.5305	21.674	7.39782
52.273	0.174	36.8030	44.7488	21.59	7.94586
1950.7	0.166	1821.34	1662.891	8.7	158.456
2497.4	0.152	2379.81	2112.149	11.2474	267.668
1147.0	0.168	1027.14	978.8515	4.7016	48.2917
1169.2	0.21	1046.08	1018.049	2.6805	28.0399
146.24	0.189	111.396	126.1341	13.23	14.7378
391.34	0.176	322.041	335.370	4.139	13.3287
309.07	0.183	249.605	265.8004	6.488	16.1952
Average Percentage Error					4.16 %