LJAST
Libyan Journal of Applied Science and Technology
مجلة ليبيا للعلوم التطبيقية والتقنية

Volume 11 Issue 01
June 2023
ISSN 2958-6119

An Estimating The Relationship Between Two Types Of Permeability Using Core Data

Khaled Taleb
Faculty of Engineering, Gharyan University
khaled.taleb@gu.edu.ly

ABSTRACT

The ratio of vertical and horizontal permeability is important when reservoir anisotropy (Kv/Kh) and heterogeneity cannot be neglected. Therefore, an accurate knowledge of vertical and lateral permeability distribution is essential for better reservoir characterization. we use routine core data for analysis to develop new correlations and characterization of a sandstone reservoir under development, also use core data to:

(1) develop correlations capable of predicting vertical permeability from horizontal permeability or mean hydraulic radius .

(2) develop another correlation capable of predicting the permeability anisotropy ratio (Kv/Kh) using effective porosity data.

To accomplish the objectives of this project, various petrophysical properties were experimentally measured for 100 core samples extracted from an actual sandstone reservoir. The measurements included vertical permeability, horizontal perme-ability, effective porosity and saturations of oil and water.

Keywords: porosity , vertical permeability, horizontal permeability

1 . INTRODUCTION AND LITERATURE REVIEW

In early studies of reservoir engineering, the reservoirs are assumed to be homogeneous, isotropic and uniform. Absolute rock permeability (K) is defined as the ability of the rock to transmit fluid(s). Horizontal permeability (Kh) is parallel to bedding plan and is generally greater than vertical (Kv). Low vertical permeability creates a larger pressure drop near Vertical permeability is essential in reservoir management and development such as, the optimal well locations and production rate, horizontal well applications, completion optimization and perforation design, and planning EOR injectors/producers.[1,2]

The ratio of vertical to horizontal permeability (Kv/Kh) represents the contrast in permeability between the vertical and horizontal planes within a formation (called anisotropic permeability). This ratio is important in reservoir simulation studies, because it is applicable in vertical wells and more important in partially penetrated or horizontal wells. In layered reservoirs, the vertical permeability of each layer is quite different from the surrounding layers. Therefore, these type of reservoirs are divided into layers based on the Clark (1969) indicated that the horizontal permeability (*K*h) would be higher than the vertical one for large and flat rock grains. He concluded that generally, vertical permeability is lower than horizontal permeability, especially, if the sand grains are small and have irregular shape. Majority of petroleum reservoirs are in this category

Prediction of permeability accurately enough from core and well logs have been achieved by several authors (Tiab 1993; Amaefule et al. 1993; Elkewidy 1996; Shedid Elga-ghah 1997). They proposed methods for integrating core and log data for formation evaluation in term of flow units.

To have a better reservoir description, we should consider the vertical variation of hydraulic properties. Osisanya et al. (1998) developed new permeability porosity correlations but without consideration of anisotropic conditions of the reservoirs.

Iheanacho et al. (2012) developed several correlations of vertical and horizontal permeability for sandstone and shaly sandstones reservoirs and made a general conclusion that vertical permeability decreases with depth. Fazelalav (2013) developed several correlations for prediction of vertical permeability for Arbuckle formation as shown in Table 1. However, these correlations suffer from poor correlating coefficients.

Correlations listed in Table 1 below indicates that vertical permeability may increase or decrease, but it does not have a general trend. Majority of other studies had confirmed a general conclusion that vertical permeability decreases with depth .[2,3,6]

The main objective of this work is to develop semi-empirical correlations between vertical permeability and horizontal permeability for the reservoirs. Actual core data are gathered and analyzed from the reservoir to achieve this goal.

The factors affecting rock permeability have been recognized to include the size, form, and shape of grains constituting the reservoir rocks. Therefore, it is important to develop a relationship between microscopic level attributes and microscopic core data based on the concept of hydraulic mean radius. This is because the hydraulic mean radius considers variations in permeability and porosity as it is defined to be equal to $\sqrt{K/\Phi}$

Recalling the modified Kozeny–Carman equation

$$K = \left(\frac{\varphi_e^3}{(1-\varphi_e)^2}\right) \times \left[\frac{1}{F_s \tau^2 S_{gr}^2}\right]$$

Correlations listed in Table 1 indicates that vertical permeability may increase or decrease, but it does not have a general trend. Majority of other studies had confirmed a general conclusion that vertical permeability decreases with depth.[5,6,7]

Table 1 Developed vertical permeability correlations for Arbuckle formation.[8,9,10]

#	Correlation	Correlating coefficient	number Of cores	Application condition and core observation
1	Kv = 0.1871 Kh	$R^2 = 0.5367$	216	Rock without fractures
2	Kv = 0.1871 Kh	$R^2 = 0.5367$	97	For Kv is less than Kh
3	Kv = 2.4484 Kh	$R^2 = 0.6916$	60	For Kv is bigger than Kh
4	Kv = 82.624 Kh	$R^2 = 0.9906$	18	For Kv is much bigger than Kh due to extremely vertical fractures

2 . Field case study

The Aswad field is located in the concession area NC74B, in the extreme southwest of the Sirte Basin. The discovery well, B1, was drilled by El Wearth in 1961.The discovery was appraised by drilling three further wells (B2, B3&B4). The results of this appraisal drilling indicated the accumulation to be uneconomic at the time & the field was abandoned.

In 1977, Occidental of Libya began development of the Aswad field. Development of the Aswad accumulation was completed by drilling a further 14 wells (B5 to B18) & B19 was drilled by Zueitina. The field was put on production in October 1978. A total of 19 wells have been drilled in the structure. Currently there are 5 active producers, all installed with ESP's. One producer, B1, has been shut in since early 1996 due to encountered mechanical problems and poor well conditions.

Table 2 presents data of only 100 samples for every 5 ft. of the cored zone and used in plots of this project.

The attained data of horizontal and vertical permeability is plotted versus depth in Fig. 3 and Fig 4 It shows a wide range of variation and a general decrease mode in vertical permeability with depth

Volume 11 Issue 01
June 2023
ISSN 2958-6119

Table 2 Routine core analysis (RCA) data for 50 core samples from 100 core data used

Core #	Depth (ft)	Perm-H [Kh (md)]	PermV [Kv (md)]	(Kv/Kh)	Sw (%)	Porosity, ϕ (%)
1	3500	102	15	0.147	19	21
2	3505	91	34	0.373	19	20
3	3510	100	4	0.04	15	14
4	3515	125	88	0.704	15	13
5	3520	35.3	12	0.339	12.5	12
6	3525	49.8	11	0.220	14	12
7	3530	54	33	0.611	13.8	18
8	3535	1532	201	0.131	18.1	17
9	3540	1600	921	0.575	17.8	17
10	3545	1112	802	0.721	16.2	11
11	3550	23	11	0.343	17.0	12
12	3555	71	54	0.760	18.2	19
13	3560	99	62	0.626	15.3	19
14	3565	85	84	0.988	16.1	14
15	3570	78	60	0.769	18.0	9
16	3575	34	20	0.588	19.2	15
17	3580	56	41	0.732	19.0	15
18	3585	120	43	0.358	18.8	17
19	3590	124	34	0.274	18.0	20
20	3595	995	512	0.514	17.02	21

21	3600	742	622	0.838	17.1	21
22	3605	65	57	0.876	17.1	14
23	3610	852	231	0.271	17.6	15
24	3615	454	300	0.660	15.4	14
25	3620	21	10	0.476	15.6	17
26	3625	14	8	0.571	15.0	19
27	3630	31	14	0.451	19.9	12
28	3635	36	23	0.638	19.1	15
29	3640	95	41	0.431	19.2	14
30	3645	47	35	0.744	18.4	14
31	3650	41	14	0.341	18.7	16
32	3655	877	126	0.143	18.3	09
33	3660	765	401	0.524	18.1	09
34	3665	951	436	0.458	19.0	10
35	3670	0.21	0.08	0.380	19.7	14
36	3675	50	31	0.62	19.6	15
37	3680	55	28	0.509	19.6	14
38	3685	255	102	0.4	19.07	14
39	3690	245	101	0.412	18.7	17
40	3695	211	180	0.853	18.0	17
41	3700	474	258	0.544	15.0	12
42	3705	501	314	0.626	15.6	15
43	3710	30	22	0.733	15.6	14
44	3715	23	21	0.913	12.9	14

45	3720	145	100	0.689	13.2	18
46	3725	111	100	0.900	14.0	23
47	3730	94	34	0.361	14.5	23
48	3735	81	24	0.296	14.4	20
49	3740	55	15	0.272	14.4	14
50	3745	33	17	0.515	14.1	11

Table 3 Routine core analysis (RCA) data for 50 core samples from 100 core data used

Core #	Depth (ft)	Perm-H [Kh (md)]	Perm-V [Kv (md)]	(Kv/Kh)	Sw (%)	Porosity, ϕ (%)
51	3750	50	13	0.26	14.0	14
52	3755	765	254	0.332	14.1	14
53	3760	782	280	0.358	14.0	17
54	3765	799	231	0.289	15.3	20
55	3770	353	211	0.597	15.3	11
56	3775	40	17	0.425	15.8	15
57	3780	47	31	0.659	15.4	21
58	3785	19	10	0.526	15.2	17
59	3790	22	9	0.409	15.2	17
60	3795	87	40	0.459	15.8	18
61	3800	120	78	0.650	17.9	21
62	3805	222	201	0.905	17.8	14
63	3810	201	164	0.815	17.5	14
64	3815	578	236	0.408	17.6	16
65	3820	598	287	0.479	15.1	20

66	3825	511	323	0.632	15.9	21
67	3830	12	03	0.25	16.2	15
68	3835	0.1	0.04	0.4	16.2	15
69	3840	0.9	0.1	0.111	15.8	14
70	3845	114	14	0.122	17.0	15
71	3850	89	16	0.179	20.0	20
72	3855	2131	1245	0.584	20.2	24
73	3860	2000	751	0.375	20.8	14
74	3865	2155	862	0.400	20.1	14
75	3870	17	13	0.764	20.1	17
76	3875	54	23	0.425	20.1	14
77	3880	98	35	0.357	19.5	16
78	3885	74	26	0.351	19.5	16
79	3890	71	41	0.577	19.4	12
80	3895	351	100	0.284	19.4	14
81	3900	366	142	0.387	19.2	17
82	3905	787	321	0.407	19.0	12
83	3910	731	511	0.699	19.0	12
84	3915	795	251	0.315	19.0	14
85	3920	357	147	0.411	19.0	15
86	3925	369	211	0.571	19.5	12
87	3930	321	170	0.529	19.8	12
88	3935	17	05	0.294	19.7	14
89	3940	23	04	0.173	19.7	14
90	3945	41	11	0.268	18.0	16
91	3950	49	15	0.306	18.1	16
92	3955	487	66	0.135	18.3	18
93	3960	456	301	0.660	18.3	18

94	3965	101	74	0.732	19.8	20
95	3970	52	18	0.346	18.9	21
96	3975	0.14	0.11	0.785	18.7	23
97	3980	0.20	0.12	0.6	17.2	14
98	3985	0.89	0.02	0.022	17.9	14
99	3990	0.31	0.14	0.451	17.5	10
100	3995	0.11	.07	0.636	19.01	10

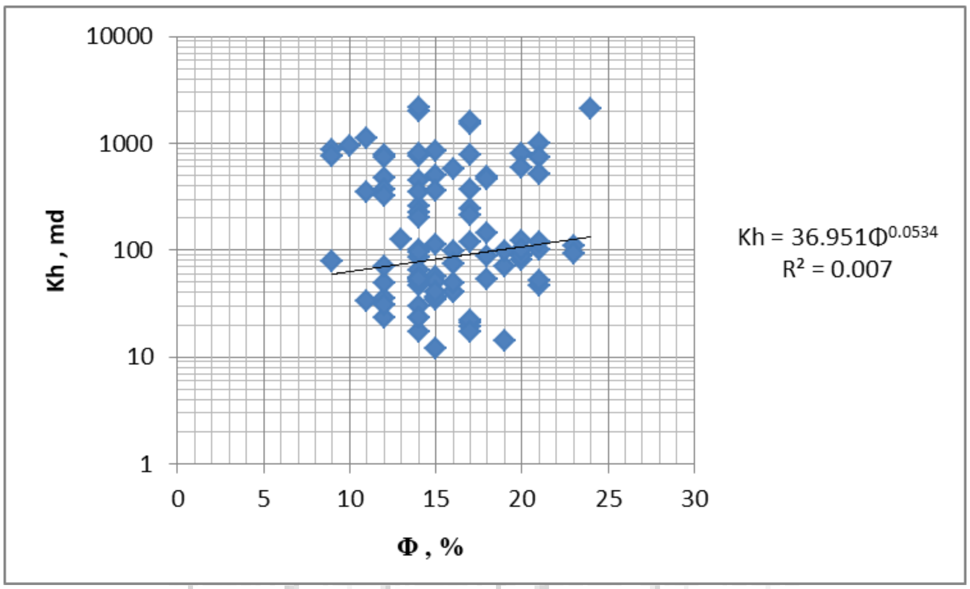

Fig. 1 Horizontal permeability and porosity relationship

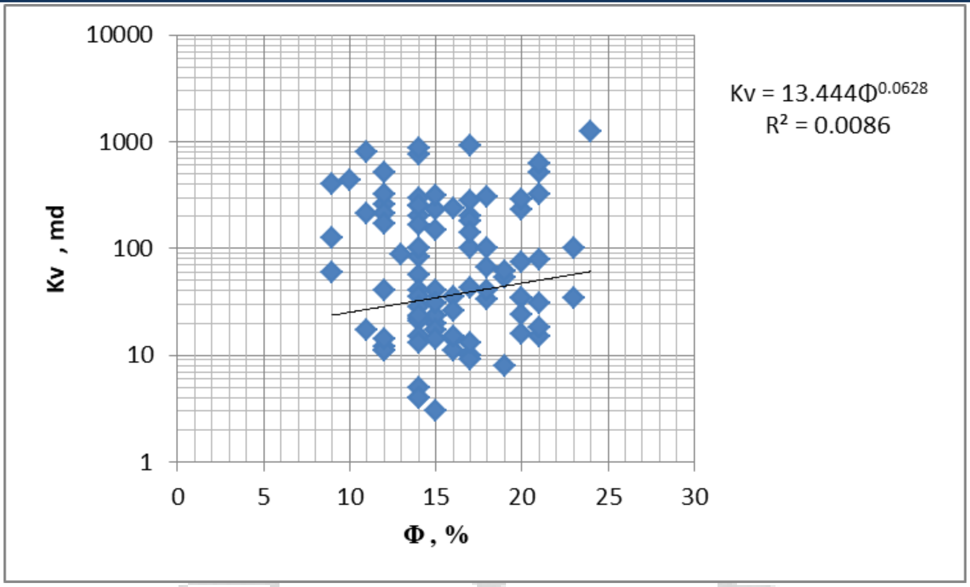

Fig. 2 Vertical permeability and porosity relationship

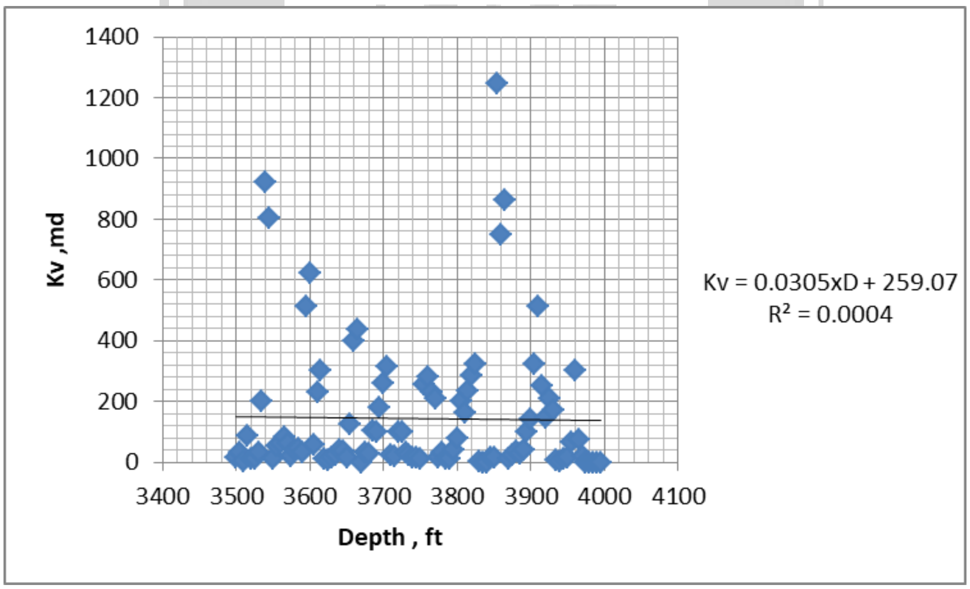

Fig. 3 Variation of vertical permeability with depth

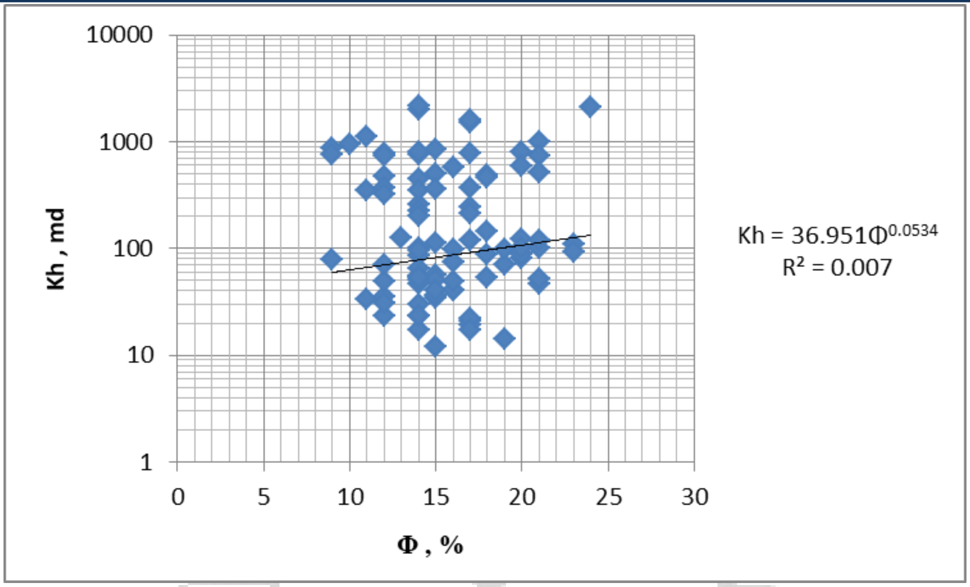

Fig. 4 Variation of horizontal permeability with porosity

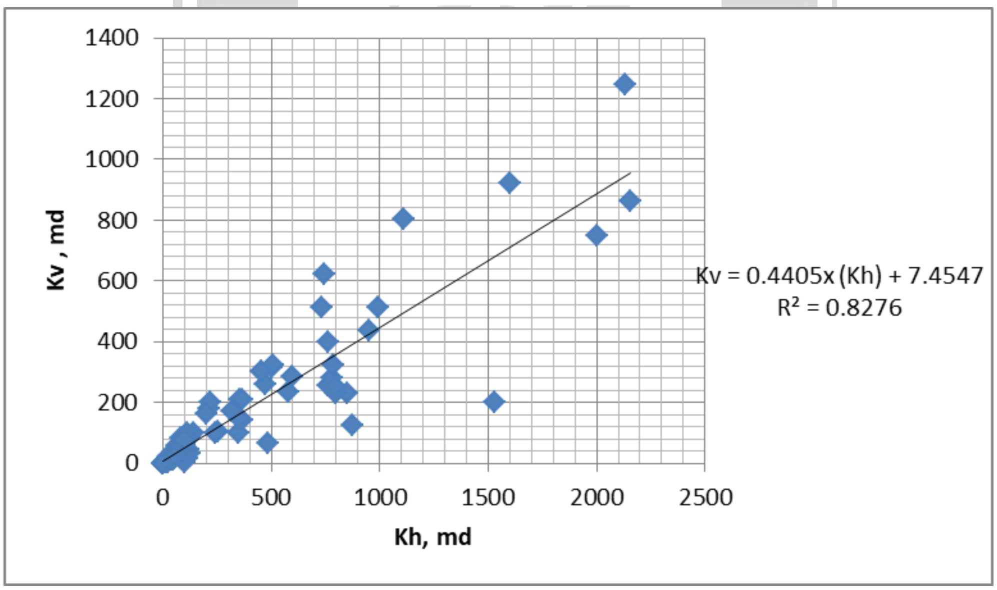

Fig. 5 Newly developed vertical–horizontal permeability relationship

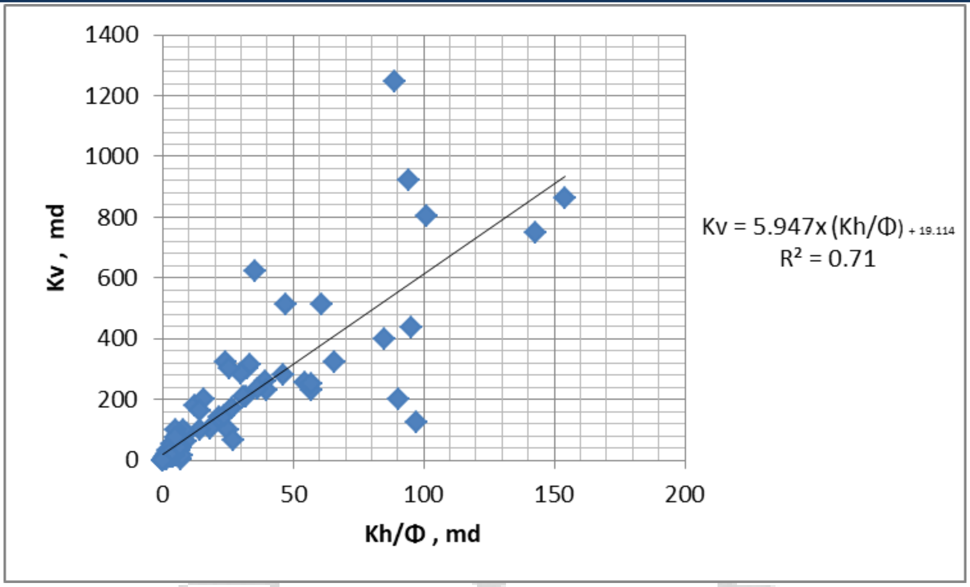

Fig. 6 A plot of vertical perm versus mean hydraulic radius

3 . RESULTS AND DISCUSSION

Using all data points of 100 cores and plotting of horizontal permeability versus porosity is presented in Fig. 1 and a correlation is developed using curve fitting as shown below,

$$K_h = 36.935 \times \Phi^{0.0534} \quad , \quad R^2 = 0.007$$

Additionally, a plot of vertical permeability versus porosity is shown in Fig. 2. This core data is used to develop the following empirical

correlation:

$$K_v = 13.444 \times \Phi^{0.0628} \quad , \quad R^2 = 0.0086$$

A plot of vertical permeability versus a horizontal one using 100 core data is shown in Fig. 5 and yields the following new equation for predicting vertical permeability;

$$K_v = 0.4405 \times (K_h) + 7.4547 \quad , \quad R^2 = 0.8276$$

This equation represents a good tool for predicting vertical permeability with a good correlating coefficient ($R^2 = 0.8276$).

For the purpose of correlating the vertical permeability to the hydraulic mean radius, the same data points were plotted in Fig. 6. Applying the curving fitting technique provides the following correlation below,

$$K_v = 5.947 \times [K_h/\Phi]^{19.114} \quad , \quad R^2 = 0.71$$

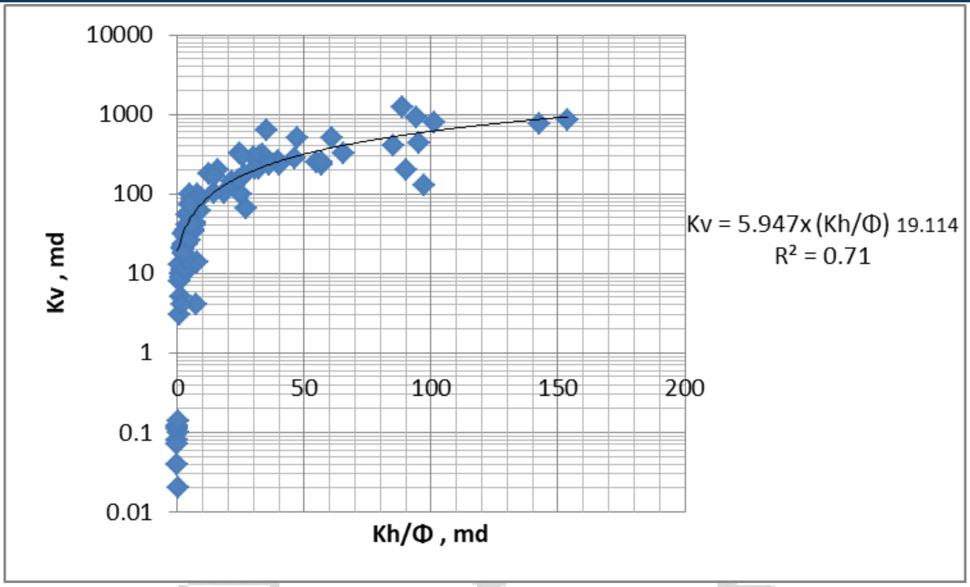

Fig. 7 Log–log plot of vertical permeability versus mean hydraulic radius

where Kv and Kh are vertical and horizontal permeability (md), respectively, and Φ is the effective porosity (fraction).

A log–log plot of vertical permeability versus mean hydraulic radius is presented in Fig. 7 with a good correlating coefficient of 0.71 .

4 . CONCLUSIONS

1. A correlation between permeability ratio and porosity is developed and can be used to predict the anisotropic ratio from porosity core data.
2. New correlations were developed as tools capable of predicting vertical permeability from porosity, horizontal permeability and/or from mean hydraulic radius.
3. The developed correlations represent useful tools for better studying reservoir management such as optimal well location, simulation studies and a better description of the reservoir.
4. Core data were gathered and used for the analysis and correlation of vertical permeability with horizontal permeability.

5. REFERENCES

1. Clark NJ (1969) Elements of petroleum reservoirs, (revised ed). Soc. Pet; Eng., Dallas, Henry L. Dohery series, pp 19–30
2. Tiab D (1993) Modern core analysis, vol 1-theory. Core Laboratories,Houston

3. Zahaf K, Tiab D (2002) Vertical permeability from in situ horizontal measurements in shaly-sand reservoirs. J Can Pet Technol.

4. Elkewidy TI (1996) Characterization of hydraulic flow units in heterogeneous clastic and carbonate reservoirs. In: PhD School of Petroleum and Geological Engineering, The University of Oklahoma, Norman

5. Shedid- Elgaghah SA (1997) Influence of stress on the petrophysical properties in clean and shaly heterogeneous formation. In: PhD School of Petroleum and Geological Engineering. The University of Oklahoma, Norman

6. Osisanya SO, Tiab D, Elgaghah SA (1998) In situ permeability-porosity relationship in clean formations. In: Annual technical meeting, 8–10 June, Alberta Petroleum Society of Canada, Calgary

7. Iheanacho P, Tiab D, Igbokoyi AO (2012) Vertical–horizontal permeability relationships for sandstone reservoirs, SPE paper 163011. In: Nigeria annual international conference and exhibition, 6–8 Aug 2012

8. Fazelalav M (2013) The relation between vertical and horizontal permeability, Arbuckle formation, Wellington field, Kansas geological survey, open-file report, June 2013

9. M. A. Mahmod , M .A .A l Marhoun, Calculation for fluid physical property prediction. Journal of Petroleum Science and Engineering 23,1996

10. Kartoatmodjo,F.,Schmidt,Z, Iranian Journal of Oil & Gas Vol.3(1994)

11. Naseri, A.,Nikazar,M.,Mousavi, Anumarical technique for an accurate determination of formation resistivity using FR – RO Overlays method "Arab J Geosic(2015)