New Correlation To Calculate Absolute Permeability From Gas Permeameter

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Abstract

In this study, two correlations are developed to calculate absolute rocks permeability from core samples tested by Gas Permeameter Apparatus. The first correlation can be applied if $K_g \leq 100$, the second correlation can be applied if $K_g > 100$. Sixty core samples having different permeabilities to give a wide range of values that necessary to achieve a correlation.

The developed correlation is easily applied and a quick method to avoid repeating the test at different pressure values. Only one pressure test is required to reach absolute permeability which is equivalent liquid permeability.

The final results show, after comparison between the values of permeability from the correlations and the value of absolute permeability by liquid permeameter, good agreement between the values.

علاقة جديدة لحساب النفاذية المطلقة باستعمال جهاز نفاذية الغاز

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الخلاصة:

تم في هذه الدراسة تطوير علاقتي ترابط لحساب النفاذية المطلقة للصخور من العينات التي يتم فحصها بجهاز قياس النفاذية باستخدام الغاز. العلاقة الأولى يمكن تطبيقها إذا كانت النفاذية للغاز ≤100 ، العلاقة الثانية يمكن تطبقها اذا كانت النفاذية للغاز >100 . تم إعداد 60 عينة صخرية مختلفة النفاذيات لتغطية مدى واسع من القيم اللازمة لعمل العلاقتان .

إن العلاقتين المطورة سهلة التطبيق وتعتبر طريقة سريعة تجنبنا لتكرار الفحص لمختلف الضغوط والاكتفاء بالفحص عند ضغط واحد ونتمكن من خلالها إلى التوصل لقيمة النفاذية المطلقة المكافئة لنفاذية السائل.

وقد أظهرت النتائج النهائية بعد اجراء المقارنة بين النفاذية المستخرجة من العلاقتين مع قيم النفاذية المطلقة المستخرجة من جهاز قياس النفاذية باستخدام السائل وجود تطابق كبير بين القيم.

Introduction

Laboratory measurement of permeability usually uses air as the flowing fluid and thus the value obtained is permeability to air (Kair).
Cole, frank (1969) said dry gas is usually used (air, N_2, He) in permeability determination because of its convenience, availability, and to minimize fluid-rock reaction.
The low pressure air permeability of core often differs from its permeability to liquid by 30 to 100 percent due to the Klinkenberg effect. These errors are avoided if the permeability to gas was measured at two or three pressures and plotted against the reciprocal of the mean pressure, and then extrapolating to infinite pressure to obtain the equivalent liquid permeability. This method is generally reliable, but has two drawbacks- it requires tedious measurements, and requires longer time to reach steady state.
New correlation is developed to calculate equivalent liquid permeability from a single run on core sample by Ruska Gas Permeameter.

THEORY OF OPERATION

The measurement of the permeability should be restricted to the low (laminar/viscous) flow rate region, where the pressure remains proportional to flow rate within the experimental error. For high flow rates, Darcy's equation as expressed by equation (1) is inappropriate to describe the relationship of flow rate and pressure drop. [Ali Hussein 1988]

$$q = \frac{KA(p_1 - p_2)}{\mu L} \qquad (1)$$

In using dry gas in measuring the permeability, the gas volumetric flow rate q varies with pressure because the gas is a highly compressible fluid. Therefore, the value of q at the average pressure in the core must be used in equation (1). Assuming the used gases follow the ideal gas behavior (at low pressures), the following equation (2) is applied:

$$K(Darcy) = \frac{Q_{av}\mu L}{A(p_2 - p_1)} \qquad (2)$$

KLINKENBERG EFFECT

Klinkenberg (1941) discovered that permeability measurements made with air showed different results from permeability measurements made with a liquid. The permeability of a core sample measured by flowing air is always greater than the permeability obtained when a liquid is the flowing fluid. Klinkenberg postulated, on the basis of his laboratory experiments, that the gases exhibited slippage at the sand grain surface.
The magnitude of the Klinkenberg effect varies with the core permeability and the type of the gas used in the experiment as shown in figure (1). The resulting straight-line relationship can be expressed as: [Klinkenberg (1941)]

$$k_g = k_L + c\left[\frac{1}{p_m}\right] \qquad (3)$$

Where:
K_g=measured gas permeability
P_m=mean pressure
K_L=equivalent liquid permeability, i.e., absolute permeability, K
C=slope of the line
Klinkenberg expressed the slope C by the following relationship:

$$C = bk_L \qquad (4)$$

b=constant that depends on the size of the pore openings and is inversely proportional to radius of capillary.
Jones (1972) studied the gas slip phenomena for a group of cores for which porosity, liquid permeability k_L and air permeability were determined. He correlated the parameter b with the liquid permeability by the following expression:

$$b = 6.9\ k_L{-0.36} \qquad (5)$$

Equations 3, 4 and 5 can be combined and arranged to give:

$$6.9K_L^{0.64} + p_m K_L - p_m K_g = 0$$

Equation (6) can be used to calculate the absolute permeability when only one gas permeability measurement (k_g) of a core sample is made at p_m. This nonlinear equation can be solved iteratively by using the Newton- Raphson iterative methods.

Experimental Work

The experimental work was performd in Pet. Eng. Dept./Univ. of Baghdad. The device used to determining (Kair) is shown Fig. (2).

The materials used for carrying out the experimental work are :

1.Core Sample: About (60) plugs are prepared and their dimensions are measured.

2.Gas Oil: Gas oil is used as a saturation liquid to test liquid permeability, does not volatile at room temperature.

The properties of gas oil are given in table (1).

3.Air: Air is used as a gas to test absolute permeability by gas permeameter.

The experiments were carried out as follows:

1.The absolute permeability is measured by Ruska Liquid Permeameter with gas oil.

2.The gas permeability is measured by Ruska Gas Permeameter with air at different pressure drop to get equivalent liquid permeability through drawing the permeability to gas at two or three pressures drop versus the reciprocal of the mean pressure, and then extrapolating to infinite pressure.

3.Two correlations are built by statistical program to get equivalent liquid permeability by single test with Ruska Gas Permeameter. The correlations are:

$$K_L = f(K_g, P) \quad (7)$$

$$K_L = A_1 \times K_g^{A_2} + A_3 \times P^{A_4} \quad (8)$$

where :

K_g = gas permeability (md)

P = mean pressure (atm)

Table (2) shows the values of the constants (A_1, A_2, A_3 and A_4).

Results

Several experiments have been carried out in this work to study the possibility of getting equation that has good agreement with equivalent liquid permeability from a single test by Ruska Gas Permeameter.

The correlations are built on about 75% of data point that covered different ranges of permeability as shown in Table (3) and use 25% of data point to check the correlations. After several trials in form of the correlations we get the final form that give acceptable agreement, as shown in Figure(3) and (4). The correlations take the Klinkenberg effect implicitly and take the effect of mean pressure explicitly, as shown in equation (8).

Conclusions

Simple, rapid and easily applied equation is developed to calculate equivalent liquid permeability that equation needs only single measurement of gas permeability .

References

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Symbols And Abbreviations

Symbol	Description	Unit
A	Area	[cm^2]
A_1, A_2, A_3, A_4	Correlation constants	-
b	Constant	-
c	Slope	-
C.P	centi poise	
K	Absolute permeability	[Darcy]
K_g	Gas permeability	[Darcy]
K_L	Liquid permeability	[Darcy]
K_o	effective permeability for oil	[Darcy]
L	Length	[cm]
P_1	Inlet pressure	[atm]
P_2	Outlet pressure	[atm]
P_m	Mean pressure	[atm]
q	Discharge	[cc/sec]
Q_{av}	Average discharge	[cc/sec]
R	Correlation coefficient	-
V%	Variance	-

Abbreviations	Definition
He	Helium
N2	Nitrogen

Greek symbols

Symbols	Description	Unit
μ	Kinematic viscosity	[csc]

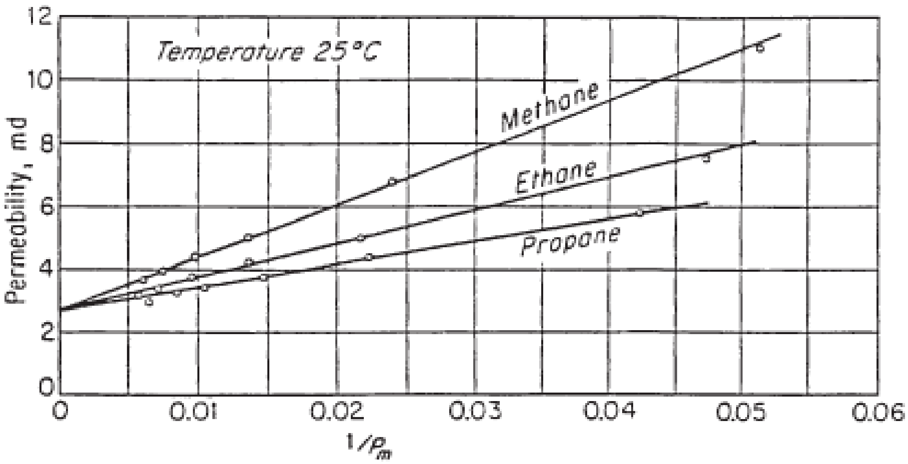
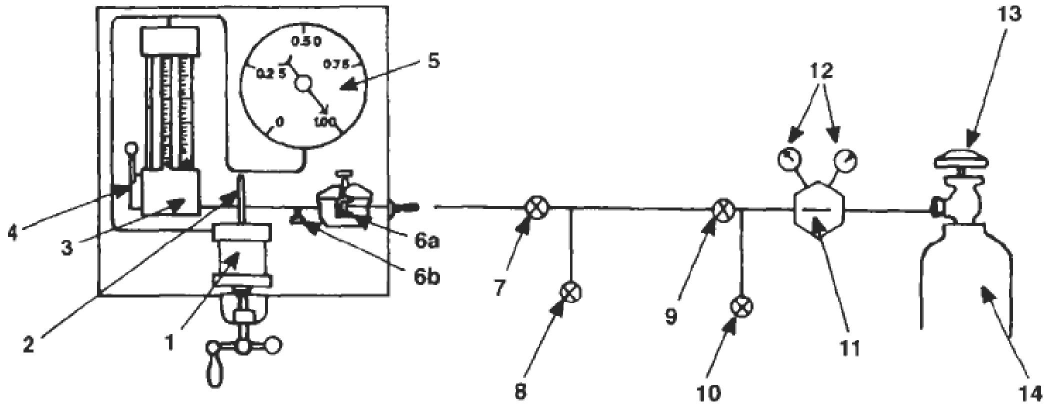


Figure (1) effect of gas pressure on measured permeability for various gases [Klinkenberg (1941)]



1. Core holder, 2. Thermometer, 3. Three flow meters, Small, medium, Large, 4. Flow meter selector switch, 5. Pressure gauge, 6. Pressure regulator, 7. Second flow line valve, 8. Bleed off valve, 9.First flow line valve, 10. Bleed off valve, 11. Flow line regulator, 12. Air pressure gauge, 13. Air tank valve, 14. Air.

Figure (2) Ruska gas permeameter

Table (1). Properties of Gas oil.

Property	Value
Sp. gr. at 24° C	0.825
Viscosity at 19 ° C (C.P.)	4.39
Viscosity at 24 ° C (C.P.)	3.7
Viscosity at 30 ° C (C.P)	3.3

Table (2) values of the corrleations coefficients

Constants				Variance (V %)	Correlation coefficient (R)	Application range
A_1	A_2	A_3	A_4			
0.477104	1.110739	-9.4060	7.309868	93.61	0.9623	$K_g \leq 100$
1.18921	0.931348	-105.314	248.0285	98.54	0.9926	$K_g > 100$

Table (3) values of the results calculation

Core No.	L(mm)	D(mm)	Area(Cm2)	Pavg(atm)	ΔP(atm)	Kg(md)	KL(md)	K_O(md)
1	33.96	25.19	4.98564	1.125	0.25	17.35586	2.740399	1.708781
				1.25	0.5	13.88469		
				1.5	1	13.63675		
2	26.31	25.3	5.02928	1.125	0.25	118.0615	102.7526	93.31896
				1.25	0.5	117.1094		
				1.5	1	114.253		
3	26.82	25.03	4.92251	1.125	0.25	83.2958	71.63126	62.66466
				1.25	0.5	80.32095		
				1.5	1	80.32095		
4	27.4	25.22	4.99752	1.125	0.25	374.2347	310.4828	316.2579
				1.25	0.5	368.2629		
				1.5	1	358.3098		
5	17.96	25.35	5.04918	1.125	0.25	186.4445	165.967	158.4175
				1.25	0.5	182.5603		

				1.5	1	181.2655		
6				1.125	0.25	124.4662		
	23.21	24.94	4.88717	1.25	0.5	121.0088		
				1.5	1	121.0088	110.9096	101.5286
7				1.125	0.25	16.23058		
	37.82	25.45	5.08909	1.25	0.5	15.14854		
				1.5	1	14.87803	10.89157	7.836816
8				1.125	0.25	40.57649		
	34.51	25.42	5.0771	1.25	0.5	30.43237		
				1.5	1	30.30866	0.299506	0.148432
				1.125	0.25	14.75841		
9	26.24	25.02	4.91857	1.25	0.5	13.78746	10.2665	7.341897
				1.5	1	13.59327		
				1.125	0.25	14		
10	33.63	25.45	5.08909	1.25	0.5	13.03729	6.128824	4.154491
				1.5	1	12.02702		
				1.125	0.25	31.79949		
11	30.85	25.44	5.08509	1.25	0.5	26.49958	2.068827	1.252938
				1.5	1	24.29128		
				1.125	0.25	829.3049		
12	40.89	25.29	5.0253	1.25	0.5	814.4959	651.207	716.3055
				1.5	1	784.8778		
				1.125	0.25	12		
13	40.65	25.62	5.15731	1.25	0.5	10.61551	2.501802	1.545329
				1.5	1	9.611338		
				1.125	0.25	79.99816		
14	23.82	25.19	4.98564	1.25	0.5	79.12861	73.06468	64.05019
				1.5	1	78.25907		
				1.125	0.25	74.71036		
15	34.49	25.33	5.04121	1.25	0.5	70.97484	41.17465	39.9756
				1.5	1	68.23546		
				1.125	0.25	270.0979		
16	30.42	25.23	5.00149	1.25	0.5	265.6701	207.8752	203.109
				1.5	1	254.6005		
				1.125	0.25	964.9403		
17	29.61	25.01	4.91464	1.25	0.5	877.2184	591.7179	644.4324
				1.5	1	870		
				1.125	0.25	117.4282		
18	21.58	25.1	4.95008	1.25	0.5	115.0638	82.61604	87.83428
				1.5	1	111.0807		
				1.125	0.25	114.9361		
19	20.44	25.35	5.04918	1.25	0.5	106.0948	70.18097	73.78142
				1.5	1	105.8738		
				1.125	0.25	162.1563		
20	26.82	25.37	5.05715	1.25	0.5	160.2259	142.852	134.2486
				1.5	1	157.3302		
				1.125	0.25	65.34619		
21	31.38	25.4	5.06911	1.25	0.5	60.83955	45.39247	37.87465
				1.5	1	60.27622		
				1.125	0.25	57.57394		
22	22.21	25.01	4.91464	1.25	0.5	54.284	24.67455	19.32622
				1.5	1	49.34909		

23	29.29	25.51	5.11312	1.125	0.25	143.8746	131.4736	122.496
				1.25	0.5	141.7895		
				1.5	1	140.7469		
24	25.03	25.44	5.08509	1.125	0.25	11.46683	8.656702	6.082099
				1.25	0.5	10.75015		
				1.5	1	10.75015		
25	36.19	25.42	5.0771	1.125	0.25	86.6604	72.24659	63.25908
				1.25	0.5	84.32524		
				1.5	1	83.02793		
26	41.23	24.56	4.73938	1.125	0.25	13.93304	9.566468	6.79134
				1.25	0.5	12.98306		
				1.5	1	12.82473		
27	23.16	25.34	5.04519	1.125	0.25	314.1376	227.8641	224.7705
				1.25	0.5	300.77		
				1.5	1	292.4153		
28	33.09	25.49	5.1051	1.125	0.25	7.549945	6.146748	4.167904
				1.25	0.5	7.31401		
				1.5	1	7.196042		
29	27.85	25.38	5.06113	1.125	0.25	66.09866	54.18614	46.05025
				1.25	0.5	64.09567		
				1.5	1	63.09417		
30	22.79	24.97	4.89894	1.125	0.25	677.3357	508	544.5687
				1.25	0.5	660.4023		
31	30.59	25.54	5.12515	1.25	0.5	11.29738	8.6903	6.108159
				1.5	1	10.86287		
32	16.47	25	4.91071	1.125	0.25	292.9959	220.3895	216.6464
				1.25	0.5	280.7877		
				1.5	1	274.6837		
33	23.83	25.6	5.14926	1.125	0.25	7.3	2.321914	1.423154
				1.25	0.5	7.07506		
				1.5	1	6.064337		
34	27.33	25.25	5.00942	1.125	0.25	714.9178	516.33	554.4331
				1.25	0.5	695.059		
35	21.95	25.18	4.98168	1.125	0.25	237.3676	170.8085	163.5259
				1.25	0.5	224.537		
				1.5	1	220.5274		
36	33.44	25.4	5.06911	1.125	0.25	86.44464	67.61386	58.797
				1.25	0.5	81.64216		
				1.5	1	81.64216		
37	29.04	25.2	4.9896	1.125	0.25	699.1111	487.26	520.0816
				1.25	0.5	677.9259		
38	27.35	24.66	4.77805	1.125	0.25	895.9347	636.9497	699.0156
				1.25	0.5	833.4277		
				1.5	1	830		
39	19.66	25.33	5.04121	1.125	0.25	93.69012	75.55354	66.46256
				1.25	0.5	89.43148		
				1.5	1	89.07659		
40	26.24	25.42	5.0771	1.125	0.25	808.943	620.82	679.5035
				1.25	0.5	790.1304		
41	31.59	25.16	4.97377	1.125	0.25	1017.227	750.861	838.214
				1.25	0.5	970.9891		

				1.5	1	950		
42	29.33	25.52	5.11712	1.125	0.25	12.51811	9.624668	6.836958
				1.25	0.5	12.01738		
				1.5	1	11.78789		
43	31.4	25.53	5.12114	1.125	0.25	214.2575	183.1878	176.6552
				1.25	0.5	209.7938		
				1.5	1	206.446		
44	36.33	25.73	5.20169	1.125	0.25	73.72598	63.59033	54.94726
				1.25	0.5	72.45484		
				1.5	1	71.18371		
45	30.7	25.5	5.10911	1.125	0.25	126.8594	100.5551	91.11862
				1.25	0.5	124.6722		
				1.5	1	120.2977		
46	30.22	24.9	4.87151	1.125	0.25	677.4134	498.8496	533.752
				1.25	0.5	643.5427		
				1.5	1	632.2525		
47	42.63	25.32	5.03723	1.125	0.25	147.8652	117.5869	108.296
				1.25	0.5	140.78		
				1.5	1	140.1639		
48	30.94	25	4.91071	1.125	0.25	110.0825	83.10504	73.83157
				1.25	0.5	103.2023		
				1.5	1	103.2023		
49	36.28	24.91	4.87542	1.125	0.25	1164.729	844.2025	953.9414
				1.25	0.5	1083.469		
				1.5	1	1083		
50	27.13	25.28	5.02133	1.125	0.25	62.93357	55.19626	46.99869
				1.25	0.5	61.16356		
				1.5	1	60.9669		
51	19.18	25.33	5.04121	1.125	0.25	285.2871	224.6436	221.2667
				1.25	0.5	276.9778		
				1.5	1	270.0533		
52	42.9	25.36	5.05316	1.125	0.25	129.7911	105.5569	96.13401
				1.25	0.5	123.6105		
				1.5	1	123.6105		
53	22.41	25.48	5.1011	1.125	0.25	9.594691	6.312297	4.291975
				1.25	0.5	9.914514		
				1.5	1	8.795133		
54	31.82	25.44	5.08509	1.125	0.25	9.11093	5.985042	4.047046
				1.25	0.5	8.313723		
				1.5	1	8.313723		
55	38.12	25.51	5.11312	1.125	0.25	16.5	8.71269	6.125532
				1.25	0.5	14.65421		
				1.5	1	14.51852		
56	29.41	24.62	4.76256	1.125	0.25	71.92927	54.30187	46.15882
				1.25	0.5	67.43369		
				1.5	1	67.43369		

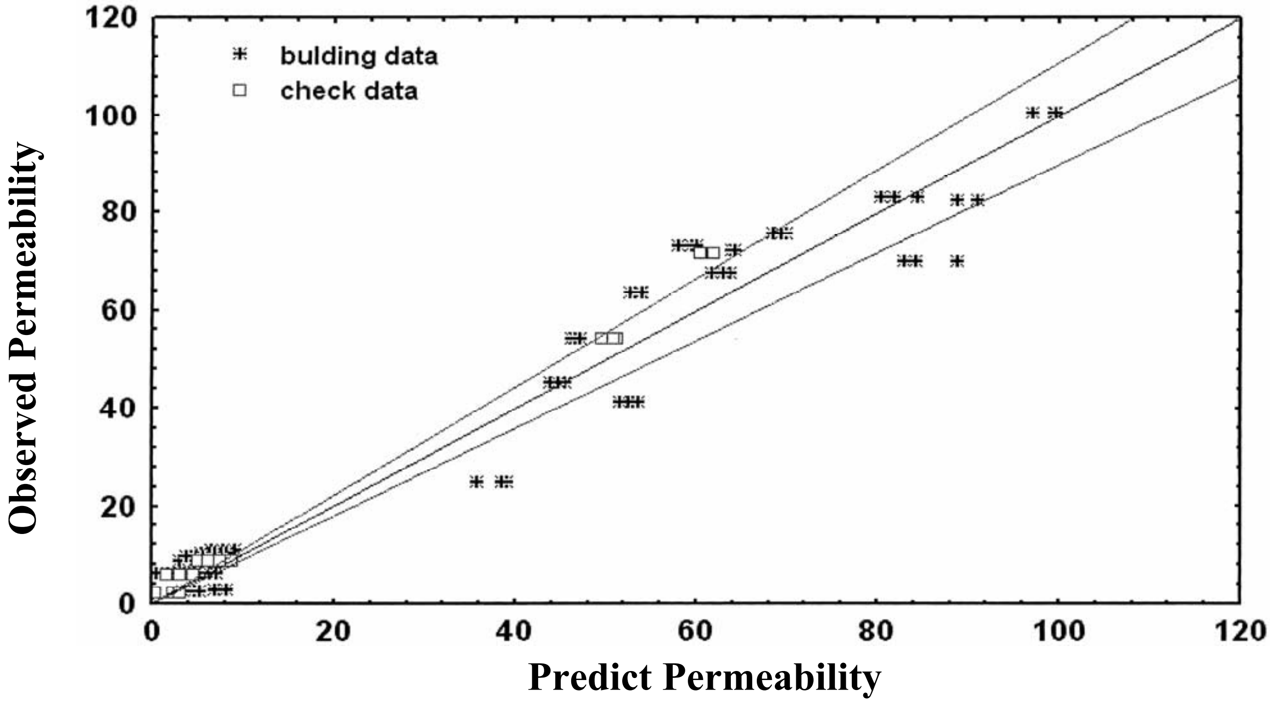


Figure (3) predict versus observed values of K_L,K_g≤100

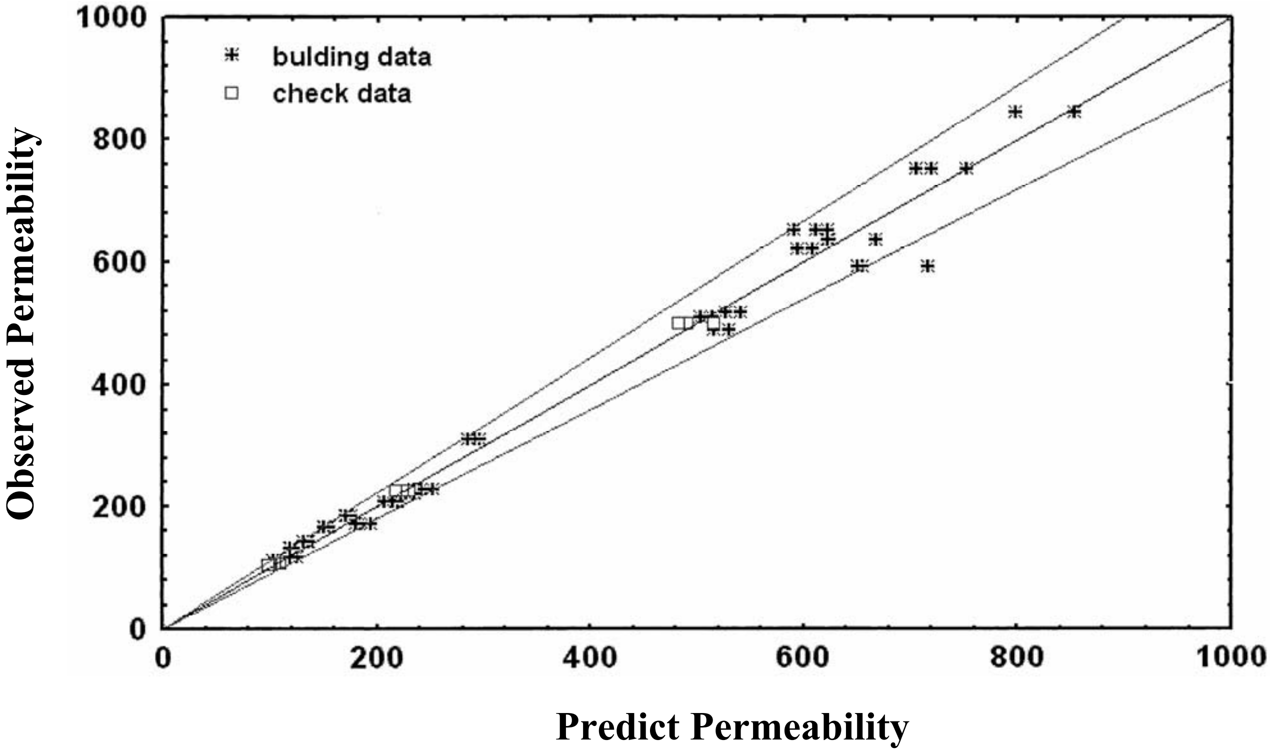


Figure (3) predict versus observed values of K_L,K_g>100