Egyptian Geophysical Society
EGS Journal, Vol. 16, No. 1, 111-121 (2018)

AN IMPROVED APPROACH TO DERIVE POROSITY FROM THE ACOUSTIC LOG

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طريقة محسنة لتعيين مسامية الصخور من تسجيلات الآبار الصوتية فى التكوينات الخالية من الطفل

الخلاصة: يتم تعيين الحجم الكلى للماء والبترول بعدم عرفة المسامية الفعالة للصخور. فى العادة يتم تعيين مسامية الصخور إما عن طريق فحص العينات الصخرية أومن تحليل تسجيلات الآبار الخاصة بأدوات تسجيلات المسامية. وفى حالة عدم توافر عينات صخرية صالحة لإجراء القياسات فإنه يتم الإستعانة بالمعلومات المتوافرة لإثنين على الأقل من تسجيلات المسامية، أما في حالة عدم وجود مثل هذه التسجيلات فإنه من الصعب تقدير مسامية الصخور. يوجد في الوقت الحاضر العديد من المعادلات الرياضية التي عن طريقها يتم حساب مسامية الصخور من بيانات زمن عبور الموجات الصوتية والتي تعتبر من أكثر البيانات توفرا لمعظم التكوينات الصخرية في أغلب الآبار. تم في البحث الحالي عمل مراجعة شاملة لكل المعادلات المستخدمة فى حساب المسامية من السجلات الصوتية و استنباط معادلة يتم من خلالها حساب المسامية الفعالة من بيانات التسجيلات الصوتية لعدد من التكوينات الصخرية. هذه المعادلة الجديدة تمثل في الحقيقة إعادة دمج لمعادلةRaymer et. Al(1980) و (1988) Raiga- Clemenceau et al. لحساب المسامية. ولقد تم تطبيق هذه المعادلة على بيانات حقلية وأعطت قيما للمسامية مساوية للقيم المعروفة عن نفس التكوينات الصخرية مثل الحجر الرملى والجيرى اما الدولوميت فيلزم استنباط معادلة مستقلة لحساب مساميته.

ABSTRACT: *It is important in log interpretation to accurately estimate porosity. With the exception of core measurements, the porosity tool responses (density; ρb, neutron; ϕN, and acoustic; Δt) can all be defined by equation in which porosity is a factor, and which can therefore be solved for porosity. Also useful information about porosity can be obtained by using a combination of at least two of these logs. This paper is mainly addressed to shed more light on some approaches used to determine the sonic-derived porosity and to introduce an equation for estimating porosity from acoustic logs. The equation can be simply achieved by merging Raymer et al. (1980) transform and Raiga-Clemenceau et al. (1988) since the first takes into account the effect of matrix and fluid transit time, whereas the second takes only the effect of matrix transit time and matrix nature into consideration. However, the proposed equation combines in its structure all parameters included in both equations, which in our opinion enhances the accuracy of computing porosity from acoustic logs. This equation was tested among a wide variety of samples representing different lithology. The results obtained from its application showed particularly a good agreement with experimental data in various cases subjected to study particularly with clean lithology material.*

1. INTRODUCTION

Acoustic logging is an important part of formation evaluation process. This type of logging uses the propagation of acoustic waves within and around the borehole. In open holes (uncased boreholes), acoustic logging consists mainly of acoustical velocity measurement. This measurement, usually called a sonic log, is a record of the time required for an acoustic wave to travel a given distance through the formation that surrounds a borehole. This parameter is referred to as acoustic transit time, □**t**, and is usually expressed in microsecond per foot. Sonic logging was originally developed to aid in the evaluation of seismic surveying.

Since the introduction of the tool, however, uncertainty has arisen regarding the accuracy of the porosity determinations made from sonic transit time recordings. The reason for this lies very likely in the lack of adequate interpretive models and relevant transform equations. Many theoretical equations based on rock mechanics were developed by many investigators including Mabrouk W.M. (2008), Raiga-Clemenceau et al. (1988), Raymer et al. (1980), Geertsma (1961), Wyllie et al., (1956 & 1958), Biot (1956-a,b), and Gassman (1951), but their mechanical complexity and difficulty in assessing correctly some of the parameters involved are obstacles to the day-to-day interpretation practice.

2. IMPORTANT SONIC-DERIVED POROSITY EQUATIONS

2-1.THE TIME AVERAGE EQUATION

A good correlation often exists between porosity and acoustic interval travel time, which universally used until recently and has been very popular to log analysts, is the Wyllie Time-Average equation (1956). This equation was proposed as a conclusion of substantial laboratory work and take the following form:

$$\Delta t = \Delta t_{ma}(1-\phi_S) + \Delta t_f \phi_S \tag{1}$$

Solving for porosity yields

$$\phi_S = \frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \tag{2}$$

Where $\boldsymbol{\Delta t}$ is the sonic transit time (μsec/ft), $\boldsymbol{\Delta t_{ma}}$ is the sonic transit time of matrix (μsec/ft), $\boldsymbol{\Delta t_f}$ is the sonic transit time of a fluid (µsec/ft), and ϕ_S is the sonic-derived porosity (Porosity Unit or Percentage).

This equation relating acoustic travel time to the matrix and fluid travel times is almost universally used to quantify the sonic porosity in consolidated sandstones and carbonates with intergranular porosity. This is an empirical equation, based on statistical analysis of large quantity of data. Practical values for the matrix travel time are used for standard types. Using equation (2), the porosity can be obtained from the log recorded travel time, Δt, provided Δt_f and Δt_{ma} are known. Consequently, Δt_f is normally taken as ***189 µsec/ft*** in fresh mud. In salt mud a value ***185 µsec/ft*** is used. The matrix interval transit times commonly used in this formula are listed in Table (1), which vary from 40-60 ***µsec/ft***, depending on lithology.

Table 1. Sonic Velocities and Interval Transit Times for Different Matrices. (Schlumberger, 1972).

	V_{ma} (ft/sec)	Δt_{ma} (µsec/ft)	Δt_{ma} (µsec/ft) Commonly used
Sandstone	18,000 to 19,500	55.5 to 51.0	55.5 to 51.0
Limestone	21,000 to 23,000	47.6 to 43.5	47.6
Dolomite	23,000 to 26,000	43.5 to 38.5	43.5
Anhydrite	20,000	50.0	50.0
Salt	15,000	57.0	67

Tixier et al. (1959) suggested the introduction of a compaction factor, C_P, in equation (2) particularly where sonic log is used to determine porosity in unconsolidated sands. Accordingly, equation (2) can be re-written in terms of C_P as:

$$\phi_S = \frac{\Delta t - \Delta t_{ma}}{\Delta t_f - \Delta t_{ma}} \times \frac{1}{C_P} \tag{3}$$

where Δt is the sonic transit time (µsec/ft), Δt_{ma} is the interval transit time of matrix (µsec/ft), Δt_f: is the sonic transit time of a fluid (µsec/ft), ϕ_S is the sonic-derived porosity (P.U. or %), and C_P is the Compaction factor ($C_P = \Delta t_{sh}/100$).

Since 1956, Wyllie equation has long been accepted as a simple and easy transform from sonic transit time to porosity, and for lithology assessment from logs. However, the equation suffers a certain number of weaknesses, from both theoretical and practical viewpoints. *Theoretically*, the formula calls for a physical model of the porous medium made up of matrix and pore elements in an in series arrangement, a model that looks oversimplified and far different from reality. *Practically*, there is often no satisfactory fitness between time average-derived porosities and those determined experimentally, unless achieved by introducing variable matrix transit times with single-mineral lithology, or, in other cases, empirical correction factors for assumed under compaction effects.

2-2. Raymer et,al. (1980) Transform

Based on extensive sets of experimental data, Raymer et,al.(1980) proposed an empirical transform (equation 4) of sonic transit time to porosity.

$$\Delta_t = \left[\frac{(1-\phi_S)^2}{\Delta_{tma}} + \frac{\phi_S}{\Delta_{tf}} \right]^{-1} \tag{4}$$

The matrix and fluid properties suggested for use in this equation are given in the following table (2).

Although totally empirical in origin, the transform does not contradict theoretical acoustic-wave propagation consideration. The transform can be approximated with adequate accuracy in the regions of interest by the algorithm

Table 2. Sonic velocities and interval transit times for different matrices used in sonic porosity formula (Raymer et.al.,1980)

Lithology	V_{ma} (ft/sec)	Δt_{ma} (µsec/ft)
Sandstone	17850	56
Limestone	20500	49
Dolomite	22750	44
Fluid	5300	189

2-3. THE ACOUSTIC FORMATION FACTOR EQUATION RAIGA-CLEMENCEAU ET AL. (1988)

The weakness of the time average equation led Raiga-Clemenceau et al. (1988) to investigate the possibilities of more accurate relationship between transit time and porosity, through working out extensive sets of experimental data published by Raymer et, al. (1980). All these results justify an equation relating the sonic transit time to porosity recorded in a porous media under the form of:

$$\phi_S = 1 - \left(\frac{\Delta t_{ma}}{\Delta t}\right)^{1/x} \tag{5}$$

where, ϕ_S is the sonic-derived porosity (P.U. or %), Δt is the sonic transit time (μsec/ft), Δt_{ma} is the sonic transit time of matrix (μsec/ft), and x is the exponent related to the matrix nature, versus the following lithology parameters are used (table 3).

Table 3. Matrix Transit Time and Exponent Used in Raiga-Clemenceau et al., (1988) equation

Matrix	**Δt_{ma} (μsec./ft)**	**x**
Silica	55.5	1.60
Calcite	47.6	1.76
Dolomite	43.5	2.00

Equation (5), however, is not merely theoretical, but is physically meaningful. The results obtained from its application showed a good agreement with core data in a great degree, particularly in clean formations.

3. PROPOSED SONIC POROSITY EQUATION

Raymer et. al.(1980), equation (4) can be rewritten as:

$$\frac{1}{\Delta t} = \frac{(1-\phi_s)^2 \Delta t_f + \phi_s \Delta t_{ma}}{\Delta t_{ma} \Delta t_f} \qquad (6)$$

Raiga-Clemenceau et. al. (1988) equation after re-arranging can be written as:

$$1-\phi_S = \left(\frac{\Delta t_{ma}}{\Delta t}\right)^{1/x} \qquad (7)$$

Where, the left hand side of equation (7) represents the matrix volume in clean formation, by substitution from equation (7); matrix volume; into (6) we get:

$$\frac{1}{\Delta t} = \frac{\left(\frac{\Delta t_{ma}}{\Delta t}\right)^{2/x} \Delta t_{f} + \phi_s \Delta t_{ma}}{\Delta t_{ma} \Delta t_f} \qquad (8)$$

Equation (8), after rearranging, can be written in terms of ϕ_S as:

$$\phi_s = \frac{\Delta t_f}{\Delta t}\left[1-\left(\frac{\Delta t_{ma}}{\Delta t}\right)^{\frac{2}{x}-1}\right] \qquad (9)$$

Where ϕ_S is the sonic-derived porosity (P.U. or %), Δt is the sonic transit time (μsec/ft), Δt_{ma} is the sonic transit time of matrix (μsec/ft), Δt_f is the sonic transit time of a fluid (189 μsec/ft for fresh water and 185 μsec/ft for saline water), and x is the exponent related to the matrix nature.

4. APPLICATION OF SUGGESTED SONIC POROSITY EQUATION

Application of equation (9) requires the knowledge of four parameters; sonic transit time *(Δt)*, fluid transit time *(Δt_f)*, matrix transit time *(Δt_{ma})*, and the exponent related to the matrix nature *(x)*, to be determined in the following manner:

a. The sonic log readings ***(Δt)*** will generally have to be corrected.

b. The fluid transit time (Δtf) depends mainly on the media either fresh (189 μsec/ft) or saline (185 μsec/ft).

c. The matrix transit time (Δtma), which is a function of lithology as published by Schlumberger (1972) and listed in Table (1), can be easily obtained from Table (1) if the type of lithology is known.

d. Once the value of matrix is known, one can easily select the exponent (x) from table (3).

e. Equation (9) cannot be applied if the matrix is dolomite, since when x = 2, the calculated sonic derived porosity from equation (9) must be zero, so another transform must be applied.

5. TESTING THE PROPOSED EQUATION

5-1. TEST #1

In the following, a number of samples representing different types of sandstone and limestone were used to test the validity of equation (9). These samples, listed in Table 4, include in-situ measurements of compressional wave velocity ***(V_P)*** and porosity ***(ϕ)***. The transit time (Δ_t) is computed from the reciprocal of compressional wave velocity listed in Table (4) and the porosity is computed via equations (2, 5, & 9) using the following parameters:

a. In the Time average equation (2), Δt_{ma} is taken equal to 55.5 μsec/ft for sandstone and 47.5 μsec/ft for limestone, and Δt_f = 185 μsec/ft for saline media

b. In Raiga-Clemenceau equation (5), on the other hand, the matrix transit time Δtma is taken equal to 55.5 μsec/ft for sandstone with x=1.6 and 47.6 μsec/ft for limestone with x=1.76.

c. In the proposed equation, the matrix transit time is taken to be equal 55.5 μsec/ft for sandstone and 47.5 μsec/ft for limestone and Δtf = 185 μsec/ft for saline muds. The exponent (x) for each type of lithology was selected from Table (3) as 1.6 for sandstone and 1.76 for limestone.

The results are listed in the same table (4) and the porosity calculated from equation (9) is compared with those obtained from the core and also compared with porosities calculated from equations (2) and (5), the result of comparisons are also illustrated in figures (1, 2, 3 and 4) from which one can easily investigate the following remarks:

a. All equations, including the new one, compared very favorably with the measured values from the core.

b. The porosity from equation (9) is compared with the porosity values from the core and those obtained from equations (2) and (5), the result of comparison is illustrated in figure (1) , where the porosities values from equation (9) is very close to those from equations (2), (5) and to that from the core.

c. The porosity calculated from equations (2) and (5) are compared by the porosity measured from the core, the results is indicated in figure (2).

d. Visually, it is indicated from figures (1) and (2) that the calculated porosity from the equation (9) is very close to the measured porosity from the core than that from equations (2) and (5).

e. Figures 4 and 5, on the other hand, indicated that the porosity from equation (9) gives the highest correlation when compared with the measured porosity than that calculated from equations (2) and (5), and also gives a good correlation when compared with equations (2) and (5).

f. From the above remarks, the porosity can be calculated safely from equation (9) if the sonic tansit time (Δt), matrix and fluid transit time (Δtm Δtf) and x are known in sandstone and limestone, whereas in dolomite equation (5) is highly recommended than equation (2), which it gives higher correlation when compared with the porosity from the core than equation (2).

Table 4. Comparison of Observed Porosity with Those Calculated Using Different Approaches Including the New Equation (9),compiled by Kamel 2002.

	Rock Type	***Reference***	***Vp ft/sec***	***Δt μsec/ft***	***ϕ %***	***ϕ Eq.2 (%)***	***ϕ Eq.5 (%)***	***ϕ Eq.9 (%)***
1	Berea	John Ston (1978)	12756.52	78.39	18.4	17.68	19.63	19.52
2	St.Peter	Tosaya (1982)	16733.1	59.76	4	3.29	4.57	5.67
3	Limestone	Burns et al.,1988	17028.39	58.73	10	8.16	11.06	8.99
4	Berea	John Ston (1978)	14223.13	70.31	12	11.43	13.9	15.11
5	Navajo	John Ston (1978)	13586.62	73.6	16.4	13.98	16.36	17.13
6	St.Peter	Tosaya (1982)	16011.28	62.46	7.5	5.37	7.2	8.62
7	Navajo	John Ston (1978)	15040.1	66.49	10	8.49	10.8	12.29
8	Gulf Coast	Gregory (1976)	12884.48	77.61	20	17.08	19.12	19.17
9	Boise	Gregory (1976)	11161.96	89.59	24	26.32	26.15	23.30
10	MAR	ARCO-data	17842.07	56.05	0.9	0.42	0.62	0.81
11	Limestone	Burns et al.,1988	20014.1	49.96	2	1.79	2.76	2.54
12	Boise	Gregory (1976)	11591.77	86.27	23	23.76	24.36	22.39
13	Berea	ARCO-data	11516.31	86.83	19	24.19	24.67	22.55
14	Travis Beak	Gregory (1976)	16372.19	61.08	4.45	4.31	5.88	6.50

15	Limestone	Burns et al.,1988	17028.39	58.73	10	8.16	11.06	8.99
16	Limestone	Burns et al.,1988	16569.05	60.35	11	9.35	12.39	9.85
17	Travis Beak	Gregory (1976)	14246.1	70.19	13	11.35	13.81	15.03
18	Travis Beak	Gregory (1976)	16408.28	60.94	6	4.2	5.75	7.01
19	Bandera	Gregory (1976)	11457.25	87.28	23	24.54	24.92	22.68
20	Limestone	Burns et al.,1988	17356.49	57.62	7.5	7.36	10.12	8.35
21	St.Peter	Tosaya (1982)	14436.4	69.27	12	10.63	13.09	14.40
22	MAR	ARCO-data	16500.14	60.61	4	3.94	5.42	6.65
23	Limestone	Burns et al.,1988	18209.55	54.92	8	5.39	7.7	6.60
24	MDP	ARCO-data	11079.93	90.25	21	26.83	26.49	23.46
25	MDP	ARCO-data	12671.22	78.92	21	18.08	19.97	19.75
26	Berea	ARCO-data	11949.4	83.69	20	21.77	22.89	21.57
27	Berea	ARCO-data	12677.78	78.88	19	18.05	19.95	19.73
28	Limestone	Burns et al.,1988	17717.4	56.44	8	6.5	9.09	7.62
29	Berea	ARCO-data	12270.94	81.49	19	20.07	21.58	20.79
30	Bandera	Gregory (1976)	12497.32	80.02	18	18.93	20.67	20.21
31	Limestone	Burns et al.,1988	20014.1	49.96	3	1.79	2.76	2.54
32	St.Peter	Tosaya (1982)	14764.5	67.73	11	9.44	11.84	13.27
33	St.Peter	Tosaya (1982)	14436.4	69.27	12	10.63	13.09	14.40
34	Limestone	Burns et al.,1988	16569.05	60.35	10	9.35	12.39	9.85
35	St.Peter	Tosaya (1982)	11811.6	84.66	20	22.52	23.45	21.89
36	Limestone	Burns et al.,1988	20014.1	49.96	3	1.79	2.76	2.54
37	Limestone	Burns et al.,1988	18373.6	54.43	7	5.04	7.24	6.25

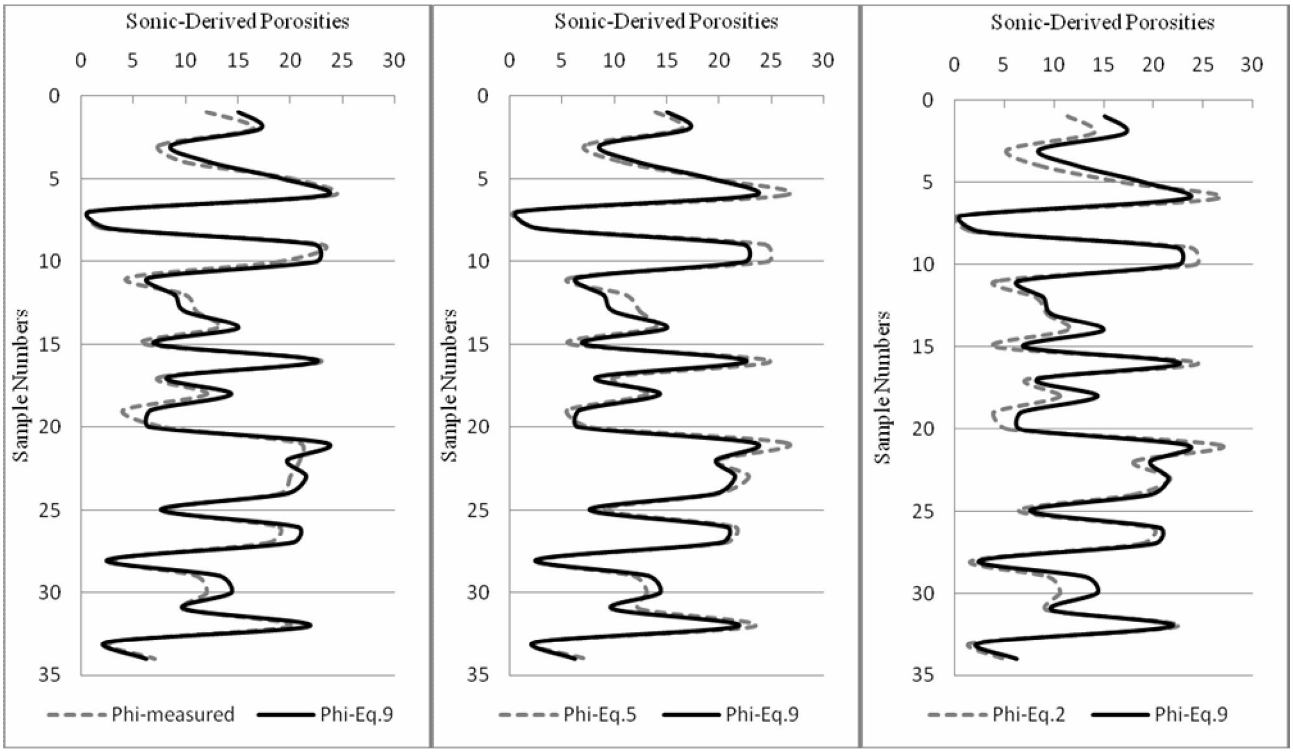

Figure 1: Comparison between The porosity calculated from Equation (9) with those measured from the core and calculated from equations (2) and (5).

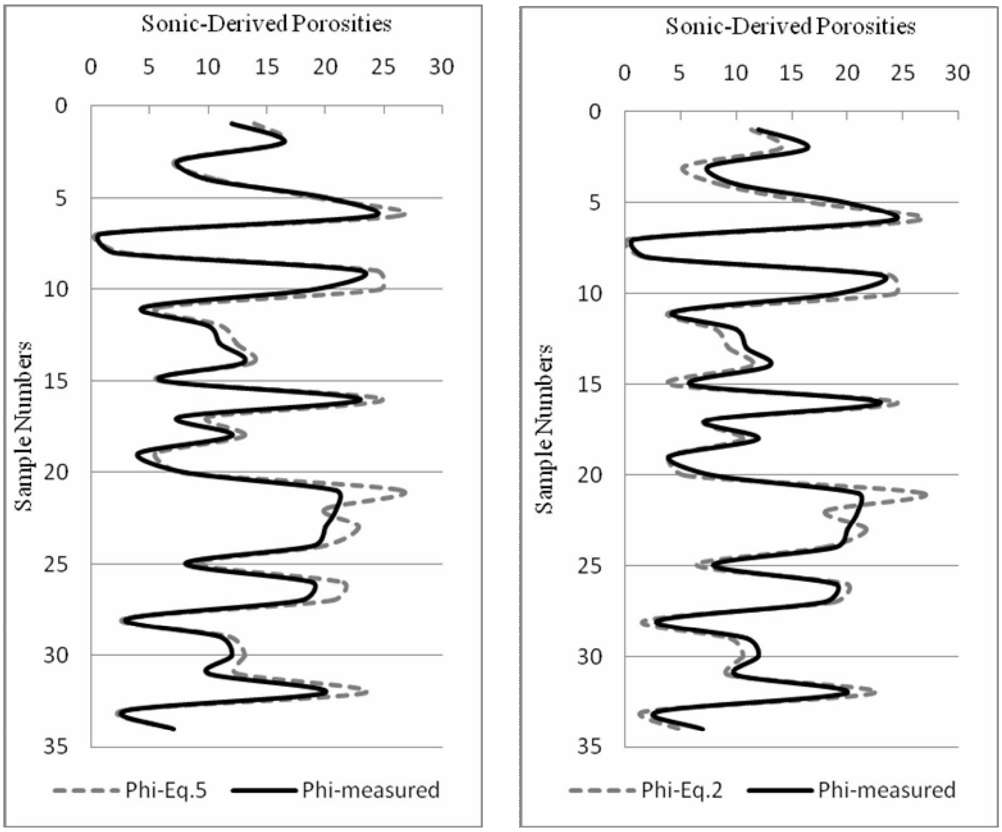

Figure 2: Comparison between The porosity calculated from both Equations (2 and 5) with those measured from the core.

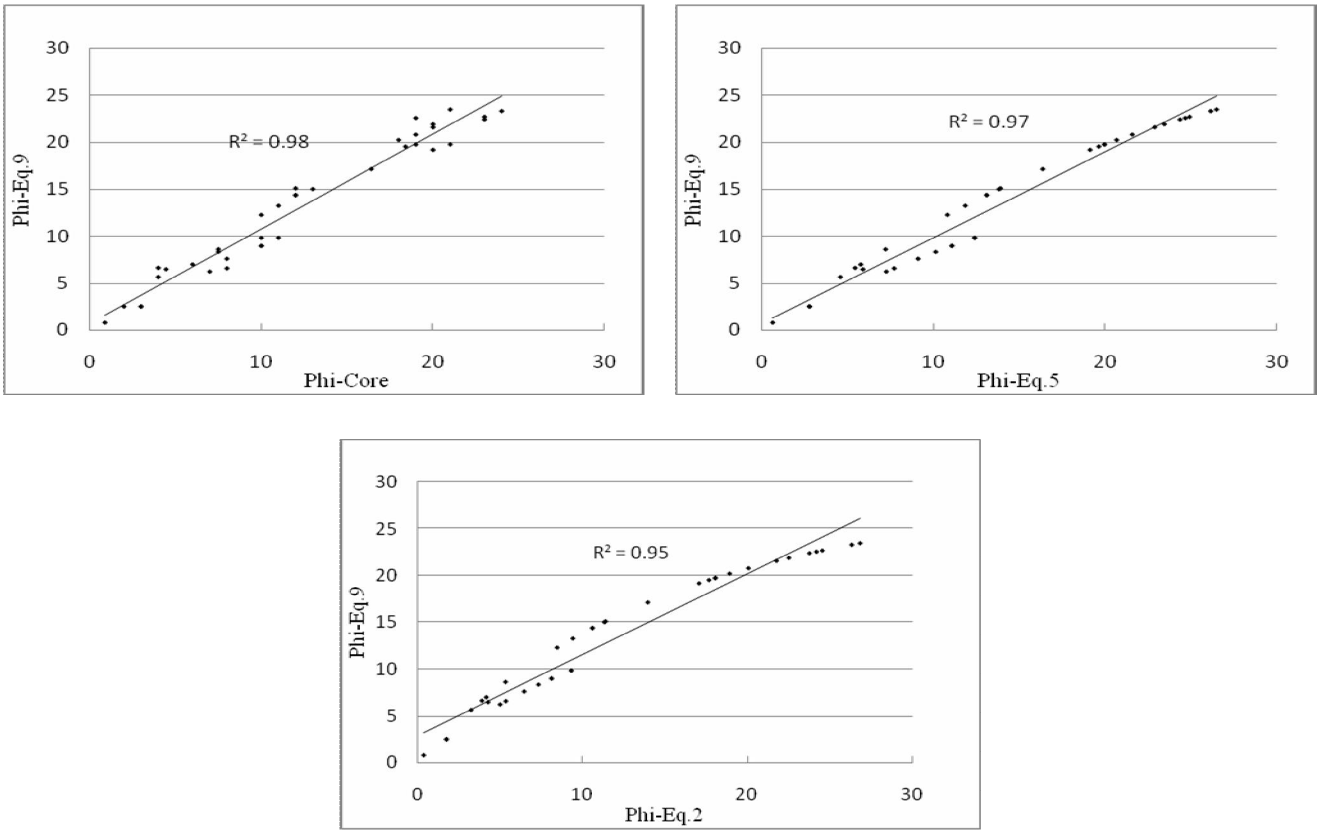

Figure 3: Observed correlation between The porosity calculated from Equation (9) with those measured from the core and calculated from equations (2) and (5).

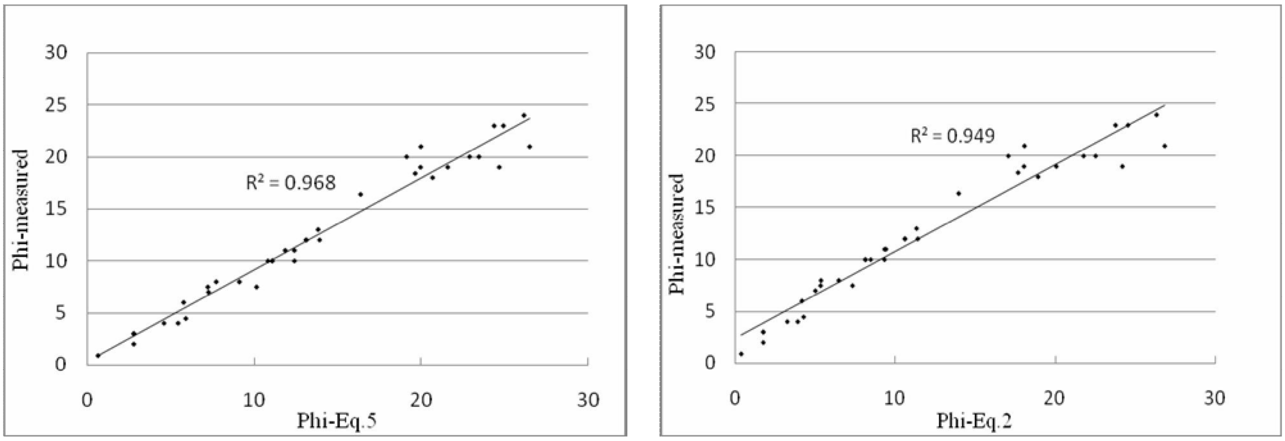

Figure 4: Observed correlation between The porosity calculated from both Equations (2 and 5) with those measured from the core.

Finally, to ensure that equation (9) is safe and accurate than equations (2 and 5) in determine the sonic-derived porosity, anther simple statistical comparison is done which depends on Standard Deviation and root mean square error (RMSE), where, by definition standard deviation measures the degree of variability or diversity among studied elements or variables. The root-mean-square error (RMSE) is a frequently used measure of the differences between values predicted by a model or an estimator and the values actually observed. Basically, the RMSE represents the sample standard deviation of the differences between predicted values and observed values, and can be measured according to the following equation:

$$RMSE = \sqrt{\frac{\sum_{t=1}^{n} (\phi_t^{*} - \phi_t)^2}{n}} \tag{10}$$

Table (5) listed the calculations of both standard deviation and RMSE for the different approaches used in computing sonic derived porosity, where the minimum standard deviation and minimum RMSE are belong to equation (9), which ensure the accuracy of our finding.

Table 5. Observed Standard Deviation for each approach and RMSE between different approaches with the measured porosity from core.

Standard Deviation			
ϕ Core	ϕ Eq.2	ϕ Eq.5	ϕ Eq.9
0.069	0.08	0.077	0.071
RMSE			
	ϕ– Core and ϕ-Eq.2	ϕ– Core and ϕ-Eq.5	ϕ– Core and ϕ-Eq.9
	2.02	1.96	1.63

5-2. TEST #2

To more rigorously test the estimated equations, Sprunt et al. (1988) assess the suitability of different methods for obtaining formation factor, cementation exponent, and saturation exponent for different types of lithology. The different laboratories participating in the project sent two samples each of Berea sandstone and Bedford limestone. The laboratories were asked to

Table 6: Berea Sandstone (20-Samples), Compiled from, Sprunt et al. (1988).

No.	ρ_b kg/m^3	Δ_t μsec/m	Δ_t μsec/ft	***Porosity P.U.***	Phi-Eq.2 ***P.U.***	Phi-Eq.5 ***P.U.***	Phi-Eq.9 ***P.U.***
1	2360	235	71.629	0.188	0.125	0.147	0.163
2	2360	246	74.982	0.188	0.150	0.171	0.183
3	2350	275	83.821	0.193	0.219	0.227	0.221
4	2340	250	76.201	0.197	0.160	0.180	0.189
5	2340	265	80.773	0.197	0.195	0.209	0.210
6	2360	237	72.238	0.186	0.129	0.152	0.167
7	2360	261	79.554	0.186	0.186	0.202	0.205
8	2350	302	92.051	0.195	0.282	0.271	0.244
9	2360	260	79.249	0.185	0.183	0.200	0.203
10	2370	259	78.944	0.183	0.181	0.198	0.202
11	2360	301	91.746	0.189	0.280	0.270	0.243
12	2350	237	72.238	0.193	0.129	0.152	0.167
13	2350	250	76.201	0.192	0.160	0.180	0.189
14	2360	253	77.115	0.188	0.167	0.186	0.193
15	2350	276	84.126	0.191	0.221	0.229	0.222
16	2360	231	70.410	0.187	0.115	0.138	0.155
17	2340	266	81.078	0.199	0.198	0.211	0.211
18	2370	230	70.105	0.182	0.113	0.136	0.153
19	2370	259	78.944	0.182	0.181	0.198	0.202
20	2360	260	79.249	0.184	0.183	0.200	0.203

measure the electrical properties at ambient temperature with 100,000 ppm sodium chloride brine at 1,000 psi effective confining pressure, and ambient pressure if possible. The experimental procedures were not specified, but a detailed reporting sheet was distributed with the samples requesting experimental details. The experimental results from 25 laboratories are compiled in paper.

The core samples ; namely, Berea sandstone; is a sedimentary rock whose grains are predominantly sand-sized and are composed of quartz sand held together by silica, the relatively high porosity and permeability of Berea Sandstone makes it a good reservoir rock; (Table 6) and Bedford limestone;also known as Indiana Limestone is a common regional term for Salem limestone, a geological formation primarily quarried in south central Indiana, United States between Bloomington and Bedford; (Table 7) was chosen to check the validity of the equation (9), since these samples contains the measured porosity.

It is indicated from the comparison of the porosities from equations (2), (5) and (9) with that for both measured porosities of Berea sandstone (table 6) and Bedford limestone (table 7) that:

1. All equations, including the new one, gives an acceptable result if compared with the measured values from the core in both lithologies; Tables (6) and (7).
2. The porosity calculated from equation (9) gives a good and more accurate results when compared with the measured porosities from the samples of both Berea sandstone and Bedford limestone than those from equations (2) and (5), where the minimum standard deviation and also minimum RMSE were belonging to the porosity calculated from equation (9) as indicated in tables (8) and (9).

Table 7: Bedford Limestone (18-Samples)), Compiled from, Sprunt et al. (1988).

No.	ρ_b **kg/m^3**	Δ_t *μsec/m*	Δ_t *μsec/ft*	***Porosity P.U.***	Phi-Eq.2 ***P.U.***	Phi-Eq.5 ***P.U.***	Phi-Eq.9 ***P.U.***
1	2480	218	66.447	0.140	0.14	0.17	0.12
2	2480	204	62.180	0.140	0.11	0.14	0.11
3	2470	241	73.458	0.150	0.19	0.22	0.15
4	2490	216	65.838	0.140	0.13	0.17	0.12
5	2490	236	71.934	0.140	0.18	0.21	0.14
6	2480	233	71.019	0.140	0.17	0.20	0.14
7	2470	213	64.923	0.150	0.13	0.16	0.12
8	2470	201	61.266	0.150	0.10	0.13	0.10
9	2500	229	69.800	0.130	0.16	0.20	0.14
10	2470	250	76.201	0.150	0.21	0.23	0.15
11	2480	247	75.287	0.140	0.20	0.23	0.15
12	2470	248	75.591	0.150	0.20	0.23	0.15
13	2500	215	65.533	0.130	0.13	0.17	0.12
14	2500	205	62.485	0.130	0.11	0.14	0.11
15	2500	214	65.228	0.130	0.13	0.16	0.12
16	2480	232	70.714	0.140	0.17	0.20	0.14
17	2480	243	74.067	0.150	0.19	0.22	0.15
18	2480	218	66.447	0.140	0.14	0.17	0.12

Table 8: Observed Standard Deviation for each approaches and RMSE between different approaches with the measured porosity from the core for Berea Sandstone.

Standard Deviation			
ϕ **Core**	ϕ ***Eq.2***	ϕ ***Eq.5***	ϕ ***Eq.9***
0.01	0.05	0.04	*0.03*
RMSE			
	ϕ– Core and ϕ-Eq.2	*ϕ– Core and ϕ-Eq.5*	*ϕ– Core and ϕ-Eq.9*
	0.046	0.036	*0.025*

Table 9: Observed Standard Deviation for each approaches and RMSE between different approaches with the measured porosity from the core for Bedford Limestone

Standard Deviation			
ϕ **Core**	ϕ ***Eq.2***	ϕ ***Eq.5***	ϕ ***Eq.9***
0.01	0.04	0.03	*0.02*
RMSE			
	ϕ– Core and ϕ-Eq.2	*ϕ– Core and ϕ-Eq.5*	*ϕ– Core and ϕ-Eq.9*
	0.035	0.055	*0.018*

6. BEST WORKING CONDITON

Equation (9) gives a good estimate and accurate porosity results if:

1. The density and neutron data are missing or absent.
2. The well suffers from rough hole conditions or irregularities.
3. The lithology is shale free (the equation designed for clean formation).
4. Sonic transit time must be less than 100 µsec/ft
5. Matrix transit time must be known and constant.
6. For dolomite, another equation is highly recommended.

CONCLUSIONS

The paper introduced an equation for estimating porosity from acoustic logs, particularly *where no* other porosity tools are available such as density and neutron logs, taking into consideration the effect of both matrix and fluid types.

This approach was simply achieved by merging Raymer et,al.(1980) transform and Raiga-Clemenceau et al. (1988) since the first takes into account the effect of matrix and fluid transit time whereas the second takes only the effect of matrix transit time and matrix nature into consideration. However, the proposed equation combines in its structure all parameters included in both equations, which enhances the accuracy of computing porosity from acoustic logs.

This equation, was tested among a wide variety of samples representing sandstone and limestone lithology and gives a very close results with those of measured values.The proposed equation is highly recommended when the sonic transit time is less than 100□sec/ft where its result is good when compared with other approaches. The proposed equation is not recommended if the matrix is dolomite, since when x = 2, the calculated sonic derived porosity from equation (9) must be zero, so another transform must be applied.

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