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An Approach for Estimating Porosity from Sonic-Logs in Shaly Formations

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Abstract. The determination of bulk volume water (BVW) and hydrocarbon (BVHC) involve the determination of effective porosity (ϕ). Log analysts evaluate porosity either from core measurements or analysis of porosity tools (density; ρ_b, neutron; ϕ_N, and acoustic; Δ_t). In the absence of core measurements, much useful information about porosity can be known by using a combination of at least two of these logs. The lack of these porosity tools makes the determination of porosity difficult. At present, there are several equations for computing porosity from sonic transit time; the most common available log in the wells and formations. An equation for estimating effective porosity values from sonic and a gamma ray (GR) log was established for different lithologies. Based on the reformulation of a certain known equation, it is essential to apply it in a shaly formation. This equation yields good porosity values when compared with the actual porosity existing in the same field. The mechanism of this equation and the results obtained, are illustrated by field example.

Introduction

In quantitative well log interpretation, the computation of formation resistivity factor (F), water saturation (S_w), permeability (k), and hence, bulk volume water and hydrocarbon (BVW and BVHC) involve the determination of porosity (ϕ). A large proportion of past effort has gone into improving the accuracy and detail with which the values of porosity can be obtained. This has included both improvements to the logging tools, and improvements to analytical techniques. Conventionally, log analysts evaluate porosity either from core measurements or from well log analysis of porosity tools (density; ρ_b, neutron; ϕ_N, and acoustic; Δ_t).

All of these logs respond in a different manner to the variations in the porosity, fluid content and lithology. With the exception of core measurements, the porosity tool responses can all be defined by equations in which porosity is a factor, and which can therefore be solved for porosity, if values of the various other factors can be defined. Thus, much useful information about porosity can be gathered by using a combination of at least two of these logs (Kamel et.al., 2002), particularly in the presence of shaliness or hydrocarbons (Alger, 1980). In most cases, the lack of these porosity tools makes the determination of porosity very difficult. In order to be able to reliably evaluate porosity of a formation free of shale, the matrix and fluid types must be taken into account. This can be done if all parameters affecting porosity are linked together in a compatible way. Since sonic transit time and GR logs are the common available logs in most of the wells and formations, this paper aims to introduce an equation solving for estimating porosity; ϕ_S, from acoustic and GR readings, which is equivalent to effective porosity, specifically in the case of absence of other porosity tools, taking into considerations the matrix and fluid parameters. This equation, after being tested in a variety of cases, reflects its ability for determining such parameter.

Sonic Derived Porosity Equation

In 1980, Raymer *et al.* introduced a simple sonic porosity transform that is currently coming into use. His equation is essentially empirical, based on comparison of transit time with core porosities and porosities derived from other logs. The transform can be approximated with adequate accuracy in the region of interest by the equation.

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

where $\mathbf{\Delta_{tf}}$ is the transit time of the fluid depending on whether saline or fresh and $\mathbf{\Delta_{tma}}$ is the matrix transit time, which equal to 54 µsec/ft for sands, 49 µsec/ft for limestone, and 44 µsec/ft for dolomite. Equation (1) can be re-written as:

$$\Delta_t = \frac{\Delta_{tma}\Delta_{tf}}{(1-\phi_S)^2\Delta_{tf} + \phi_S\Delta_{tma}} \tag{2}$$

By re-arranging equation (2), we obtain:

$$\phi_s^2 + \phi_s\left(\frac{\Delta_{tma}}{\Delta_{tf}} - 2\right) - \left(\frac{\Delta_{tma}}{\Delta_t} - 1\right) = 0 \tag{3}$$

The above equation yields an expression of the type:

$$Ax^2+Bx+C=0 \tag{4}$$

The roots of equation (4) are:

$$x = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \tag{5}$$

Where: A= 1, B= $\left(\frac{\Delta_{tma}}{\Delta_{tf}} - 2\right)$, C= -$\left(\frac{\Delta_{tma}}{\Delta_t} - 1\right)$, and $x = \phi_S$

Equation (5) to be applicable in shaly formation, another shale term, represented by its volume "V_{sh}", must be added, which takes the form of:

$$V_{sh}\left(\frac{-B \pm \sqrt{B^2 - 4AC_{sh}}}{2A}\right) \tag{6}$$

Where: C_{sh}= -$\left(\frac{\Delta_{tma}}{\Delta_{tsh}} - 1\right)$

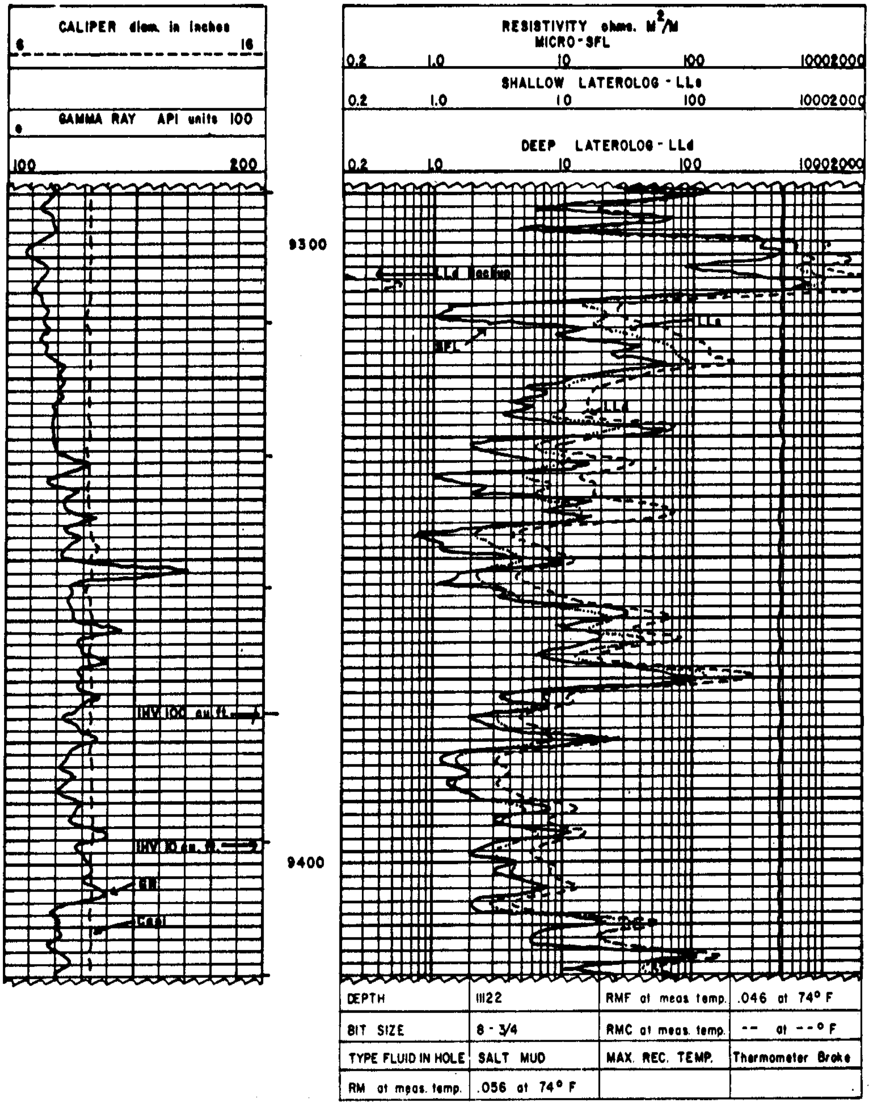
From equations (5) and (6), proposed effective porosity can be calculated using the following equation:

$$\phi_e = \left(\frac{-B \pm \sqrt{B^2 - 4AC}}{2A}\right) - V_{sh}\left(\frac{-B \pm \sqrt{B^2 - 4AC_{sh}}}{2A}\right) \tag{7}$$

Testing the Suggested Equation

Asquith & Gibson (1982) presented several case studies for evaluating major petrophysical parameters. One of these cases, confined to the Mississippian Mission Canyon Formation of Williston Basin, USA within the interval from 9308 to 9400 ft., was taken as a good example to serve the author’s objectives. This well includes the complete log package in the form of electric log suite for resistivity measurements

(*MSFL, LLD,* and *LLS*), and both a combination Neutron-Density Log and a sonic log for porosity measurements as being shown in Fig.1 (a-b-c and d). These logs were digitized every 0.1 foot. The available core indicates that this interval consists of microcrystalline dolomite, limestone and anhydrite rocks.



DEPTH	11122	RMF at meas. temp.	.046 at 74° F
BIT SIZE	8 - 3/4	RMC at meas. temp.	-- at --° F
TYPE FLUID IN HOLE	SALT MUD	MAX. REC. TEMP.	Thermometer Broke
RM at meas. temp.	.056 at 74° F		

Fig. 1 (a). Dual Laterolog-MSFL with Gamma Ray Log and Caliper, Mississippian Mission Canyon Formation, Williston Basin, USA (After Asquith and Gibson, 1982).

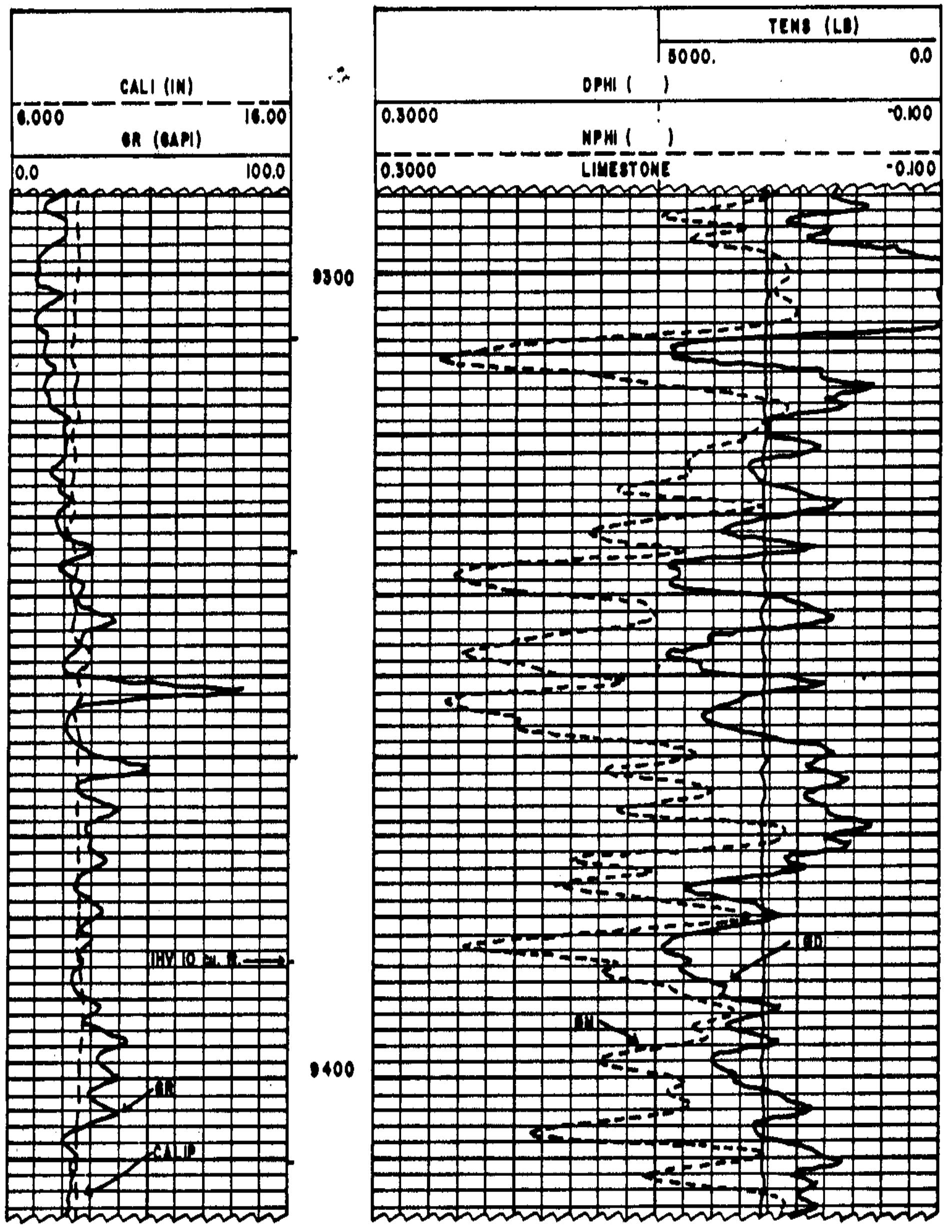


Fig. 1 (b). Combination Neutron-Density Log with Gamma Ray Log and Caliper, Mississippian Mission Canyon Formation, Williston Basin, USA (After Asquith and Gibson, 1982).

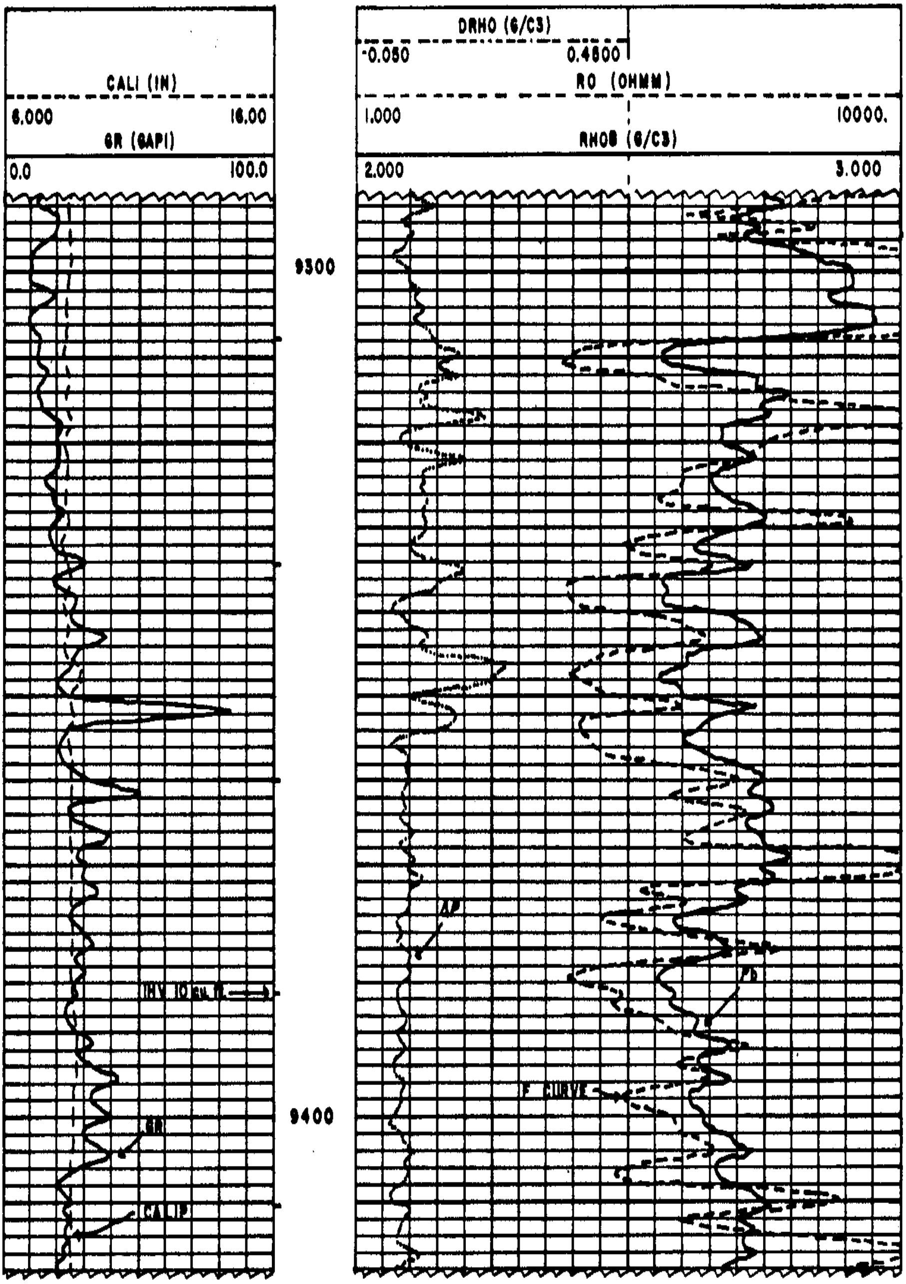


Fig. 1 (c). Density Log with F Curve, Gamma Ray Log and Caliper, Mississippian Mission Canyon Formation, Williston Basin, USA(After Asquith and Gibson, 1982).

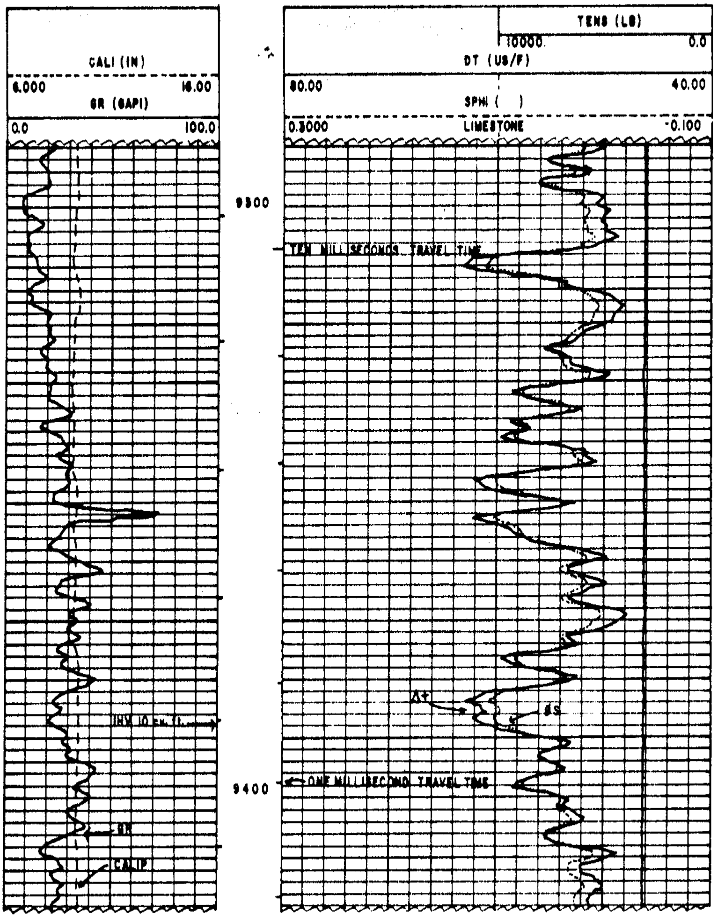


Fig. 1 (d). Sonic Log with Gamma Ray Log and Caliper, Mississippian Mission Canyon Formation, Williston Basin, USA (After Asquith and Gibson, 1982).

For each depth, the analysis takes the following steps:

1. Compute the sonic derived porosity from the available sonic data using the equation adopted by Dresser Atlas (1979) which takes the following form:

$$\phi_s = \frac{\Delta_t - \Delta_{tma}}{\Delta_{tf} - \Delta_{tma}} - V_{sh}\frac{\Delta_{tsh} - \Delta_{tma}}{\Delta_{tf} - \Delta_{tma}} \tag{8}$$

taking $\Delta_{tma} = 44.4$ μsec/ft, $\Delta_{tf} = 185$ μsec/ft, $\Delta_{tsh} = 70$ μsec/ft and shale volume can be determined using GR readings (Schlumberger, 1975).

2. With the help of sonic transit time “Δt” and all constants for matrix, fluid and shale parameters mentioned above, one can easily compute the effective porosity using the proposed formula (Eq.7).
3. Comparing the porosity derived from Dresser Atlas (equation 8) and the suggested equation (7) with those computed using the traditional technique, which is based on the density-neutron data via the following equation:

$$\phi_e = \phi_{ND} - V_{sh}\phi_{sh} \tag{9}$$

to come with the benefits of the new proposed approach.

Figure 2 shows comparison between porosities calculated using Dresser Atlas (1979) equation (Eq.8) and that derived from porosity logs (Eq.9). A close correlation, expressed by high correlation factor of 0.96 could be noticed. In Fig. 3, correlatable results are obtained from the comparison of the values of the porosity derived from the proposed equation (Eq.7) and those derived using equation 9 (R-squared equal to 0.97). Figure 4 shows comparison between the minimum, maximum and average values of the porosity obtained form different approaches. It is clear that the results of Eq. (7) is more close to the measured values (Eq.9), which is obtained from the neutron-density porosity than Dresser Atlas Equation (Eq.8).

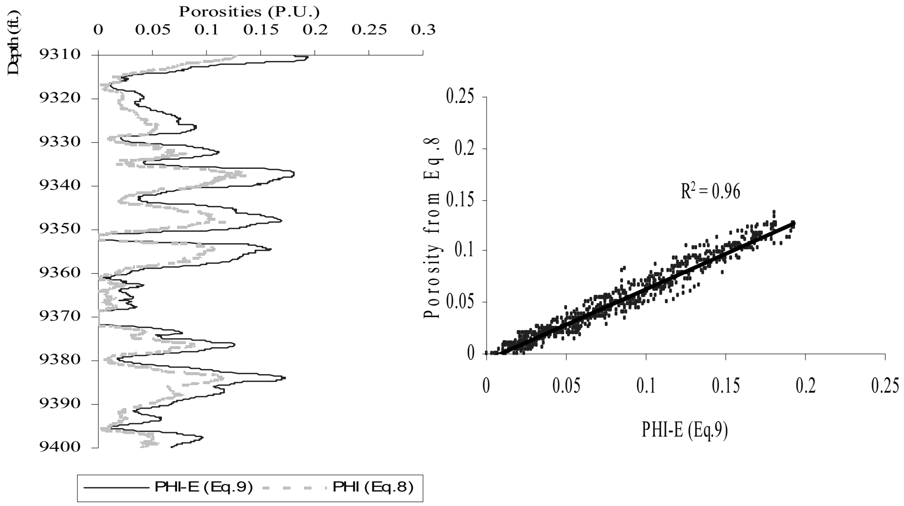


Fig. 2. Comparison between porosity measured and calculated from Dresser Atlas, with correlation, Mississippian Mission Canyon Formation, Williston Basin, USA.

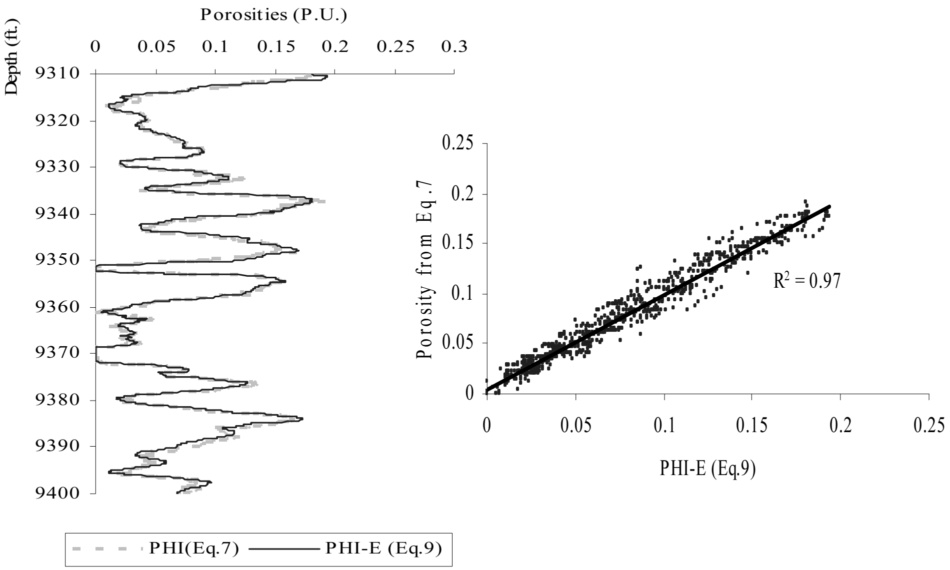


Fig. 3. Comparison between porosity measured and calculated from suggested Eq. (7), with correlation, Mississippian Mission Canyon Formation, Williston Basin, USA.

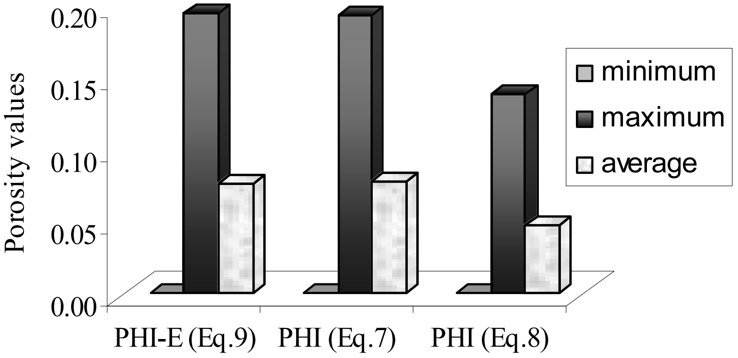


Fig. 4. Comparisons of minimum, maximum and average values of the obtained porosity of different approaches, Mississippian Mission Canyon Formation, Williston Basin, USA.

Application

Equation (7) is applied for computing effective porosity to one well in the central part of the Gulf of Suez Basin of Egypt. The choice of this well is based mainly on its completeness of the well log suites required to test the validity of the proposed equation. A depth interval of 00 to 050 was selected as an example for computing effective porosity using suggested formula. A comparison could be established between the computed porosity values using Eq. (7) and those (PIGN) computed using petrophysical interpretation program "ELANPlusTM" of Schlumberger (1997). ELANPlus depends on the three porosity tools (density; $\Delta \boldsymbol{b}$, neutron; $\Delta \boldsymbol{N}$, and sonic; $\Delta \boldsymbol{t}$) in calculating porosity

The results are shown in Fig. 5 which indicates that the suggested equation gives an accurate porosity values as compared with that derived by the well-established Schlumberger (1997) scheme.

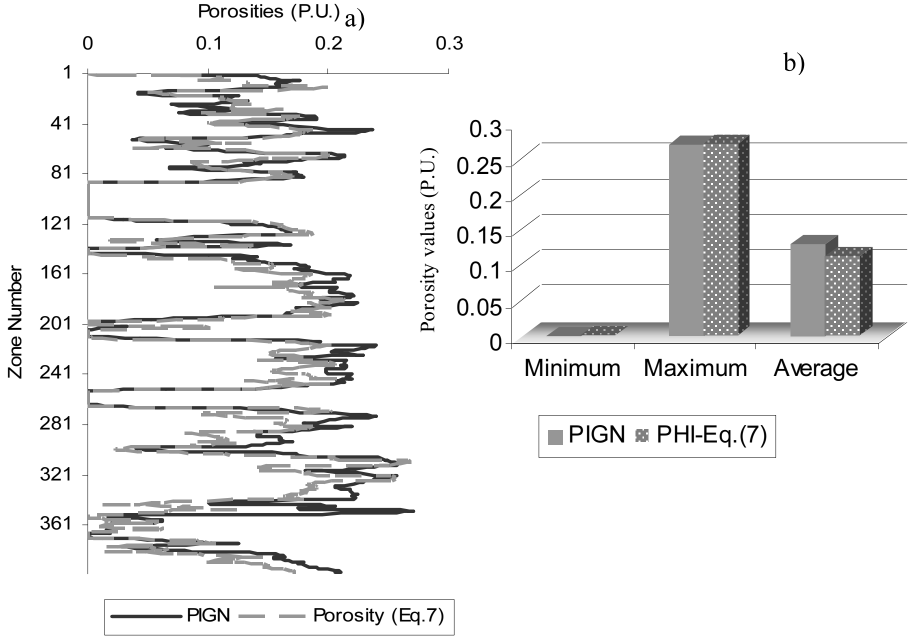


Fig.5. a) Vertical variation of the porosities calculated from ELAN's program and Eq. (7). b) Minimum, maximum and average values of the calculated porosities from both approaches, Gulf of Suez Basin, Egypt.

Conclusion

An equation for estimating sonic-derived porosity from acoustic logs, in the absence of density and neutron information, was introduced. It includes the effect of matrix, shale and fluid parameters. It is essentially based on the reformulation of Raymer *et al*., (1980) equation to be applicable in shaly formation. This equation yields good porosity values when compared with the porosities derived by other published approaches. Two field examples are used to test and apply the suggested formula; one form USA and the other from Egypt, to illustrate how far such treatment is reliable and accurate. Finally, there are still many raised questions needed to be answered; 1) What is the limitation of the proposed equation? 2) Can this equation be used with any types of lithology? Considerable extensive data are needed to more rigorously test the equation.

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Nomenclature

BVW: Bulk Volume Water.

ρ_b : Bulk Density (gm/cc).

F: Formation Resistivity Factor.

ϕ_s : Sonic-Derived Porosity (% or P.U.).

Δ_{tma} : Matrix Transit Time (msec/ft).

P.U. : Porosity Unit.

LLS: Laterolog Shallow.

S_w : Water saturation.

V_{sh} : Shale volume (%).

PHI-E: effective porosity(ϕ_e).

ϕ_t : total porosity (Density-Neutron Porosity).

PIGN: Effective Porosity from ELAN's Program.

Δ_t: Sonic transit time (msec/ft).

ϕ_n : Neutron-Derived Porosity (% or P.U.).

K: Absolute Permeability (md).

Δ_{tf} : Fluid Transit Time (msec/ft).

Δ_{tsh} : Shale Transit Time (msec/ft).

RMS-error: Root Mean Square Error.

MSFL: Micro-Spherically Focused Log.

ϕ : Measured porosity.

Lld: Laterolog deep.

BVHC: Bulk volume hydrocarbon.

ϕ_{sh} : Shale porosity.

GR: Gamma ray readings.(API.).

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طريقة لتعيين مسامية الصخور من تسجيلات الآبار الصوتية في تكوينات الطفلة

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المستخلص. يتم تعيين الحجم الكلي للماء والبترول بعد معرفة المسامية المؤثرة للصخور. فى العادة يتم تعيين مسامية الصخور إما عن طريق فحص العينات الصخرية أو من تحليل تسجيلات الآبار الخاصة بأدوات تسجيلات المسامية. وفى حالة عدم توافر عينات صخرية صالحة لإجراء القياسات، فإنه يتم الاستعانة بالمعلومات المتوافرة لاثنين على الأقل من تسجيلات المسامية، أما في حالة عدم وجود مثل هذه التسجيلات فإنه من الصعب تقدير مسامية الصخور. ويوجد في الوقت الحاضر العديد من المعادلات الرياضية التي عن طريقها يتم حساب مسامية الصخور من بيانات زمن الموجات الصوتية (sonic transit time)، والتي تعتبر من أكثر البيانات توفرًا لمعظم التكوينات الصخرية في أغلب الآبار. تم في البحث الحالي استنباط معادلة يتم من خلالها حساب المسامية المؤثرة من بيانات تسجيلات الصوت، وأشعة جاما لعدد من التكوينات الصخرية. هذه المعادلة الجديدة تمثل في الحقيقة إعادة لصياغة معادلة تصلح لتكوينات الطفلة، ولقد تم تطبيق هذه المعادلة على بيانات حقلية وأعطت قيم للمسامية مساوية للقيم المعروفة عن نفس التكوينات الصخرية.