

Determination of Archie's Tortuosity Factor from Stoneley Waves in Carbonate Reservoirs

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Abstract: One of the fundamental equations in calculate the saturation of fluid in hydrocarbon reservoirs is the Archie's equation. In addition to the parameters measured by well logging such as porosity and resistivity, there are others parameters that called Archie's coefficients. Archie provides constant values for this coefficient base on experimental core's data, accordance with saturation formula in sandstone. In carbonate reservoirs nevertheless the sandstone reservoirs, high heterogeneity, variety in lithology and texture, shape and distribution of pores, due to this coefficient is not constant. So, variation of tortuosity as a coefficient that depends on the way correlation between pores, is high and considering a constant value due to error in calculation of fluid saturation. In this study, with the stoneley waves measured from DSI tools and required calculation, the value of tortuosity coefficient calculated continuously in well no.10 Darkhovin field. The regression of calculated values with the core data is 83.16 percent, that showed this method is useable for calculation the tortuosity.

Keywords: Archie's equation, tortuosity, DSI tool, Stoneley waves.

1. INTRODUCTION

Geological surveys, which include geophysical and geochemical methods and remote sensing, are widely used [1-13]. One of these applications is using in carbonate reservoirs. One of the most important parameters in reservoir, is fluid saturation [14-17] which can be studied by geophysical methods and well-logging [18, 19]. Several formulas are given for saturation calculation. The fundamental equation provides by Archi. In his formula, addition the parameters that measured from well logging such as the resistivity and porosity, there are three parameters called Archie's coefficient (equation1)

$$F = \frac{a}{\phi^m} \quad (1)$$

where F is formation factor, m is cementation coefficient, a is tortuosity coefficient and ϕ is porosity.

Archie provided constant values for this coefficient base on core analysis and correlating them with saturation formula defined for sandstone. In carbonate rocks, unlike sandstone rocks, the high degree of heterogeneity, variety of lithology and texture, pores shape and their distribution due to have large variety. So variation of tortuosity coefficient, which depends on the way of pores connection and form of relevant conduits, is high and considering a constant value of this parameter as done in sandstone reservoirs cause large error in fluid saturation calculation. There are direct and indirect methods for determining this coefficient. Direct method and in direct method such as core's experimental and NMR logging respectively. Another method is using the DSI

logging. With this method can determining tortuosity and permeability by less cost and time. An acoustic waveforms contain valuable information. With used the Stoneley wave can provide relation for calculating the permeability and tortuosity.

Quantitative modeling by resonbeaum(1974),Schmitt and Bouchon(1984) [20], and by Schmitt et al.(1988)[21] supports the conclusion that attenuation increases with permeability and with pore fluid mobility; i.e., attenuation decrease as pore fluid viscosity increase. Resonbaum based his finding on synthetic acoustic signals covering a wide range of frequencies. Hornbyetai. (1989), Tang and Cheng (1988) [22], and Giiler and Toksoz (1987) [23] have studied the propagation of Stoneley wave across borehole fractures. Beri and et.al (2000) [24] proposed equation that by using it, can calculated the Stoneley slowness in nonpermeable zone. Al-adani and Barati (2003) [25], studied the effect of permeability on Stoneley slowness. They presented Stoneley slowness in around the borehole is divided in to stoneley slowness in nonpermeable and permeable zones. Hadavand and Moradzadeh (2007) [26] used Al-adany's method in sandstone reservoir. They showed this method in carbonate and sandstone reservoirs is useable. Mosalman Nejad (2008) compared the permeability that obtained from Stoneley waves, with permeability from NMR logging and showed that the result of Stoneley waves is more similarities with cores analysis. Sun and et al. in 2012 studied the full spectrum of sonic waves and examining permeability associated with each type of sonic waves. They found that changed in the speed and extent of slowness in Stoneley wave is more appropriate with permeability. Guan and et al. (2013) [27] investigated

Stoneley waves in pore water saturated and obtained a continuous log that showed the permeability changes in around of the borehole.

In this study by using Stoneley slowness and shear waves from DSI tools, the tortuosity has calculated as a continuous log around the borehole [25].

It is worth mentioning that in addition to all studies on mineral and organic resources, in any study can be discussed the beauties of the area and the discussion of geotourism [28].

2. METHODOLOGY

At low frequency the Stoneley mode become the tube wave and propagates as a piston-like compression of the borehole. When the borehole crosses permeable zones or permeable fractures, some fluid movement occurs between the borehole and the formation. this results in some energy loss, hence attenuation and a slowing down of the wave, hence increased Stoneley wave slowness (Brie 2000) [24]. The elastic slowness of a Stoneley wave at low frequencies in an elastic formation (non-permeability) is calculated using the expression in equation 2:

$$\Delta t_{st-el}^2 = \frac{\rho_m}{\rho_b} (\Delta t_{sh})^2 + \Delta t_{bf}^2 \quad (2)$$

Δt_{st-el} is the slowness in nonpermeable zone

ρ_b is the bulk density of the rock

Δt_{bf} is the borehole fluid(mud)slowness.

ρ_m is the density mud

Δt_{sh} is the shear slowness of the rock

The difference between Δt_{st-el} and Δt_{st} indicates a fluid mobility indicator.

By cross plotting Δt_{st-el} versus $\frac{\Delta t_{sh}}{\rho_b}$ across non permeable

zones, the slope of the straight line is ρ_m and y-intercept is Δt_{bf}^2 . There is one condition on such linear fit, that all data on cross plot should be above or on the fit line. With determining Δt_{bf}^2 , can calculate the Δt_{st-el} around the borehole, according to the equation 3.

$$\Delta t_{st} = \Delta t_{st-el} + \Delta t_p \quad (3)$$

The ratio of $\frac{\Delta t_{st-el}}{\Delta t_{st}}$ represent the way pores media that called permeability index. Permeability index is not permeability estimation, but it is an index of fluid movement in porous media around the borehole. Since fluid movement is a function of pore throat distribution, pore shape and pore size, the Stoneley permeability index is a tortuosity index only.

3. DATA ACQUISITION

In this study target is determination the tortuosity factor by Stoneley waves in one of the carbonate reservoirs in Southern Iran. This reservoir is located at the oil field with limestone lithology that belongs of construction to the flat plateau Arabic. Fahlian formation is the reservoir rock of this field that has about 500 meters carbonate deposit. In this present

study well, Resistivity, SGR, NPFI and Sonic logs were acquired. That showed in figure 1. Clay type cannot be identified accurately due to very low concentration of clay in the zone of study. Illite was assumed as main clay in this formation.

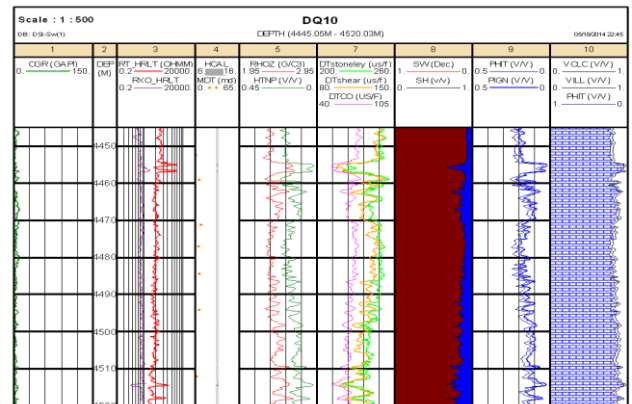


Figure1. Petrophysical logs in well study

4. RESULTS AND DISCUSSION

Using the Stoneley wave that measured by DSI tool for calculate the tortuosity factor in this well according above Descriptions.

First with petrophysical logs determined the non-permeable zone. A cutoff 5% was applied to total porosity. Only those zones were taken in to consideration to predict a non-permeable zone that had total porosity less than 5%. The zone that considers as non-permeable zone, locate at 3330 m to 3360m. In this zone the total porosity is less than 5% and the main lithology is limestone. Cross plotting Δt_{st-el}^2 versus $\frac{\Delta t_{sh}}{\rho_b}$ in this zone, showed in figure 2. The slope of straight line is 2.9 that represent the ρ_m and 39000 is refer to Δt_{bf}^2 .

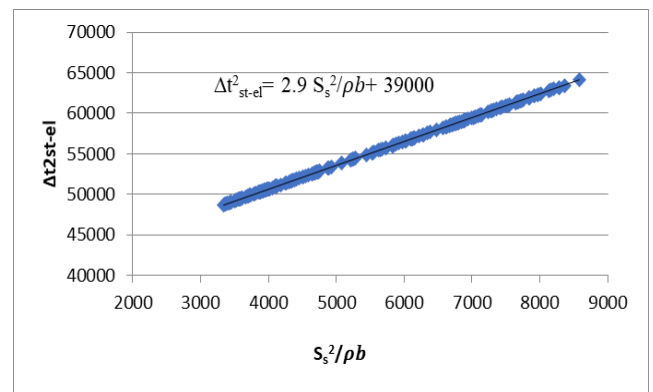


Figure2. Cross plot Δt_{st-el}^2 versus $\frac{\Delta t_{sh}}{\rho_b}$

Now with obtained Δt_{bf}^2 , can calculating the Δt_{st-el} around the borehole. Then with constitute ratio $\frac{\Delta t_{st-el}}{\Delta t_{st}}$, determining the permeability index that can consider as tortuosity factor. In figure 3 and table 1 showed the log of variation of tortuosity continuously and the point that shown on log is tortuosity calculated from core's experimental.

Table1. Comparison between calculated tortuosity and core's tortuosity

Core's tortuosity	Calculated tortuosity
0.98879	0.993344
0.97546	0.976247
0.9823	0.985364
0.98011	0.973307
1	1.001924
1	1.005411

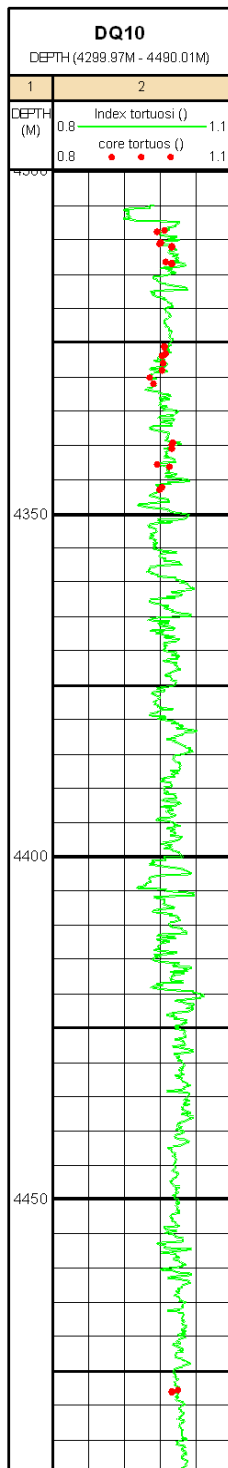


Figure3. Variation of tortuosity continuously and the point that shown upon the log is tortuosity calculated from core's analysis

The regression of calculated values with the core data is 83.16 percent (figure 4), that showed this method is useable for calculation the tortuosity.

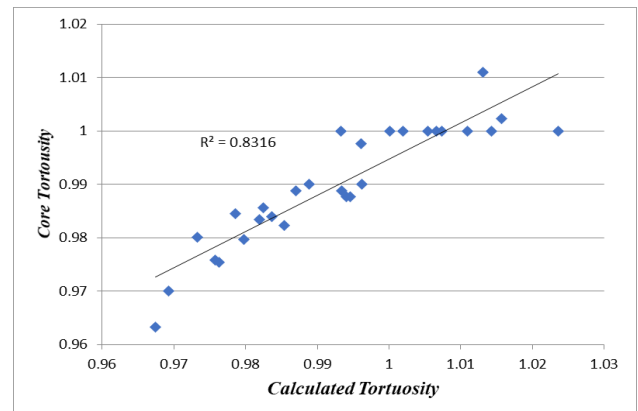


Figure4. comparison between calculated tortuosity and tortuosity from core's experimental.

5. CONCLUSIONS

High heterogeneity, variety in lithology and texture, shape and distribution of pores, in carbonate reservoirs due to tortuosity not constant and has variation. The method that usually used for determined this coefficient is core's experimental. This method is very time consuming and not economically and could not give a continuous log. In this study using the Stoneley wave that measured by DSI tool to calculate the tortuosity coefficient as a continuous log. Results represent to good performance of this method. The regression of calculated values with the core data is 83.16 percent, so this method is useable for calculation the tortuosity. With continuous tortuosity log can calculate water saturation with higher accuracy when use Archie's low.

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