THE EFFECT OF OIL CONTENT ON SONIC WAVE PROPAGATION (Analyses from Well Log Data)

by

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ABSTRACT

The effect of fluid content to the sonic wave propagation in the reservoir rock has been studied experimentally using the well log data. Evidence shows that the water content affects the sonic wave propagation only in a specific interval, while oil content also affects the sonic wave propagation but at a specific low interval. There is a discontinuity where the effect of oil content changes suddenly with an increasing oil content. Higher than this value it seems that there is no effect of oil content on sonic wave transit time.

Key words: Sonic log, sonic transit time, oil content, water content, sonic log interpretation.

I. INTRODUCTION

Oil exists in the pore space of the reservoir rock. Reservoir rock likes sandstone usually contains a certain percentage of clay and other materials. Since they can enter into the pore space, as a result the porosity of the reservoir rock decreases. Porosity is thought to be the pore volume divided by gross volume.

There are two kinds of porosity, i.e., primary porosity and secondary porosity. Primary porosity refers to the porosity which remains after the sediments have been compacted but without considering changes because of subsequent chemical action or flow of water through the sediments. Secondary porosity is additional porosity created by subsequent chemical changes, especially fissures, fractures, solution vugs, and in limestones, porosity created by dolomitization (Sheriff, 1984). There is also effective porosity which is the porosity available to free fluids, excluding unconnected porosity and space occupied by bound water and disseminated shale.

Porosity can be determined from cores, from neutron porosity log, from sonic logs, or from resistivity logs. The determination of porosity from sonic log is due to the fact that the sonic wave propagation is affected by the pore spaces of the reservoir rock.

This paper discusses the effect of oil content on the propagation of the sonic wave which is used in the sonic logging tool. The knowledge is derived from experimental works. The author hopes that this knowledge will be useful in identifying oil in the reservoir rock from well log data. This evidence will certainly complement the existing method which uses resistivity log.

II. THEORETICAL BACKGROUND

Although sonic logging tool may generate acoustic and elastic waves, we limit our investigation in the acoustic case only. As can be seen in Figure 1., the sonic logging tool measures the transit time of the acoustic compressional wave around the borehole from level A to level B. The transmitter of the sonic logging tool emits the compressional waves with a frequency around 20-25 kHz (Debrandes, 1985; and Ellis, 1987). If the wall around the borehole consists of reservoir rock, this transit time is affected by the matrix, the pore space and the fluid within the pore space, more specifically the transit time depends on clay content, grain size, shape distribution, cementation and many others.

The effect of fluid content on the propagation of sonic wave can be explained in a simple manner using the time-average equation introduced by Wyllie

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et al. (1956). This is the commonly used relation in the interpretation of sonic logs. This equation is applicable in the determination of the intergrain porosity of reservoirs and has provided satisfactory results. It must be noted that this is an engineering equation without scientific basis in fact and has been extrapolated beyond reason (Geerstma and Smit,1961). The time-average equation is given by:

$$\boxed{\frac{1}{V}=\frac{\phi}{V_f}+\frac{(1-\phi)}{V_m}} \qquad (1)$$

Where: ϕ is the porosity

is the average velocity of the compressional wave of the reservoir rock

V_m is the compressional wave velocity in the matrix or grain.

V_f if the compressional wave velocity in the fluid filling the pore space.

More detail investigation of the Wyllie's time- average equation can be presented using the model given below (see Figure 2). In this model the pore spaces and the grains are grouped into two different parts (Figure 2b). Rearranging equation (1) algebraically, we obtain:

$$\boxed{\frac{1}{V}=\left(\frac{1}{V_f}-\frac{1}{V_m}\right)\phi+\frac{1}{V_m}} \qquad (2)$$

In the coordinate system where absica represents ϕ (porosity) and ordinate represents (slowness or) equation (2) graphically can be illustrated as a straight line with a slope equal to α and intercept equal to (see Figure 3). This slope is:

$$\boxed{\tan\alpha=\left(\frac{1}{V_f}-\frac{1}{V_m}\right)} \qquad (3)$$

The slope here is positive which represents that the slowness increases when the porosity decreases, in other word, the velocity decreases when the porosity increases.

It can be seen that the slope changes when V_f changes and V_f changes when there is an increase of fluid content in the pore space.

Despites the Wyllie's time average equation which has been used to explain the velocity in a porous res

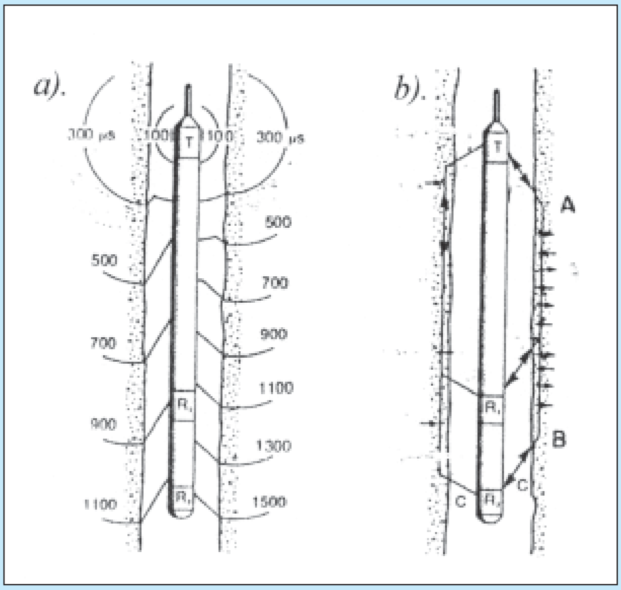

Figure 1
The sonic logging tool in the borehole
a). Wavefronts. b). Ray paths

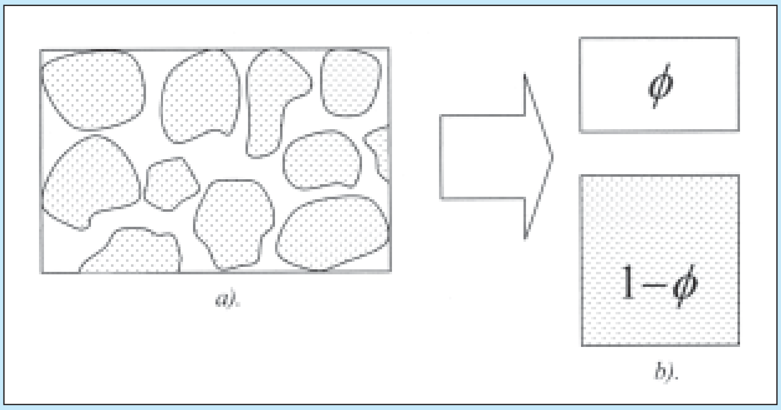

Figure 2
Modeling of porous rock according to Wyllie's time average equation. a). The reservoir rock model. b). The basic constituent

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ervoir rock containing fluid, there is also another theoretical approach proposed by Gasmann (1951) which can be used for the same purpose. In principle, his theorem explain that the wave propagation in a porous rock containing fluid can be expressed as:

$$Cp = (M / \rho)^{1/2} \qquad (4)$$

Where according to White and Sengbush (1987) and Schon (1996):

$$M = \overline{M} + \frac{\left(1 - \bar{k} / k_s\right)^2}{\phi / k_f + (1-\phi)/k_s - \bar{k}/k_s^2} \qquad (5)$$

k_s is the bulk modulus of the matrix or grain.
k is the density of the porous saturated rock.
$\bar{k}$ is the bulk modulus of the rock skeleton.
is the plane wave modulus of the rock skeleton.
M is the plane wave modulus of the saturated rock
k_f is the bulk modulus of the fluid.
ρ is the bulk density of the porous saturated rock
ϕ is the porosity of the porous rock.

It can be concluded that the bulk modulus plays an important role in the propagation of the compressional wave, and that the bulk modulus of the saturated rock equals to the bulk modulus of the skeleton plus a term which depends on the fluid. Besides, there is another elastic constant which is referred to as the plane wave modulus which governs the speed of the compressional wave, i.e.,

$$M = k + \frac{4}{3}\mu \qquad (6)$$

Where μ is the rigidity.

III. METHODOLOGY

The methodology used in this study consists of several steps listed below :

1. Determine specific field and collect well log data.
2. Understanding reservoir geology of the study area.
3. Select specific reservoir intervals.
4. Read digital well log data : gamma ray, resistivity, density, neutron porosity and sonic transit time.
5. Cross plotting reservoir parameters versus sonic transit time.
6. Critically analyse the behavior of the cross plots which correspond to oil content.

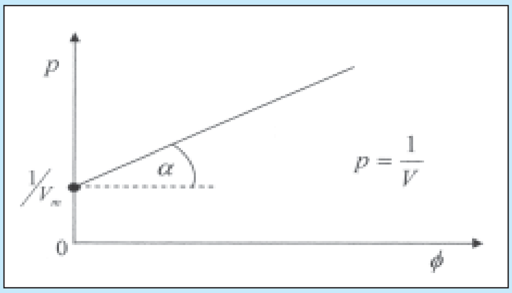

Figure 3
Relationship between porosity and slowness of the compressional wave in a porous rock containing fluid

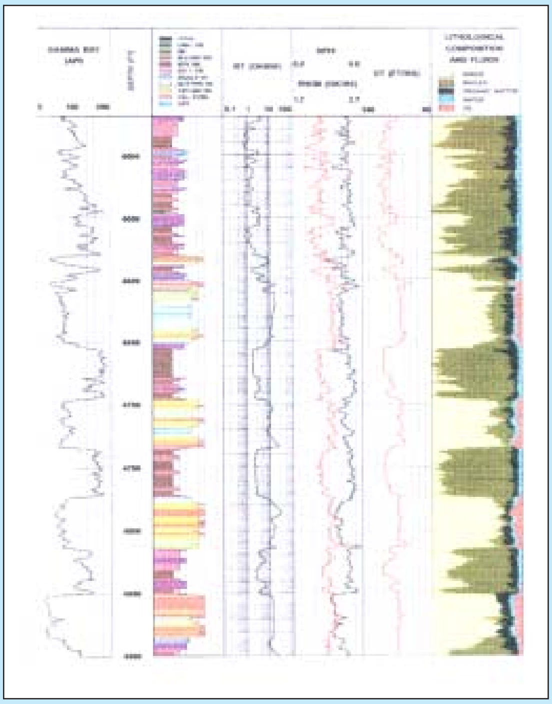

Figure 4
Well log data and the result of log analysis in a specific formation which contains reservoir rock. The well log data consists of gamma ray, density, resistivity, sonic and neutron

7. Drawing conclusion from the behavior mentioned above.

IV. RESULTS AND DISCUSSION

In this study the field is located in Central Sumatra Basin where a specific well is chosen, and for the sake of secrecy we do not want to mention the name of the field neither the name of the well. The result of well log analysis from the selected formation along this well is illustrated in Figure 4 (Suprajitno, 1998). We hope that this figure explains itself the necessary information related to reservoir rock in terms of the measured petrophysical properties.

Investigation has been carried out to study the behavior of sonic wave transit time if the oil and water content within the reservoir is changed. For this purpose reading log data values every inches has been carried out. The result is depicted in Figure 5.

Figure 5 is the behavior of sonic transit time when the fluid content is changed. It is taken from the well log data from Central Sumatra basin. It can be seen that for an oil content less than 2 %, the value of the sonic transit time decreases gradually from 114ms/ft down to 100 ms/ft. Then, with the increase of oil content from 0.00 to 0.14, there is a discontinuity which is located around 0.02 which marks the sudden drop in the sonic transit time from 100 ms/ft to 90 ms/ft. This drop seems to be caused by the increase of water content. Further increase of oil content from 2 % up to 13 % shows that there is no effect of oil content on sonic transit time.

The above figure explains that oil content in the reservoir rock increases the velocity of the sonic wave. The sudden transition in the velocity perhaps is due to sand shale ratio of and coal content in the reservoir.(we have the corresponding sand shale ratio as a function of sonic transit time and the corresponding organic matter/coal content as a function of sonic transit time) and the increase of water content.

Another interesting fact is the evidence on the effect of water content to the propagation of the sonic wave. Figure 5 demonstrates the existence of two clusters which show the density of the water content falls in two separate regions, i.e., the region above 90 ms/ft and the region below 90ms/ft. Both are located within an interval of the fluid content between 0.02-0.07. This fact explains that the water content in the reservoir rock affects the sonic wave propagation only in a specific interval. Outside this interval, there is no influence of water content to sonic wave propagation. This is by contrast to oil content. Its influence happens over a very specific interval which indicates low oil content.

V. CONCLUSION

Oil content affects the sonic wave propagation in a specific manner: at low interval of oil content, the sonic transit time decreases gradually and drops suddenly at a specific value, above this value the sonic transit time seems does not change with the increase of oil content. The water content affects the sonic wave propagation in a specific interval of water saturation.

Although the result reported in this study is not conclusive and cannot be generalized , however this work gives some idea about the effect of oil and water content on the propagation of the sonic waves in the reservoir rock. We hope that this result may give specific contribution for the interpretation of sonic log related to fluid content of the reservoir rock.

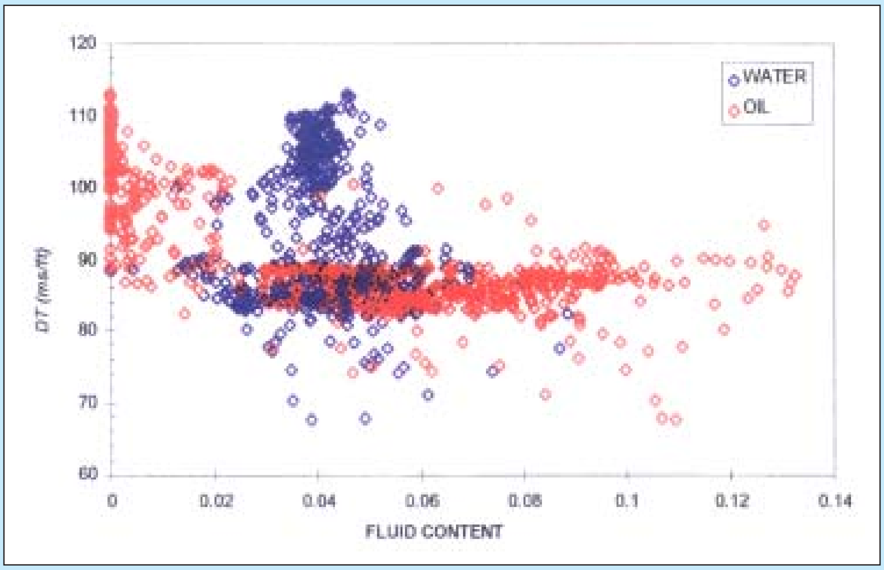

Figure 5
The behavior of sonic transit time in the reservoir rock as fluid content increases. Red indicates oil and blue indicates water. Unit msec means micro second

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