THE EFFECT OF GRAIN SIZE DISTRIBUTIONS ON ACOUSTIC WAVE VELOCITIES IN POROUS ROCKS

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Abstract:

This paper presents the result of the study to established correlation between grain size distribution and a acoustic wave velocity of the sandstone and limestone sample by using Ultrasonic Pulse Velocity Method (UPVM). This result also can be used in density and porosity determination . By knowing the rock acoustic velocity data which normally can be estimated from acoustic log and seismic data.

Key words: grain size, acoustic wave velocity

1. INTRODUCTION

Advances in acoustic wave and sonic logging technology have resulted in enhanced formation evaluation capabilities. Acoustic wave velocities in reservoir rocks depend on many parameters, for example , grain size distribution, porosity, pore fluid properties and level of saturation, lithology, clay content, pore structure and geometry, and other physical characteristics. The application of acoustic and sonic wave technology in the petroleum industry has ben limited to measurement of compressional and shear waves. Compressional and shear waves correspond respectively to particle vibration parallel and perpendicular to the direction of wave travel. Acoustic wave measurement in the laboratory and in the field have been used for various applications ranging from determination of porosity , interpretation and calibration of sonic logs. identification of lithology , determination of classical elastic rock parameter and formation , enhanced seismic interpretation , micro fracture recognition and formation damage evaluation.

Acoustic wave from seismic and sonic well log can be correlated from acoustic wave of ultrasonic data in the laboratory. Ultrasonic tester is non destructive testing, and than core sample is not destroyed (non destructive), while correlation between acoustic velocity from physical rock properties can be used to determine and the characteristic of rock will be drill, stimulation (fracturing), and evaluation of reservoir rock. The parameters of rock physical properties can be measured by using two methods, laboratory test and well log analysis. In this paper work had been determined the carried out to physical rock properties from acoustic velocity tester.

The result of this study can predict correlation between grain size distribution be used to acoustic velocity of the rock. The findings care also be used to calculation density and porosity of the rock.

II. LITERATURE REVIEW

The velocity in a rock may be related with the velocities in its various grain size and mineral components. Therefore, it is apt to discuss briefly about these two properties in order to understand the relationship between wave propagation and rock texture. Grains are the particles which support the framework of a rock. They are thus generally of sand grade or larger (Friedman and Sanders, 1978).

The effect of average grain size and sorting on porosity and permeability has been examined periodically. Graton and Fraser (1935) showed that porosity of uniformly sized spheres but are affected by the packing arrangement. However, studies of natural sands and gravels indicate porosity is greater in fine-grained sands than in coarse-grained sands (Lee 1919; Todd 1959). Griffiths (1952) examined the grain size distribution in various reservoir rocks and concluded that no generalized statement could be made as to the effects of size and sorting on porosity and permeability. Rogers and Head (1961) in their study of synthetic sands concluded that in well sorted sands, porosity is independent of actual grain size (Hayes, 1977).

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Theoretically, porosity is independent of grain size. A mass of spheres of uniform sorting and packing will have the same porosity, regardless of the size of the spheres. The volume of pore space varies in direct proportion to the volume of the spheres. Finer sands tend to be more angular and be able to support looser packing fabrics, hence they may have a higher porosity than coarser sands (Friedman and Sanders, 1978).

Whatever the cause of the relationship, it has been shown empirically that porosity generally increases with decreasing grain size for unconsolidated sands of uniform grain size. Permeability, by contrast, increases with increasing grain size (Fraser, 1935; Krumbein and Monk, 1942; Pryor, 1973). This is because in finer sediments the throat passages between pores are smaller and the higher capillary attraction of the walls inhibits fluid flow. This relationship is found in both unconsolidated and lithified (composite) sand (Friedman and Sanders, 1978).

The velocity of waves is influenced by the size of the grains constituting the rock. The velocity is greater in fine-grained rocks than in coarse-grained ones,as had been waiting that finer sediments tends to have smaller throat passages, (grains is well-packed, leaves a compact medium for wave propagation) allow the acoustic wave to propagate faster than in the coarse-grained and loose packing rocks.

III. METHODOLOGY

3.1. SAMPLE PREPARATION

A total of forty-five samples of sandstone and limestone namely S, R and E were taken from Sarawak, Rompin, Pahang of Malaysia and Indonesia basin respectively. Sandstone samples are from Sarawak and Rompin while limestone samples were taken from Indonesia. Three sets of experiment have been carried out, which are SEM Test, Porosity Test and Acoustic Velocity Test.

Malaysian sandstone samples and Indonesian limestone samples of 1 inch diameter and 1 inch length were cored in the laboratory. The samples is conditioning in on oven at 60 ° C for 8 hours and than tested for density, porosity and acoustic compressional wave velocity with Pundit. This procedure permits the *measurement of both P wave velocities.*

Sample Coring

The coring machine has been used along with 1 inch iron bit, had been used to prepared cylinder shapes cores with 1 inch diameter. Then by using cutter machine, the cores were cut into 1 to 1.5 inches length. To ensure there are no fluid left in the cores, all cores has been heated in an oven for 8 hours at 60^{0}C. Core preparation were based on ASTM (ASTM D4543-85). The bulk volume were determined by using the following equation,

$$V_b = 3.142\,(d/2)^2 \qquad (1)$$

Where V_b = bulk volume, d = diameter of core samples, L = length of core samples and 3.142 = constant

Sample for SEM Test

A piece of rocks were taken from each samples and were crushed into 'individual grain' separately. The grains then were scattered onto piece of double-sided tape which attached to a specimen pedestal to produce only a thin layer of grain and labeled as S, R and E samples.

The specimens are coated with gold by thin film deposition, to give the surface electrical conductivity. Thickness of the coating is 100 to 200 angstroms, so thin that the coating does not mask true surface features.

3.2. TEST PROCEDURE

3.2.1. SCANNING ELECTRON MICROSCOPE TEST

SEM Test is important to understand the size of grain that forms the rock samples. The effect of grain size on porosity would be established from the results of the test. The steps to precede the SEM test are as follow;

1. *The labeled sample is place inside a vacuum chamber.*
2. Vacuum pump is switched on to discharge any gas from the chamber.
3. Finely focused electron beam (100A) will scan the specimen surface.
4. Interaction of the electron beam with the specimen surface generates a signal that results ultimately in brightness modulation, thereby producing an image of the specimen surface (SEM image).
5. Grain size were measured from both X and Y-axis of SEM image.
6. The grain size data are recorded.

3.2.2. *HELIUM POROSITY TEST*

The porosity of rock depicts the dimension of pore space of a rock filled by fluid, either oil, gas, water or a combination of thus. In laboratory, the porosity of a rock can be measured using both porosimeter and weighting method.

The procedure to determine the porosity of dry samples by helium porositymeter are ;

1. The source of helium gas from the tank is connected to the panel with all valves of the tool are closed.
2. The core sample is placed in the core holder followed by the discs until it become leveled or slightly lower than the matrix container (core holder). Then, the container is tightening in its place.
3. The source and supply valve are open until the pointer is pointing at 100psi (if not, use the regulator to adjust the pointer). Both valves are then closed.
4. By opening the core holder valve, the movement of the pointer is observed to move anti-clock-wise.
5. Then, when the pointer stops moving, the reading at the outer scale of the Porosimeter is recorded. Moreover, this is the 'volume with sample' (core sample volume + discs).
6. The core holder valve is closed to ensure the gas cannot escape.
7. The exhaust valve is now open to allow zero pressure inside the matrix container.
8. By loosening the cap, get the core sample out of the core holder and tighten the cap again with the disc inside.
9. Steps 3 to 7 are repeated to get the 'volume without sample' (the volume of disc). Gauge reading is taken as 'volume without sample'.
10. Steps 2 to 9 are repeated for another core samples.

Porosity is calculated using Equation (2).

$$\Phi = (V_b - V_g) / V_b \times 100\% \qquad (2)$$

Where Φ = porosity, V_b = bulk volume and V_g= grain volume

3.2.2. ACOUSTIC TEST

Effect of acoustic wave depend on medium elasticity spreading. The transit time of rock is time needed by acoustic wave to principle within is. Acoustic velocity of wave can be determined by the following equation ;

$$\Delta t\ ma = 1/\ Vma\ \times 10^6 \qquad (3)$$

when : Δt ma = transit time , μ sec / ft and V ma = Velocity of acoustic wave in the rock, ft /sec

The instrument indicates the time taken for the earliest part of the pulse to reach the receiving transducer measured from the time it leaves the transmitting transducer when these transducers are placed at suitable points on the surface of the material . In this study a direct method , when the surface of the specimens tasted direct contact whit transducer, had been used.

The direct transmission arrangement is the most satisfactory one since the longitudinal pulses I leaving the transmitter by propagated mainly in the direction normal to the transducer face. In this Non Destructive Test (NDT) Test, electrical wave energy from pulse generator travels from transducer (Tx) as mechanical wave , and than spreading in the rock sample (material). After reaching the receiver transducer (Rx), the wave energy can be retransformed to electrical wave and then it is spread through booster which finally can be used determined time transit by digital numerical or oscilloscope.

Prior to the step, the time of flight for wave is required and can be obtained by placing the transducer holders and the end pieces in face to face condition with a disc of lead foil between them.

The velocities are calculated by dividing the length of the specimen, L, by the appropriate 'pulse time-of-flight, corrected for Δtp. Portable Ultrasonic Non-Destructive Digital Tester (PUNDIT) is a pulsing unit that being used in this study to obtain the acoustic velocity of rocks. Using a frequency of 1MHz, the compressional wave (P-wave) and shear wave (S-wave) velocities are calculated by dividing the length of the specimen, L by the appropriate pulse time-of-flight:

$$V_p = L / t_p \text{ and } \qquad V_s = L / t_s \qquad (4)$$

Where V_p = P-wave velocity, V_s = S-wave velocity, L = length of specimen and t_p and t_s = transit time compress ional and shear wave (pulse time-of-flight)

IV. RESULT & DISCUSSION

Several sets of experiment have been carried out. In order to achieve the correlation between acoustic velocity and porosity, some factors which are now is identified as factors that affecting the correlation will be discussed in this chapter. The discussion will include the results of petrography test, porosity test and acoustic velocity test. The distribution of samples grain size has been determined by scanning electron microscope (SEM) test. And acoustic velocity test by PUNDIT Plus Unit with 1 MHz P & S Wave transducer.

Figures 1, 2 and 3 shows the grain size distribution for Sarawak samples, Pahang Samples and Indonesia samples respectively.

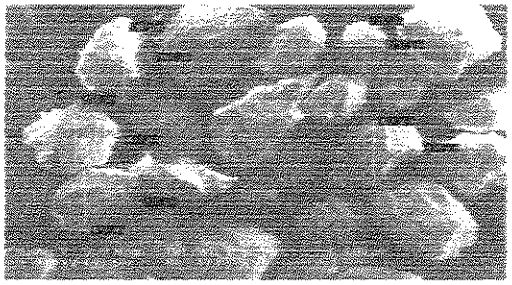

Figure 1: SEM image for Sarawak sandstone sample.

Figure 2: SEM image for Rompin ,Pahang sandstone .

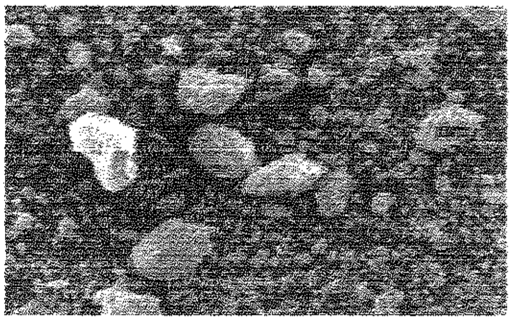

Figure 3: SEM image for Indonesia limestone.

Based on these images, the distributions of grain size are as below;

- Sarawak sandstone: ranges between 286.5µm to 487.5µm.,Average grain size : 418.5µm.
- Pahang sandstone : ranges between 235µm to 324.5µm, Average grain size : 268.3µm
- Indonesia limestone : ranges between 145.5µm to 197µm, Average grain size : 167.1µm

From the analysis, it shows that Sarawak sandstone samples have the biggest grain, followed by Pahang sandstone samples, and the smallest grain size for Indonesia limestone samples. Figures 4 and 5 show graph of acoustic velocity versus grain size for each sample using P-wave and S-wave respectively. Both graphs show that acoustic velocity decreases when grain size increases. This is in line with the theory which stated that velocity is greater in fine-grained rocks than in coarse-grained rocks (R.D.Lama & V.S.Vutukuri, 1978).

The inversely proportional between acoustic velocity and grain size is due to the space between grains. Acoustic waves need medium to travel which is to say the grains. Less grain allow more air between them, and air is not a good medium to transfer acoustic wave. The results of using P-wave and S-wave are same although the velocity of S-wave is slower than P-wave. The correction factor in this result is between R = 0.8492 to R= 0.9683 as significant phenomenon for linear equations.

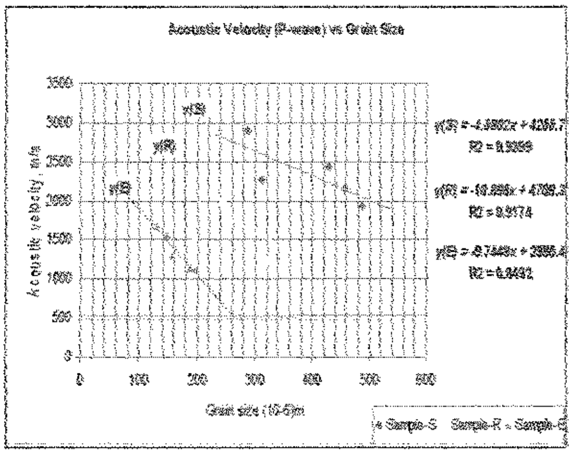

Figure 4: Acoustic velocity by using P-wave versus grain size distribution .

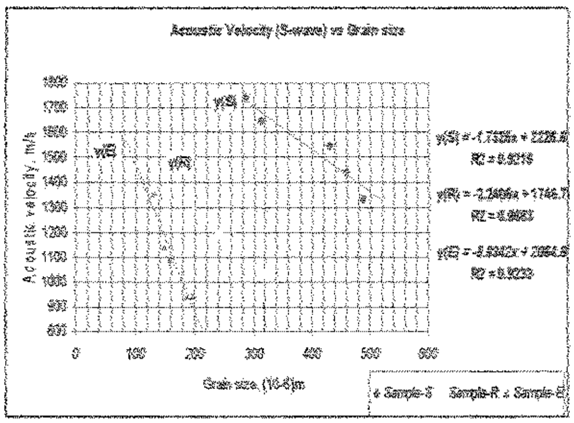

Figure 5: Acoustic velocity by using S wave versus grain size distribution.

V. CONCLUSION

From the study, we can concluded that ;

- There is linear correlation between grain size distribution and acoustic wave velocity of the rock.
- The finer the grain, the greater is the acoustic wave velocity, with the correction factor ranging from 0.8492 to 0.9683.

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REFERENCES

1. Ariffin Samsuri, Herianto, Jarot Setyowiyoto, Petrophysics Study of Sandstone Core To The Accuracy of Ultrasonic Pulsa Velocity, SOMChe 2004, Universiti Teknologi Petronas, Ipoh, Perak, Malaysia, 13-14 December 2004
2. Mohamed Sutan, N. Hamdan S and Jin E.C.C,: The Influence of Porosity To The Accuracy of *Ultrasonic Pulse Velocity Method*; Faculty of *Engineering, UNIMAS, NDT*.net-November 2002, Vol 7 No. 11
3. *Mubarak, S.A, Somerton, W.H., The Effect of Temperature and Pressure on Wave Velocities in* Porous Rocks, SPE 3571, Fall Metting Alternate-October 4, 1971
4. Wyllie, M.R.J., Gregory.A.R., and Gardner.L.W., : Elastic Wave Velocities in Heterogenitas and Porous Media , Geophysics (1956) 21, 41-47.
5. Raymer L.L., Hunt, E.R., and Gardner.J.S : An Improved Sonic Transite Time-To Porosity Transform, SPWLA Twenty-Fist Annual *Conference, July 8-11, 1980*
6. *Nation J.F.,: Lithology and Porosityf rom Acoustic* Shear and Compressional Wave Transite Time Relationships. SPWLA Fifteenth Annual Logging Symposium, June 1974.
7. Domenico. S. N. : Rock Lithology and Porosity determination from Shear and Compressional Wave Velocity : Geophysics (1984) 49, 1188-1195
8. Skopec ,R.A. : In-Situ Stress Evaluation in Core Analysis , Society of Core Analysis Paper # SCA 9103, Fifth Annual Technical Conference, August 21—22, 1991.
9. Coppens , F. and marei J.L. : Application of The Intercept Time Method to Full Wave from Acoustic Data , Paper Presented at the 55 th Meeting of the European Association of Exploration Geophysics in Stavanger , Norway , Vol 13 No 1, January 1995.
10. *Halmshaw, R,: Non Destructive Well Testing,* Edward Arnold London, England, 1987
11. Medlin W. I. And Alhilai, K.A.Shear Wave *Porosity Logging in Sands, SPE Formation Evaluation , March 1992, 106-112.*
12. *Dewan, John T. : Essensial of Modern Opeen Hole Log interpretation, Pennwell Publishing* Coompany, Tulsa , Oklahoma (1983).
13. Marion Dominique P. and Pallerin Francois, M. : Acoustic Measurements on Cores as a Tool for Calibration and Quantitative Interpretation of Sonic Logs, SPE Formation Evaluation , June *1994 p100-104.*
14. Schopper, J.R , Porosity and Permeability, in Landolt-Bornstein Numerical Data and Functional Relationship in Science and Technology, New Series, Group V, Geophysics and Space Research, *Vol 1 Physical Properties of Rocks, Sub Vol.a Springer -Verlag Berlin, Heidelberg, New York, 1982*
15. Schon , J.C, Physical Properties Of Rocks ; Fundamentals and Principles Of Petrophysics, Handbook of Geophysical Exploration , Seismic Exploration, Volume IV, Pergamon, Elsevier Science Ltd, The Boulevard , Langford lane, Kidlington Oxford OX5 1GB, UK, 1996
16. Ajufo, A. O., Chapman D.J. and Kier J.S. : *Improved Reservoir Characterization and Delineation Using Acoustic Measurements on Cores, Socienty of Petroleum Engineer* 1996, SPE 35654.
17. Jibutoh C.K., Sams, M.S., King,M.S.and Worthington, MH.,: Field Studies of anisotropic properties of sedimentary rocks, Abstracts Eur.Assoc. Exploration Geophysicists 54 th Annual Meeting , Florence,1991, pp 284-285
18. Whife , J.E. Martineu Nicoletis, L, and Monash, C.: *Measured Anisotropy in Pierre Shale, Geophysics Prosp. V 31, 1983, pp.709-725.*
19. Winterstein , D.F.and Paulsson B.N.P., : Velocity Anisotropy in shale determined from cross hole seismic and vertical seismic profile data, Geophysics, 1991, V.55,pp.470-479