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# USING WELL LOGS DATA TO ESTIMATE DYNAMIC ELASTIC PROPERTIES OF CARBONATE FORMATION

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**ABSTRACT:** *Dynamic elastic properties are derived from the measurement of elastic wave velocities in the carbonate rock texture. Sonic logs provide the data of compressional velocity and shear wave velocity, which are used to calculate values of dynamic elastic properties. Five wells in Nasiriya oil field is the studied wells, the study made across the Mishrif and Yamamma carbonates formation. The NeuraLog software was used to digitize the scanned copies of available sonic logs, which are used as input data for the Interactive Petrophysics software. Compressional and shear wave velocities had been calculated from logs data. In this study, Poisson's Ratio, Bulk Modulus, Young Model, and Biot's constant are determined using the Interactive Petrophysics software. The results show that the compressional to shear wave velocity ratio ($V_p/V_s$) is ranged from 1.866 to 1.905, Poisson's ratio values are varied from 0.252 to 0.309, whereas bulk modulus is ranged between 24.75GPa and 66.56Gpa. Y oung model values are varied from 29.98GPa to 75.32GPa, while Biot's constant is ranged between 0.766 and 0.889.*

**KEYWORDS**: Well Logs, Dynamic Properties, Carbonate Formation

## INTRODUCTION

The mechanical property derived from testing rock samples in the laboratory, such as the measurement of the strain for a given applied stress is static elastic constant (Fjaer *et al*., 1992; K limentos *et al*., 1998. The values of compressional velocity ($V_p$) and shear wave velocity ($V_s$) can be obtained if the compression transit time ($\Delta t_p$) and corrected bulk density are available (Entyre, 1989;

K adhim *et al*., 2013) as explained in equation (1)

$$\Delta t_p = PHI.(\Delta t_f - \Delta t_m) + \Delta t_m \quad (1)$$

The Sonic log measures the interval transit time ($\Delta t$) required for compressional and shear waves to traverse within one foot of formation. The $\Delta t$ is the reciprocal of $V_p$ and $V_s$. To avoid fractions, the ($\Delta$t) is scaled by ($10^6$) and reported in microseconds per meter (μsec/m). Thus, $V_p$ and $V_s$. can be calculated by the following equations (Tixier*et al*., 1980; Peters, 2011; Wafa and Al-Ameri, 2012):

$$V_p = \frac{10^6}{\quad} \quad (2)$$



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$\square t_p$

The ratio of $V_p/V_s$ can be used to interpret geophysical data of oil and gas fields as well as it is correlative to sedimentary lithology (Tatham, 1982). Because of the porosity and clay content can affect the $V_p/V_s$ ratio; therefore it is useful as a correlative tool for carbonate lithologies (Johnston and Christensen, 1993). In recent years there has been increased use of $V_P$ and $V_s$ for estimation of petrophysical properties such as porosity, lithology, and fluid saturation (Fjaer *et al.*, 1992). Pickett was the first researcher suggested the correlation between $V_p/V_s$ ratio and rock type, and found the velocity ratio in limestone is 1.9, dolomite is 1.8, and sandstone is ranged from 1.6 to 1.75 (Pickett, 1963; Burger, 1992; Zinszner and Pellerin, 2007). Schlumberger Company introduced an empirical correlation between compressional velocity and shear wave velocity for different rock types as follows (Schlumberger, 2008):

$$Vs \square a.V_P^2 \square bV_P \square c \qquad (3)$$

Where *a, b* and *c* are constants, depend on the lithology of the formation. For limestone *a*= -0.05508, *b*=1.01677, and *c*=-1.03049, $V_p$ and *Vs* are in km/sec.

Carroll in1969 used 185 data points from different rocks (Basalt, Granite and Quartzite) to predict shear velocity (*Vs*) from compression velocity (*Vp*) as follows (Wadhwa *et al*., 2010).

$$V_S \square\ 0.756090.V_P^{\ 0.81846} \qquad (4)$$

Where velocities are in (Km/sec)

Brocher in 2008 derived a non-linear empirical correlation for prediction of shear wave velocity in sandstone, carbonate and shale rocks. He used thousands of wave velocity data of very low porosity rocks. This equation is valid for a compressional velocity from 1.5 to 8.5 km/s.

$$Vs \square\ 0.7858\ \square 1.2344..Vp \square\ 0.7949.Vp^2\ \square 0.1238..Vp^3\ \square\ 0.0064.Vp^4 \qquad (5)$$

The elastic rock properties evaluation can be used as a reference for mud weight control to avoid hydraulic fracturing and loss of mud circulation. Moreover, it should be used for selection of rock bit type and characteristics. Basic dynamic elastic mechanical properties of rocks must be calculated or estimated for all studies in the oil and gas reservoirs. Elastic rocks have the ability to deform elastically, i.e. the deformation is not permanent, and the rock will go back to its original state after the applied force is removed. Bulk modulus ($K_B$), Young's modulus (*E*), and Poisson's Ratio (*P.R*) are examples of formation dynamic elastic properties.

## Poisson's Ratio

Poisson's ratio (*P.R*) is an important mechanical property that can be used to predict the geo-mechanical behaviour during the wells drilling and the following recovery processes. Well instability, sand production and hydraulic fracturing are greatly affected by strength parameters, which may relate to its magnitude. Poisson's Ratio is a dimensionless parameter that measures the ratio between lateral strain and axial strain (Walls and Jack, 1994).The sonic log tool is the best tool that uses to compute the. $V_P$ and

$V_S$ that require for determination of the Poisson's ratio as follows (Entyre, 1989; Gatens *et al*., 1990; Schlumberger, 2008; Karakan, 2009):



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$$P.R = \frac{(V_p/V_s)^2 - 2}{2\left[(V_p/V_s)^2 - 1\right]} \qquad (6)$$

Poisson's ratio was calculated from well log data in 1975 by Stein, when he introduced method for calculation of the mechanical properties from available well log data to the consideration of stability of friable sands, under different conditions of drilling or production. The determining properties include the strength of cementation between sand grains formation compressibility and Poisson's ratio. Common values for Poisson's ratio by rock types can be seen in Table 1.

**Table 1 : Common values for Poisson's ratio (Gercek, 2007)**

| **Lithology** | **Dolomite** | **Limestone** | **Sandstone** | **Shale** | **Siltstone** |
|---|---|---|---|---|---|
| Poisson's Ratio | 0.1-0.35 | 0.1-0.325 | 0.05-0.4 | 0.05-0.325 | 0.012-0.35 |

## Bulk Modulus

Bulk modulus ($K_B$) is a description of the ratio of the pressure applied to the cube of the rock to the amount of volume change that the cube undergoes. If $K_B$ is very large, then the rock is very stiff, meaning that it doesn't compress very much even under high pressure. For example, gases have a very small value of Bulk modulus, while this value in solids and liquids is higher. Bulk modulus relationship in terms of elastic wave velocities or transit times and bulk density ($\rho$) is shown as follows (Gatens, *et al*., 1990; Schlumberger, 2008; Yu and Smith, 2011):

$$K_B = \rho\left(V_p^2 - \frac{4}{3} V_s^2\right) \qquad (7)$$

The bulk modulus is also referring to the measure of rock's resistance to change in volume. When porosity increase in the rock that lead to decrease the rock's resistance to change in volume and thus decrease its bulk modulus. This makes the bulk modulus a good porosity indicator especially in stiffer rocks like carbonates. Simmons and Brace (1965) measured compressibility, which is the inverse of bulk modulus for various rock lithologies. A good agreement between static and dynamic properties of high stresses is concluded by researchers. Cheng and Johnson in 1981 suggested the difference between static and dynamic bulk modulus is caused by micro-cracks in rocks because micro cracks will influence differently on static and dynamic modulus. The porosity values in the interval of 0.2% to 12% in dry sandstone were calculated by Jizba et al. in 1990. Also, they measured dynamic bulk modulus from pulse transmission method with a frequency, and static bulk modulus are from strain gauges and found the ratio between dynamic and static bulk modulus for the sandstones is 1.1-1.6.The dynamic modulus based on laboratory measurements and from log data in North Sea chalk was studied by Gommesen and Fabricius in 2001. They also obtained static bulk modulus under drained conditions. Bulk modulus values were calculated by Zinszner and Pellerin in 2007 at different types of saturation. They used a number of experimental points and found the value


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of $K_B$ ranged from 58GPa to 68GPa for rock grains, and they estimated the value of Bulk Modulus about 70GPa for calcite and 80GPa for dolomite.

**Y oung's Modulus**

Young’s modulus is defined as the ratio of the extensional stress to the extensional strain, which is the rock ability to resists compression by uniaxial stress (Fjaet *et al*, 1992). Young’s modulus can be calculated from the following equation depending on elastic waves velocities (Gatens*et al*., 1990; Schlumberger, 2008; Yu and Smith, 2011):

$$E = 3K_B(1 - 2P.R) \tag{8}$$

Young's modulus is also representing to the measure of the rock stiffness. If the porosity of rock increases, the stiffness will decrease and thus lower its Young's modulus (Yu and Smith, 2011).Saturated consolidated and unconsolidated sandstones are studied by Montmayeur and Graves in 1986. They did not obtain any clear relationship between static and dynamic Young’s modulus. For fully water-saturated samples, static and dynamic Young’s modulus was calculated by Tutuncu and Sharma in 1992. They found the ratio of dynamic and static Young’s modulus depended on the content of clay in the formation. This is in agreement with the observation for bulk modulus by Jizba *et al*. (1990). Young’s modulus and strain amplitude for dry sandstone, limestone and Austin chalk were studied by Tutuncu *et al*. in 1998. They observed that Young’s modulus decreased with increasing of strain amplitude. Dynamic and static Young’s modulus on saturated sandstone was calculated by Yale and Jamieson in 1994. They found the ratio between dynamic and static Young’s modulus depended on the porosity of the sample and the quartz cementation of sandstone. In saturated sandstone the static and dynamic Young’s modulus was introduced by Tutuncu *et al*. in 1998. They concluded that the difference between static and dynamic Young’s modulus is caused by a difference in strain amplitude which increases with decreasing of Young’s modulus under static test. Dry sandstone samples were used in measuring of static and dynamic Young’s modulus. The results show that the quartz overgrowth cementation for sandstones has a significant on the difference between static and dynamic Young’s modulus (Al-Tahini *et al*., 2004).

**Biot C onstant**

Biot Constant (*B.C*) is a complex function of porosity, permeability, clay content, grain to grain contact, grain strength, and overburden pressure. Thus, it should not be calculated as a function of porosity only. This elastic constant decreases as overburden pressure increase (Schlemberger, 1989; Fjaer *et al*., 1992). Pore space compressibility of the rock is strongly related to cementation while the Biot’s coefficient is largely related to the pore space compressibility. Therefore, the degree of cementation could be measured depending on Biot’s coefficient. Acoustic velocities may be used to predict a degree of cementation that has a significant influence on different physical properties. However, cementation factor depends on cementation (Archie, 1942), then cementation factor may be estimated from Biot’s coefficient. The Biot constant can be obtained from Bulk Compressibility ($C_b$) and Rock Matrix Compressibility ($C_r$) as follows (Klimentos *et al*., 1998; Lashin, 2005; Atashbari and Tingay, 2012):

$$B.C = 1 - \frac{C_r}{\quad} \tag{9}$$



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$C_b$

Van Golf-Rachet in 1982 achieved the following relationship:

$$C_r = C_b \frac{PHIT}{1-PHIT} \quad (10)$$

Biot's constant can be defined as a function of porosity by substituting equation (10) in (9) as follows:

$$B.C = 1 - \frac{PHIT}{1-PHIT} \quad (11)$$

In 1990, K rief *et al*. proposed an equation to calculate Biot's constant as a function of total porosity as follows:

$$B.C = 1 - (1 - PHIT)^{3/(1-PHIT)} \quad (12)$$

Biot's constant was estimated by Zinszner and Pellerin in 2007 at different types of saturation. They used a number of experimental points and found that the value of *B.C* ranged from 0.75-0.79.

## METHODOLOGY

Neura-Log software (NL-V 5,2008) used to digitize the scanned copies of sonic logs for studied well in the Nasiriya oil field, the results are LAS files, which are uploaded into the Interactive Petrophysics software (IP- V3.5, 2008), then the reading measurements taken as one reading per 0.15 meters of Mishrif and Yammama carbonates formation. Porosity and dynamic elastic properties ($V_p/V_s$, $P.R$, $K_B$, $E$, and $B.C$) are determined by using IP software.

## Results and Discussion

### Validation of digitalized Well L ogs Data

The correlation coefficient ($R^2$) and standard errors (*SE*) are used to indicate the performance of digitalized and log reading data at the perforation depth of production units for studied carbonate formations in the NS-3 well. The origin pro8 software is used to determine the $R^2$ and *SE* of digitalized and log reading data for sonic log reading (*DT*) as shown in Figure 1.



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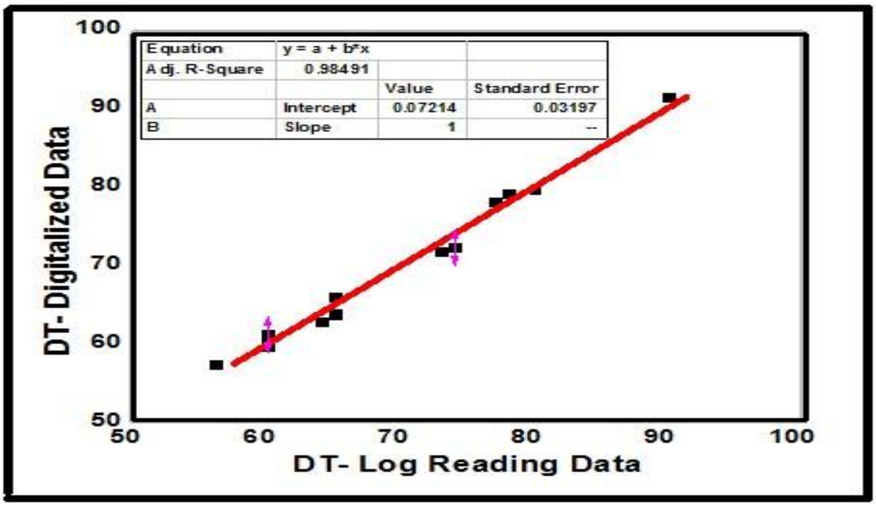


**Figure 1 :** Correlation between digitalized and log reading data of *DT* log

## Porosity

In sonic logs, porosity can be calculated from interval transit time (Δt) of the compressional waves that travel through the rock texture. The compressional wave velocity depends on the porosity and lithology. Figure 2 shows the sonic porosity (PhiS) results for Mishrif and Yamamma carbonate reservoirs. The sonic porosity values are determined by using Wyllie's time-average formula still applies as follows (Tixier`, 1965; Entyre, 1989):

$$PhiS = \frac{DT_{log} - DT_{mat}}{DTf - DT_{mat}} \quad (13)$$

Where PhiS is sonic-derived porosity, DT*mat* is the interval transit time in the matrix [Its value is 47.6µsec/ft for limestone and 43.5µsec/ft for dolomite] and $DT_{log}$ is the interval transit time in the formation, µsec/ft. $DT_f$ is the interval transit time in the fluid within the formation [For freshwater mud = 189µsec/ft; for salt-water mud = 185(µsec/ft)].


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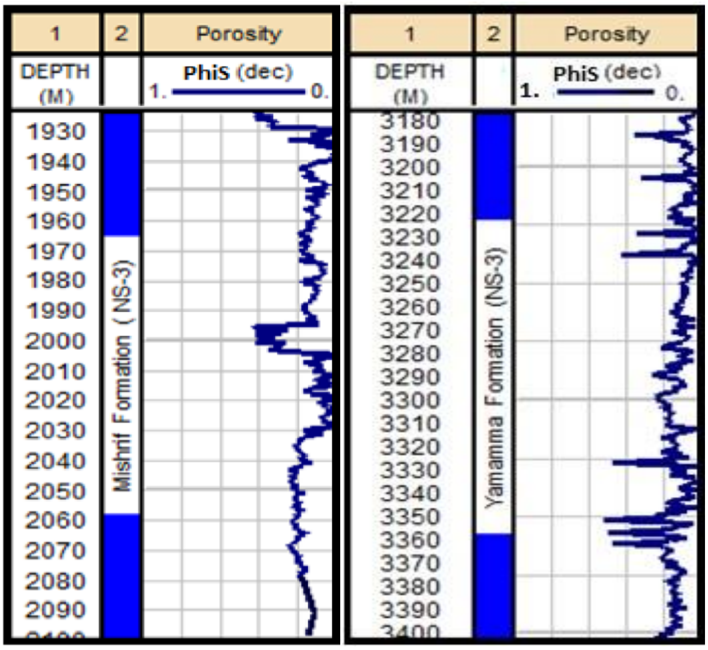


Figure 2 : Sonic p orosity results of Mishrif and Yamamma formation

Table 2 illustrates porosity values of core samples ($PHI_{CORE}$) and computer processed interpretation ($PHI_{CPI}$) as well as their changes with depth interval. The average values of $PHI_{CORE}$ and $PHI_{CPI}$ are ranged from 0.18 to 0.20 and from 0.12 to 0.15 respectively for Mishrif formation, while average values of $PHI_{CORE}$ and $PHI_{CPI}$ are from 0.1 to 0.13 and from 0.09 to 0.14 respectively for Yamamma formation. The prediction accuracy for porosity based on mean absolute percent error ($APE$) criteria is as follows:

$$APE = \left| \frac{PHI^{predicted} - PHI^{calculated}}{PHI_{calculated}} \right| * 100\% \quad (14)$$

The computer processed interpretation ($CPI$) is predicted effective porosity ($PHI_{CPI}$) from log data. The absolute percentage error between $PHI_{CPI}$ (predicted) and calculated core porosity ($PHI_{CORE}$) by INOC (2007) for the studied formations are ranged from 7% to 35% as shown in Table 2.The relationships between $PHI_{CORE}$ and average $PHI_{CPI}$ for Mishrif and Yammama formations are shown in Figures 3 and 4 respectively. From these relationships, the correlation coefficient ($R^2$= 0.91573) and standard error (SE=0.00129) for Mishrif formation, whereas ($R^2$= 0.87408) and (SE= 0.0017) for Yamamma formations. These results are in agreement with Aifa *et al*., (2014) establishments of ($R^2$= from 0.9275 to 0.9879) and mean square error ($MSE$= from 1.575 to 0.3915) for porosity using different artificial intelligent techniques. The corrected equations for $PHI_{CPI}$ are produced from statistical analysis in Figures 3 and 4 as shown in equations (15) and (16) for Mishrif and Yamamma formation respectively.

$$PHI_{CPI} = 0.00204 + PHI_{CORE} \quad (15)$$

$$PHI_{CPI} = -0.00344 + PHI_{CORE} \quad (16)$$


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These corrected equations are used to correct the $PHI_{CPI}$ values (i.e. the effective porosity for studied formation) that mean the corrected values of the $PHI_{CPI}$ are used to calculate Biot's constant. The main reason that leads to differences between the porosity value from core and log (APE from 11% to 25%) is the varying between properties of formation water and the mud filtrate (Amin *et al*., 1987; K adhim *et al*., 2015).

**Table 2 : Core - log average porosity comparison results**

| FM. | Well | Depth interval (m) | $PHI_{CORE}$ | $PHI_{CPI}$ | APE % |
|---|---|---|---|---|---|
| Mishrif | NS-1 | 2012-2109 | 0.19 | 0.15 | 21 |
| | NS-2 | 1989-2089 | 0.19 | 0.16 | 16 |
| | NS-3 | 1924-2100 | 0.18 | 0.20 | 11 |
| | NS-4 | 1999-2106 | 0.20 | 0.17 | 15 |
| | NS-5 | 1996-2100 | 0.20 | 0.15 | 25 |
| Yamamm a | NS-1 | 3178-3416 | 0.12 | 0.15 | 20 |
| | NS-2 | 3156-3386 | 0.11 | 0.13 | 15 |
| | NS-3 | 3177-3403 | 0.10 | 0.13 | 23 |
| | NS-4 | 3165-3392 | 0.13 | 0.15 | 13 |
| | NS-5 | 3168-3390 | 0.13 | 0.16 | 19 |

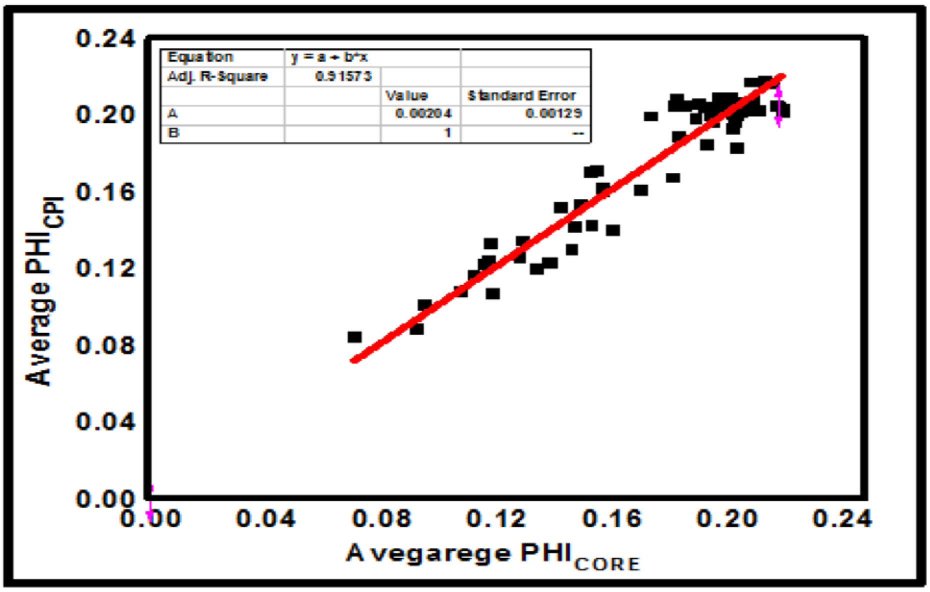


**Figure 3: Average $PHI_{CPI}$ and average $PHI_{CORE}$ relationship for Mishrif formation**


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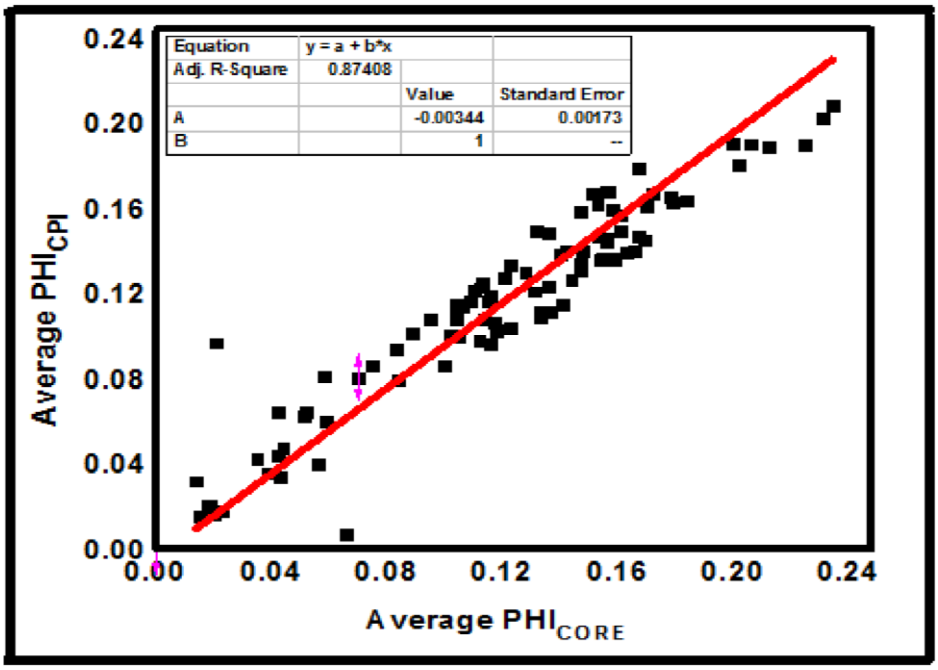


**Figure 4 : Average $PHI_{CPI}$ and average $PHI_{CORE}$ relationship for Yamamma formation**

## Dynamic E lastic Properties

Bulk modulus ($K_B$), Young model ($E$), Biot constant ($B.C$), compressional wave velocity ($V_p$), shear wave velocity ($V_s$),compressional wave velocity ratio ($V_p/V_s$), and Poisson's ratio ($P.R$) are fundamental of elastic dynamic properties of reservoir which are calculated in this section to achieve the second cementation factor model based on these parameters. The CPI results of these properties are determined for Mishrif and Yamamma carbonate formations as shown in Figures 5 and 6 The relationship between average compressional velocity ($V_p$) and average shear wave velocity ($V_p$) is a polynomial with a correlation coefficient ($R^2$= 1) and standard error is nil for Mishrif formation as shown in Figure 7. The same correlation of velocity in Yamamma formation also recorded an excellent correlation coefficient ($R^2$= 1) and very low standard error as shown in Figure 8. That means the output results of velocities from CPI have an excellent accuracy and closed matching with Schlumberger model (2008).

Figures 5 and 6 shows the compressional velocity ($V_p$), shear wave velocity ($V_s$), velocity ratio

($V_p/V_s$), Poisson's ratio ($P.R$), Bulk modulus ($K_B$), Young Model ($E$), and Biot's constant ($B.C$) for Mishrif and Yamamma formations. The average values of velocity ratio ($V_p/V_s$) from studied wells are between 1.866 and 1.905 for both studied formations as shown in Table 3. These results are closed to Pickett (1963), Zinszner and Pellerin (2007) and Fjaer *et al*. (2008) establishments of ($V_p/V_s$) values from core measurement which is 1.9 for limestone. Meanwhile the Poisson's ratio ($P.R$) results in track five are in the same range that established by Gercek (2007) and Fjaer *et al*. (2008). The average bulk modulus ($K_B$) values are ranged from



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24.75GPa to 66.56GPa as listed in Table 3. This is in agreement with the observation for bulk modulus by Zinszner and Pellerin (2007). The average values of Young's Model (*E*) are agreed with estimated static ranges by Fjaer *et al*. (2008). Whereas Biot's constant (*B.C*) results in track eight in the same table are also closed to Zinszner and Pellerin (2007) establishments of (B.C=0.79) for limestone.

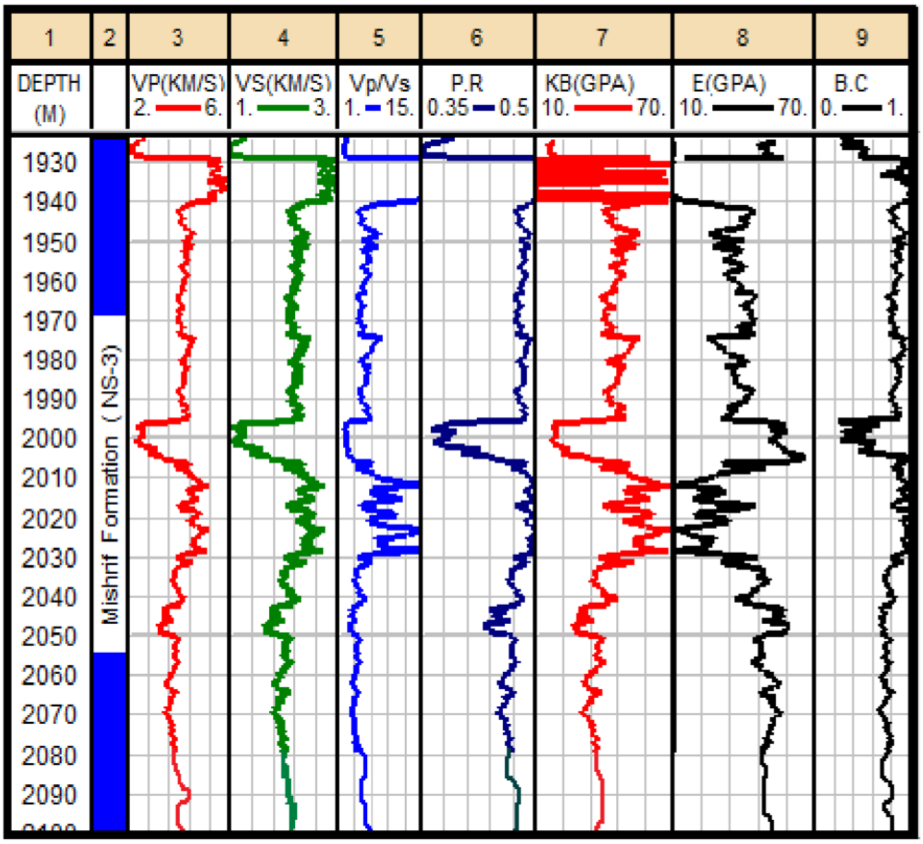


**Figure 5:** Dynamic elastic properties results for Mishrif Formation (NS-3)


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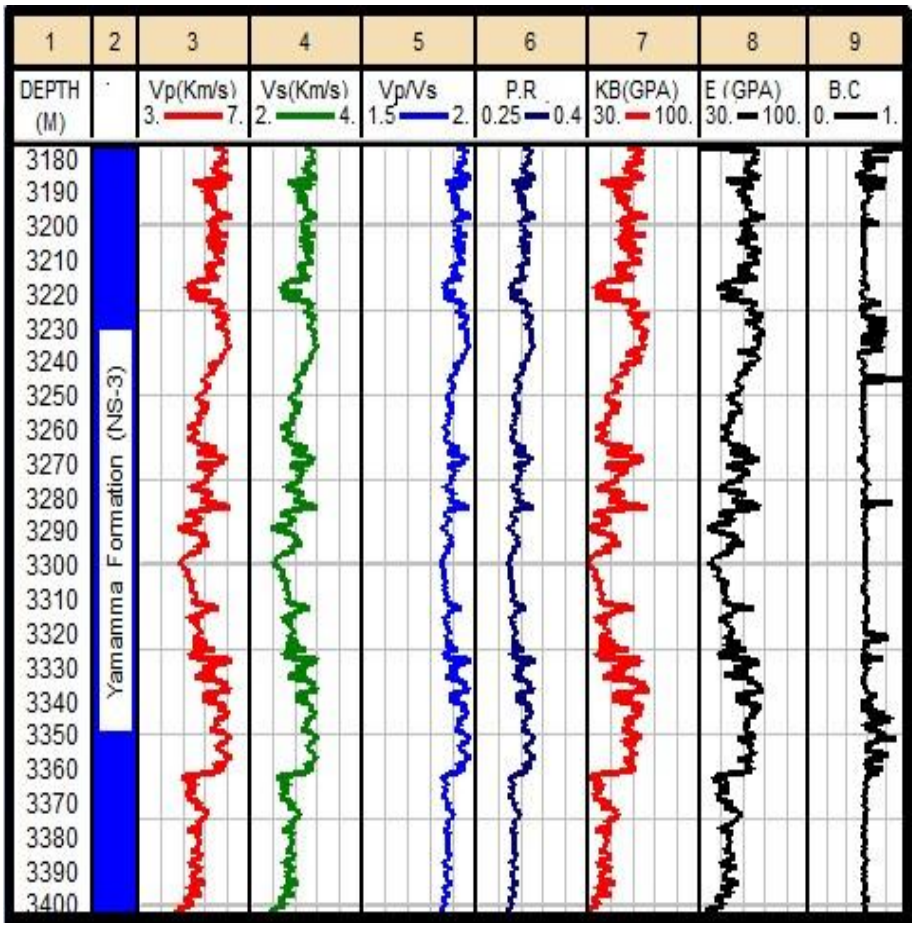


**Figure 6:** Dynamic elastic properties results for Yamamma formation (NS-3)

**Table 3:** Dynamic elastic properties results

| FM. | Well | Depth interval (m) | $V_p/V_s$ | *P.R* | $K_B$ (GPa) | *E* (GPa) | *B. C* |
|---|---|---|---|---|---|---|---|
| **Mishrif** | **NS-1** | 2012-2109 | 1.887 | 0.304 | 42.44 | 50.71 | 0.867 |
| | **NS-2** | 1989-2089 | 1.881 | 0.252 | 27.12 | 40.25 | 0.874 |
| | **NS-3** | 1924-2100 | 1.888 | 0.303 | 26.75 | 32.04 | 0.766 |
| | **NS-4** | 1999-2106 | 1.874 | 0.300 | 33.40 | 40.04 | 0.856 |
| | **NS-5** | 1996-2100 | 1.866 | 0.298 | 24.75 | 29.98 | 0.812 |
| **Yamamma** | **NS-1** | 3178-3416 | 1.890 | 0.305 | 44.62 | 51.52 | 0.847 |
| | **NS-2** | 3156-3386 | 1.889 | 0.305 | 41.80 | 48.22 | 0.889 |
| | **NS-3** | 3177-3403 | 1.905 | 0.309 | 66.56 | 75.32 | 0.889 |
| | **NS-4** | 3165-3392 | 1.897 | 0.307 | 46.25 | 52.88 | 0.842 |
| | **NS-5** | 3168-3390 | 1.889 | 0.255 | 45.46 | 66.27 | 0.894 |


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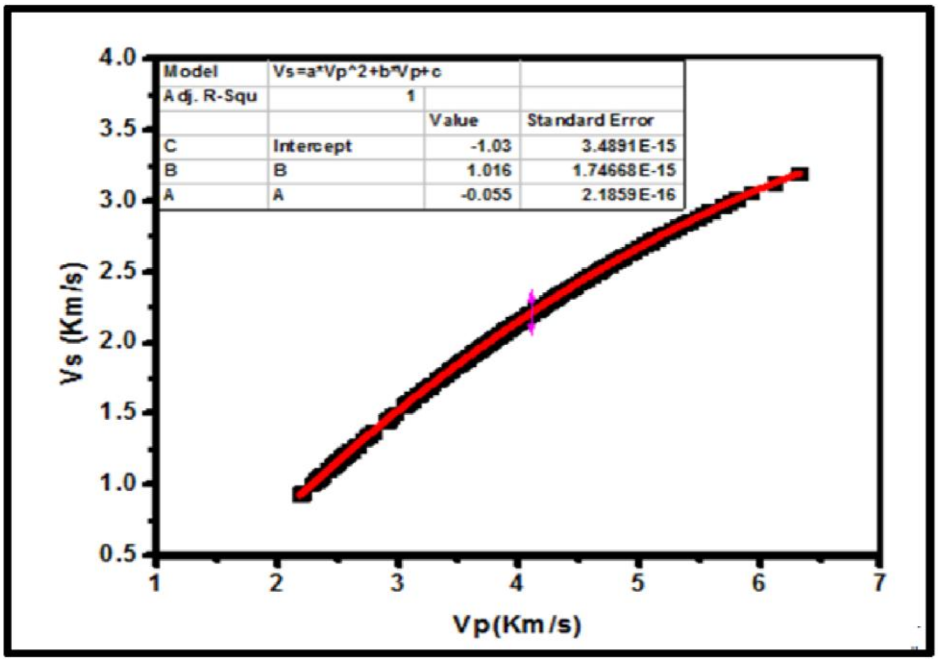


**Figure 7:** Relationship between average $V_p$ and average $V_s$ for Mishrif Formation

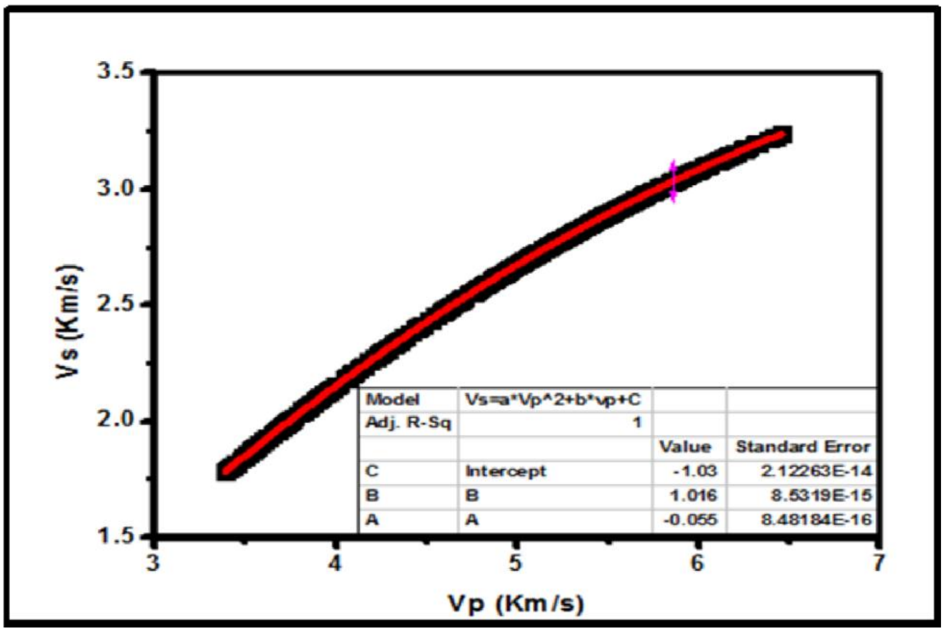


**Figure 8:** Relationship between average $V_p$ and average $V_s$ for Yamamma Formation.

## CONCLUSION

In this study, sonic logs copies have been digitalized and converted to LAS files by using Neuralog software. The Interactive Petrophysics software is used to determine sonic porosity



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and dynamic elastic properties based on LAS files data of two carbonate formations in five wells in the NS oil field.

The CPI results of dynamic elastic properties are recorded accurate values in comparison with previously studied for carbonates formation. As well as the relationship between average compressional velocity (*Vp*) and average shear wave velocity (*Vs*) is a polynomial with a correlation coefficient (R2= 1) and a very low standard mean error, that means the output results of velocities from IP software have an excellent accuracy and close to Schlumberger model (2008).

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**References**

Al-Tahini, A. M. Sondergeld, C. H and Rai, C. S. (2004). The Effect of Cementation on Static and Dynamic Properties in Jauf and Unayzah Formations at Saudi Arabia, *SPE Annual Technical Conference and Exhibition*, 26-29 September, Houston, Texas, SPE-90448-MS.

Archie, G. E. (1942).The Theoretical Resistivity Log as an Aid in Determining Some Reservoir Characteristics, *Transactions of the AIME*, Vol. 146, Issue 01, SPE-942054-G.

Atashbari,V. and Tingay, M. (2012). Pore Pressure Prediction in Carbonate Reservoir. *SPE Latin America and Caribbean Petroleum Engineering Conference*, 16-18 April, Mexico City, Mexico, SPE-150835-MS.

Brocher, T.M .(2008). Key Elements of Regional Seismic Velocity Models for Long Period Ground Motion Simulations, *J. Seismology*, 12(2), 217–221.

Burger, H. (1992). *Exploration Geophysics of the Shallow Subsurface*, Englewood Cliffs, N.J., PrenticeHall.

Carroll, R.D. (1969). The Determination of Acoustic Parameters of Volcanic Rocks from Compressional Velocity Measurements, *Int. Jl. Rock Mech. Min. Sci*., 6 (6), 557- 579.

Cheng, C. H. and Johnson, D H. (1981). Dynamic and Static Moduli, *Geophysical Research Letters*, 8 (1), 39-42.

Entyre, L.M. (1989). *Finding Oil and Gas from Well Logs*, (pp.91-145), New York, Van Nostrand Reinhold.

Fjaer, E. Holt, R. M. Horsrud, P. Raaen, A. M. and Risnes, R. (1992). *Petroleum Related Rock Mechanics*, $2^{nd}$ edition, Vol.53, Amsterdam, Elsevier.

Gatens, J.M. Harrison, C.W. Lancaster, D.E. and Guidr, F.K. (1990). In-Situ Stress Tests and Acoustic Logs Determine Mechanical Properties and Stress Profiles in the Devonian Shales. *SPE Formation Evaluation*, 5 (03), SPE-18523-PA.

Gercek, H. (2007). Poisson's Ratio Values for Rocks, *International Journal of Rock Mechanics and Mining Sciences*, 44 (1), 1–13.

Gommesen, L. and Fabricius, I. L. (2001). Dynamic and static elastic moduli of North Sea and deep sea chalk, *Physics and Chemistry of the Earth*, (A), 26 (2), 63-68.



ISSN: 2052-6377(Print), ISSN: 2052-6385(Online)

Jizba, D., G. Mavko, and Nur, A. (1990). Static and dynamic moduli of tight gas sandstones, *SPWLA 31st Annual Logging Symposium*, 24-27 June, Lafayette, Louisiana,SPWLA-1990-BB.

Johnston, J., and Christensen, N. (1993). Compressional to shear velocity ratios in sedimentary rocks, *International Journal of Rock Mechanics and Mining Sciences*, 30 (7), 751–754.

Kadhim, F.S., Samsuri, A., and Kamal, A., (2013). A review in correlation between cementation factor and carbonate rock properties, *Life Sci. J*, 10(4), 2451-2458.

Karakan, C.O. (2009). Elastic and shear moduli of coal measure rocks derived from basic well logs using fractal statistics and radial basis functions, *Int J Rock Mech Min Sci*, 46(8), 1281-1295.

Klimentos, T. Harouaka, A., Mtawaa, B., and Saner, S. (1998). Experimental Determination of the Blot

Elastic Constant: Applications in Formation Evaluation (Sonic Porosity, Rock Strength, Earth Stresses, and Sanding Predictions).*SPE Annual Technical Conference and Exhibition* , Dallas, 22-25 October, SPE 30593.

Lashin, A. (2005). Reservoir Parameter Estimation Using Well Logging Data and Production History of the Kaldarholt Geothermal Field, *S-Iceland, Geothermal Training Program*, United Nations University, Reykjavik, Iceland.

Montmayeur,H. and Graves, R. M. (1986). Prediction of static elastic/mechanical properties of consolidated and unconsolidated sands from acoustic measurements, *SPE Annual Technical Conference and Exhibition*, 22-26 September, Las Vegas, Nevada, SPE 14159-MS.

Peters, E., J. (2011). *Petrophysics*, the University of Texas, Austin, Published by Hadi Al-Sinan.

Pickett, G. R. (1963). Acoustic Character Logs and Their Applications in Formation Evaluation**,** *Journal of Petroleum Technology*, 15 (6), 659-676, SPE-452-PA.

Schlumberger, (1989). *Log Interpretation-Principles/Applications*, Eight Printing, Sugar-Land, Texas.

Schlumberger, (2008). *IP- Interactive Petrophysics* V-3.5, Manual.

Simmons, G., and Brace, W. F. (1965). Comparison of Static and Dynamic Measurements of Compressibility of Rocks, *Journal of Geophysical Research*, 70(22), 5649-5656.

Stein, N. (1975). Mechanical Properties of Friable Sands from Conventional Log Data, *Journal of Petroleum Technology*, 28 (7), SPE-5500-PA.

Tatham, R. (1982). Vp/Vs and lithology, *Geophysics*, 47 (3), 336–344

Tixier, M.P., Alger, R.P., and Doh, C.A. (1980). Sonic Logging, Petroleum *Transactions, AIME*, 216 (1959), 106-114,SPE-1115-G.

Tutuncu, A. N., and Sharma, M. M. (1992). Relating Static and Ultrasonic Laboratory Measurements to Acoustic log Measurements in Tight Gas Sands, *SPE Annual Technical Conference and Exhibition*, 4-7 October, Washington, D.C, SPE-24689-MS.

Tutuncu, A. N., Podio, A. L., and Sharma, M. M. (1998). Non-linear Viscoelastic Behaviour of Sedimentary Rocks, Part I: Effect of Frequency and Strain Amplitude, *Geophysics*, 63 (1), 184194.

Wadhwa, R.S., Ghosh, N., and Subba, C.R. (2010). Empirical Relation for Estimating Shear Wave Velocity from Compressional Wave Velocity of Rocks, *J. Ind. Geophysics. Union*, 14 (1), 21-
30.

Wafa, A.,and Jasim, A. (2012). Estimation of the Rock Mechanical Properties Using Conventional Log Data in North Rumaila Field, *IJCPE*, 13 (4), 27-33.



ISSN: 2052-6377(Print), ISSN: 2052-6385(Online)

Walls, J.D., and Jack, D.R. (1994). Measured and Calculated Horizontal Stresses in the Travis Peak
Formation. *SPE Formation Evaluation*, 9(04), SPE-21843

Yale, D. P., and. Jamieson, W. H (1994). Static and Dynamic Rock Mechanical Properties in the Hugoton and Panoma Fields, Kansas, *SPE Mid-Continent Gas Symposium*, 22-24 May, Amarillo, Texas, SPE-27939-MS, 209-219.

Yu, J.H.Y. and Smith, M. (2011). Carbonate Reservoir Characterization with Rock Property Invasion for Edwards Reef Complex, *the 73rd EAGE Conference and Exhibition incorporating SPE Europe*, 23 -26 May, Vienna, Austria, 346-350.

Zinszner, B., and Pellerin, F. M. (2007). *A geoscientist's guide to Petrophysics*, Editions Ophrys. (pp.
221-249), Paris, IFP Publications.


ISSN: 2052-6377(Print), ISSN: 2052-6385(Online)