Iraqi Geological Journal

Journal homepage: <https://www.igi-iraq.org>

Integrated 3D Mechanical Earth Modelling to Intensively Investigate the Wellbore Instability of Zubair Oil Field, Southern Iraq

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Received: 19 June 2021; Accepted: 30 July 2021; Published: 30 November 2021

Abstract

Wellbore instability in the Zubair oil field is the main problem in drilling operations. This instability of the wellbore causes several problems including poor hole cleaning, tight hole, stuck pipe, lost circulation, bad cementing, and well kick or blowout that lead to an increase in the nonproductive time. This article aims to set up an appropriate drilling plan that mitigates these instability issues for further well drilling. Field data from six wells (logs, drilling and geological reports as well as offset well tests) were used to build a one-dimensional mechanical earth modeling for each well. The constructed model of selected wells was combined to construct the three-dimensional mechanical earth modeling, which can enable the distribution of all estimated geomechanical parameters along the field of interest. The results revealed that the strip slip and normal faults are the common fault regimes in Zubair oil field located in carbonate rocks and clastic rocks, respectively. The Mogi-Coulomb failure criterion is conservative in determining the minimum and maximum mud weight, and it agrees with the determination of real failure from the image and caliper logs. The best direction to drill the deviated and horizontal wells was towards the minimum horizontal stress with 140° azimuth from the north. The recommended ranges of mud weight along the sections of 12.25" and 8.5" of the highly deviated and horizontal wells were (between 1.46 and 1.58 gm/cm³) without any expected wellbore instability problems. Based on the outcomes of 3D model, it is expected that the wellbore instability issues are most likely to occur in the domes of; Shauiba and Hamma and in formations; Tanuma, Khasib and Nahr-Umr. In contrast the less wellbore instability problems are expected to expose in Rafidya dome. The study presents an appropriate mud window that can be used to design to minimize the wellbore stability problems when new wells will be drilled in Zubair oil field.

Keywords: Dome; Wellbore stability; Zubair Oil field; Rock

1. Introduction

Zubair oil field is one of the largest fields in Iraq (Al-Jaberi and A-Jafar, 2020). It was discovered in 1949, and produced for the first time in 1951, it is located in southern Iraq. The Zubair field has anticline structure with four domes; Al-Hammar, Shuaiba, Rafidya and Safwan, (Program, 2015). It is primarily consisted of four reservoirs; Upper Cretaceous Mishrif Limestone, Lower Cretaceous Upper Shale Member, Lower Cretaceous Upper Sandstone (3rd Pay) and Lower Cretaceous Lower Sandstone (4th Pay), (Fig. 1). The Lower Cretaceous Zubair reservoir is a main producing horizon in the Zubair oil Field, southern Iraq, (Al-Jafar and Al-Jaberi, 2019). The well design in the Zubair oil field is generally consisted of four sections; 23", 17.5", 12.25": and 8.5". Sections 12.25" and 8.5" are among the most

DOI: [10.46717/igi.54.2E.4Ms-2021-11-20](https://doi.org/10.46717/igi.54.2E.4Ms-2021-11-20)

challenging and dangerous for drilling operations in the Zubair oil field. The most drilling problems through drilling these sections are the lost circulation problems at the top of Mishrif formation and the wellbore stability problems at Tanuma, Khasib and Nahr-Umr formations. Such these instability problems are poor hole cleaning, tight hole, stuck pipe, lost circulation, bad cementing, and well kick or blowout. As a results the nonproductive time (NPT) of the well is increased, and thereby the cost of drilling the wells is also increased, (Program, 2015). In general, most of wellbore instability problems can be attributed to the stress state around the borehole. Stresses are in an equilibrium state in volcanically inactive areas, (Mohammed and Al-Rahim, 2020), but during the life of the oil field, there are many operations that would disturbed this equilibrium, such as drilling operations etc. The result is redistribution of the stresses around the wellbore that cause a lot of stability problems, (Zoback, 2007). A geomechanical model (rock mechanical properties, pore pressure, far field stress) can assist to understand the stresses status around the wellbore and to determine the critical wellbore pressure, or mud weight to maintain the wellbore from either collapse or tensile fracturing, (Al-Wardy & Urdaneta, 2010), (Hadi and Nygaard, 2018). The geomechanical model can be constructed based on available wells data prior to the well stability analysis. As a consequence, the geomechanical model helps to understand wellbore failures and predicts the stability of new wells paths. on the other hand, if wellbore stability forecasting necessarily to be conducted for a new well location prior to drilling the well depend on the single well geomechanical model, at the new well site, it is generally assumed that the formation properties are the same as those of the offset well site, but the seismic analysis and geological data show lateral variations in properties between formations,(Abdulridha, 2020).

Fig. 1. Map of the area of study (Program, 2015)

three-dimensional mechanical earth modeling (3D MEM) has become a modern method to handle well instability issues, (Hadi et al., 2017). To understand the rock properties, pore pressure and stress concentration around the borehole, 3D MEM is built. In this model the properties will be distributed among the selected wells in order to explain these properties distribution throughout the oil field. In addition, the 3D MEM gives more accurate results and better visualization of issues in each horizon for the entire field. The aim of this study is to establish a 3D mechanical earth modeling for Zubair oil field. This model is based on 1D geomechanical earth modelling for available wells (six wells). These wells are Zubair-210, Zubair-232, Zubair-236, Zubair-284 (these wells in the Hammer dome.), Zubair-229 (this well in Shuaiba dome) and Zubair-233 (this well in Rafdiya dome). The 3D MEM construction be composed of three major steps, first model geometry construction, second model properties definition and finally initial stress modeling. The required strength properties (cohesion, internal friction angle FANG, tensile strength and unconfined compressive strength UCS), and elastic properties include Poisson's ratio, Young's modulus. All these properties were previously available at the six wells locations from the 1D MEMs. Population of material properties throughout the entire 3D model was carried out using a Co-Kriging algorithm. After 3D MEM is built, the prediction of wellbore stability can be made for any future well in Zubair oil field (at any dome even at any formation) with the data from the 3-D model.

2. Materials and Methods

2.1. 1D MEM

Geomechanical model is a combination of many parameters including in-site stresses, pore pressure, rock strength mechanical and elastic rock properties, (Alhussainy, 2020). After 1D MEM is built, it could be utilized in any geomechanical analysis, (Rasouli et al., 2011). Six wells were selected in the Zubair oil field to construct a 1D MEM for each well. These wells are located in Hammar, Shauiba and Rafdiya domes. It is worth noting that the field is composed of a fourth dome (Safwan dome), but it was not included in the study due to the lack of basic data for the construction of the mechanical earth model. The data used to estimate the strength and properties of elastic rocks, pore pressure and in situ stresses are classified into; field reports, logs and well offset tests. The field reports included; daily drilling reports, mud reports, final well reports, geological reports, survey reports and master logs. The logs included; Delta-T Compressional (DTC, us/ft), Delta-T Shear (DTS, us/ft), Density logs (ZDEN, gm/cm³), Neutron logs (CNC, PU), bit size (BS, in), Gamma Ray (GR, gAPI), Caliper (CAL, in) and Image logs. The offset tests included; core data (triaxial and Brazilian test that are available in the Zubair oil field for interested sections (12.25" and 8.5")), pore pressure points that are used to calibrate the predicted pore pressure profile are measured by several methods; Modular Dynamic Tools (MDT), Reservoir Description Tools (RDT) and Repeated Formation Tester (RFT). The mini-frac data is also used to calibrate the minimum horizontal stresses.

Equations 1 to 6 represent the correlations which were used to determine the mechanical rock properties. Equation (1) represent the dynamic Young's modulus, and the static Young's modulus was determined by John fuller correlation, (Schlumberger Techlog, 2015). Equation (2 and 3) denoted the dynamic and static Poisson's ratio, respectively, (Schlumberger Techlog, 2015). The UCS was determined by equation (4), (Jaeger, n.d.). Equation (5) utilized to determine internal friction angle in shaly sedimentary rock, while equation (5) utilized to determine internal friction angle in shale rocks and equation (6) utilized to determine internal friction angle in sandstone rocks, (Zoback, n.d., 2007).

$$E_{dyn} = \frac{9 * G_{dyn} * K_{dyn}}{G_{dyn} + 3 * K_{dyn}} \quad (1)$$

$$\nu_{dyn} = \frac{3K_{dyn} - 2G_{dyn}}{6K_{dyn} + 2G_{dyn}} \quad (2)$$

$$\nu_{sta} = \nu_{dyn} * \nu_{multiplier} \quad (3)$$

$$UCS = 330.7 + 0.0041 * E_{stat} \quad (4)$$

$$\phi = 70 - 0.417GR \quad (5)$$

$$\phi = \tan^{-1} \left(\frac{78 - 0.4GR}{60} \right) \quad (6)$$

$$\phi = 57.8 - 105 GR \quad (7)$$

Where:

E_{dyn} : Dynamic Young's modulus, G_{dyn} : Shear modulus, K_{dyn} : bulk modulus, ν_{dyn} : Dynamic Poisson's ratio, ν_{sta} : static Poisson's ratio, UCS : unconfined compressive strength, ϕ : Internal friction angle, GR : Gamma ray.

Vertical stress can be exerted by integrating the weights of the overlying rocks with the formation thickness, it can be derived from density logs, (Aadnoy and Looyeh, 2011). Pore pressure is a crucial mechanical parameter used in a vital way to determine the magnitudes of the in-situ horizontal principal stresses and to predict a safe mud weight window for drilling a stable wellbore, (Zhang, 2011). It was determined using the Eaton method, then the pore pressure profile was calibrated using pore pressure points that directly measured using rebated formation test (RFT). The magnitudes of the horizontal stresses are essential in the mechanical analysis of rocks, (Reynolds et al., 2006). Poro-elastic model is used to estimate the magnitudes of horizontal stresses (Maximum σ_H and minimum σ_h horizontal stresses), equations (8 and 9), (Bjorlykke, 2010). The magnitudes of the minimum horizontal stress were then calibrated using the results of mini-frac. Whereas there is no direct method to calibrate the maximum horizontal stress, it is worth noting that the match between the predicted and actual failures can be used to calibrate the maximum horizontal stress magnitudes that have been estimated utilizing poro-elastic constitutive model. Interpreted Formation Micro-Imager (FMI) and processed data for the last section 8.5 "as show in Fig. 2 were surveyed to determine the horizontal stresses orientation. The orientation of σ_h was 140° and thus σ_H was 50° since they must be perpendicular based on the Andersonian stress state.

$$\sigma_h = \frac{\nu}{1-\nu} * \sigma_v - \frac{\nu}{1-\nu} * \alpha P_o + \alpha P_o \frac{S * \nu}{1-\nu} * \varepsilon_h + \frac{\nu * E}{1-(\nu)^2} * \varepsilon_H \quad (8)$$

$$\sigma_H = \frac{\nu}{1-\nu} * \sigma_v - \frac{\nu}{1-\nu} * \alpha P_o + \alpha P_o \frac{S * \nu}{1-\nu} * \varepsilon_H + \frac{\nu * E}{1-(\nu)^2} * \varepsilon_h \quad (9)$$

Where ν : static Poisson's ratio, E : static Young's modulus, α is Biot's coefficient, P_o : pore pressure, and ε_h and ε_H are tectonic strains, they determine by equations (10 and 11).

$$\varepsilon_h = \frac{\sigma_v * \nu}{E} * \left(1 - \frac{\nu^2}{1-\nu} \right) \quad (10)$$

$$\varepsilon_H = \frac{\sigma_v * \nu}{E} * \left(\frac{\nu^2}{1-\nu} - 1 \right) \quad (11)$$

2.2. Steps of Constructing 3D

- Prepare the data needed to construct the 3D MEM model in a special form and import it to the software (Petrel). These data included (the wells tops, the wells heads, the wells survey and the Zubair oil field contour maps. In addition to 1D MEMs obtained from six wells (pore pressure, rock properties and horizontal stresses (σ_H and σ_h) magnitude).

- Design the polygon according to the points of the Zubair contour maps.
- 2D grid surfaces is created depend on; point data, line data, polygons, surfaces maps, and well tops.
- Create a simple grid 3D modeling, grid cells (nI x nJ x nK) 1617x3490x14 and the total number of the grid cells were (79006620).
- Scaling up well logs using the arithmetic technique based on the results that are uniform with the well logs (1D MEMs outputs).
- Filling the 3D MEM space using a Kriging algorithm based on the outcomes that are most consistent with the well logs (1D MEMs outputs).
- When compared the well logs (input data of six wells), upscale values and property values that were obtained after distributing the properties along the Zubair oil field using the Kriging algorithm. The results are show a good match between the logs, upscale and property data.

3. Results and Discussion

3.1. 1D MEM

Based on the Anderson's classification, the fault regime in the sections of 12.25" and 8.5" were into two regimes. The first region was extended from the Sadi formation to the end of the Maaddud formation, the fault regime here was strike slip ($\sigma_H > \sigma_v > \sigma_h$), except Tanuma formation, fault regime was normal. These results were agreeing with previous studies that the strike-slip regime is the most common regimes in the southern Iraqi field, (Najibi et al., 2017), (Fig. 3). In the second region that extended from the top of the Nahr-Umr formation to the end of the Zubair formation, the normal fault regime was appeared here in this interval except at the top of the Nahr-Umr and Shuaiba formations showing that the fault regime was strike-slip, (Fig. 3). This outcome agrees with the further studies in the Zubair oil field, (Alhussainy, 2020), (Dawood, 2020).

Rock failure was verified by three failure criteria, Mohr-coulomb, modified lade and Mogi-coulomb. Mohr-coulomb overestimated the failure than actual failure (image log), while Modified lade was very conservative in estimated failure (lower than actual failure). Mogi-coulomb was better than other two criteria and revealed a good agreement with actual wellbore failure in image log or caliper. The breakouts problems were the main wellbore stability was issues in; Tanuma, Khasib and Nahr-Umr formations. A 1D MEM for six wells was constructed. The construction of the geomechanical model was carried out by determination; the vertical stress, pore pressure, rock mechanical properties, and horizontal stress orientations and magnitudes as presented in Fig. 3. The stability analysis was initiated with the validation of the geomechanical model using the most applicable failure criteria to predict rock failure for each well before construction the 3D MEM.

3.2. 3D MEM

3.2.1. Vertical Stress

The 3D model shows clearly that the vertical stress increases with depth (Fig. 4). The amounts of vertical stress of the constructed model from Sadi to the end of Zubair formations were between 5000 - 10000 psi.

3.2.2. Horizontal stresses

The 3D distribution of the horizontal stresses (σ_H and σ_h) is shown in Fig. 5 and Fig. 6 respectively, clearly there were horizontal homogeneity and some difference in vertical distribution. Contour maps of the horizontal stresses showed high values of σ_H in Maudud, Nahr-Umr, Shuaiba and Zubair formations.

Fig. 2. FMI log for 8.5", (Program, 2015)

Fig. 3. 1D MEM components of a well (ZB-210) in Zubair oil field, (techlog Schlumberger, 2015)

Fig. 4. 3D distribution of the vertical stress, (Schlumberger, 2017)

Fig. 5. 3D distribution of the maximum horizontal stress, (Schlumberger, 2017)

Fig.6. Distribution of the minimum horizontal stress (Shlumberger, 2017)

3.2.3. Pore pressure

The 3D distribution of pore pressure is illustrated in Fig. 7, there was a clear homogeneity in the pressure distribution horizontally and changes in the pressure values vertically depending on the pressure of the layers. The distribution of pore pressure was shown an area of depletion in Mishrif formation throughout Zubair oil field, but in Shuaiba dome the depletion was more significant than the other domes. The range of normal pore pressure of Mishrif formation (3600- 3900 psi), but the outcomes of 1D and 3D MEM were showed the pore pressure at top of Mishrif formation about 3150 psi. In addition, there was a depletion in the Zubair Formation (in upper sandstone), especially in parts of Hammar dome. The range of normal pore pressure of sand stone formation (5150-5320 psi), but the results of 1D and 3D MEM were showed the range of pore pressure of sand stone formation (3850-5200 psi). While the Nahr-Umr formation appeared increasing in pore pressure due to shale existence, but the pore pressure decreases in Shauiba formation. 3D distribution of Mishrif, Zubair and Nahr-Umr formations is showed in Fig. 8-a, b and c respectively. In the comparison of the 3D distribution with the result of the 1D, there is a good agreement between them.

Fig. 7. 3D distribution of the pore pressure (Schlumberger, 2017)

3.2.4. Rocks properties

Fig. 9 illustrates the 3D distribution of Young's modulus from the Sadi formation to the bottom of the Zubair formation. As shown in this figure, there is a small vertical difference between Young's modulus values. Horizontally, there is a clear homogeneity among the formations Sadi, Rumaila, Tanuma, Mishrif, Maudad and Zubair, Fig. 10-a, b, c and d respectively. On the other hand, in Rafidya dome Tanuma formation has some different values (14 Gpa), while in Shuaiba dome Mishrif has lower values than other domes (4.5 Gpa). Whilst there is a clear heterogeneity among the formations (Shuaiba, Khasib, Nahr-Umr and Ahmedi) in particular in the northern part of the field (Hammar and Shuaiba domes). As noticed in 1D MEM (Fig. 3), the Young's modulus has a low value in shale and sandstone, (7-9 Gpa), whereas it has a high value in limestone, (11-13.5 Gpa). So there was an agreement between the 1D and 3D MEMs' outcomes.

Fig. 8.: 3D contour map of pore pressure distribution for (a) Mishrif; (b) Zubair and (c) Nahr-Umr formations, (Schlumberger, 2017)

Fig. 9. 3D distribution of the Young's modulus, (Schlumberger, 2017)

Fig. 10. 3D contour map of Bulk modulus for (a) Sadi Formation; (b) Shauiba Formation; (c) Nahr-Umr Formation and (d) Zubair Formation, (Schlumberger, 2017)

3D distribution of Poisson's ratio from the Sadi Formation to the bottom of the Zubair Formation represent in Fig. 11. There are several observations: first, as shown in this figure and the Fig. 12-a, b and c, there is a heterogeneity vertically and horizontally. Second, Poisson's ratio increases as the depth increases, but it decreases in the Zubair Formation (even it is the deepest formation), because the Poisson's ratio has a low value in shale and sandstone. Third, in each dome approximately Poisson's ratio was homogeneous. Rock strength or UCS is the key parameter to determine the optimum mud weight, select bits and analyze well stability, (Abdul Aziz and Abdul Hussein, 2021). The 3D distribution of the UCS is illustrated in Fig. 13. Formations contour maps show a number of notices. First, highest values appeared in limestone formations, particularly (Khasib, Mishrif, Rumaila, Mauddud and Shauiba formations), while lowest values are noticed in shale formations (Tanuma, Upper shale and Middle shale). Second, the USC values in the Rafidya dome were higher than the other domes. Third, the distribution of UCS in most formations was apparently heterogeneous, Fig. 14-a, b, c and d.

Fig.11. 3D distribution of the Poisson's ratio, (Schlumberger, 2017)

Fig. 12. 3D contour map of poisson's ratio for (a) Khasib formation, (b) Rumaila formation and (c) Mauddud formation (Schlumberger, 2017)

Rock strength or UCS is the key parameter to determine the optimum mud weight, select bits and analyze well stability, (Abdul Aziz and Abdul Hussein, 2021), (AbdulMajeed and Alhaleem, 2020). The 3D distribution of the UCS is illustrated in Fig. 13. Formations contour maps show a number of notices. First, highest values appeared in limestone formations, particularly (Khasib, Mishrif, Rumaila, Mauddud and Shauiba formations), while lowest values are noticed in shale formations (Tanuma, Upper shale and Middle shale). Second, the USC values in the Rafidya dome were higher than the other domes. Third, the distribution of UCS in most formations was apparently heterogeneous (Figs. 14-a, b, c and d).

Fig.13. 3D distribution of UCS (Schlumberger, 2017)

Another strength property of the rock is the internal friction angle (FANG). A 3D distribution of FANG is illustrated in Fig.15. The contour maps of the formations revealed high values of FANG in limestone and moderate values in sandstone, while low values in shale formations. In Rafidya dome, the FANG values were higher than in the other domes, so the instability problems will be lower in this dome. Fig. 16-a, b, c and d, outline the contour maps of the FANG distribution for some formations. The 3D distribution of last property was tensile strength, there were a homogeneous distribution horizontally and approximately vertically. As a summary of rock properties, calculation of static Young's modulus (1 D MEM) appears lower values in shale and sand, while higher values in limestone. For the Poisson's ratio, high values in limestone, low values in sandstone and in shale between them. Regarding FANG appeared high values of FANG in limestone and moderate values in sandstone, while low values in shale formations. For UCS appeared highest values in limestone formations and low values appeared in shale formations. From 3D MEM, the wellbore instability issues more likely to be faced in the formations, Trauma, Ahmedi, Nahr-Umr and Zubair formations in Shauiba and Hammar domes, because these formations have high poisson's ratio, low young's modulus, low friction angle and low strength property, while in the Rafdiya dome these formations have high (young's modulus, friction angle and strength property) and low poisson's ratio. So, when drilling these formations in the Hammar and Shuaiba domes, we expect to face wellbore instability problems and we have to design a proper weight of drilling mud to drill these formations. While, in Rafdiya dome these formations were more stable. Contour maps of the horizontal stresses showed high values of σ_H in Maudud, Nahr-Umr, Shauiba and Zubair formations.

Fig. 14. 3D contour map of UCS for (a) Sadi Formation; (b) Rumaila Formation; (c) Maudad Formation and (d) Shuaiba Formation, (Schlumberger, 2017)

Fig.15.3D distribution of internal friction angle, (Schlumberger, 2017)

3.3. Sensitivity Analysis of Single Depth

The single depths sensitivity analysis was applied at critical depths of six formations (Tanuma, Khasib, Mishrif, Ahmedi, Nahr-Umr and Zubair formations), where the rock failure is occurred against the used actual mud weight. A Single depth sensitivity has been performed in order to recognize the effect of accuracy of the inclination and azimuth. The outcomes of sensitivity analysis (stereonet and line plots) showed that the wells that inclined (0 to 45 °) are more stable with respect to the tensile failure than other inclinations. The breakdown is most likely occurred when the inclination is greater than 60, and in the direction of σ_H and which required to be conservative in selecting the mud weight to prevent the rock from tensile fracturing. In contrast, the results showed that the breakdown or tensile fracturing failure doesn't occur in the direction of the minimum horizontal stress, even at high mud weights. With respect to the shear failure the stereonet plots showed that the wells with orientations ranged from (0 to 45°) are most stable than other wells even at low weights, especially in the orientation of the minimum horizontal stress and the shear failure is expected to occur in the inclinations of (50 to 90 °) even with high mud weight in both direction minimum and maximum horizontal stress. Furthermore, the results showed that there is no any influence for the azimuth on the drilling mud weight window, but the mud weight window is narrowing when the well inclination is equal or greater than for 35°. Hence, the main wellbore instability is expected to expose with highly deviated and horizontal wells. The proposed scenario to drill a 12.25" section (production section) is by using arrange of mud weight (1.2-1.22 s.g) to the end of Mishrif formation (depletion zone), and progressively increase the weight of the mud until (1.29-1.32 g/cm³) before entering the Nahr-Umr Formation. For 8.5" section (production section), the suitable mud window (1.37-1.56 g/cm³), while the minimum breakdown of Zubair formations was predicted to develop at mud weight of 1.63 g/cm³. Figs. 17, 18 and 19 represent the stereonet and line plots at specific depths of Tanuma, Khasib and Nahr-Umr formation, respectably. These depths are selected depend on the in-site stresses, pore pressure and mechanical rock properties, when these properties in normal trend.

Fig.16. 3D contour map of friction angle for (a) Tanuma Formation,;(b) Khasib Formation (c) Maudad Formation and (d) Zubair formation (Middle shale layer), (Schlumberger, 2017).

Fig.17. (a) Shear failure; (b) Breakdown; (c) Mud window VS azimuth and (d) Mud window VS deviation and of Tanuma Formation

Fig.18. (a) Shear failure; (b) Breakdown; (c) Mud window VS azimuth and (d) Mud window VS deviation and of Khasib Formation

Fig.19. (a) Shear failure; (b) Breakdown; (c) Mud window VS azimuth and (d) Mud window VS deviation and of Nahr-Umr Formation

4. Conclusions

- Regarding the pore pressure, 3D distribution of pore pressure in Zubair oil field seems heterogeneous between the domes. Where the pore pressure in Rafdiya dome was generally higher than other two domes (Hammar and Shauiba), whilst the values of pore pressure in Shauiba dome was the lowest one. For the Hammar dome, the value of the pore pressure was intermediate between Rafdiya and Shauiba domes.
- Concerning pore pressure for formations, as per the 1D MEM, lower of the pore pressure is observed in top of Mishrif Formation (depletion zone) throughout the field, but in Shauiba dome the depletion was more significant than other domes. On the other hand, increasing in pore pressure is observed in Nahr-Umr formation. These observations in 1D MEM were confirmed by the 3D MEM.
- Elastic properties: 3D MEM of Young's modulus appeared low values throughout Hammar and Shauiba domes, while being slightly increased in Rafdiya dome. Regarding the formation, noticed low values in shale and sand formations, while high values in limestone.
- For Poisson's ratio, the 3D distribution appeared clear heterogeneity along Zubair oil field, while homogeneous distribution for each dome. The results appeared high value of the Poisson's ratio in Hammar and Shauiba domes if compared with Rafdiya dome (slightly decrease). Concerning the formations, low values in shale and sandstone, while high values in limestone. Hence, Poisson's ratio noticed to increase with depth, however, it decreased in Zubair Formation, this due to the fact the Poisson's ratio decrease in shale formations.
- Strength properties: 3D distribution of UCS appeared high values in Rafdiya dome if compared with other two domes (Hammar and Shauiba). With regards to formations, noticed high values in limestone formations, while low values in the shale formation, especially in Tanuma and Upper shale formations.
- 3D distribution of internal friction angle appeared high values in Rafdiya dome compared with other domes. In relation to formations distribution, the results appeared high values in limestone and moderate in the sandstone layers, while low in shale layers. Another observation, the internal friction angle increases as the Young's modulus increase in shale formations.
- Mogi-coulomb appeared shear failure only with current mud weight, and this prediction agreed with actual failure (image log), also with suggested mud weight only shear failure appeared.
- The forecasting plan for highly deviated and horizontal wells (65-89 degree) designed increased the mud weight up to (12-13 ppg/1.44-1.56 gm/cm³) as static mud weight, while ECD (12.2-13.2 ppg/ 1.47-1.58 gm/cm³), The minimum breakdown of Zubair Formation was predicted to develop at mud weight of 1.63 g/cm³.

Acknowledgements

I would firstly like to thank Basra Oil Company for providing the data. The authors are very grateful to the Editor in Chief Prof. Dr. Salih M. Awadh, the Secretary of Journal Mr. Samir R. Hijab and the Technical Editors for their great efforts.

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