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Research article

# Formation Pressures Determination Utilizing the Integration of Fractal and Geostatistical Modelling in a Hydrocarbon Formation of SW Iran

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**P-V Fractal model**
**Logratio matrix**

***English Extended Abstract***

## Summary

An authentic understanding of formation pore and fracture pressures is essential to define a safe and optimum mud window in drilling oil and gas wells. This investigation is a challenge in formation pressure studies in the South Azadegan field, which is typically carbonated with very low traces of shale beds, except in the Kazhdumi Formation. The wells drilled in this field hinged on the geological information and pore pressure alterations, can be categorized into three classes; Gachsaran, Pabdeh, and surface formations containing marl. These parameters directly affect the selection of the casing shoe depth and the well schematic. Correspondingly, target reservoir formations, i.e., Sarvak, Kazhdumi, Gadvan, and Fahliyan, and well profiles are other parameters that can classify wells in terms of drilling. It is necessary to analyze and model all upper formation pressures to obtain more precise results to investigate the pore pressure profile in these formations. Effective pressure log data reveals an increasing trend in formation pressure with depth in all wells. Besides, there are a few effective pressure-velocity data pairs in the total data of the Fahliyan Formation of Azadegan wells. With the small number of effective pressure-velocity data pairs in the total data of the Fahliyan Formations of Azadegan wells and the very low correlation coefficient of the Bowers relation for the wells of the Fahliyan Formations, it was necessary to separate this formation into two upper and lower parts. So the modeling has been performed by constructing compressional velocity-effective pressure cubes. This research was based on the data gathered from various drilled wells in this region and the interpretation of seismic data. Also, the effective, pore and formation fracture models have been determined from the integrated geostatistical models validated with the pressure-volume fractal model. The most heightened correlation between the final velocity and effective pressure cubes corresponds to the Ilam with 0.71 and the lower Fahliyan Formations with 0.86, which signifies the model's accuracy with the original data. Based on the final pressure cubes of the formation, the maximum pore pressure of 10,000 psi in the Gadvan to Upper Fahliyan Formations and the maximum fracture pressure of 13,000 psi in the lower Fahliyan to Gotnia Formations have been obtained. In this research, an innovation has been made to study the formation pressures utilizing fractal pressure-volume (P-V) methods. Also, for the construction of the final formation pressure cube model in the entire area of the South Azadegan field, for the first time, the combination of geostatistical methods of sequential Gaussian simulation (SGS) and co-kriging with the acoustic impedance

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(AI) cube obtained from seismic inversion has been used together. Computation of the Logratio matrix resulting from the fractal pressure-volume model revealed the maximum overall accuracy (OA) in the dominant limestone intervals as 0.74 at the depths of 2000-3000 meters, corresponding to the Sarvak to Asmari Formations. The results exhibit the high correspondence of the pore pressure cube model, obtained by sequential Gaussian simulation (SGS) combined with co-kriging and acoustic impedance inversion.

## Introduction

Generally, an initial pore pressure estimation employs surface seismic data before drilling. The best technique to predict the pore pressure in the pre-drilling phase is utilizing seismic data. It evaluates the pore pressure according to the wave velocity effect on pressure differences [1-3]. Drilling information, well logs, and Seismic data are mandated for pore pressure gradient determination in an oilfield. In case the necessary information is lacking in a part of the field, the necessary well logs are prepared to employ model estimation after available data screening and database preparation. Integrating available geological information and well logs can prevent errors in formation pressure estimating, especially in carbonate formations [3-5]. Shear velocity calculation is necessary for fracture pressure estimation. Employing petrophysical logs like DSI can estimate the reservoir's shear wave velocity in the quickest feasible time [6, 7]. The Bowers method (1995 and 2002) is the traditional approach for pore pressure calculation in reserve, in which an effective stress cube is developed utilizing the relationship between effective stress and velocity. It is suggested in sediments under normal pressure as Eq. (1) [8-10]:

$$V = V_0 + A\sigma^B \tag{1}$$

Where V0 is the velocity of unconsolidated fluid-saturated sediments, and A and B describe the velocity variation with raising effective stress (σ) and can be derived from offset well data [11-14] .

According to the effective pressure information at wells (DST/RFT/MDT) and the overburden pressure cube created in the previous section, the effective stress at points of these wells can be obtained [12, 13, 15, 16].

The Sequential Gaussian simulation (SGS) is standard in geostatistical simulations and has responded to permeability, porosity, and other regional variables in numerous simulators [7, 17]. In the co-kriging technique with a shortage of samples, the evaluation is performed utilizing the correlation between the auxiliary variable and the desired regional variable [17-20]. Fractal geometry approaches mainly utilize complex shape analysis of geological structures, particularly in geophysics, mining, and economic geology. This study has faced a new challenge in studying the fracture, effective, and pore pressures by the fractal formation pressure-volume (P-V) technique. A 2*2 logarithmic matrix has been utilized to examine the overall accuracy between mathematical and geological models, which was suggested by Caranza in 2011 for the first approach. After calculating the overall accuracy (OA) by employing data with the highest overlap between mathematical and geological models, it is considered a definite outcome with the least error amount [21, 22]. Of 42 wells in the South Azadegan field, 23 have been selected with the most selected information. The effective pressure data were available in 17 wells in the southern parts, western, and central of the field in the Fahliyan to Ilam reservoir formations, which are discontinuous and do not exist in the field's side sections. This log should be estimated for the wells in the side sections to calculate the pore pressure gradient in the entire field. For this goal, the initial data cube with geostatistical techniques like sequential Gaussian simulations (SGS) and co-kriging with the exact coordinates and inverse distance method has been modeled by defining the relationships between the existing reservoir data. Separate surfaces of depth-domain seismic horizons are constructed employing Petrel 2016 software from the surface of the Aghajari to the Gotnia Formations. Then, the total formation pressure models are presented, integrating time-domain seismic horizon interpretation and correlated with geological information acquired from exploratory oil and gas drilling.

## Methodology and Approaches

It is necessary to calculate effective and overburden pressures for estimating the pore pressure. The overburden pressure cube is computed by integrating the average density value from the surface to the expected depth. Two of the most prominent relationships employed in seismography to produce the

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relationship between density and velocity are the Amoco experimental and the Gardner relationships [23]. In Gardner's method, preferably, the completed logarithmic diagram of the density logs cubes is plotted in a manner comparable to the compression velocity logs, and the logarithmic relation acquired evolves the exponential Eq. (2).

$$\rho = aV_P^b \tag{1}$$

The equation becomes RHOB = 10 (-0.427706) VP 0.229185, converting the above relation to exponential; thus, the Gardner relation coefficients are calculated as a = 0.38 and b = 0.23, respectively. Accordingly, the check shot data and vertical seismic profiling (VSP) cubes have been generated to calculate the average density employing the average velocity cube. The programming language of Petrel 2016 software was employed for each cube to construct the relationships.

Assuming that the outcome of density (grams per cubic centimeter) in gravity acceleration (9.81 grams per square centimeter) at depth (meters) is obtained in kilopascals, calculating the overburden pressure in pounds per square inch (psi) needs a 145.038/1000 conversion factor. Therefore, the relationship is as Eq. (3):

$$P_{O.B} = \frac{9.81 * \rho_{avg} * Depth * 145.038}{1000} \tag{2}$$

Consequently, most variations in overburden pressure are in the range of 10,000 psi-16,000 psi. The initial modeling of the effective pressure was accomplished utilizing three Bowers methods: velocity cube (co-kriged with acoustic impedance), SGS (co-kriging with velocity cube), and IDW. In the next phase, the outcomes of the primary pressure cubes utilizing a neural network are completely propagated by the feed forward back propagation (FFBPNN) method, and cube determination of accepted data by the principal component analysis (PCA) technique was done. Then, each completed effective pressure cube is deducted from the overburden pressure cube as the Terzaghi relationship (Eq. 4). Moreover, the SGS model (co-kriged with VP and AI cubes), which has the highest correlation coefficient is verified for distinct formations correlating the pore pressure cubes created with the primary effective pressure data. So, data acquired from this approach are assumed to estimate the ultimate pore pressure gradient. Accordingly, the effective pressure data of the final cube are compared with the compressional velocity cube data for the same formations. Eventually, the Bowers coefficients are recalculated.

$$P_{Pore} = P_{O.B} - P_{eff} \tag{3}$$

Hence, the highest correlation coefficient between the final velocity and effective pressure cubes is associated with the lower Fahliyan Formation with 0.86 and the Ilam Formation with 0.71, demonstrating the high precision of the modeled data with the authentic data. Poisson's ratio (υ) has been computed, including the final completed shear and compressional velocity cubes employing Eq. (5) in the log form and ultimately as a cube. Generally, Poisson's ratio values are between 0.1 and 0.2, which are admissible. Eventually, the formation fracture pressure is calculated employing Poisson's ratio, pore pressure, and overburden pressure and utilizing Eaton's equation (Eq. (6)):

$$\vartheta = \frac{V_P^2 - 2V_S^2}{2(V_P^2 - V_S^2)} \tag{4}$$

$$P_{Fraction} = (P_{Overburden} - P_{Pore}) * \left(\frac{\vartheta}{1-\vartheta}\right) + P_{pore} \tag{5}$$

Due to the less than 200 psi changes between the maximum and minimum values of pore and fracture pressure histograms in Kazhdumi to Gadvan Formations, safe interval values of drilling mud window designing have been suggested up to 50 psi. Consequently, the increase of fracture and pore pressures of the formation is particularly outstanding with rising depth, excluding the lower Fahliyan Formation, in which, with an increasing depth, we see a pressure reduction. The maximum fracture pressure of 13,000 psi in the Lower Fahliyan to Gotnia Formations and the maximum pore pressure of 10,000 psi in the Gadvan to the upper Fahliyan Formations have been obtained in the modeled pressure cubes.

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## Results and Conclusions

After finalizing the final pressure cube data modeling of the south Azadegan field, the data at 1000-meter intervals have been analyzed due to the high volume of data rows of roughly 1.5 million. The outcomes are proposed as a pressure-volume (P-V) fractal model based on Eq. (7).

$$V(\geq P) \propto P^{-\beta} \tag{6}$$

In this regard, V possesses the sample volume of equal and more enormous formation pressures (P), and β is the fractal dimension.

The amount-volume fractal diagrams acquired from the effective pressure cube (E.P-V) for one-thousand-meter intervals are plotted. Commonly, the formation changes are demonstrated by the diagram's breaking points. Moreover, the amount-volume fractal diagrams acquired from the Pore pressure cube (P.P-V) for one-thousand-meter intervals are plotted and interpreted from surface to 5590 in six individual diagrams. Ultimately, the amount-volume fractal diagrams of the Fracture pressure cube (F.P-V) are interpreted like other models.

As the pore and formation fracture pressures regimes' breakpoints comparison, the pore pressure has one regime less than the fracture pressure from the surface up to 3000m, the number of regimes is equal at 3000-4000m, the fracture pressure has two regimes less at 4000-5000m, and eventually, pore pressure has one regime more than the fracture pressure at 5000-5590m interval.

Twenty-four pore pressure different interval regimes are divided from 1000m to 5590m, and the dominant geological model of each regime is determined, including 17 pure limestone intervals, five sandstone and limestone intervals, and two intervals of limestone and marl. Consequently, the highest overall accuracy (OA) of 0.74 in the dominant limestone intervals of 2000m-3000m and less than 5248.1 psi pore pressure are correlated to the Sarvak to Asmari Formations, and the lowest 0.31 OA between 6918.3 to 7498.8 psi pore pressure is associated to Sargelu to Gadvan Formations in 4000m-5000m intervals. Furthermore, the highest OA of 0.79 in total geological intervals belongs to 2000m-3000m in sandstone and limestone layers. An OA sample of the pore pressure intervals calculated from the Logratio matrix is presented in Table 2 and Fig. 2.

**Table 1. Variations in fracture and pore pressures according to formation pressure modeling of the study field**

| Formation | Pore Pressure (psi) | Fracture Pressure (psi) |
|---|---|---|
| Aghajari | 76.2 - 87.2 | 94 - 142 |
| Gachsaran | 10 - 440 | 80-640 |
| Asmari | 100 - 3900 | 100 - 4900 |
| Gurpi | 2250 - 4700 | 2500 - 4900 |
| Tarbur (Member) | 3550 - 4900 | 3825 - 5125 |
| Ilam and Laffan | 4240 - 6160 | 4500 - 7550 |
| Sarvak | 4300 - 6550 | 4750 - 7550 |
| Kazhdumi | 4800 - 7100 | 5000 - 8200 |
| Dariyan | 5025 - 6425 | 5780 - 6680 |
| Gadvan | 4900 - 9900 | 5200 - 12600 |
| Khalij (member) | 4800 - 10000 | 5000 - 12600 |
| Upper Fahliyan | 3500 - 10000 | 4200 - 10000 |
| Lower Fahliyan to Gotnia | 5000 - 9700 | 5400 - 13000 |

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**Table 2. The mathematical model's Logratio matrix of more than 7834 psi pore pressure and the dominant limestone geological model of 5000m-5590m**

| | | | | | |
|---|---|---|---|---|---|
| | | Geological Model (Pure limestone) | | | |
| | | Outside zone | | Outside zone | |
| Mathematical Model (Pore pressure over 7834.4 psi) | Inside zone | True Positive (A) | 6 | False Positive (B) | 56 |
| | Outside zone | False Negative (C ) | 7083 | True Negative (D) | 21187 |
| | | Type I Error: C/(A+C) | 0.9992 | Type II Error: B/(B+D) | 0.0026 |
| | | Overall Accuracy: (A+D)/(A+B+C+D) | | | 0.7480 |

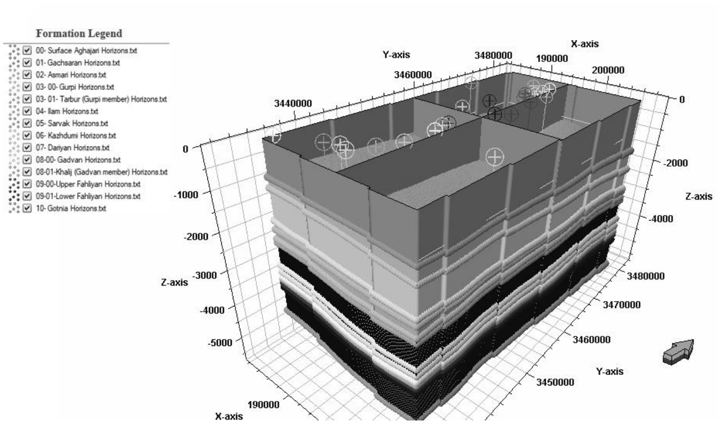


**Fig. 1. South Azadegan field's 3D geological model utilizing seismic sections, drilling data, and used wells' locations**

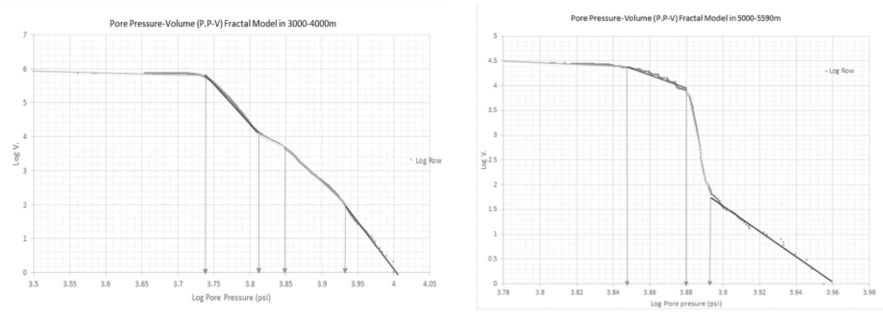


**Fig. 2. Sample of the pore pressure-volume (P.P-V) fractal model a) 3000m-4000m (Kazhdumi to Gadvan Formations), b) 5000m-5590m (Najmeh to Neyriz Formations)**

1- The lowest relative error values compared to Bowers' and the IDW's two methods belong to the effective pressure cube created with a neural network based on the initial SGS model. So, the absolute pore pressure gradient of the SGS model (co-kriged with VP and AI cubes) is accrued.
2- The Ilam Formation with 0.71 and lower Fahliyan with 0.71 have the highest correlation between the velocity cube and the final effective pressure cube, which implies the precision of the modeled data with the initial data.
3- According to the modeled formation pressure cubes, the maximum fracture pressure is in lower Fahliyan to Gotnia Formations with 13,000 psi, maximum pore pressure in Gadvan to Upper Fahliyan Formations with 10,000 psi, and the most variations in overburden pressure are in the range of 10,000-16,000 psi have been acquired.
4- Based on the final pressure models, except for the lower Fahliyan Formation with a decrease in pressure in this formation with increasing depth, the increase of fracture and pore pressure is particularly evident.

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5- Safe interval values of approximately 50 psi are recommended to design a drilling mud window to prevent well-flowing and formation loss in Gadvan to Kazhdumi Formations with less than 200 psi changes between the fracture and pore pressures.
6- Final velocity and pressure cube data of the south Azadegan field are organized for every 15 cm difference in-depth for every 1000 meters in various formations due to the high volume of data (about 1.5 million data rows).
7- The maximum overall accuracy (OA) of 0.78 in depths of 3000-4000 meters and less than 544.4 psi is related to the Kazhdumi Formation up to the Khalij member due to the Logratio matrix in the geological model in the dominant limestone ranges and the mathematical model of effective pressure. Furthermore, the highest OA value of all geological ranges related to the sandstone and marl at 1000-2000 meters is achieved at 0.94.
8- Moreover, the maximum OA of 0.74 at depths of 2000-3000 meters and less than 5248.1 psi pressure is related to the Asmari to Sarvak Formations due to the Logratio matrix of the geological model in the dominant limestone ranges and the mathematical pore pressure cube model. Correspondingly, the highest OA of all geological ranges associated with the limestone and sandstone at depths of 2000-3000 meters is achieved at 0.79.

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