# Analysis of core scale fracture network using fractal geometries

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**Abstract:** Characterization of reservoirs, has a widely spread application in petroleum industry. An effective strategy for modeling can be applied only after obtaining a detailed image of the spatial distribution of the reservoir heterogeneities such as fractures. However, characterization of fractures needs appropriate techniques. Fractal geometry is a useful model which can be used at specific conditions and determine the reservoir properties. Also the results can be verified through various scales. One of the most important parameters is the fracture networks and their distribution which can be evaluated by deterministic and stochastic methods. In this research, the available data of core images from Golshan gas field (south east of Bushehr, IRAN) has been used and the information such as fracture coordinates recorded by some image processing tools. Statistical analysis used to obtain the fracture structure properties (such as fracture length and angle) at each layer. At the end, the fractal dimension of studied environment calculated at each layer and it's relation with Hurst coefficient investigated. Eventually, the results compared with the analysis models which express the fractal structure.

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**Keywords:** Fractal Geometry; fracture Network; Image Processing; Statistical Analysis; Fractal Dimension; Hurst coefficient; Fractal Structure

## 1. Introduction

Since the hydrocarbon resources are non-renewable, the most appropriate methods for gas and oil recovery should be used. In view of the fact that the oil recovery process is a highly cost demanding project, estimating the properties of reservoir rocks such as correlated fractures and proper drilling and completion methods of oil well will rise the operation and utilization of reservoir rocks and consequently lead in economic growth.

In many static modeling, static model of fracture network and various fractures containing zones at reservoir scale has been ignored and simple standard models has been used for dynamic simulation which necessarily cannot express the true fractured zones at under study reservoir.

The flow of fluids in sedimentary rocks containing fractures, is very important. Most of the reservoirs have so many fractures which can supposed such as naturally fractured reservoirs.

According to the definition of Nelson (2001), fractures are discontinuities in reservoir rock which created as the consequence of physical change of reservoir rocks. The role of fractures at natural depletion, secondary recovery and EOR is very important. Investigation and effective modeling of these reservoirs, demands primal knowledge of natural fracture system and regular method of related data collecting and analysis.

Since the fracture reservoirs are very complicated, encountering with their modeling is more difficult in comparison with the conventional reservoirs. This complexity is the result of many of dependent and independent variables which influence the reservoir recovery. Since 1985, more developments happened in study of fractured reservoirs. Also, recently in Iran it has been initiated the use of core data to determine the reservoir rock parameters.

One of the fracture analysis methods is core analysis. Core is a sample from a rock layer which is in cylindrical shape with some centimeters diameter and different sizes. Results analysis of core samples is one of the most important resources for oil reservoirs.

Core sampling in oil wells in two directed and undirected way can be done. Analysis results can be performed in order to get the reservoirs properties and production ability when sample selections and tests are accurate enough. However the results may represent some parts of reservoir rock properties. This is due to complexity and heterogeneity of reservoir rock and can influence the results. In quantitative analysis of core, some properties of reservoir rock such as porosity, diffusivity, oil and gas and water saturation will determine. On the other hand, in qualitative analysis of core, subterraneous stratigraphic information which involves formation boundaries and large-scale sedimentary structures related to depositional environments, fossils and geochemical non-infected samples are provided.

Various models and methods exist for fractured rocks:

- Continuous Models
- Object and Pixel Base Models
- Deterministic and Probabilistic Methods
- Geomechanical and mechanical methods

Undoubtedly, if the fracture intensity is not so much that can hinder the core recovery, the best procedure for detection of fractures in the reservoir is cores investigation of desired zone. The complete cores which have been carefully picked, are able to provide the fracture intensity and related data, rock strength data, rock fabric, the interactions ability of the fractures and the rock matrix.

Directed cores may also provide related data of azimuth of fracture, and ease the quantitative and comprehensive study of distribution and shape of fractures.

Fractal geometry comprehension is a useful method and a kind of mathematical expression from nature architecture which in specific conditions can determine the reservoir properties and is considered as a structure and reservoir fractal behavior tool of study. Fractal geometry has high capacity structures however Euclidean shapes have very limited data which are also repetitive.

**2. Description of the understudy Field**

G Gas Field is one of the Iranian gas fields which is located at approximately 180 km south east of Bushehr, 65 km offshore the Persian Gulf. The volume of gas in place (GIP) of the field is estimated at 40 to 50 trillion cubic feet (TCF).

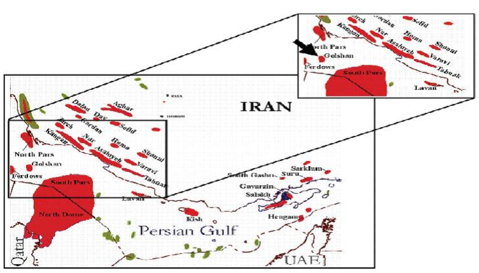


**Fig. 1.** G Gas Field Location Map at Persian Gulf

**3. Data Analysis**

At early stages of modelling, data quality and accuracy were investigated. To have an appropriate model which can cover the natural phenomena, it should be cared that abnormal fractures have not any role at produced model.

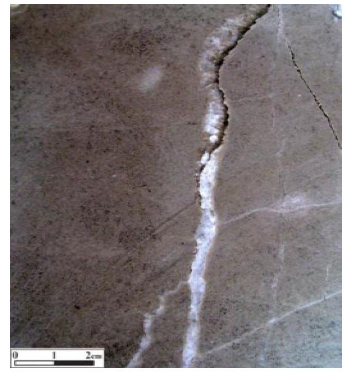

**Fig. 2.** Digital image of a Core sample

For a 2D modeling by core data, it is required to follow a standard scale which is designed by desired software.

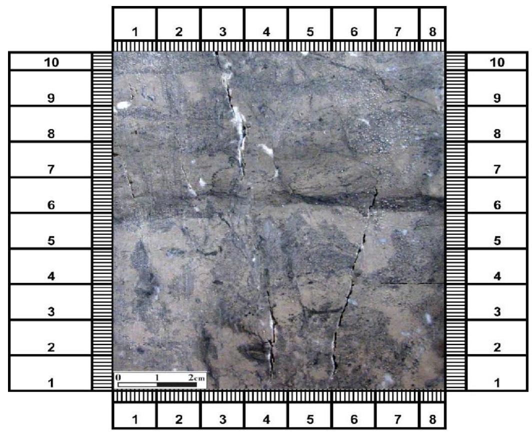

**Fig. 3.** Schematic scaling on a core digital image

Figure 3 depicts the cracks on a core and shows the desired range of modelling. Cracks coordinates has been extracted and digitized carefully by desired software and the consequence data has collected in Table 1 to vast the considered model.

**Table 1.** Digitized spatial statistics of fractures in a core image sample.

| Fracture | No | X (Cm) | Y (Cm) | Xc (Cm) | Yc (Cm) | Teta | L (Cm) |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 7.6 | 5.70805 | 7.438985 | 6.106565 | -67.9994 | 0.859628 |
| | 2 | 7.27797 | 6.50508 | 6.95996 | 7.092795 | -61.5824 | 1.336472 |
| | 3 | 6.64195 | 7.68051 | 6.573515 | 7.85763 | -68.8746 | 0.379762 |
| | 4 | 6.50508 | 8.03475 | | | | |
| 2 | | | | | | | |
| | 1 | 5.95763 | 9.45975 | 5.38602 | 8.70297 | 52.93557 | 1.896791 |
| | 2 | 4.81441 | 7.94619 | 4.782205 | 7.71674 | 82.01031 | 0.463398 |
| | 3 | 4.75 | 7.48729 | 4.78623 | 7.366525 | -73.3005 | 0.252165 |
| | 4 | 4.82246 | 7.24576 | 4.878815 | 7.189405 | -45 | 0.159396 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 4.93517 | 7.13305 | 4.91907 | 7.024365 | 81.5738 | 0.219742 |
| | 6 | 4.90297 | 6.91568 | 4.94725 | 6.806995 | -67.8332 | 0.234718 |
| | 7 | 4.99153 | 6.69831 | 4.967375 | 6.509115 | 82.72427 | 0.381461 |
| | 8 | 4.94322 | 6.31992 | 4.90699 | 6.199155 | 73.30054 | 0.252165 |
| | 9 | 4.87076 | 6.07839 | 4.83856 | 5.933475 | 77.47245 | 0.296899 |
| | 10 | 4.80636 | 5.78856 | 4.701695 | 5.687925 | 43.87544 | 0.290394 |
| | 11 | 4.59703 | 5.58729 | 4.576905 | 5.478605 | 79.50947 | 0.221065 |
| | 12 | 4.55678 | 5.36992 | | | | |
| 3 | | | | | | | |
| | 1 | 4.45212 | 5.27331 | 4.40784 | 5.17267 | 66.25127 | 0.219901 |
| | 2 | 4.36356 | 5.07203 | 4.34746 | 4.91504 | 84.14454 | 0.315627 |
| | 3 | 4.33136 | 4.75805 | 4.315255 | 4.66949 | 79.69316 | 0.180025 |
| | 4 | 4.29915 | 4.58093 | 4.34343 | 4.48432 | -65.3762 | 0.212548 |
| | 5 | 4.38771 | 4.38771 | | | | |

Recorded data in Table 1, are digitized fractures of a core digital image at x, y columns. Xc (Cm) column follows I formula, Yc (Cm) follows II formula and Teta column follows III formula and L (Cm) column follows IV formula. (Xc , Yc) is fracture center coordinate, teta is fracture angle and L is fracture length.

$$Xc = \frac{X1 + X2}{2} \quad \text{(I)}$$

$$YC = \frac{Y1+Y2}{2} \quad \text{(II)}$$

$$\Theta = \tan^{-1}\left(\frac{y2-y1}{x2-x1}\right) \quad \text{(III)}$$

$$L=\sqrt{(Y2-Y1)^2 + (X2-X1)^2} \quad \text{(IV)}$$

**4.Modeling and controlling methods**

Digitized coordinates of fractures observed in figure 2 are summarized in Table 1 and, rebuilt in figure 4. Figure 5 shows the accuracy of the model.

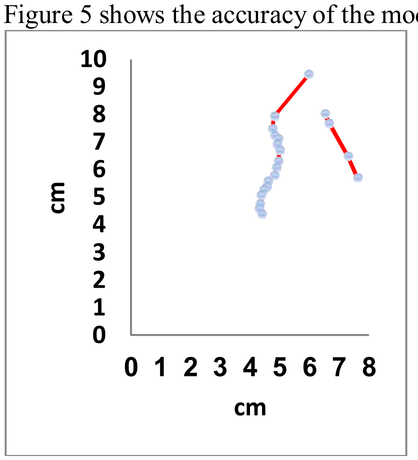


**Fig. 4.** Macroscopic view of fractures in a core image

The results of fracture center determination (Yc,Xc) through formulas I and II can be seen in figure 6. Also, figure 7 shows the accuracy of model.

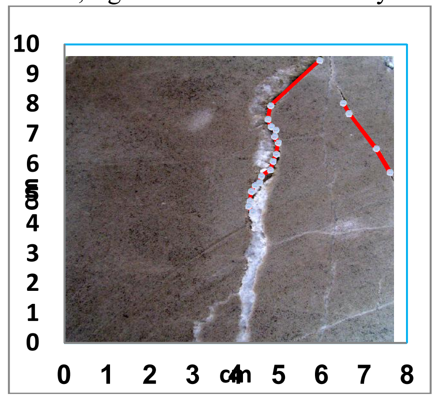


**Fig. 5.** Fracture model accuracy on an image

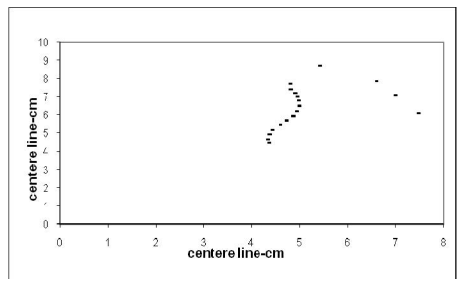


**Fig. 6.** Fracture midpoints sketch in a core image

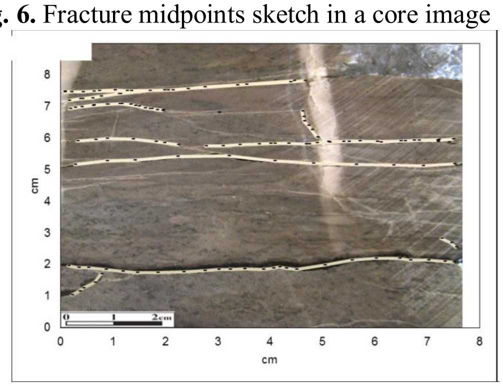


**Fig. 7.** Fracture midpoints sketch on a map

The analysis is done through formulas III, IV which shows fracture angles in figure 8 and fracture length in figure 9 respectively.

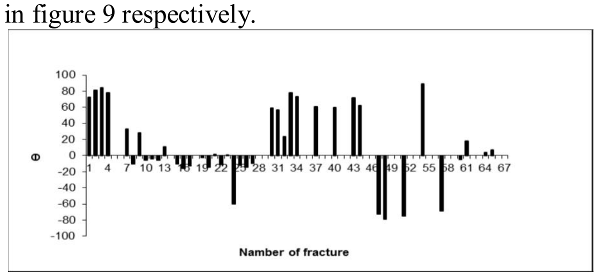


**Fig. 8.** Angle graph for a number of fractures in a core image

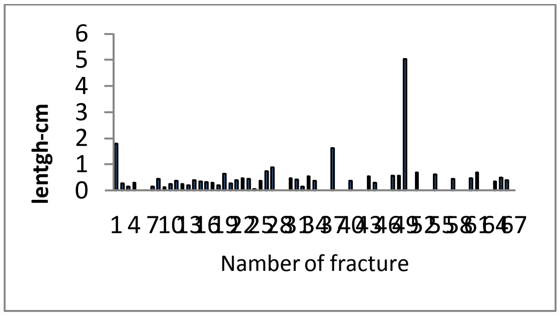


**Fig. 9.** Length graph for a number of fractures in core image

**5.Fractal Model**

Geometrically, fractal has 3 properties:

1) Being self-similar
2) Being very complicated in small scale
3) Do not have an integer dimension.

Fractals are being distinct with Euclidean geometry forms by these properties.

**6.Dimension determination**

Box counting model has been used for dimension determination. Networks with different sizes have been placed on the surface of core images. Then the number of places with the size of "r" which include fractured networks, calculate.

Through the slope, the logarithm graph on the basis of N(r) according to the size of (r) has drawn, and then the D fractal is obtained.

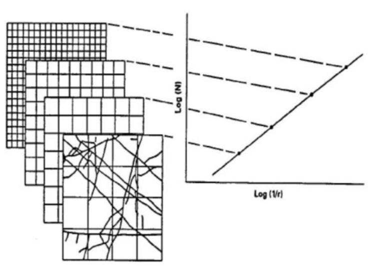


**Fig. 10.** Schematic of slope calculation (Borton & Larsen 1994 )

In figure 11 the number of fractured places being counted and recorded. Table 2 may used to determine the fractal dimension in the under study image.

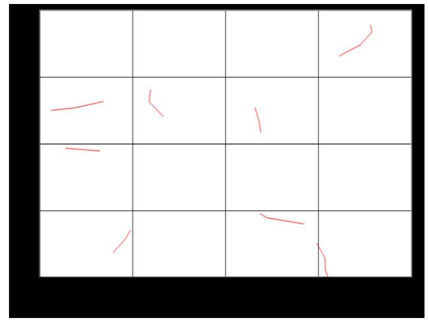

**Fig. 11.** A grid with a sample size of 2 cm on the surface of the core image

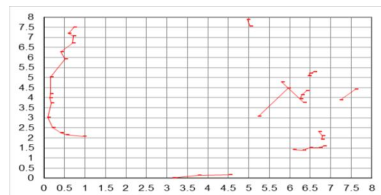

**Fig. 12.** A grid with a sample size of 0.5 cm on the surface of the core image

Statistical analysis of a grid with four different size of fractured networks for a sample on the surface of the image has shown in Table 2.

**Table 2.** Size properties and analysis of the network numbers for a sample of the core image

| total | box size | 1/r | N(r) |
|---|---|---|---|
| Box | r | | |
| 16 | 2 | 0.5 | 8 |
| 64 | 1 | 1 | 9 |
| 256 | 0.5 | 2 | 26 |
| 1024 | 0.25 | 4 | 43 |

Four points which is shown in figure 13, depicts the results of gridding of 4 sizes with different scales on fractured network of a sample in the Table 2 to analysis and determine the line slope.

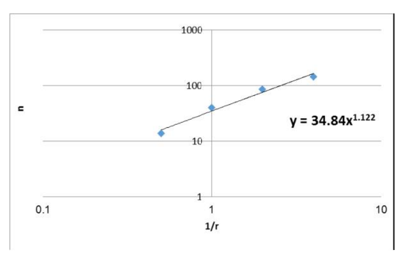


**Fig. 13.** Logarithmic graph and networking results obtained from four different scales with the fractured netwroks for a sample and dimension determination

The same analysis shown in figure 13 were performed for 23 core image samples and in the results are shown inTable 4 for fractal dimension according to the depth.

**Table 3.** Size and the number of networks for all samples

| Box Size | Total box | Total Interval |
|---|---|---|
| R | 1 core | 23 core |
| 2 | 16 | 368 |
| 1 | 64 | 1472 |
| 0.5 | 256 | 5888 |
| 3 | 336 | 7728 |

**Table 4.** Comparing the value of dimension in terms of the depth, for the whole samples in the desired formation

| D | Deepth | Formation |
|---|---|---|
| 1.21 | 2993.6 | KF-3, 2993.60m |
| 1.077 | 3004.6 | KF-5, 3004.60m |
| 1.255 | 3036.8 | KF-13, 3036.80m |
| 1.122 | 3042.7 | KF-13, 3042.70m |
| 1.051 | 3072.5 | KF-22, 3072.50m |
| 1.128 | 3113 | KF-33, 3113m |
| 1.017 | 3158.2 | UDF-1, 3158.20m |
| 1.257 | 3167.1 | UDF-1, 3167.10m |
| 1.316 | 3184.1 | UDF-1, 3184.10m |
| 1.049 | 3201.9 | UDF-2, 3201.90m |
| 1.046 | 3207.8 | UDF-2, 3207.80m |
| 1.04 | 3217.5 | UDF-4, 3217.50m |
| 1.204 | 3220 | UDF-4, 3220m |
| 1.259 | 3232.4 | UDF-6, 3232.40m |
| 1.032 | 3255.8 | UDF-11, 3255.80m |
| 1.202 | 3259 | UDF-11, 3259m |
| 1.035 | 3268.3 | UDF-13, 3268.30m |
| 1.019 | 3282 | UDF-13, 3282m |
| 1.42 | 3287.5 | UDF-14, 3287.50m |
| 1.35 | 3300.3 | UDF-15, 3300.30m |
| 1.039 | 3307.3 | UDF-17, 3307.30m |
| 1.012 | 3311.6 | UDF-17, 3311.60m |
| 1.025 | 3316 | UDF-18, 3316m |

## 7. Hurst Coefficient

Hurst coefficient indicates a stable trend which is used for determining the correlation between the fractures. Hurst coefficient is calculated by the following formula. The coefficient change proves the correlation between fractures in the study area.

$$H=2(d+1-D) \qquad (V)$$

In the above equation, d is the fractal dimension and D is dimension. Hurst coefficient can be between 0 and 0.5. The Hurst coefficient slope is always between 0 and 1. If Hurst coefficient be between 0 and 0.5, it means that will have no lasting value, the 0.5 is the area which the disturbance in the series begins. Values between 1 and 0.5 for the Gaussian model (fractional Gaussian noise) and show the persistence of the series.

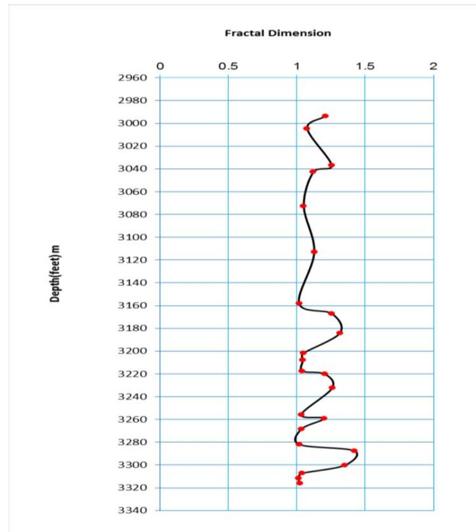


**Fig. 14.** Graphs of logarithmic fractal dimension based on the depth for the whole samples in under study formation

**Table 5.** Hurst coefficient value versus the depth for all samples in formation

| H | Depth | formation | |
|---|---|---|---|
| 0.42 | 2993.6 | KF-3, 2993.60m | |
| 0.154 | 3004.6 | KF-5, 3004.60m | |
| 0.51 | 3036.8 | KF-13, 3036.80m | |
| 0.244 | 3042.7 | KF-13, 3042.70m | |
| 0.102 | 3072.5 | KF-22, 3072.50m | |
| 0.256 | 3113 | KF-33, 3113m | |
| 0.034 | 3158.2 | UDF-1, 3158.20m | |
| 0.514 | 3167.1 | UDF-1, 3167.10m | |
| 0.632 | 3184.1 | UDF-1, 3184.10m | |
| 0.098 | 3201.9 | UDF-2, 3201.90m | |
| 0.092 | 3207.8 | UDF-2, 3207.80m | |
| 0.08 | 3217.5 | UDF-4, 3217.50m | |
| 0.408 | 3220 | UDF-4, 3220m | |
| 0.518 | 3232.4 | UDF-6, 3232.40m | |
| 0.064 | 3255.8 | UDF-11, 3255.80m | |
| 0.404 | 3259 | UDF-11, 3259m | |
| 0.07 | 3268.3 | UDF-13, 3268.30m | |
| 0.038 | 3282 | UDF-13, 3282m | |
| 0.84 | 3287.5 | UDF-14, 3287.50m | |
| 0.7 | 3300.3 | UDF-15, 3300.30m | |
| 0.078 | 3307.3 | UDF-17, 3307.30m | |
| 0.024 | 3311.6 | UDF-17, 3311.60m | |
| 0.05 | 3316 | UDF-18, 3316m | |

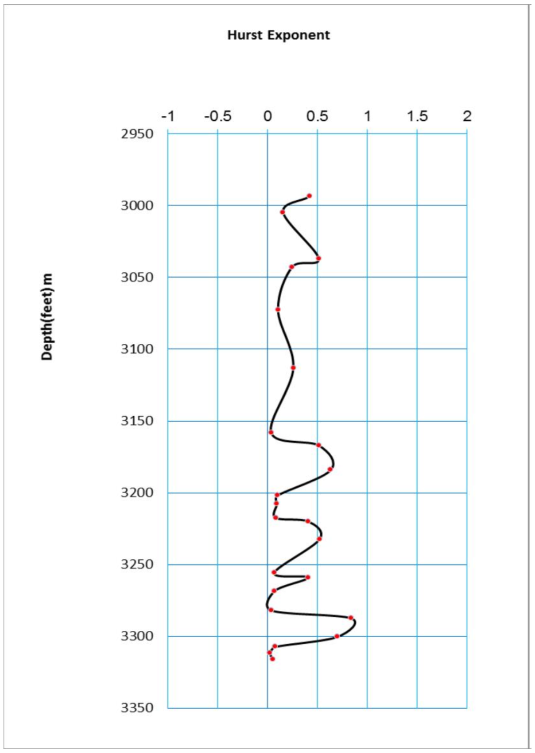


**Fig. 15.** Logarithmic drawing of the Hurst coefficient according the depth for the whole samples in the formation

## 8. Conclusion

In this study, by the use of 23 digital core image data the structure of fracture in a gas reservoir has been analyzed. Structural analysis, statistical distribution and the distribution of fractures in the core has done and the results have obtained as follows:

- Fractal geometry structure is useful (Mandelbrot, 1983) to model and analyze faults and fractures on a large scale.
- Spatial correlation of fractures was investigated by the fractal properties.
- Directed cores can provide the data related to the fractures azimuth which eases the comprehensive and quantitative study of three-dimensional distribution and fractures orientation.
- Hurst coefficient indicates a stable trend in the distribution of fractures and correlation between them.

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