3rd National Conference on Petroleum Geomechanics
National Iranian Oil Company Exploration Directorate
Tehran, Jan,22-23,2019

Reservoir perforation optimization using fuzzy logic from geomechanical point of view

O. Saeidi[1*]; H. Mohammadrezaei[2]; J. Yazdaniyan[3]; M. Rahbar[4]

ABSTRACT

Reservoir perforation, with the aim of production increase, is carried out by making a constant number of shots/ft in our oilfields. However, many parameters affect the shots/ft in perforating a reservoir that include reservoir permeability and porosity, formation UCS, Poisson's Ratio, well direction relative to minimum horizontal stress, liner outer diameter (OD), reservoir pressure and temperature, water saturation, and formation resistivity. An optimized shots/ft number can help to decrease reservoir excessive damage, proper production rate, and optimum shooting charges. It is difficult to define a unique analytical solution between those parameters and shots/ft for reservoir perforation in practice. Fuzzy logic inference system is an attractive tool to solve multi-parameter problems as it considers parameters fuzziness sharing in a solution. Using linguistic variables to describe complex problems is more useful in practical engineering. In this paper formation geomechanical parameters and reservoir properties have been determined from a full-set well log for a reservoir in an offshore oilfield. Fuzzy model has been built in Matlab using mentioned parameters as inputs and shots/ft numbers from previous applications as output. Finally, using the input and output parameters which introduced to the model, reasonable results have been obtained that can be applied in practice, economically.

***Keywords**: reservoir perforation, geomechanical parameter, Fuzzy logic, production increase.*

1. INTRODUCTION

Reservoir perforation conventionally still is a popular method among reservoir engineers used for production increase in many reservoirs around the world. Perforation hole as the only flow channel between the formation and the liner plays an important role on the drawdown performance. The most effective parameters on reservoir production are permeability and porosity. However there are other parameters as formation strength, in-situ stress direction, water saturation and liner diameter that affect the whole process of perforation. To achieve an ideal production rate, the perforation pattern in low-permeability reservoir should be higher than that in high-permeability reservoir [1].

[1] Corresponding Author: Geoscience department, Geomechanics division, Kish Petroleum Engineering Company, No. 12, 6th Koohestan St., Nobonyad Sq., Tehran, E-mail: o.saiedi@yahoo.com
[2] Head of Geology Department, Iranian Offshore Oil Company, Tehran
[3] Project manager, Geology department, Iranian Offshore Oil Company, Tehran
[4] Geomechanics expert, Geology department, Iranian Offshore Oil Company, Tehran

Fuzzy logic is a popular method to solve multi-parameter problems with strong background in decision-making in engineering projects. Fuzzy logic is a type of logic that includes more than just true or false values. It is the logic that deals with situations where one cannot give a clear yes/no (true/false) answer. It uses a continuous range of truth values in the interval [0, 1] rather than just true or false values [2]. In this paper, reservoir properties along with geomechanical parameters are imported in a fuzzy model to evaluate number of shots/ft that required in a reservoir perforation operation to achieve a proper production level. As usually in practice a constant number of shots/ft are used in perforation, results of this research show that according to input parameters these numbers can be different in any interval which can be cost-effective and time-saving for the client in general.

2. Case study description

The studied Y-reservoir is located in the northern part of Persian Gulf. The upper and middle parts of this formation are the major reservoirs. As it is seen in Figure 1 the middle part consists of porous limestone that has been divided into 5 major units, namely, G, H, I, J, and K layers. The upper part corresponds to poor reservoir quality limestones. It has been divided into 3 major units, E, F, C, and D whereas C and D grouped into one unit (CD) later.

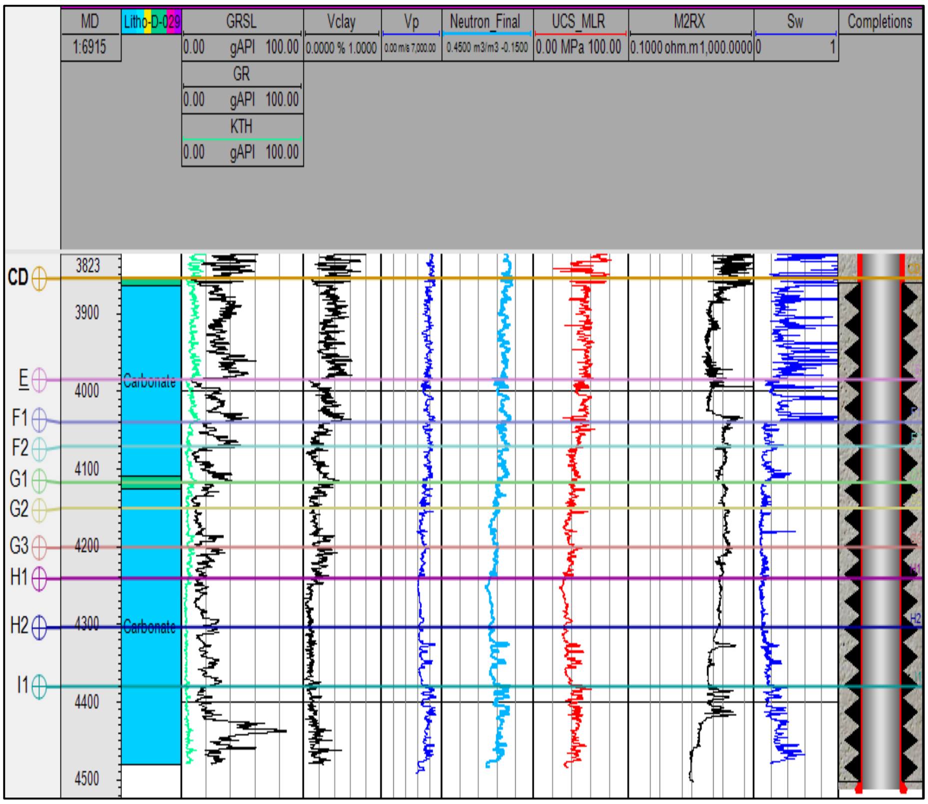


Figure 1. Well section of Y-reservoir including perforation sketch, petrophysical and geomechanical properties.

3. Material and methods

3-1 Geomechanics

Petrophysical and reservoir properties obtained from well logs (Figure 1). Among the geomechanical properties, UCS, Poisson's Ratio (υ) and well direction relative to minimum horizontal stress ($S_{h\text{-}min}$) have been selected as the most effective parameters in perforation. These parameters have been determined from well logs. UCS and υ are obtained as follow:

$$UCS = 11.95 \times \Delta t^{-0.83} \times \rho^{5.67} \times \varphi^{0.15} \quad (1)$$

$$\upsilon = \frac{V_p{}^2 - 2V_s{}^2}{2(V_p{}^2 - V_s{}^2)} \quad (2)$$

Where Δt is the sonic travel time, ρ is the bulk density, φ the is porosity, V_p is the compressional velocity, and V_s is the shear velocity of formation. In-situ stress direction has been estimated from Image Log. Based on the observed breakouts, minimum stress direction was determined and its quality ranked using World Stress Map project (WSM) [3].

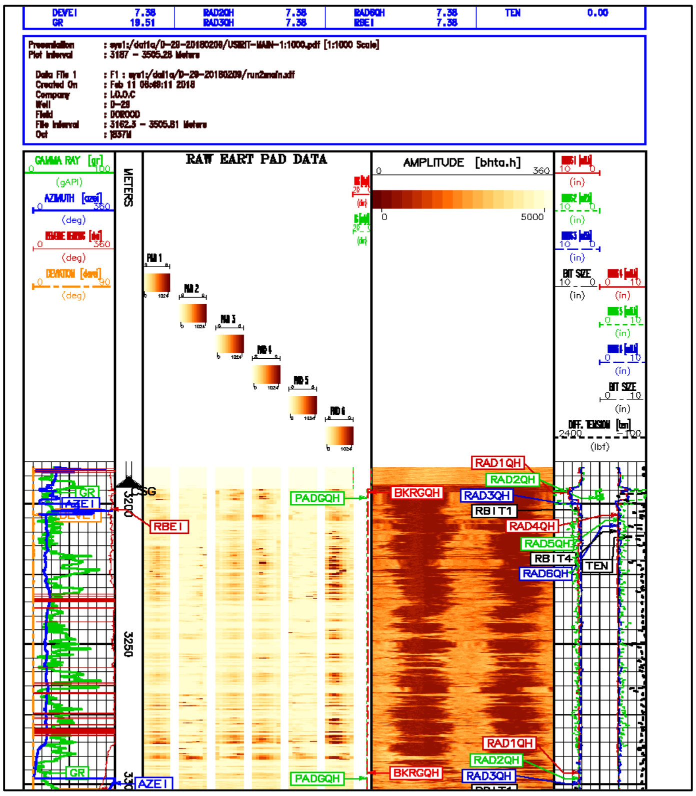


Figure 2. Image log has been run in Y-reservoir

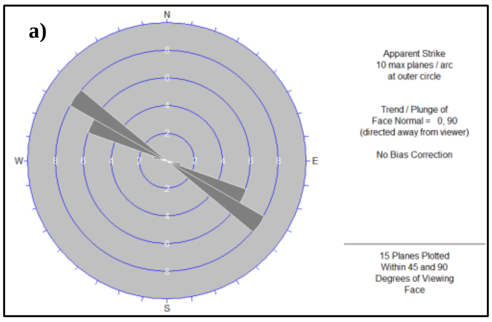
From an image log shown in Figure 2 the direction of $S_{h\text{-}min}$ was determined to be at azimuth of 119° and $S_{H\text{-}max}$ directed at 29°, perpendicularly. Based on the WSM quality ranking shown in Table 1 for the observed breakouts from image log following results were obtained:

- Mean break out azimuth ($S_{h\text{-min}}$) = 119° with standard deviation = 6°,
- Break-out length = 59m,
- Break-out span = 7-130°

According to the WSM the observed data ranked as B-Quality with more than 6 distinct breakout zones and combined length more than 40m in a single well with standard deviation less than 20°. Using differential stress concept the two critical directions for drilling and reservoir perforation are NE-SW with easy condition and NW-SE as difficult condition.

Table 1. WSM quality ranking criteria for breakouts from image log [3]

A-Quality	B-Quality	C-Quality	D-Quality	E-Quality
≥ 10 distinct breakout zones and combined length ≥ 100 m in a single well with s.d. ≤ 12°	≥ 6 distinct breakout zones and combined length ≥ 40 m in a single well with s.d. ≤ 20°	≥ 4 distinct breakout zones and combined length ≥ 20 m in a single well with s.d. ≤ 25°	≥ 4 distinct breakout zones and combined length ≥ 20 m in a single well with s.d. ≤ 40°	Wells without reliable breakouts or with s.d. > 40°



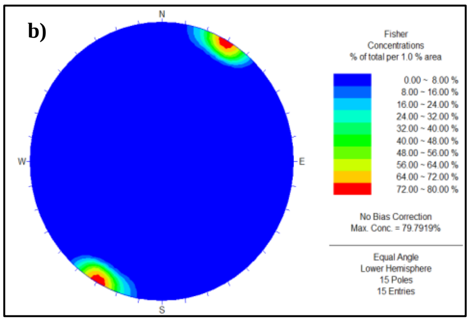


Figure 3. $S_{h\text{-min}}$ direction (a), and $S_{H\text{-max}}$ direction (b)

Table 2. Average of rock properties and reservoir properties used in fuzzy calculation for each zone

Zone	TVD(m)	UCS (MPa)	ϕ	Pressure (psi)	Permeability(md)	Poisson's Ratio	Well-Shmin	Liner-OD (inch)	Temp(°F)	S_w	R_t (ohm.m)	$\rho(\frac{gr}{cm^3})$
CD	3267	61	0.08	2940	3.22	0.21	90	5	117	0.17	60.94	2.43
E	3314	50	0.11	2983	3.36	0.20	90	5	117	0.05	120.41	2.47
F1	3338	50	0.11	3004	1.87	0.21	90	5	117	0.14	95.82	2.43
F2	3353	50	0.11	3018	1.87	0.20	90	5	117	0.13	59.79	2.47
G1	3371	30	0.16	3034	4.35	0.21	90	5	117	0.1	54.33	2.46
G2	3406	27	0.17	3065	7.71	0.23	90	5	117	0.11	75.75	2.34
G3	3423	27	0.17	3080	7.71	0.23	90	5	117	0.11	146.26	2.36
H1	3446	33	0.15	3101	7.45	0.22	90	5	117	0.09	85.28	2.37
H2	3482	40	0.14	3134	5.43	0.22	90	5	117	0.09	32.52	2.39

Rock properties and required parameters have been averaged in each zone (as in Table 2) and have been applied in fuzzy logic calculations.

3-2 Fuzzy logic inference system

A fuzzy inference system consists of a set of “if-then” rules defined over fuzzy sets. Fuzzy sets generalize the concept of a traditional set by allowing the membership degree to be any value between 0 and 1 [2]. If X is a collection of objects denoted generically by x, then a "fuzzy set" A in X is defined as a set of ordered pairs [4].

$$A = \{(x, \mu_A(x)) | x \epsilon X\} \qquad (3)$$

Where $\mu_A(x)$ is called membership function (MF) for the fuzzy set A. The MF maps each element of X to a membership value between 0 and 1. The definition of a fuzzy set is a simple extension of the definition of a classical set in which the characteristic function is permitted to have any values between 0 and 1. If the values of the membership function $\mu_A(x)$ are restricted to either 0 or 1, then A is reduced to a classical set and $\mu_A(x)$ is the characteristic function of A. The most common function to define Mfs is triangular membership function that is shown in Figure 4.

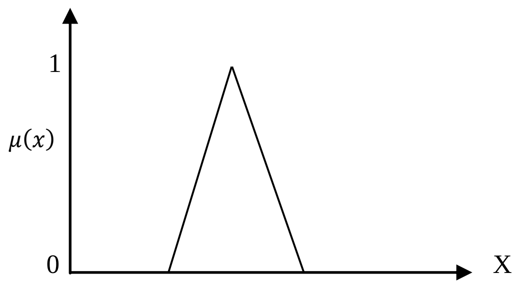


Figure 4. Triangular membership function

All of the parameters have been categorized in three levels to define linguistic variables e.g., low, medium, high or weak, medium, strong and etc.

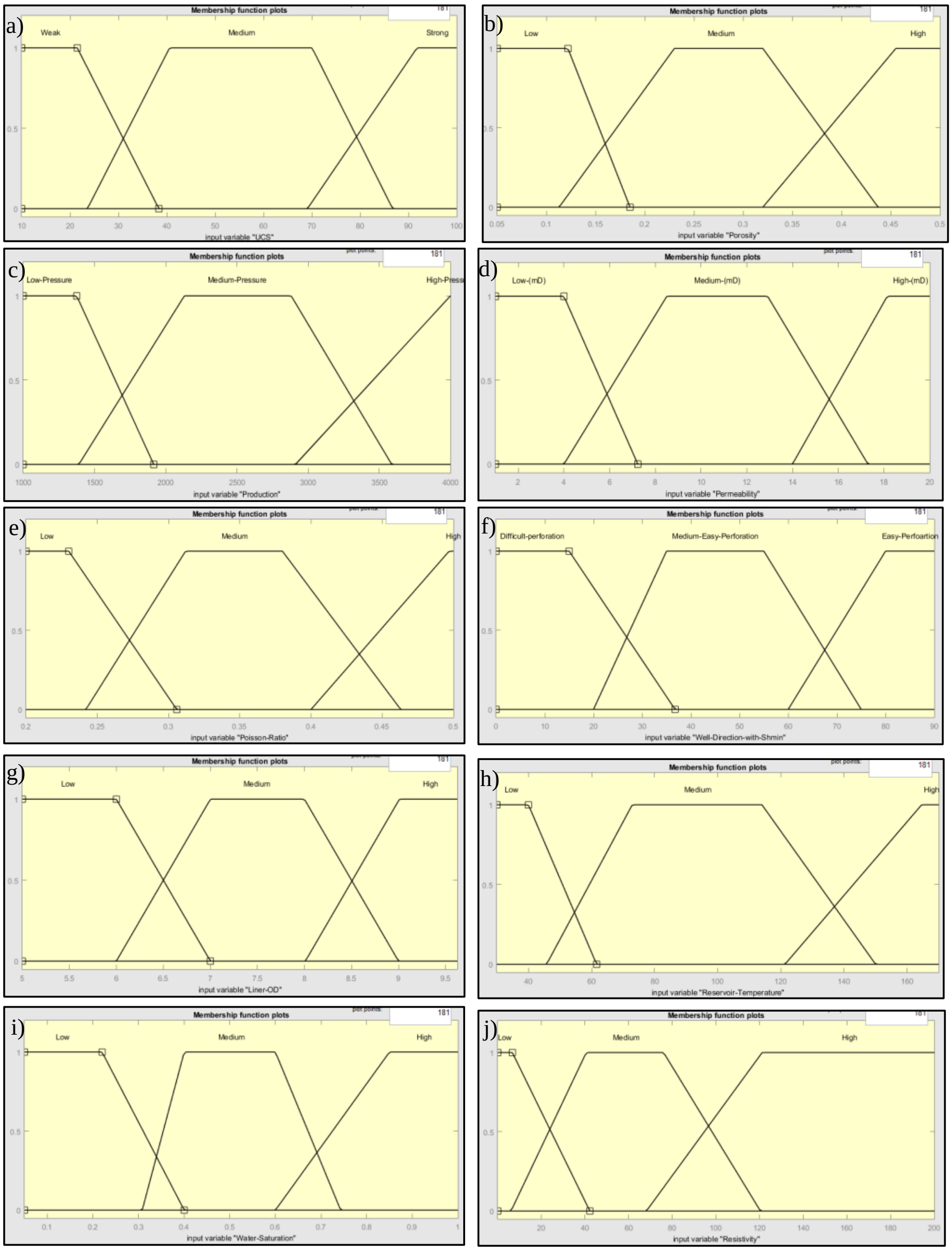
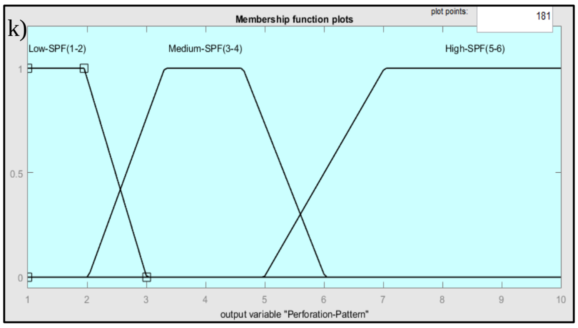


Figure 5. MFs for input parameters; a) UCS, b) Porosity, c) Production pressure, d) Permeability, e) Poisson's Ratio, f) well direction relative to Shmin, g) Liner-OD, h) Temperature, i) Water saturation, j) Resistivity,



Continued (Figure 5). MFs for input parameters and output parameters; k) Perforation pattern

The MFs in this paper are trapezoid membership functions for ten input and one output parameters that are displayed in Figure 5. Out of 59049 total rule numbers, 1722 rules are reasonable and acceptable which applied in the parameters fuzzification system. Defuzzification method of centroid effect has been used in this calculation. Input parameters of Table 2 have been used for evaluation of the fuzzy system. The results of evaluation lead to select number of shots/ft for perforation in the limestone of Y-reservoir different units as it is seen in Table 3.

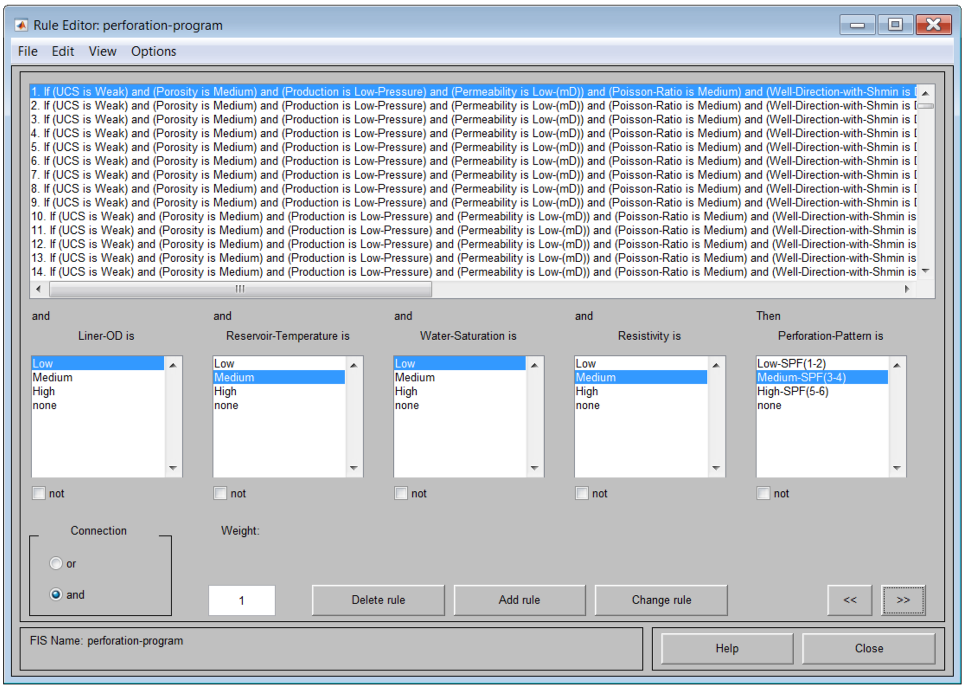


Figure 6. Some parts of the rule base FIS with case study parameters

Some parts of the rule base inferences using input and output parameters are shown in Figure 6. The rule base inferences are based on the Mamdani method that is more useful method in engineering applications [5].

Table 3. Perforation number of shots/ft in Y-reservoir

Zone	CD	E	F1	F2	G1	G2	G3	H1	H2
Shots/Ft	6	6	6	6	4	4	6	4	4

At present in our perforation operation maximum number of 6 shots/ft are applied in practice, whereas, using fuzzy technique adapted in this paper it was decreased to 4 shots/ft for G1, G2, H1 and H2 zones that can be cost-effective for operation.

4. Conclusion

Reservoir perforation is a common way to increase oil production from formations with non-connected pores. Constant number of shots/ft by the shooting gun, commonly, six shots/ft is used to perforate the reservoir. In this paper reservoir properties and geomechanical parameters as input and shots/ft number as output is optimized using fuzzy logic inference system. As the fuzzy logic with reasoning rules takes non-sharp membership degree of a multi-parameter problem into account, then, it's a strong method for optimizing number of shots/ft in reservoir perforation. Input parameters included porosity, permeability, resistivity, bulk density, water saturation, temperature, reservoir pressure, liner-OD, and well direction to S_{hmin}, UCS and Poisson's Ratio against number of shots/ft as output, have been collected in a limestone reservoir in north-western part of Persian Gulf oilfield. Results of calculations using fuzzy inference system lead to decrease in the number of shots/ft in several zones that can be cost-effective and time-saving for operation.

5. Acknowledgment

Dr. Elham Hajikazemi is thanked for noting and language revision of this paper.

6. References

[1]. Guo, J., Qianlin, L., Haiyan, Z., Yonghui, W., Ma, L.; (2015); "*Perforating cluster space optimization method of horizontal well multi-stage fracturing in extremely thick unconventional gas reservoir*", Journal of Natural Gas Science and Engineering, 1-15.

[2]. Zadeh, L.A.; (1965); "*Fuzzy sets*", Information and Control, 8:338-353.

[3]. Reinecker, J., Tingay, M., Müller, B.; (2003); "*Borehole breakout analysis from four-arm caliper logs*", World Stress Map Project.

[4]. Castillo, O., Melin, P.; (2008); Type 2 Fuzzy logic: Theory and applications, Springer, Berlin, Germany.

[5]. Mamdani, E.H.; (1974); *Applications of fuzzy algorithms for simple dynamic plant*. Proceedings of the IEEE 121: 1585–1588.