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Application of Fuzzy Analytical Hierarchy Process (FAHP) for Selecting the Suitable Hydraulic Fracturing Method in Oil Recovery Enhancement

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Abstract: *Hydraulic fracturing is one of the applicable methods for well stimulating to enhance oil recovery. Hydraulic fracturing operations are designed according to the parameters such as tectonic conditions of the area and the harnessing technology which was used. The present study was conducted to select the best hydraulic fracturing method in order to increase the oil recovery by using multi-criteria decision making methods; in respect of the way, fuzzyAnalytic Hierarchy Process (FAHP) is used to analyze the hydraulic fracturing techniquesin one of oilfields in Iran.Consequently, the results of analyses showed that Hydra-Jet Fracturingand Zipper Fracturingwith the scores of 0.150 and 0.149are found as the most preferable methodologies, respectively. Since then, Hydraulic Fracturing with Foam-Based Fluids and Hydraulic Fracturing with Oil-Based Fluids in the third and fourth ranks. The last priorities are related to the Exothermic Hydraulic Fracturing and Hydraulic Fracturing with Acid-Based Fluids with the scores of 0.088 and 0.065, respectively.*

Keywords: *Hydraulic Fracturing, FAHP, Oil Recovery Factor, Hydra-Jet Fracturing*

1. INTRODUCTION

Hydraulic fracturing, commonly considered as the fracking, is an applicable technique which was used by the petroleum industries for several decades to drill hydrocarbons trapped deep under the surface; in respect of the way, the principles of this methodology are not recently utilized. Fracturing approach firstly established at the commercial level in the United States as early as 1947, and after that it considered as the preferable techniques in numerous countries such as Russia, Iran and Canada. By and large fracking was not an economically competitive process and had limited applications until the last decade. Several factors altered the importance of this technology which the affordability and the ubiquity use of recent innovation in the technological tools in the drilling and exploration industries especially in the well construction processes and the recovery of gas regarding the massive volume of natural gas sources worldwide. Thereby, this recent and harnessing technologies revolutionize the way petroleum industries drill oil and gas reservoirs along the coming decades [1-6].

However, reservoir characteristics and the wrong orientation in the design of the hydraulic fracturing operations make the fractures inefficient and they squander vast sums of money for operating the procedures. One of the primary ways of studying the created fractures is imaging logs such as FMI and FMS which are based on the electrical resistance of the formation, well fluid, and on the basis of sound waves [7-12]. The interpretation of these logs can determine the degree of opening, the length of the created fracture, the effect of initial fractures on the whole process and the direction of the fracture; in respect of the way, the operational accuracy will be examined. Hydraulic fracturing has taken place in many Iranian wells (over the past three decades), and now that fields are under development. Moreover, the FMI logs with high horizontal resolution provide a nearly complete picture of the well [3]. Among the significant factors which affecting the hydraulic fracturing, the following phenomena could be mentioned as the operational activities that needs to be done;

- Choosing the appropriate fluid to create fracture and the preferable method of fracturing which has a very important effect on the efficiency of this operation and if these two factors are not corrected in accordance with the reservoir characteristics, the operation of the hydraulic fracturing would not have a significant effect on the production process of the reservoir. In addition, the fluid used to create the fracture is one of the most complex fluids made up of many materials; one of these is propane. Propane is a material made of various particles such as ceramic, and polymer glass. By creating a fracture in the layer, these materials are placed inside the slots to prevent them from closing.
- How to choose a well or the proper level for gutter operations; It may not be necessary to create a fracture in all wells in a reservoir and therefore, in order to economically save the selection of the well and the formation in which an artificial fracture is to be created. It has a high sensitivity.
- How the mechanical properties of the rock affect the gutting operations; rock properties must be fully determined so that during the formation of the fracture, no deterioration is created and the operation is successful.
- How the effects of artificial and natural fractures on each other; hence, their effects should be properly studied [6, 7-14].

An illustration of the basic hydraulic fracturing is schematically shown in figure 1. Moreover, a schematic of fracturing operations is shown in figure 2. For horizontal and vertical wells.

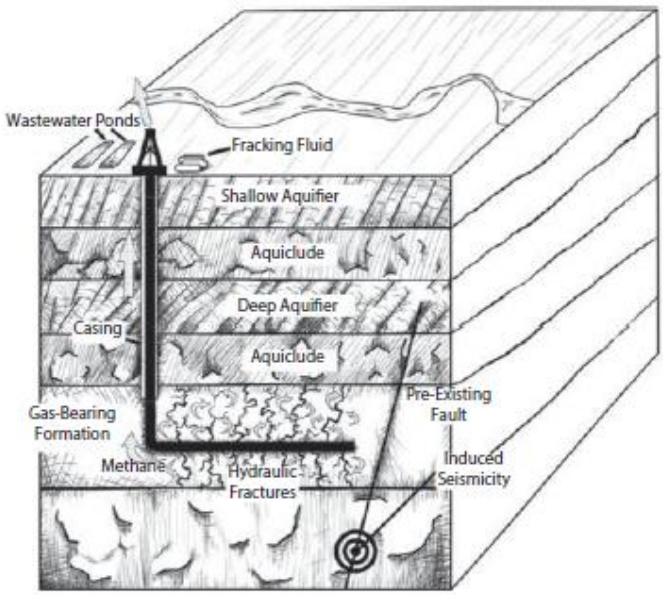

Figure1. *Illustration of the basic fracturing process [6]*

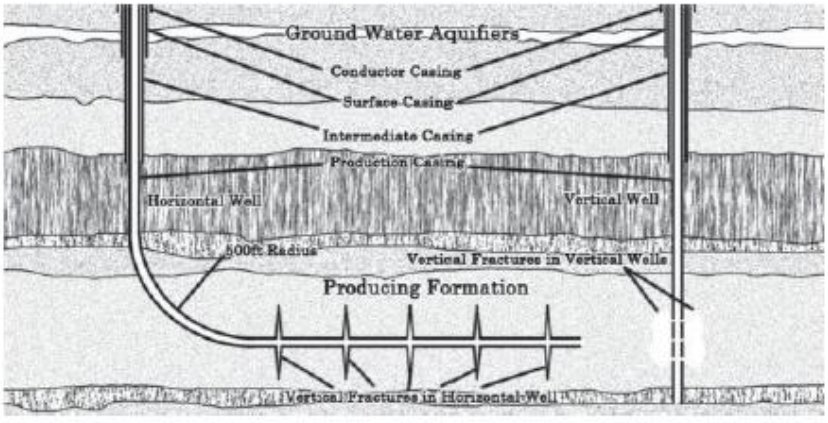

Figure2. *Illustrates horizontal and vertical wells [6]*

Some interesting technologies have been recently developed. These are reviewed in the following[15-17].

1- Zipper Fracturing

2- Hydra-jet fracturing

3- Exothermic Hydraulic Fracturing

4- Hydraulic Fracturing with Foam-based fluids

5- Hydraulic Fracturing with Oil-based fluids

6- Hydraulic Fracturing with Acid-based fluids

Deciding and choosing the best model involve expressing the objectives accurately, identifying the various possible solutions, evaluating their feasibility, evaluating the consequencesof implementing each solution, and finally selecting and implementing it. In most cases, decisions are desirable and with the consent of the decision maker, which has been decided on several criteria. Criteria may be quantitative or qualitative. In multi-criteria decision-making methods that have been respected by researchers in recent decades, a multi-criteria measure is used instead of an optimization measurement. Multi-criteria decision making models are divided into two main categories of multi-objective decision models (henceforth; MODM) and multi-criteria decision models (henceforth; MCDM). In general, MODM s are used to design and multi-index models to select the best option. The main difference between MODM models and MCDM models is that the former is defined in the continuous decision space and the latter is defined on the discrete decision space. In general, there are three things to be done about the criteria used in the issues [18-24]:

- Converting qualitative criteria into quantitative.
- Alter current criteria into the Non-Scale Criteria.
- Determine the relative weights of the criteria.

2. METHODOLOGY

2.1. Decision Making Methods Procedure

Generally, one of two following methodologies are available to implement a decision:

- Trial and error method
- Modeling method

In the test and error method, the decision maker confronts the reality by choosing one of the options and seeing the result, if the decision error is high and the problems occur, the decision would alter and other options might be chosen. On the contrary, in modeling, the decision maker models the real problem, identifies its elements and their impact on each other, and analyzes the model and predicts the performance of a real problem. In a general review, it is said that modeling is generally a process that requires a decent undergraduate work. The use of experts in modeling is necessary and, on the contrary, the following benefits are obtained;

- Cost and time savings
- Use in design
- Predicting the behavior and performance of the system
- Contribute to educational goals

2.2. Fuzzy Hierarchical Analysis Method (FAHP)

This method has provided a broad field for facilitating the decision-making process and is one of the most comprehensive systems designed for decision making with multiple criteria, since it enables the formulation of the problem to be hierarchical and possible to consider getting quantitative and qualitative criteria simultaneously. After introducing the Fuzzy AHP method by the year of the 1970s, many models have been presented by FAHP. In these methods, fuzzy and hierarchical concepts are

used in combination. Given that the provision of verbs is verbally easier for decision makers than providing a response, it is important to use fuzzy concepts in decision making. Although the purpose of the hierarchical analysis method is to obtain the opinion of experts and experts, the method of hierarchical analysis of classics does not correctly reflect the way human thinking, because in pair wise comparisons of this method of numbers accurately used. Other cases that are often criticized for hierarchical analysis are the existence of an unbalanced scale in judgments, the uncertainty and inaccuracy of pair comparisons. Decision makers are often unable to express their opinion on excellence due to the fuzzy nature of pair comparisons. For this reason, in their judgments, they prefer to present an interval in place of a fixed number. In 1996, a method called the "Fuzzy Analytical Hierarchy Process" was developed by a Chinese researcher named Chang. The numbers used in this method are fuzzy triangular numbers.

2.3. Gathering Data

In this research, experts from the Global Petrochemical Company Kish have been interviewed to extract the factors affecting the outcome of hydraulic fracturing and, in fact, to find the appropriate criteria and options for research, as well as to complete the questionnaires of the multi-criteria decision making methodology. Global Petrotek Kish is an Iranian Oilfield Services Co., which operates in the field of drilling, logistics and drilling support, maintenance and repair consulting, engineering consultancy, and supply of materials.

2.4. Method of Investigation

One of the most important stages of the investigation is the gathering Information. The information needed to conduct the research can be collected in different ways. Various tools like observation, interviews, questionnaires, etc. are available to obtain data. Each of these tools has some disadvantages and advantages that should be taken into consideration when using them so that the validity of the research is not compromised and the strengths of the tool are strengthened. Each researcher should choose one or several tools according to the nature of the problem and, after obtaining the necessary conditions for the validity of these tools, use them to collect the data. The choice of tools should be such that the interrogator can defend his choice of instrument and thereby validate his research achievements.Decision-making criteria are demonstrated in table 1.

Table1. *Making Decision Criterion*

Row	Decision-making criteria for Hydraulic Fracturing
1	Existence of porous materials in the source rock
2	Non-Linear Parameters like Rock characteristics
3	Sidewall pressure
4	Geometry of injected section
5	Current discontinuity in the rock
6	In-situ stresses and formation strain

3. RESULTS AND DISCUSSION

As can be seen in Table 2, in order to increase the hydraulic fracture to increase the recovery rate of oil, the Earth Strain with a weight of 0.306 was chosen as the best significant criteria among other Criterion. Since then, Sidewall pressure, Current discontinuity in the rock, and Non-Linear Parameters like Rock Expansion are in the sequential level of importance; 0.289, 0.162, and 0.120 respectively. Regarding the experts responding, Existence of porous materials in the source rock and Geometry of injected section are categorized as the least criterion.

Table2. *Criteria normalized weights*

Decision-making Criteria for Hydraulic Fracturing	Criteria normalized weights
Existence of porous materials in the source rock	0.073
Non-Linear Parameters like Rock characteristics	0.120
Sidewall pressure	0.289
Geometry of injected section	0.051
Current discontinuity in the rock	0162
In-situ stresses and formation strain	0.306

As shown in Table 3, in order to increase the hydraulic fracture up to the FAHP analysis to increase the recovery rate of oil, the Zipper Fracturing and Hydra-jet fracturing with the weight of 0.150 and 0.149 respectively was chosen as the best method among other methods. After that, Exothermic Hydraulic Fracturing and Hydraulic Fracturing with Foam-based fluids with the normal weight of 0.109 and 0.104 are in the following ratings. The least preferred techniques are Hydraulic Fracturing with Oil-based fluids and Hydraulic Fracturing with Acid-based fluids with the weights of 0.088 and 0.065 respectively.

Table3. *Hydraulic Fracturing Techniques rating according to the FAHP*

Hydraulic Fracturing Techniques	Normal Weight	Rating
Zipper Fracturing	0.150	1
Hydra-jet fracturing	0.149	2
Exothermic Hydraulic Fracturing	0.109	3
Hydraulic Fracturing with Foam-based fluids	0.104	4
Hydraulic Fracturing with Oil-based fluids	0.088	5
Hydraulic Fracturing with Acid-based fluids	0.065	6

4. CONCLUSION

Hydraulic fracturing is one of the most preferable techniques for increasing the oil recovery factor and due to the comprehensive interviews among petroleum experts Zipper Fracturing and Hydra-jet fracturing with the weight of 0.150 and 0.149 are the most common. Next, Hydraulic Fracturing with Oil-based fluids and Hydraulic Fracturing with Acid-based fluids with the weights of 0.088 and 0.065 are the least preferable techniques in FAHP analysis. In addition, Earth Strain and Sidewall pressure with the weight of 0.306 and 0.289 are the best criterion on the selection of hydraulic fracturing techniques.

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