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A Review on Conventional Candidate-well Selection for Hydraulic Fracturing in Oil and Gas Wells

ABSTRACT

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Hydraulic Fracturing (HF) which is an ever-increasing focus area for upstream industry is the pumping of fluids at high rates and pressures in order to break the rock, and it is using to accelerate hydrocarbon production and improving ultimate recovery in many reservoirs. It is clearly indicated in HF experience's literature, to be successful conducted, it is directly depending on rigorous candidate-well selection. The techniques applied in HF candidate-well selection could be divided into two methods; conventional and advanced approaches. Being familiar with the conventional methods in candidate-well selection that mainly deals with engineering, geological, etc aspects in decision making process, is of particular importance in order to increase the performance of the advanced techniques that mainly utilized artificial intelligence methods. This paper is a review of the conventional candidate-well selection for hydraulic fracturing in oil and gas wells.

Keywords: *Candidate selection, Conventional, Hydraulic fracturing, oil and gas wells, Hydrocarbon reservoirs.*

1. INTRODUCTION

Due to the recent high prices of hydrocarbons and the difficulty in finding new reserves, the oil and gas industry has made efforts to increase the rate of recovery in mature fields. The average rate of recovery is 35% for oil and 70% for gas; the oil and gas industry is trying to reach a rate of recovery of 50% for oil and more than 80% for gas (Rückheim *et al.*, 2005). HF increases the ultimate recovery factor that corresponds to the economic cutoff of production. For these and other reasons, HF is one of the most common completion operations in oil and gas reservoirs (Daneshy, 2010). The capability of HF to increase the reserves has been shown by Veatch *et al.* (1989). The process of HF is schematically shown in Figure 1.

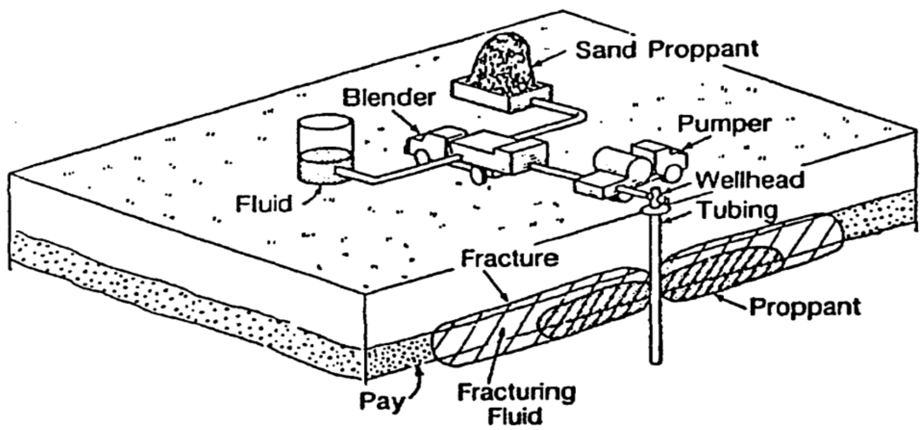

Figure 1. The HF Process (Veatch et al., 1989)

HF is the pumping of fluids at high rates and pressures in order to break the rock. In an Ideal assumption, a fracture will be formed with two wings of equal length on both sides of the borehole. After the creation of the fracture, pumping will stop and the fluids will progressively leak off into the formation. This would close the fracture, which in turn eliminate the conductivity. In order to remain it open, two methods will be applied: acid or proppant. Actually, the classification of HF is based on the mentioned methods that act to hold the fracture open. Acid is used to etch the fracture faces to prevent them to fit closely together. Proppant is used to pack the fracture to hold it open. Numerous advantages of later over the former discussed by Zoveidavianpoor et al, (2011a), (in press).

Choosing a target well and a target formation is considered the first stage in HF and of course regarded as a critical decision-making in the whole process of HF treatment. The success of HF treatment mainly achieved by high quality candidate-well selection (Vincent, 2011; Malik *et al.*, 2006; JPT online, 2006; EPA, 2004; Burnstad *et al*., 2004; Guoynes *et al*., 2000; Reeves *et al.*, 1999; McMillan and Suffron, 1995; Conway *et al.*, 1985). Although a common practice, candidate-well selection is not a straightforward process and up to now, there has not been a well-defined and unified approach to universally select candidate-wells across different geological settings (Mohaghegh, 2001; Economides and Martin, 2007; Reeves *et al.*, 2000; Reeves *et al.*, 1999). In order to successfully performing HF, the selection of the first well through candidate-well selection phase is of particular importance. Indeed, accurate candidate-well selection for HF treatment not only saves money and time but also will establish this technology as a proper replacement stimulation method in carbonate reservoirs. So, the need for accurate candidate-well selection to eliminate possible failures becomes very important.

The objective of this study is to explore the literature that relevant to the HF candidate-well selection in oil and gas well, in one major category; conventional methods. Firstly, an outline of the HF process and its common application will tend to show the application of HF in upstream petroleum industry. Second, a brief description on production increases mechanisms by HF is presented in section 3. As any other technology, HF will work when selecting the right well and conducting the correct design. So, HF candidate-well selection is presented in section 4. Section 5 will review the main objective of this study, which is conventional candidate-well selection. Discussions and conclusions will be covered in section 6.

2. HYDRAULIC FRACTURING

The Stanolind Oil & Gas Company (later on Pan American Petroleum Company) successfully conducted the first HF treatment in the Hugoton oil field in Kansas in July 1947 (Clark, 1949; Gidley, 2001). Initially, fracturing was a low technology operation consisting of the injection, at low temperature, of a few thousand gallons of napalm into low-pressure reservoirs. Substantially, HF has evolved into a highly engineering and complex procedure. As a technology has improved, so has the number of wells, formations, and fields that can be successfully fractured, increased. The development of high pressure pump units, high strength proppant, and sophisticated fracturing fluids, has meant that deep, low permeability, high temperature, reservoirs can now be fractured (Veatch *et al.*, 1989).

HF is a well-known technology, which was originally applied to overcome near wellbore skin damage (Smith, 2006). Since then, it has been expanded to such applications as reservoir stimulation (Economides and Nolte, 2000) for increase hydrocarbon deliverability, increase drainage area, and decrease pressure drop around the well to minimize problems with asphaltene and/or paraffin deposition (Rückheim *et al.*, 2005), geothermal reservoir recovery (Robinson *et al.*, 1971), waste disposal (Shadizadeh *et al*., 2011), and control of sand production (Wedman *et al.*, 1999). The same technology has also been adapted to measure the in-situ stress field (Haimson *et al.*, 1988). Obviously, there could be other uses of HF, but the majority of the treatments are performed for the mentioned reasons.

A fracturing chart along with different treatment stages is shown in Figure 2. Typically, a fracturing job starts with injection of a mixture of mid- to low-strength acid and water, which called "pre-pad". Usually a polymer follows that acts as a friction reducer, which called "pad". The fracture width will be created and controls the initial fluid loss but contains no proppant. The "slurry" then follows, which is a mixture of proppant and the fracturing fluid. The specific details of fluid mixture and proppant type vary between reservoirs. Once the desired amount of proppant is pumped, in the last step, the slurry inside the wellbore is displaced into the fracture (Daneshy, 2010).

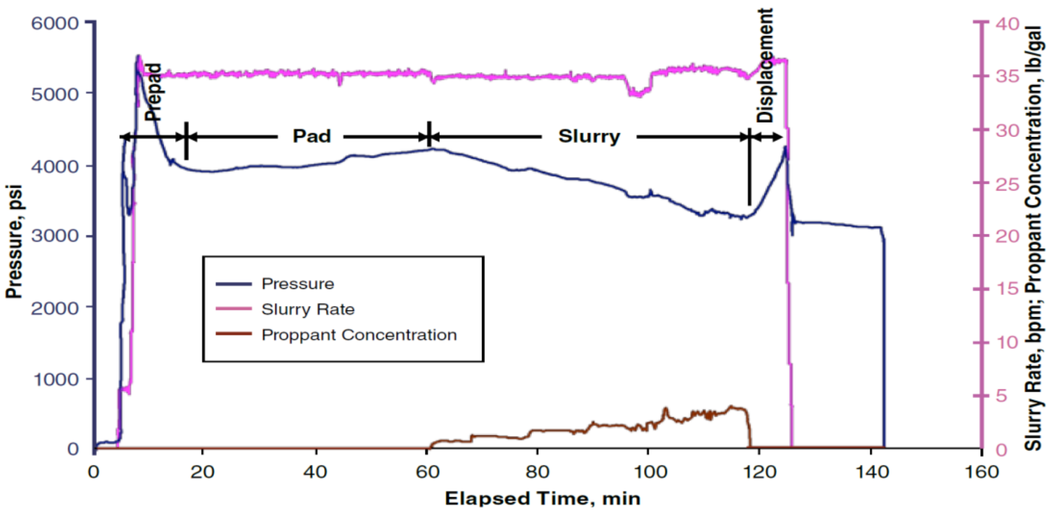

Figure 2. A typical fracturing chart illustrates the steps to HF a well (Daneshy, 2010)

HF technology has made significant contributions to the petroleum industry since its inception (Veatch *et al.*, 1989). By 2009 HF activity has increased 5-fold compared to the investment of a decade earlier and has become the second largest outlay of petroleum companies after drilling (Economides, 2010).

3. PRODUCTION INCREASES BY HYDRAULIC FRACTURING

HF creates highly conductive paths from deep in the reservoir to the wellbore and is aimed at raising the well productivity by increasing the effective wellbore radius for wells completed in low permeability carbonate formations (Daneshy, 2010; Mukherjee, 1999). The radial well inflow equation shows that the well production rate (Q) can be increased by:

$$Q = \frac{Kh(P_r - P_{wf})}{141.2\mu B_o\left[\ln\left(\frac{r_e}{r_w}\right) + s\right]} = \frac{Kh(P_r - P_{wf})}{141.2\mu B_o \ln\left(\frac{r_e}{r'_w}\right)} \quad \text{……………………………… Eq. 1}$$

From Eq. 1, it is clearly shown that (1) increasing the formation flow capacity ($K.h$); the fracture may increase the effective formation height (h) or connect with a formation zone with a higher permeability (K). (2) bypassing flow effects that increase the skin (S) e.g. near wellbore formation damage. (3) increasing the wellbore radius (r_w) to an effective wellbore radius (r'_w) where r'_w is a function of the conductive fracture length L_f.

Radial flow from the reservoir into the wellbore is not an efficient flow regime. As the fluid approaches the wellbore, it has to pass through successively smaller and smaller areas. This causes "jamming" of the fluid and reduction in flow. If one were to complete the well such that the radial flow changes to nearly linear, then the change in flow pattern will increase well productivity. As shown in Figure 3, a properly designed and executed HF can change flow from radial to nearly linear (Daneshy, 2010).

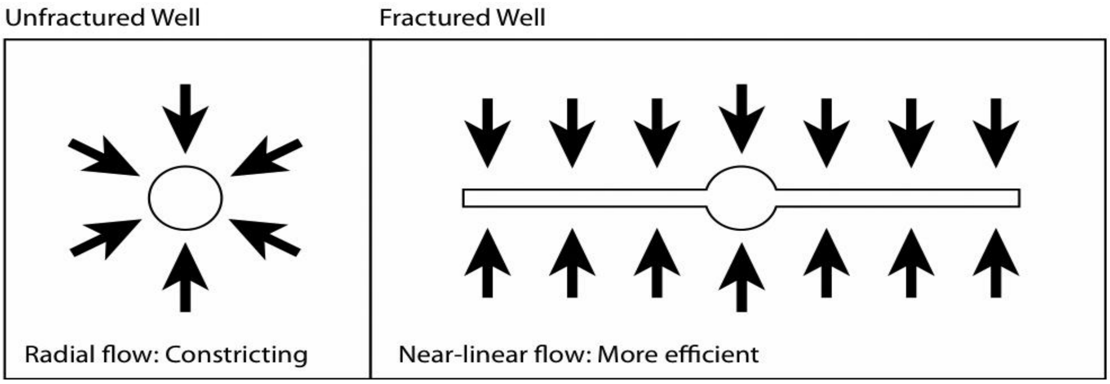

Figure 3. Mechanics of production increase by hydraulic fracturing (Daneshy, 2010).

Under most promising production conditions, an induced fracture with appropriate geometry minimizes near-wellbore pressure losses very efficiently. The most practical explanation to describe the profound implications of extended well bores by HF derives from understanding the pressure losses in the area of drainage. Darcy's law states that the pressure gradient in the direction of flow is directly proportional to the velocity. Eq. 2 states these mathematically in consistent units:

$$dp/dx = v\mu/k \quad \text{……………Eq. 2}$$

where v=q/A.

This relationship also implies that the lower the velocity, the lower the pressure gradient in the path of flow. In radial drainage, with constant volumetric rate, the flow velocity in the radial-flow path is maximum at the wellbore (Mukherjee, 1999).

A highly permeable fracture needs to be created for a successful treatment. This is not to say that a less-permeable fracture will be ineffective, but rather that a substantial production increase requires a very permeable fracture. As formation permeability increases, the fracture permeability required to achieve a significant production improvement becomes very large. At present, use of HF is much more prevalent in low- and ultra low-permeability reservoirs.

In low-permeability area, fracture treatments were so successful in increasing oil production that operators are drilling areas previously skipped (Howard and Fast, 1970). Wells that responded to the first fracturing job typically respond to retreatment, often with production rates equal to or greater than after the original stimulation. Successful treatment is because of 1) extension of existing fracture system, 2) reopening of previous fractures, 3) washing of fracture faces, 4) replenishing of embedded proppant, and 5) opening new fractures in previously unfractured areas. Previously unstimulated wells responded better to propped fractures than wells that had been previously stimulated with nitroglycerin. Of 2000 initial fracture treatments studied, more than 85% were economically successful. Exploration of the reservoir will be more economical when fundamental geological aspects are thoroughly understood. Many dry holes have been converted into commercial producers and marginal leases changed into valuable properties (Sallee and Rugg, 1953).

4. HYDRAULIC FRACTURING CANDIDATE - WELL SELECTION

It has been emphasizing, that the success rate has improved with improved candidate-well selection procedure (Vincent, 2011). Various investigations show that the success of HF operation mainly acquired by better candidate-well selection (Vincent, 2011; Malik *et al*., 2006; JPT online, 2006; EPA, 2004; Burnstad *et al*., 2004; Guoynes *et al*., 2000; Reeves *et al.*, 1999; McMillan and Suffron, 1995; Conway *et al.*, 1985). It could be say that candidate-well selection is the process of choosing or recognizing wells that have potential for higher production and better return of investment after stimulation job. In order to successfully performing HF treatment, the selection of the first well through well-defined methodology is of particular importance. This objective not only saves money and time but also will establish this technology as a proper stimulation method in carbonate reservoirs. So, the need for accurate HF candidate-well selection to eliminate possible failures becomes very important.

Besides reservoir quality and completion, the effectiveness of the HF treatment is a function of three critical parts, which are tying together: candidate-well selection, treatment design, and field operation (Figure 4). Actually, they are the triangle success factors that must link together. Applying the best treatment design and field procedures to the wrong candidate-well will results in a failure of the whole operation. In other words, all of the three factors should perform well to guarantee the success of HF treatment.

Different investigations are available for choosing techniques for candidate-well selection. Reeves *et al.* (1999) and (2000) classified it into three methods: (1) production performance comparisons, (2) pattern recognition technology/virtual intelligence methods, and (3) production type curve matching. Economides and Martin (2007) categorized candidate-well selection methodologies on three types: (1) conventional, (2) mixed conventional and advanced, and (3) advanced methods. In another study, Zoveidavianpoor (2012) merged the mixed conventional and advanced methods into the advanced methods. So, two methods for HF candidate-well selection presented; conventional, and advanced approaches, which described in the following sections. These later method is not intended to pursue as the main objectives in this study, because the focus of this study is on conventional HF candidate-well selection procedure. Being familiar with the conventional methods that mainly deals with engineering, geological, etc aspects in decision making process, is of particular importance in order to increase the performance of the advanced techniques that mainly utilized artificial intelligence methods. So, this paper is a review of the conventional candidate-well selection for hydraulic fracturing in oil and gas wells.

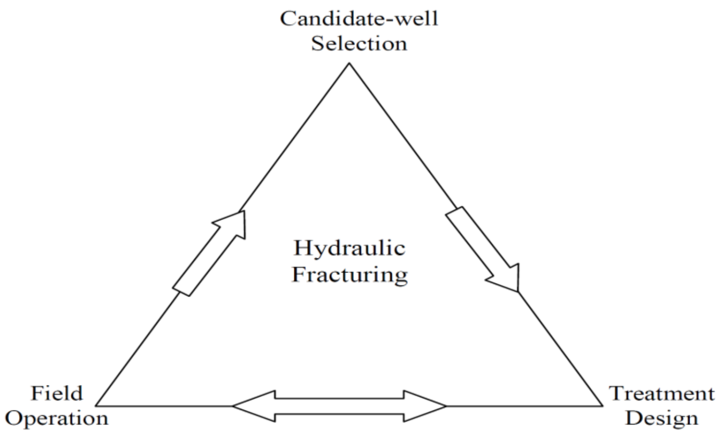

Figure 4. The HF triangle success

5. CONVENTIONAL HYDRAULIC FRACTURING CANDIDATE-WELL SELECTION

Gas Research Institute (GRI) believes that candidate-well selection phase is where the greatest industry benefit resides. Moreover, many stimulations fail because of poor-candidate selection. GRI also argue that good producers often are the best candidate, even though that seems counterintuitive (Ely *et al.*, 2000).

There are wide ranges of parameters that must be undertaken prior to performing HF operation. Also due to the availability of the finite financial resources in each HF treatment, engineers must select the wells with the highest potential of improvement after stimulation. For a HF treatment to be successful, the gas or oil must be produced at a higher rate than before the treatment. Obviously, for this to occur, the reservoir must have sufficient fluids in place. In addition, the potential gradients must be sufficient to move the fluids to the wellbore when the fracture has been created (Howard and Fast, 1970). Guoynes *et al.* (2000) showed that success attributed to custom treatments based on accurate identification of damage mechanisms, using new testing methods and candidate selection. In fact, one of the current typical issues related to HF is selection of candidate-wells. Smith (2006) best describes HF as "THE Multi-Disciplinary Technology." If any single issue within fracturing most accurately epitomizes this, it would be the complex and multifaceted subject area of candidate-well selection. Martin, (2010) described the process of selecting candidate-wells for HF treatment for the increase of their productivity, as a challenging task. Although a common practice, researchers (Martin and Raylance; 2010; Martin and Economides, 2008; Mohaghegh, 2001) have a common view about candidate-well selection; there is not a straightforward process and up to now, there has not been a well-defined and unified approach to address this process. However, Moore and Ramakrishnan (2006) believed that it is possible to formulate a framework for proceeding with the candidate-well selection for a certain field.

How we can recognize a well as a HF candidate? The top-level act is determining the reason for the low productivity. Low productivity must result from one or more of the following conditions (Veatch *et al.,* 1989):

1. Reduction of near-wellbore permeability, which can result in an uneconomic well even though there is a substantial amount of recoverable oil available. Near-wellbore damage can be removed by matrix acidizing or by the creation of short, wide, hydraulic fractures which by-pass the damaged zone.
2. The formation permeability is too low for oil/gas to be removed economically. Large increases in production can be achieved by the creation of deeply penetrating fractures.
3. Insufficient reservoir pressure. HF is generally not successful under such circumstances.

Howard and Fast (1970) as the main contributors to this field, explained general criteria for HF candidate-well selection as follows; (1) depletion state of the reservoir, (2) formation permeability, (3) previous stimulation treatments, (4) well productivity history, (5) offset production history, (6) location of water-oil and gas-oil contact, (7) fracture confinement, and (8) degree of consolidation. Crowell and Jennings (1978) primary contribution was the development of a diagnostic technique for re-stimulation candidate-well selection, which included a comparison between production analysis and fracture simulation. Lack of agreement between type curves and computer analyses had indicated potential problem areas such as proppant transport or lack of fracture confinement. Krasey (1988) presented high-grading fracture candidate-well selection by utilization of pressure build-up techniques. This approach is only a screening method for determining the best possible fracture stimulation candidate, which calculates the present skin factor and then calculates the stabilized production rate at a skin=-4 for all wells. With the estimated stabilized production rate at skin=-4, the wells with the greatest increase in oil production rates were the wells which had investigated as potential fracture stimulation candidates. . Rock mechanical properties, remaining reserves, petrophysical properties, and stress profile had been determined as the key factors for candidate-well selection by Shadizadeh et al. (2009) and Shadizadeh and Habibnia (2009). Economides *et al*. (2000) pointed out that well screening should be based on the potential production increase and incremental economics. Obviously, wells with the greatest potential should be selected as candidates. Utegalyev *et al.* (2006) demonstrated that by using a multi-disciplinary team, creating and concentrating on variables that could be directly affected (e.g., the operational aspects of the process), they were able to perform a highly successful stimulation campaign. It is worth here to note that this technique was mainly applicable for a situation where no available data existed. Smith (2006) proposed that successful candidate-well selection should be based on three distinct scales; regionalized, neighborhood, and localized (Table 1).

Table 1. Scaled candidate-well selection considerations

Scale	Variables
Regional (*Macro*)	Reservoir Heterogeneity Reservoir Continuity Geographical Information System (GIS) Gathering and Production (GAP)
Neighborhood (*Meso*)	Offset Well Performance Drainage Shape and Area Areal Connectivity Publicly Available Data
Localized (*Micro*)	Reservoir Characteristics Pressure Transient Analysis Production History Matching Mechanical Integrity

Conway *et al.* (1985) determined that candidate consideration could be readily broken up into four simpler stages: (1) estimation of the remaining reserves, (2) assessment of fracture quality/parameters, (3) evaluate fracturing parameters/success, and (4) evaluate economics based on drivers and costs. Bailey and Wickham (1984) demonstrated that the factors control the design of candidate for a production are; (1) bottom hole pressure, (2) net height (production interval), (3) porosity, and (4) permeability. Moore and Ramakrishnan (2006) discussed a preliminary candidate-well selection methodology used to rank the wells based on a weighted parameter approach. Those parameters are listed in Table 2.

Table 2. Weighted parameters approach used for preliminary candidate-well selection

Percentage	Parameters
20	Kh (perm. times net pay)
20	Cumulative production
20	Previous treatment (proppant/m net pay)
10	Cumulative production time
15	Gas saturation
10	Current performance
5	Recovery ration

Moore and Ramakrishnan (2006) determined that drainage area has significant effects on long term production, and so it was a key to obtain longer fracture half-length and optimize well placement. Lantz *et al.* (2007) argued that performance analysis and offset comparison are of increased importance in candidate-well selection. Productivity index and formation permeability were used as key parameters by different researchers. In a study conducted by Bustin and Sierra (2009), wells with low productivity index: 1.14 bbl/psi/day, and matrix permeability between 1-4 mD were selected. Recently, Sinha and Ramakrishnan (2011) presented a method in which a cross-plot of production indicators and the completion index utilized for the initial screening of potential candidates.

As discussed by Martin and Economides (2010) the main limitations in candidate-well selection are not the technical aspects of reservoir and fracture performance; instead, more mundane reasons may cause an interval or a wellbore to be rejected as a candidate for HF. Gutor *et al.* (2003) showed that well age is a poor criterion to select restimulation candidates, presuming the mechanical wellbore condition is acceptable. Well preparation before stimulation is essential to reduce overall costs. Pongratz *et al.* (2009) investigated the factors that are under the control of the engineers, such as the size, number, phasing and position of the perforations. However, during a redevelopment, treatments are usually pumped through existing perforations. This can severely restrict the effectiveness of a treatment, as the perforations will define the position of the fracture and can often leak to the problem with multiple fractures and/or tortuosity. As a result, it is a common practice to use pretreatment calibration's tests (minifracs and step rate tests) to help improve treatment design. In order to have well-adapted HF technology, detailed geomechanical studies and well integrity test such as leak-off test, minifrac test, calibration test, etc., have to be conducted. Zoveidavianpoor *et al.* (2011b) and Shadizadeh and Zoveidavianpoor (2010) addressed the crucial advantages of those bottom-line studies.

By reviewing both successful and unsuccessful results of fracturing treatments, Jenning (1991) and Parrot (1979) showed that better wells make better fracture stimulation candidate. Indeed, various investigations confirmed that good wells (with high deliverability) have highest potential to be the best candidates (Green *et al.*, 2006; Husen *et al.*, 2003; Sencenbaugh *et al.*, 2001; Jenning, 2000; Reeves *et al.*, 2000; Ely *et al.*, 2000; Reeves *et al.*, 1999; Smith and Hannah, 1996; Reese, 1994; Branch and Drennan, 1991; Niemeyer and Reinart, 1986).

4. DISCUSSIONS

The techniques applied in HF candidate-well selection could be divided into two methods; conventional and advanced approaches. The reason for their entitle has comes from the approach that each of them is applying to choose a target well or target formation. The former mainly deals with engineering, geological, etc aspects in decision making process. The later mainly fill the gap for classification and manipulation of the parameters and mainly employs AI methods. Major works in conventional candidate-well selection is shown in Table 3.

Table 3. Major works in conventional candidate-well selection for hydraulic fracturing.

Howard and Fast (1970)	Identification of parameters that are important in candidate-well selection
Crowell and Jennings (1978)	Comparison between production analysis and fracture stimulation
Bailey and Wickham (1984)	Identified the main variables for candidate-well selection
Conway *et al.* (1985)	Using important parameters and fracture simulation
Krasey (1988)	Using a screening method such as pressure build-up techniques
Veatch *et al.* 1989	What is (are) the reason(s) for the low productivity?
Guoynes *et al.* (2000)	Accurate identification of damage mechanisms and using new testing methods
Economides *et al.* (2000)	Potential production increase
Gutor *et al.* (2003)	Mechanical wellbore condition
Utegalyev *et al.* (2006)	Identifying important variables that affect the treatment
Smith (2006)	Classification of the parameters into three distinct scales; regionalized, neighbourhood, and localized.
Moore and Ramakrishnan (2006)	Using a screening method such as weighted parameter approach
Lantz *et al.* (2007)	Using performance analysis and offset comparison
Bustin and Sierra (2009)	Based on productivity index and matrix permeability
Pongratz *et al.* (2009)	Factors that are under the control of the engineers, such as the size, number, phasing and position of the perforations.

As the volume of data increases, human cognition is no longer capable of deciphering important information from it by conventional techniques. Mohaghegh *et al*. (2005) demonstrated that data mining and machine learning techniques must be used in order to deduce information and knowledge from the raw data that resides in the databases. Although the required parameters for selecting a well for HF are relatively identical, classification and manipulation of the structure data is different. This fact comes from the different characteristics for each reservoir. Thus, there is a need to provide a candidate-well selection methodology that allows selecting the desired well/layer with minimum time and costs, and provide a framework to overcome the difficulties in conventional techniques. It is believed that advanced methods such as FL could be better handle uncertainties (Zadeh, 2006) existed in candidate-well selection.

5. CONCLUSIONS AND RECOMMENDATION FOR FUTURE WORKS

Finally, four key issues, which concluded from the literature of conventional candidate-well for HF, are as following:

a. Screening the wells and formations based on influencing variables such as skin, permeability, etc is a common practice in the literature.
b. The most important parameters for HF candidate-well selection are: permeability, porosity, in-situ stress magnitude and distribution, viscosity, skin factor, reservoir pressure, wellbore condition, formation net pay thickness, and water cut.
c. The process of selecting candidate-wells for HF treatment for increase of their productivity is considered as a complex and challenging task.
d. There is not a straightforward process and up to now, there has not been a well-defined and unified approach to address this process.
e. Good wells (with high deliverability) have highest potential to be the best candidates.

To be adopted as a successful stimulation method in new and mature hydrocarbon reservoirs, the development of optimal candidate-well selection procedure has a large impact on the long-term economic capability of the wells as well as viability of HF technology and its development. Selection a target well and formation for HF treatment is still associated with inaccuracy because of uncertain (fuzzy) nature of data and information. This problem comes from several reasons including incomplete data, handwriting error, different types of data formats, device error, etc. Thus, to improve the quality of data and execution time, for example in a reservoir with huge amount of data to process, there is a need to manage uncertainty of data to be able to extract desired data and proper decision-making. Therefore, handling uncertainty and process the data required intelligent methods with knowledge based approaches.

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