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Hydraulic Fracturing for Improved Oil Recovery

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Abstract –*Reducing discovery of hydrocarbon resources has prompted oil and gas companies to focus on the improved oil recovery (IOR) methods. Numerous methods have indicated great potential to IOR. Stimulation of the wells as one of these methods performed with using hydraulic fracturing (HF) technique. HF can be divided into acid fracturing and propped hydraulic fracturing (PHF). PHF is widely used in the petroleum industry to stimulate wells, and it has employed for different reservoirs such as sandstone, carbonate, and shale formations. The efficiency of the HF depends on numerous parameters. Of these parameters, proppant, fracturing fluid, field consideration, candidate well selection, and developing data set are investigated in the study. The aim is to provide an opportunity for researchers to find more about HF and related activities.*

Keywords: Hydraulic Fracturing, Acid Fracturing, Proppant, Fracturing Fluid, HF Design

1.0 INTRODUCTION

Reducing discovery of hydrocarbon resources has prompted oil and gas companies to focus on the improved oil recovery (IOR) methods. Numerous methods have indicated great potential to improve oil recovery. Stimulation of the wells as one of these methods plays an important role in the petroleum industry [1]. Several methods can be used for stimulating of wells, and each method must be applied in the right place. Well stimulation can be performed via matrix acidizing, hydraulic propped fracturing, and acid fracturing techniques. The main objective of well stimulation is creating a conductive fracture from the formation to the wellbore to enhance well productivity of formation. Several drawbacks such as wellbore damage, uncontrollable growth of the fracture, and so on have restricted the application of some stimulation techniques [2]. Acid fracturing as another type of well stimulation method has wide application to stimulate carbonate reservoirs [3]. Hydraulic propped fracturing, which will hereafter be referred to hydraulic fracturing (HF), has indicated better performance. HF treatment is originally used to remove near wellbore damage and then it is considered as an appropriate replacement for matrix acidizing and acid fracturing [2]. A lot of publications have been devoted to describing the HF and its corresponding elements [4-7]. Most of the efforts have been performed to improve the quality of HF treatment and its corresponding parameters. Of these parameters; proppant, fracturing fluid, field consideration, candidate well selection, and developing data set have an influential effect on the performance of the HF treatment. Propping agent (proppant) as small spheres that are used to keep open the fracture is playing an essential role in the performance of HF treatment [3].

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With the development of science and technology, most of the efforts are concentrated on the improving the quality of proppant to convert the HF treatment as a cost effective method. At the early age of HF treatment, sand was used as proppant. After that, researchers were substituted other materials such as ceramic and resin coated proppant (RCP) with sand because of some drawbacks that are occurred during HF treatment of deep wells. In recent years, researchers have focused on the utilization of low-weight and ultra-low-weight proppant [8]. Transferring of proppant within the fracture performs with fracturing fluid. The influential role of fracturing fluid on the efficiency of HF treatment cannot be denied. It has wide application for opening and developing the fracture. In addition, fracturing fluids can be extensively used to transfer proppant within the fracture. Water-based fluids, oil-based fluids, methanol-based fracturing fluid, viscoelastic surfactant-based (VES) fluids, and foam are the main type of fracturing fluids. Selection of the well candidate and field consideration (operation) has an influential effect on the efficiency of HF treatment because they can lead to the success and failure of HF treatment [4]. Therefore, investigating capability of the wells for stimulation and providing required conditions for operation prior exposing wells to hydraulic fracturing is compulsory.

Developing sets data is an important part of each design and simulation in the process that is related to the oil and gas industry, and it takes a lot of time and energy. Essential data that is required for modeling and simulating of HF treatment can be classified into controllable and uncontrollable data. Since all of the parameters that mentioned above are required for successful conduction of HF treatment, provision of appropriate information about them helps researchers to obtain more information about HF treatment and its corresponding parameters. Therefore, this article provides a great opportunity for researchers to know more about HF including proppant, various types of proppant including of conventional and ULW proppant, physical properties of proppant, evaluation the quality of proppant, fracturing fluids, field considerations (operation), developing data sets and candidate-well selection.

2.0 IMPROVED OIL RECOVERY

IOR processes consist of three main categories: infill drilling enhanced oil recovery (EOR) and well stimulation. EOR process are categorized into three groups; primary, secondary and tertiary. First stage of oil production includes displacement of oil by natural mechanisms such as the natural drive, solution gas drive, water influx, and gravity drainage that dominated on the reservoirs. When the role of natural mechanisms of production has decreased, secondary recovery has usually implemented. Maintenance of pressure with using gas and water injection is the target of the second stage of operations. Whenever, secondary methods become uneconomical, unfeasible tertiary recovery is applied. Mechanisms as injection of miscible gases and chemicals or thermal energy are usually applied in the third stage of production. The IOR approach is screening processes where different relevant technologies and their combinations are tested in the model and planning tool for suitability. Methods may compete for extracting the same oil volume with different profitability or risk. Common methods that are used for IOR is indicated in Fig. 1.

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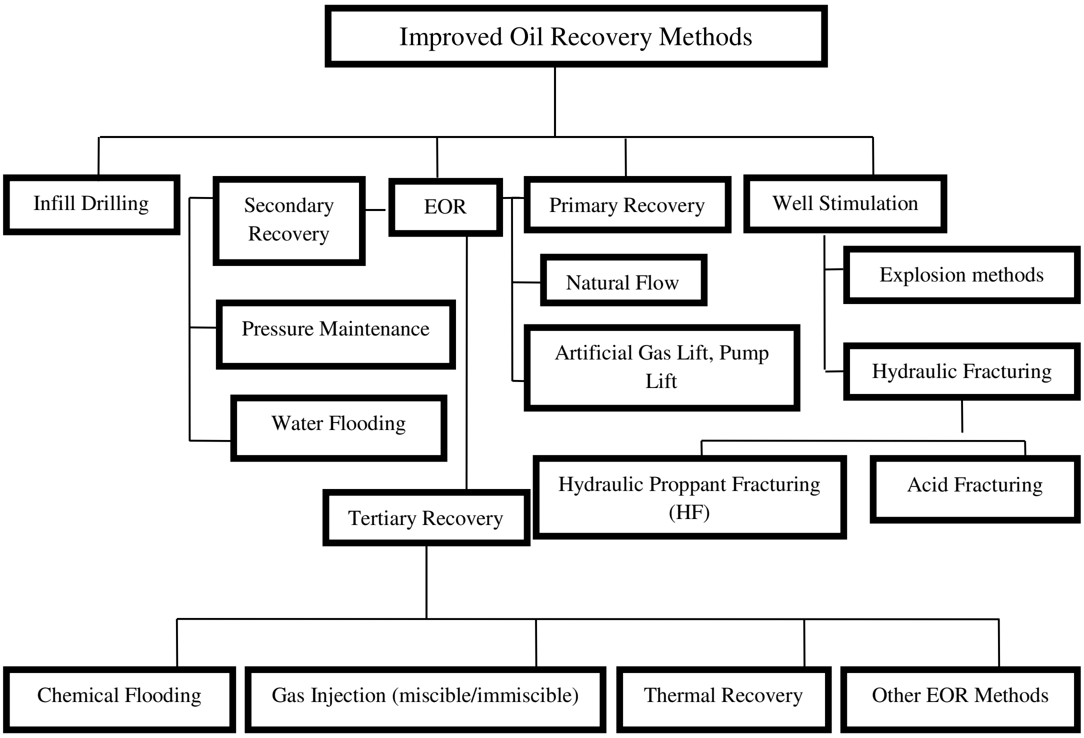

Figure 1: A schematic of different methods which are commonly used for IOR

2.1 Well Stimulation

Well stimulation includes a variety of operations that is performed to improve the productivity of a well [5]. The main objective of a stimulation treatment is enhancement of the rate at which the formation delivers hydrocarbons naturally [1]. The primary goal of well stimulation technique was creating conductive pathways to facilitate the flowing of fluids from the formation to the wellbore. Operations that are performed to stimulate wells have a lot of flexibilities. These operations can be employed for stimulation of the wellbore or the reservoir and stimulation of the old or new wells. In addition, well stimulation methods can be applied to facilitate the acid placement and the leak-off control. Thousands of well stimulation jobs are performed with various treatments that change from pumping hydrochloric acid into the formation to dissolve or fracture the rock. In addition, stimulation of wells can be performed with very advanced technologies that use VES fluids. Today's, well stimulation method is converted to the appropriate method in the oil and gas industry to maintain or increase of well productivity. Stimulation of the wells can be performed with hydraulic fracturing and explosive fracturing [6]. In the recent years, well stimulation performs with HF treatment because of its great performance to stimulate of subterranean formations.

2.1.1 Explosion Methods

Well stimulation started with explosive methods to improve oil recovery. The basic of explosive method is not complicate. Resistance of the rock to tension is more than compression. Therefore, the high pressure that is created due to explosion method causes creation a fracture within the formation. The procedure of explosive method is including of placement a nitroglycerine charge within the wellbore and detonating it. Common type of the material that used for this purpose was liquid nitroglycerin. Because of high sensitivity of this material for handling, transferring, and pumping into the formation, it must be taken care to place liquid nitroglycerin within the formation. Solid explosives have also been used, but they are difficult to get into the well bore and cannot make to fill the bore, let alone the productive formation, and consequently are of limited effectiveness in increasing the porosity of the formation. Numerous problems such as enhancement of damages to the wellbore, increase in the growth of the fracture, and decrease in the oil production during stimulation of wells with explosive methods have restricted its utilization.

2.1.2 Hydraulic Fracturing

HF as a well stimulation technique is designed to enhance the productivity of the subterranean formations. Initiation of HF treatment in oil and gas industry related to 1930s when Dow Chemical Company found that with employment of sufficient downhole fluid pressure, deformation of rock formation and creation of fracture is possible to obtain great acid stimulation. First HF treatment was successfully conducted in the Hugoton Field (Kansas) in 1947. Since that time, HF has been increased recoverable reserves more than any other technique, and it has been converted as a standard treatment to improve production [1].

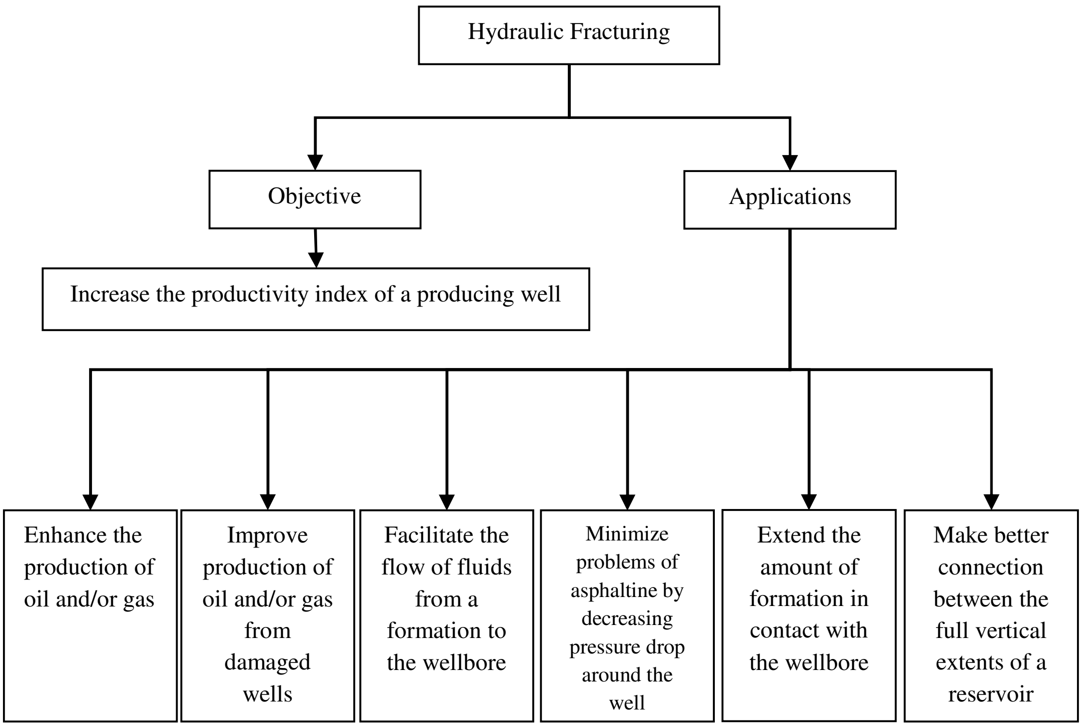

Figure 0: A schematic of objective and different applications of HF treatment

More than the last sixty years, HF technology has obtained supremacy for economic improvement of the exploration and output of hydrocarbon wells. For an HF operation, 100 to 500 tons and infrequently up to 1,500 tons of proppant are consumed [7]. Expense of the propping agent alone could be 67% ($300 to $500/ton) of the total stimulation costs and has converted proppants as an important parameter for technological research [8-10]. At present, HF is extensively used for improvement of oil and gas wells' productivity. HF treatment was widely used in the North America as approximately 70 % of gas wells, and 50% of oil were under this treatment [11]. During these years, thousands of HF treatments on a wide range of

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geological formation such as low permeability reservoirs, weakly consolidated offshore sediments, and complex geometrical structures are performed.

In addition to increased well productivity, HF is extensively used for other purposes such as solid waste disposal that are harmful to health [12], determine the amount of in-situ stress [13, 14] and so on. Classification of concepts that used for HF treatment is a function of rock, formation, and fluid properties. A schematic of objective and different applications of HF treatment is indicated in Fig. 2.

2.1.2.1 Acid Fracturing

Acid fracturing considered as one of the effective technical processes to stimulate injection/production wells. In addition, it is also known as one of the most extensively used work-over and stimulation operation in the oil and gas industry [15]. Acid fracturing is capable of dissolving those components of rock formation that are soluble into acid. In addition, it is capable of eliminating material at the wellbore face that leads to increasing the flow rate of oil or gas within production wells [1]. The mechanism of creating the fracture with acid for carbonate reservoirs rely on injection of acid into the formation at pressures above fracture pressure of rock formation [15].

2.1.2.2 Hydraulic Propped Fracturing

Hydraulic proppant fracturing (hereafter, it is called HF) is the most extensively applied technique in stimulation of oil and gas wells, and it has an influential effect on productivity. These features have converted HF treatment as a superior method compared to other stimulation techniques [16]. Formations with medium to high permeability (10-1000 mDa) are commonly exposed to HF treatments. These formations can provide a comprehensive control system for stimulation parameters like conductivity of fracture and parameters that are related to geometry of the fracture (width, height, and length of the fracture).

HF treatment usually performed at two steps. First step includes injection of fracturing fluid with pressure more than breaking pressure to create a fracture into formation. Second step consists of the injection a slurry that is comprised of proppant and fracturing fluid to keep the fracture open [17]. Control of improvement in productivity can be affected with propped fracture area, conductivity of the propped fracture, reservoir permeability, and drainage radius. HF treatment has wide application and it can be performed on various reservoir depths ranging from very shallow levels from 500 ft in case of muddy fine-grained sandstones, shales and chalks bearing oil and/or gas, to very deep depths in excess of 20,000 ft in case of tight sandstone, shale and coal seam gas pay horizons.

HF treatment includes two main parts: propping agent (proppant) and fracturing fluid. Proppant is a material that is employed in HF in order to keep the fissures open and thereby aid extraction. Fluid that is used to carry proppants into the fracture is known as fracturing fluid. To accomplish the placement of the proppants inside the fracture, proppants are suspended into fluid and then pumped to subterranean formations. Viscous fracturing fluids are often required to prevent the particles from settling before reaching the end of the fracture. The best way to control viscosity of fracturing fluid is addition of synthetic or naturally-based polymers.

2.2 Comparison of Various Types of Well Stimulation Methods

Comparison of various types of well stimulation methods indicated that the way of creating fracture conductivity is different from each method. In HF, created fracture usually keeps open with slurry that composed of small sphere particles and fracturing fluid. From the other hand, acid fracturing method uses acid to etch the fracture to keep it open. In contrast to other two methods, explosion methods have created fracture conductivity with using the power of explosive materials. HF can be used for stimulating of all reservoirs while stimulating of sandstone reservoir with acid fracturing cannot lead to appropriate results. These days, explosion methods are eliminated for stimulation of the wells because of the several drawbacks that they have indicated during stimulation of the wells. For example, explosive methods enhance damages to the wellbore and cause the increase in the growth of the fracture. In addition, stimulation of the wells with explosive methods causes decrease in the oil production. Another main difference between well stimulation methods is related to their capabilities to control losing of the fracturing fluid. HF has indicated great performance to control fracturing fluid while controlling fracturing fluid loss during stimulation of the wells with acid fracturing and explosive method is difficult. Creation of the long fracture with HF is possible while it is not possible to create long fracture with acid fracturing method. The best method to create fracture into low permeability carbonate reservoir is HF. However, the execution of acid fracturing is easier than HF because acid fracturing does not require complicated equipments. Stimulation of the wells with acid fracturing accompanied with low cost and fewer risks than HF. Therefore, selection the best method of well stimulation is related to the condition that dominated on the each formation, type of the formation, accessibility to equipments and experiences of those who are expert in the HF treatment. More details on the comparison of acid fracturing and HF can be found in [3].

2.3 Hydraulic Fracturing Design

Before the initiation of the HF treatment, HF design must be performed. Successful design of the HF treatment required accurate application of an extensive scope of proficiency and technologies. HF design is usually performed with fracture design simulators. Fracture design simulator is designed to simulate, as closely as possible, the actual downhole events that occur during the performance of a fracturing treatment. Numerous consistent fracture design simulators are presently accessible on the market [18]. The essence of simulation of HF with simulators is according to utilization of fundamental laws, constitutive laws, and previously mentioned domains to simulate the propagation and geometry of the fracture. Figure 4 indicates some of the simulators that perform fracturing design using 2D, pseudo-3D, and 3D modeling.

HF design deals with four main domains: proppant characteristics, the treatment fluid characteristics, field consideration, and developing data set. Improvement of elements that are involved into HF design can lead to saving time and money during HF treatment.

2.4 Proppant

Proppant as small spheres transfers with the fracturing fluid to be deposited inside the fracture and keep it open at the end of the HF treatment [19]. These small spheres must be strength enough to withstand the high temperatures and pressures associated with a fracture. To investigate the capability of material for possible use as proppant in HF treatment, several factors must be considered, and they have to pass various characterization. Key factors to evaluate the quality of proppant are conductivity or crush resistance of proppant that can be measured in particular conditions such as a diverse range of stress and a broad range of

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temperature. Proppants that are made artificially should have high potential to withstand high closure pressure that tends to deform proppant particles. They should be capable of resistance to the impact of aggressive well fluids such as moisture, sour gasses, and saline solutions.

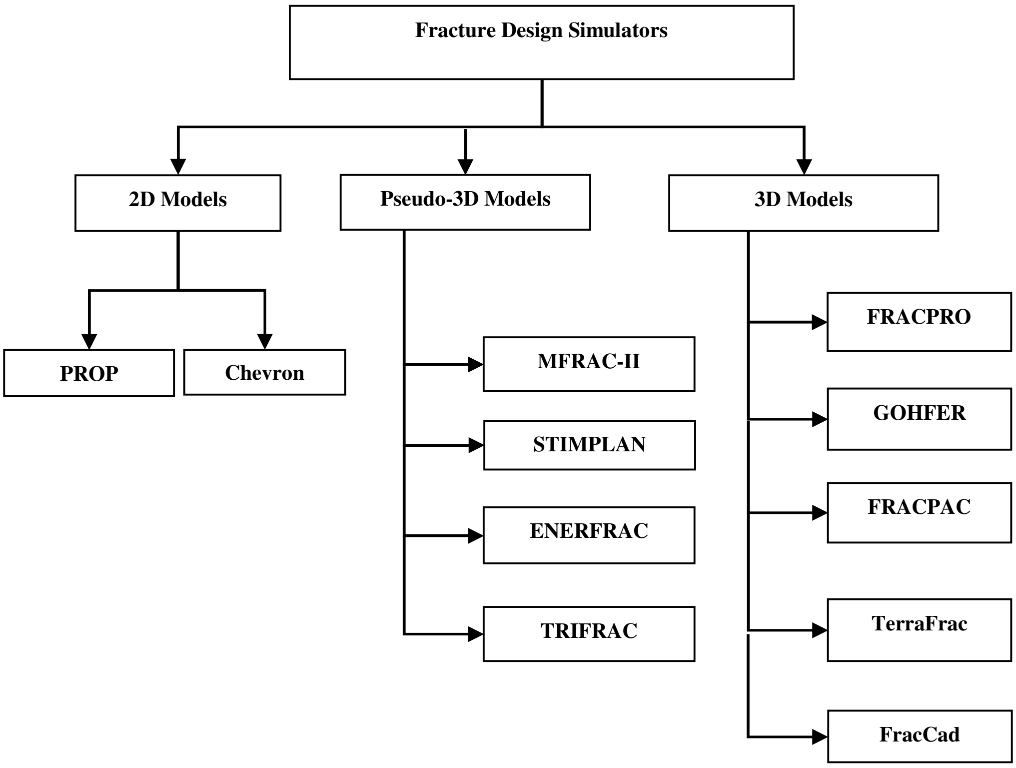

Figure 1: Different types of fracture design simulators

The materials that are used as proppant consist of different components that each of which will act differently during the fracturing process. So, it is required to know physical properties and compositions of these components. These materials must be extremely durable to maintain their shapes under exerted load. When these particles cannot provide enough strength, they produce fines that plug the fractures and it prevents from the flowing of oil and gas from the fracture to wellbore. It is also required to use material as proppant that have less tendency to absorb fracturing fluid or oil and gas because absorption of fluids leads to increase in the amount of impurities into system.

An ideal proppant must be lighter than water, higher than iron, and cheaper than dirt to be used in HF treatment [20]. Integrating all of these requirements is not possible in one product. However, with employment of monolayer concept in the fracture, it is possible to obtain more resistance and appropriate fracture conductivity for longer periods of times at subterranean formation conditions. The quality of the proppant is also related to the purity (the amount of fines and impurities) of the proppant. Fines or impurities can significantly reduce the proppant-packed permeability. In addition, roundness and sphericity of the grains have an important effect on the amount of fracture conductivity. Roundness as a feature of proppant is defined as the measurement of the relative sharpness of the grain corners. Sphericity can be defined as the measurement of the tendency of grains to approach the shape of the sphere [16]. Higher roundness and sphericity of grains provide more conductivity of the fracture and higher load to support before crushing. Investigation the quality of proppant before

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introducing into the formation is required. Various standard procedures including of API RP 56, API RP 60 and ISO 135302 are used to evaluate the quality of materials for possible use as proppant. Tests, required equipment, function of each test, standard procedure, and desirable amount of each test to evaluate quality of materials for possible use as proppant are mentioned in Table1.

Table1: Requirements of quality evaluation of materials for possible use as proppant

Tests	Required equipment	Functions	Standard	Desirable
Sieve Analysis	Hammer ,Grinding Machine, Sieve Equipment	Preparation of coconut shells for using as substrate, finding desirable particle size	API RP56& 60, ISO135302	20/40 Mesh Size Particle
Acid Solubility	Hot Plate, Beakers, Graduated Cylinder	Investigation resistance of particles to acidic medium	API RP56& 60, ISO135302	Less than 2%
Turbidity	Turbiditimeter	Finding the amounts of fines on the surface of particles	API RP56& 60, ISO135302	Less than 250 (NTU or FTU)
Roundness And Sphersity	Microscope	Finding the tendency of particles to approach to spherical shape	API RP56& 60, ISO135302	More Than 0.7
Apparent Density	Pycnometer, Beakers	Finding the weight of a unit volume of coated and uncoated coconut shells	API RP56& 60, ISO135302	Less Than 2 (gr/cm^3)
Bulk Density	Beaker, weighting machine	Finding how amounts of particles fills a determined volume	API RP56& 60, ISO135302	Less Than 2 (gr/cm^3)
Crush Resistance Test	Crush Resistance Test Equipment	Finding strength of a pack of proppant under different range of pressure	API RP56& 60, ISO135302	Production of fine (less than 5%)
Fracture Conductivity Test	Fracture conductivity tester	Finding the capability of coated and uncoated particles to pass flow from the fracture to wellbore	API RP 65, ISO 135303-5	Higher amount of fracture conductivity is desirable

Fracture conductivity plays an essential role in the efficiency of HF treatment. Items that must be considered to evaluate the effects of proppant on the fracture conductivity are strength, size and distribution of the proppant size, quality, roundness and sphericity, and density of proppant [16]. Proppant strength is the capability of proppant to withstand to closure stress of fracture for prevention of breaking or crushing. If the proppant is not strength enough, the permeability of the fracture can be considerably reduced. The conductivity of the fracture depends on the grain size and grain size distribution of proppant. Proppant with higher grain size can provide more conductivity. However, larger grain size is not capable of using in deep wells because of the low strength to crushing [16]. It is to be noted that fracture conductivity test is performed according to ISO 135303-5 and API RP65.

Some factors that had influential effects for selection the appropriate type of proppant in the HF treatment are fine generation, resistance of proppant to cyclic stress variations, embedment of proppant into the formation, flowback of proppant into the wellbore, and pack rearrangement in the fracture as well as conductivity, cost and availability [21]. Particles such as glass beads, nut shells, aluminum pellets, and sand were capable of using as proppant. However, by increasing closure pressures of the formation, materials were crushed resulting in the closure of the fracture. Therefore, proppants with higher strength that were capable of withstanding to higher closure stress had been designed. Although, these proppants had indicated sufficient strength to resist to high closure stresses, but their higher specific gravities had restricted their utilizations for stimulating of wells. It means that they were not capable of suspending into low viscosity of fracturing fluids [16]. ULW proppant was introduced to the industry to remove this drawback. It was capable of withstanding to high closure pressure and suspend into low viscosity fracturing fluid to reach the end of the fracture.

Comprehensive information about various types of proppants is presented in Table1. From the first column of Table1, comparison of the specific gravity of various types of proppant indicated that higher amount is related to the ceramic. Therefore, settling velocity of this type of proppant is more than other types, and it is required to use viscous fracturing fluid to transfer ceramic proppant within the formation. From the other hand, lower amount of the specific gravity is related to ULW and nut shells. It means that they have great capability to suspend into fracturing fluid. In the point of the cost, lower price is related to the sand proppant while production cost of the ceramic and coated proppant is more than other propping agents. When various proppant compared in the point of the compatibility with the environment, nutshells have indicated more capability to be eco-friendly while production of other types of proppant causes emission to be released into air, water and land. Comparison various proppants in the point of strength indicated that ceramic has higher strength while lower strength is related to sand, glass beads, and nut shells. From Table1, it is observed that nutshells are renewable while other types are not renewable.

2.5 Treatment Fluid Characterization

Gasses and liquids that transmit pressure from the surface into the subterranean formation to make fracture and transfer proppant from the wellbore into fracture are known as fracturing fluids [22]. Fracturing fluids can be comprised of a mixture of sand and water to complicated polymeric components that are used as additives to enhance viscosity of fracturing fluid. Each fracturing fluid has its unique properties and each of which is designed for the special purpose. To achieve high efficiency of fracturing fluid, fracturing fluid must be tacky enough to make a fracture of sufficient width, be capable to move to large distance within the fracture for enlargement of fracture length, and be capable to transfer high percentage of proppant within fracture [22]. The choice of HF fluid is reliant on the properties within the reason, the fracturing fluid must not only have good viscous properties, but also many other properties that can be summarized as follows: Low friction pressure in tubing/casing and in the fracture, good fluid-loss control and low damage on the productive formation, rapidly break at the end of the treatment, have appropriate viscosity to transfer proppant within the formation, high capability to remove easily from the fracture with low residues, and low cost.

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Table2 : Comprehensive information about various types of proppants

Proppant	**Conventional**							**Advanced**	
	Sand	**Ceramic** **Low density**	**Intermediate Density**	**High density**	**Nut shells**	**Glass beads**	**Resin coated sand**	**Ultra low weight**	**Low weight**
Specific gravity	2.50-2.65	1.75	2.7-3.3	3.4-3.75	1-1.35	2.65	2.55	1.25-1.75	1.60-2.10
Bulk density	1.49-1.55	1.65	1.84	1.91	0.85-1.04	1.55	1.65-1.75	0.86—1.15	0.95-1.30
Closure pressure (psi)	2500-6000	5000-8000	5000-10000	>10000	2500-5000	3000-5000	6,000 - 10,000	5000-8000	7000-10000
Price	Low	High			Low	High	High	High	High
Eco-friendly	No	No			Yes	No	No	No	No
Renewable	No	No			Yes	No	No	No	No
Settling velocity	Low	High			Low	High	High	Low	Low
Strength	Low	High			Low	Low	Appropriate	Appropriate	Appropriate
Advantages	Inexpensive, ready accessible	High strength, capable of withstanding to high closure pressure			Low density, inexpensive, renewable, eco-friendly		High strength, capable of providing appropriate propped fracture length	Low weight, high strength capable of providing appropriate propped fracture length	Low weight, high strength capable of providing appropriate propped fracture length
Disadvantages	Low strength (high crush values), lower flow capacities, and brittle	Expensive, High density (requiring more pounds of proppant to fill the created fracture volume), procedure of production is not safe (causes emissions to be released into air)			Low strength, brittle	Low strength, brittle	Expensive, limited to apply in the certain closure pressure, not eco-friendly	Expensive, not eco-friendly	Expensive, limited to apply in the certain closure pressure, not eco-friendly

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Water is the main component of fracturing fluid. However, other materials such as methanol or hydrocarbons including of diesel, or liquified propane or methane has been used in the fracturing fluid. Various additives have also been used into fracturing fluid to control their properties. For example, gelling agent has been used to control viscosity and facilitate suspension of propping agent to transfer within the formation. Breakers as another type of these additives have been used to reduce the viscosity of fracturing fluid. Breakers allow propping agents to deposit in the fracture. In addition, it facilitates the recovery of fracturing fluids that are used during HF treatment. Injection of the fracturing fluid within the formation is performed at sufficient pressure and flow rate to overcome the overburden stress, and thereby the creation of the fracture. It has wide application for opening the fracture. In addition, it can be extensively used to transfer proppant within the fracture.

Common types of fracturing fluids and their properties are presented in Table 3. Of these fracturing fluids, most extensively used is water-based fracturing fluids. Those positives points which have converted water-based fracturing fluid as most extensively used type of fracturing fluids are high accessibility of water, cost saving, and creation of less damage to environment and those who are exposure to fracturing fluid during HF treatment. In addition, they have great flexibility that can easily convert to viscous fracturing through addition of some additives. To improve its capability for transportation of proppant, water-based fracturing fluid are mixed with guar polymers [23]. However, water-based fracturing fluid suffers from drawbacks that are mentioned in Table 3.

Slickwater fracturing systems are used especially for stimulation of highly pressurized deeper shale formations. They are water-based fluids containing friction-reducing agents so that large volumes of fluid can be pumped rapidly through the wellbore and into the formation.

From Table 3, as well as water-based fluids, other types of fracturing fluids that are made from oil, methanol, and a mixture of water and methanol can be used. Methanol based fracturing fluid can be used for minimization of leak-off that leads to enhancement of fluid recovery [24]. Although, fracturing fluids that are based on polymeric substances and made with methanol can improve the HF treatment, but they are required more amount of breaker (50 to 100 times) [25].

Mixing gasses such as nitrogen or carbon dioxide with fracturing fluid can lead to the formation of foam that is used to make foam based fracturing fluid. Low volume of foam based fracturing fluid is required to transfer proppant within the fracture. Sometimes, diesel fuel can be used as a component in the composition of fracturing fluid.

There are diverse types of additives that can be used in the composition of fracturing fluid. Some of these additives are presented in the last column of Table 3. They can be used to clean up the formation from impurities, to stabilize the foam (surfactants), to prevent or decrease the leak off (fluid loss agents), or to reduce the surface tension (friction reducers). Advantages and disadvantages of various types of fracturing fluid, as well as their application, are presented in Table 3.

2.6 Field Considerations

Pumping of fracturing fluid into the formation can be conducted after optimum design of HF treatment. For successful conduction of field operation, all of the parts that are involved in HF treatment must be coordinated and cooperated with each other. Continues supervision of the treatment and applying measurements of quality control will lead to improvement in the execution of HF treatment. Safety must be considered as an important item during field operation. It can be performed with a briefing with all parts that are involved in the field operation with mentioning their duties. To obtain high efficiency of the HF treatment, all of the parts of field operation must be coordinated with the design of treatment. The Engineer-in-charge should not be forgotten inspection of field after HF treatment. In addition, it is also required to do fracturing fluid analysis to determine the components that are present in the fracturing fluid. This data analysis can improve understanding of operators to select the appropriate additives for fracturing fluid to create a wide fracture and improve transportation of propping agent.

2.7 Candidate Well Selection

Candidate well selection is an important factor that plays a critical role on the success and failure of HF treatment. The primary step of each HF treatment is selecting a target well and formation [4]. Selection of well candidate that has great potential for execution of HF treatment can lead to improvement in the success rate [26]. In contrast, failure in choosing well candidate can lead to poor efficiency of HF treatment. Determining of HF candidate-well selection depends on the status of the reservoir depletion, permeability of formation, providing of appropriate stimulation treatments, history of well productivity, location of water-oil and gas-oil contact, history of offset production, confinement of the fracture, and consolidation degree [27].Selection, the best candidate, is required to consider many variables by the design engineer. Permeability of formation as one of these variable plays an important role for design engineer especially when low permeability reservoirs are under treatment. Conventional and advanced techniques are usually used to select well candidate for the HF treatment. Conventional methods use engineering, geological, etc. aspects in decision-making process. From the other hand, advanced approach uses artificial intelligence method to perform classification and manipulation of parameters [4]. Comprehensive information about the procedure of distribution of in-situ stress in the formation can help design engineer to evaluate the exact amount of pressure that is required to break the formation. To investigate conditions that are governed on the wells, skin factor of the well is required to know that well is damaged or stimulated before. Positive amounts of the skin factor indicate that the well is damaged and can be an appropriate choice for well stimulation. In addition, pressure and depth of the reservoir must be determined for design engineer to evaluate the conditions that are dominated on the reservoirs. Those wells that are considered as the best candidates for HF treatment must be contained appropriate volume of oil and gas in place.

2.8 Developing Data Sets

Developing sets data is an important part of each design and simulation in the process that is related to the oil and gas industry. It takes a lot of time and energy [13]. Essential data that is required for modeling and simulating of HF treatment can be classified into two groups. First type includes those data that must be controlled by the engineers such as comprehensive information about well completion, required volume of fracturing fluid for initiation of HF, volume of fracturing fluid for slurry, rate and time of injection, density and viscosity of fracturing fluid, weight and type of propping agents. Second type includes uncontrollable data that can be estimated or measured by engineers. Uncontrollable data are depth, thickness, pressure, porosity, permeability of subterranean formation, distribution of in-situ stresses in the formation, Poisson ratio, module of elasticity, shear stress of the formation, and finally compressibility of formation. Table 4 illustrates typical data that is required to design a fracture treatment and their possible sources.

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Table3: Common types of fracturing fluids and their properties

Type of the fracturing fluid	Application	Advantages	Disadvantages	Components
Guar-Based Fluids	Shale oil applications, water sensitive formation, Dry Gas Wells, wells damaged with water	Great capability to carry proppant, creation of the high conductivity	High price, Formation damage, Gel damage	Guar, water, crosslinking agents, breakers, acid, friction reducer, surfactant, potassium chloride, scale inhibitor, pH adjusting agent, iron control agents, corrosion inhibitors, and biocides
Slickwater Fluids	Shale gas wells	Lower cost, Reduced gel damage, Reduced fracture height growth as a result of lower viscosity	Large water source is required, Poor proppant transport and suspendability, creation of complex fracture geometry, Higher leak-off, Narrower fracture widths	Water, friction reducer, acid, friction reducer, surfactant, potassium chloride, scale inhibitor, pH adjusting agent, iron control agents, corrosion inhibitors, and biocides
Viscoelastic Surfactant (VES)-Based Fluids	Shallow gas projects, Tight Formations, coal bed methane wells, Wells with Complex Fracture Issues	leave minimal to no residues within the fracture, no additional breaker is required to remove residues	High fluid leakoff volumes due to the absence of wall-building, high cost, and undesirable viscosity reduction at high temperature	Nanoparticle surfactant, Surfactant with a hydrophilic and a hydrophobic group, cationic and anionic surfactants, acid, friction reducer, potassium chloride, scale inhibitor, pH adjusting agent, iron control agents, corrosion inhibitors, and biocides
Energized Fluids	Tight and ultra-tight unconventional formations with high clay contents, Fluid Sensitive Formation, Coal Bed Methane Wells, dry gas reservoirs	Limiting the amount of water invasion into the matrix, Improved recovery of hydraulic conductivity, Minimizing the contact between water sensitive clays and water	potential safety concerns of pumping gases or flammable fluids at high pressure, operational issues related to handling gas onsite, higher costs, and sand concentration limits, Higher injection rates required	Water, foaming agent ,acid, friction reducer, surfactant, potassium chloride, scale inhibitor, pH adjusting agent, iron control agents, corrosion inhibitors, and biocides ,CO2, N2, zirconate crosslinked CMHPG, Polyemulsions

Table 4: Required data for HF design

Data	Units	Sources
Formation permeability	md	Cores, well tests, correlations, production data
Formation porosity	%	Cores, logs
Reservoir pressure	psi	Well tests, well files, regional data
Formation modulus	psi	Cores, logs, correlations
Formation compressibility	psi	Cores, logs, correlations
Poisson's ratio	-	Cores, logs, correlations
Formation depth	ft	Logs, drilling records
In-situ Stress	psi	Well tests, logs, correlations
Formation temperature	°F	Logs, well tests, correlations
Fracture toughness	psi -in	Cores, correlations
Water saturation	%	Logs, cores
Net pay thickness	ft	Logs, cores
Gross pay thickness	Ft	Logs, cores, drilling records
Formation lithology	-	Cores, drilling records, logs, geologic records
Wellbore completion	-	Well files, completion prognosis
Fracture fluids	-	Service company information
Fracture proppants	-	Service company information

3.0 DISCUSSIONS

Hydraulic fracturing has been used widely to stimulate wells and consequently improving oil recovery. It has indicated several priorities on the other techniques that are used for well stimulation. One priority of HF treatment over other two methods is related to the way of creating the fracture. Creating fracture in HF treatment is usually performed by injecting slurry that is a controllable method. In contrast to HF treatment, creation of the fracture with using acid fracturing and explosion methods are not controllable. In addition, HF treatment can be used for stimulating of various reservoirs while stimulating of sandstone reservoir with acid fracturing is not economical. Furthermore, HF treatment has a lot of flexibilities, and it is considered as a safe method for stimulating of wells. To improve the quality of HF treatment, comprehensive information about HF and their corresponding elements is required. Improving the quality of corresponding elements of HF treatment has led to increasing the efficiency of this treatment. Proppant as one of the main parts of HF treatment plays an important role in the efficiency of HF treatment. Previously, conventional proppants such as sand, ceramic, glass beads, and nut shells were extensively used to stimulate subterranean formation. Sand proppant is the first type of proppant that is introduced into proppant industry. Two main features including of low price and high availability of this type of propping agent have converted the sand as most commonly used proppant. However, low strength to closure pressure has restricted its utilization for stimulating of formation with high closure pressure. Ceramic proppant as another type of conventional proppant has indicated great crush resistance to high closure pressure. However, high weight of ceramic has created a lot of problems such as proppant settling before reaching the fracture. In addition, production of ceramic proppant is not cost saving. Therefore, researchers have focused on the production of new type of proppants that are composed of conventional proppant as substrate and polymers as coating layers. Resin coated sand was the first type of these proppant that was introduced to stimulate wells. The performance of sand coated proppant was better than sand however its application was restricted to certain depths. Also, production of sand coated proppant was so expensive. Light weight and ULW proppant were introduced to remove these problems. They have indicated great performance for stimulating shallow and intermediate wells. However, they are not capable of providing enough strength at high closure pressure. Also, production of these types of proppants similar to other types of coated proppant is not cost saving. To transport proppant within the fracture, fracturing fluid that is composed of a base fluid and some additives has been used. Two main functions of fracturing fluid are creating fracture and transferring proppant within the fracture. Selecting the best type of fracturing fluid for stimulating formation is related to the type of formation and proppant. For example, transferring ceramic proppant within fracture is usually performed with viscous fracturing fluid while carrying light and ULW proppant is usually performed with slick water fracturing fluid. Water-based fluids, oil-based fluids, methanol-based fracturing fluid, VES fluids, and foam are the main type of fracturing fluids. Of fracturing fluid, most extensively used are water-based fracturing fluids. It is because of high accessibility to water, cost saving, and make less harsh damage to the environment. In addition, they have great flexibility to convert to viscous fracturing through addition of some additives. Production of viscous fracturing fluid is not cost saving but stimulating of some formation without using viscous fracturing fluid is not possible. Experience and art of those who are expert in HF treatment can reduce the cost of operation especially about selecting the best type of proppant and fracturing fluid. Before performing of each HF treatment, coordinating between several parts of HF treatment must be performed. In addition, cooperation between various elements that are involved in HF treatment is required. These two factors play the key role in the success of each HF treatment. Also, continues supervision of the HF treatment and applying measurements of quality control will lead to improvement in the execution of HF treatment. Another main factor that must be considered during each HF treatment is safety. Justifying workers who are dealing with equipments about safety is a main factor for successful conduction of each HF treatment. Other main corresponding elements of HF treatment are selecting the well candidate for stimulating of wells. Selecting the well candidate for stimulating has important effect on the success and failure of HF treatment. Therefore, it is required to investigate the potential of wells for stimulation before exposing to HF treatment. Determining of well candidate for stimulating is related to the status of the reservoir depletion, permeability of formation, providing of appropriate stimulation treatments, history of well productivity, location of water-oil and gas-oil contact, history of offset production, confinement of the fracture, and consolidation degree. All these requirements must be considered before stimulating of formation. Developing sets data is an important part of each design and simulation in the process that is related to the oil and gas industry, and it takes a lot of time and energy. Essential data required for modeling and simulating of HF treatment can be classified into controllable and uncontrollable data. Since all of the parameters that mentioned above are required for successful conduction of HF treatment, provision of appropriate information about these parameters helps researchers to obtain more information about HF treatment and its corresponding parameters.

4.0 CONCLUSSION

Hydraulic propped fracturing has indicated the best performance to stimulate wells because it has removed the drawbacks of explosion methods. In addition, it is capable of stimulating both carbonate and sandstone reservoir while the capability of acid fracturing is restricted to stimulate carbonate reservoirs. Of corresponding elements of HF treatment, improving the quality of proppant through removing the problems that conventional proppants have created during application in the HF treatment can increase the economic value of HF treatment. ULW proppant as a new type of proppant has indicated the great capability to remove the drawbacks of conventional proppant. Using ULW proppant can reduce the cost of the HF operation. Selection, the best type of fracturing fluid, is related to the depth, type of formation and conditions that are dominated on the formation. Of fracturing fluid, most extensively used are water-based fracturing fluids. It is because of high accessibility to water, cost saving, and make less harsh damage to the environment. In addition, they have great flexibility that can easily convert to viscous fracturing through addition of some additives. Other main corresponding elements of HF treatment are selecting the best type of well candidate for stimulation. Selection of well candidate that has great potential to be stimulated can lead to enhancement of the efficiency of HF treatment. In contrast, failure in choosing well candidate can cause the reduction in the efficiency of HF treatment. Essential data are required for modeling and simulating of HF treatment can be classified into controllable and uncontrollable data. Controllable data includes those data that must be controlled by the engineers while uncontrollable data that can be estimated or measured by engineers. For successful conduction of HF operation, all of the corresponding parts of HF treatment must be coordinated and cooperated with each other. Continues supervision of the treatment and applying measurements of quality control will lead to improvement in the execution of HF treatment. To obtain high efficiency of the HF treatment, all of the parts of field operation must be coordinated with the HF design.

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REFERENCES

[1] M. Zoveidavianpoor, S.R. Shadizadeh, S. Mombeini, Evaluation and improvement of well stimulation by matrix acidizing in one of the southern Iranian oilfields, Petroleum Research 20 (2010) 94-106.

[2] M. Zoveidavianpoor, A. Samsuri, S.R. Shadizadeh, The needs for hydraulic fracturing in iranian carbonate oilfields: Acid or propped fracture?, Presented at the 1st National Conference of Novel Technologies in Oil & Gas Industries, IAU, Iran 3-4 March (2011).

[3] M. Zoveidavianpoor, A. Samsuri, S.R. Shadizadeh, Well stimulation in carbonate reservoirs: The needs and superiority of hydraulic fracturing, Energy Sources, Part A: Recovery, Utilization and Environmental Effects 35 (2013) 92-98.

[4] A. Gharibi, M. Zoveidavianpoor, F. Daraei Ghadikolaei, On the application of well stimulation method in improvement of oil recovery, Applied Mechanics and Materials, Trans Tech Publ (2015).

[5] M. Zoveidavianpoor, A. Samsuri, S.R. Shadizadeh, Development of a fuzzy system model for candidate-well selection for hydraulic fracturing in a carbonate reservoir. 2012.

[6] M.J. Economides, K.G. Nolte, U. Ahmed, D. Schlumberger, Reservoir stimulation, Vol. 18, 2ND ed., Wiley Chichester, New York, (2000).

[7] M.W. Conway, S.W. Lindeman, R.D. Barree, Selection of stimulation fluids and treatment design for low permeability reservoirs, Presented at the SPE Hydraulic Fracturing Technology Conference, College Station, Texas, U.S.A (2007) 1-7.

[8] M. Zoveidavianpoor, A. Gharibi, M. Farokhi, M.M. Nasef, Low weight composite proppant for hydraulic fracturing of subterraneous formation: Experimental analysis, Presented at The 4th International Conference on Composites: Characterization, Fabrication and Application, Iran University of Science & Technology, Tehran, Iran 16-17 Dec. (2014).

[9] M. Zoveidavianpoor, A. Samsuri, S.R. Shadizadeh, A review on conventional candidate-well selection for hydraulic fracturing in oil and gas wells, International Journal of Engineering and Technology 2 (2012) 51-60.

[10] M. Zoveidavianpoor, A. Samsuri, S.R. Shadizadeh, Fuzzy logic in candidate-well selection for hydraulic fracturing in oil and gas wells: A critical review, International Journal of the Physical Sciences 7 (2012) 4049-4060.

[11] M. Zoveidavianpoor, A. Samsuri, S.R. Shadizadeh, Hydraulic fracturing candidate-well selection by interval type-2 fuzzy set and system, Paper IPTC-16615 presented at the 6th International Petroleum Technology Conference (IPTC), Beijing, China 26–28 March (2013).

[12] M. Zoveidavianpoor, A. Samsuri, S.R. Shadizadeh, Development of a fuzzy system model for candidate-well selection for hydraulic fracturing in a carbonate reservoir. Paper SPE 153200 presented at the SPE Oil and Gas India Conference and Exhibition, Mumbai, India, 28-30 March (2012).

[13] A. Hashemi, S.R. Shadizadeh, M. Zoveidavianpoor, Selection of hydraulic fracturing candidates in iranian carbonate oil fields: A local computerized screening of zone and well data, Paper IPTC-17192 presented at the 6th International Petroleum Technology Conference (IPTC), Beijing, China, 26-28 March (2013).

[14] O.T. Allen, A.P. Roberts, Production operations: well completions, workover, and stimulation 1 (1978).

[15] J. Grebe, M. Stoesser, Increasing crude production 20,000,000 bbl. from established fields, World Petroleum (1935) 473.

[16] J.L. Gidley, Recent advances in hydraulic fracturing (1989).

[17] P. Valkó, M.J. Economides, Hydraulic fracture mechanics: Wiley Chichester, UK, (1995).

[18] S.R. Shadizadeh, M. Zoveidavianpoor, Investigation of drill cuttings re-injection (DCRI): environmental management in Iranian Ahwaz oil field, Petroleum Science and Technology 29 (2011) 1093-1103.

[19] M. Zoveidavianpoor, Artificial intelligence-based techniques for prediction of minimum horizontal stress profile, The International Conference on Engineering and Applied Sciences Optimization held in Kos Island, Greece, June (2014).

[20] B. Meyer, Design formulae for 2-D and 3-D vertical hydraulic fractures: model comparison and parametric studies, Presented at the SPE Unconventional Gas Technology Symposium, Loulswlle, KY (1986).

[21] T.T. Palisch, M.C. Vincent, P.J. Handren, Slickwater fracturing: Food for thought, Paper presented at the SPE Annual Technical Conference and Exhibition, Denver, colorado, USA (2008) 1-20.

[22] J.M. Terracina, J.M. Turner, D.H. Collins, S. Spillars, Proppant selection and its effect on the results of fracturing treatments performed in shale formations, Presented at the SPE Annual Technical Conference and Exhibition, Florence, Italy (2010) 1-17.

[23] M. Zoveidavianpoor, A. Samsuri, S.R. Shadizadeh, Health, safety, and environmental challenges of xylene in upstream petroleum industry, Energy & Environment, 23 (2012) 1339-1352.

[24] R. Powell, M. McCabe, B. Slabaugh, J. Terracina, J. Yaritz, D. Ferrer, Applications of a new efficient hydraulic fracturing fluid system, Presented at the Latin American and Caribbean Petroleum Engineering Conference, Rio de Janeiro, Brazil (1997) 1-7.

[25] H.D. Brannon, M.R. Malone, A.R. Rickards, W.D. Wood, J.R. Edgeman, J.L. Bryant, Maximizing fracture conductivity with proppant partial monolayers: Theoretical curiosity or highly productive reality?, Paper presented at the SPE Annual Technical Conference and Exhibition, Houston, Texas 26-29 September (2004) 1-23.

[26] J. Thompson, C. McBain, G. Gregory, D. Gerbrandt, New continuous-mix process for gelling anhydrous methanol minimizes hazards, Journal of Petroleum Technology, United States, 44 (1992).

[27] J.W. Ely, Stimulation Engineering Handbook, Secondary recovery of oil, oil wells, hydraulic fracturing, Pennwell Corp (1985).