Sudan University of Science & Technology

College of Petroleum Engineering &Technology

Department of Petroleum Engineering

Effect of Fracture Length on Wells Performance for Inverted Nine Spot Wells

تأثير طول الشق علي أدائية الابآر في شبكات النمط التساعي المعكوس

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مشروع تخرج مقدم إلي كلية هندسة وتكنولوجيا النفط - جامعة السودان للعلوم والتكنولوجيا
إنجاز جزئي لأحد المتطلبات للحصول على درجة البكالريوس في هندسة النفط

إعداد الطلاب:

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إستهلال

قال تعالى:

(أمَّنْ هُوَ قَانِتٌ آنَاءَ اللَّيْلِ سَاجِدًا وَقَائِمًا يَحْذَرُ الْآخِـرَةَ وَيَرْجُـو
رَحْمَةَ رَبِّه قُلْ هَلْ يَسْتَوِي الَّـذِينَ يَعْلَمُـونَ وَالَّـذِينَ لَا يَعْلَمُـونَ
إِنَّمَا يَتَذَكَّرُ أُولُو الْأَلْبَابِ آ

(سورة الزمر للآية (9

DEDICATION

To our beloved parent who always encouraging, inspiring and advising us. Nothing of this could be done without them and their blessing. May Allah save them always for us... ....

...▯▯▯▯▯ **...**

To our wonderful supervisor D.Elham M. M. Khair who donated us her knowledge and never disappoints us or lets us down ……………

...▯▯▯▯▯**...**

To our dears, all of our family members who were there when we need them and always near……….

To our best friends & our colleagues who were with us step by step, supporting us to go forward…..

...▯▯▯▯▯**...**

To our school teachers who firstly taught us how to write our first words and we are still following their Advices and wish the best for them…..

...▯▯▯▯▯**...**

To everyone who is an integral part of our support group. We dedicate this work…..

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Our first and greatest thanks to almighty Allah for his mercy and help; without his support none of this work would have been done…

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We would like to express our deep gratitude to everyone who helped us throughout this work at any step of it…

…□□□□□…

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…□□□□□…

Abstract

Hydraulic fracturing has been used for many years to increase well productivity; and injectivity for many years. This study using reservoir simulation combined with the fracture models, 3D reservoir simulation program (FRACTURE PACKAGE), to study the effect of fracture length in well performance for inverted nine spot wells under constant fracture conductivity and constant reservoir properties for fracture angle of 0; degree and 45 degree.

The simulations show that the impact on oil recovery due to hydraulic fracturing can be positive or negative depending on fracture angle for constant injection pressure and fracture conductivity. Unfavorable fracture should be avoided because they can severely restrict both production and sweep improvement. Some wells in the pattern need to be fractured, while other wells have to be without fracture to achieve favorably oriented fractures for the patterns.

The term “optimization” in this study is based on maximum production and is not meant to take the place of the proper economic optimization that would consider well spacing, formation thickness, porosity, production, and treatment cost.

Key words:

Fracture Lengths, Fracture Conductivity, Fracture Angle, Pattern, Inverted Nine Spot

تجريد

استخدم التشقيق الهيدروليكي لسنوات عديدة لزيادة ولتجنب انخفاض الحقن وزيادة الضخ في ابآر الحقن. وفي هذا البحث تم استخدام تمثيل المكامن بجانب نماذج التشقيق الهيدروليكي وبرنامج تمثيل المكامن ثلاثية الابعاد لدراسة اثر طول الشق علي ادائية الابآر في شبكات الغمر المائي التساعية المعكوسة: حيث تم دراسة تأثير أطوال مختلفة للشق في مع ثبوت خصائص المكمن وموصلية الشق في شبكة تم التشقيق فيها بزاوية شق مقدارها صفراً وأخري كان التشقيق بزاوية 45^0.

أظهرت نتائج التمثيل أن طول الشق يؤثر علي أدائية الابار إيجابياً أو سلبياً إعتمادا زاوية التشقيق عند ثبوت الموصلية. وينبغي تجنب الشقوق غير الإيجابية والتي يمكن ان تحدث في بعض الابار لنفس شبكة الحقن حيث لأنها يمكن أن تحد بشدة من تحسن كل من الإنتاج الإكتساح. فقد يحدث ان تكون بعض الآبار في شبكة الحقن تحتاج إلى شق، في حين الآبار الأخرى يحافظ عليها من دون شق لتحقيق شقوق إيجابية لكل شبكة الحقن.

ويستند مصطلح الطول الأمثل للشق في هذه الدراسة على أقصى قدر من الإنتاج وليس المقصود أن الإختيار إعتماداً علي التحسين الاقتصادي السليم الذي يدرس تأثير مواقع الابار، سمك الطبقة، المسامية إضافة الي تكاليف عملية التشقيق.

كلمات دلالية:

طول الشق، موصلية الشق، زاوية الشق، أنماط الحقن، الشبكات التساعية المعكوسة

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Chapter 1

Introduction

1.1. General Background

Hydraulic fracturing is the process of pumping a fluid into a wellbore at an injection rate that is too great for the formation to accept in a radial flow pattern. As the resistance to flow in the formation increases, the pressure in the wellbore increases to a value that exceeds the breakdown pressure of the formation open to the wellbore. Once the formation ‘breaks down,’ a facture is formed, and the injected fluid begins moving down the fracture. The technique has been used for more than 60 years to increase well productivity and injectivity.

Water is often injected into the reservoir to maintain the reservoir pressure. The injection wells are located at carefully chosen points so that as much oil as possible is displaced by the water to the production wells before water starts to break through in the producers. During the water flooding process, injectivity decline can occur due to rock and fluids characteristics, well geometry, and formation damage caused by fines migration, salt precipitation and by solids and oil particles present in water entrainment. One of the best ways to avoid injectivity decline is the Injection with Fracture Propagation.

For favorably oriented fractures, the relative amount of improvement in areal sweep efficiency increase as the mobility ratio increases. Long conductive fractures at both the injector and are required to improve sweep for a five spot pattern. The improvement occurs when both the injector and producer are fractured, while the smallest improvement occurs when only the producer is stimulated. Care must be taken to ensure that fractures are oriented in a favorable direction, however, because a significant reduction in areal sweep efficiency occurs if the fractures are oriented in an unfavorable direction. Since fracture orientation is not known or cannot always be controlled, this also identifies which length fractures prevent detrimental effects to sweep for unit and adverse mobility ratio floods with unknown fracture orientation.

1.2. Problem Statement:

Hydraulic fracturing has been applied in Sudan for different purposes; the productivity of some wells was improved due to good fracture job in Heglig oil field, sand production problems were also treated using the technique of Frac-packing in Fulla North oilfield, Recently, the use of conductive fracture in water injection wells was not stated; moreover, no fully patterns were found for water flood. This work however studies the effect of fracture length on well productivity and injectivity for inverted nine spot patterns.

1.3. Objectives:

The main objective of this work to study the effect of fracture length and angle on fluids production for a reservoir of inverted nine spot patterns; this can be achieved through the analysis and the study of the effect fracture length and angle on:

I. The water production rate.
II. The oil production rate.
III. The cumulative of oil and water for 10 years.

1.4. Methodology:

To study effect of fracture length in well performance using reservoir simulation and the mathematical equations that connects the fracture with reservoir:

I. Select a model and assumption for the reservoir
II. Using the reservoir and fracture model proposed by CHEN ZHI HAI to present reservoir and fracture models
III. Use 3D reservoir simulation program called (FRACTURE PACKAGE) to simulate the reservoir and to predict the fluids production during the simulation period.

Chapter 2

Theory Background and Literature Review

2.1. Theory Background

Oil and gas discoveries were initially found as seeps where hydrocarbons were naturally present at surface. Early exploration efforts were focused on ending reservoirs that easily and energetically - owed oil or gas to surface. During the last 127 years oil and gas have been extracted from reservoirs in many regions across Canada. Initially, these reservoirs were easy to produce and in many cases did not require stimulation. These types of highly permeable and easy to produce sources of oil and gas are called conventional reservoirs. Over time many of these sources of oil and natural gas have been found and are being depleted.

In most cases, the new oil and gas resources currently being developed are in more difficult to produce reservoirs. These sources of hydrocarbons are referred to as “unconventional resources”, and usually require different or unique technologies to recover the resource. The most dramatic technological advancement occurred post World War II with the development of hydraulic fracturing techniques.

Permeability represents the ability for a fluid to flow through a (somewhat) porous rock. In order for natural gas or oil to be produced from low permeability reservoirs, individual molecules of fluid must find their way through a tortuous path to the well. Without hydraulic fracturing, this process would produce too little oil and/or gas and the cost to drill and complete the well would be could not be justified by this low rate of production. Very low permeability formations such as fine sand and shale tend to have fine grains (limited porosity) and few interconnected pores (low permeability).

2.1.1. Hydraulic Fracturing

Hydraulic fracturing is a well stimulation technique that has been employed in the oil and gas industry since 1947. The first commercial hydraulic fracturing job was at

Velma, Oklahoma in 1949 (Halliburton, 2010).The process increases the exposed area of the producing formation, creating a high conductivity path that extends from the wellbore through a targeted hydrocarbon bearing formation for a significant distance, so that hydrocarbons and other fluids can flow more easily from the formation rock, into the fracture, and ultimately to the wellbore. Hydraulic fracturing treatments are designed by specialists and utilize state-of-the-art software programs and are an integral part of the design and construction of the well. Pretreatment quality control and testing is carried out in order to ensure a high-quality outcome. (API GUIDANCE, 2009)

In general, hydraulic fracture treatments are used to increase the productivity index of a producing well or the injectivity index of an injection well. The productivity index defines the rate at which oil or gas can be produced at a given pressure differential between the reservoir and the wellbore, while the injectivity index refers to the rate at which fluid can be injected into a well at a given pressure differential.

The main objective of process of hydraulic fracturing is to increase the productivity of well sand by increasing the reservoir layer in the delivery of fluids into bottom of the well, (Smith, 1990). Moreover, Gidley, et al. 1989 presented many applications for hydraulic fracturing includes:

1) Increase the flow rate of oil and/or gas from low-permeability reservoirs
2) Increase the flow rate of oil and/or gas from wells that have been damaged
3) Connect the natural fractures and/or cleats in a formation to the wellbore
4) Decrease the pressure drop around the well to minimize sand production
5) Enhance gravel-packing sand placement
6) Decrease the pressure drop around the well to minimize problems with asphaltine and/or paraffin deposition
7) Increase the area of drainage or the amount of formation in contact with the wellbore Connect the full vertical extent of a reservoir to a slanted or horizontal well.

The process of Hydraulic fracturing is pressurized fluid is pumped into underground formations to create tiny fractures or spaces that allow crude oil and natural gas to flow from the reservoir into the well, so that it can be brought to the surface. Since its introduction, hydraulic fracturing has been, and will remain, one of the primary engineering tools for improving well productivity. This is achieved by:

I. Placing a conductive channel through near wellbore damage, bypassing this crucial zone

II. Extending the channel to a significant depth into the reservoir to further increase productivity placing the channel such that fluid flow in the reservoir is altered (Smith, 1990).

When decided to perform Hydraulic fracturing, the equipment is then brought to the surface location and connected to the wellbore for the fracture treatment. Hydraulic Fracturing is essentially 4-steps as presented by Halliburton, 2010, includes:

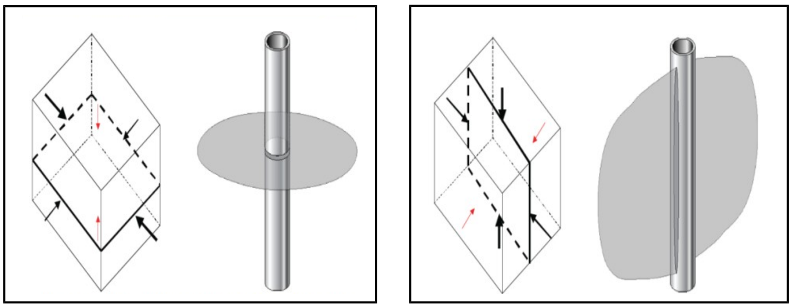
Step 1: Pressure the reservoir rock using a -fluid to create a fracture

Step 2: Grow the fracture by continuing to pump -fluids into the fracture(s)

Step 3: Pump proppant materials into the fracture in the form of a slurry, as part of the fracture -fluid

Step 4: Stop pumping and -flow back to the well to recover the fracture -fluids while leaving the proppant in place in the reservoir).

Mainly, two types of fractures can occur in the formation, namely are Horizontal and Vertical Fractures. Horizontal Fractures: is a horizontal incision that is centered vertically on the slot where the well bore and after a process of hydraulic fracturing the slit width and length can be controlled accurately, but in most cases the high slit determined by the properties of the reservoir and classes more than determined by the optimization process Fig (2-1-a). However, as depth increases, overburden stress in the vertical direction increases by approximately 1 psi/ft. As the stress in the vertical direction becomes greater with depth, the overburden stress (stress in the vertical direction) becomes the greatest stress. This situation generally occurs at depths greater than 2000 ft and historically known as vertical fracture Fig (2-1-b) (API GUIDANCE, 2009).



(a) **(b)**

Fig (2-1) Type of Fractures: (a) is Horizontal Fracture and (b) is Vertical Fracture (API GUIDANCE, 2009)

Normally, the pressure required to initially break down the formation is greater than that one required propagating fracture. Once a fracture is formed, the fluid in the fracture acts as a wedge, forcing the fracture to grow. A fracture is more easily created using a low viscosity, penetrating fluid than with a high viscosity non-penetrating fluid, a penetrating fluid pressurizes a larger area, and the total force on the formation is greater than if a non-penetrating fluid, which acts only on the area near the wellbore, is used. Once of the important measurements that can help distinguish between horizontal and vertical fractures is the bottomhole pressure measured during the treatment.

1) Breakdown pressure: the pressure required to break down the formation and initiate fracture.
2) Propagation pressure: the pressure required to continually enlarge the fracture.
3) Instantaneous shut-in pressure: The pressure that is required to just hold the fracture opens (S. Schechter, **1990**)

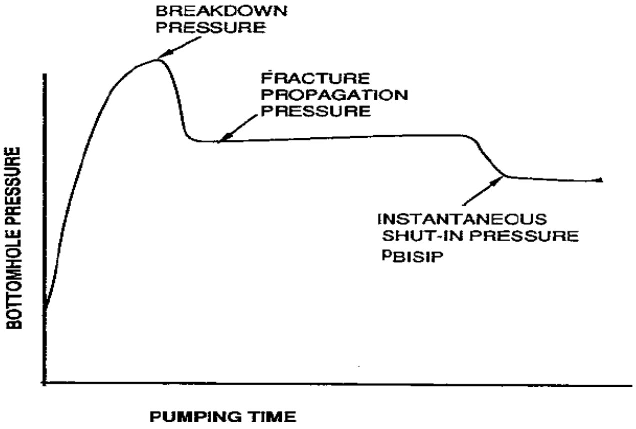


Fig (2-2) Pressure Behaviors during Fracturing **(S. Schechter, 1990)**

2.1.2. Hydraulic Fracturing Equipment and Material:

A) The Fracturing Fluid:

Fracturing fluids are pumped into the well to create conductive fractures and bypass near-wellbore damage in hydrocarbon-bearing zones. The net result is an expansion in the productive surface-area of the reservoir, compared to the unfractured formation. The conditions that must be provided in a fracturing fluid:

1) Be able to transport the propping agent in the fracture
2) Be compatible with the formation rock and fluid
3) Generate enough pressure drop along the fracture to create a wide fracture
4) Minimize friction pressure losses during injection Be cost-effective.

5) Be easy to clean and displacement of the formation after the end of the fracturing process.

Based on the objectives of the fracturing fluids many types of fracturing fluid were introduced; manly they can be divided to Water –Based Fracturing Fluids, Oil-Based Fracturing Fluids, and Foam Fracturing Fluids.

I. Water –Based Fracturing Fluids:

Water-based fracturing fluids are used in most stimulation applications. Most formations can be successfully treated with a compatible formulation of a water based fluid consisting of fresh water, acid or light brine. The Water –Based Fracturing Fluids has many advantages such as: The Economical penfite of this type of fluid as it can do a good job with low cost. Also it is readily available in the most application; and it is ease and safe to use, and a good handling can achieved to any places.

II. Oil- Based Fracturing Fluids:

Oil-based fracturing fluids are primarily used for water sensitive formation. They normally employ gelled kerosene, diesel, distillates, and many crude oils. Aluminum salts of organic phosphoric acids are generally used to raise viscosity, proppant carrying capability, and improve temperature stability. The Oil –Based Fracturing Fluids has many advantages such as: It have not a negative impact on the formation because it is composition is similar to the composition of the fluid layer. It is also has a good viscosity that is suitable to injection in low rates. However due to some physical properties, the Oil –Based Fracturing Fluids has some limitations such: it is more expensive than the water - based fluids. Also it is more difficult to handle. In the other hand it loses his viscosity when exposed to high temperatures.

III. Foam Fracturing Fluids:

Foam fracturing fluids are gas and liquid dispersions. Foams can use nitrogen and/or CO2. The Foam Fracturing Fluids has many advantages such as: It can be used in low pressure and fluid sensitive formations to aid in clean-up and reduce fluid contact. However due to some physical properties such as: it cannot be loaded with high proppant concentration. Also it is very uneconomical as compared to water and oil-based fracturing fluids the cost of foam fluid systems including field equipment is very high.

The Selection of Fracturing Fluid is manly depending on the formation lithology and well conduction. General fracturing fluid selected based on physical and chemical properties. The hydraulic fracturing process requires an array of specialized equipment and materials. This section will describe the materials and equipment that are necessary to carry out typical hydraulic fracture operations in vertical and horizontal wells. The equipment required to carry out a hydraulic fracturing treatment includes fluid storage tanks, proppant transport equipment, blending equipment, pumping equipment, and all ancillary equipment such as hoses, piping, valves, and manifolds. Hydraulic fracturing service companies also provide specialized monitoring and control equipment that is necessary in order to carry out a successful treatment.

B) Propping Agents:

The process of maintaining the fractures after the fracturing fluid from the formation is very important to the success of this treatment process , which is done by injecting a solid material removed from the surface by the fracturing fluid In the second phase after occur the fracturing. The most common propping agents are: Sand or quartz which classified into Northern sand, White sand, Ottawa sand, Jordan sand, St. Peter’s sand, and Wonewoc sand. Another type of proppant is the Ceramic Proppant, which is known as Intermediate-strength proppants (ISP). Other type of proppant is the Resin Coated Proppant (RCP) Either Sand or Ceramic, in which resin coatings may be applied to sand to improve proppant strength. The Sintered Bauxite which is known as High-Strength Proppants are generally limited to wells with very high closure stresses greater than 10,000 psi as they have high costs.

Ottawa **Resin Coated** **Bauxite**

Fig (2-3) Type of Proppant Agent Gidley, et al. 1989

There are some requirements for the above mentioned materials to be used as Proppant; it can be summarized as follows:

a) Have a high resistance against breakage.
b) Have a high conductivity.
c) Do not dissolve in acid.

d) With a low content of salt and mud.

The dimensions of the grains depends on the permeability of the layer where the use grains ranging from (0.5 to 0.8 mm) in order to permeability low , but for layers with permeability larger grains with dimensions ranging from (0.8 to 1.5 mm) in order to secure capacity flow large through the formation formed.

2.1.3. Water Flooding and Hydrocarbon Recovery:

Hydrocarbon recoveries are classified into two categories: Primary Oil Recovery and Supplementary or Secondary Hydrocarbon Recovery. The Primary recovery refers to the volume of hydrocarbon produced by the natural energy prevailing in the reservoir and/or artificial lift through a single wellbore (Dake, 1978; Lyons and Plisga, 2005). Primary oil recovery factors range from 20% and 40%, with an average around 34%, while the remainder of hydrocarbon is left behind in the reservoir (Satter et al., 2008). The natural driving mechanisms of primary recovery are Rock and liquid expansion drive, Depletion drive, Gas cap drive, Water drive, Gravity drainage drive and the combination drive.

The other recovery method is the Supplementary or secondary hydrocarbon recovery, which is refers to the volume of hydrocarbon produced as a result of the addition of energy into the reservoir, such as fluid injection, to complement or increase the original energy within the reservoir (Dake, 1978; Lyons & Plisga, 2005). Usually secondary recovery include water flooding, water Alternating Gas Injection (WAG), where slugs of water and gas are injected sequentially, and Simultaneous injection of water and gas (SWAG) is also practiced, however the most common fluid injected is water because of its availability, low cost, and high specific gravity which facilitates injection (Satter et al., 2008).

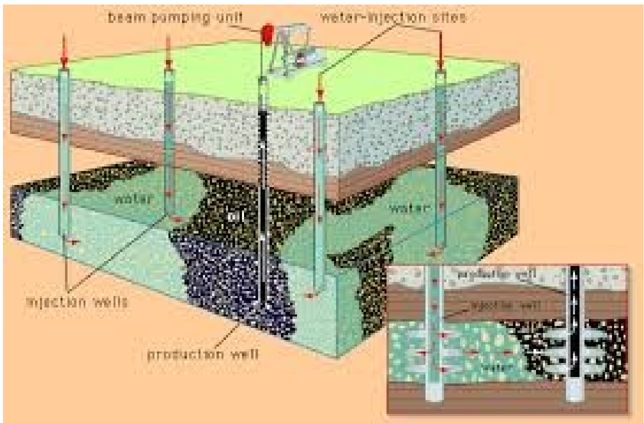


Fig (2-4) Hydrocarbon Recovery (Satter et al., 2008)

Water flooding is implemented by injecting water into a set of wells while producing from the surrounding wells. The technique was first used over 100 years ago, but it was not until the 1950’s that it gained popularity when field applications increased at a rapid rate. At the present time, water flooding is so well regarded as a reliable and economic oil recovery technique that almost every field that does not have a natural water drive, is being or soon will be water flooded. Water flooding projects are generally implemented to accomplish any of the following objectives or a combination of them:

1) Reservoir pressure maintenance
2) Dispose of brine water and/or produced formation water
3) As water drive to displace oil from the injector wells to the producer wells (Satter et al. 2008).

Other key factors that drove water flooding’s development and increasing use were the Water is inexpensive, Water generally is readily available in large quantities from nearby streams, rivers, or oceans, or from wells drilled into shallower or deeper subsurface aquifers, and Water injection effectively made production wells that were near the water-injection wells flow or be pumped at higher rates because of the increased reservoir pressure.

The injection pattern for an individual field or part of a field is based on the location of existing wells, reservoir size and shape, cost of new wells and the recovery increase associated with various injection patterns. The flood pattern can be altered during the life of a field to change the direction of flow in a reservoir with the intent of contacting un-swept oil. The Most Common Patterns Are: Direct- Line Derive, Staggered –Line Drive, Four- Spot, Five- Spot, Seven-Spot, and the Inverted Nine Spot pattern.

In the Direct- Line Derive pattern the lines of injection and production wells are directly opposed. The system is characterized by the two parameters: the spacing between wells of the same type and the spacing between of injection and production wells (Fig (2-5-a). In this type, the injectors and producers being no longer directly opposed but laterally displaced, normally by a distance of (a/2).

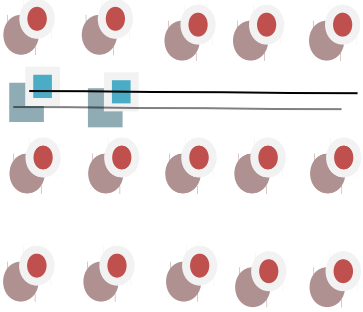


Fig (2-5-a) Direct-Line Derive Pattern

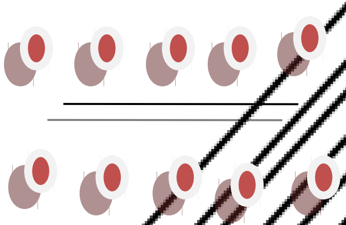


Fig (2-5-b) Staggered –Line Drive Pattern

The Four- Spot pattern is a type of flow pattern in which an injection wells are located at the corners of a triangle and the production well sits in the center.

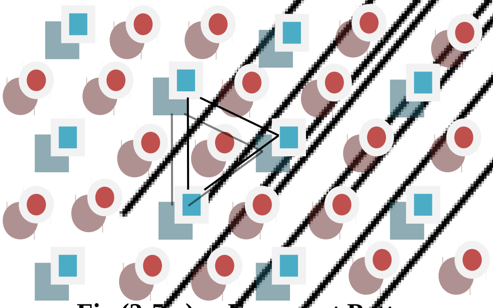


Fig (2-5-c) Four-spot Pattern

Another type of pattern is the Five- Spot pattern, in which injection pattern in which four input or injection wells are located at the corners of a square and the production well sits in the center. The injection fluid, which is normally water, steam or gas, is injected simultaneously through the four injection wells to displace the oil toward the central production well (Fig (2-5-d)). The injection pattern in which four production wells are located at the corners of a square and the injector well sits in the center is known as inverted Five- Spot pattern

The injection pattern
hexagon with a productio
2-5-e) .They are twice as m

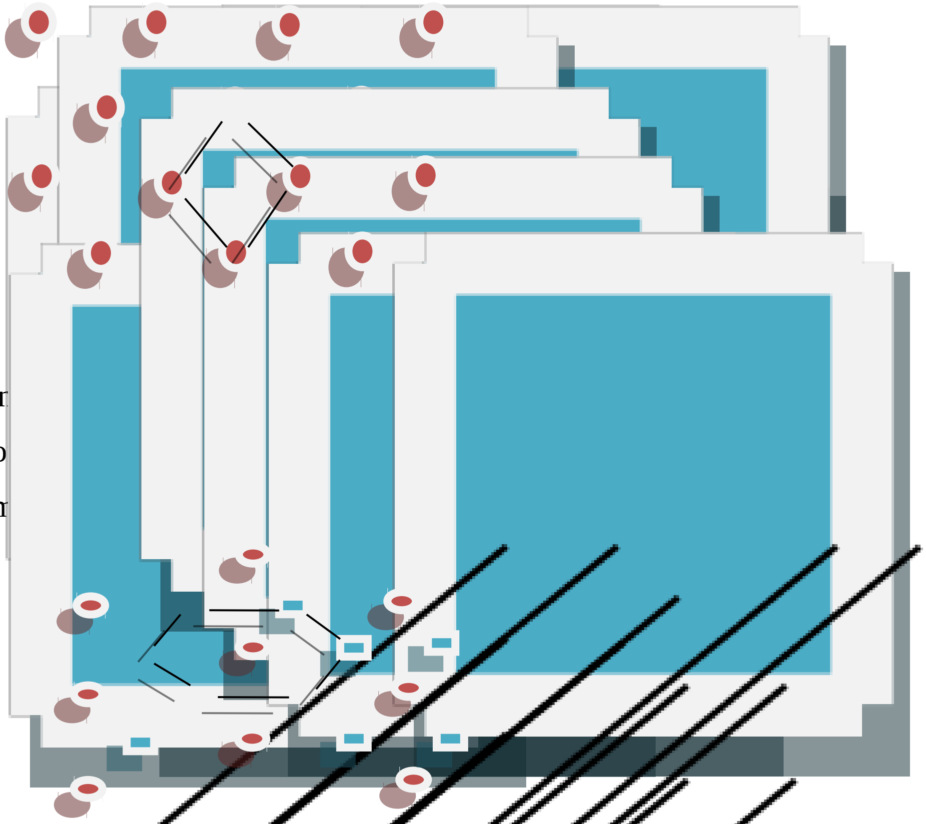


Fig (2-5-e) Seven-Spot Pattern

Nine spot pattern similar to the pattern of five but there are additional injection wells dug in the middle of each side of the square, style, consists of eight injection wells in the center of a well producing.

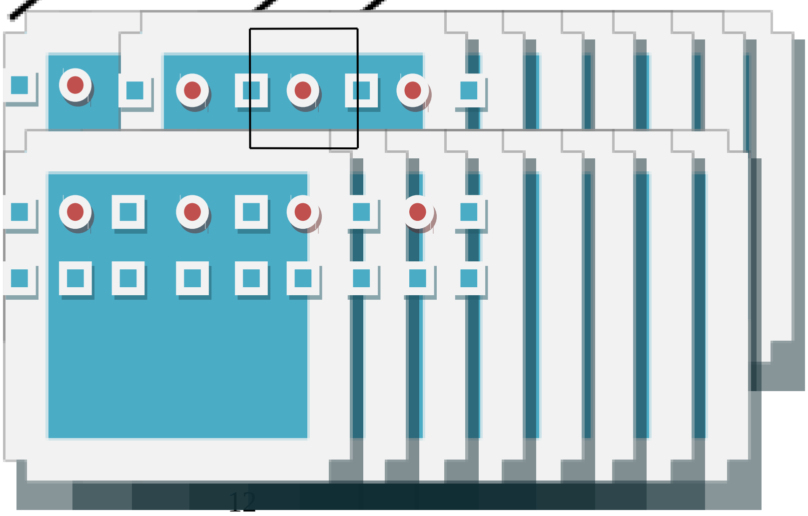
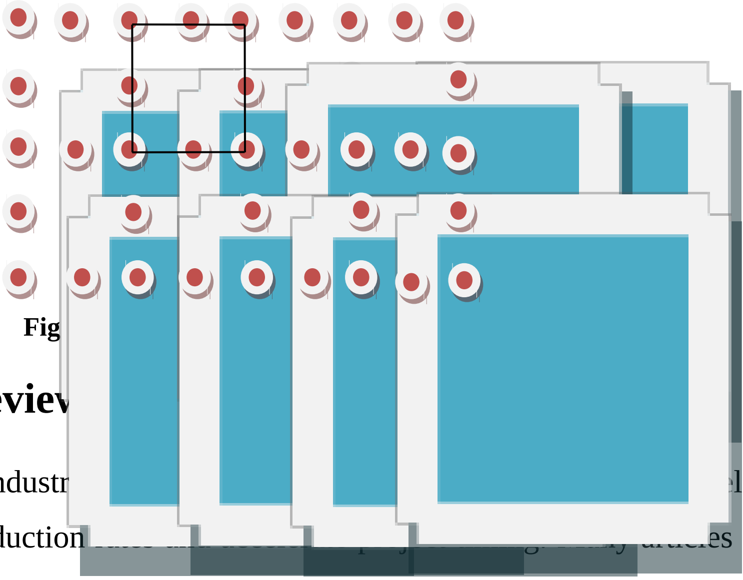


Fig (2-5-f) Nine-Spot Pattern

Inverted nine spot patterns however, it is more suitable for natural fracture reservoirs, the artificial fracturing scale of corner wells and injection wells should be limited to a low degree. Otherwise, a water flow path between injectors and corner wells will be established quickly. Rectangular pattern may resolve this problem, but the defect is the difficulty of adjustment.

Generally the selection of suitable spot pattern depend on number of the wells and their location, the heterogeneous of the reservoir and the directional permeability, the direction of the fracture in the formation, the predict age of the injection, the well spacing between the wells, the productivity index and the injectivity index, the oil maximum recovery and the available injection fluid.



Fig

2.2. Literature Revie

Historically, the industr lls in order to increase oil production es have been published which document the relationship between vertical fractures and areal sweep for five-spot and line-drive systems under unit mobility ratio conditions. These results have been used to provide insight into how hydraulic fractures affect sweep in pattern water floods.

Considerable theoretical work has been published on the nature of fractures induced in boreholes. Although discussion persists concerning the Possibility of forming a horizontal fracture at a given point within the wellbore, it is generally conceded that only vertical fractures will develop below a given depth, i.e., where the fracturing pressure is less than the overburden load.

Some of these hydraulically fractured wells are Located in fields that are now undergoing or being evaluated for enhanced oil recovery processes such as carbon dioxide or enriched gas injection. These enhanced gas drive (EGD) floods are adverse mobility ratio displacement which creates unique sweep efficiency concerns not typically encountered in water flood operations. In un-fractured homogeneous patterns, the difference in sweep between a water flood and adverse mobility ratio displacement occurs because the injection volume at which flow deviates from radial behavior and begins to cusp toward the producer decreases as the mobility ratio increase Cusping also becomes more pronounced as the mobility ratio increases which causes earlier breakthrough and decreased sweep efficiency at a given injection volume (C.L.Baragս et al, 1988).

Petroleum companies have been manipulating increasing volumes of produced and injected water in offshore field in the last few years. Injection rate maintenance is the most related to operational efficiency and loss of injectivity, during water injection, several factors contribute to change the water flow rate and pressure. In the other terms, the well injectivity index, Rock and fluid characteristics, well geometry and mobility ratio are some of these mechanisms. However, Operational efficiency and formation damage are by far the main factors. The of effect water injection flow rate maintenance with a fixed length on sweep efficiency was deeply studied by many authors. In general, it is assumed that all wells are fractured and directed along the same compass direction. Using the electrical analog to steady state, two-dimensional fluid flow in porous media, boundary conditions are obtained from which flood fronts are tracked numerically. The numerical computations require a particle tracking routine for approximating flood front histories. It is shown that recovery is sensitive to the length and orientation of fractures for the pattern studied. With the proper design of fracture pattern systems, recovery can be enhanced considerably.

Given the fact that fractures will be vertical in most cases of interest, it is also important to know whether there is order to fracture orientations within a given geological region. Kehle (1964) has suggested that in tectonically relaxed areas of uncomplicated geology, the stresses are fairly uniform and all fractures in the region should be parallel. Dunlap (1963) arrived at a similar conclusion in a theoretical investigation of localized stress conditions surrounding the borehole. He concluded that most vertical fractures are propagated in a preferred azimuthally direction. Fraser and Pettitt (1962), in extending these theoretical suggestions to a specific field case, used an impression packer to record both a vertical fracture and the orientation of this fracture in the wellbore of a well in the Howard Glasscock field; Tex. Use of this information enhanced the water flood recovery of the field.

A number of studies have been published that indicate the effect of an induced vertical fracture on flow behavior within the vicinity of a wellbore. Crawford and Collins (1954) noted the effect of vertical fractures on sweep efficiency of a line drive pattern. They showed that both the direction and orientation of fractures located in the injection wells could change the sweep efficiency of a five-spot pattern where the center well is fractured. They found that sweep efficiencies at breakthrough are reduced substantially by unfavorable orientations but that the ultimate swept area approaches that of the un-fractured case.

Dyes et al. (1958) investigated fracturing effects on a five -spot pattern using the X-ray shadowgraph technique. Fractures were located in either injection wells or production wells and were oriented favorably (between offset wells) or unfavorably (toward offset wells). Mobility ratio was considered as a variable (from 0.1 to 3.0). They found that fractures with a favorable orientation have little effect on sweep behavior regardless of length, while unfavorable orientation reduces sweep efficiencies at breakthrough. Short fractures induced to increase either injectivity or productivity with a little effect on over-all behavior.

Hartsock et al. (1958), also, used an X-ray shadowgraph model to investigate sweep performance in a bounded five-spot. He found that a single fracture in the most favorable orientation made only a slight difference in sweep efficiency regardless of the fracture Length. No studies, other than some recent work at Penn State U., have been reported to indicate the effect of fracture length and orientation on sweep efficiency of a confined five-spot when all wells are fractured. McGuire and Sikora (1960), further discuss the limitations and assumptions involved in the study presented by Hartsock (1958). Another study by E1kins and Skov (1960) demonstrated that a natural, oriented, vertical fracture system exists within the Spraberry field.

Heck et al. (1960) suggests that sandstone formations in the Appalachian basin, having undergone extreme folding, are jointed. At depth the joints are closed but they are reopened during fracturing. He suggests that, because of the nature of jointing systems (observed in recently exposed outcrops), induced fractures at depth will be vertical and, for a given geological area, will be oriented along a specific azimuth direction. Through numerous field tests using a privately fabricated impression packer he has demonstrated that this is the case in the Bradford field.

Anderson and Stahl (1967), also used impression packers on three fractured wells in the Allegheny field, N. Y., and found that the fractures were oriented more or less along the same compass Direction. Orientation of the fractures in this manner depends on the stress condition within the formation during fracturing Experimental and computational models were developed and used to calculate the areal sweep efficiency at breakthrough for a confined five-spot where oil wells were assumed to be fractured vertically along a specific depth (Donuhue -1968). Idealized fluid flow conditions were imposed on the phenomenon being simulated. Areal sweep efficiency at breakthrough was found to be sensitive to both the relative length of the fracture and its angle of orientation. The study presented that areal sweep efficiency of a 0° fracture orientation five-spot is always greater than that for an unfractured pattern, but Little effect is noted until the fracture lengths are at least equal to one-quarter the distance between like wells.

A major step was the numerical model presented by Hagoort et al (1980) that have stimulated the growth of a vertical fracture of constant height in a simple, vertically homogeneous reservoir. They studied fracture propagation as a function of reservoir and injection/production conditions. One of the important conclusions of this study was that the leak-off from the fracture into the reservoir should essentially be modeled as two-dimensional in the plane of the reservoir. Therefore the study presented that the previously developed analytical models with a one-dimensional description of leak-off are generally inadequate for modeling water flood-induced fractures.

In addition Hagoort et al. (1981) presented apart from the numerical simulation model, analytical calculations of sweep efficiency for a 5-spot containing a fractured injector with a fixed fracture length. The calculations were also extended to stratified reservoirs. The effect of reservoir pressure on rock stress and fracture propagation pressure were discussed using two-dimensional poro-elastic stress calculations. The declining fluid pressure with time has been analyzed to get an indication of fracture length.

In 1988 Bargas et al. presented the results of a simulation study using a finite element model to determine the effects of hydraulic fractures on the areal sweep efficiency of contact miscible displacement in five spot and line drive pattern. The influence of fracture orientation, length, and conductivity for mobility ratios ranging from one to ten is reported for patterns where either the producer or injector, or both the producer and injector are fracture stimulated.

Van den Hoek (2004) presents the results of a study addressing the impact of induced fractures on the "present value" recovery and on the reservoir management in pattern water floods. Based on streamline simulations on two types of patterns (five-spot and nine-spot), in which the fracture lengths and orientations, in addition to the fluid mobility ratios, were varied, it is concluded that induced fractures in pattern floods generally result in a significant recovery improvement, even for cases in which the induced fractures are "long" (exceeding roughly 25% of the pattern unit cell size).

Antonio et al. (2005) presented the impact of fracture propagation on sweep efficiency during a water flooding process; a methodology for modeling fracture propagation is presented, as well as the sweep efficiency effects due to IFPP, using an in-house geo-mechanical simulator combined with a commercial reservoir simulator was presented . By the other hand, the study presented that the benefits of injection rate maintenance with fracture can overcome a possible negative impact on sweep efficiency.

Petroleum company have been manipulating increasing volumes of produced and injected water in offshore field in the last view years; in Brazel petrobras manipulated over 3 million barrels of water per day including injection production and re-injection injection rate maintenance and produced water management are the main challenge for the next years (Souza , 2005).

Dongmei et al. (2006) investigates the potential of various approaches for improving sweep in parts of the Daqing Oil Field that have been EOR targets; included gel treatments through fractures. The studies indicated that the polymer flood should have provided excellent sweep throughout the vast majority of the patterns.

Paul et al. (2009) presented a new modeling strategy that combines fluid flow and fracture growth (fully coupled) within the framework of an existing "standard" reservoir simulator. The study demonstrate the coupled simulator by applications to repeated five-spot pattern flood models; also demonstrate how induced fracture dimensions (length, height) can be very sensitive to typical reservoir engineering parameters, such as fluid mobility, mobility ratio.

Van den Hoek (2009) presents a new modeling strategy that combines fluid flow and fracture growth (fully coupled) within the framework of an existing "standard" reservoir simulator. The work addressed various aspects that often play an important role in water floods: shortcut of injector and producer, fracture containment to the reservoir layer, and areal and vertical reservoir sweep. Also demonstrate how induced fracture dimensions (length, height) can be very sensitive to typical reservoir engineering parameters, such as fluid mobility, mobility ratio, 3D saturation distribution, 3D temperature distribution, positions of wells (producers, injectors), and geological. The results presented in that work are expected to also apply to (part of) enhanced-oil-recovery operations (e.g., polymer flooding).

Chapter 3

Mathematical Model

3.1. Description of Reservoir Model:

Pressure behavior of a well intercepting by a finite- conductivity vertical fracture, can be studied by the models proposed by Chenzhi Hai as described below:

3.1.1. General Assumptions:

1- The reservoir is considered to be a horizontal, tow – phase (oil, and water), and three dimensional flow (X, Y, Z –direction).
2- Homogeneous formations ((Kx, KY, Kz) = constant) and anisotropic formations (Kx ≠ KY ≠ Kz).
3- The reservoir fluids with small constant compressibility.
4- Gravitational effect and pressure gradient between the phases (capillary pressure) are assumed to be negligible.
5- No flow across the outer boundaries

$$\frac{\partial P}{\partial x}|_{x=L_X}=0 \qquad \frac{\partial P}{\partial y}|_{y=Ly}=0 \qquad \frac{\partial P}{\partial z}|_{Z=L_Z}=0$$

6- The well located in finite reservoir, and producing at constant pressure, while the injector well has a constant invective pressure, or constant injection rate.
7- Considered sweep of inverted nine spot pattern.
8- Darcy’s law applicability.

$$Ux=-\frac{Kx}{\mu}\frac{\partial P}{\partial x} \qquad Uy=-\frac{Ky}{\mu}\frac{\partial P}{\partial y} \qquad Uz=-\frac{Kz}{\mu}\frac{\partial P}{\partial z}$$

3.1.2. Mathematical Equations:

The mathematical model consists of the flow and continuity equations for two- phase flow in the reservoir and the fracture.

Liquid Flow Equations:

For oil phase: $\vec{U}_O = -\frac{K.K_{RO}}{\mu_O}\nabla P$ …………………………………

(3-1)

For water phase: $\vec{U}_W = -\frac{K.K_{RW}}{\mu_W}\nabla P$ ………………………………..…

(3-2)

Continuity Equations:

For Oil Phase: $div(\rho_o \vec{U}_O) = -\frac{\delta(\rho_o \phi S_O)}{\delta t}$ ……………………..……

(3-3)

For water phase: $div(\rho_w \vec{U}_w) = -\frac{\delta(\rho_w \phi S_w)}{\delta t}$ …………………..… (3-4)

Substituting the flow equation we can rewrite the continuity equation as follows:

$$\frac{\delta}{\delta x}\left(\frac{\rho_L k k_{rL}}{\mu_L}\frac{\delta P_L}{\delta x}\right)+\frac{\delta}{\delta y}\left(\frac{\rho_L k k_{rL}}{\mu_L}\frac{\delta P_L}{\delta y}\right)+\frac{\delta}{\delta z}\left(\frac{\rho_L k k_{rL}}{\mu_L}\frac{\delta P_L}{\delta z}\right)=\frac{\delta(\rho_L \phi S_L)}{\delta t}$$ …… (3-5)

3.1.3. Primary and Boundary Conditions:

a. Primary conditions:

$$P(x,y,z,t)\big|_{t=0} = \left\{ \begin{array}{l} Pi \\ f1(x,y,z) \end{array} \right.$$

$$S_W(x,y,z,t)\big|_{t=0} = \left\{ \begin{array}{l} Swi \\ g1(x,y,z) \end{array} \right.$$

b. Outer Boundary Conduction:

$$\frac{\delta P}{\delta x}|_{x=0}=0 \qquad \frac{\delta P}{\delta y}|_{Y=0}=0 \qquad \frac{\delta P}{\delta z}|_{z=0}=0$$

$$\frac{\delta P}{\delta x}|_{x=L_X}=0 \qquad \frac{\delta P}{\delta y}|_{y=Ly}=0 \qquad \frac{\delta P}{\delta z}|_{Z=L_Z}=0$$

c. Inner Boundary Conditions:

The well has a constant Flowing pressure

$$P_{wf} = \text{Constant} = C_1$$

d. Subsidiary Equations

$$P_C = P_O - P_W = 0$$ ………………………………………………….… (3-6)

$$S_o + S_w = 1$$ ………….…………………………………………….… (3-7)

$$k_{ro} = k_{ro}(S_o)$$ …………………...…………………………….… (3-8)

$$k_{rw} = k_{rw}(S_w)$$ ………………….…………………………….… (3-9)

$$S_{WAVGE} = \frac{\sum S_w(i, j, k) * Dx * Dy * Dz}{\sum Dx * Dy * Dz}$$ ………………...….… (3-10)

3.2. Fracture model:

3.2.1. General Component and Assumptions

1- The well is intercepting by a finite conductivity symmetrical vertical fracture.

2- The fracture has a homogeneous and isotropic pours medium.
3- Fluid flow within the fracture considered obeying Darcy's law.
4- The fracture considered as a plane source with two-dimensional.
5- Well bore storage and skin effect are not considered in this study
6- Neglecting the flow from the tip of the fracture.
7- The fracture conductivity dose not changes with time.

Note that the fracture direction in this study considered being favorable for both productive and injective wells.

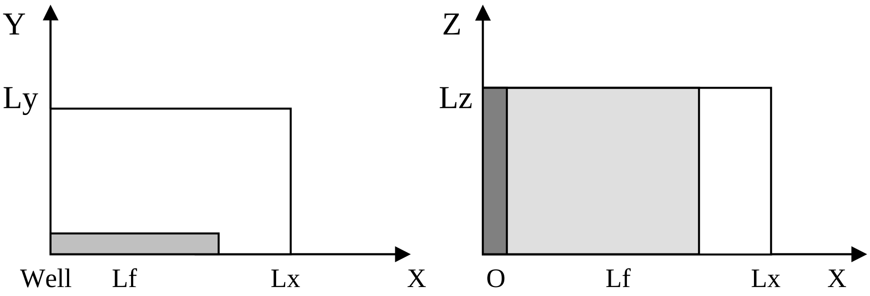
3.2.2. The Mathematical Model

$$\nabla[\frac{K_f K_{RO}}{\mu_O \beta_O}] + q_{Ofin} = \frac{\delta}{\delta t}(\phi \rho_O S_O)$$ ………..………………….… (3-11)

$$\nabla[\frac{K_f K_{RO}}{\mu_w \beta_w}] + q_{wfin} = \frac{\delta}{\delta t}(\phi \rho_w S_w)$$ ……............…………..… (3-12)

$$S_o + S_w = 1$$ ………………………………………...…………..… (3-13)

3.2.3. Primary and boundary conditions



a. Primary conditions

$$P_f(x,z,t)\big|_{t=0} = \left\{ \begin{matrix} Pi \\ f_2(x,z) \end{matrix} \right.$$

$$S_{Wf}(x,z,t)\big|_{t=0} = \left\{ \begin{matrix} Swi \\ g_2(x,y,z) \end{matrix} \right.$$

b. Outer conditions

$$\frac{\delta P_f}{\delta x}\Big|_{x=Lf}=0 \qquad \frac{\delta P_f}{\delta z}\Big|_{Z=0}=0$$

$$\frac{\delta P_f}{\delta x}\Big|_{y=0}=0 \qquad \frac{\delta P_f}{\delta z}\Big|_{Z=L_Z}=0$$

c. The two models relationship is

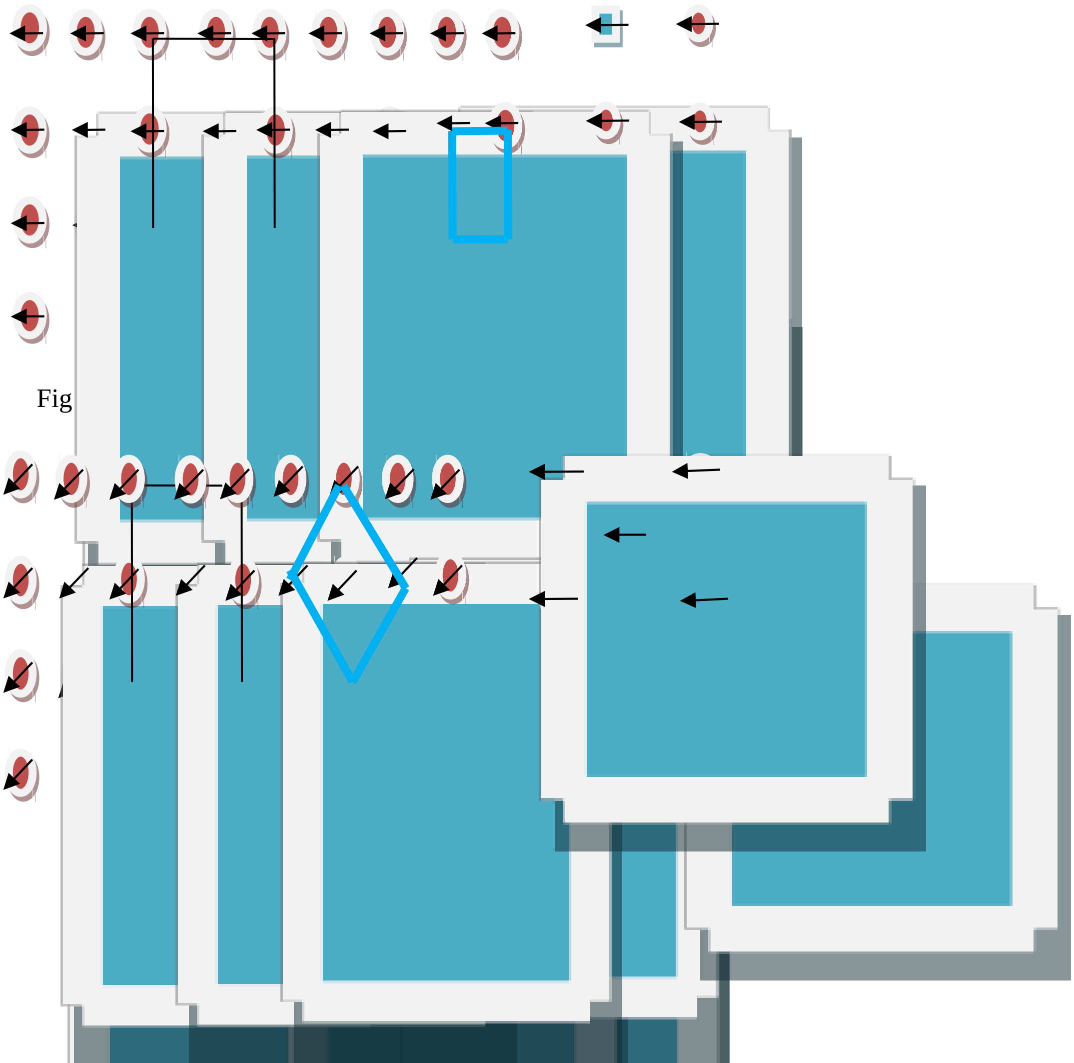
$$P_r\,(i,\,j,k)=P_f\,(i,k)$$ ……………………………...……..…

(3-14)

3.3. Inverted Nine Spot with Fracture:

The model under study has two models, the first model is the pattern with 0 fracture angle; in this case the well networks will have four wells as presented in Fig (3-1); three wells is production wells while the fourth well is water injection well.

The second model is the pattern with 45 degree fracture angle; in this case the well networks will have five wells as presented in Fig (3-2); three wells is production wells while the other wells is water injection well.



Fig

Fig (3-2) Inverted Nine Spot with Fracture Angle of 0 Degree

3.4. Numerical Simulation Study to Optimize Fracture Geometry

The main objective of this step is to optimize fracture length for the wells in inverted nine spot through a numerical simulation study. Based on the available petrophysical parameters and the geological data presented an oil well in A Sudanese oil field. In fact the field has no flow pattern; however the assumption was made to continue the study

The model presented here has the following assumption for reservoir, fluids and simulation parameters:

Max production time (day)= 3600 day

Maximum economic water cut is 98%

Economic production limitation 30 B/d,

Producers’ minimum flowing pressure set to 12 Mpa,

Injector Well Maximum injection Pressure 30Mpa

Water viscosity (pa.s) = 0.008

Water density (ton/m^3) =1

oil compressibility (1/MPa) = 0.00907

Water compressibility (1/MPa) = 0.0001417

Rock compressibility (1/MPa) = 0.00025

Oil saturation (%) = 45

FVF for water (%) = 1

Oil density (ton/m^3) = 0.85

Porosity (%) = 0.12

Initial water saturation (%) = 35

Initial reservoir pressure (MPa) = 19

Bubble point pressure (MPa) = 13

The number of grid is 20×20×2. The average cell sizes in X and Y directions are 15 m and 15 m ft respectively with an average cell thickness (DZ) of 3.6 m with Single.

Table (3-1); PVT Properties for the Model

Pressure (MPa)	Viscosity (pa.s)	FVF
0.1	0.003	1.014

0.5	0.003	1.014
1	0.003	1.014
1.5	0.003	1.014
2	0,003	1.014
2.5	0.003	1.014
3.1	0.003	1.014
4.2	0.003	1.014
5	0.003	1.014
6.3	0.003	1.014

Table (3-2); The Relative Permeability for the Model

Water saturation	Kro	Krw
0.35	1	0
0.36	0.90	0.004
0.38	0.42	0.01
0.40	0.22	0.031
0.42	0.098	0.034
0.44	0.058	0.048
0.46	0.019	0.058
0.47	0.008	0.062
0.48	0.002	0.068
0.55	0	0.11

The wells coordinate and the type was presented in table (3-3) for inverted nine spot with fracture angle of 0 degree. While wells coordinates and the type was presented in table (3-4) for inverted nine spot with fracture angle of 45.degree.

Table (3-3); The wells coordinate and the type with fracture angle of 0 degree

Well No	X coordinate	Y coordinate	Well symbol	Pwf (MPa)
1	1	20	1	30
2	20	20	-1	12
3	20	1	-1	12
4	1	1	-1	12

Table (3-4); The wells coordinate and the type with fracture angle of 45 degree

Well No	X coordinate	Y coordinate	Well symbol	Pwf (MPa)
1	1	20	1	30
2	20	20	-1	12

3	20	1	-1	12
4	1	1	1	30
5	10	10	-1	12

Chapter 4

Result and Discussion

The reservoir simulation program (FRACTURE PACKAGE) has been run several times using data presented through chapter 3 and different fracture length for both 0 degree fracture angle and 45 degree.

The results was presented as explain pressure distribution, water saturation distribution in reservoir and liquid flow rate. In addition, cumulative oil flow rate, the water flow rate and injection rate was obtained for all cases.

4.1. Effect of Fracture Length on Saturation Distribution:

Examples of result was selected to present the effect of fracture length on saturation distribution through the network after five years as presented through Fig (4-1) to Fig (4-5)

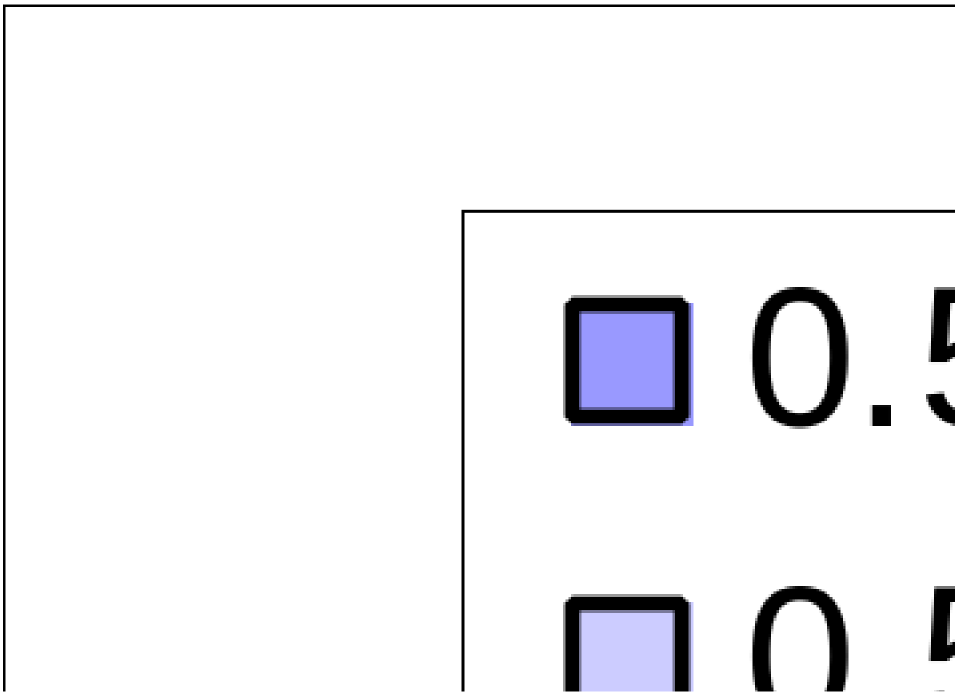


Fig (4-1) Water Saturation Distribution with Fracture Half Length of 10% for oil wells and 0% for water Wells after Five Years

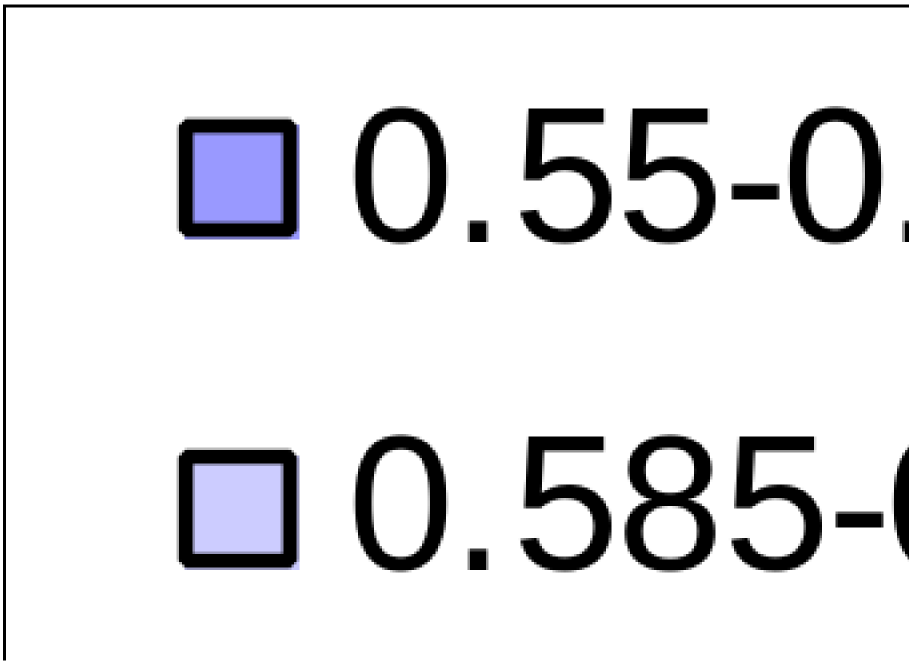


Fig (4-2) Water Saturation Distribution with Fracture Half Length of 10% for oil wells and 10% for water wells after five years

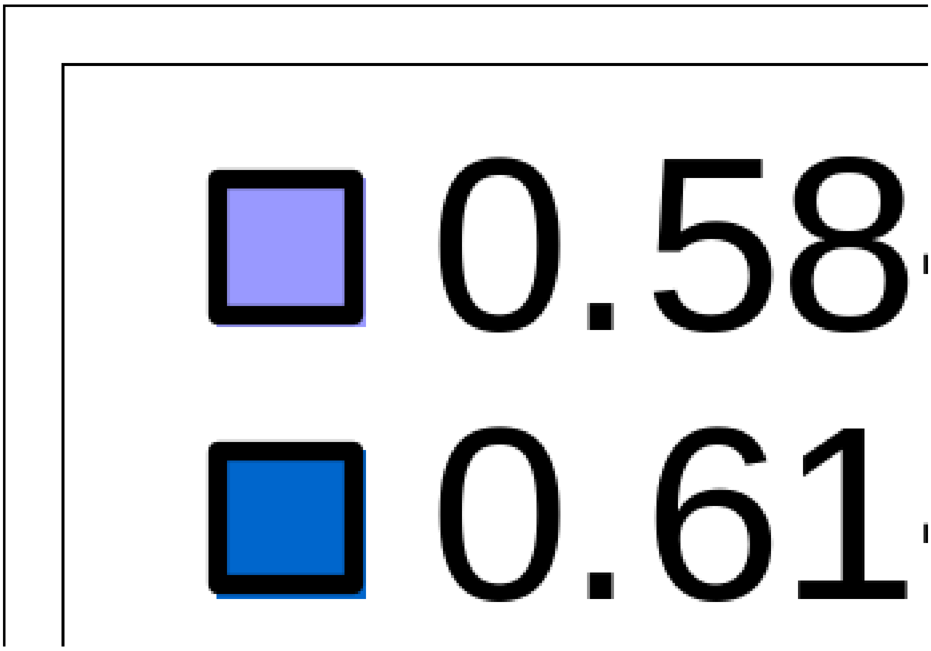


Fig (4-3) Water Saturation Distribution with Fracture Half Length of 10% for oil wells and 20% for water wells after five years

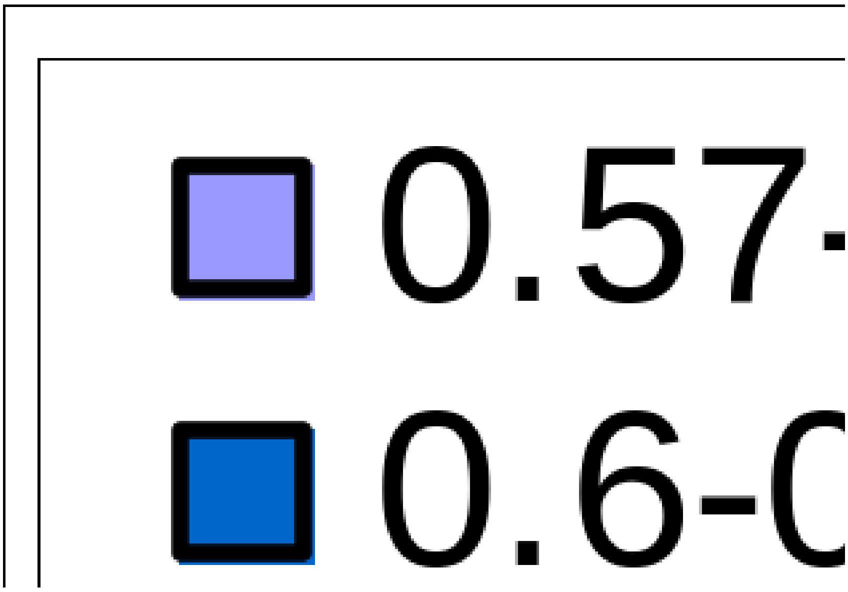


Fig (4-4) Water Saturation Distribution with Fracture Half Length of 10% for oil wells and 30% for water wells after five years

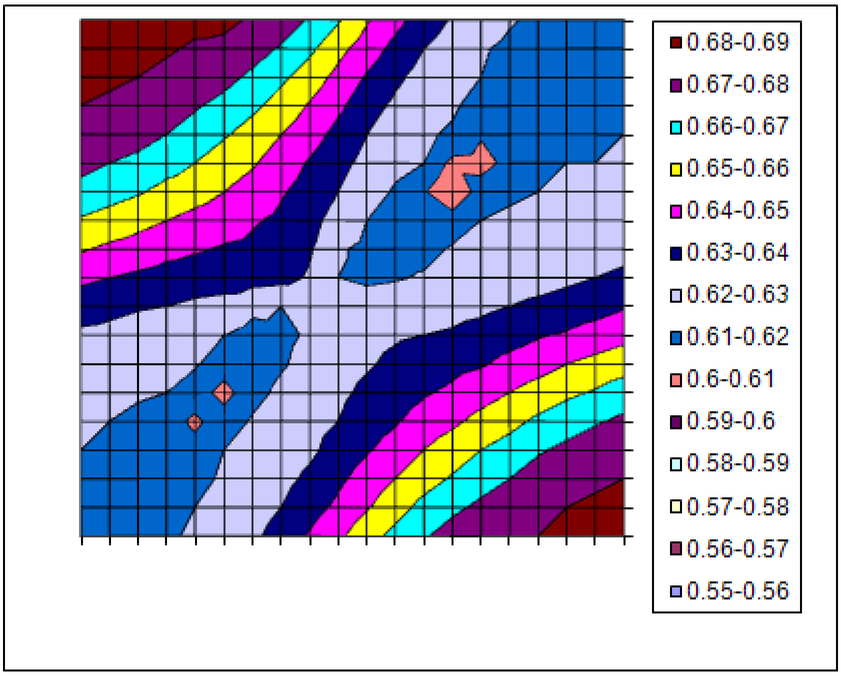


Fig (4-5) Water Saturation Distribution with Fracture Half Length of 10% for oil wells and 30% for water wells after five years (Fracture Angle = 45 Degree)

It can be observed that water saturation distribution increases with the increments of fracture length around the same wells.

4.2. Effect of Fracture Length on Well Productivity:

The effect of fracture length on well productivity should be studied for every well as individual case, that the fracture is favorable in some wells and unfavorable in other wells.

For 0 degree angle, Fig (4-6) present the well’s network; it is observes that the well No. 2 have a fracture direction toward the injection well, while the other production wells was not linked directly to the water well (well No. 1).Therefore the effect of each well will be discussed as individual case.

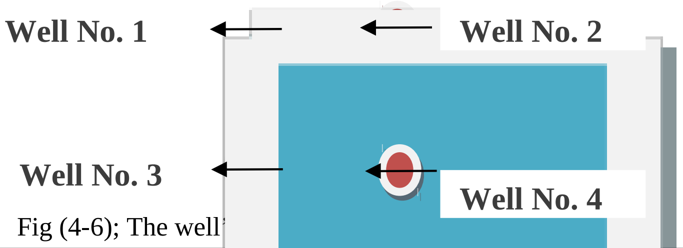


Fig (4-6); The well’

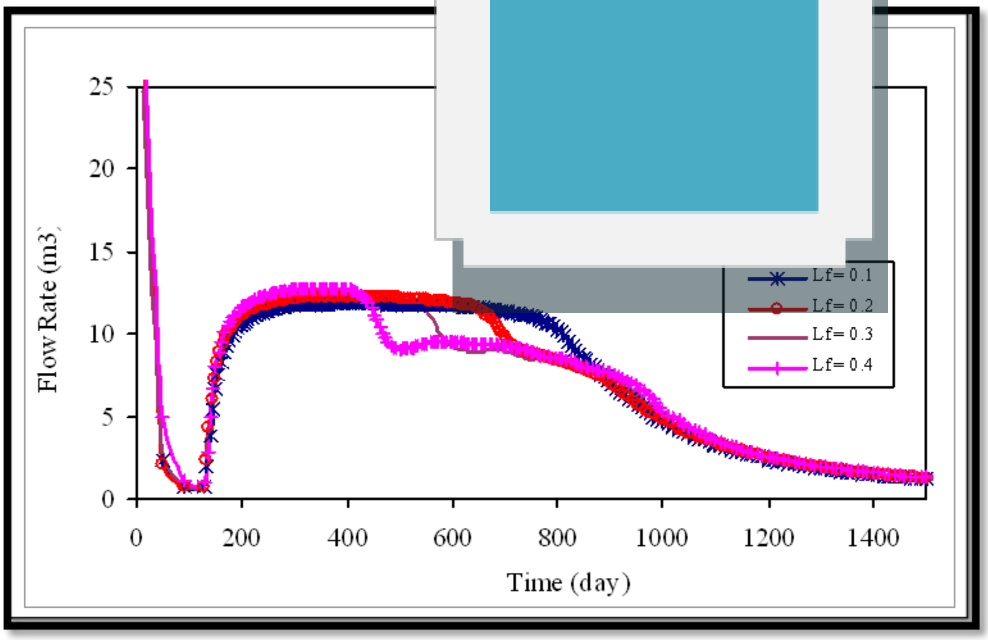


Fig (4-7-a) Effect of Fracture Length on Well Productivity for Well No. 2

Fig (4-7-a) and Fig (4-7-b) show that when the fracture length increase, the productivity increases for period of time, however, after 500 days the productivity begins to decrease due to the increment of water cut because the fracture is unfavorable. If the well was not fractured the productivity will remain constant for a period grater than that of fracture.

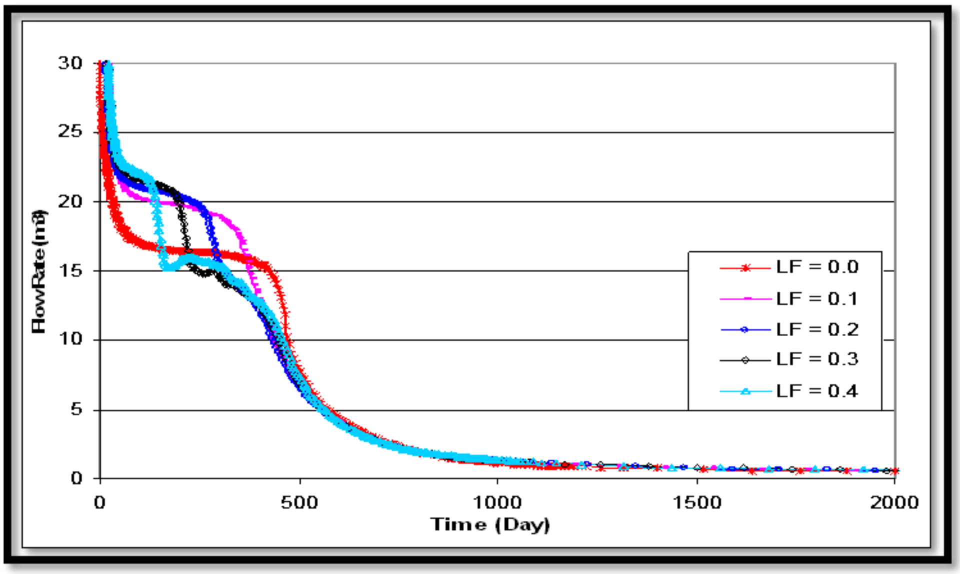


Fig (4-7-b) Effect of Fracture Length on Well Productivity for Well No.2 - Water Well with 30 % Fracture

This result can be observed in Fig (4-8-a) and Fig (4-8-b) clearly as the water cut of the well increased with the increment of fracture length, and the time for water breakthrough is early for long fracture.

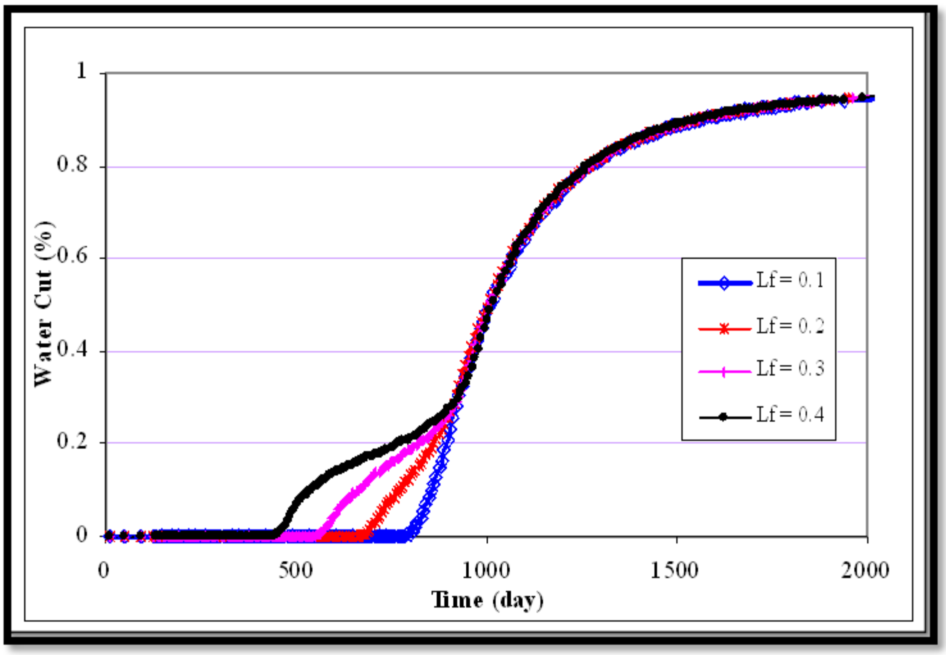


Fig (4-8-a) Effect of fracture Length on Water cut for Well No. 2

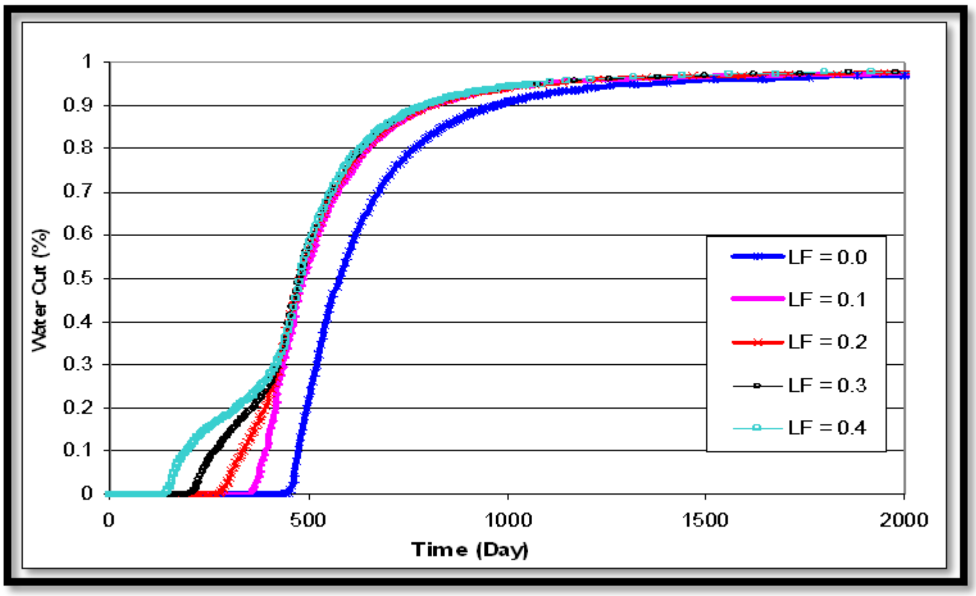


Fig (4-8-b) Effect of fracture Length on Water cut for Well No. 2 - Water Well with 30 % Fracture

However for well No. 4, Fig (4-9-a) and Fig (4-9-b) presented that the well productivity increases with the increment of fracture length, and the increments of productivity has no constant formula, it can be observed that the fracture length of 0.3and 0.4 have the same effect which indicate that only fracture of 0.3% is enough. The same result can be achieved through Fig (4-10-a) and Fig (4-10-b).

Fig (4-9-a) Effect of Fracture Length on Well Productivity for Well No.4

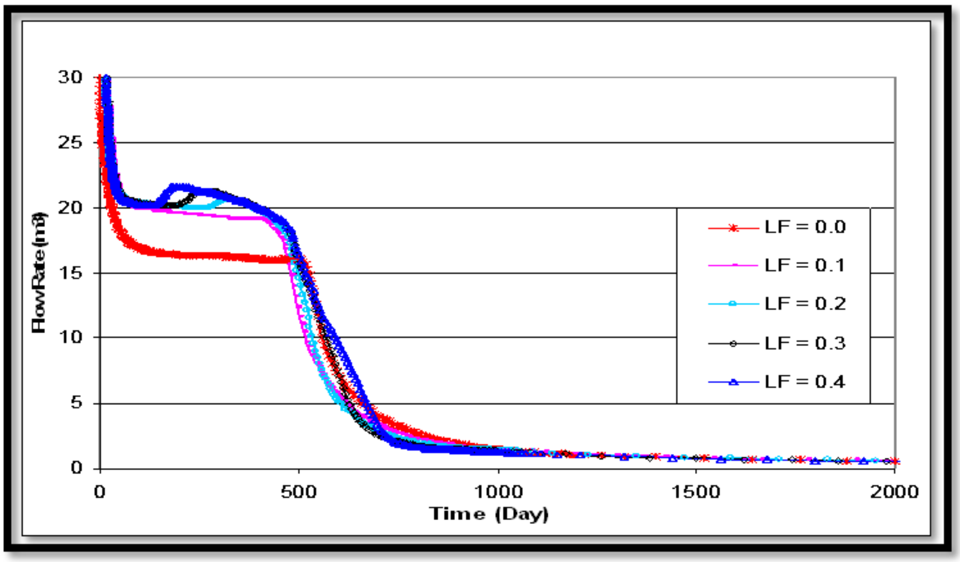


Fig (4-9-b) Effect of Fracture Length on Well Productivity for Well No.4 – Water Well with 30 % Fracture

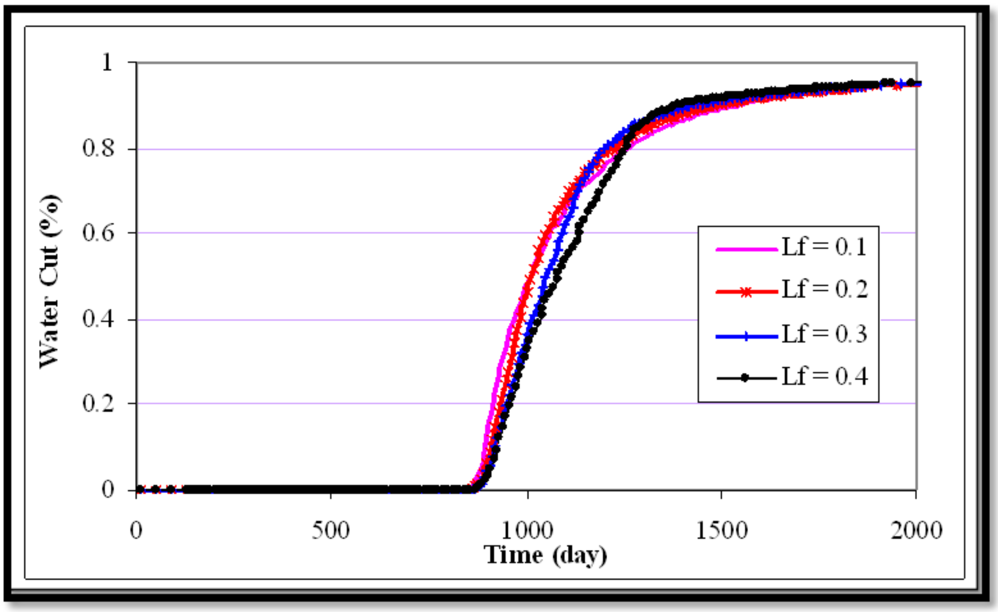


Fig (4-10-a) Effect of fracture Length on Water cut for Well No. 4

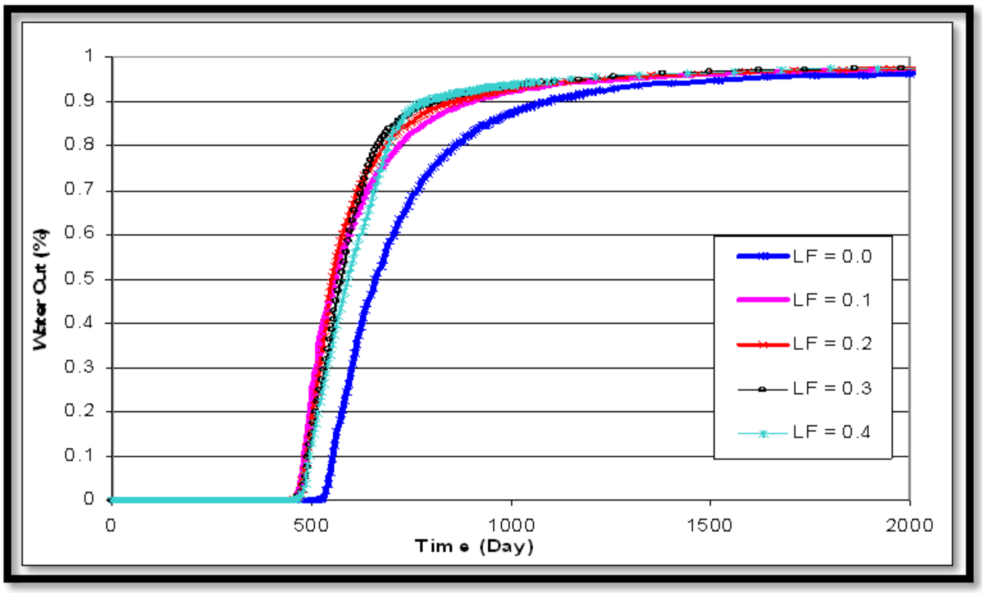


Fig (4-10-b) Effect of fracture Length on Water cut for Well No. 4- Water Well with 30 % Fracture

The fracture length of the injection well (Well No. 1) has a considerable effect in well No. 2 also as presented through Fig (4-11).

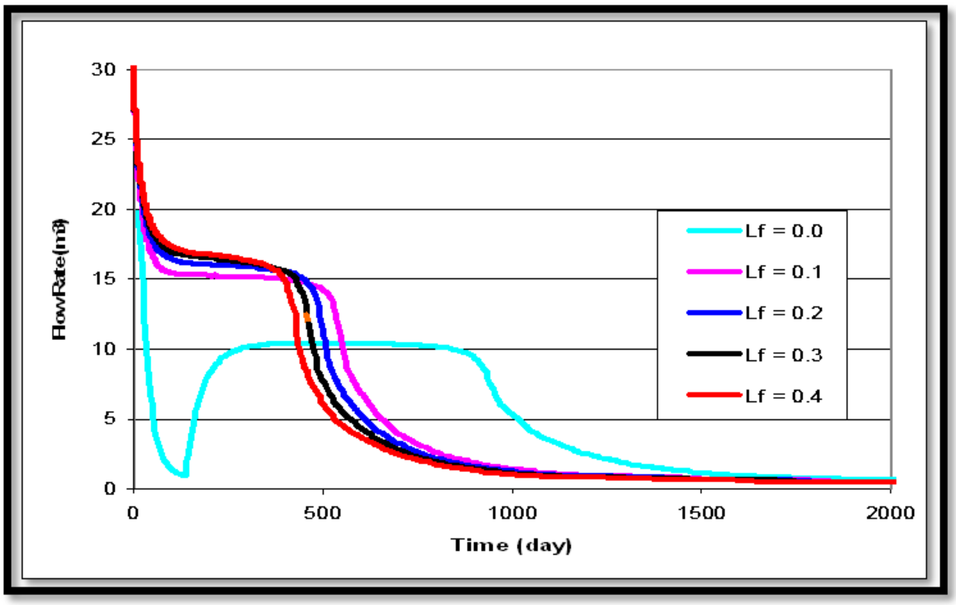


Fig (4-11) Effect of Injection Well Fracture Length on Well Productivity for Well No. 2

By the same way foe fracture angle of 45 degree, Fig (4-6) present the well's network; it is observes that the well No. 2 and No. 3 have a fracture direction toward the injection well, while only well No. 5 has no direct link with the injection well.

Therefore the effect of each well will be discussed as individual case; however Well No. 2 and Well No. 3 has the same condition and has the same result, that only well No. 3 will be discussed beside will No. 5.

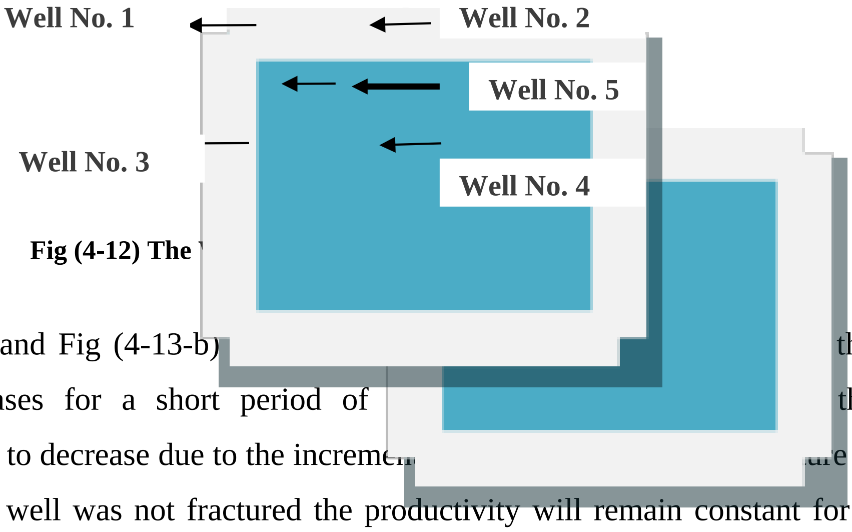


Fig (4-12) The

Fig (4-13-a) and Fig (4-13-b) the productivity increases for a short period of the productivity begins to decrease due to the increme e is unfavorable. If the well was not fractured the productivity will remain constant for a period grater than that of the case of fracture.

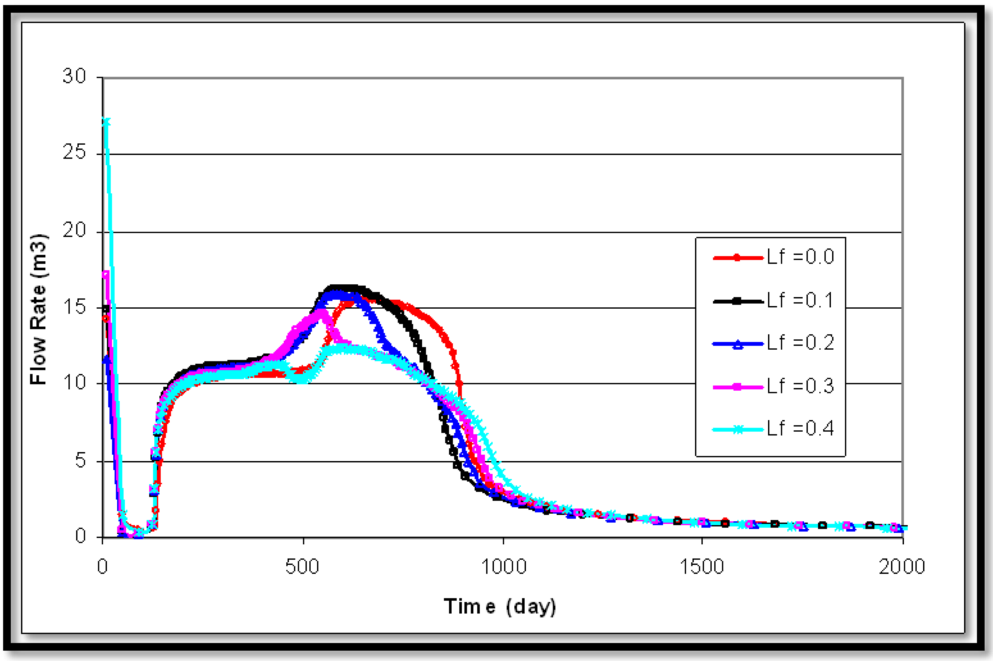


Fig (4-13-a) Effect of Fracture Length on Well Productivity for Well No. 3

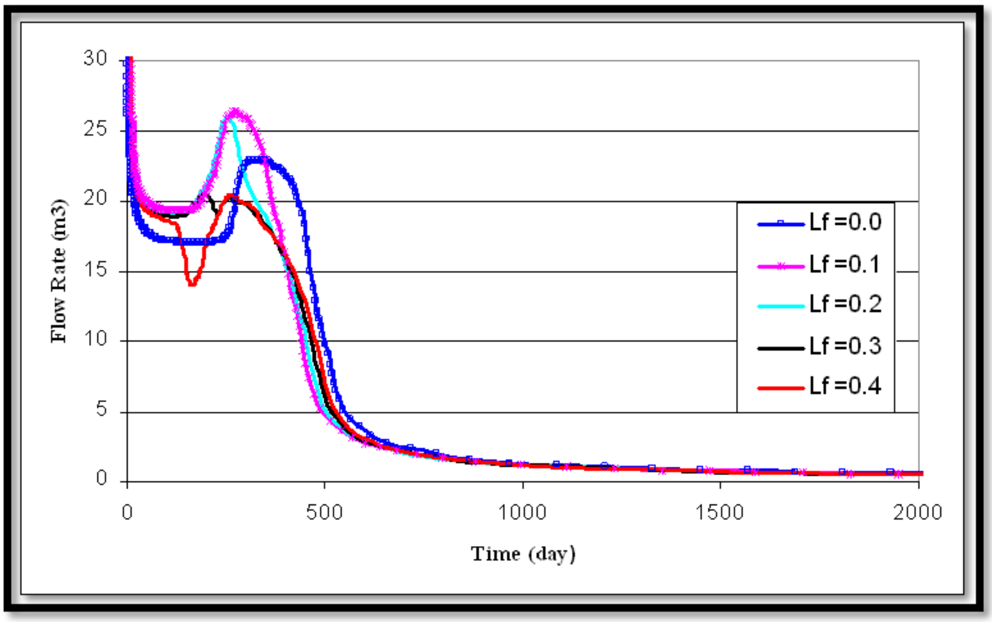


Fig (4-13-b) Effect of Fracture Length on Well Productivity for Well No. 3 - Water Well with 30 % Fracture

This result can be observed in Fig (4-14-a) and Fig (4-14-b) clearly as the water cut of the well increased with the increment of fracture length, and the time for water breakthrough is early for long fracture.

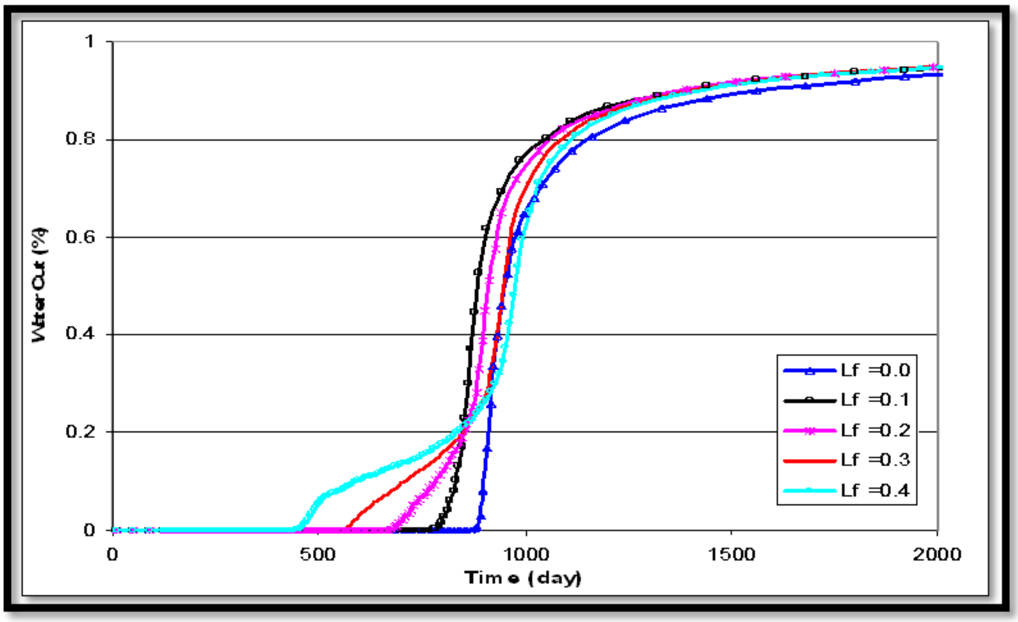


Fig (4-14-a) Effect of fracture Length on Water cut for Well No. 3

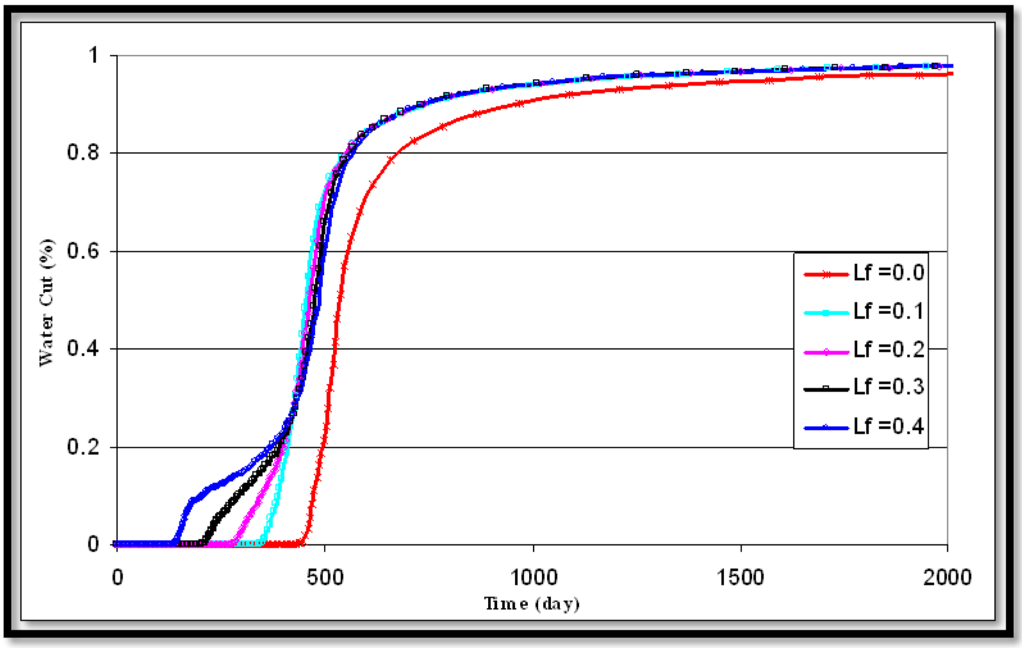


Fig (4-14-b) Effect of fracture Length on Water cut for Well No. 3- Water Well with 30 % Fracture

However for well No.5, Fig (4-15-a) and Fig (4-15-b) presented that the well productivity increases with the increment of fracture length, and the increments of productivity has no constant formula, it can be observed that the fracture length of 0.3and 0.4 have the same effect which indicate that only fracture of 0.3% is enough. The same result can be achieved through Fig (4-16-a) and Fig (4-16-b).

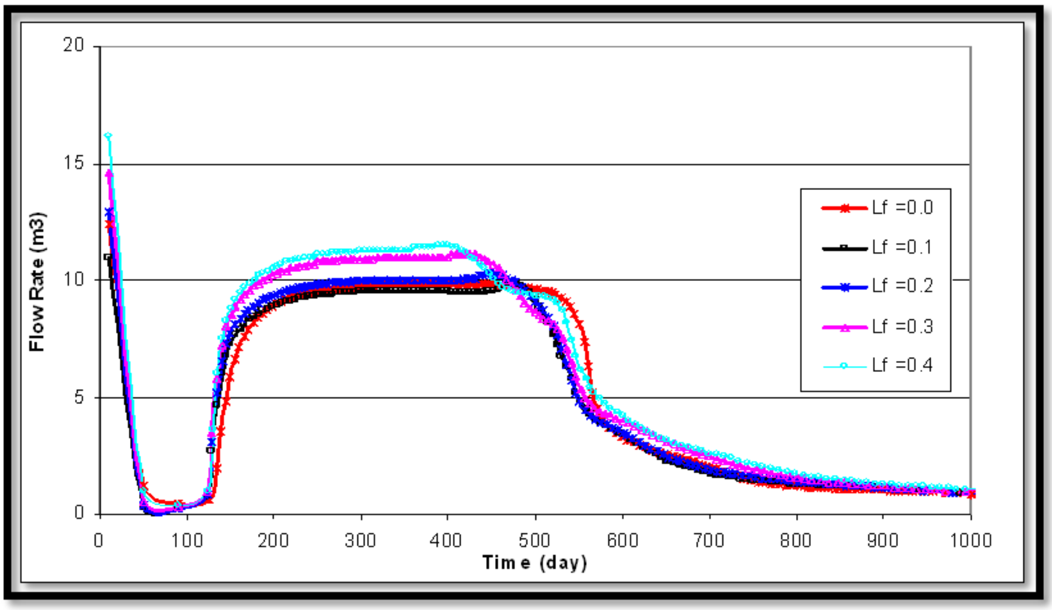


Fig (4-15-a) Effect of Fracture Length on Well Productivity for Well No. 5

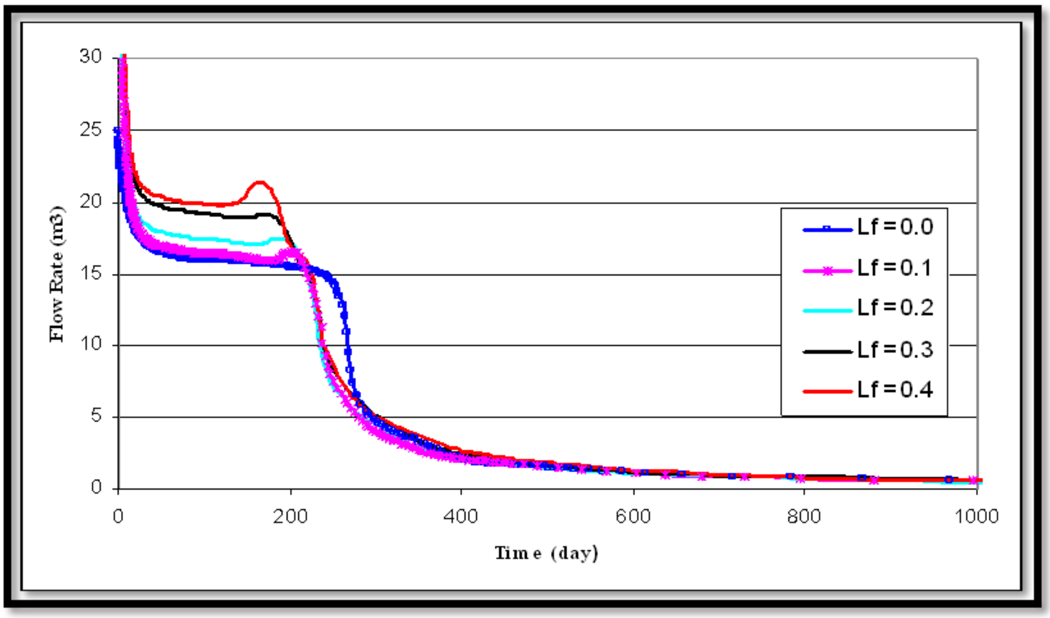


Fig (4-15-b) Effect of Fracture Length on Well Productivity for Well No. 5 - Water Well with 30 % Fracture

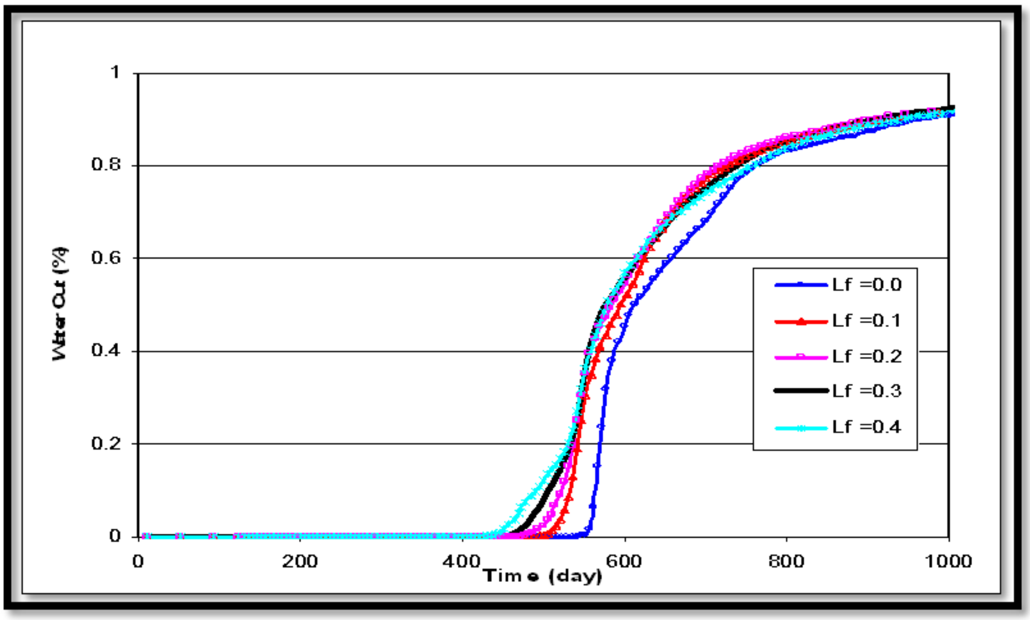


Fig (4-16-a) Effect of fracture Length on Water cut for Well No. 5

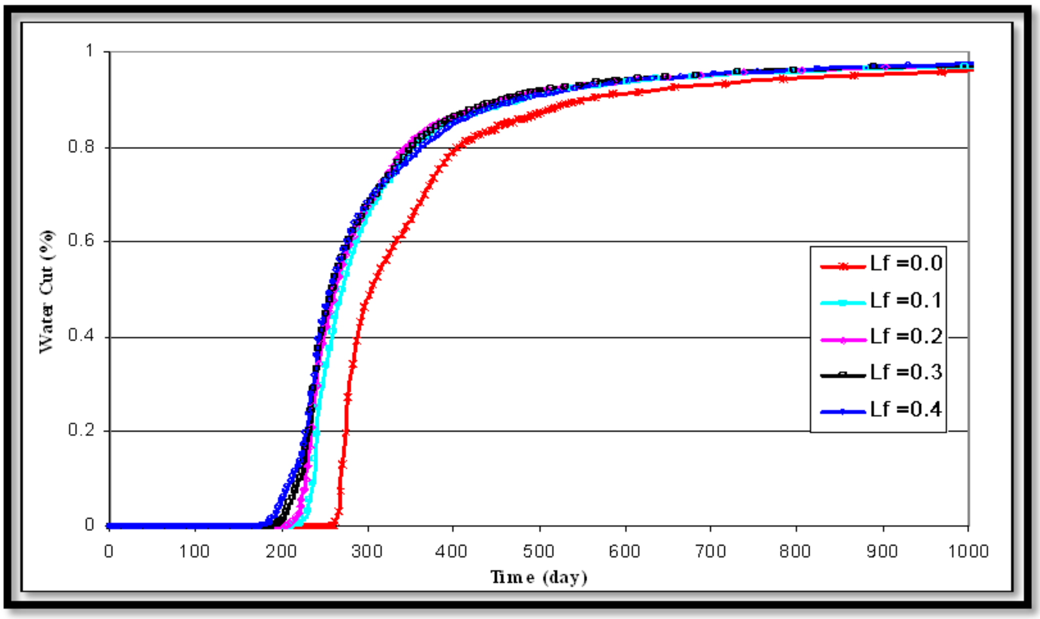


Fig (4-16-b) Effect of fracture Length on Water cut for Well No. 5

4.3. Effect of Fracture Length on Well Injectivity:

Fig (4-17) and Fig (4-18) presented the effect of fracture length on both delay injection rate and the cumulative injection rate respectively for Well No. 1 in Fig (4-6) (the case of fracture angle of 0 degree). From these figure it can be observed that as fracture length increases the injectivity is rise increasing, however, the effect of fracture length of 0.4% is equivalent to the effect of 0.3%. While small different was observed between fracture length of 0.3% and 0.2% and 0.1%, which indicates that the fracture has impact on oil recovery.

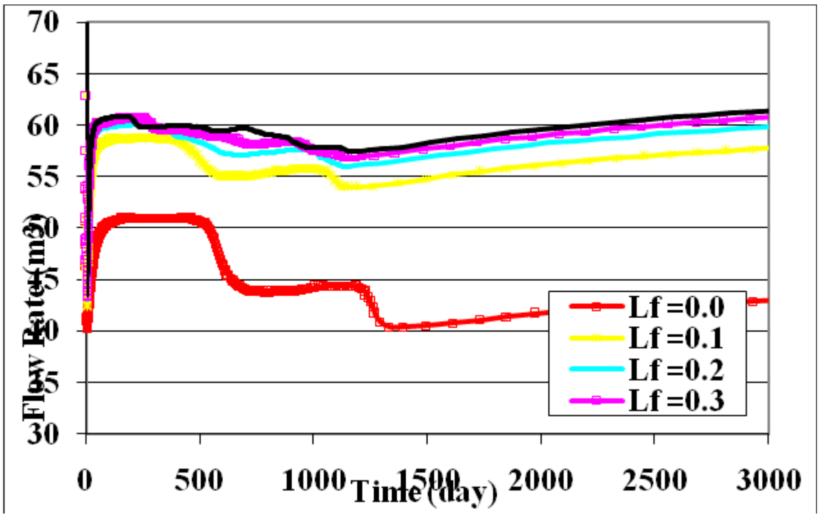


Fig (4-17) Effect of fracture Length on Water Injection Rate for Well No. 1

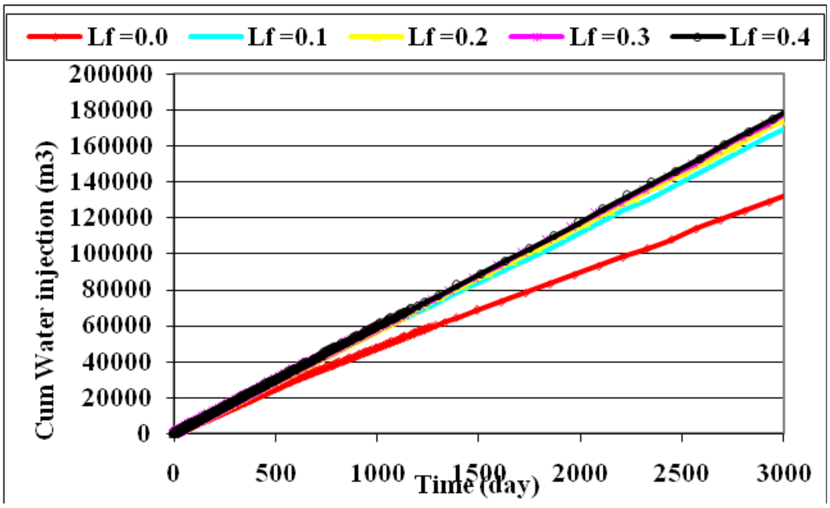


Fig (4-18) Effect of fracture Length on Cumulative Water Injection for Well No. 1

Chapter 5

Conclusions

The study presented the effect of fracture length on well productivity and injectivity for inverted nine spot pattern with fracture angle of 0 degree and 45 degree; from the study the following conclusions are made:

The breakthrough time can occur early for wells with unfavorable fracture and the free water period decreases with the increments of fracture length.

Well with favorable fracture can achieve a good recovery improvement; however the long fracture may not consider the optimum fracture.

Inverted nine spot with fracture angle of 0 degree have only one well of unfavorable fracture in the well network; while two wells with unfavorable fracture were found in the case fracture angle of 45 degree.

Although the fracture length can improve the injectivity of the wells, however it can decreases the productivity of the production wells which are in the direction of the fracture.

To have a favorable fracture, the wells which in the direction of water injection well have to be remained without fracture.

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