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-THÈME-

PERFORMANCE OF A HORIZONTAL WELL

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Abstract

The study of the flow behaviour of the fluid (oil or gas) in a horizontal drain is very important for the operation and management of so-called non-economic reservoirs. Since the contact between porous rock and horizontal drain is much greater than in a conventional well, then the impact of the flow field inside the drain is very significant on the total output of a well. As well The study of the performance of the horizontal wells is of major importance for the exploitation and the management of the not economic reservoirs. Considering the contact between the porous rocks and the horizontal well much more significant than in a conventional well, then the flow inside the well is very meaning compared to the production of oil reservoir or gas, especially in the mature fields. Several parameters act directly on the performance of a horizontal well should be studied. Horizontal wells afford a variety of options that a vertical ones couldn’t give because the multiple types of wells and the different available drilling processes, a technical study regarding different parameters such as the skin factor, productivity index, drainage surface .. etc shows a greater performance on the horizontal side, moreover on the economical side the horizontal technique is a formidable found solution for many companies that work in fields under contract as it comes in handy when timing is a valuable parameter. Therefore, in this work, we studied the technical performance of horizontal wells compared to vertical stimulated by highlighting the various parameters that affect productivity such as the length of the drain, vertical permeability, thickness of reservoir, damage training ... etc. Arguing with well chosen case studies. Also the economic assessment in which we compared the cost price and the damping time (POT) of the two types of drilling (horizontal and vertical)

Keywords: Performance Study, Horizontal Drain, Flow States, Influence, Horizontal well

Résumé

L'étude du comportement d'écoulement du fluide (pétrole ou gaz) dans un drain horizontal est très importante pour l'exploitation et la gestion des réservoirs dits non économiques. Le contact entre la roche poreuse et le drain horizontal étant beaucoup plus important que dans un puits conventionnel, alors l'impact du champ d'écoulement à l'intérieur du drain est très important sur le rendement total d'un puits. Aussi bien L'étude de la performance des puits horizontaux est d'une importance majeure pour l'exploitation et la gestion des réservoirs non économiques. Considérant le contact entre les roches poreuses et le puits horizontal beaucoup plus important que dans un puits conventionnel, alors le débit à l'intérieur du puits est très significatif par rapport à la production de gisement de pétrole ou de gaz, surtout dans les champs matures. Plusieurs paramètres agissant directement sur les performances d'un puits horizontal doivent être étudiés. Les puits horizontaux offrent une variété d'options que les puits verticaux ne pourraient pas offrir en raison des multiples types de puits et des différents procédés de forage disponibles, une étude technique concernant différents paramètres tels que le facteur de peau, l'indice de productivité, la surface de drainage … etc montre un une plus grande performance du côté horizontal, de plus du côté économique la technique horizontale est une formidable solution trouvée pour de nombreuses entreprises qui travaillent dans des domaines sous contrat car elle est pratique lorsque le timing est un paramètre précieux. Ainsi, dans ce travail, nous avons étudié les performances techniques des puits horizontaux par rapport aux verticales stimulées en mettant en évidence les différents paramètres qui influent sur la productivité tels que la longueur du drain, la perméabilité verticale, l'épaisseur du réservoir, l'endommagement de la formation...etc. Argumenter avec des études de cas bien choisies. Aussi le bilan économique, dans lequel nous avons comparé le prix de revient et le temps d'amortissement (POT) des deux types de forage (horizontal et vertical)

Mots clés : Etude de performance, Drain horizontal, Etats d'écoulement, Influence, Puits horizontal

ملخص

تعتبر دراسة سلوك تدفق السائل (النفط أو الغاز) في الصرف الأفقي مهمة جدًا لتشغيل وإدارة ما يسمى بالخزانات غير الاقتصادية. نظرًا لأن الاتصال بين الصخور المسامية والصرف الأفقي أكبر بكثير مما هو عليه في البئر التقليدية ، فإن تأثير حقل التدفق داخل الصرف يكون مهمًا جدًا على الناتج الإجمالي للبئر. كذلك تعتبر دراسة أداء الآبار الأفقية ذات أهمية كبرى لاستغلال وإدارة الخزانات غير الاقتصادية. بالنظر إلى التلامس بين الصخور المسامية والبئر الأفقي أكثر أهمية من البئر التقليدي ، فإن التدفق داخل البئر له معنى كبير مقارنة بإنتاج مكمن النفط أو الغاز ، خاصة في الحقول الناضجة. يجب دراسة العديد من المعلمات التي تعمل مباشرة على أداء البئر الأفقي .توفر الآبار الأفقية مجموعة متنوعة من الخيارات التي لا يمكن للآبار الرأسية تقديمها بسبب الأنواع المتعددة من الآبار وعمليات الحفر المختلفة المتاحة ، ودراسة فنية تتعلق بالمعايير المختلفة مثل عامل الجلد ، ومؤشر الإنتاجية ، وسطح الصرف ... إلخ. أداء أفضل على الجانب الأفقي ، علاوة على ذلك ، من الناحية الاقتصادية ، تعد التقنية الأفقية حلاً هائلاً تم العثور عليه للعديد من الشركات التي تعمل في المجالات بموجب عقد لأنها تكون في متناول اليد عندما يكون التوقيت معلمة قيمة. لذلك درسنا في هذا العمل تحفيز الأداء الفني للآبار الأفقية مقارنة بالرأسية من خلال إبراز العوامل المختلفة التي تؤثر على الإنتاجية مثل طول الصرف ، والنفاذية الرأسية ، وسمك الخزان ، والتدريب على التلف ... إلخ. و كذلك التقييم الاقتصادي الذي قمنا فيه بمقارنة سعر التكلفة ووقت التخميد (POT) لنوعي الحفر (الأفقي والعمودي)

الكلمة المفتاحية: دراسة الأداء, الصرف الأفقي, حالات التدفق, التأثير, البئر الأفقي

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Dedication

We dedicate this modest work to our parents, no tribute could be to the height without the love they never cease to fill us with, with all ourgratitude for their unlimited patience, their continued encouragement, their tremendous help and their great sacrifice. That god gives them good health and long life. To our brothers and my sisters.

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List of figures

- **Fig.1 :** "Fractured reservoir." .... (5)
- **Fig.2 :** "Multi-layer reservoir." .... (6)
- **Fig.3 :** "Water conning." .... (7)
- **Fig.4 :** "Horizontal well." .... (10)
- **Fig.5 :** "Types of wells." .... (11)
- **Fig.6 :** "Classification of horizontal wells." .... (12)
- **Fig.7 :** "Multilateral wells." .... (13)
- **Fig.8 :** "Inclined well." .... (13)
- **Fig.9 :** "Completion of horizontal wells." .... (16)
- **Fig.10 :** "Formation-well relationship by perforation (vertical well)." .... (17)
- **Fig.11 :** "Test on reservoir rock samples." .... (21)
- **Fig.12 :** "Drainage section for both types of wells." .... (22)
- **Fig.13 :** "evolution of the drainage surface with length." .... (23)
- **Fig.14 :** "the relativity of the length of the drain." .... (24)
- **Fig.15 :** "influence of drain length on the efficiency (Jh/Jv)." .... (25)
- **Fig.16 :** "turbulence phenomenon in the two types of wells." .... (26)
- **Fig.17 :** "Evolution of the cumulative production of the two wells." .... (30)

List of tables

- **Table 1:** “influence of skin on the efficiency of horizontal wells.” ………………………………… (21)
- **Table 2:** “evolution of the drainage surface with the length.” …………………………………….. (23)
- **Table 3:** “influence of the length of the drain on the efficiency (Jh / Jv).” ……………………… (25)
- **Table 4:** “Evolution of the cumulative production of the two wells.” …………………………… (29)

Abreviations list

- **MWD:** Measurement While Drilling.
- **HMD:** HassiMessaoud.
- **LD2:** Lactate dehydrogenase
- **ft:** Feet
- **Fig:** Figure
- **Ip:** Productivity index of a horizontal well.
- **Qp:** The flow of a horizontal well.
- **ΔP:** Pressure difference.
- **h:** producing height, ft
- **(ΔP) skin:** the pressure drop due to damage, psi
- **Q:** STB / day flow μ: viscosity, cp
- **B:** the volumetric factor, RB / STB
- **μo:** oil viscosity; cp
- **Sh :**horizontal well drainage section, ft^2.
- **r :**vertical shaft drainage radius, ft.
- **L :**length of horizontal well, ft.
- **K:** permeability, md
- **Kh:** horizontal permeability; md
- **Kv:** vertical permeability; md
- **POT:** Pay out time
- **rw:** radius of the well; ft
- **re:** drainage radius; ft
- **Ih:** Horizontal productivity index
- **Iv:** Vertical productivity index
- **Ih/Iv:** Efficiency
- **Sw:** Water saturation
- **So:** Oil saturation

Table of Contents

General introduction **1**
Chapter I **2**
1.1 Introduction **3**
1.2 Trajectories of wells **3**
1.2.1 Applications of directional drilling **3**
1.2.2 Profiles of directional drilling **4**
1.3 Horizonal drilling **4**
1.3.1 Introdcution **4**
1.3.2 Objectives of horizontal drilling **5**
1.3.1 Advantages and disadvantages of horizontal drilling **5**
1.4 The problems encountred during drilling **8**
Chapter II **9**
2.1 Introduction **10**
2.2 Definition of a horizontal well **10**
2.3 Types of wells **11**
2.4 Classification of horizontal wells **11**
2.4.1 Ultra Short Radius **11**
2.4.2 Short Radius **12**
2.4.3 Medium Radius **12**
2.4.4 Long Radius **12**
2.4.5 Multilateral Wells **13**
2.4.6 Inclined Well **13**
2.5 The reason of horizontal wells **14**
2.6 The advantages and disadvantages of horizontal wells **14**
2.6.1 Advantages **14**
2.6.1 Disadvatnages **14**
2.7 Completion **15**
2.8 Perforation **16**
2.8.1 Perforation techniques **16**

2.8.2 Perforation process **17**
Chapter III **18**
3.1 Performance parameters **19**
3.2 Influence of skin on productivity **20**
3.3 The drainage surface **22**
3.3.1 Influence of the length of the drain **22**
3.3.2 Influence of the length of the drain and the thickness of the layer **24**
3.4 Gas reservoirs **26**
Chapter IV **27**
4.1 Setting a plan **28**
4.1.1 Calculation of reserves in place **28**
4.1.2 Volume to be recovered to deplete the tank **28**
4.2 Economic calculation **30**
General conclusion **32**
Bibliography **35**

General Introduction

A horizontal well is drilled parallel to the reservoir bedding plane, whereas a vertical well intersects the reservoir bedding plane at 90 degrees. A slant well would be one tha tintersects the reservoir at an angle

Multilateral well drilling involves the drilling of two or more horizontal production holes from a single surface location

The normal objective of both horizontal and multilateral wells is to produce more oil or gas from a well and to reduce the overall cost of producing each barrel of oil or eachcubic foot of gas.

Generally, the productivity of a horizontal well is two to five times more than the productivity of a vertical well. This productivity improvement occurs because of the contact area between the reservoir and the well. Oil and gas reservoirs generally vary in thickness from 20 ft to 300 ft (6 to 90 m). Thus, with a conventional vertical well, the contact area between the well and the reservoir is 20 ft to 300 ft (6 to 90 m), depending upon the reservoir thickness [1].

In a horizontal well, a typical well length is 2000 ft to 3000 ft (600 to 900 m) long, resulting in a very long contact area between the well and the reservoir. Hence, a horizontal well provides 10 to 200 times more contact area with the reservoir than the contact area provided by a vertical well. This large contact area results in higher well productivity for horizontal wells as compared to vertical wells.

In this project we'll study the horizontal wells in a bit more detailed way to evaluate and examinate the performance of the horizontal wells compared to the vertical ones, either it's better or worse and in which way and side. First & second chapters " Brief overview about the horizontal technique" Types of wells & drillings … etc

Third chapter " Technical study " enlighting the important parameters of production. Fourth chapter "Economical study" studying both cost price and pay out time.

At last we'll come to conclude either the horizontal technique is much more recommended than the vertical one or not, which technique could be better for general cases, and in which way is the petroleum science is going to develope the next years.

Chapter I

Horizontal **D**rilling **O**verview

1.1 Introduction :

First, we will briefly review the principle and constitution of most commonly used drilling systems today (rotary drilling).

The principle of rotary drilling involves rotating a tool to which a force is applied oriented in the direction of progress. This process makes it possible to dig a hole with a radius equal to that of the tool. The chips (cutting) generated at the bottom of the hole following the destruction of the rockby the tool continuously rise to the surface thanks to the circulation of the drilling fluid which isusually a water or oil based bentonic mud. This fluid is pumped from the surface in the drill pipes to be injected through the tool on the cutting face. The sludge then rises in the annular space between the rods and the walls of the well and thus causes rock chips to the surface. The torque is obtained either from a torque insurface transmitted to the tool via a drill string or from a downhole motor above of the tool and controlled on the surface [2].

1.2 Trajectories of wells:

In the past, all wells drilled were vertical. But to hit targets of increasingly rare and less and less accessible (for geographical reasons, to pographic, geological, etc.) and thanks to increasingly sophisticated techniques, directional (or directional) drilling has become very common and essential these days.

- **Vertical drilling:** Most used in the past (Old system).
- **Directional drilling:** From the nineties, this type of drilling found its development technological in several applications such as long offset wells horizontal drilling and multilateral drilling in several stages.

1.2.1 Applications of directional drilling:

They are numerous and more and more numerous. Among the main ones we can mention:

- Relief well
- Side-track drilling
- Directional drilling for geological reasons
- Impassable surface locations

- Multi-well production platforms
- Multilateral wells.

Outside the oil industry, directional drilling is used for the installation of cables and ducts under water ways and roads for telecommunications, electricity, fibers optics, gas, fuel oil, water supply lines and sewer lines [3].

1.2.2 Profiles of directional drilling

The shape of a well between the surface and the target (s) is called the well profile. The classic profiles:

- J-well
- S-shaped well
- Double rise well
- Horizontal wells
- Long reach wells
- Wells inclined from the surface
- Re-entry well
- Multilateral wells.

1.3 Horizontal drilling :

1.3.1 Introduction:

Horizontal drilling is a set of engineering and operations which consists of drill a section of a well inclined or sub-inclined relative to the vertical until you reach a desired target.

This type of drilling is used to improve the productivity of the reservoir, i.e. to considerably increase the contact surface between the tank and the column of production. It is also a good candidate for vertical fracture reservoirs or multilayer tanks since a single horizontal well can replace several wells vertical. Other than these advantages on the productivity of the reservoir, it allows the resolution of acertain problems such as the inaccessibility of the city (mountain), drilling near the salt domes, presence of fault, etc. ...

Horizontal drilling is also among the most developed techniques in the oil drilling field at HMD.

1.3.2 Objectives of horizontal drilling:

Horizontal drilling makes it possible to:

- Develop fields that could not have been exploited commercially otherwise.
- Increase production in many reservoirs and improve the rate of
- recovery, this by better drainage and delaying the arrival of water.
- Limit the number of wells drilled in a field.

1.3.3 Advantages and disadvantages of horizontal drilling :

1.3.3.1 Advantages of horizontal drilling :

The advantages of horizontal drilling are numerous and we can cite:

- ✓ horizontal drilling allows the development of fields that could not have been otherwise commercially exploited.
- ✓ in many reservoirs, horizontal drilling increases the production but also to improve the recovery rate, through better drainage and delaying the water supply [3].

Horizontal drilling is preferred in the following cases:

- **Fractured reservoirs :**

Fractured reservoirs are among the best candidates for development by horizontal drilling. The fractures of these reservoirs being sub-vertical, a direct consequence is that the best way to intercept the greatest number is to drill a well horizontal perpendicular to their main direction.

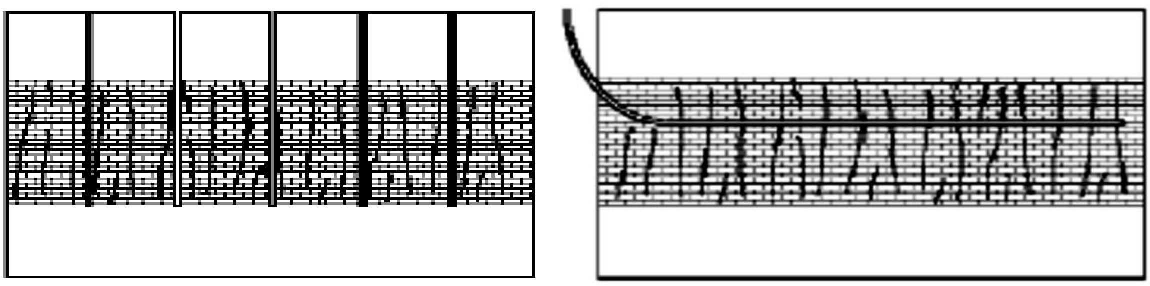


Fig.1 : “Fractured reservoir” [3].

- **Multi-layer reservoirs :**

In most multi-layer reservoirs a horizontal well can replace several vertical or deviated wells.

The figure below illustrates such a case of a compartmentalized reservoir where a single horizontal well replaces six vertical wells and furthermore improves production by delaying conning [4].

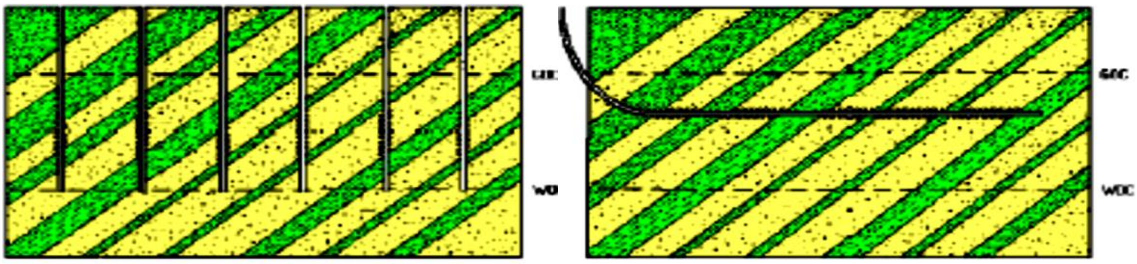


Fig.2 : “Multi-layer reservoir” [4].

- **Low thickness reservoirs :**

In such a reservoir, a vertical well can only have a small penetration into the drain, and the goal of horizontal drilling is to have a greater penetration in order to reduce the number of wells.

- **Low permeability reservoirs :**

Horizontal drilling in a low permeability reservoir is an alternative to fracturing this reservoir.

The horizontal drain behaves like a fracture, with several advantages:

It is easier and more economical to drill a long drain rather than trying to create an equivalent fracture; the steering is perfectly controlled, which is not possible with the fracking.

- **Non-consolidated formation :**

The production of unconsolidated sands presents serious problems in limiting the amount of sand entering the well. This sand production depends on the viscosity forces at the wall of the well, itself proportional to the production flow. A horizontal drain drilled in such a tank allows the velocity to the wall to be reduced and consequently, the production of sand, which can go so far as to be completely eliminated.

- **Gas and water conning :**

Many reservoirs are produced using an active aquifer or by injection artificial. The production will decline very quickly if the water level rises too quickly in well [5].

Horizontal drilling helps enormously in the production of such reservoirs:

- ✓ By increasing the distance between the drain and the oil / water contact;
- ✓ by improving productivity by dispersing the withdrawal and therefore by reducing thesucking on the water.

Similar considerations can be made regarding the gas supply.

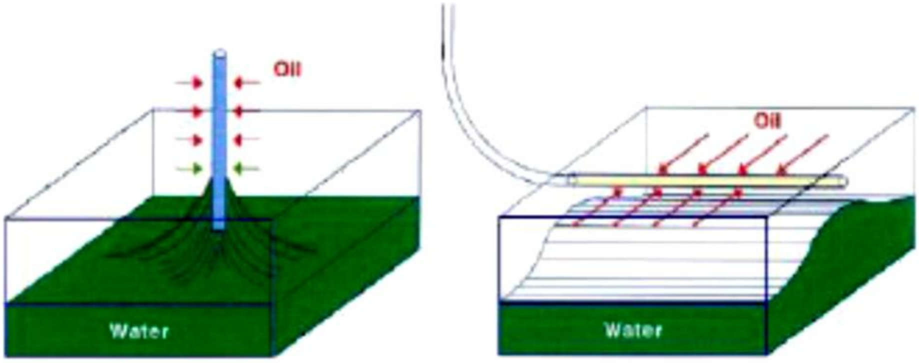


Fig.3 :"Water conning" [5].

- **Heavy oil reservoirs :**

Heavy oil tanks are a direct application of the above considerations. As water is much more mobile than oil, the amount of water increases very quickly from the break through of the body of water. The duration of the waterfree period increases with the help of the boreholehorizontal.

1.3.3.2 Disadvantages of horizontal drilling :

✓ **Additional costs :**

It is obvious that horizontal drilling has a higher cost than vertical drilling or little of life. The additional costs are due to two main factors:

- Horizontal wells are longer, therefore require more time fordrill, more tools, more fluid, etc
- The cost of directional drilling services is not negligible, in particular by the obligation to use a downhole motor and a MWD at all times.

✓ **Operative risks :**

Compared to vertical or slightly deviated wells, horizontal wells represent during their realization, a certain number of additional risks.

- reach the target;
- Cleaning of the well;
- The behavior of the formations;
- Damage to formations;
- The evaluation of the production potential.

1.4 Problems encountred during drilling :

Among the problems encountered during the drilling of wells, in particular those drilling in horizontal, we can cite:

- **Risk of deviation:**

Risks of deviation may exist because this formation is very friable.

- **Fluent salts:**

Drill string jams are observed in the Sénonien Lagunaire Saliferous (672 - 815 m). Fluent salts constrict the walls of the hole. Usually This type of jamming is encountered at each end of phase 16 "and this during the raising of the lining.

- **Landslides and excavations:**

The risk of land slides and the formation of cavities may appear in the limestone and clay formations of the Mio-Pliocene and Eocene, in soluble massive saltsin the water of the Sénonien Lagunaire.

- **Inflows of chlorinated calcium water from LD2:**

At the level of LD2, there is a risk of the arrival of calcium chloride water trapped in LD2 dolomites, under a pressure of 549 bar.

Chapter II

Horizontal **W**ells **O**verview

2.1. Introduction :

The idea of drilling Horizontal drains had been around for a long time, the first well dates back to 1940, with the rapid development of drilling technologies this type of well to find its place and participate enormously in the extraction of Hydrocarbons remaining inaccessible.

This section discusses the different horizontal and deviated wells. These new technologies have for the purpose of better recovery of inaccessible Hydrocarbons, of which we briefly discusses conventional and unconventional types of drilling, as well well completions [6].

2.2. Definition of a horizontal well:

Typically, horizontal wells are drilled vertically from the surface to a predetermined depth, this is the vertical section and deflected from a point called "kickoff point "with a radius of curvature R which differs from one type to another, then directed horizontally in the tank, this is the drain [7].

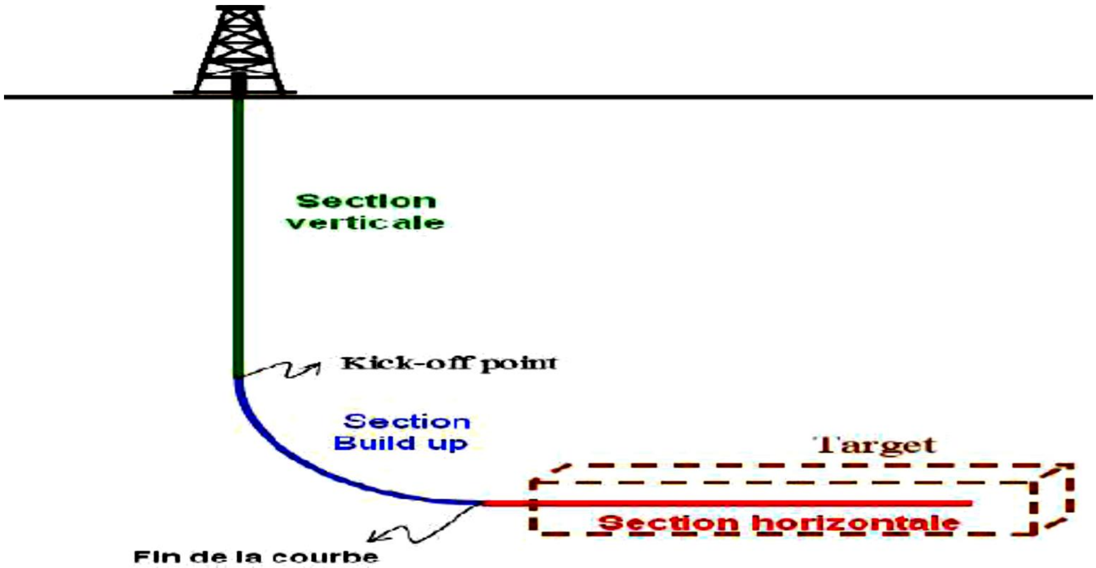


Fig.4 :“Horizontal well” [7].

2.3. Types of wells:

We can cite the following types of wells :

- Vertical (conventional drilling)
- Partially deviated ‘Slant‘
- Directional (multi drains)
- Horizontal (90 ° inclination)

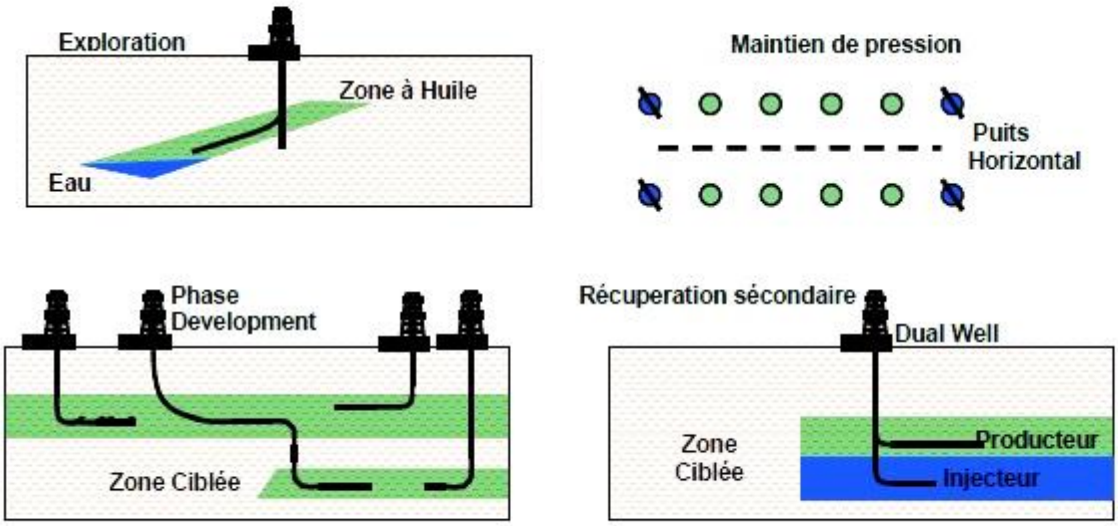


Fig.5 :“Types of wells” [8].

2.4.Classification of horizontal wells:

Horizontal wells are subdivided intoseveral categories which are:

2.4.1 Ultra short radius :

These wells have a drain length of less than 200 ft, with a build up rate of 45 to ,60 ° /ft, a tubing radius of 1.25 to 2.5 inches and a bend radius of 1 to 2 ft. This type of well requires specific equipment such as articulated fittings. it is drilled by water jets and generally used for the injection of water vapor. Due to its small length and small diameter, it is completed as a pre slotted liner perforated or gravel packed. In this type of well, it is not possible to sample or logging [9].

2.4.2 Short radius :

This type has a tubing radius of 4 ¾ to 6 inches and a bend radius of between 20 and 40 ft. The length of the drain varies between 250 and 450ft and its build up rate between 2 and5 ° / ft. The first wells were drilled using flexible rods to facilitatethe operation, but currently we use the MWD with a "down hole mud motor" whichallow better control of the trajectory. They can be diverted from a cased or uncased vertical well. They are completed as an open hole or with a slotted liner. In that case sampling and logging is not possible.

2.4.3 Medium radius

The length of the drain of this well varies between 500 and 3000 ft with a radius of curvaturefrom 300 to 700 ft respectively and a build up rate of 8 to 20° / 100 ft. Its deflection radiusmakes it easier for us to descend from the casing and gives us the opportunity to intervene on the bottom. All types of completion are possible. Logging, sampling and stimulation can also take place.

2.4.4 Long radius

This type of well has a radius of curvature of 1000 to 3000 ft with a length of the drainfrom 1000 to 4000 ft and a build up rate of 1 to 6 ° / 100ft. All types of completion as well as logging, sampling and stimulation are achievable. They allow the use of all conventional drilling procedures. In this type of well, drilling with standard equipment and for wells without restriction of diameters is possible.

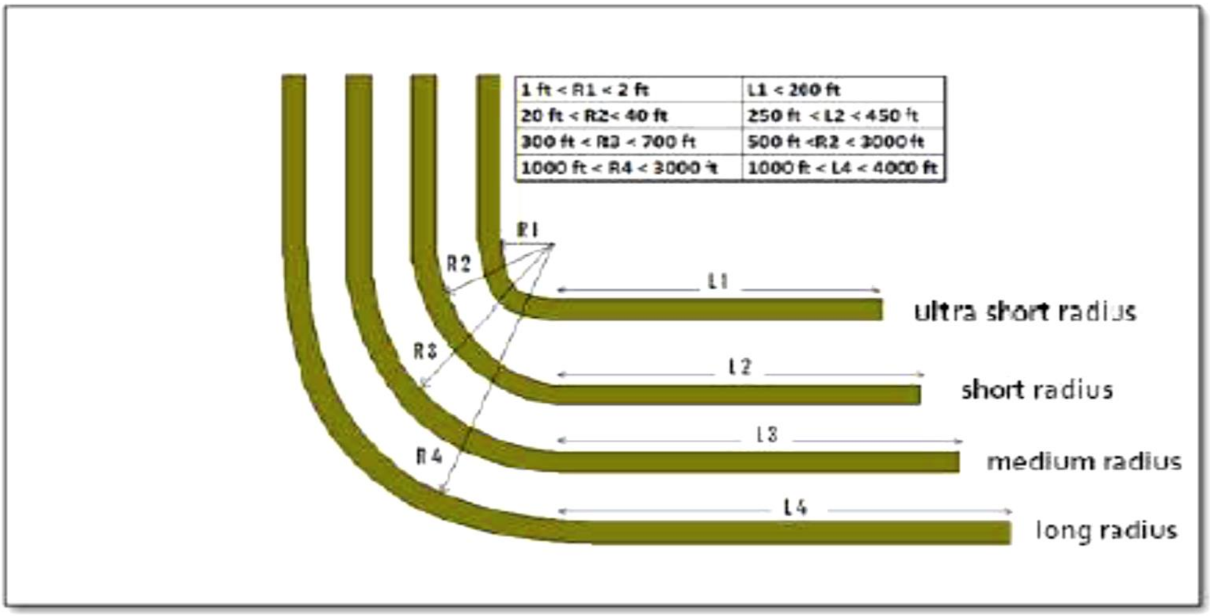


Fig.6 :"Classification of horizontal wells" [8].

2.4.5 Multilateral wells :

These are a development of horizontal drilling. They consist of drilling several drainshorizontal from a single drain which can be vertical, deflected or horizontal.

These wells allow multiple layers to be exploited by drilling a single well on the surface. So they are applicable for the operation of layered tanks [10].

There are many types of multilateral sinks, but we will cite only two examples:

• A vertical well with horizontal branches.

• A well called “fishbone” having several drilled lateral branches alternately from a main drain.

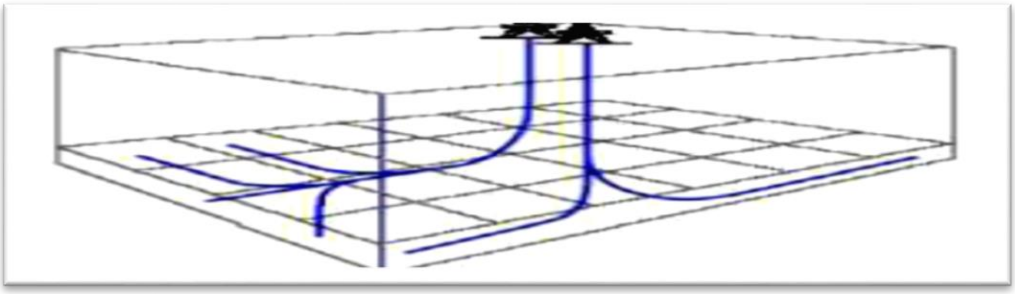


Fig.7 :“Multilateral wells” [10].

2.4.6 Inclined wells :

It is a well drilled with a slope from the surface. This type requires a special drilling device called a "tilt or slant rig" on the surface. The angle of inclination varies from one well to another and can reach the maximum with 45 degrees

The use of inclined wells makes it possible to exploit shallow horizons.

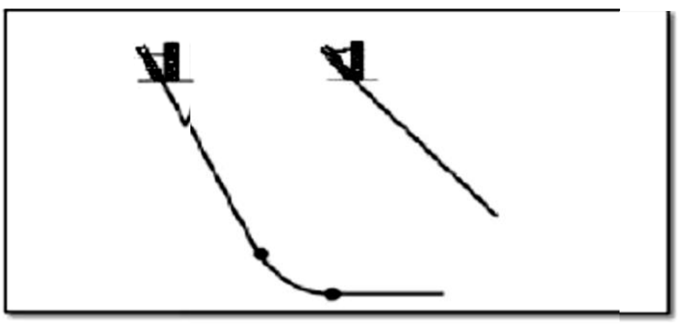


Fig.8 :“Inclined well” [8].

2.5. The reason of Horizontal wells :

- Have a productivity of 3 to 5 times that of a vertical well.
- Reduce the inflow of Gas and Water.
- Cross the maximum surface area in the formation (maximum volumein the tank) and therefore a larger drainage radius.
- Increase the recovery rate by crossing regions and strataisolated and not accessible.
- Increase the rate of injectivity (polymers, steam, gas ..., etc.) [11].

2.6. The advantages and disadvantages of horizontal wells:

2.6.1 Advantages

- Allows the development of a field that cannot be exploited commercially (low permeability reservoirs) through vertical wells.
- Allows an increase in production, and this, by increasing the surface ofcontact.
- Improve the rate of recovery of reserves with better drainage of the productive layer.
- Allows the speed of the fluid to be reduced, thus reducing the occurrence of sand and the phenomenon turbulence (especially in the high permeability gas field).
- They can be applied in assisted recovery especially for recovery thermal.
- Reduce water and gas coning problems [11].

2.6.2 Disadvantages:

2.6.2.1. The additional cost:

The cost of horizontal drilling is greater than vertical drilling since the time drilling is important and the drain requires more tools, and the use of a motor MWD for trajectory control. The additional cost is proportional to the depth and type of completion and its position (onshore, offshore).

2.6.2.2. operational risks :

Horizontal wells present an operational risk during their constructionand additional difficulties:

- To reach the target:It is usually very difficult to target the diaper with a narrow tolerance.
- Cleaning of the well. During drilling, we can have the accumulation of cuttings in the horizontal part, therefore, it is necessary to have a fluid which ensures the rise of these last to the surface to have a good cleaning.
- The behavior of formations and their instabilities. Behavior varies depending on the formation and instability of horizontal drainspose a lot of problems in unconsolidated formations.
- The stability of some formations decreases sharply when the inclination increases [12].

2.7. Completion :

The choice of the type of completion plays a very important role in the performance of horizontal wells.

Before completing the well with one of the completions mentioned above, there ismany parameters to take into consideration:

- The nature of the rocks and the formation: the well is completed as an open hole,the engineer must be sure that the formation is stable and does not produce sand. Experience has shown that wells drilled in the direction of horizontal stress minimum are very stable.

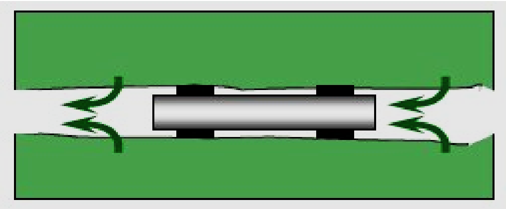
- The nature of the fluids in place: for gas fields with high permeability or high viscosity oil deposits, the well must be completed in such a way as to maximize production by avoiding the phenomenon of turbulence by controlling the flow rate production (the size of the slots for a slotted liner or the length of theperforated in the LCP).

- The supply of the deposit: for deposits fed by an aquifer or agas cap we must complete the drain so as to isolate the areas likely to have break throughs.

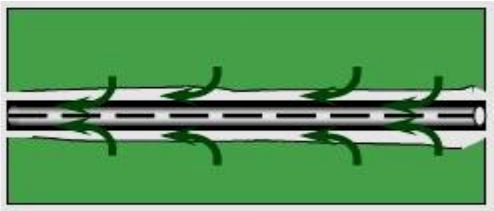
- Type of drilling: for an ultra short radius or short radius well, it is completed by open hole or with a slotted liner, while for the medium and long radius, it is possible to use all types of completion [13].

- Drilling fluid: damage to the formation in horizontal wells is abig problem especially in low permeability formations because of time high exposure (large invasion compared to verticals), so the well must be cleaned, which is not possible in open hole (short radius) and difficult in slotted liner, on the other hand in the medium and long radius cleaning is possible with a toolcalled "swabtool".

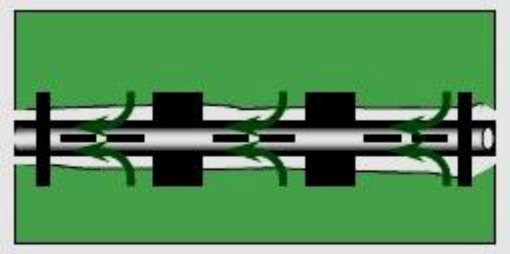
- Stimulation: if you plan to fracture the well, it is preferable to use an LCP to facilitate the fracturing operation using insulators with plugs [14].



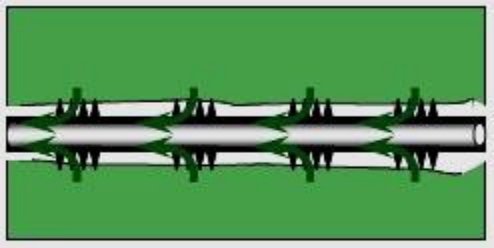
"Open Hole"



" Perforated tubing"



"Liner with ECP"



"Cemented, Cased and perforated"

Fig.9 :"Completion of horizontal wells" [13].

2.8 Perforation:

2.8 1 Perforation techniques:

A good completion amounts to saying: make a good perforation. The perforation is the technique of creating a formation-well relationship in theaim to produce over a long period with better performance. Each cased and cemented well is subject to perforation, to allow the fluid to flow from training to the surface, a 'design' pre-job must be planned andoptimized to have a clean tunnel and conductive perforation [15].

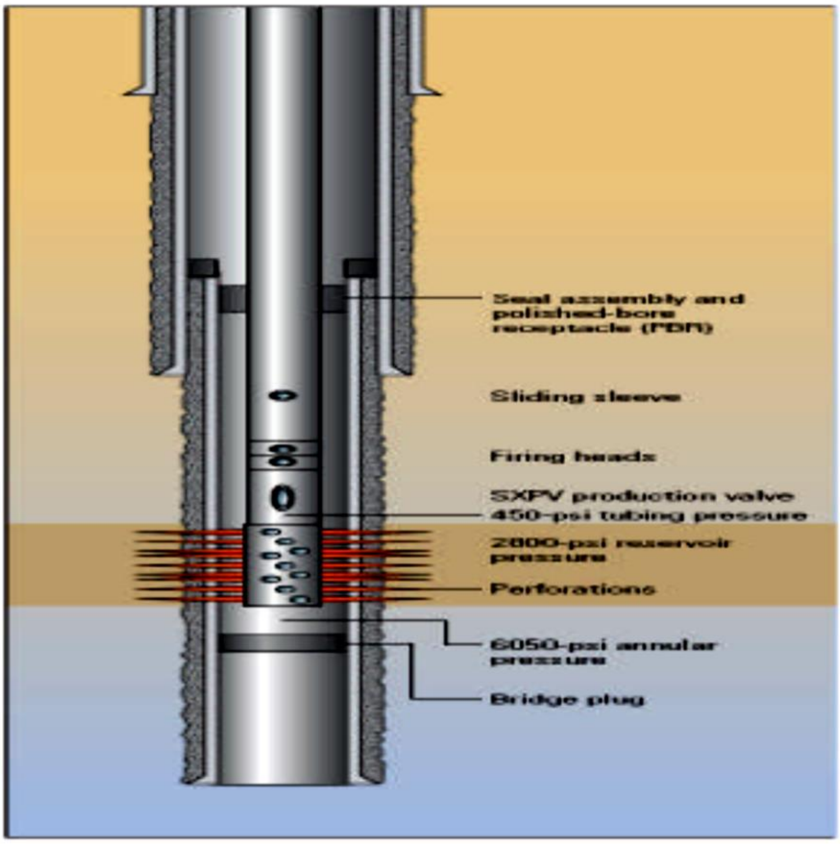


Fig.10 :“Formation-well relationship by perforation (vertical well)” [15].

2.8.2 Perforation process:

The figure below illustrates the sequences of perforation with shaped charges, it is a perforation with explosives among others (there are several modes and types of perforation in the oil industry), this type of perforation has itsdrawbacks: it damages the formation, and leaves explosive debris which reduce the permeability and promote the occurrence of sand especially inunconsolidated tanks. The figures below illustrate the sequences of a detonation to create a tunnel, thus a typical perforation.

Chapter III

Technical **S**tudy **O**f **H**orizontal **W**ells **P**erformance

3.1 Performance parameters :

The performance of horizontal versus vertical wells can be studied byone of these two parameters :

- **The productivity index :**

The essential goal of horizontal drilling is to obtain the productivity gain on each well. **[16]** The productivity index designates the ratio between the flow rate produced by the well and the withdrawal pressure applied to this well compared to the average pressure of the deposit. The expression of the productivity index is given as follows: **Ip = Q /ΔP.**

Ip: Productivity index of a horizontal well.

Qp: The flow of a horizontal well.

ΔP: Pressure difference.

In the study of performance, what interests us is the efficiency expressed by **(Ih / Iv).**

- **Equivalent skin :**

The actual downhole pressure is lower than that calculated theoretically because of a pressure drop around the well. In addition, this pressure drop does not depend on the weather, they then found that it is due to the decrease in permeability in the area near the well caused **by** damage during drilling, this is what they called the “skin factor” or the effect damage. It is defined as follows:

$$S = k\,h\,(\Delta P)_{skin} / (141{,}2.\ Q\ .\mu o.Bo)$$

As :

k: permeability, md

h: producing height, ft

(ΔP) skin: the pressure drop due to damage, psi

Q: STB / day flow μ: viscosity, cp

Bo: the volumetric factor, RB / STB

- **Flow states:**

Typically, there are three flow states in the reservoir that one should know in order to describe the behavior of the flow and the distribution of pressure as a function of time [16], these states are:

- ***The transitional state***
- ***The steady state: i***n this state, the pressure in any point of the reservoir remains constant (does not change with time).$(\partial P/\partial t) = 0$
- ***The pseudo regular state :*** The pressure variation over time at any point in the reservoir is constant $(\partial P/\partial t) = cste$

3.2. Influence of skin on productivity:

As already defined by **Van Everdingen** and Hurst, the skin is the damage that

causes the pressure drop around the well called (ΔP) skin, defined by:

$$(\Delta P)\ skin = S\ (141{,}2\ .Q\ .\mu o.Bo)\ /\ k\ h$$

$$(\Delta P)\ skin = S\ (141{,}2.\mu o.Bo\ /\ k)\ .\ (Q/\ h)\ \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

(Q / h): is the unit production flow rate of a vertical well.

For a horizontal well, the unit flow is (Q / L), and the expression of (ΔP) skin becomes:

$$(\Delta P) skin = S\ (141{,}2.\mu o.Bo\ /\ k)\ .\ (Q/\ L)\ \ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

From the two relations **(1)** and **(2)** we deduce that the pressure drop caused by

the damage in a horizontal well is much smaller than that of a well vertical, i.e. the influence of the skin is much less on horizontal wells than on vertical wells from a productivity standpoint.

For a reservoir of characteristics:

kv = kh = 10md **Bo=1,34 RB/STB** **h = 25 ft**

μo=0,62cp **rw=0,365 ft**

results obtained are illustrated in the following table:

Table 1:"influence of skin on the efficiency of horizontal wells."

L(ft)	S	Qv(STB/day)	Qh(STB/day)	tiPsv(psi)	tiPsh{psi)	Ih/Iv
200	0.5	3150	7437.1695	738.99	218.094996	1.30318173
600	0.5	3150	12242.1419	738.99	119.666937	1.3823768
1000	0.5	3150	16071.1587	738.99	94.2573459	1.4044094
1600	0.5	3150	21483.5214	738.99	78.7505329	1.4182038
2000	0.5	3150	25100.1134	738.99	73.6060825	1.4228402
200	1	3150	7437.1695	1477.98	436.189991	1.53806187
600	1	3150	12242.1419	1477.98	239.333873	1.71213822
1000	1	3150	16071.1587	1477.98	188.514692	1.7636684
1600	1	3150	21483.5214	1477.98	157.501066	1.79666853
2000	1	3150	25100.1134	1477.98	147.212165	1.80789097
200	2	3150	7437.1695	2955.96	872.379982	1.87826572
600	2	3150	12242.1419	2955.96	478.667747	2.25200012
1000	2	3150	16071.1587	2955.96	377.029383	2.37394259

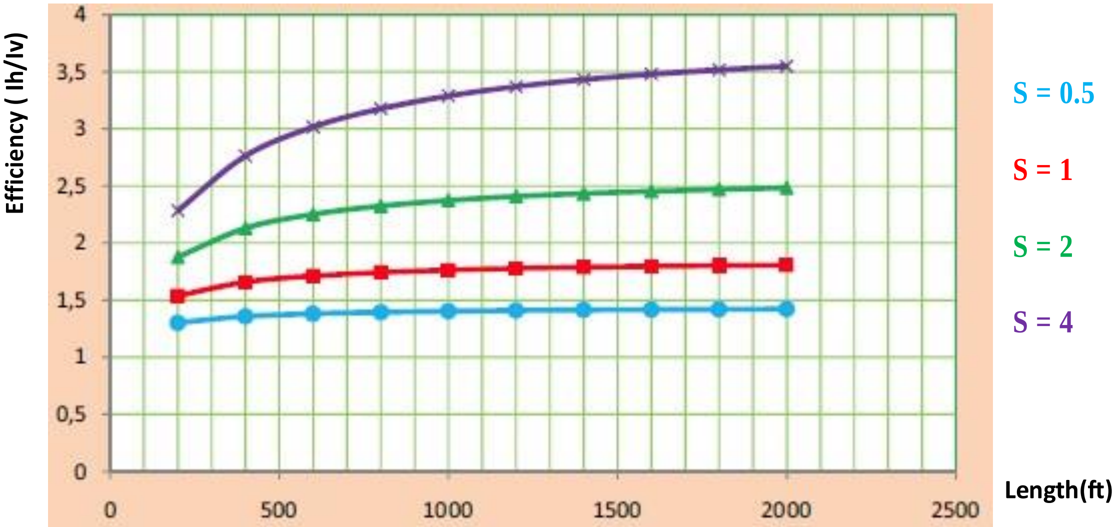


Fig.11:"influence of skin on the efficiency of horizontal wells.

The performance of horizontal wells compared to vertical is all the greater with the increase of the skin {S}. Damage to low permeability formations due to pore clogging and poor self clean up is one reason for the application of horizontal wells in this type of formations

3.3 The drainage surface:

3.3.1 Influence of the length of the drain :

Horizontal wells are able to drain larger areas than wells vertical. Assuming that the drainage surface for a vertical well is circular [17], that of a horizontal well will be as below:

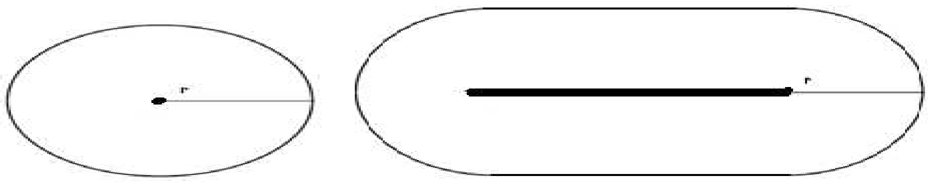


Fig.12 :"Drainage section for both types of wells." [17].

$$\mathbf{Sh = \pi r^2 + 2rl}$$

As :

Sh : horizontal well drainage section; ft^2.

r : vertical shaft drainage radius; ft.

l : length of horizontal well; ft.

The areas drained by a horizontal well as a function of length are shown in the next board:

Table 2:“evolution of the drainage surface with the length.”

L (ft)	Sh (acre)	L (ft)	Sh (acre)
250	48.5601125	2250	116.971499
500	57.1115358	2500	125.522922
750	65.6629591	2750	134.074346
1000	74.2143825	3000	142.625769
1250	82.7658058	3250	151.177192
1500	91.3172291	3500	159.728616
1750	99.8686524	3750	168.280039
2000	108.420076	4000	176.831462

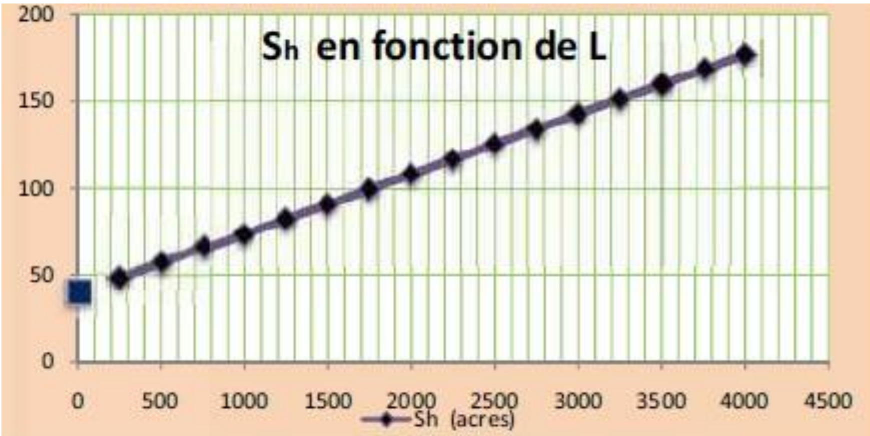


Fig.13 :“evolution of the drainage surface with length.”

The drainage area increases with increasing length of the drain, almost a 1000 ft well can drain twice the area of a vertical and another 2000 ft can drain threetimes the area of the vertical one.

3.3.2 influence of the length of the drain and the thickness of the layer:

The term "long" for a horizontal drain is relative, as it depends on the thickness of the layer. For the same layer 100 ft thick, a 200 ft drain is considered short while another 2000 ft is considered long, in other words the layer is considered thick for the first and thin for the second.

For that, it is necessary to play on the ratio (h / L) or the dimensionless length.

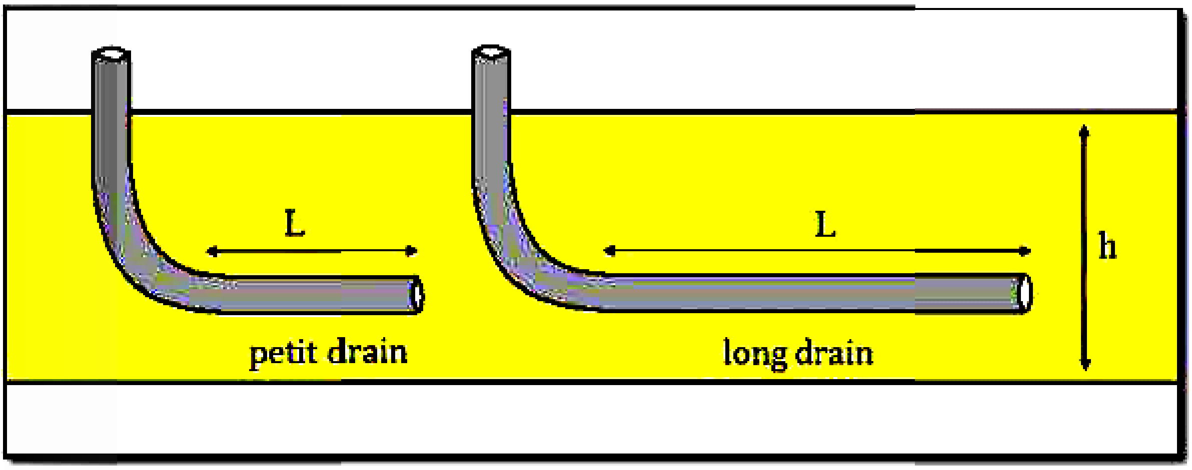


Fig.14 :“the relativity of the length of the drain.”

For a reservoir of characteristics:

kv=kh=75md **Φ=0,038** **μo=0,62cp**

Bo=1,34 RB/STB **rw=0,365 ft** **Sv= 40 acres**

The results obtained are illustrated in the following table :

Table 3:"influence of the length of the drain on the efficiency (Ih / Iv) "

h(ft)	L(ft)	reh(ft)	a(ft)	Ih	Jh(STB/day.psi)	Ih/Iv
25	200	806.181741	809.28872	2.1	4.958113	2.36100619
25	400	863.037079	874.700788	2.1	6.72284331	3.20135396
2	600	916.371649	941.244851	2.1	8.16142791	3.88639424
25	1000	1014.66497	1078.00999	2.1	10.7141058	5.10195515
25	1400	1104.24318	1220.13234	2.1	13.1259607	6.2504575
25	1600	1146.41048	1293.31106	2.1	14.3223476	6.82016551
25	2000	1226.40328	1443.95144	2.1	16.7334089	7.96828996
50	200	806.181741	809.28872	4.2	8.32686767	1.98258754
50	400	863.037079	874.700788	4.2	11.9051199	2.83455236
50	600	916.371649	941.244851	4.2	14.7754335	3.51796035
50	1000	1014.66497	1078.00999	4.2	19.7952685	4.71315916

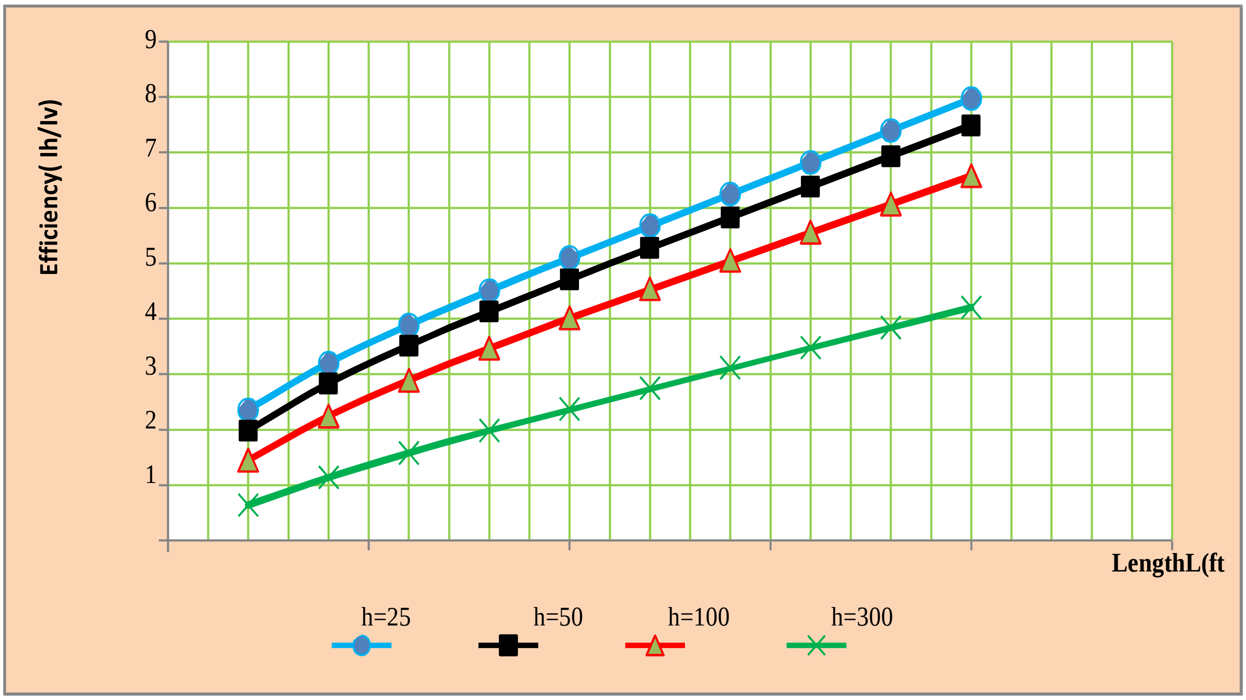


Fig.15 :"influence of drain length on the efficiency (Ih / Iv) of horizontal wells

Horizontal wells become more efficient with the increase in their lengths **{L}.** The productivity of vertical wells increases faster than that of horizontal wells with increasing thickness **{h},** hence the efficiency **" Ih/Iv"** decreases. It is for this reason that horizontal wells are preferred in thin layer

3.4 Gas reservoirs :

Horizontal wells are very applicable in low and high permeability gas reservoirs.

- ***Low permeability gas reservoirs:*** In this case, horizontal wells are a good solution to improve drainage and productivity.
- ***Gas reservoirs with high permeability:*** Horizontal wells are also applicable in gas reservoirs with high permeability to reduce the phenomenon of turbulence caused by the high flow velocity around the well, and this by increasing the penetration interval.

The following figure shows this phenomenon in the two types of wells:

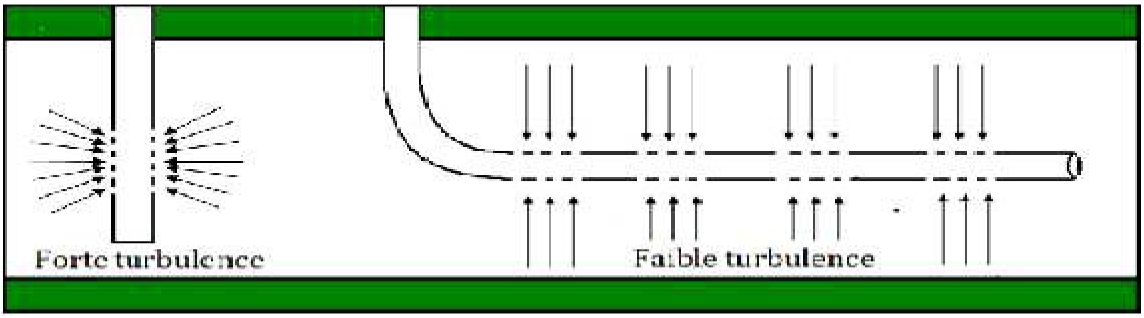


Fig.16 : turbulence phenomenon in the two types of wells [18].

The pressure drop caused by turbulence in a horizontal well is much smaller than that of a vertical well. This drop decreases with the effective length of the drain and increases with the anisotropy [1

Chapter IV

Economic **S**tudy **O**f **H**orizontal **W**ells **P**erformance

4.1 Setting a plan :

We have assumed that we have a reservoir to be exploited with the characteristics following :

X= { 15840 ft , Y= 10560 ft } ⟶ S = 3840 acres

Kh =60 md   Sw = 0,21D   Depth = 3000 m.

Kv = 12 md   Sor = 0,20   h = 120 ft

Bo = 1,2 RB/STB   Φ = 0,11   μo = 0,6 cp

Δρ = 16,26 lb/ft3   Rf = 50% (very active aquifer) the recovery coefficient.

First, we will exploit it with vertical wells each draining 40 acres, for that we need 96 wells.

4.1 1. Calculation of reserves in place:

Vres = [S.h.Φ (1 –Sw–Sor)]/(5,615 .Bo).

Vres = 139934 ,7840 barels.

4.1 2. Volume to be recovered to deplete the tank:

Vrecovered = Vres . Rf

Vrecovered = 69967,39200 barels.

With the use of horizontal wells, each well will recover a cumulative production from:

Vch = Vrecovered / 32 => Vch= 2186,481 barels.

And with the use of vertical wells, each well will recover a cumulative production of:

Vcv = Vrecovered / 96 => Vcv= 728,827 barels.

The table below illustrates the evolution of reservoir depletion by the use of critical flows with the two exploitation techniques

Table 4:"Evolution of the cumulative production of the two wells"

t (day)	Mt(day)	Qcv(STB/day)	Vcv	Qch(STB/day)	Vch
0	0	183,470789	0	1903,369809	0
3	3	183,359403	550,412368	1900,430373	5710,10943
10	7	183,099825	1833,92819	1893,591081	19013,122
30	20	182,360503	5495,92469	1874,188001	56884,9436
50	20	181,626046	9143,13475	1855,082015	94368,7037
70	20	180,89641	12775,6557	1836,267081	131470,344
90	20	180,17155	16393,5839	1817,737309	168195,686
110	20	179,451424	19997,0149	1799,48696	204550,432
200	90	176,246172	36147,643	1719,302389	366504,258
298	100	172,789952	53772,2602	1637,818073	534995,892
450	150	167,785576	79690,753	1521,03976	783944,239
650	200	161,443616	113247,868	1384,19467	1088152,19
950	300	152,560185	161680,953	1207,789456	1503410,59
1200	250	145,786138	199820,999	1087,054402	1805357,96
1800	400	135,800058	258135,455	847,9094171	2457590,6
2400	800	118,364786	377639,505	681,9249559	2966336,25
2480	400	111,230417	414984,525	665,1952445	3020890,24
3346	546	102,480679	475646,721		
4400	1054	88,0046905	583543,97		
5400	1000	77,2047941	671462,334		
6400	1000	68,4392849	748597,684		
7400	1000	61,2055521	816980,09		
8400	1000	55,151198	878138,34		
9600	1200	49,0329369	944271,957		
10886	1286	43,6059111	1007286,09		

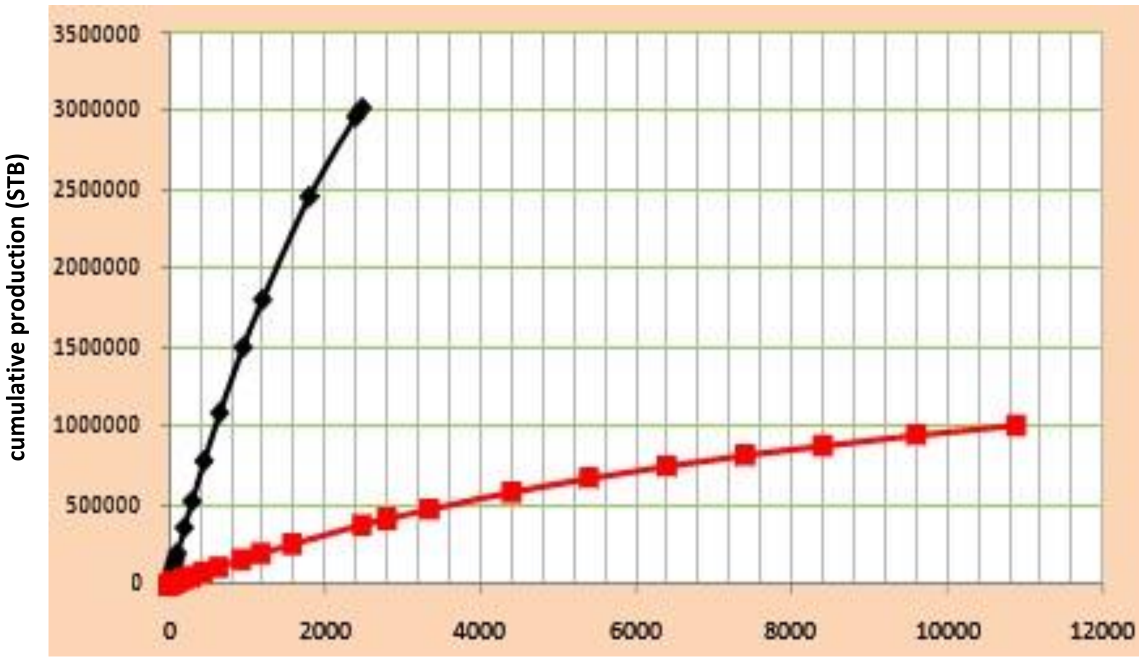


Fig.17 :"Evolution of the cumulative production of the two wells **(Ph and Pv)**"

The reservoir will be depleted in 2480 days using the horizontal wells, sothat it takes 10,886 days if vertical wells are used.

4.2. Economic calculation:

✓ Definitions:

- The cost price: is the equivalent cost of all the expenses of a barrel.
- The "Pay Out Time" amortization time: this is the time from which we begins to show net profits (the well recovers its capital cost) [15].

❖ ***Vertical wells:***

- ✓ The overall cost of constructing a vertical well: $ 2,5. 10^6
- ✓ The cumulative production of a vertical well is: 1007286,09 barrels.
- ✓ The average operating cost per barrel is assumed to be $ 03, and the selling price: $ 75.
- ✓ The cost price of a barrel is: (2,5. 10^6 / 1007286,09) + 03 = $ 5.48 / barrel.
- ✓ The POT (the amortization time) of a vertical well. Let **Vcv** be the volume at the **POT**, then:

$$2{,}5.\ 10^6 + 3.Vcv = 75.Vcv \Rightarrow Vcv = 34722{,}22 \text{ barrels.}$$

According to the figure for the cumulative production evolution, we will have the **POT ≈ 192 days.**

❖ ***Horizontal wells:***

- ✓ The overall cost of constructing a horizontal well: $ 7. 10^6
- ✓ The cumulative production from a horizontal well is: 3020890,24 barrels.
- ✓ The average operating cost per barrel is assumed to be $ 03, and the selling price: $ 75. The cost price of a barrel is:

$$(7.\ 10^6 / 3020890.24) + 03 = \$\ 5.31 / \text{barrel.}$$

- The POT of a horizontal well. Let **Vch** be the volume at the **POT**, then:

$$7.\ 10^6 + 3.Vch = 75.Vch \Rightarrow Vch = 97222{,}22 \text{ barrels.}$$

According to the figure of the evolution of cumulative production, we will have the **POT ≈ 52 days.**

According to the economic study that we did, we see that:

- The cost price of a barrel from a horizontal well is very close to that from a vertical well.
- Despite its high production cost, the POT of a horizontal well is much smaller than that of a vertical well.
- From an economic point of view, the technique of horizontal wells represents a solution for the production companies which exploit reservoirs under contract because of the rapidity of depletion.

Conclusion

General conclusion

At this the very last point we can group our splitted knowledge into what we have learned and concluded from the previous chapters, from the first chapter concerning the horizontal drilling, we have learned that there are multiple ways and strategies for horizontal drilling which in its turn gives a variety of options that we wouldn't have in the vertical drilling such as covering a wider and deeper drilling area and reaching hard-to-reach reservoirs, also it offers the potential of drilling multiple holes at once, suspend drilling to switch to another path and control the drilling direction freely.

As for the second chapter we have accomplished our knowledge about the horizontal technology through learning about the multiple types of horizontal wells and its completion and perforation.

Then we have made a technical study seeing which parameters infects the drilling process and how could it make difference between the horizontal and vertical drilling which lead us to conclude that the horizontal one is more efficient, faster and preferable from the technical side.

Finaly we attended to make an economical study so we can figure out if we should permanently stick to the horizontal technology but we found that the vertical drilling is more economical than the horizontal drilling leaving the horizontal technique as an operation to be used only for the very urgent needs.

The technical study carried out on the performance of horizontal wells and their comparison with inclined, vertical and vertical fractured wells led us to conclude that:

- The skin, and despite its high value in horizontal wells does not affect productivity much because the pressure drop caused by damage is smaller than that of vertical wells.
- In reservoirs with high vertical permeability such as naturally fractured reservoirs, horizontal wells are more efficient because they intercept the fractures and take advantage of their permeability to improve vertical drainage and therefore have good productivity.

- In reservoirs with low permeability, due to the poor drainage of vertical wells and the ineffectiveness of hydraulic fracturing, horizontal wells are the only possible alternative for the exploitation of this type of reservoir.
- The efficiency of horizontal wells compared to inclined wells increases with vertical permeability and decreases with layer thickness.

Economically, horizontal wells:

- Have a cost price close to that of verticals. Cost price for vertical wells was **$ 5.48 / barrel**. While the cost price for horizontal wells was **$ 5.31 / barrel**. A 0.17$ isn't that much to be considerable.

- Have a POT smaller than that of the verticals. The pay out time for vertical wells was **192 days**. While it was only **52 days** for horizontal wells. A difference of 140 days is real important consideration for companies i.e those that work under a short time contract.

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