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MASTER'S THESIS

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Option: Production

Presented By:

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-THEME-

EVALUATION OF THE EFFECIENCY OF MATRIX ACIDIZING OPERATION ON WELL ODZ-1BIS

Defended on: 10 /06/2023 before the examination committee

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DEDICATION

I would like to dedicate this project to my beloved ones my family,

To my father who sacrificed his life for me, your sacrifices and tireless efforts have shaped the person I am today.

I am forever grateful for your unwavering belief in me.

My mom, the person who waited for this moment the most This achievement is as much yours as it is mine, your unwavering support, sacrifices, and belief in my abilities have propelled me forward, may I made u proud.

And for every member of my family individually

Finally, my dearest friends thank for staying until the end.

BENABED Hiba

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As I come to the end of my studies, it is my great pleasure to dedicate this modest work:

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To my entire family.

To all my friends.

To my study partners.

To all those whom I love and respect.

BENBRAHIM Sofiane

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I dedicate this present dissertation to my family.

To the beings who are dearest to me, my father whom God bless

and who sacrificed his entire life to see me become who I am.

To my loving mother who has been by my side and supported me

Throughout my life, thank you to my parents.

To my brother and sisters.

To my dear friends.

ELANSARI Nada

Abstract:

There are various types of damage that can occur in oil and gas wells, either related to production or to well intervention operations such as drilling, workover, completion, and stimulation. Acidizing is a technique used to improve the productivity or injectivity of oil and gas wells by injecting acid into the formation to remove damage near the wellbore that can reduce well productivity. The treatment fluids are injected at a pressure lower than the rock's fracturing pressure limit. Matrix acidizing has been successfully applied in several wells studied, such as bis1 in the ODZ field, resulting in a significant increase in production throughput.

Keywords: ODZ, damage, acidizing, drilling, skin.

Résumé:

Il existe différents types d’endommagements qui peuvent survenir dans les puits de pétrole et de gaz, liés à la production ou aux opérations d'intervention dans le puits telles que le forage, le workover, la complétion et la stimulation. L'acidification est une technique utilisée pour améliorer la productivité ou l'injectivité des puits de pétrole et de gaz en injectant de l'acide dans la formation pour éliminer les dommages près du puits qui peuvent réduire la productivité du puits. Les fluides de traitement sont injectés à une pression inférieure à la limite de pression de fracturation de la roche. L'acidification de la matrice a été appliquée avec succès dans plusieurs puits étudiés, tels que bis1 dans le champ ODZ, ce qui a entraîné une augmentation significative du débit de production.

Les mots clés: ODZ, endommagement, acidification, forage, skin.

الملخص:

هناك أنواع مختلفة من الأضرار التي يمكن أن تحدث في آبار النفط والغاز، سواء كان ذلك مرتبطة بالإنتاج أو بعمليات التدخل في الآبار مثل والعمليات الإصلاحية والإكمال والتحفيز. التحميض هي تقنية تستخدم لتحسين إنتاجية أو حقنية آبار النفط والغاز عن طريق حقن حمض في التكوين لإزالة الأضرار بالقرب من فوهة البئر التي يمكن أن تقلل من إنتاجية البئر bis1. يتم حقن السوائل المعالجة بضغط أقل من حد الضغط الذي يؤدي إلى تكسير الصخر. لقد تم تطبيق التحميض المصفوفي بنجاح في عدة آبار درست، مثل bis1 في حقل ODZ، مما أدى إلى زيادة كبيرة في معدل التدفق.

الكلمات المفتاحية: الأضرار، آبار، التحميض، الحفر، حقن.

Nomenclature

WOC	Water Oil Contact	
GOC	Gas Oil Contact	
S	Skin	
K	Reservoir permeability	md
KS	Permeability of the damaged zone	md
Rs	Radius of the damaged zone	ft
Rw	Well radius	ft
KH	Horizontal permeability	md
Se	Actual damage around the wellbore	
S	Pressure drop due to perforations	
Sc	Flow restriction due to partial penetration	
IP	Productivity index	m^3 /h/ bar
Qo	Oil flow rate	m^3/d or bbl/d
Pi	Reservoir pressure	bar or psi
Pwf	Dynamic bottomhole pressure	bar or psi
ΔP	Additional pressure drop due to skin	bar or psi
Qo	Oil flow rate under bottomhole conditions	m^3/d or bbl/d
Qw	Water flow rate under bottomhole conditions	m^3/d or bbl/d
qg	Gas flow rate under bottomhole conditions	m^3/d or bbl/d
μo	Oil viscosity	cp
Bo	Formation volume factor (FVF)	m^3 / m^3
H	The effective height of the producing layer	m or ft
P	Static bottomhole pressure	bar or psi
T	Production time	hours
Ct	Total compressibility	psi^{-1}
Φ	Porosity	fraction
WOR	Water Oil ratio	fraction
GOR	Gas Oil ratio	fraction
Ht	Total height	m or ft
Hu	Effective height	m or ft
PLT	Production logging tool	
W.O	Work over	
BU	Build-up	
Pt	Wellhead pressure	psi
Sw	Water saturation	fraction
Sg	Gas saturation	fraction
gf	Fracture gradient	psi.ft
AOF	Absolute open flow	m^3/d or bbl/d
IPR	Inflow performance relation ship	
VLP	Vertical Lift Performance	
Vacid	Volume of acid used for the main treatment	m^3

Pfond	Treatment pressure at the bottom of the well	psi
Phy	Hydrostatic pressure	psi
Pinj	Maximum injection pressure at the surface	psi
PT	Treatment pressure at the bottom of the well	psi
HF	Hydrofluoric Acid	
HCL	Hydrochloric Acid	

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General Introduction

Introduction:

The extraction of hydrocarbon resources from subsurface formations is of utmost importance in meeting global energy demands. Well stimulation techniques play a critical role in optimizing production rates and recovering additional reserves. Among these techniques, acidizing has emerged as a highly effective method for improving well productivity and reservoir permeability by addressing wellbore damage. This thesis aims to provide a comprehensive examination of acidizing as a well stimulation technique, encompassing various aspects, assessing its real-world impact, and analyzing a detailed case study.

The thesis begins by addressing the significant issue of wellbore damage, which poses a challenge to well productivity and reservoir performance. Understanding the diverse types and causes of wellbore damage, such as drilling mud invasion, formation damage during drilling and completion operations, fines migration, scale deposition, and organic matter accumulation, is crucial. The study emphasizes the adverse effects of wellbore damage on the flow of hydrocarbons, emphasizing the need for effective well stimulation techniques like acidizing.

Next, the thesis explores the process of acidizing, delving into its fundamental components. This encompasses the identification of suitable wells for acidizing treatments, taking into account factors like formation type, well configuration, and reservoir characteristics. The steps involved in acidizing treatments, from pre-job evaluation to acid selection, design considerations, and operational procedures, are comprehensively examined. The thesis also discusses the various types of acids and additives commonly employed in acidizing treatments, elucidating their mechanisms of action and compatibility with different reservoir types. Moreover, it underscores the importance of environmental considerations during acidizing operations and the implementation of measures to minimize environmental impact.

Furthermore, the thesis presents a comprehensive case study illustrating the effects and outcomes of acidizing treatments in real-world scenarios. The case study encompasses the evaluation of pre-job assessment, acid selection, and operational considerations. Detailed findings pertaining to the impact of acidizing on well productivity, reservoir performance, and overall hydrocarbon recovery are presented. This evaluation includes improvements in reservoir permeability, the mitigation of wellbore damage, and subsequent enhancements in production rates. The thesis also addresses challenges encountered during the acidizing process, thereby providing valuable insights gained from the case study.

Through this comprehensive exploration and analysis, the thesis endeavors to enhance our understanding of acidizing as a well stimulation technique and its broader implications for the efficient extraction of hydrocarbon resources from subsurface formations.

CHAPTER I :
Notion of damage

I. Notion of damage

I.1 Introduction

The detection of well damage is based on observing a decrease in the well's flow rate. This decrease is expressed by a reduction in the productivity index and by the skin factor (damage coefficient) when it is positive. In this chapter, we will review the nature of well damage, its origin, location, and the consequences of damage on production.

I.2 The definition of wellbore damage

Wellbore damage refers to any impairment or alteration of the wellbore that reduces its productivity or injectivity. This can be caused by various factors such as drilling fluids, completion fluids, solids invasion, fines migration, scale deposition, corrosion, and other damaging mechanisms. Wellbore damage can significantly impact the performance of a well and may require interventions such as stimulation or workover operations to restore or enhance its productivity **[1].**

I.3 Localisation of damage

I.3.1 At the bottom of the well

Generally, deposits consisting of sediments of various origins (particles from the formation, corrosion products from equipment) or precipitates (salts, paraffins, asphaltenes) are found **[1].**

I.3.2 At the wellbore well

- **External cake**

External cake refers to the layer of filter cake that forms on the outside of the wellbore wall during drilling operations. The filter cake is composed of solid mineral or organic particles that are deposited on the wellbore wall to help stabilize the wellbore and reduce the invasion of drilling fluid into the formation.

I.3.3 Around the wellbore

a. **Internal cake**

Internal cake refers to the layer of fine solid particles that accumulates on the wellbore wall in the immediate vicinity of the wellbore. This layer is composed of fine particles from the drilling mud, cement, and completion fluids that have been deposited on the wellbore wall during the operation [1].

b. **The invaded zone**

The invaded zone refers to the area beyond the internal cake that is invaded by the filtrates from the drilling mud and cement. This area can modify the natural environment of the porous formation and can result in various effects such as:

- Change in wettability
- Formation of emulsions
- Swelling and/or disintegration of clays
- Precipitation of various minerals and sometimes organic materials in the case of incompatibility between the filtrate and the fluids in place **[1].**

I.3.4 Particle build-up

Particle build-up in oil wells refers to the accumulation of solid particles, such as sand, silt, clay, and other minerals, in the wellbore or on the production equipment. These particles can come from several sources, including the reservoir rock, drilling fluids and muds, formation fines, and corrosion products [1].

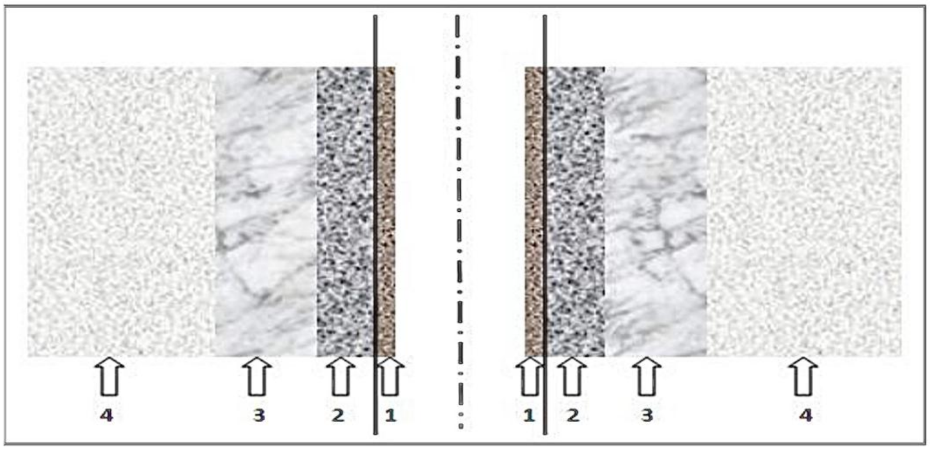

Figure I. : Different zones of damage **[7].**

-Zone 1: External cake lining the walls of the wellbore.

-Zone 2: Internal cake composed of solids that have penetrated the porous formation.

-Zone 3: zone invaded by the sludge filtrate.

-Zone 4: Virgin zone where the permeability is not affected.

I.4 The origin and causes of formation damage

Understanding the origin and causes of formation damage is crucial for selecting the appropriate treatment. The causes of formation damage can be numerous and can be categorized into several broad categories. We develop them in what follows **[2].**

I.4.1 Damage due to the formation

This damage is the main cause of decreased well productivity, and it is characterized by two important parameters: its composition and its location. Controlling these parameters is key to the success of an acidizing treatment, through the selection of appropriate fluids and placement methods.

In the oil and gas industry, there are several types of damage that can be more or less difficult to remove using acidizing treatment, including:

- Salt deposits
- Organic deposits (asphaltenes)
- Paraffin deposits
- Sulfate deposits
- Fines migration
- Clay swelling.

a. Salt deposits

The temperature and pressure changes associated with production can cause the precipitation of salt from highly saline formation fluids. This type of precipitation can cause damage to the reservoir matrix and blockage of perforations or even production tubing. Salt deposits can be easily dissolved by injecting fresh water through a concentric string, but if this water is incompatible with the formation water, it can lead to the formation of another type of deposit, which is BaSO4 (Barium Sulfate).

b. Organic deposits (asphaltenes)

Organic deposits, specifically asphaltenes, can form in oil and gas wells due to the chemical composition of the produced fluids. Asphaltenes are complex molecules that can precipitate out of the produced fluids and accumulate in the formation or on the production equipment, causing formation damage and reduced productivity. To mitigate asphaltene deposits, various techniques can be used, such as the use of solvents or surfactants to dissolve or disperse the deposits, or the application of heat or pressure to break up the deposits **[2].**

c. Paraffin deposits

Paraffin deposits are a type of organic deposit that can form in oil and gas wells. Paraffins are naturally occurring hydrocarbons that are present in crude oil, and they can precipitate out of the produced fluids and accumulate in the formation or on the production equipment, causing formation damage and reduced productivity.

Paraffin deposits can be especially problematic in cold environments, as the paraffins can solidify and become more difficult to remove. To mitigate paraffin deposits, various techniques can be used, such as the use of chemical solvents or mechanical methods to dissolve or remove the deposits. Additionally, proper selection of production fluids and procedures can be done to prevent the formation of paraffins and reduce the risk of deposition **[2].**

d. Sulfate deposits

Sulfate deposits are a type of inorganic deposit that can form in oil and gas wells. Sulfates are naturally occurring minerals that are present in the formation water, and they can precipitate out of the produced fluids and accumulate in the formation or on the production equipment, causing formation damage and reduced productivity.

Sulfate deposits can be especially problematic in high-temperature environments, as the sulfates can form hard, scale-like deposits that are difficult to remove. To mitigate sulfate deposits, various techniques can be used, such as the use of chemical treatments to dissolve or prevent the formation of the deposits, or the application of mechanical methods to remove the deposits.

e. Fines migration

Fines migration is a type of formation damage that can occur in reservoirs where there are small particles of rock, called fines, present in the formation. These fines can become dislodged and migrate towards the wellbore under the influence of fluid flow, and can eventually accumulate in the wellbore or production equipment, causing blockages and reducing production rates.

f. Swelling and dispersion of clays

Swelling and dispersion of clays is another type of formation damage that can occur in wells. This damage is caused by the invasion of water-based drilling fluids, work-over fluids, and completion fluids, which can disrupt the balance between the formation water and the clays, causing the clays to swell and severely reduce the permeability of the formation. Other types of clays, such as kaolinite, illite, and chlorite, can also be dispersed and subsequently block the pore channel **[2].**

I.4.2 Damage due to perforation

Most drilling operations are performed in an overbalanced condition, which leads to the formation of a cake filtrate in the perforation tunnels. This can cause skin damage and pressure drop in the vicinity of the wellbore.

I.4.3 Cement filtrate invasion

During liner cementing, cement filtrate can invade the formation matrix, causing damage. When liners are cemented in place, cement is pumped into the annulus between the liner and the wellbore to provide support and prevent fluid flow. However, this process can also cause cement filtrate to invade the formation matrix, which can lead to damage to the reservoir rock.

I.4.4 Damage due to stimulation

Stimulation treatments, such as hydraulic fracturing or acidizing, are commonly used to increase the production of oil and gas reservoirs. However, these treatments can also cause damage to the reservoir by altering the properties of the formation and reducing the permeability of the reservoir rock.

I.4.5 Damage due to well operations (Drilling, Work-Over and Snubbing)

For safety reasons, drilling, workover, and sometimes snubbing operations are carried out by killing the well, which involves the use of an oil-based mud that can cause severe damage to the reservoir.

When drilling or performing workover or snubbing operations, it may be necessary to kill the well by introducing a heavy fluid into the wellbore to stop the flow of fluids from the reservoir. This heavy fluid is typically an oil-based mud, which can cause damage to the reservoir by reducing the permeability of the formation and creating a filter cake in the wellbore.

a. perforation plugging

When performing workover or snubbing operations, it's common for filter cakes to form in the perforations, which can cause perforation plugging and reduce well productivity. To manage the effects of filter cakes in the perforations, a range of strategies may be employed, such as using chemical treatments to dissolve or remove the plugging material, or using mechanical methods to clean out the perforations **[2].**

b. wettability alteration

Wettability refers to the ability of a fluid to wet or adhere to a solid surface. In oil and gas reservoirs, wettability can play a crucial role in determining the efficiency of oil recovery. When the reservoir rock is water-wet, oil tends to be trapped in the pore spaces and is difficult to recover. However, when the reservoir rock is oil-wet, oil can flow more easily through the pore spaces and is more easily recovered.

Wettability alteration can occur due to several factors, such as changes in the composition of the reservoir fluids, the introduction of chemicals into the reservoir, or changes in the pressure or temperature conditions in the reservoir **[2].**

c. Water block

Water block can occur due to several factors, such as high water saturation, low permeability of the reservoir rock, or the presence of natural barriers such as faults or fractures. Water block can also be caused by poor well completion practices or by the introduction of chemicals or other substances that can block the flow of fluids in the reservoir.

To manage the effects of water block, various strategies may be employed. One common approach is to use chemical treatments such as surfactants or polymers to reduce the interfacial tension between water and oil, allowing the oil to flow more easily through the reservoir. Another approach is to use mechanical methods such as drilling or hydraulic fracturing to create channels or fractures in the reservoir, which can bypass the water blockage and improve the flow of hydrocarbons.

d. Emulsification

Emulsification is the process of creating an emulsion, which is a mixture of two immiscible liquids (such as oil and water) that are stabilized by an emulsifying agent. During emulsification, small droplets of one liquid are dispersed throughout the other liquid to create a stable mixture. Emulsification can be achieved through various methods, such as agitation, homogenization, or the use of an emulsifying agent.

I.4.6 Damage due to water injection

Damage due to water injection refers to the negative effects that injecting water into a reservoir can have on the productivity of a well. Water injection is a common technique used to enhance oil recovery by maintaining reservoir pressure and pushing oil towards the producing wells. However, the injection of water can also cause damage to the reservoir and the wellbore **[2].**

One of the main causes of damage due to water injection is the saturation of the formation with water near the wellbore, which is called "Water-Block". This can occur if the injection rate or pressure is not properly controlled, causing the water to accumulate and block the flow of oil towards the producing wells. Water-Block can significantly reduce the productivity of the well **[2].**

I.5 Detection of damage

Several commonly used methods are available, including:

- Laboratory sampling and analysis
- Complete well history
- Well testing
- Analysis of the production system **[3].**

I.5.1 Laboratory sampling and analysis

Laboratory sampling and analysis is a crucial tool for identifying damage or degradation in oil and gas production systems. By analyzing samples of formation fluids, rock, or other materials in a laboratory, operators can gain a detailed understanding of the chemical and physical properties of the materials involved, which can inform effective remediation strategies.

I.5.2 Complete well history

A complete well history includes a comprehensive record of all activities and events that have occurred throughout the life of a well, from the initial drilling and completion stages to the current production and maintenance activities.

This includes data such as the well's construction and completion details, the formation characteristics, production rates over time, and any maintenance, workover, or stimulation activities that have been performed.

This information can then be used to develop targeted remediation strategies to address any issues and optimize well performance and to help detect the causes of damage.

I-5-3 Well tests

Well tests are an important method for evaluating the productivity and performance of a well. Pump tests with good pressure responses are a preferred method for assessing whether there is a restriction to production from the reservoir. However, it is important to note that the Total Skin Effect includes parasitic factors (pseudo skins) that must be subtracted to determine if a real formation damage exists.

In addition to determining the potential productivity of a well, pump tests can provide other important information about the reservoir and wellbore. This includes changes in static reservoir pressure over time, virgin permeability under downhole conditions which can differ significantly from surface measurements, productivity index, and flow efficiency **[4].**

I-5-4 The analysis of a production

The analysis of a production system involves evaluating the various components of the system to identify potential issues or opportunities for optimization. This can include the reservoir, wellbore, completion, production facilities, and any associated infrastructure **[4].**

I.6 Skin

I.6.1 Definition

Skin refers to a parameter used to quantify the negative effects of formation or well damage on production flow rate. The skin represents an altered zone around the well that reduces the effective permeability of the formation and increases resistance to fluid flow towards the well. The skin factor is expressed in units of permeability and can be positive or negative, depending on whether the damage has a beneficial or negative effect on production flow rate **[5].**

- S>0: Damaged reservoir

- S<0: Stimulated reservoir

- S=0: Undamaged and unstimulated reservoir

A positive skin factor indicates that the formation around the wellbore is damaged or altered, which can reduce the productivity of the well. A negative skin factor indicates that the formation has been stimulated or enhanced, which can increase the productivity of the well. A skin factor of zero indicates that the formation is neither damaged nor stimulated, and is therefore expected to have normal productivity.

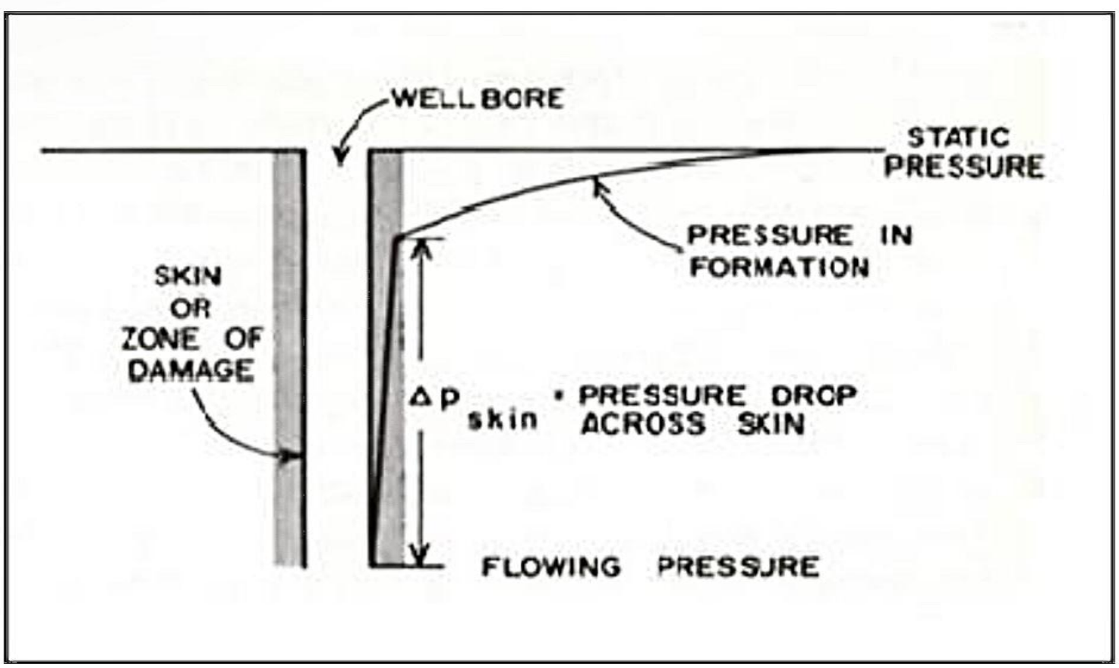

Figure I. 2: Zone of skin **[8].**

I.6.2 The origin of skin

The skin has several origins, the most important of are:

I.6.2.1 Perforations

The ideal well model assumes it has 360-degree contact with the formation, but with perforations it is clear that production is constrained through the openings only. This results in a pressure loss characterized by the skin factor Sp called the wellbore skin effect coefficient, which depends on the number of perforations, their distribution and penetration efficiency.

I.6.2.2 Partial penetration

Partial penetration is characterized by the fact that a well produces from a formation thickness less than the total exploitable height. This will be the case when one wants to protect against premature water or gas inflow, or when there is an argillaceous barrier.

It contributes to the existence of a positive skin (pseudo skin Sc) which varies according to the thickness of the formation, the diameter of the well and the perforated height **[5].**

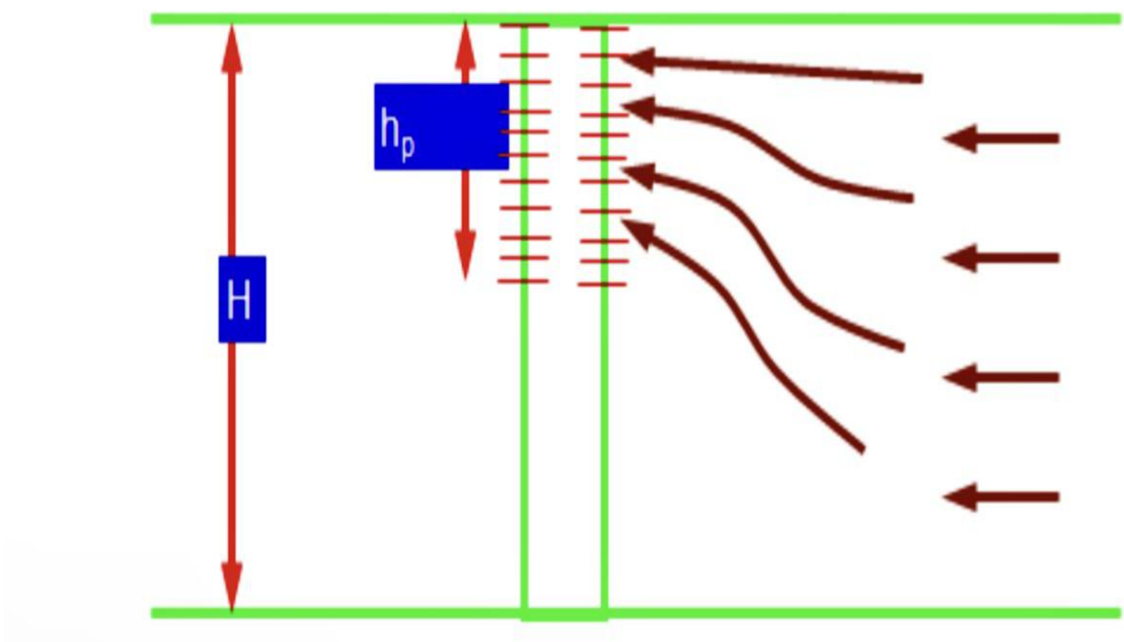

Figure I. 3: The partial penetration effect **[8].**

I.6.2.3 Overall damage

In all cases, the additional pressure losses localized around the wellbore (matrix) can be treated as a skin. So the skin that will be measured during a test is the result of all these skins **[5].**

$S = Se + Sp + Sc$**...............................(I.1)**

• Se: the real damage around the wellbore (matrix)

• Sp: the pressure loss due to perforations

• Sc: the choke of the flow due to partial penetration.

All of these contribute to increased pressure losses and flow restrictions, resulting in an overall positive skin factor. The measured skin is the net result of all these separate skin components **[5].**

I.6.2.4 Stimulation treatments

Treatments like acidizing and fracturing are done to improve well productivity but they can also leave an altered zone around the wellbore, contributing to skin.

I.6.2.5 Mechanical effects

Issues like pipe eccentricity, improper well completion, solids deposition etc. can lead to mechanical effects that increase skin **[5].**

I.6.3 The skin effect on permeability

The radius (re) and permeability (Ke) of the damaged zone are related to the skin factor (S) by Hawkins' expression:

$\boldsymbol{S = (\frac{ki}{ke} - 1)ln(\frac{re}{rw})}$ **...............................(I.2)**

rw **:** the outer radius of the damaged zone

re **:** the inner radius of the damaged zone

Hawkins' expression can be used to estimate the skin factor based on the radius and permeability of the damaged zone. A positive skin factor indicates that the near-wellbore region is damaged and has reduced permeability, while a negative skin factor indicates that the near-wellbore region has been stimulated and has increased permeability. The magnitude of the skin factor will depend on the extent and nature of the damage or stimulation around the wellbore **[6].**

I.6.4 The skin effect on productivity

I.6.4.1 Notion of productivity index

The productivity index (or injectivity index) of a well is defined as the flow rate associated with a pressure drop between the bottom of the well and the reservoir. It is a measure of the well's potential, expressed for the case of a liquid in a circular flow, in steady state **[6]:**

$$IP = \frac{Q}{(Pg - Pf - \Delta Ps)} \quad \text{.................................(I.3)}$$

Where:

Q : the flow rate

Pg : the pressure at the bottom of the well,

Pf : the pressure at the top of the formation bar/psi

ΔPs : the pressure drop due to skin effect and other factors

If the permeability around the wellbore is reduced due to damage, this can increase the pressure drop required to achieve a given flow rate, and thus reduce the well's productivity index. Conversely, if the permeability is increased through techniques such as hydraulic fracturing, the well's productivity index may increase **[6].**

$$\Delta s = \frac{141.2 q_0 \mu_0 B_0}{Kh} \quad \text{.................................(I.4)}$$

S = skin factor (dimensionless)

q_o = oil flow rate (m^3/h)

μ_0 = oil viscosity (centipoise)

B_o = oil formation volume factor (m^3/STB)

K = permeability (darcy)

H = net pay thickness (m)

– There are two types of PI:

API: actual productivity index in (m^3/h)/(Kg/cm^2).

This is the measured productivity taking into account the skin factor.

TPI: theoretical productivity index in the same units.

This is the productivity without considering near-wellbore effects [6].

The theoretical productivity index (IPo) is given by:

$$IPo = \frac{\alpha\, hk}{\mu\beta ln\,(\frac{re}{rw})} \quad \text{.................................(I.5)}$$

Where:

α = coefficient depending on units used

h = formation thickness

k = permeability

μ = fluid viscosity

β = volumetric factor

re = drainage radius

rw = wellbore radius

1.6.4.2 The effect of skin on productivity

Understanding the IPR (Inflow Performance Relationship) curve and Hawkins' equation is essential to understand how formation damage (skin) affects well productivity **[6].**

For an oil well, the IPR equation is written as:

$$q = \frac{(PG - Pwf)}{141{,}2\,(\ln(\frac{re}{rw} + S)} \quad \text{.................................(I.6)}$$

Where:

q = Oil flow rate at bottomhole conditions (STB/day)

k = Permeability (mD)

h = Reservoir net pay (ft)

PG = Reservoir pressure (psi)

Pwf = Flowing bottomhole pressure (psi)

μ = Oil viscosity (cP)

β = Oil formation volume factor (RB/STB)

re = Drainage radius (ft)

rw = Wellbore radius (ft)

S = Skin factor

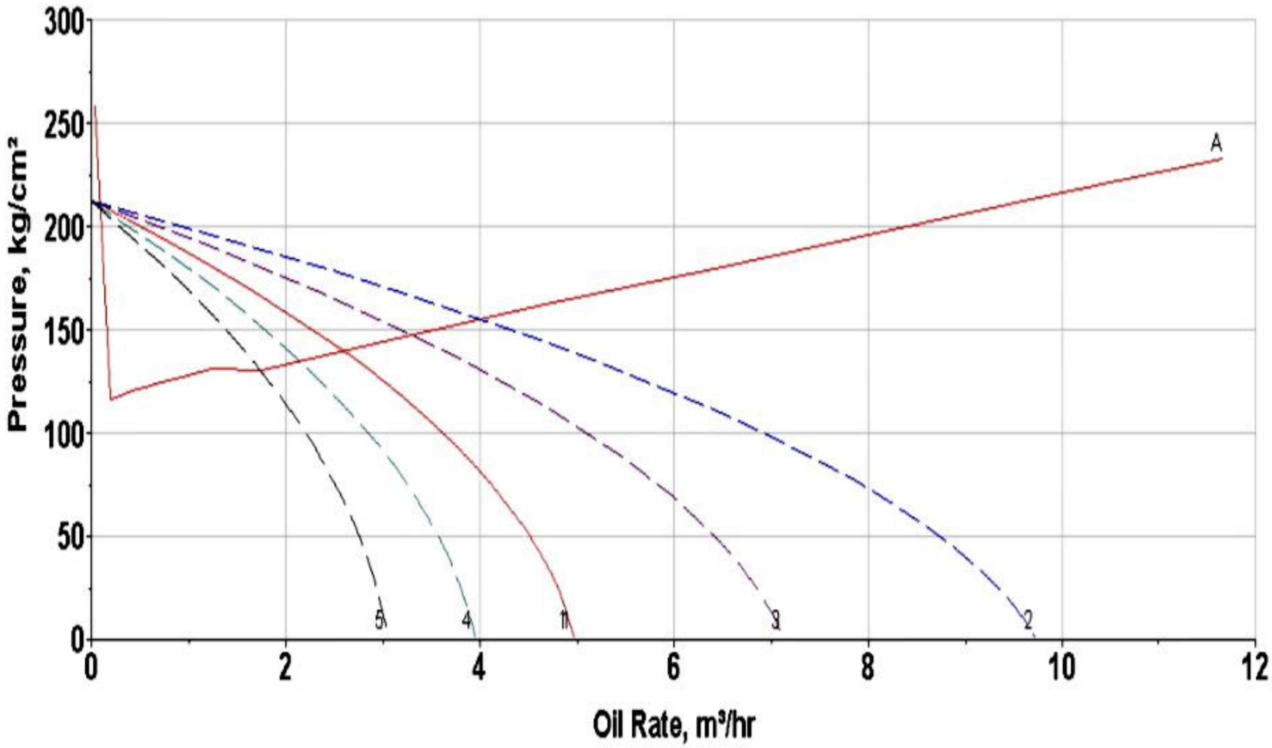

Figure I. 4: Influence of the skin on productivity **[8].**

The above graph represents the influence of skin on productivity, by plotting the pressure curve as a function of flow rate. It can be observed that the relationship between flow rate and skin is an inverse relationship **[6].**

I.7 Expression of damage

I.7.1 Ideal well

An ideal well is defined as a well with a radius of a, open over the entire height h of the layer whose permeability K has not been altered. If, after a time T of production at a constant flow rate QF, the well is shut-in, the evolution of the bottomhole pressure PWF(t) at time (T+Δt) can be expressed as follows:

$$\mathbf{Pwf}(t) = PG - \frac{\mu QF}{4\pi hk} ln(\frac{T+\Delta t}{\Delta t}) \text{..................................(I.7)}$$

The graphical representation in semi-logarithmic coordinates of the variation of pressure is a straight line whose slope allows for the calculation of the reservoir's transmissibility **[8].**

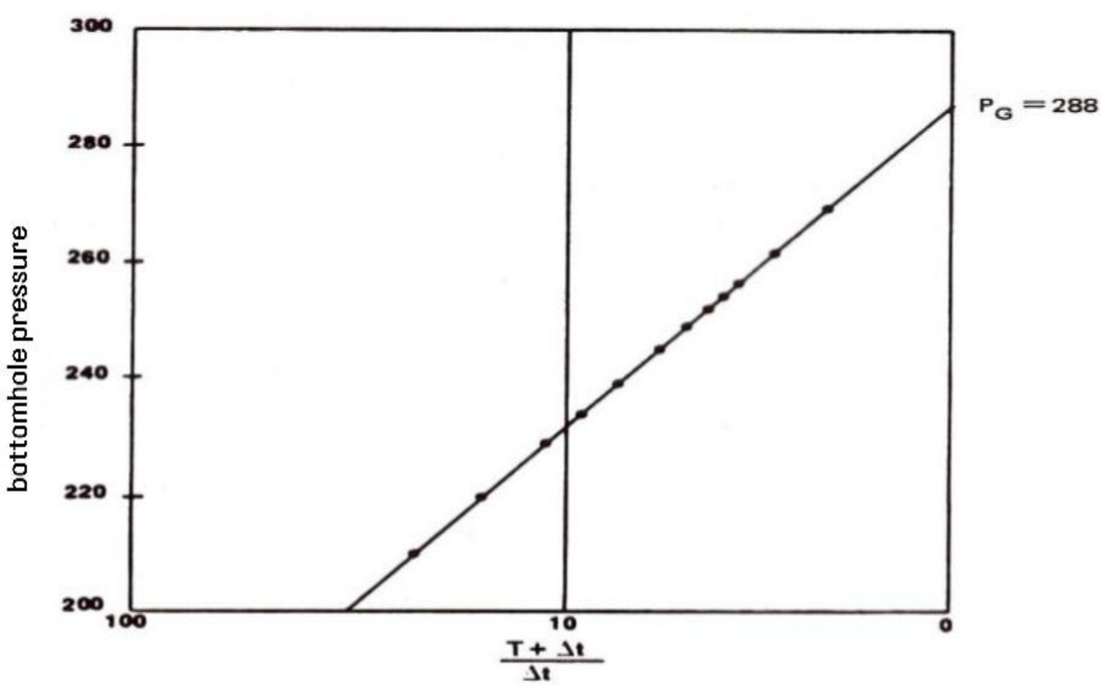

Figure I. 5: Evolution of bottomhole pressure after well shut-in (case of the ideal well) **[8].**

I.7.2 Damaged well

In the case of a damaged well, the transmission of pressure is not uniform throughout the reservoir and is affected by local heterogeneity in the immediate vicinity of the well (3 to 5 ft), meaning that the permeability near the wellbore, KS, becomes different from the far-field permeability, K **[8].**

As a result, any decrease in permeability will have a similar effect to an additional pressure drop "ΔPs" in the near-wellbore region due to the skin effect (boundary effect) **[8].**

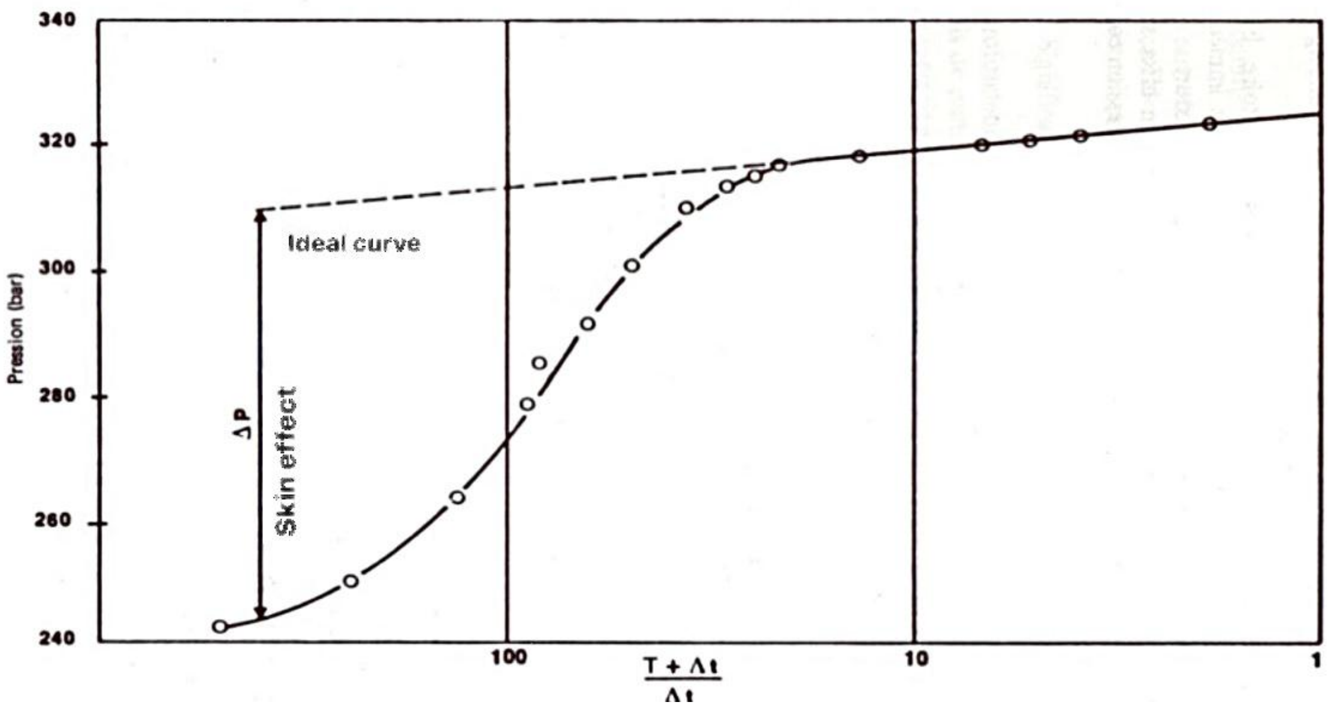

Figure I. 6: Evolution of bottomhole pressure after well shut-in (Case of the damaged well) **[8].**

I.8 Conclusion:

At the end of this first chapter, it becomes evident that the phenomena of damage and failure around oil installations (through a few examples) present the state of knowledge and methods for taking into account these phenomena. This knowledge is crucial for solving the phenomenon in question.

CHAPTER II:

The process of acidizing

II. The process of acidizing

II.1 Introduction

Acidizing is a widely employed technique in the oil and gas industry to enhance hydrocarbon production from reservoirs. This chapter focuses on the operational aspects and provides valuable insights into the practice of acidizing. By delving into the various methods, chemical formulations, and considerations involved, we aim to provide a comprehensive understanding of this technique's efficacy and its potential environmental implications. Through this exploration, we aim to contribute to the optimization of acidizing operations while ensuring responsible resource extraction practices.

II.2 Well stimulation

Well stimulation is a highly technical and precise solution to decreased reservoir flow and production resulting from the accumulation of particles and fluids near the wellbore or formation damage resulting from the well drilling and completion process. Vital to the industry, well stimulation is a necessary intervention intended to enhance permeability and improve the flow of hydrocarbons from the reservoir to the wellbore. This significantly enhances productive well capacity, allowing a more timely return on investment **[9].**

II.3 Primary methods of well stimulation

II.3.1 Hydraulic Fracturing

Hydraulic fracturing is a well-stimulation technique that is most suitable to wells in low- and moderate-permeability reservoirs that do not provide commercial production rates even though formation damages are removed by acidizing treatments. Hydraulic fracturing jobs are carried out at well sites using heavy equipment including truck-mounted pumps, blenders, fluid tanks, and proppant tanks. A hydraulic fracturing job is divided into two stages: the pad stage and the slurry stage. In the pad stage, fracturing fluid is injected into the well to break down the formation and create a pad. During the slurry stage, the fracturing fluid is mixed with sand/proppant in a blender and the mixture is injected into the pad/fracture **[10].**

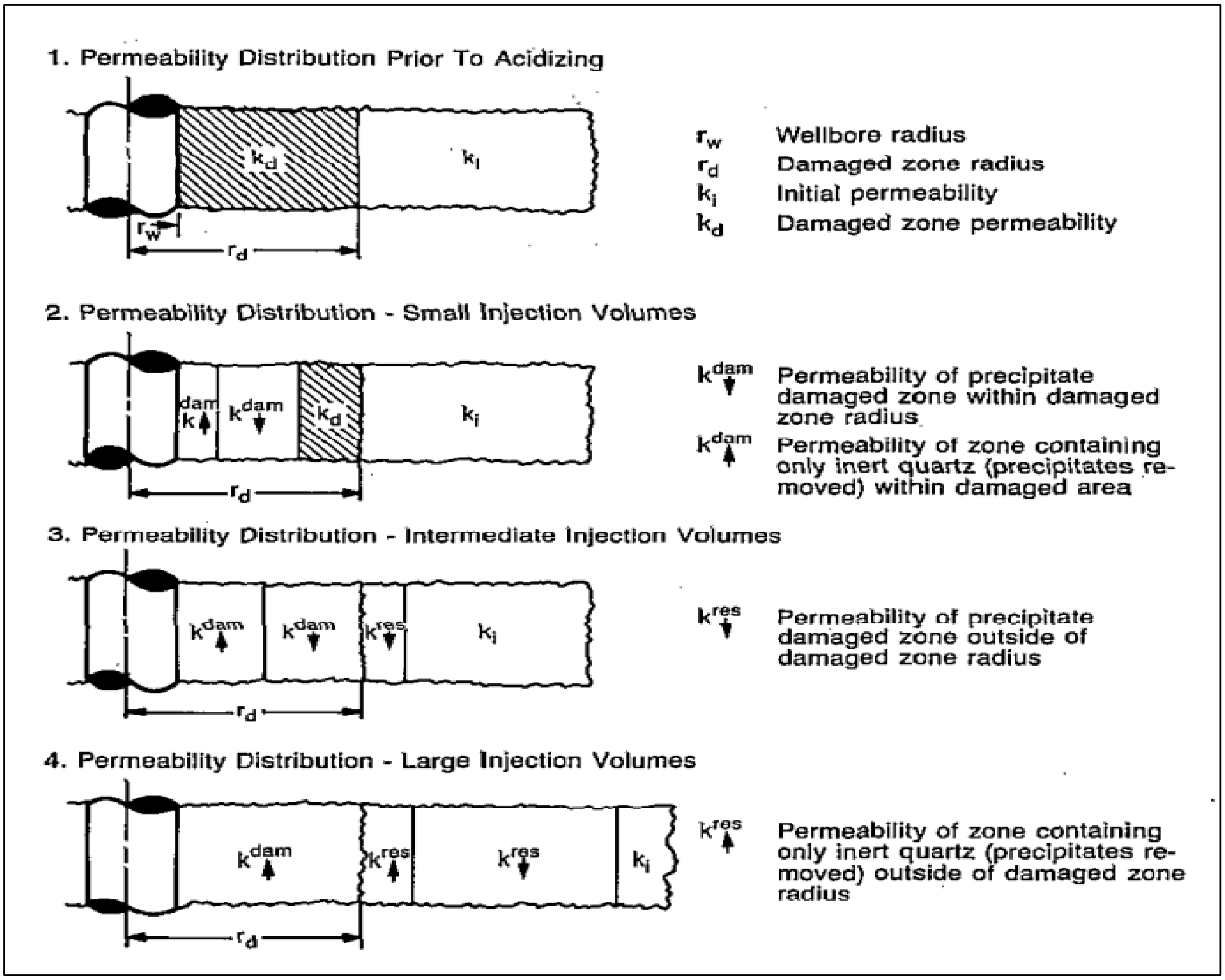

Figure II. : Permeability changes when acidizing a damaged well.

(From Walsh et al., 1982) **[11].**

II.3.2 Acidizing

Acid is injected into the well penetrating the rock pores at pressures below fracture pressure. Acidizing is used to either stimulate a well to improve flow or to remove damage. During matrix acidizing the acids dissolve the sediments and mud solids within the pores that are inhibiting the permeability of the rock. This process enlarges the natural pores of the reservoir which stimulates the flow of hydrocarbons. Effective acidizing is guided by practical limits in volumes and types of acid and procedures so as to achieve an optimum removal of the formation damage around the wellbore.

II.4 Other methods

In addition to acidizing and hydraulic fracturing, there are several other methods used for well stimulation in the oil and gas industry. Here are a few examples:

a. **Nitrogen Fracturing:** This method involves injecting nitrogen gas into the reservoir to create formation damage from fluids used in hydraulic fracturing.
b. **CO2 Fracturing:** Carbon dioxide (CO2) fracturing involves injecting CO2 into the wellbore to create fractures and stimulate production. CO2 can act as both a fracturing fluid and a displacing agent, improving the flow of oil or gas.
c. **Proppant Selection:** Proppant selection is a technique where different types of proppants (such as sand, resin-coated sand, or ceramic materials) are used during hydraulic fracturing to optimize fracture conductivity and improve well performance.
d. **Explosive Fracturing:** In certain situations, explosives can be used to create fractures in the reservoir. This method involves detonating explosives in the wellbore, which generates shockwaves that fracture the surrounding rock formations.
e. **Thermal Stimulation:** Thermal stimulation methods involve injecting steam or hot fluids into the reservoir to heat the oil and reduce its viscosity, making it easier to flow and extract. Steam injection and cyclic steam stimulation (CSS) are commonly used thermal stimulation techniques.
f. **Microbial Stimulation:** Microbial stimulation, also known as microbial enhanced oil recovery (MEOR), involves introducing bacteria or other microorganisms into the reservoir to enhance oil recovery. These microorganisms can alter the reservoir conditions, such as by producing gases or chemicals that improve oil mobility.
g. **Electromagnetic Stimulation:** Electromagnetic stimulation techniques use electrical or electromagnetic fields to enhance well productivity. These methods can include electromagnetic heating or electromagnetic pulse technologies to increase the flow of oil or gas.

II.5. Acid treatments

There are two general categories of acid treatments:

II.5.1 Acid washing:

The objective is simply tubular and wellbore cleaning. Treatment of the formation is not intended. Acid washing is most commonly performed with hydrochloric acid (HCl) mixtures to clean out scale (such as calcium carbonate), rust, and the debris restricting flow in the well. Matrix and fracture acidizing are both formation treatments.

II.5.2 Matrix acidizing:

The acid treatment is injected below the formation fracturing pressure. In fracture acidizing, acid is pumped above the formation fracturing pressure.

The purpose of matrix or fracture acidizing is to restore or improve an oil or gas well's productivity by dissolving material in the productive formation that is restricting flow, or to dissolve formation rock itself to enhance existing, or to create new flow paths to the wellbore. Two key factors dominate the treatment selection and design process when planning an acid job; formation type – carbonate, sandstone, or shale, and formation permeability – the ability of fluid to flow through the formation in its natural state. Formation type determines the type(s) of acid necessary and formation permeability determines the pressure required for pumping the acid into the formation.

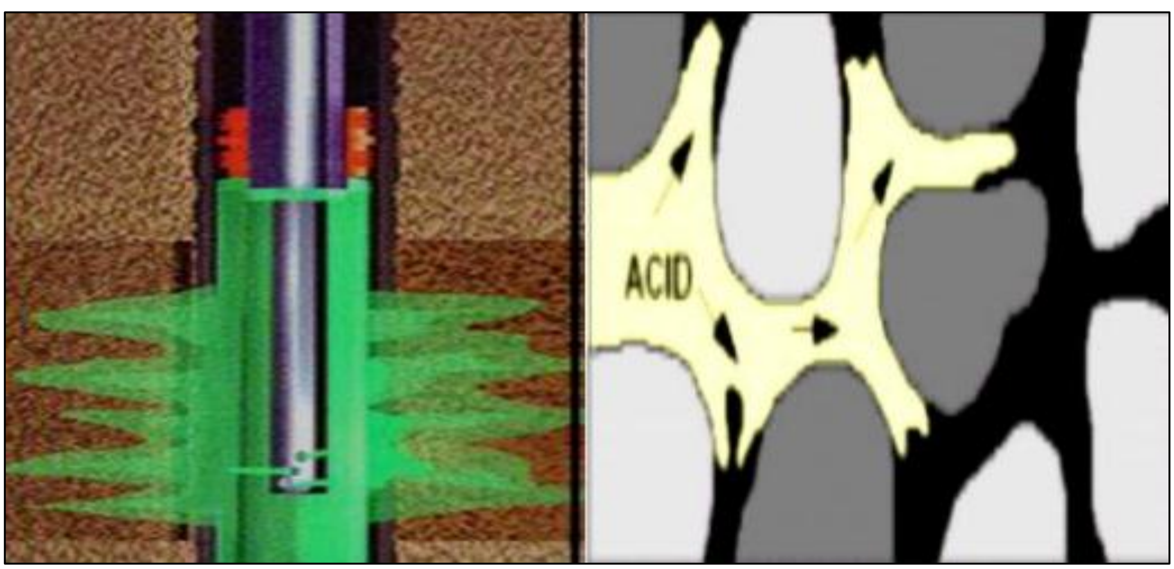

Figure II. : Matrix Acidizing **[12].**

II.6 Acidizing Candidates

When selecting a candidate well for acidizing, several factors should be considered, including:

- **Formation type:** Acidizing is most effective in carbonate formations, but can also be used in sandstone formations.
- **Permeability:** Acidizing is most effective in wells with low to moderate permeability, as it can help increase the effective permeability of the formation.
- **Formation damage:** Acidizing can help remove formation damage caused by drilling or completion activities, making it a suitable option for wells that have experienced reduced productivity due to formation damage.
- **Production history:** Acidizing can help rejuvenate older wells that have experienced declining production over time.
- **Reservoir characteristics:** Acidizing is most effective in reservoirs with high heterogeneity and significant variations in rock properties.
- **Reservoir temperature:** Acidizing can be more effective in reservoirs with high temperatures, as this can help increase the rate of reaction between the acid and the formation.

Overall, the selection of a candidate well for acidizing will depend on a range of factors specific to the well and the reservoir, and should be determined on a case-by-case basis by a qualified engineer, whether a well is a good candidate for acidizing.

II.7 Steps of an acidizing operation

II.7.1 Evaluation and Design

The first step is to evaluate the well and reservoir conditions. This includes studying well logs, production data, and formation properties to determine the type and concentration of acid needed for effective stimulation. Based on the evaluation, engineers design the acidizing treatment, considering factors such as the type of acid, injection rates, volumes, and the placement of packers or plugs.

II.7.2 Well Preparation

Before acidizing, the wellbore is prepared by cleaning out any obstructions, such as scale, paraffin, or debris, using mechanical or chemical methods. Temporary isolation devices like packers or plugs may be installed to control fluid flow during the acidizing process and prevent the acid from entering undesired zones.

II.7.3 Acid Injection

Acid is injected into the wellbore under controlled conditions. The acid selected depends on the formation characteristics and the purpose of stimulation. The acid can be hydrochloric acid (HCl), hydrofluoric acid (HF), or a blend of various acids. It is often mixed with other additives to enhance its performance and reduce potential formation damage. Acid injection can be performed through coiled tubing, bullheading (direct pumping), or through perforations in the casing and production tubing.

II.7.4 Acid Reaction and Dissolution

Once the acid enters the formation, it reacts with the mineral components of the reservoir rock, such as carbonates (e.g., limestone) or silicates (e.g., sandstone). The acid dissolves the minerals, creating pathways and enlarging existing pore spaces. This helps to increase the permeability and porosity of the formation, facilitating the flow of hydrocarbons towards the wellbore.

II.7.5 Soaking Period

After the acid injection, a soaking period is typically allowed to enhance the dissolution and reaction between the acid and the formation. The soaking period can vary from a few minutes to several hours, depending on the specific treatment design and the type of acid used. During this time, the acid continues to react with the formation, further dissolving minerals and improving the near-wellbore permeability.

II.7.6 Fluid Recovery and Cleanup

Once the soaking period is complete, the well is flowed back to recover the spent acid and any formation fluids. The produced fluids are typically monitored to assess the effectiveness of the acidizing treatment and to ensure the well is ready for production. Special attention is given to removing residual acid, ensuring that the wellbore is clean and free from any potential damage-causing substances.

II.7.7 Post-Treatment Evaluation

Following the acidizing process, the well's performance is monitored to evaluate the effectiveness of the stimulation treatment. Parameters such as production rates, pressure data, and fluid composition are analyzed to assess the success of the acidizing operation. Based on the evaluation, further actions, such as additional acid treatments or other stimulation techniques, may be considered to optimize well productivity. It’s important to note that the specific steps and details of an acidizing process can vary depending on the reservoir characteristics, the objectives of the stimulation, and the engineering practices of the operating company.

II.8 Acids used

Several types of acids are used in acidizing operations, including:

- **Hydrochloric acid (HCl):** Hydrochloric acid is the most commonly used acid in acidizing operations. It is highly effective at dissolving carbonate rocks and is often used to stimulate wells with carbonate formations.
- **Hydrofluoric acid (HF):** Hydrofluoric acid is used for acidizing operations where sandstone formations are present. It is highly effective at dissolving silica-based minerals and can improve the permeability of sandstone formations.
- **Organic acids:** Organic acids, such as formic acid and acetic acid, are used in acidizing operations where the use of mineral acids like HCl and HF is not practical. Organic acids are milder and are typically used to stimulate wells with low permeability formations.

- **Sulfamic acid:** Sulfamic acid is used in acidizing operations where the presence of iron or other metals can cause precipitation and reduce the effectiveness of other acids. Sulfamic acid is highly effective at dissolving mineral scales and is often used in acid cleaning applications.
- **Mud acid:** Mud acid is a mixture of hydrochloric and hydrofluoric acids and is used in acidizing operations where both carbonate and sandstone formations are present. The mixture of the two acids creates a more versatile acid that can dissolve both types of minerals.

II.9 Additives used

Additives are often used in acidizing operations to enhance the effectiveness of the acid and improve the overall performance of the treatment. Some common additives used in acidizing operations include:

- **Surfactants:** Surfactants are used to reduce surface tension and improve acid penetration into the formation. They can also help to emulsify oil and water, making it easier to remove oil deposits.
- **Corrosion inhibitors:** Corrosion inhibitors are used to protect wellbore equipment from damage caused by the acidic solution. They work by forming a protective layer on the surface of the metal, which prevents the acid from corroding the equipment.
- **Iron control agents:** Iron control agents are used to prevent the precipitation of iron compounds, which can clog the formation and reduce the effectiveness of the treatment. They work by binding with the iron ions and preventing them from reacting with the acid.
- **Clay stabilizers:** Clay stabilizers are used to prevent swelling or disintegration of the clay minerals in the formation. They work by inhibiting the swelling or reducing the cation exchange capacity of the clay minerals.
- **Fluid loss control agents:** Fluid loss control agents are used to prevent excessive fluid loss into the formation during the acidizing treatment. They work by reducing the permeability of the formation or by forming a filter cake on the surface of the formation.
- **Mutual solvents:** Mutual solvents are used to improve the solubility of oil in the acid solution, allowing for more effective removal of oil deposits from the formation.

II.10 Acid choice

When choosing an acid for acidizing, several factors should be taken into consideration, including:

- **Formation type:** The type of acid used will depend on the type of formation being treated. Carbonate formations typically require stronger acids such as hydrochloric acid, while weaker acids such as acetic acid or formic acid may be more appropriate for sandstone formations.
- **Mineralogy:** The mineral content of the formation will also impact the choice of acid. Some minerals, such as calcite and dolomite, are more easily dissolved by certain acids than others.
- **Reservoir temperature:** The temperature of the reservoir can affect the reactivity of the acid. For example, stronger acids may be required in high-temperature formations to increase the rate of reaction.
- **Formation damage:** The extent of formation damage, such as drilling mud invasion or scale buildup, may impact the choice of acid. Stronger acids may be required to remove more extensive damage.
- **Safety:** The safety of the acid chosen must also be considered, including factors such as corrosiveness, flammability, and toxicity.
- **Compatibility with wellbore materials:** The acid chosen must be compatible with the materials used in the wellbore, including tubing and completion equipment, to prevent damage to the equipment.

II.11 Operational considerations

As mentioned above, acidizing oil and gas wells is a routine practice that has been used for a very long time. As a result, oil and gas operators and their service providers have considerable expertise and experience in safely and effectively conducting this work. Similarly, regulators that steward oil and gas operations have developed a well-founded regulatory framework to manage this work, protect the environment, and protect public health and safety **[13].**

The volume of acid used in an acid job is generally determined by the length of the formation (footage) being treated in the well. Acid volumes used per foot of formation can vary depending on the design objectives and the characteristics of the specific formation. Typical acid volume ranges are between 10 and 500 gallons per foot. While a volume of 500 gallons per foot may appear to be large, in a matrix acid job, assuming 25% porosity, the acid would be displaced less than 20 feet from the wellbore. In fracture acid jobs, the acid will be displaced further, but is still limited by the fracture length. Fracture lengths are usually a few hundred feet at most **[13].**

When acidizing, the acid is chemically consumed and neutralized as the target material is dissolved. In carbonate formations the reaction is relatively simple and occurs in a single step. The hydrochloric acid (HCl) reacts with the carbonate to form a salt, carbon dioxide, and water. When acidizing sandstones with HF the reactions are more complex, occurring in three stages. In the primary stage, the mud acid reacts with the sand, feldspar and clays to form silicon fluorides and aluminum fluorides. In the secondary stage the silicon fluorides can react with clay and feldspar to release aluminum and silicon precipitates, however with proper design, formation of these damaging precipitates, which can restrict flow of oil or gas through the formation, can be avoided. In the final stage the remaining aluminum fluorides react until all the remaining acid is consumed.

Geologic formations are rarely homogeneous (pure carbonate, sandstone, or shale) but will be a blend of carbonate, sandstone, and clay minerals. As a result, most acid jobs are composed of both hydrochloric and hydrofluoric acid, with the ratios and strengths depending on the mineralogy and temperature of the formation being treated. Other types of acids can be used in more specialized situations (e.g., organic acids such as acetic and formic acid as alternatives to hydrochloric acid).

Additionally, specialized additives can be included in cases where specific chemical reactions are anticipated to be particularly severe and require control or mitigation.

A challenge in performing acid jobs is ensuring the acid goes where it can do the most good. To facilitate placement of the acid across the entire target interval in the well, operators often use coiled tubing units. A coiled tubing unit is a specialized piece of equipment that utilizes a reel mounted tubing string that can be run concentrically inside the well's production tubing to the point directly across the interval that is targeted for treatment. The acid is pumped through the coiled tubing and into the productive formation. This equipment allows precise placement and pumping of the acid. It also provides the added benefit of not exposing the production tubing to the acid **[13].**

When pumping any fluid into a well it will have a natural tendency to follow the path of least resistance and flow into those parts of the formation with the highest permeability. In an acid job, this is not the most desired result since the objective of an acid job is to improve the permeability of a well by dissolving material from lower permeability or plugged areas. To direct acid to the lower permeability parts of the formation, either chemical or physical flow diverters can be used. Use of diverters forces the acid into those lower permeability sections and thereby provides the potential for the most positive results.

In all cases, once the acid job has been pumped the well is brought on production. When this is done, the spent acid is produced along with the oil, gas, and water in the formation. Since the acid is chemically consumed when it contacts the formation, the recovered fluid is relatively benign **[13].**

II.12 Environmental management considerations

The oil and gas industry has been using acids for well treatment for well over 100 years. As a result, the industry has a great deal of experience with the safe and environmentally sound handling and management of these fluids both before and after their use. Operator, service companies, and regulatory agencies have sound procedures in place that protect both workers and the public **[13].**

Acids must be transported and used with proper precautions, safety procedures, and equipment. Transportation of the acid and related materials must be done in USDOT (or equivalent) approved equipment and containers, properly labeled, and follow approved routes to the work site. Personnel working directly with the acids must utilize the personal protective equipment (PPE) specified in the Safety Data Sheet (or equivalent) and be properly trained and experienced in the use of these materials.

All equipment used in pumping the acid should be well maintained and all equipment components that will be exposed to pressure during the acid job should be tested to pressures equal to the maximum anticipated pumping pressure plus an adequate safety margin prior to the start of pumping operations, in accordance with industry standards and pressure pumping service provider operating guidelines. The operator should consider the use of barricades to limit access to areas near acid and additive containers, mixing and pumping equipment, and pressure piping **[13].**

After the acid job is successfully pumped and the well is brought to production, the operator should consider using separate tanks or containers to isolate the initial produced fluids (spent acid and produced water). The fluids that are initially recovered will contain the spent acid (acid that is largely chemically reacted, neutralized, and converted to inert materials) and it will typically have a pH of 2-3 or greater, approaching neutral pH. These fluids can be further neutralized to a pH>4.5 prior to introduction into the produced water treatment equipment, if necessary. Once neutralized, the spent acid and produced water can be handled with other produced water at the production site. Most produced water, including spent acid, is treated as needed and then injected via deep injection wells that are permitted by the jurisdictional regulatory authority **[13].**

II.13 Necessary calculations for an acidizing process

II.13.1 Acid volume calculation

The volume of injected acid is determined using the geometric method. It is an older method. It is based on calculating the volume of the damaged cylinder around the well, which is estimated by:

$$Vacid = Vcylinder = \pi(Rs^2 - rw^2) * Heff * \emptyset eff \quad \text{(II. 1)}$$

Where:

$Vacid$: volume of acid used for the main treatment in (m3).

Rs : radius of wellbore damage in (m) (determined by well tests).

$Heff$: effective height of the reservoir in (m).

rw : well radius in (m).

$\emptyset eff$: effective porosity of the reservoir (%).

II.13.2 Injection rate

The injected acid flow rate is calculated using the following formula derived from Darcy's law:

$$Qmax = \frac{4.917*10^{-6} KH[(Gf*Hmi.perf) - \Delta Psecurity - Pres]}{\mu\beta(ln\frac{Rd}{rw} + S)} \quad \text{(II. 2)}$$

Where:

KH: flow capacity (md.ft).

Gf: fracturing gradient (psi/ft).

Hmi.perf: well height, taken at the middle of the perforations (ft).

ΔP security: safety margin (psi).

Pg: reservoir pressure (psi).

μ: acid viscosity (cp).

β: bottomhole volumetric factor (bbl/STB).

S: skin or damage factor (dimensionless).

Rd: drainage radius (ft).

rw: well radius (ft).

II.13.3 Maximum injection pressure

This refers to the injection pressure that we need to apply at the surface for the acid to reach the damaged area and treat the matrix. The maximum treatment pressure should be the lower of the two following pressures:

- Fracturing pressure.
- Equipment's limited pressure

II.13.4 Surface treatment pressure

$$PTsurface = (PTbottom - Phyd) + \Delta Ptbg \text{..............................} \quad \textbf{(II. 3)}$$

Where :

PT.bottom: treatment pressure at the bottom of the well (psi).

Phyd: hydrostatic pressure (psi).

Ptbg: pressure losses in the tubing (psi).

II.13.5 Treatment pressure at the bottom of the well

$$PTbottom = Pfrac - \Delta Psecurity \text{..............................} \quad \textbf{(II. 4)}$$

With :

$$Pfrac = Gf * Hmi.perfo \text{..............................} \quad \textbf{(II. 5)}$$

Where :

ΔP security: pressure safety margin, ranging from 200 to 500 psi.

Gf: fracturing gradient in psi/ft (gf = 0.7 psi/ft).

2.3.6 Hydrostatic pressure

$Phyd = Hmi.perfo * \frac{d}{10}$ **................................ (II. 6)**

With: d: the density of the mud acid.

II.14 Conclusion

In conclusion, acidizing is a well stimulation technique that involves the use of acids to dissolve mineral deposits and increase the permeability of oil and gas reservoirs. The technique is commonly used in carbonate formations, but can also be effective in sandstone formations with the right acid selection. The choice of acid for an acidizing operation depends on several factors, including the type of formation, mineralogy, reservoir temperature, formation damage, safety, and compatibility with wellbore materials. Proper planning and execution of an acidizing operation is crucial to its success, and working with a qualified engineer is essential to ensure the appropriate acid is selected and that the operation is carried out safely and effectively.

CHAPTER III:
Real-life acidizing case study (procedures and results)

Ⅲ. Real-life acidizing case study (procedures and results)

Ⅲ.1 Introduction

The primary objective of this chapter is to present a comprehensive analysis of the acidizing stimulation conducted in ODZ-1bis. It seeks to evaluate the impact of acidizing on the well's productivity and the overall performance of the reservoir. By exploring the challenges faced during the acidizing treatment and the subsequent outcomes achieved, we can gain valuable insights into the effectiveness of acidizing as a stimulating technique.

Ⅲ.2 Regional framework

The Adrar oil field is located in the Adrar region in southwestern Algeria. It was discovered in 1956 and is operated by the Algerian national oil company, Sonatrach.

The Adrar field is one of the largest oil fields in Algeria, with estimated reserves of several billion barrels of oil. It is also rich in natural gas, with significant reserves estimated at several billion cubic meters.

Production in the Adrar field began in 1961 and increased rapidly in the following years. The field is operated by Sonatrach in partnership with international oil companies, including the French company Total and the Italian company ENI.

Oil production from the Adrar field is transported by a network of pipelines of several hundred kilometers to the Mediterranean coast of Algeria. Natural gas is also transported by pipeline to processing facilities located on the coast.

The Adrar field is a key element of the Algerian oil and gas industry and contributes significantly to the country's economy. However, the exploitation of oil and gas resources has also raised environmental and social concerns, including waste management and the impact on local communities.

Ⅲ.3 Local framework of the structure

Ⅲ.3.1 Static modelling

The objective of the geological phase of Touat Oil FDP project was to perform a study of the Shaa basin and then build 3D static models for six fields.

These models will serve for the simulation process in the reservoir engineering phase of the project. The six structures are:

- Hassi lllatou (LT)
- Sbaa
- Oued Zine (ODZ)
- Oued Tourhar (OTRA)
- Foukroun (FOK)
- Foukroun East (FOKE)

This part of the study and this report specifically cover the 3D static modelling for ODZ field. The field is a two-way closure structure bounded by one west-east reverse fault and one north-south reverse fault.

Grés de Sbaa sandstone is the main reservoir for this field, while Tournaisian and Strunian also show potential in metric sand layers **[14].**

Ⅲ.3.2 Regional geology background

The Sbaa basin is a NW-SE narrow trench located in the western part of the Sahara platform. The basin is limited to the west and south-west by the Ougarta mountains, to the east and north-east by the Voute d'Azzéne and Timimoun basin, and finally to the south-east by the Anhet basin (Figure Ⅲ-1).

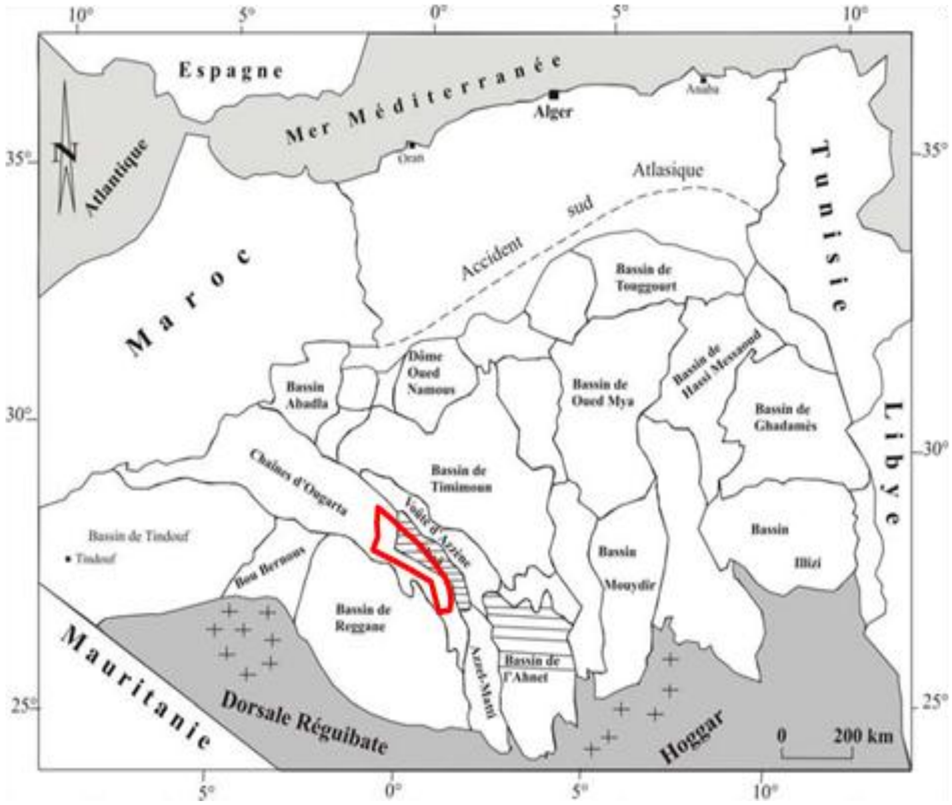

Figure Ⅲ. : Location of the Sbaa in the Sahara platform **[14].**

70km wide and 200km long, the Sbaa basin is the only oil-prone province in the South West of Algeria.

11 structures with oil-bearing formations have been discovered.

The current structural geometry of the Sbaa basin was acquired during three major tectonic phases:

Panafrican phase: the convergence and collision of the “Craton Ouest Africain” (C.0.A) and the “Craton Est Africain” (C.E.A)} has structured the Precambrian basement, on top of which the Paleozoic basins will later develop. The major structural trends observed in the basin at the present day came from this phase and have been reactivated during the Hercynian phase.

Caledonian phase: after the Panafrican orogeny, a major NW-SE extension phase and a subsidence of the platform occurred. This is the period of the formation of the main Paleozoic basins in the Sahara platform. The opening of the Paleo-Tethys in the north has highly controlled the paleo-current and depositional environment (from the south to the north). Minor compressional movement occurred at the end of this period.

Hercynian phase: it is the most important tectonic phase in North Africa since the Panafrican phase.

The Sbaa basin, which is closely linked to the Ougarta Mountains history, stood out from the surrounding basins at this period. At the end of the Carboniferous, a NW-SE compressional direction called "Ougartienne™ controlled the complex structuration of the Sbaa basin.

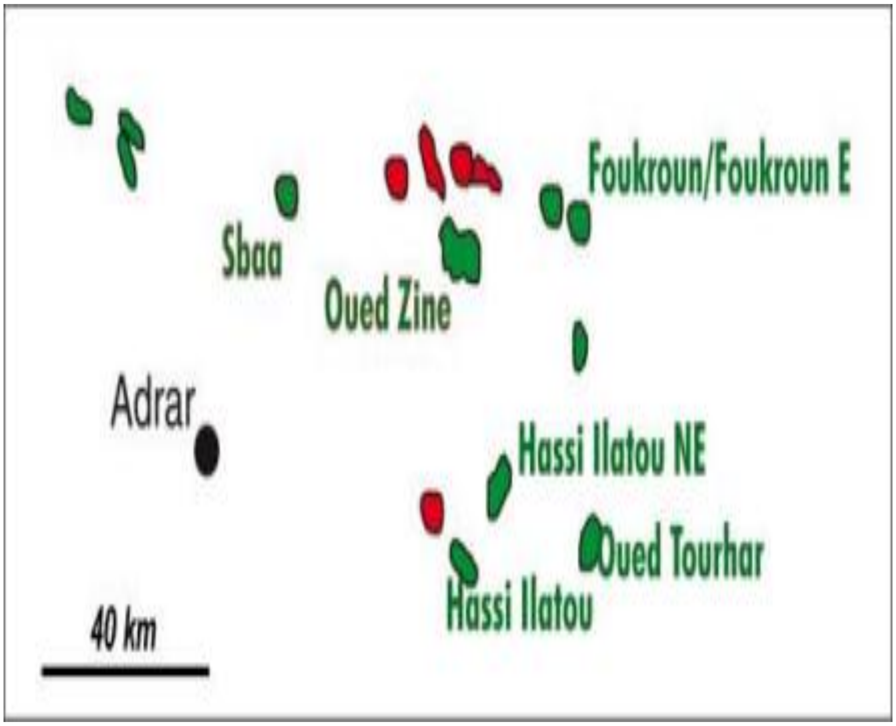

Figure Ⅲ. : The Sbaa basin **[14].**

Compressive phases during tectonic history led to local and basin-scale uplifts. Multiple unconformities and intense erosion periods control the present-day stratigraphy and the complexity of the geology in the basin. Below are listed the major unconformities:

- Intra-Arenigian (Ordovician Ill)
- Intra-Caradocian (Ordo Ill — Ordo IV)
- Caledonian (Silurian)
- Frasnian (Middle Devonian)
- Late Visean (Carboniferous)
- Hercynian (Paleozoic)

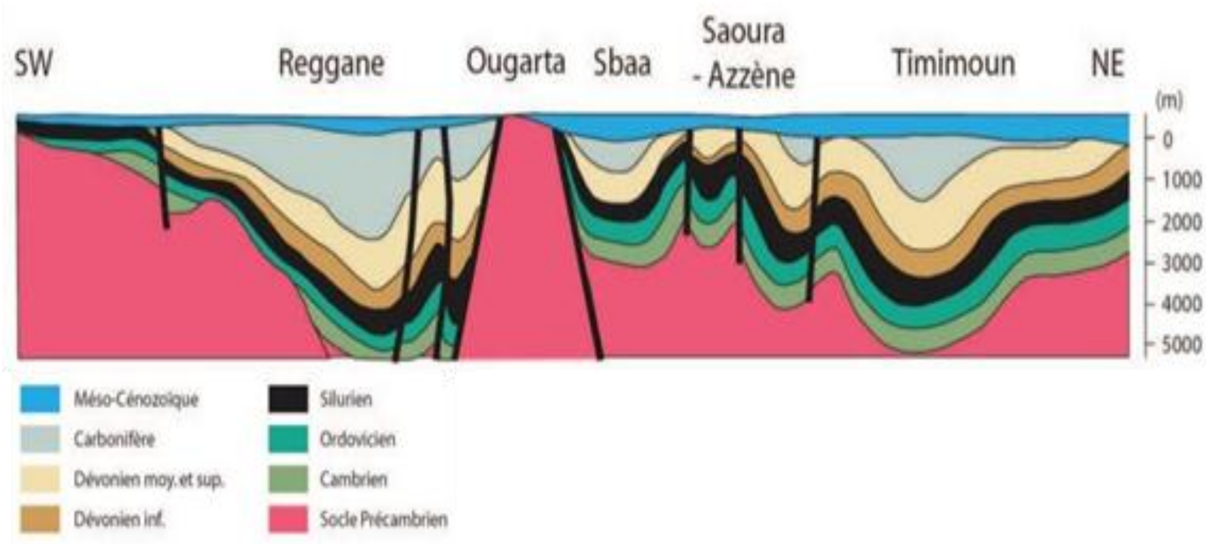

Figure Ⅲ. : SW-NE cross –section in the western Sahara **[14].**

The sediment thickness reaches a maximum of 2500-3000m in the Sbaa basin, significantly less than in the surrounding Timimoun or Reggane basins.

The south of the basin is characterized by pinch-outs and thinning of Paleozoic formations due to the presence of the Qugarta mountains. In the north, the Sbaa basin is open towards the Timimoun basin and presents thicker and complete Paleozoic sequences. From an exploration point of view, there is potential for stratigraphic traps in the south **[14].**

Ⅲ.3.3 Study Area

The study area for ODZ field covers around 40km and available data of nine wells were provided to be used in the static model process.

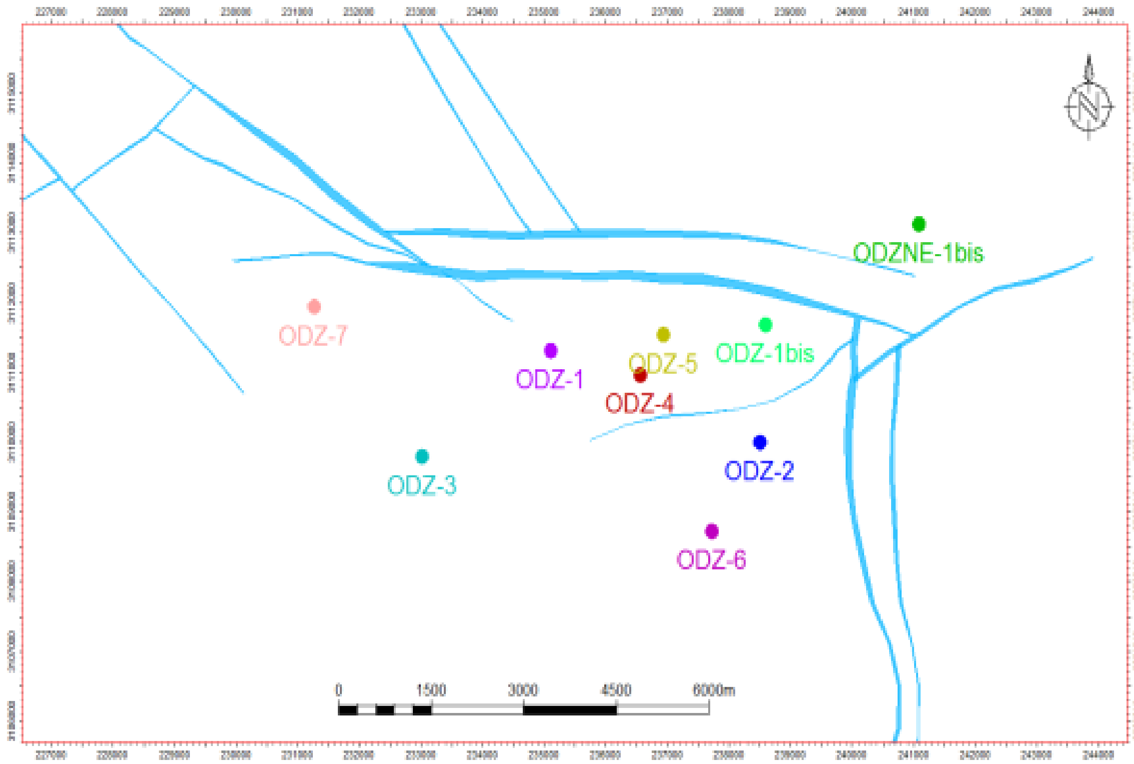

Figure Ⅲ. : ODZ field study area and wells location **[14].**

The studied area is Oued Zine field, it is a part of Touat oilfield, and it includes 10 wells.
Oued Zine structure is a monocline against a fault with an E-W trend.

Ⅲ.3.4 Petrophysical evaluation

The data audit and interpretation evaluation were effected and the following points summarize the work performed:

Petrophysical evaluation of ODZ field, covering a total of 4 wells.

Reservoir summation for the 4 wells in ODZ field **[14].**

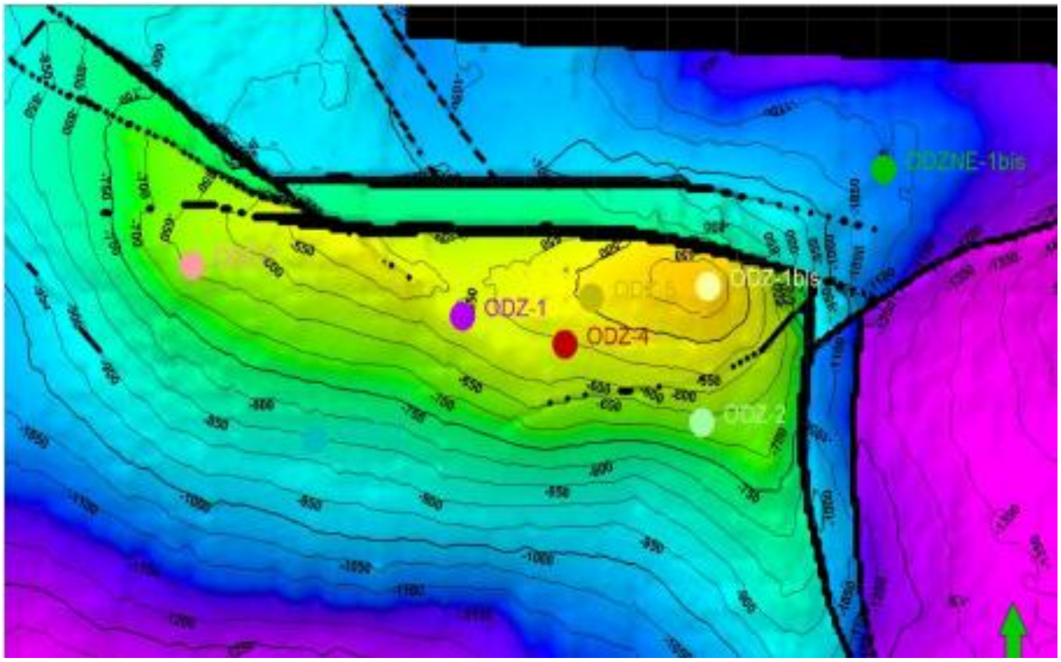

Figure Ⅲ. : ODZ field structural map **[14].**

Ⅲ.3.5 Reservoir evaluation

For reservoir evaluation the lithology model defined is the following: quartz, illite, oil, gas and water.

Water saturation method used is Indonesian with the following parameters: a=1, n=2, m=2,

For reservoir summation the cut-offs used were communicated and taken from well reports found by the client: VCL<50%, POROSITY>9%, SW, 60%.

❖ **ODZ-1bis**

This well contains as logs: GR, DT, CAL, NPHI, RHOB, LLS, LLD, SP and Cpor and Kperm. Perforation intervals are inside reservoirs Strunian and Gres de Sbaa, the core porosity matches with porosity logs, and ODT is estimated at -463m. Many tests on openhole were carried out showing oil in Tournaisian, Gres de Sbaa and Strunian

DST-2: Formation Tournaisian: 633.2-652.5m: Recovered of 2130 L of oil (d=0.8)

DST-3: Formation Tournaisian: 636.02-662.5m: Recovered of 2000 L of oil {(d=0.8)

DST-4: Formation Grés de Sbaa: 737.09-751m: Production of dry gas.

DST-5: Formation Grés de Sbaa: 748.25-760m: Production of gas with trace of oil

DST-8 Formation Gres de Sbaa + Strunian: 759.35-769m: Production of oil with gas.

DST-7: Formation Grés de Sbaa + Strunian: 759-778m: Production of 2931 L of oil.

DST-8: Formation Strunian: 760.53-787m: Production of 2092m3/h of gas.

DST-9: Formation Strunian: 787.4-796m: Production of 1943m3/h of gas+2.01 m3/h of oil

DST-11: Formation Strunian: 795.5-805m: Production of 20 L of oil (d=0.8).

DST-12: Formation Strunian: 821.6-841m: Production of gas (weak).

DST-13: Formation Strunian: 840.4-881m: Production of gas (weak).

DST-14 Formation Strunian: 879.6-889m: Production of gas (weak).

DST-15 Formation Strunian: 893.2-905m: Dry Test

DST-18 Formation Strunian: 952.6-966m: Production of 3209m3/h of gas.

DST-17 Formation Strunian: 990.73-1002.53m: Dry Test

- In June 2005 a casing test was done, as follows:

TF-31: Formation Tournaisian: 625-636/ 644-649; 7606 m3/h of gas

TF-30: Formation Gres de Sbaa: 722-740: 3629 m3/h of gas

TF-29: Formation Strunian: 781-T87/787-793: 2243 m3/h of gas+0.1 m3/h of oil **[14].**

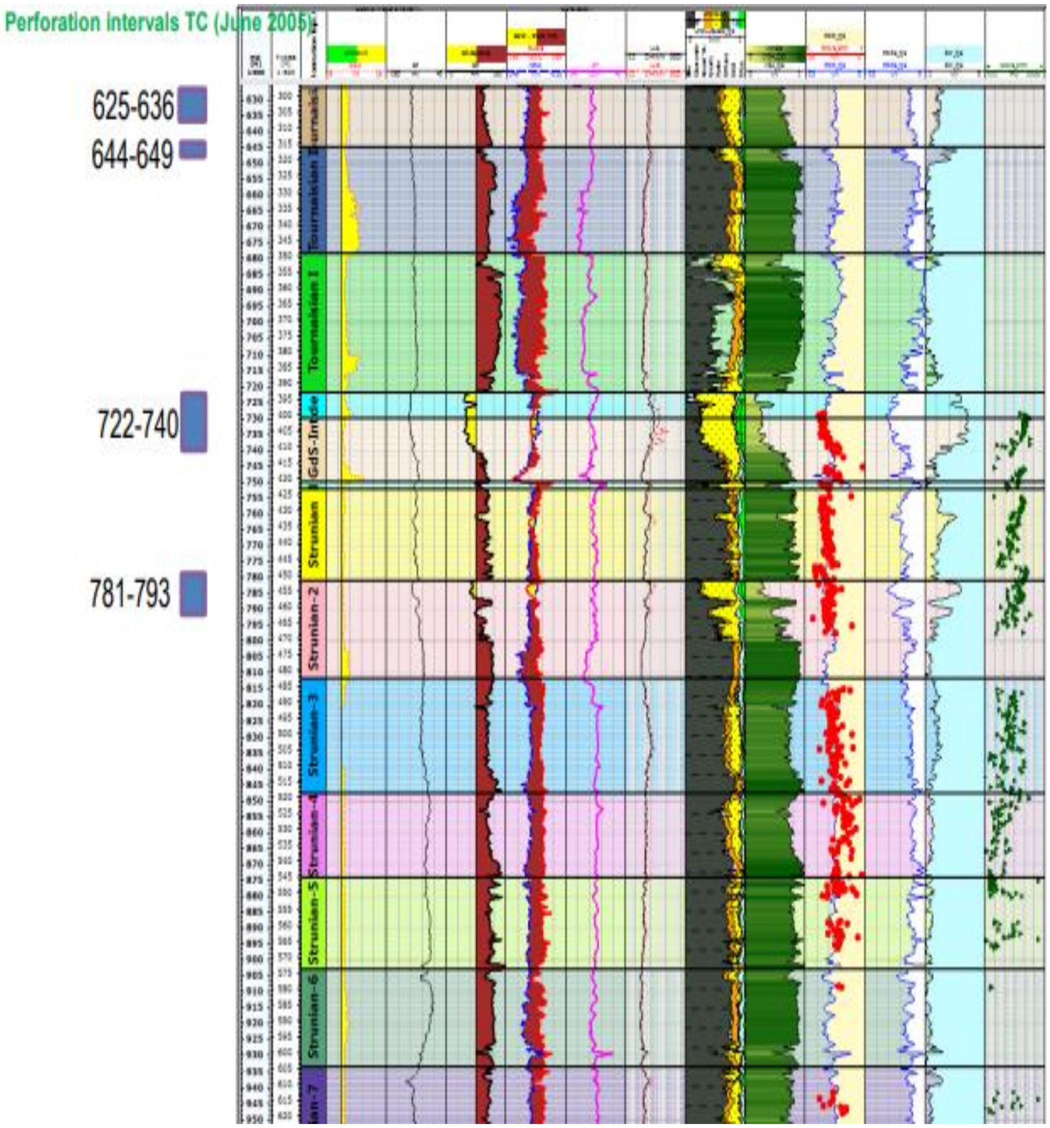

Figure Ⅲ. : ODZ-1bis reservoir evaluation **[14].**

Intervals of interest in this well are:

Strunian-2: Net pay 6.85m with average effective porosity 16% and water saturation 47%

Grés de Sbaa- Int: Net Pay 9.79m with average effective porosity 16% and water saturation 35%

Grés de Sbaa: Net Pay 7.89m with average effective porosity 16% and water saturation 37%

Ⅲ.4 Treatment Objective

The main purpose of the proposed intervention is to restore the well productivity by performing a meticulous CT operation within a given period of time.

Ⅲ.5 Recommended Treatment:

The following treatment is recommended to restore the well productivity:

Ⅲ.5.1 Stage 1

Perform intensive washing of the interval of the Perforated interval from 625 m to 685 m with high pressure jetting Nozzle using tube clean HCl 7.5% and treated water 2% KCL, flow back all washing fluid out to flare line using Nitrogen as needed and prepare for the matrix treatment.
Fill the well with Treated water through 2’’ 7/8 tubing & Annulus 9’’ 5/8 then Squeeze the Versol I into the formation. Keep the well under pressure squeeze for Four hours. After reaction time, open the well for kick-off using nitrogen to evacuate all treatment fluids.

Ⅲ.5.2 Stage 2

Stimulate the well with BJ Sand Stone Acid. Acetic Acid 7.5% will be pumped as a Pre-flush/over-flush followed by Sandstone Acid low strength. All fluids will be displaced with treated water followed by kick-off well for one or two days, then put the well under treated water 3% NH_4CL.
Note: concerning the squeeze of BJSSA (LS) depends on the injection rate during the squeeze of Versol I (Stage1), if the injection rate is less than 0.6 BPM, the second phase is canceled and the well will be filled with 3% NH_4CL in stage 1 **[15].**

Ⅲ.6 Course of operations

Ⅲ.6.1 Well ODZ -1bis

The Well ODZ-1bis is an oil producer located in Oued Zine Field and it was drilled with a total depth of 2472 m in the Tournaisien formation. The well is equipped with 2”7/8 suspended tubing and produced from perforated casing 9” 5/8 **[15].**

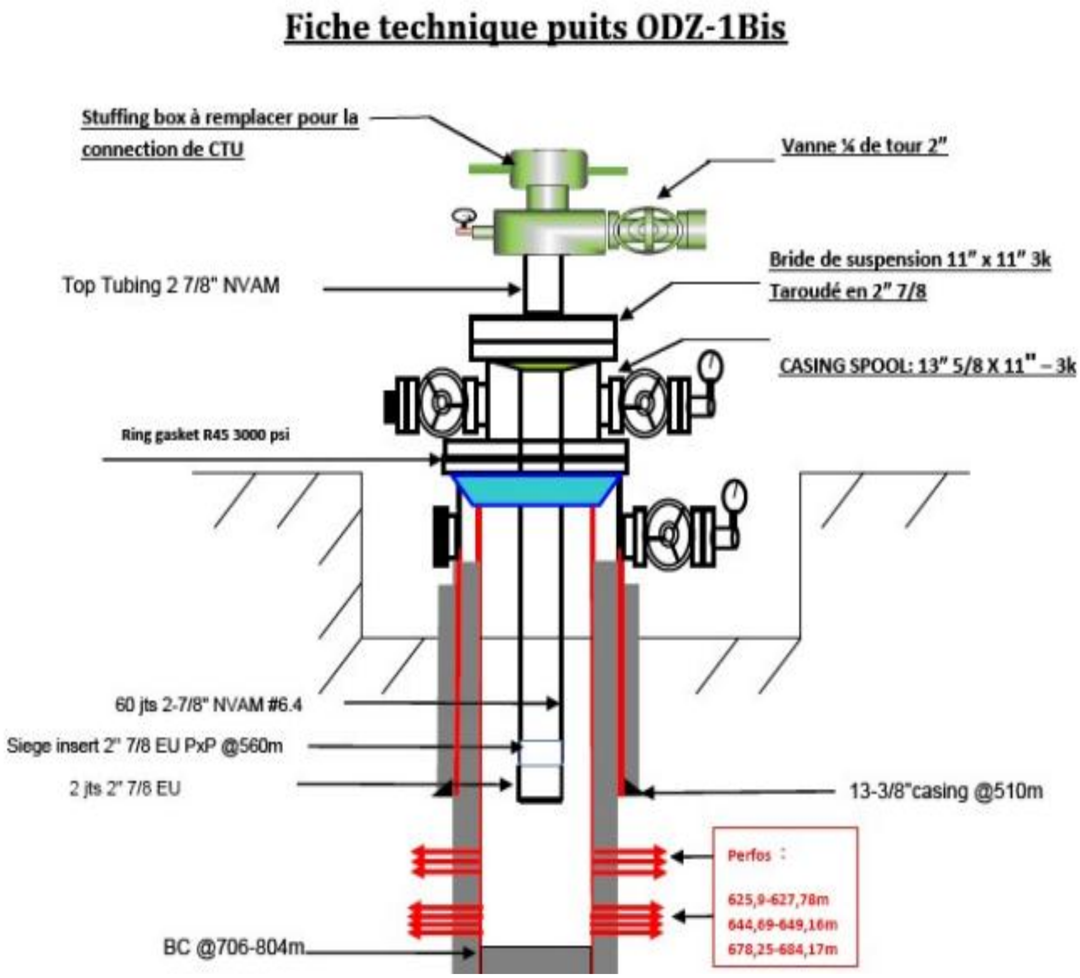

Figure Ⅲ. : ODZ -1bis well **[15].**

Ⅲ.6.2 Type of damage

The well doesn’t flow during the last CT intervention on march 14, 2023 due probably to mud invasion during the recent work over **[15].**

Ⅲ.6.3 Well Data

Table Ⅲ. : Jaugeage test 2020 **[15].**

Date	16/08/2020
Duse	/
WHP (psi)	84,3
Line P (psi)	43,5
Gas flow (m^3 /day)	515
Gas flow (m^3 /h)	21
Separation P (psi)	38,2
System diameter (pouce)	2,900
Orifice diameter	0,375
Oil flow (m^3/J)	36,987
Oil flow (m^3 /h)	1,541
Gas density : (air = 1)	1,014
Oil density : sp .gr /15°c	0 ,799
G.O.R (m^3 /m^3)	13,93
Water volume (m^3/J)	0 ,00
Salinity water %	0,00
BSW (water) %	0,00
BSW (sediment) %	0,00
W CUT %	0,00

Table Ⅲ. : Reservoir pressure **[15].**

PUITS	TYPE	INTERVAL (m)	PG (bar)
ODZ-1bis	Tournaisien	625-710	66
	Sbaa gres	710-750	76
	struniem	750-910	NA
ODZ-5	tournaisien	@627	63
	sbaa gres	@734	70

- Present Situation

Well is closed with WHP=0 psi.

Ⅲ.6.4 Equipment and personnel

Table Ⅲ. : Acidification equipment and personnel **[15].**

EQUIPMENT		PERSONNEL	
Coiled Tubing 171/2			
Pump Unit	01	CT Supervisor	1
Nitrogen Unit	01	CT Operator	1
Data acquisition (Isoplex)	01	PT Operator	1
Cittern of Treated water	01	CT Helper	1
Cittern of Acid	03	PT Helper	1
Cittern Versol |	01	LN2 Operator	1
N2 Cittern & Tractor	01	LN2 Helper	1
Standard BHA with HP jetting nozzle +Tandem double stripper	01	Chauffeur	8

Ⅲ.6.5 Fluids Composition

- **Stage One: Tube Clean Acid HCL 7.5%+VERSOL |**

Table Ⅲ. : Treated water system @ 2% KCL **[15].**

Aditif	description	by m^3	for 40 m^3
Water	Fresh water	987 Lts	39481 Lts
KCL	Clay Stabiliser	20 Kgs	800 Kgs

Table Ⅲ. : Acid system (HCL 7.5%)-Tube Clean **[15].**

Additif	Description	by m^3	for 3 m^3
Water	Fresh water	793 Lts	2379 Lts
Cl 25	Corrosion inhibitor	4 Lts	12 Lts
Hcl (32%)	Hydrochloric acid	203 Lts	609 Lts

Table Ⅲ. : VERSOL Ⅰ **[15].**

ADDITIF	Description	by m^3	for 6m^3
Water	Fresh water	865 Lts	5192 Lts
NH4CL	Argile stabilizer	20 Kgs	120 Kgs
F900	Chellating Agent	25 Kgs	150 Kgs
NE118	Surfactant	5 Lts	30 Lts
FAW25	Foaming Asgent	2 Lts	12l Lts
Inflo 40	Solvent Mutuel	100 Lts	600 Lts

Table Ⅲ. : Neutralizing Solution **[15].**

Additif	Description	by m ^{3}	for 2m^3
Water	Fresh water	998 Lts	1996 Lts
Na2CO3	Soda Ash	5 Kgs	10 kgs

- **Stage Two: Matrix Treatment BJSSA (LS)**

Table Ⅲ. : Treated water system @ 3%NH4CI **[15].**

Additif	Description	by m^3	for 37 m^3
Water	Fresh water	980 Lts	36242 Lts
NH4CL	Argile stabilizer	30 Kgs	1110 Kgs
NE118	Surfactant	1 Lts	37 Lts

Table Ⅲ. : Treated water @ 2%KCL **[15].**

Additif	Description	by m^3	for 27 m^3
Water	Fresh water	987 Lts	26649 Lts
KCL	Clay stabiliser	20 Kgs	540 Kgs

Table Ⅲ. : Preflush-Overflush 7.5% Acetic acid **[15]**

Additif	Description	by m^3	for 27 m^3
Water	Fresh water	980 Lts	5343 Lts
F300	Reducing control	6 Kgs	36 Kgs
CL 25	Corrosion inhibitor	4 Lts	24 Lts
NE118	Surfactant	2 Lts	12 Lts
Clatrol 6	Clay stabiliser	2 Lts	12 Lts
Inflo 40	Mutual solvent	25 Lts	150.0 Lts
Acetic Acid	Acetic acid	73 Lts	438.0 Lts

Table Ⅲ. : BJ Sandstone Acid (low Strength) **[15].**

Additif	Description	by m^3	for 5 m^3
Water	Fresh water	753 LTS	3767 lts
HCL 32%	Concentrated hydrochloric acid	15 LTS	75 lts
ABF	Ammonium bilfuoride	15 kgs	75 kg
HV	HV additif	15lts	75 lts
CL-25	Corrosion inhibitor	4 lts	20 lts
Z-5	Formic Acid	90 lts	450 lts
Clatrol 6	Clay stabilizer	2lts	10 lts
NE-118	Non–emulsifier	5 lts	25 lts
Ferrotrol300	Ieon control	6 kg	30 kg
MMR-2	Fines suspending Agent	2 lts	10 lts
Inflo 40	Mutual solvent	100 lts	500 lts

Table Ⅲ. : Neutralizing Solution **[15].**

Additif	Description	by m^3	for 5 m^3
Water	Fresh water	998 Lts	1996 Lts
$Na_2 Co_3$	Soda Ash	5 Kgs	10 Lts

Table Ⅲ. : Gel System **[15].**

Additif	Description	by m^3	Total quantity
Water	Fresh water	981 litres	491 liters
KCL	Argile stabilizer	20 Kg	10 Kg
$Na_2 Co_3$	Soda Ash	0,5 Kg	0,25 Kg
HEC 10	Agent : Gelling	5 Kg	2,5 Kg

Ⅲ.6.6 Treatment procedure

Washing perforation interval with Treated water & tube clean HCL 7.5% using an HP jetting Nozzle followed by matrix treatment with Versol I & and stimulate the well by BJSSA (LS) **[16].**

The treatment results have been provided in a table. (annex)

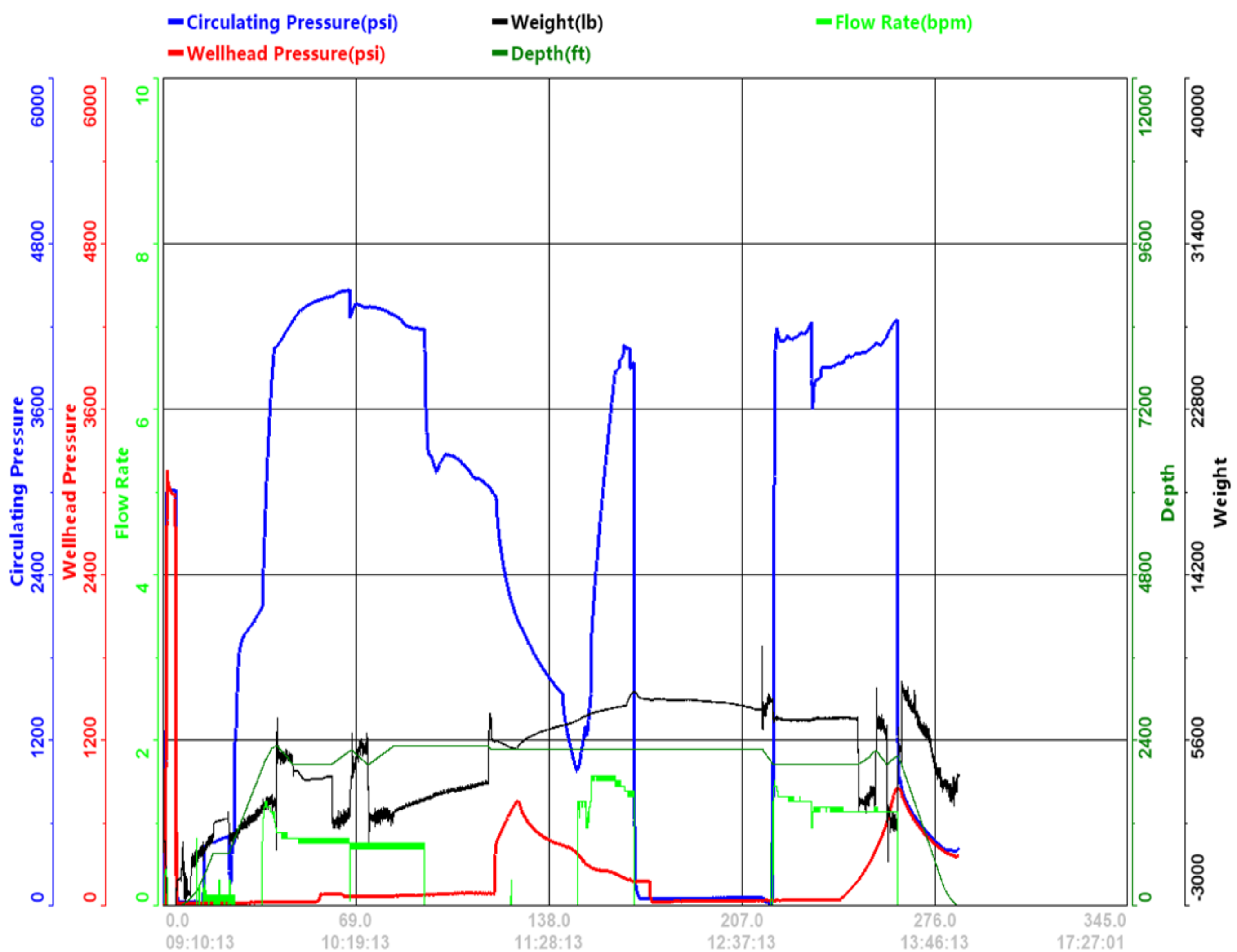

Figure Ⅲ. : Chart of squeeze acid operation using coil tubing , ODZ-1bis well **[16].**

This chart shows progress in time of the deference parameters unregistered while feeling and squeezing of acid trough the wellbore in order time enhance well production by dissolving the mineral scales deposited around the perforations and plugs the oil flow inside the tubing ..

Ⅲ.7 Evolution of flow rates and WHP

Table Ⅲ. : flow rates and WHP in ODZ-1bis well

	Q m^3/h	WHP bar
Actual state	1,541	6
During closed well	0	0
After : acidification	1,459	11

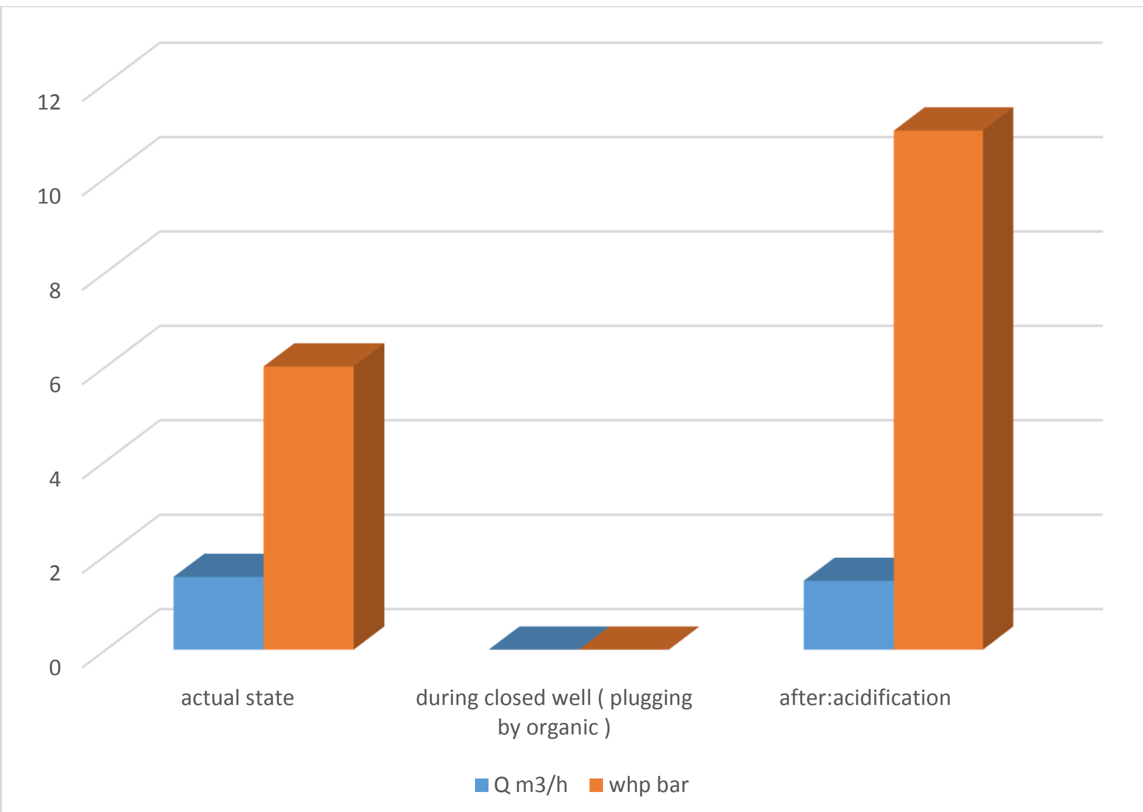

Figure Ⅲ. : Evolution flow rates and WHP in ODZ-1bis well

Interpretation

The data provided in the table shows the flow rates of oil before, during, and after an acid treatment performed to reduce damage in the ODZ:1bis well. Here is an interpretation of the data:

Before Treatment: The flow rate of oil before the acid treatment was 1.541 m^3/h. This indicates the initial production rate of oil from the well. , while the wellhead pressure was 6 bars (84 psi).

During Treatment: the flow rate and wellhead pressure are listed as 0. wishes due to damage in the well, leading to a complete cessation of oil flow. The treatment was likely focused on addressing the damage and improving the flow potential of the well.

After Treatment: Following the acid treatment, the flow rate improved to 1,459 cubic meters per hour, with the wellhead pressure reaching 11 bars.. This signifies that the treatment was successful in reducing the damage or blockage in the well, allowing for improved oil production.

Overall, the data suggests that the acid treatment was effective in mitigating the damage in the ODZ: 1bis well, as evidenced by the significant increase in oil flow after the treatment. This indicates a positive outcome in terms of restoring or enhancing the productivity of the well.

Ⅲ.8. Economic study

Ⅲ.8.1 Definitions

Ⅲ.8.1.1 Payout of operations

The term "payout" in operations refers to the number of days of production that a treated well must deliver after treatment in order to cover the cost of the operation with the net gain achieved as a result of the treatment. In other words, the payout represents the time it takes for the generated revenue from the well's increased production to offset the expenses incurred during the treatment operation. It is a measure used to assess the economic viability and profitability of the treatment by determining how long it takes to recover the investment made in the operation.

$$Payout\ (days) = \frac{Equivalent\ Volume\ Cost\ (m^3)}{Net\ Production\ Gain} \quad \text{(Ⅲ.1)}$$

Ⅲ.8.1.2 Annual production gain from acidification

The annual production gain is calculated as the difference between the actual cumulative production of the well and the projected production, determined by extrapolating the behavior of the damaged well.

- For 1 Barrel = 0,159 m^3 → 75 $

- $1m^3$ = 471,698 $

GAIN = 35-0= 35

35 × 471,698 = 16 509,43 $

Ⅲ.8.2 The entirety of the operations

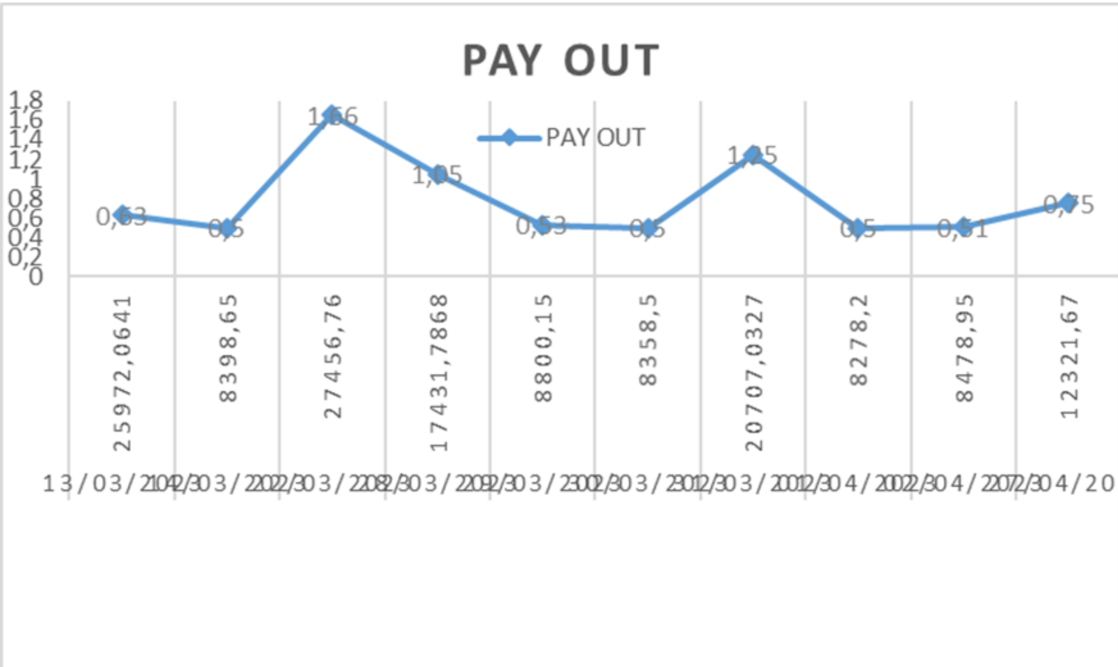

Figure Ⅲ. 10: Analysis of PAYOUT.

Table Ⅲ : Analysis of CT operation and the financial impact .

Intervention Date	Operation Type	Costs (Algerian Dinar)	Costs (US $)	PAYOUT (days)
13/03/2023	T/C & pompage Versol	3 557 817,00	25972,0641	0,63
14/03/2023	Kick off	1 150 500,00	8398,65	0,50
22/03/2023	T/C clean out	3 761 200,00	27456,76	1,66
28/03/2023	T/C & traitement	2 387 916,00	17431,7868	1,05
29/03/2023	Kick off	1 205 500,00	8800,15	0,53
30/03/2023	Kick-off Day-2	1 145 000,00	8358,5	0,50
31/03/2023	Kick-off Day-3	2 836 579,82	20707,0327	1,25
01/04/2023	Kick-off	1 134 000,00	8278,2	0,50
02/04/2023	Neutralisation	1 161 500,00	8478,95	0,51
27/04/2023	Neutralisation avec boue (mud), D=1,13	1 687 900,00	12321,67	0,75
		Total		7days 21h

Interpretation

It looks like this is a list of intervention dates and associated operation types and costs, presented in both Algerian Dinar and US dollars. The "PAYOUT" column may refer to the amount of money paid out for each operation, but it's not entirely clear without additional context.

The list includes several "Kick off" operations, which are not described in detail. There are also some operations involving T/C (which refers to tubing/casing) and pompage (pumping), as well as clean out, traitement (treatment), and neutralisation (neutralization). The costs for these operations range from around 8,000 to 27,000 US dollars.

The list covers a period of 7 days and 21 hours, suggesting that these interventions took place over the course of just under 8 days.

General conclusion

General conclusion:

This thesis provides a comprehensive analysis of acidizing as a well stimulation technique and its impact on enhancing well productivity. Through the exploration of wellbore damage, acidizing process principles, and a real-life case study, several valuable points emerge regarding the process of acidizing.

The investigation of wellbore damage underscores its significance in well stimulation operations. Understanding the mechanisms and effects of wellbore damage is crucial for successful acidizing treatments. Acidizing offers an effective solution by dissolving and removing damaging materials, improving fluid flow pathways within the formation and ultimately enhancing well productivity.

Furthermore, the understanding of acidizing principles and applications is essential for optimizing treatment design. By evaluating reservoir characteristics, such as lithology, mineralogy, and fluid properties, the acidizing treatment can be tailored to maximize its effectiveness. The selection of appropriate acids and additives, customized for the specific reservoir conditions, plays a vital role in facilitating effective acid-rock interactions and preventing potential formation damage.

The real-life acidizing case study presented in this research provides empirical evidence of the effectiveness of acidizing in improving well productivity. It offers practical insights into the challenges faced during the acidizing operation, the treatment design considerations, and the subsequent improvement in well performance. The case study demonstrates the real-world application of acidizing techniques and reinforces the value of its implementation.

Moreover, this thesis highlights several other significant points regarding the process of acidizing. Thorough pre-treatment assessments, including reservoir characterization, formation evaluation, and potential risk analysis, ensure a well-informed and tailored acidizing treatment design. Economic viability and environmental considerations are essential factors to be evaluated when deciding on the utilization of acidizing techniques.

Additionally, continuous monitoring and evaluation of the well's performance post-acidizing treatment are imperative. Analyzing production data, conducting periodic well tests, and implementing reservoir surveillance techniques provide valuable insights into the long-term effectiveness and sustainability of the acidizing treatment. This ongoing assessment allows for necessary adjustments to optimize well productivity and ensure the longevity of positive outcomes.

In conclusion, this thesis contributes to a comprehensive understanding of acidizing as a well stimulation technique and its significance in enhancing well productivity. By addressing wellbore damage, optimizing treatment design, and presenting a real-life case study, this research offers valuable insights and practical recommendations for industry professionals. Implementing these recommendations, including well preparation, customized treatment design, economic feasibility assessment, and continuous monitoring, can lead to improved well performance, increased hydrocarbon production, and the sustainable development of oil and gas resources.

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Annex

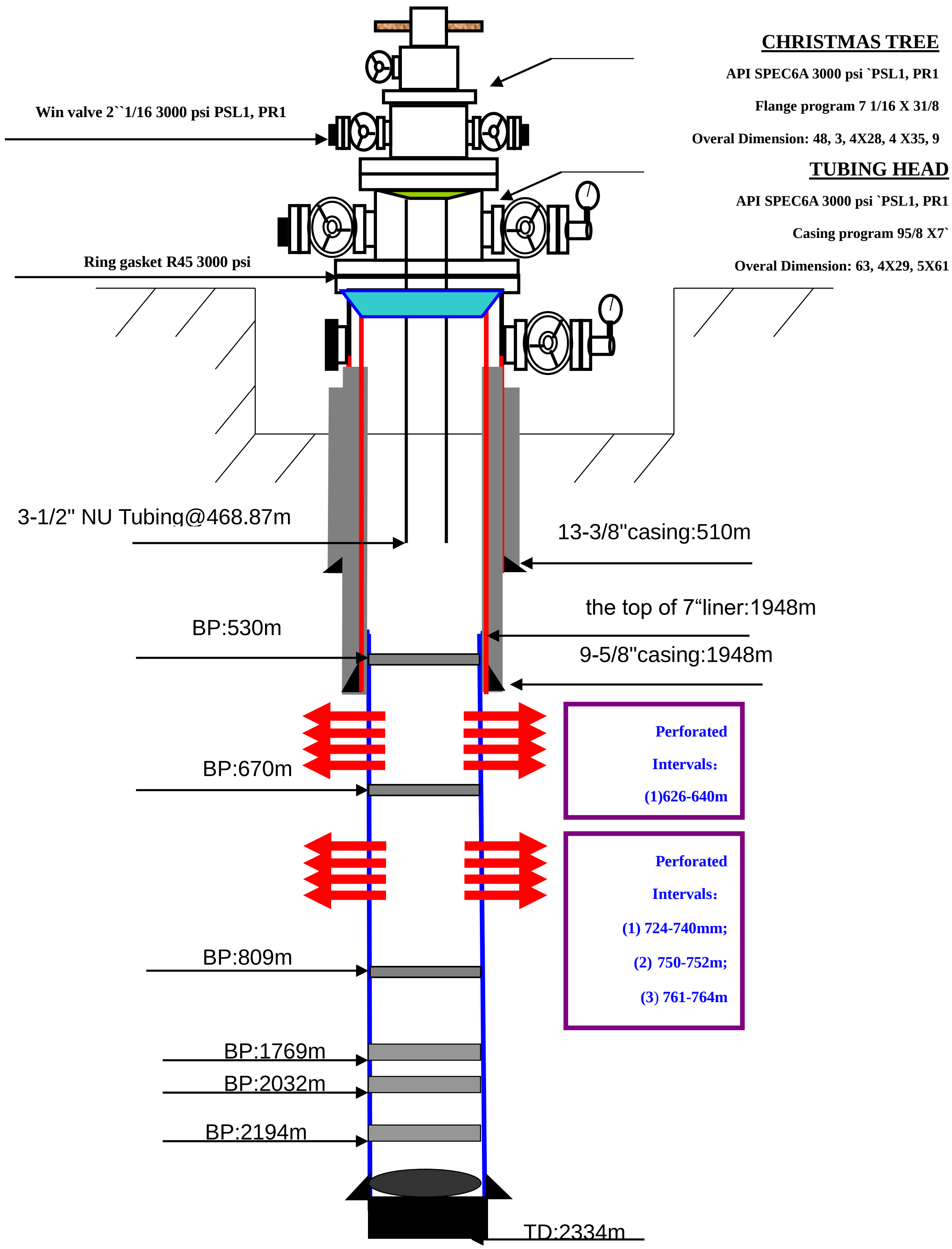
Well data

Well name	OUED ZINE-1bis
Field	**OUED ZINE**
Type of well	**Exploration**
Location	**Adrar**
Coordinates	**X= 238592.62 Y= 3111692.53**
Elevation	
KB-GL	**KB= 329.02 m GL= 323.62 m**
Purpose of the well	**Tournaisian and Sbaa Sandstones**
Drilling rig	**ENTP 179 C-1200**
Spud Date	**21.04.1985**
Total depth	**2472 M**
Cementing quality	
Perforated intervals	**625-636m/644-649m 722-740m 784-787/788-793m 1991-2028m 2035-2142m 2157-2179m 2263-2335m**
Plug	**B603 B665 B763 B1769 B2032 B2194 C527 C2344**

Casing Data

Diameter	**Lb/ft**	**Grade**	**Depth**	Observation
13 3/8”			**0-510m**	
9 5/8”			**0-1948m**	
7” liner			**1948-2334m**	
The casing 7” doesn’t cover to the final depth 2472m				

Well completing profile



Puits	ODZ-1bis	Appareil	Coiled Tubing
Contractant	BJSP	Date	**12/3/2023**
Superviseur	**BERKANE Salem**		
Operation: Clean sweap			

Job Sequence				
1st Day: 11-03-2023				
Time	Events	WHP	CPT	FLARE
11h00	rig up injecteur avec grue SH négatif suite puissance insuffisante de grue			
13h00	attente 2 éme grue 50T de Gtp, rig up injecteur et test équipement OK			
15h00	Fin de montage, job prévu pour demain matin			

Field operation Report

Specific comments

12/03/2023

- Sup-Information:
  Production Tubing: ……
  Perforation: 625.9 à 627.78 m.

- Consumed volume:
  Treated water: …..m^3.
  Reformat: ……....m^3.
  Clean sweap III: …………m^3.
- Note:
  Clean sweap over night

Table : log data (min)

Time	Pressure1	Pressure2	Circulating Pressure	Wellhead Pressure	Weight	Speed	Depth	Flow Rate	Flow Total
HH:mm:ss	psi	psi	psi	psi	lb	ft/min	ft	bpm	bbl
09:10:13	0	0	0	0	0	0	0	0	0
09:11:13	0	0	1551.5	1283.25	-1432.59	0	-0.52	0.44	698.19
09:12:13	0	0	3036.3	3042.1	-4098.63	-1.97	-0.56	0	698.32
09:13:13	0	0	3013.1	2989.9	-3977.22	0	-0.56	0	698.32
09:14:13	0	0	3010.2	2982.65	-3911.32	0	-0.56	0	698.32
09:15:13	0	0	102.95	14.5	-1686.78	0	-0.89	0	698.32
09:16:13	0	0	29	13.05	-1622.26	0	-0.89	0	698.32
09:17:13	0	0	27.55	13.05	-687.34	27.89	11.91	0	698.32
09:18:13	0	0	27.55	14.5	-2356.33	27.89	40.29	0	698.32
09:19:13	0	0	27.55	14.5	-2311.61	40.68	74.02	0	698.32
09:20:13	0	0	29	14.5	-828.2	46.59	116.34	0	698.32
09:21:13	0	0	29	14.5	-570.98	48.56	163.62	0	698.32
09:22:13	0	0	20.3	15.95	-472.2	29.2	210.67	0.63	698.44
09:23:13	0	0	14.5	14.5	-290.88	86.95	289.29	0.06	698.5
09:24:13	0	0	15.95	15.95	-144.63	90.56	378.07	0	698.5
09:25:13	0	0	430.65	15.95	120.22	95.15	470.79	0.13	698.57
09:26:13	0	0	443.7	17.4	341.27	99.09	569.12	0	698.69
09:27:13	0	0	455.3	15.95	358.82	102.04	670.67	0.06	698.82
09:28:13	0	0	450.95	17.4	1232.62	0	761.82	0.06	698.88
09:29:13	0	0	465.45	17.4	1323.02	0	761.82	0.06	698.94
09:30:13	0	0	472.7	17.4	1432.9	0	761.82	0.25	699.01
09:31:13	0	0	482.85	17.4	1449.48	0	761.82	0.13	699.13
09:32:13	0	0	490.1	18.85	1494.2	0	761.82	0.13	699.26