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-THEME-

Operational Strategies for Enhancing Injectivity and Protecting Against Corrosion in Gas Injection Wells in Hassi Messaoud field

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DEDICATION

Praise be to Allah for His grace and assistance in completing this research.

This work is sincerely and proudly dedicated to our dear parents, to both of our families, to our classmates, and to our circle of friends for their love, encouragement, and patience. They have been the support, the source of strength, and inspiration throughout our academic journey, and particularly in the completion of our thesis.

Abstract

Abstract

This work presents the main operational interventions aimed at improving injectivity and protecting injection wells from corrosion. Efficient fluid injection into the reservoir is essential for maximizing production. Operational strategies to enhance injectivity include: cleaning interventions, matrix acidizing, and hydraulic fracturing. Strategies to protect wells from corrosion include: detecting aggressiveness factors and installing impressed current systems for electrochemical corrosion. These protective measures reduce corrosion risks, ensuring safe and reliable operation of injection wells while extending their lifespan in the Hassi Messaoud field.

Keywords: injection wells, injectivity, protection, corrosion, cathodic protection.

Résumé

Ce travail présente les principales interventions opérationnelles visant à améliorer l'injectivité et à protéger les puits d'injection contre la corrosion. L'injection efficace de fluides dans le réservoir est essentielle pour maximiser la production. Les stratégies opérationnelles pour améliorer l'injectivité incluent : les interventions de nettoyage, l'acidification matricielle et la fracturation hydraulique. Les stratégies pour protéger les puits contre la corrosion incluent : la détection des facteurs d'agressivité et l'installation de systèmes de courant imposé pour la protection contre la corrosion électrochimique. Ces mesures protectives réduisent les risques de corrosion, assurant une opération sécurisée et fiable des puits d'injection tout en prolongeant leur durée de vie dans le champ de Hassi Messaoud.

Mots-clés : puits d'injection, injectivité, protection, corrosion, protection cathodique.

ملخص

يعرض هذا العمل التدخلات التشغيلية الرئيسية التي تهدف إلى تحسين الحقن وحماية آبار الحقن من التآكل. يعد الحقن الفعال للسوائل في الخزان أمرًا ضروريًا لزيادة الإنتاج إلى الحد الأقصى. وتشمل الاستراتيجيات التشغيلية لتحسين الحقن ما يلي: تدخلات التنظيف، وتحميض المادة الأساسية، والتكسير الهيدروليكي. تشمل استراتيجيات حماية الآبار من التآكل ما يلي: الكشف عن العوامل العدوانية وتركيب أنظمة التيار المؤثر للحماية من التآكل الكهروكيمياوي. تقلل هذه الإجراءات الوقائية من مخاطر التآكل، مما يضمن التشغيل الآمن والموثوق لآبار الحقن مع إطالة عمرها الافتراضي في حقل حاسي مسعود

الكلمات المفتاحية : آبار الحقن، قابلية الحقن، الحماية، التآكل، الحماية الكاثودية.

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List of symbols

Symbol	Explanation	Unit
A	battery autonomy	Days
C	capacity of battery	Ah
Dp	Diameter of the pipeline	M
D	deep discharge limit	%
Dext	Outer diameter of the pipe	M
d	diameter of the anode	m
E	Thickness of the tube	M
Ef	Energy to be provided	Wh/day
En	Energy required for the sinking station	Wh/day
e	Thickness of the tube	m
Gf	fracturing gradient	psi/ft
H	thickness of the formation	Ft
H mi.perf	well height	ft
Hu	Useful reservoir height	M
I	Current intensity during the test	A
Id	Current density	mA/m
Idr	Solar irradiation	Kwh/m²
Is	Sinking current	A
K Daniel	coefficient of Daniel's orifice	-
K	Permeability	Henry/m
KH	flow capacity	md.ft
L	Length	M
L	length of the anode	m
N_b	Number of batteries.	-
Nps	Number of solar panels	-
P line	line pressure	Bar
P	Sinking power	W
PC	Peak power of the solar panel	Wc
PCG	Peak power of the photovoltaic generator	Wc
P_{fw}	bottom-hole flowing pressure	psi
Pg	reservoir pressure	psi
Phyd	The hydrostatic pressure	psi
Psafety	safety margin	Psi
Q	flow rate	m3/j
R trans	Transversal resistance of the pipe	Ω·m

List of symbols

Ravg	**R**: Approximate average insulation value in Ω.m²	Ω.m²
R_d	Radius of damage	m
R_e	drainage radius	ft
Rc	Characteristic resistance	Ω
R_{IS}	Insulation resistance	Ω·m
r	Longitudinal resistance of the pipeline	$\Omega \cdot m^{-1}$
R_v	earth resistance	Ω
Rw	Well radius	m
S	skin or the damage factor	-
Se	Exterior surface area of the structure (to protect)	m²
Tt	Temperature	K
Ti	injection time	Hour
Tf	Operating time of the solar generator station	h/j
U	system operating voltage	V
U_b	Voltage provided by a single battery	V
Vacide	Volume of acid used for the main treatment	m³
α	Attenuation coefficient	m^{-1}
β	formation volume factor	bbl/STB
Δp	different of pressure	Bar
ΔPsafety	pressure safety margin	Psi
ΔU	Average potential gain	V
f	Losses	%
μ	viscosity of the acid	CP
η	Efficiency of the rectifier in general	%
ρa	Resistivity of steel	Ω·m
ρs	soil resistivity	Ω·m
ρ	resistivity of copper	Ω·m
$\emptyset u$	Useful porosity of the reservoir	%

General introduction

Hassi Messaoud is a significant oil field located in Algeria, known for its extensive operations and contribution to the country's oil production. The field utilises gas injection wells as an important part of its reservoir management strategy.

Gas injection wells in Hassi Messaoud play a vital role in maintaining reservoir pressure. By injecting gas into the reservoir, the pressure is enhanced, which helps sustain or increase oil production rates over time. Injecting gas into the reservoir can improve the displacement of oil towards production wells, thereby increasing the overall recovery factor from the reservoir.

In Hassi Messaoud, like in many mature oil fields, injector gas wells can face significant problems such as decreased injectivity and corrosion. The decreased of Injectivity is caused by various factors as formation damage and reservoir compaction, Corrosion in gas injector wells can have significant impacts on operations, equipment integrity components such as casing, tubing, valves, and surface equipment and overall production efficiency, this can lead to structural weakening, leaks and eventual equipment failure.

The objective of our work is firstly to investigate the effectiveness of intervention methods such as mechanical cleaning, acidizing and hydraulic fracturing, in restoring or enhancing injectivity in corroded or damaged injector wells. Assess the operational outcomes and ensure the success of these techniques. Secondly to Study the corrosion mechanisms prevalent in gas injector wells at Hassi Messaoud. This involves identifying the corrosive agents present in the soil and to propose a cathodic protection system with impressed current to safeguard surface installations in the gas injection zone at Hassi Messaoud fields.

This work is divided into three chapters and a general conclusion. The first chapter provides a general aspects of gas injection wells and different methods of protection. The second chapter illustrates the presentation of the injectors wells operations and interventions. The third chapter presents the problem of corrosion in the surface installations of injector wells and the method for assessing soil aggressiveness.

Chapter 1

General aspects of gas injection wells

Introduction:

The extraction of oil through natural drainage refers to direct production without the use of any processes to maintain the natural energy of the reservoir; it rarely exceeds 30%, that's why it is necessary to inject energy into these fields to achieve better recovery. Maximizing recovery and preserving reservoir efficiency is the primary goal of oil field development, and for this purpose, several recovery mechanisms are employed.

I.1.The performance of injectors wells

I.1.1 Mechanisms of oil recovery

The first issues in definitions are about the way of enhanced oil recovery in the last of 19th century. One of the theories about the definition of enhanced oil recovery ways which has a long time history classifies different kinds of recovery as follows:

- Primary recovery.
- Secondary recovery.
- Tertiary recovery.

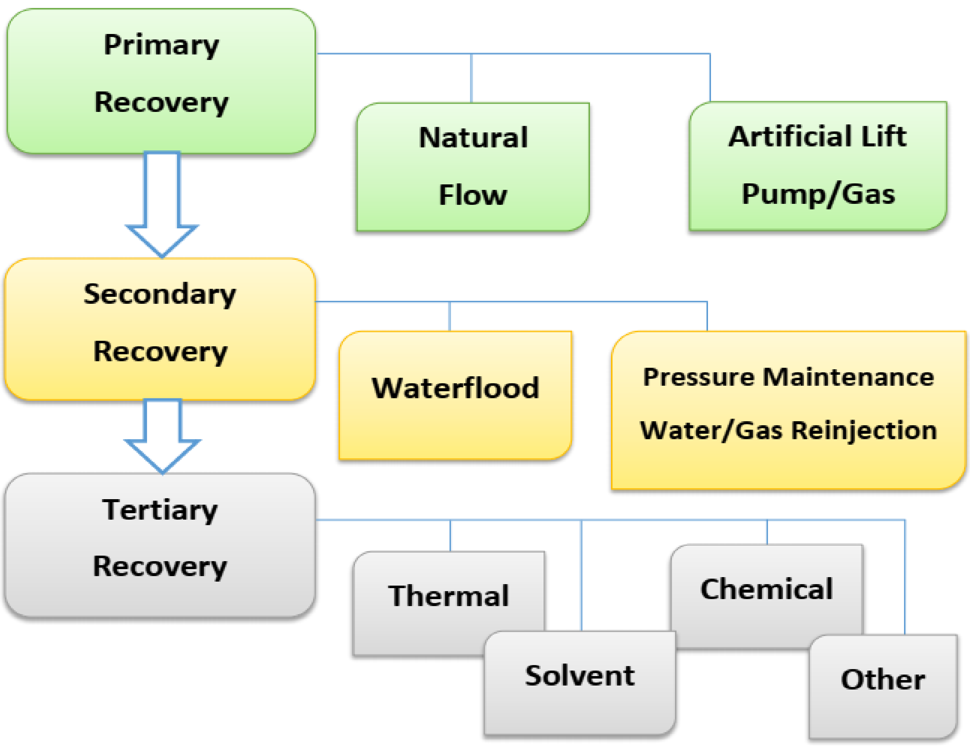


Figure I.1: Mechanisms of oil recovery [2].

I.1.1.1 Primary recovery in this classification is the only use of reservoir natural energy the main sources of energy in natural depletion are:

- Dissolved gas
- Gas cap.
- Rock grains and liquid effect
- Aquifer (water drive).
- Gravity drainage drive
- Combination drive [2].

I.1.1.2.The secondary recovery is also each recovery which is done after the primary recovery in order to maintain reservoir pressure .The recovery of oil after its initial phase is achieved through natural depletion, utilizing the reservoir's energy. This primary recovery typically does not yield a satisfactory production rate due to the pressure drop resulting from the depletion of this energy. For this reason, it was necessary to employ another method, known as secondary recovery, to restore the reservoir closer to its initial state. we can distinguish three main classes according to the nature of the agents employed:

- **Miscible processes:** injection of hydrocarbon gas or carbon dioxide, depending on availability and prices.
- **Thermals processes:** steam injection, or hot water injection, and in-situ combustion by air injection (suited for heavy oil deposits).
- **Chemicals processes:** direct enhancement of water injection, through the addition of water-soluble polymers and/or surfactants playing a beneficial role in displacing crude from the reservoir rock.

I.1.1.3.Tertiary oil recovery techniques are employed extensively in unconventional oil and gas plays across the brownfields, where they help operators recover up to 75% of the oil initially in place . Consequently, this ramps up existing production by up to 300%.[1]

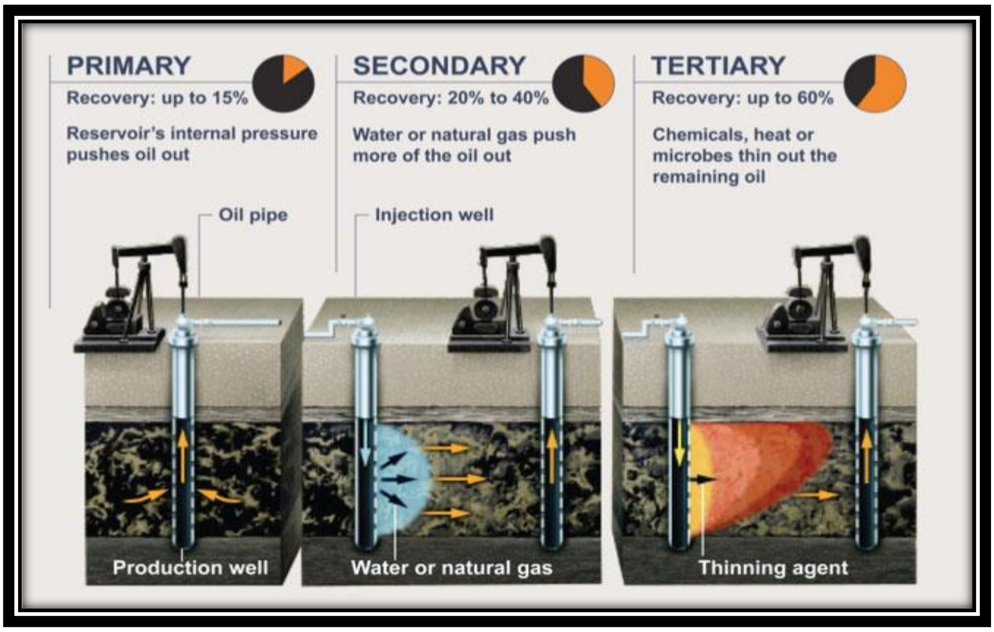


Figure I.2: Different types of recovery. [2]

I.1.2 Mechanism of secondary recovery

Secondary recovery involves injecting another fluid to maintain pressure in the reservoir and thus recover more oil. The injection of water or gas in large reservoirs is distributed throughout the reservoir, displacing the oil towards the production wells. Secondary recovery reaches its limits when the proportion of water or gas exceeds that of the oil in the recovered mixture. Injection processes are implemented after the decompression of the reservoir to stabilize the pressure above the "bubble point" and increase the amount of oil recovered. [3]

1.1.2.1.Water injection

Water injection or water flooding is a secondary hydrocarbon recovery technique where produced water, treated or demineralized water, or freshwater is injected into a well's formation under high pressure and temperature conditions to recover more of the oil initially in place, involving these steps:

- Injection wells are first drilled close to the producing well to be remediated. (An injection well is a well that is designed to channel water or other fluid into the surrounding formation in close proximity of a producing well to stimulate hydrocarbon production or for fluid disposal purposes).
- Produced water or treated water is pumped into the formation under high pressure. Tests may be carried out to ensure that the produced water to be injected is compatible with

the formation, therefore the water may be treated to remove fine particles that might clog the well and oxygen that encourages the growth of bacteria.

- The pressurized fluid exerts a sweeping force that ‘mops up’ existing hydrocarbon from hard-to-reach areas in the formation, driving the products toward a nearby producing well for collection via a production casing.

The selection of water injection is typically determined under the following circumstances:

- Reservoirs exhibiting low natural energy
- Oil reservoirs characterized by low permeability or substantial size
- Aquifers that are inactive or of negligible volume.[4]

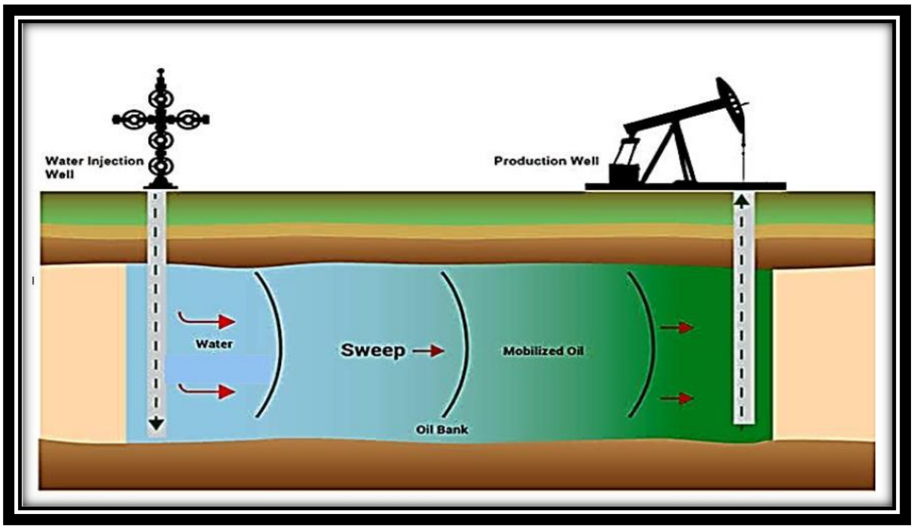


Figure I.3: water injection recovery.[4]

1.1.2.2.Water alternate gas injection

The Water Alternating Gas process is a cyclic process of injecting alternating gas followed by water and repeating this process for number of cycles. The main purpose of WAG injection is to improve oil production recovery, which help to improve both macroscopic and microscopic sweep efficiency, maintaining reservoir pressure, slow down the gas breakthrough, viscosity reduction caused by the gas dissolution in oil, fluid composition variation and decrease the residual oil saturation resulted from the flow of three phases and effects associated with relative permeability hysteresis. [5]

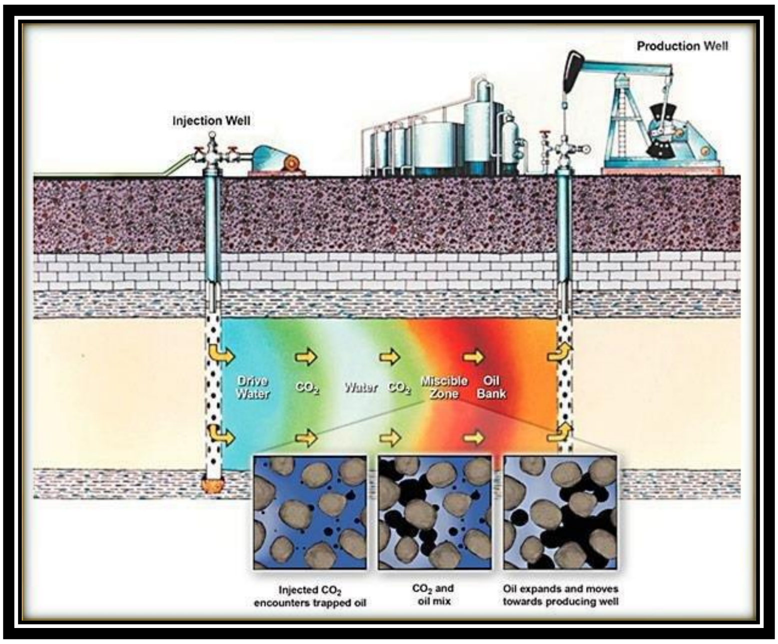


Figure I.4: Water Alternate Gas recovery. [6]

I.1.3 Gas injection

Gas injection is a method of enhancing oil production that involves the use of gases that dissolve in the oil to reduce viscosity and improve flow rates, such as natural gas, nitrogen, and CO2 that expand in a reservoir to push more oil to a production wellbore.

It is used for light oil reservoirs and highly permeable formations. The injected gas does not wet the rock and simultaneously displaces the oil as soon as its saturation reaches about 5 to 10%. However, the investments required are lower compared to water injection. There are two possible types of drainage:

- Gas injection into an existing gas cap.
- Direct injection of gas into the oil. The injected gas then has a radial movement.

The goal of gas injection is to enhance the recovery rate and optimize production by ensuring the following two factors:

- Maintaining pressure.
- Sweeping of the oil. [7]

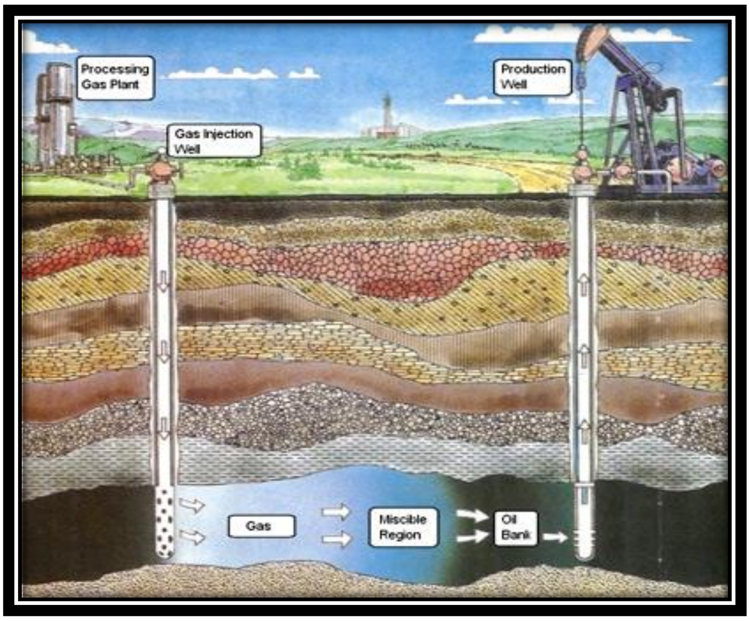


Figure I.5: Gas injection recovery. [7]

I.1.3.1.Types of Gas Injection

The beginning of a gas injection project represents the choice of the oil. This project initially started with injection into a single well. However, the expansion of the area and the increase in the number of wells have led to converting producing wells into injector wells or drilling new injector wells.

The initial design to extend oil sweep was called "circle flooding" and can gradually be replaced by other types of injection, such as:

- **Irregular Injection:** This type may occur in cases where surface conditions or underground geometry and the presence of horizontal wells in the reservoir result in non-uniform positioning of producing or injector wells.
- **Peripheral Injection:**_ Injector wells are located at the boundaries of the reservoir, and oil is displaced towards the interior of the reservoir, such as in an anticlinal reservoir with an underlying aquifer subjected to water injection, as depicted in Figure I.5. [8]

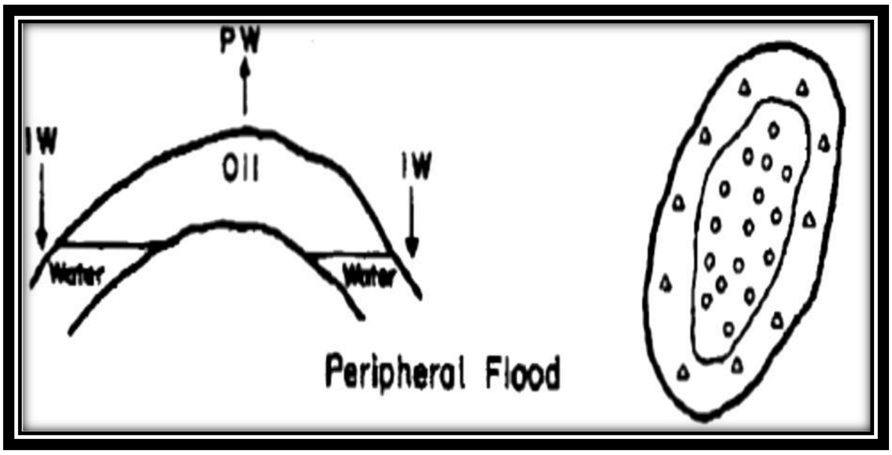


Figure I.6: Peripheral injection. [8]

- **Central Injection:** Centralized injection is the opposite case of peripheral injection, in which the injectors are located at the center of the field, and injection progresses outward, such as in a gas-capped anticlinal reservoir. Injection wells are typically clustered around the top of the anticlinal, as depicted in Figure I.6. [8]

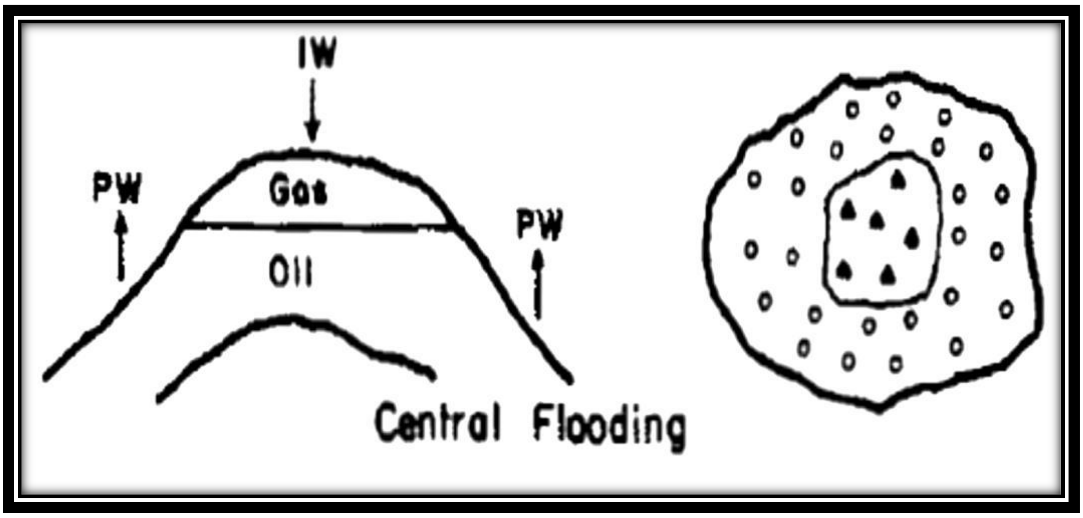


Figure I.7: Central injection. [8]

- **Regular Injection:** This type of injection corresponds to reservoirs with low dip and extensive extent. To achieve uniform sweep, producing wells and injector wells are interspersed. In this case, a distribution as regular as that developed for the natural exploitation phase of the reservoir is obtained. The most common arrangements are represented in Figure I.7. [8]

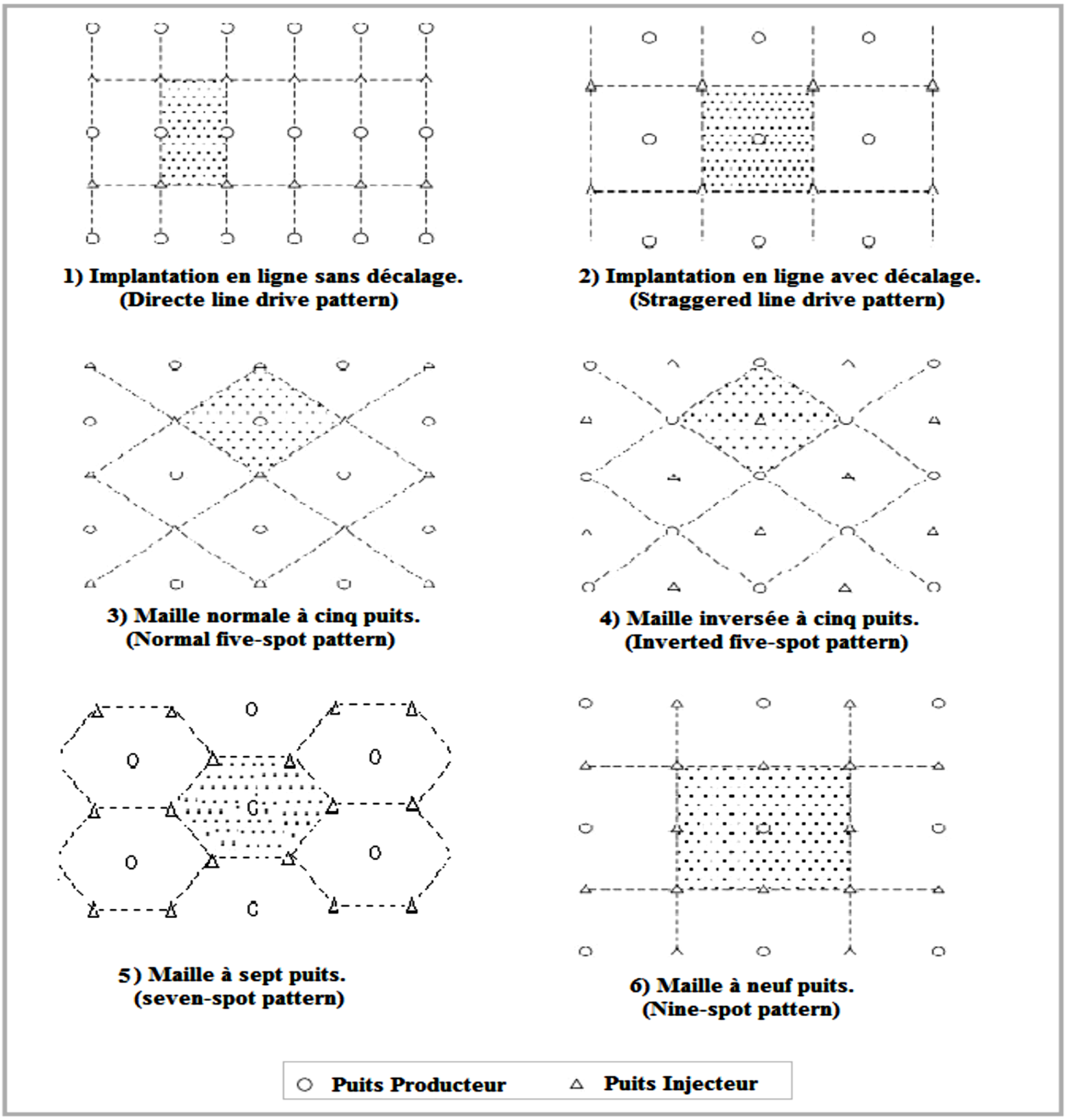


Figure I.8: regular injection. [8]

I.1.3.2.Reservoir Characteristics

As drainage occurs due to flow between wells, one of the prerequisites for successful injection is the absence of impermeable barriers hindering this circulation. The homogeneity or heterogeneity of the reservoir, stratigraphy, and fracturing significantly influence water breakthrough and the establishment of preferred pathways.

- **A- Depth**: from a technical standpoint: If the depth is shallow, there are limitations regarding the pressures to be applied, which must be lower than the fracturing pressure, and the injection rate per well is thus limited.
  From an economic standpoint: The implementation cost of a process is closely related to depth, either drilling costs or compressor power in the case of gas injection.
- **B- Lithology and Rock Properties:** Within the domain of reservoir engineering, the lithological composition and petrophysical attributes of rocks wield considerable influence over the efficacy of gas injection initiatives within a reservoir. Key among these attributes are parameters such as porosity, permeability, clay content, and reservoir thickness. These characteristics collectively dictate the reservoir's ability to store and transmit injected gas, impacting the overall success and efficiency of gas injection strategies.
- **C- Porosity:** Higher porosity facilitates greater oil saturation, which is beneficial for both primary and secondary recovery processes.
- **D- Permeability:** High permeability is advantageous for secondary recovery efforts. However, there exists an upper threshold beyond which permeability becomes excessively high, leading to uneconomical recovery. The distribution of permeability within the reservoir is influenced by its homogeneity.
- **E- Degree of Heterogeneity:** Effective recovery relies on unhindered fluid flow paths. Obstacles to flow can arise from tectonic factors like impermeable faults or stratigraphic variations such as lateral facies changes, lenses, or wedges. Preferential pathways, such as fault networks, fractures, or more permeable strata, enable fluid displacement without significant drainage of the in-place oil.
- **F- wettability:** Wettability essentially refers to the affinity of a fluid to adhere to the surface of a rock in the presence of other immiscible fluids. In injection projects, such as those involving gas or water injection for enhanced oil recovery, understanding and managing wettability is crucial. However, the challenge arises when wettability undergoes changes over time due to various processes occurring within the reservoir.
  These changes can occur due to factors such as:
  - Fluid interactions: The composition and properties of injected fluids can influence wettability. For instance, interactions between injected fluids and reservoir fluids can alter the wettability of the rock surface.
    - Rock alteration: Chemical reactions or mineral dissolution within the reservoir can modify the surface properties of the rock, affecting its wettability.

- Reservoir dynamics: Changes in reservoir pressure, temperature, or fluid saturation levels can also impact wettability over time. These changes may be induced by production activities or natural reservoir processes.
- Microbial activities: Biological processes occurring within the reservoir can also influence wettability through the production of by-products that interact with the rock surface.

The evolving wettability profile adds complexity to injection projects by affecting fluid displacement patterns, sweep efficiency, and ultimately, the effectiveness of enhanced recovery efforts. To address this challenge, reservoir engineers employ advanced modeling techniques and experimental studies to predict and mitigate wettability alterations, ensuring optimal project outcomes.

- **F- Interference tests:** Prior to initiating any enhanced recovery project, interference tests are conducted to verify communication between wells, ensuring optimal reservoir connectivity and fluid flow pathways. [9]

I.1.3.3.Characteristics of the fluid

a. Fluid Viscosity: The essential characteristic of fluids to consider in establishing an enhanced recovery project is viscosity. If the fluids are highly viscous, displacement velocities are low, and pressure gradients are limited.
b. Fluid Saturation: the higher the oil saturation, the greater the amount of oil available for recovery. A higher oil saturation increases oil mobility, resulting in higher recovery efficiency. [9]

I.1.4 Selection of the number of injection wells and spacing

The number of injection wells is contingent upon injectivity, which is influenced by pressure and the ratio of permeability thickness to viscosity. It is also dictated by the volume slated for injection. In parallel, spacing decisions hinge on the total count of wells (both producers and injectors) and the surface area earmarked for injection. Some experts advocate for the drilling of additional intermediary wells (both injectors and producers) between existing ones to more effectively deplete heterogeneous zones, thereby enhancing recovery rates and expediting production. The optimal number of wells and their configuration are discerned solely through a techno-economic appraisal of various strategies. Gas injection wells typically exhibit higher flow rates under bottomhole conditions compared to oil production wells. This discrepancy arises from the gas's inherent characteristics, characterized by lower viscosity and density, despite the utilization of a quadratic well function. Consequently, a smaller number of injection wells suffice relative to production wells.

I.1.5 The implementation of injection

Equipment of wells

A common outcome of having a limited number of injection wells, particularly in oil zone injection, is the necessity to repurpose production wells for injection purposes. In all scenarios, a specialized surface installation is mandatory as standard protocol.
Additionally, injection wells are equipped with a downhole safety system known as the flapper valve.

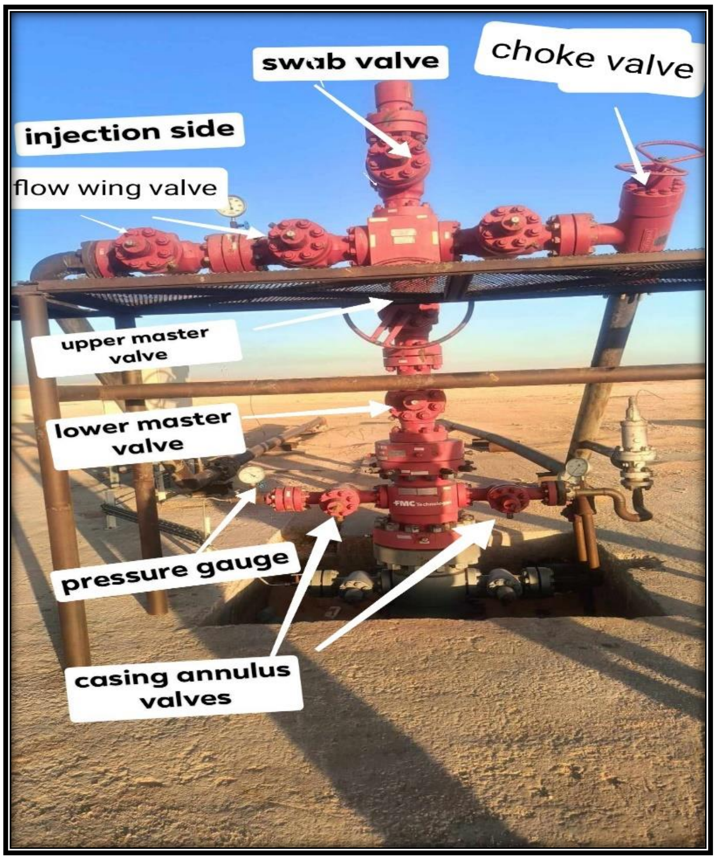


Figure I.9: Wellhead of the gas injector well.

Gas treatment: The injected gas is sourced from the field separators, either solely from the reservoir itself, which is the most common scenario, or occasionally from another overlying reservoir, and less frequently from a neigh boring field. Troublesome impurities include hydrogen sulfide (H2S), carbon dioxide (CO2), oxygen (O2), and water vapor (H2O). The first three are corrosive; water vapor can also promote corrosion but primarily leads to hydrate formation in pipelines. Therefore, the gas undergoes desulfurization, dehydration, and filtration. Additionally, any condensable components (LPG: liquefied petroleum gases) are extracted unless they can ensure miscibility.

Gas compression: typically involves reciprocating compressors driven by gas turbines.

Injection monitoring: Like water injection, gas injection often involves adding small amounts of radioactive substances like tritium derivatives to the injected gas. Detecting the breakthrough of injected gas isn't always straightforward since the gas can migrate through drains, and breakthrough is typically indicated by the most permeable drain. If the pressure surpasses the bubble point pressure, even a minor rise in the Gas-Oil Ratio holds significance. Conversely, if the pressure falls below the bubble point pressure, the Gas-Oil Ratio has already increased, and breakthrough detection relies solely on tracer tagging. [10]

I.2. Interventions on Injectors wells

Table I.1: Different Types of Interventions Applied to Injection Wells. [11]

Operations	At the wellhead	In the tubing	At the bottom of the well
Measuring Operation	-These are particularly the measurements of pressure and temperature at the wellhead and downstream of the choke. - A variation in one or more of these parameters alerts us to a change in operating conditions (clogging, variation in the percentage of water or gas, blockage…).	- It is primarily the calibration to check whether a wireline operation (such as the descent of a logger, etc.) is possible or to address an issue of corrosion or deposition.	- This could be a sediment "top," with or without sample collection, to verify that a tool (such as a logger) can be lowered by wireline to the bottom of the well or to monitor the sand accumulation in a well. - Could involve simple measurements at a given depth of pressure and temperature, possibly accompanied by fluid sample collection (or sediments from the bottom of the well) for analysis.

Maintenance Operation	-the adjustment of flow rate. - the opening or closing of a well. - the lubrication of valves. - the replacement of defective parts located downstream of the master safety valves. - the periodic inspections of the control systems for subsurface and surface safety devices (SSV: Surface Safety Valve; SSSV: Subsurface Safety Valve).	- operations related to deposition and/or corrosion issues, such as tubing cleaning by scraping, paraffin dispersant injection, or the injection of a hydrate or corrosion inhibitor… - the replacement of equipment that can be changed via wireline operations: subsurface safety valves of the "Wireline Retrievable" (WLR) type, flapper valves, and the retrieval of "fish" accidentally left in the well during these wireline operations.	- cleaning" the bottom of the well with a sediment spoon or performing additional perforations. - pumping from the surface, such as acid washing the perforations (which requires reinjecting all the well effluent back into the formation).

I.3.Corrosion of Injectors wells:

I.3.1 Definition:

Corrosion is an irreversible interfacial reaction of a material with a corrosive agent from its environment (corrosive medium), which involves consumption of the metal and production of a reduced form of the corrosive agent. From the perspective of the engineering constructor, corrosion is the degradation of the material or its properties, rendering it unusable for its intended application due to chemical reaction with the environment. This definition acknowledges corrosion as a detrimental phenomenon [3].Corrosion is the phenomenon whereby metals tend, under the action of atmospheric agents or chemical reactants, to return to their original oxide state.[12]

I.3.2 The types of corrosion in wells :

Depending on the nature of the surrounding environment with which the material interacts, corrosion can be classified into four main types:

A.Chemical corrosion :

This phenomenon arises when the metal surface and the surrounding reaction mixture are both uniformly homogeneous. Under these conditions, the metal undergoes a uniform attack without any internal flow of electrons within the metal. An instance of this occurrence is the oxidation of regular steel at elevated temperatures by atmospheric oxygen. This is the reaction between the metal and a gaseous phase. If this corrosion occurs at high temperature, it is then called "dry corrosion" or high-temperature corrosion. During chemical corrosion, the oxidation of the metal and the reduction of the oxidant occur in a single action, meaning that the metal atoms directly form chemical bonds with the oxidant, which removes valence electrons from the metal atoms.

Figure I.10: Chemical corrosion in wellhead.

B.Electrochemical corrosion:

This is the mos.t significant corrosion phenomenon and it occurs when the reactant is a liquid or when there is heterogeneity either in the metal or in the reactant, presenting a compositional asymmetry. The presence of these heterogeneities leads to the formation of a galvanic cell, causing an electric current to flow between the anode and cathode in the reactant, resulting in the areas constituting the anodes being attacked (corroded).

Figure I.11: Electrochemical corrosion in wellhead.

C.Biochemical corrosion:

This is the bacterial attack on metallic materials, especially in buried pipelines and tanks. The metabolism of certain bacteria leads to the formation of sulfuric acid, which attacks the metal.

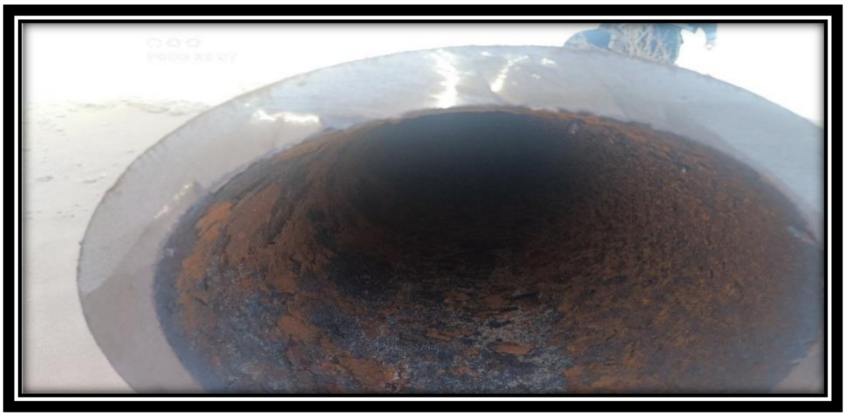


Figure I.12. Biochemical corrosion

I.3.3 Forms of corrosion :

Generalized or Uniform Corrosion: Generalized or uniform corrosion manifests with the same rate at all points of the metal, resulting in a regular decrease in thickness or simply a change in coloration (tarnishing).

Localized Corrosion: This mode of corrosion is the most common and troublesome as it targets only certain distinct areas of the material.[14]

Table I.2: Different forms of corrosion in injectors wells.

Forms of Corrosion	Definiton	Forms on injectors wells
Pitting Corrosion	Pitting corrosion is a localized form of corrosion that leads to the creation of small holes or pits in the metal surface. This type of corrosion is typically caused by the breakdown of a protective oxide film on the metal, often in the presence of chloride ions.	
Intergranular Corrosion	Intergranular corrosion is a form of corrosion that occurs along the grain boundaries of a metal, rather than uniformly across its surface. This type of corrosion typically arises due to the presence of impurities or precipitated phases at the grain boundaries, which are more susceptible to attack than the bulk material.	
Erosion corrosion	Erosion corrosion is a form of deterioration that occurs when a corrosive fluid flows rapidly over a metal surface, leading to a combined effect of mechanical wear and chemical attack. This process accelerates the removal of the protective oxide layer on the metal, making it more susceptible to further corrosion.	

I.4.Corrosion protection of Injector Well Facilities

I.4.1 Corrosion protection by coating:

The principle of this type of protection is the electrical isolation of the pipeline by eliminating any direct contact with the surrounding environment, which allows us to anticipate any formation of corrosion cells on the metal surface. These thick coatings (a few millimeters) also serve a mechanical protection function for the pipe during backfilling of excavations, although it is not their primary role. However, this protection is not entirely effective because experience has shown that the majority of coating defects observed on pipelines have been caused by stones falling on the pipe or penetrating the coating. [15]

I.4.2 Different types of coatings:

Metallic coatings: They are particularly used as coatings against atmospheric corrosion, especially for steel. They can also be applied to other substrates such as copper or brass, as in the case of chrome coatings on faucets. Based on their compositions. [15]

Organic coatings: The principle of this type of coating is the formation of a more or less impermeable barrier between the material and the environment. Among these coatings, we distinguish: A) Paints and varnishes B) Bitumen C) Polymeric coatings

Non-metallic inorganic coatings come in two types:

Conversion coatings: These coatings are obtained through a reaction of the metal with a chosen medium, thus always containing ions from the substrate.

Coatings foreign to the substrate: among the non-metallic inorganic coatings foreign to the substrate, we have: those that are more noble than the substrate, enamels, cements, and refractory ceramics. [15]

Figure I.13: welhead treated by paint coating.

I.4.2 Cathodic Protection:

Cathodic protection involves lowering the electrode potential of the metal. When two different metals immersed in a corrosive environment are electrically connected, the corrosion rate of one increases while that of the other decreases. This lowering of potential is achieved by passing a current between the surface to be protected (cathode) and an auxiliary electrode (anode). [16]

A.Sacrificial anode cathodic protection:

These anodes have a more electronegative potential than the metal to be protected. The anode corrodes instead of the protected metal, hence the term –sacrificial.

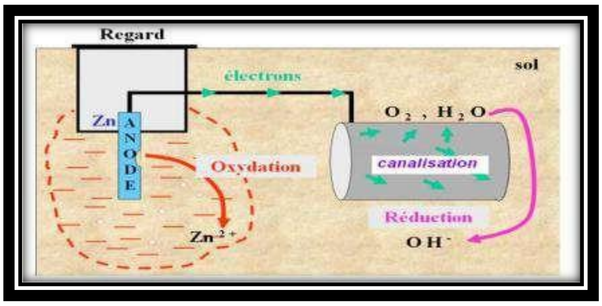


Figure I.14: schema represents sacrificial anode cathodic protection.

B.Impressed current cathodic protection:

These anodes are connected to a power source that imposes a potential difference between the two metals. This method is known as impressed current cathodic protection or current drainage protection.

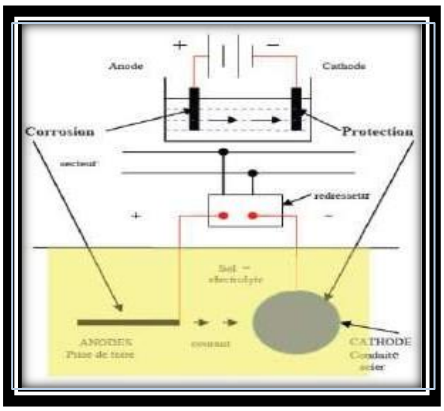


Figure I.15: schema represents impressed current cathodic protection.

C.Comparison between two cathodic protection systems.

Table I.3: Comparison between two cathodic protection systems.

	sacrificial anode	impressed current system
installation complexity	Simple	Complex
power source	Not necessary	necessary
current distribution on the structure	Homogeneous	Sometimes heterogeneous
weight of the structure	Significant weight overload for long service life	Little increase
influence of the medium's resistivity	Not feasible if the resistivity of the medium is too high	No difficulty
output per anode	Low	High
number of anodes	Significant	Low
Ease of adapting the consumed current based on demand	Adaptation possible through a resistive connection	Easy adaptation
risk of over protection	Practically none	Possible
Interference with other structures	Not	Possible
human risks	Not	Possible(drainage station)
Monitoring	Easy and occasional	Frequent monitoring required by a specialist

Conclusion:

In oil and gas production, injector wells are used to inject gas into the reservoir to maintain pressure and increasing oil production efficiency. Improving the protection and intervention of injectors is important for enhancing oil production efficiency. by focusing on these aspects; intervention, maintenance, optimization, enhanced recovery techniques of injection, corrosion monitoring and protection, we can effectively protect injectors and intervene when necessary to maximize oil production from reservoirs.

Chapter 2

Injectors wells operations and interventions

Introduction:

The profitability of an investment in a well is linked to the longevity of the well. This longevity is certainly influenced by the initial characteristics of the reservoir, but it also depends on maintaining the well in good order and condition. By "interventions on the wells," we mean all measures applicable to the wells themselves, aimed at, on the one hand, understanding the evolution of the well's state or the reservoir, and, on the other hand, maintaining or adapting the wells to remain in conditions of use as optimal as possible. The main objective of our work is firstly to study the injection parameters in the Hassi Messaoud field, and to characterize the various interventions to maintain the operating condition of injection and production wells.

II.1 Situation of the Hassi Messaoud Field:

II.1.1 Geographical Location:

The Hassi Messaoud field is located in the northeast of the Algerian Sahara, 850 km southeast of Algiers and 350 km from the Algerian-Tunisian border. The field covers an area of 25,000 km². It is bordered to the north by Touggourt, to the south by Gassi-Touil, to the west by Ouargla, and to the east by El Bourma. Its location in Lambert coordinates is as follows:

- X = 790,000 - 840,000 East
- Y = 110,000 - 150,000 North. [19]

II.1.2 Geological Situation :

The Hassi Messaoud field occupies the central part of the Triassic province and is bordered by:

- To the north, the structures of Djemââ-Touggourt.
- To the west, the Oued Mya highlands.
- To the east, the Dehar highlands and the Ghadamès structure.
- To the south, the Amguid El Biod highland. [19]

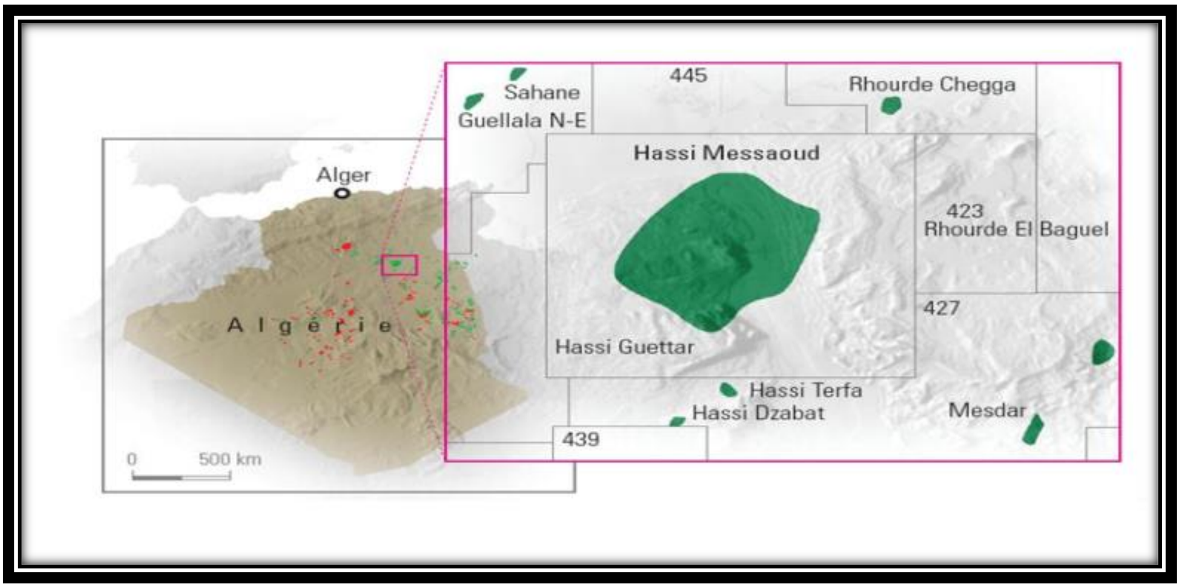


Figure II.1: Geographical location of the Hassi Messaoud field. [19]

II.1.3 Field Structure:

- The structure of Hassi Messaoud develops into a vast subcircular anticline with a diameter of 45 km, oriented northeast/southwest.

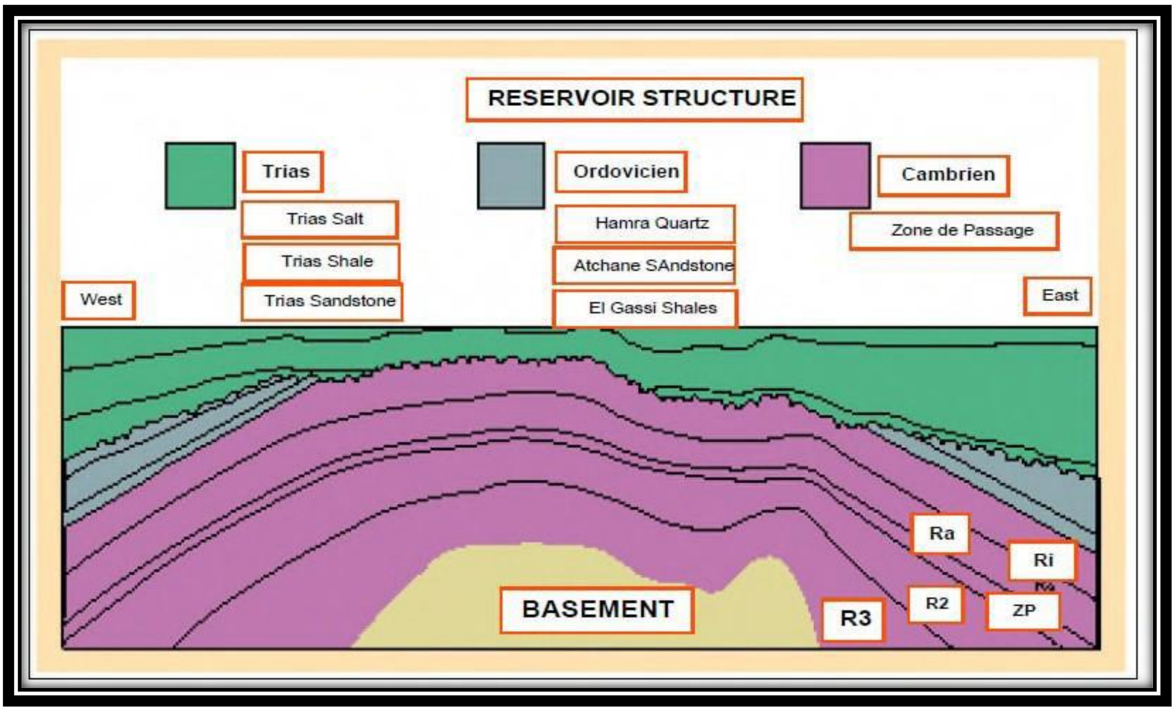


Figure II.2: Structural map of the Hassi Messaoud reservoir. [20]

II.1.4 History of the Hassi Messaoud Field:

The Hassi Messaoud oil field was discovered in 1956 but was not practically exploited until three years later. The main characteristics of the field are:

- Its significant heterogeneity,
- Its considerable depth,
- The lightness of its distinctly undersaturated oil,
- The highly variable, but on average high, productivity of its wells,
- The presence of oil in considerable quantities.

The Hassi Messaoud field is divided into numbered zones. This division naturally arises from the characteristics of production and geology. The evolution of well pressures, in relation to production, has allowed the field to be subdivided into 25 production zones. A production zone is defined as a set of wells that communicate with each other but not, or only slightly, with those in neighboring zones. It should be noted that the current subdivision is not entirely satisfactory, as a single zone can be further subdivided into sub-zones. [21]

Tableau II.1: wells distribution in HMD field. [21]

oil-producing wells	**Water injection wells**	**Water producing wells**	**Gas injector wells**	**Gas,Inj Temporary abandoned wells**	**Gas,Inj permanently abandoned wells**
1700	64	39	153	14	3

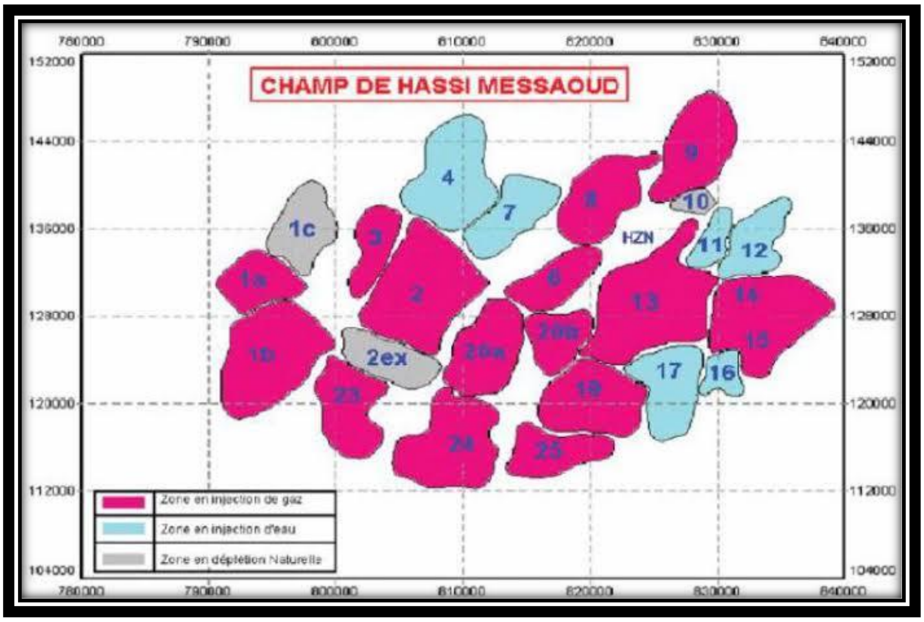


Figure II.3: Zones and numbering of the Hassi Messaoud fields. [21]

II.1.5 Reservoir Characteristics:

The characteristics of the Hassi Messaoud (HMD) field can be summarized as follows:

- **Light Oil**: The oil has an average density of 0.8 (43.5-45 API).
- **Reservoir Pressure**: Varies from 120 to 400 kg/cm².
- **Temperature**: Approximately 120°C.
- **Gas-Oil Ratio (GOR)**: About 219 v/v, except for wells with gas breakthrough where the GOR can exceed 1000 v/v.
- **Porosity**: Low, around 5 to 10%.
- **Permeability**: Ranges from 0.1 millidarcies (md) to 1000 md.
- **Oil Saturation**: Ranges from 80% to a maximum of 90%.
- **Bubble Point Pressure**: Between 140 and 200 kg/cm².
- **Reference Depth**: -3200 meters.
- **Thickness of Productive Zone**: Can reach up to 120 meters.
- **Oil/Water Contact**: -3380 meters. [22]

II.1.6.Fluid Characteristics in the Reservoir:

At a pressure of 183 kg/cm², the oil has the following characteristics:

- **Bottom Volume Factor**: Bo = 1.67 Rm³/stm³.
- **Density in Storage Conditions**: 0.8 g/cm³ (45° API).
- **Dissolution Gas-Oil Ratio**: Rs = 219 m³/m³.

- **Relative Density to Air**: 0.9. [22]

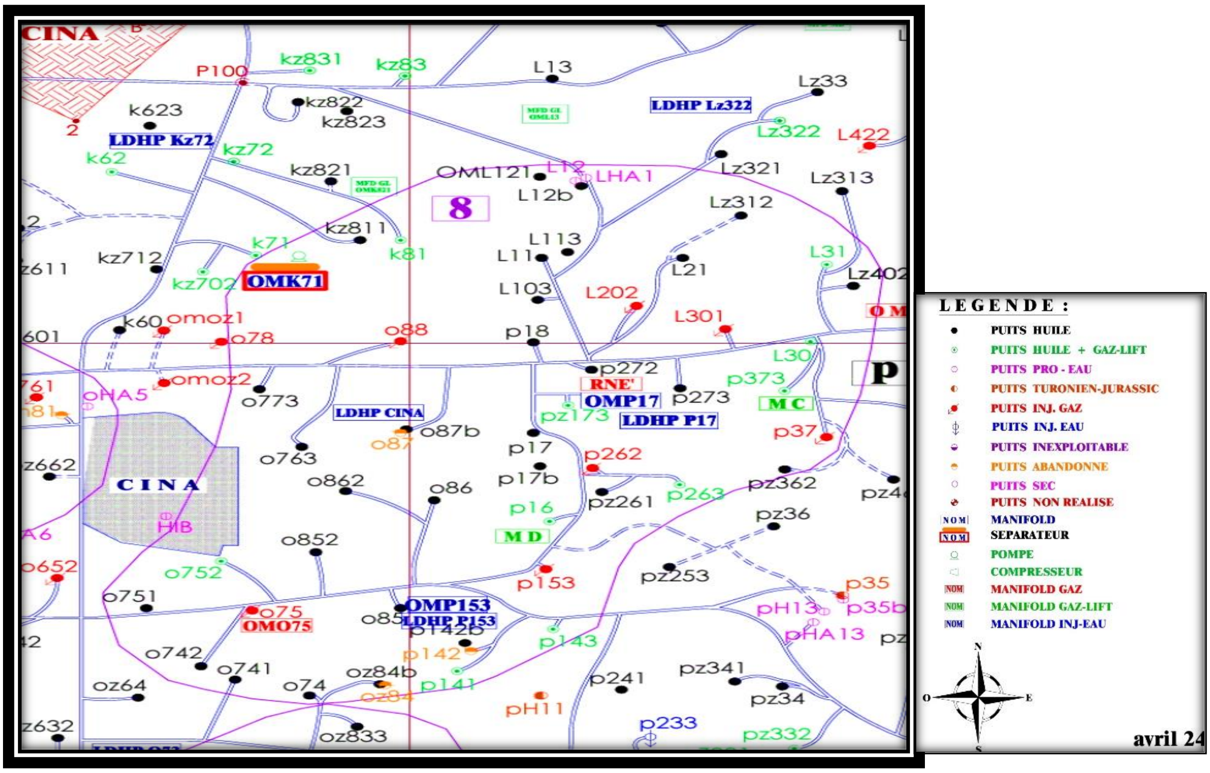
Characteristics of Formation Water:

The formation water is highly saline, containing 315 g/l of salt. In initial reservoir conditions (480.2 kg/cm² and 120°C), this water has a viscosity of 1 centipoise (cp). In storage conditions, its density is 1.2 g/cm³

II.2 The effect of gas injection on production (zone 8 case):

II.2.1 Situation of zone 8:

Zone 8 is our study area. It is located in the north-eastern part of the Hassi Messaoud field. Overall, Zone 8 has lateral positioning, surrounded by Zones 6, 7, and 9. [21]



FigureII.4: Location of wells in Zone 8. [21]

Tableau II.2: Summary Report of Wells in Zone 8 "04/2024": [21]

oil-producing wells	gas injection wells	Water injection wells	Temporary abandoned wells	permanently abandoned wells
16	06	00	5	1

II.2.2 Injection parameters:

Injection is primarily adjusted based on available fluid volumes, the type of fluid being injected, and the configuration of injection wells.

Injected fluid flow rate: This is calculated by the following formula: [23]

$$Q=K\sqrt{\frac{P}{T}}\Delta p \times t \qquad (II.1)$$

Q : injection flow rate (m3/j).

K : the coefficient of Daniel's orifice.

P : line pressure.

T : temperature (K).

Δp : different of pressure (bar).

t : injection time (hour).

Table II.3: coefficient orifice and diameter value. [21]

WELLS	Ǿ Tubes int (mm)	Ǿ Orifice daniel (mm)	Daniel's orifice coefficient K
OML202	163.2	50.8	94.47
OML301	163.2	50.8	94.47
OMO75	163.2	63.5	150.52
OMO88	163.2	63.5	150.52
OMP153	163.2	50.8	94.47

Table II.2: Injection Parameters of injectors wells at the zone 8. [21]

WELLS	Injection time (h)	Line pressure (bars)	ΔP (bars)	T (K) Temperature	Flow rate (m^3/d)
OML202	24	187	0.21	314	363711
OML301	24	267	0.07	325	245027
OMO75	24	266	0.03	318	258061
OMO88	24	247	0.09	324	426819
OMP153	24	266	0.25	306	476116
OMP262	24	187	0.14	337	286051

The evolution of wells injectivity in the zone 8 has also supported advancements in gas injection techniques for oil production, High injectivity wells are essential for achieving effective gas sweep efficiency and maximizing the displacement of oil towards production wells.

The evolution of injectivity in injector wells reflects ongoing advancements in technology, reservoir management practices, and environmental considerations. These advancements are aimed at maximizing oil recovery efficiency, ensuring sustainable operations, and meeting regulatory requirements in the oil production well.

II.2.3 Impact of gas injection on production:

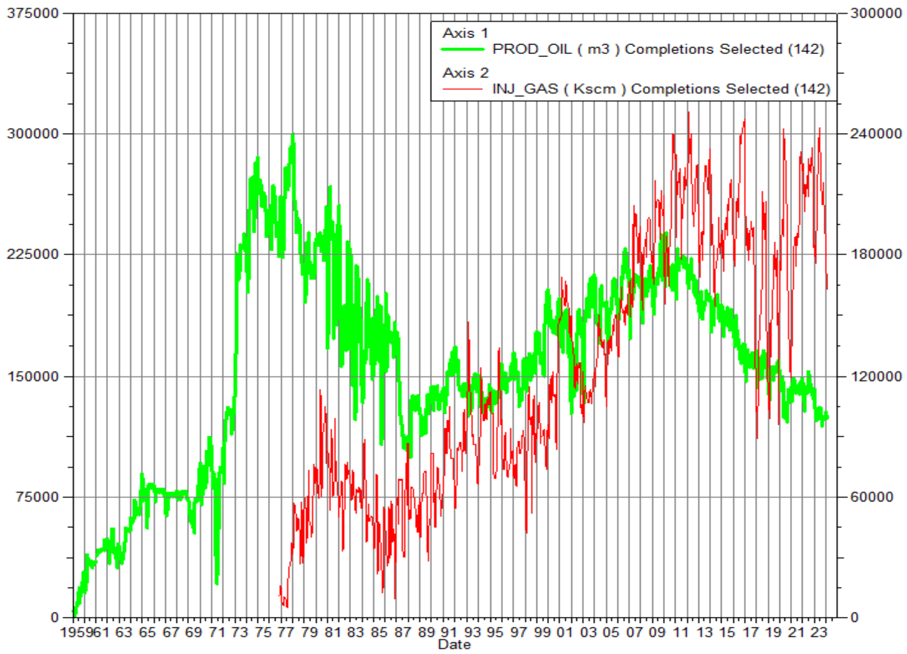


Figure II.5: Curve of injection and production in zone 8. [21]

The injection and production parameters of the injector and producer wells are determined in order to study the effect of gas injection on oil production in zone 8. According to the curve, we observe that:

- Gas injection into the reservoir promotes an increase in oil production from the producer well, which has been applied since 1973.
- The increase in injection rate serves to raise the pressure in the reservoir, which increases daily production and subsequently the annual oil production in zone 8.
- The injection of gas is used to maintain reservoir pressure.
- Maintaining the pressure in a reservoir for optimizing oil and gas recovery, ensuring structural integrity, and enhancing the economic viability of the reservoir.
- Gas injection, such as injecting natural into the reservoir can increase the reservoir pressure. This pressure augmentation helps maintain or restore the pressure that has declined due to oil extraction. Higher reservoir pressure can improve the flow of oil towards production wells, thereby increasing oil productivity.

II.3 Different types of interventions: the diminution of injectivity in gas injector wells can be caused by various factors such as formation damage, deposits, or mechanical issues. Cleaning interventions, including mechanical, chemical, and hydraulic methods, are essential to mitigate these problems, restore flow capacity, and optimize the performance and efficiency of gas injection operations to improving the oil production in Hassi Messaoud fields.

II.3.1.Cleaning:

II.3.1.1.Flow back:

In case of a gas flow disruption inside the well (complete or partial), the initial intervention involves purging the tubing (opening the discharge side and closing the injection side). This process allows for cleaning the pipes internally due to the pressure force coming from the bottom and directed upwards.

II.3.1.2.Water plug:

If the first intervention doesn't yield satisfactory results, we proceed with the second intervention. This involves depressurizing the pipes and injecting a quantity of water ranging from 5 to 6 m. Then, we wait for a period ranging from 2 to 24 hours before opening the discharge side to allow the water to exit due to bottom pressure force. This technique allows for dissolving the salt formed on the pipe walls.

II.3.1.3.Nitrogen cleaning (by coiled tubing):

The third intervention relies on nitrogen, where a quantity of 2 cubic meters of liquid nitrogen is injected. It condenses inside the tubing, providing a thorough cleaning of the pipe walls. If this intervention fails, the issue likely stems from the formation itself, leading us to utilize compounds such as HCl acid.

Cleaning of the injectors well OML431

The decrease in injectivity of gas injector well OML431 can arise from various factors, necessitating interventions such as cleaning to restore or improve injectivity. The causes is according to the scale deposition, organic deposits, and presence of salts we use the cleaning intervention to improve injectivity of this wells.

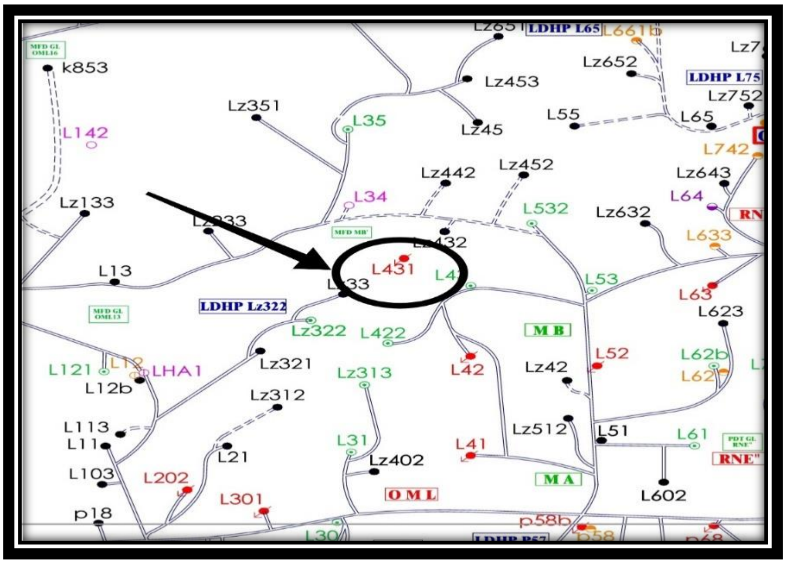


Figure II.6: OML43 location.

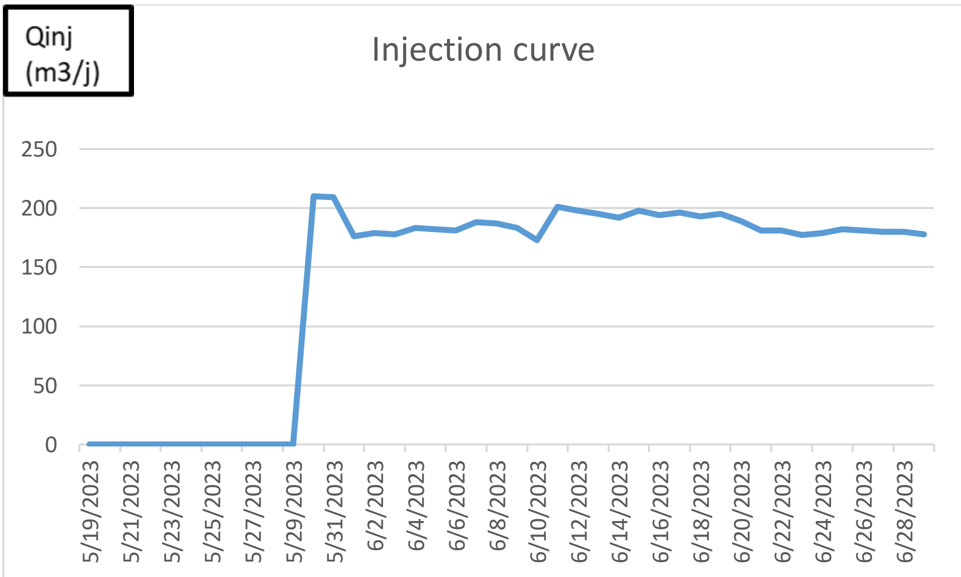


Figure II.7: The effect of the cleaning process on injection (OML431 case). [21]

According to the curve, we observe that:

- Before the cleaning operation, the injection rate is null.
- As soon as the process is completed, a significant increase in the injection rate of gas at this well is observed, indicating the success of the procedure.
- Relative stability of the flow, meaning the resumption of the injection process and the maintenance of pressure is ensured.

- Cleaning injector wells is critical to maintaining or enhancing injectivity of gas by removing deposits and obstructions that hinder fluid flow. The choice of cleaning method depends on the type of deposits, well conditions, and specific objectives of improving injectivity in oil and gas production operations.

II.3.2 Matrix acidizing procedure stimulation:

II.3.2.1.Acidizing Matrix Treatment:

These are treatments (acidizing, solvent injection, etc.) carried out at a pressure lower than the fracturing pressure. They only act near the wellbore and are particularly useful in cases .

f formation damage. If properly applied, they can restore productivity. The productivity increase expected from these treatments (if successful) is more significant when the natural permeability of the formation is high. [24]

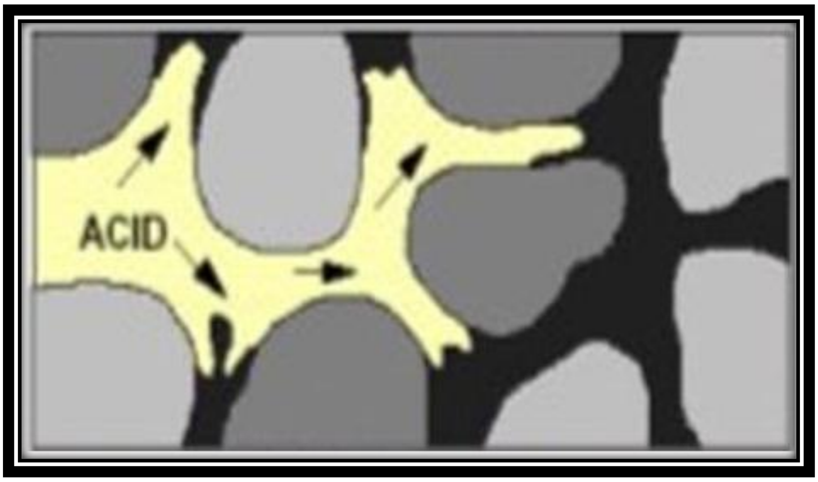


Figure II.8: Penetration of acid into the formation.

II.3.2.2.The different steps of an acid treatment:

1. Cleaning:

Objective:

➤ to clean the injection string.

➤ to prevent dirty materials in the tubing from entering the formation

Fluids:

➤ Inhibited 5%-15% HCI.

➤ Standard: 7.5% HCI + iron control agent + corrosion inhibitor.

➤ Special pickling solutions, including non-acid solutions. [24]

2. Overflush:

Objective:

- ➤ to displace acid to the perforation.
- ➤ to remove the spent acid.
- ➤ to maintain the wettability.
- ➤ to clean the formation.

Fluid:

- ➤ Fresh water.
- ➤ KCI water.
- ➤ Nitrogen (in gas well). [24]

3. Main Acid (and Pump Overflush Fluid):

Objective:

• to bypass formation damage (carbonate acidizing).

to remove plugging materials (sandstone acidizing).

Fluid:

- ➤ HCI 15% (carbonate acidizing).
- ➤ HCI-HF (sandstone acidizing). [24]

4 . Preflush (and Pump Main Acid):

Objectives:

➤ to remove organic or inorganic scale from the wellbore tubulars prior to injection of the acid stage.

- ➤ to displace oil from the near-wellbore area to prevent emulsion or sludge formation
- ➤ to displace fluid containing incompatible cations.

Fluid:

- ➤ 5%-7.5% HCI → rust and inorganic scales.
- ➤ aromatic solvent, such as xylene remove HC.

Deposits:

- ➤ xylene or fresh water containing surfactant → oil.
- ➤ terpene-based solvent → asphaltene deposits.
- ➤ brine (NHCI).

HCI (organic acid) to remove CaCO3 to prevent the precipitation of CaF2 (sandstone acidizing). [24]

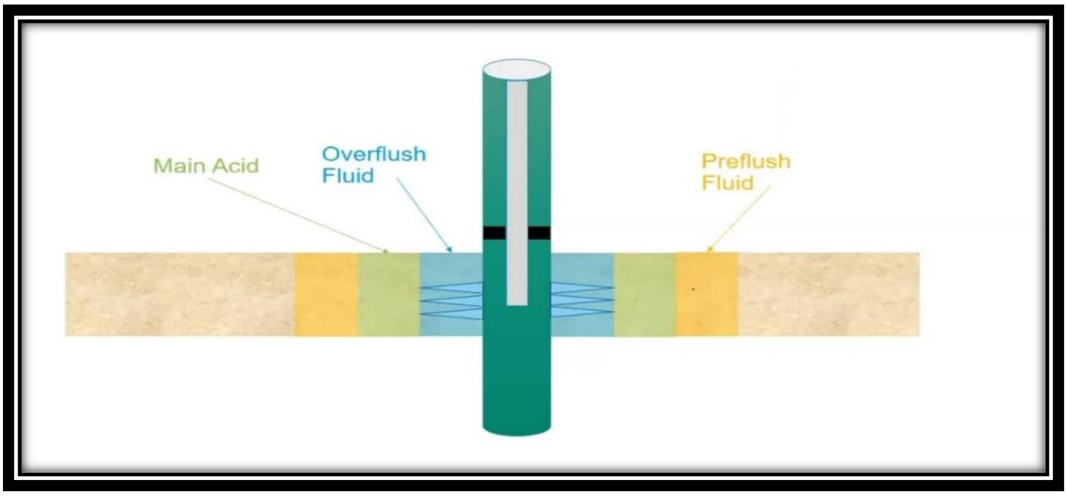


Figure II.9: steps of an acid treatment

II.3.2.3.Calculations Required for Establishing a Matrix Acidizing Project:

II.3.2.3.1.Acid volume:

This is the oldest method and is based on calculating the volume of the damaged cylinder around the well. This volume is estimated by the following formula: [24]

$$V_{acide}=V_{cylinder}=\pi({R_d}^2 - rw)\ Hu\emptyset u \qquad (II.2)$$

Where:

- **Vacide:** Volume of acid used for the main treatment in cubic meters (m^3).
- R_d**:** Radius of damage in meters (m), determined by well tests, generally between 1 and 1.5 meters.
- **Hu:** Useful reservoir height in meters (m).
- $\emptyset u$ **:** Useful porosity of the reservoir (%).
- **rw:** Well radius in meters (m).

II.3.2.3.2.Calculation of Injection Rate:

The injection rate of the acid will be controlled to:

- Avoid fracturing the formation.
- Prevent damage to surface equipment.

It is recommended to have the highest possible injection rate because the neutralization time of the acid, and thus its penetration into the matrix, depends on pressure, temperature, and flow rate. The acid injection rate is calculated using the following formula derived from Darcy's law: [24]

$$qi = \frac{4.917\times10^{-6}\,KH\,[(Gf\times Hmi\,perfos) - \Delta Psafety - Pg]}{\mu\beta\,(\ln\frac{Rd}{rw} + S)} \qquad \textbf{(II.3)}$$

KH: flow capacity (md.ft)

Gf: the fracturing gradient (psi/ft).

Hmi.**per**f: the well height, taken at the midpoint of the perforations (ft).

Psafety: the safety margin (psi).

; **Pg:** the reservoir pressure (psi).

μ : the viscosity of the acid (CP).

β the formation volume factor (bbl/STB).

S : the skin or the damage factor (dimensionless).

II.3.2.3.3.Calculation of Maximum Injection Pressure:

This is the injection pressure we need to apply at the surface for the acid to reach the location of damage and treat the matrix.

The maximum treatment pressure should be the lower of the following two pressures:

- Fracture pressure (to avoid fracturing the formation)

- Equipment-limited pressure

The surface treatment pressure is calculated as follows: [24]

$$PT_{surface} = (PT_{bottom} - P_{hyd}) + \Delta P_{tbg} \qquad \textbf{(II.4)}$$

II.3.2.3.4.Treatment pressure at the bottom of the well:

This is calculated by the formula: [24]

$$\mathbf{PT\ bottom = P_{frac} - \Delta P_{safety}} \qquad \textbf{(II.5)}$$

With:

$$\mathbf{P_{frac} = Gf \times Hmi_{\,perfors}} \qquad \textbf{(II.6)}$$

Where:

ΔPsafety: The pressure safety margin is between 200 and 500 psi.

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

II.3.2.3.5 The hydrostatic pressure:

To allow a squeeze into the formation, the squeeze pressure must be higher than the reservoir pressure and lower than the fracturing pressure.

The hydrostatic pressure is given by: [24]

$$\mathbf{P_{hyd} = \frac{Hmi\ perfors \times d}{10}} \qquad \textbf{(II.7)}$$

II.3.2.3.6.Acidizing of the injectors well OMO 323:

The decrease in injectivity of gas injector well **OMO 323** can arise from various factors, necessitating interventions such as acidizing to enhance injectivity by removing formation damage, scale, and dissolve carbonate formations, and other inorganic deposits that restrict fluid flow. Acidizing restores permeability and improves injectivity by creating or enhancing flow channels in the reservoir other obstructions that hinder fluid flow into the reservoir.

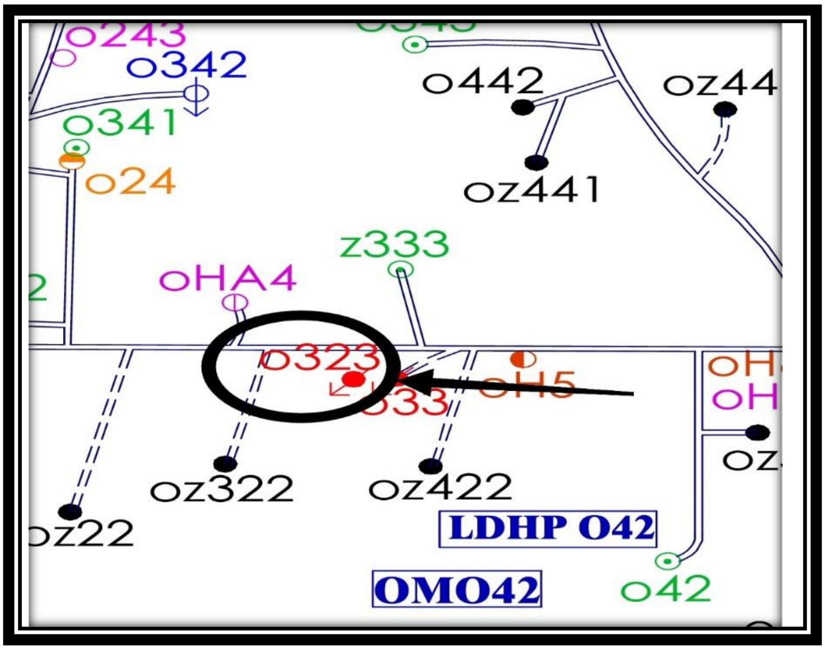


Figure II.10. : OMO323 location.

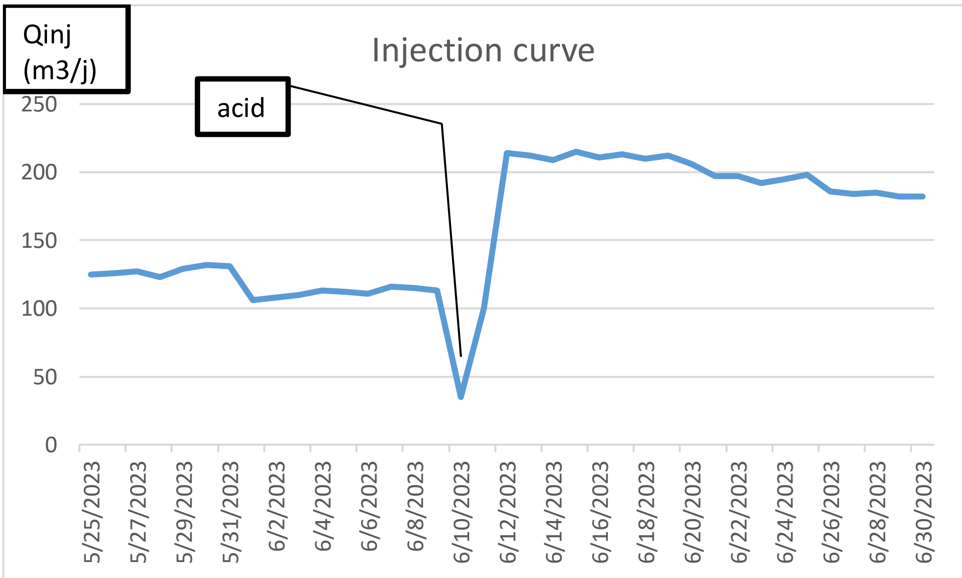


Figure II.11: the variation in injection flow before and after the acidizing operation (OMO323 case). [21]

We observe:

- A decreasing flow rate that eventually becomes non-existent indicates a reduction in the formation's permeability, necessitating the acidizing process.

- The return of the flow to an increase and then to stability within its field is due to the success of the acid in reopening the pores inside the reservoir, thus restoring its original permeability.
- acidizing is an effective intervention for restoring injectivity in gas injector wells by dissolving and removing mineral scales, deposits, and other formations that hinder fluid flow. Proper planning, execution, and evaluation are important for maximizing the effectiveness of acidizing treatments and maintaining the productivity of gas injection operations to increase oil production wells in hassi messaoud field

II.3.3Fractruration:

II.3.3.1.Fractruration objectives:

Hydraulic fracturing is performed on a well for one (or more) of three reasons, summarized in three main objectives:

a) **Bypass near-wellbore damage**: This damage is caused by the invasion of drilling fluids into the formation during drilling and the chemical incompatibility between the drilling fluids and the formation, which reduces the injectivity.

b) **Improvement of petrophysical properties**: This is achieved by creating and extending conductive channels deep into a tight formation (K < 0.1 md).

c) **Injectivity enhancement**: This is accomplished by increasing the flow area in the formation, thereby increasing the flow surface according to Darcy's law:

$$q = \frac{k.h\,(P_G - P_{fw})}{141.2.B.\mu(\ln\frac{R_e}{r_w} + S)} \qquad \textbf{(II.8)}$$

Where:

- **q:** is the flow rate.
- ;P_{fw}**:** bottom-hole flowing pressure (psi).
- **K:** the permeability (ft).
- ;r_w: wellbore radius (ft).
- **h**: :is the thickness of the formation (ft).

- **μ:** is the viscosity (cp).
- P_G: reservoir pressure (psi).
- R_e: drainage radius (ft).
- S: is the total skin.

II.3.3.2.Chronology of a Hydraulic Fracturing Operation:

The sequence of a hydraulic fracturing stimulation operation generally follows the chronology below (Figure):

a) **Initiation of the fracture**: Applying pressure to the reservoir rock using a fluid to create a fracture.

b) **Extension of the fracture**: Developing the size of the created fracture by continuous pumping of fluids.

c) **Maintaining the fracture opening**: Pumping proppants into the fracture, carried by a viscous fluid.

d) **Stopping the pumping and closing the well**: Ceasing the pumping and flowing back the fracturing fluids into the well for recovery while leaving the proppant in place in the reservoir.

e) **Flow-back and production start-up**: In this phase, it is necessary to evacuate the treatment fluid contained in the fracture.

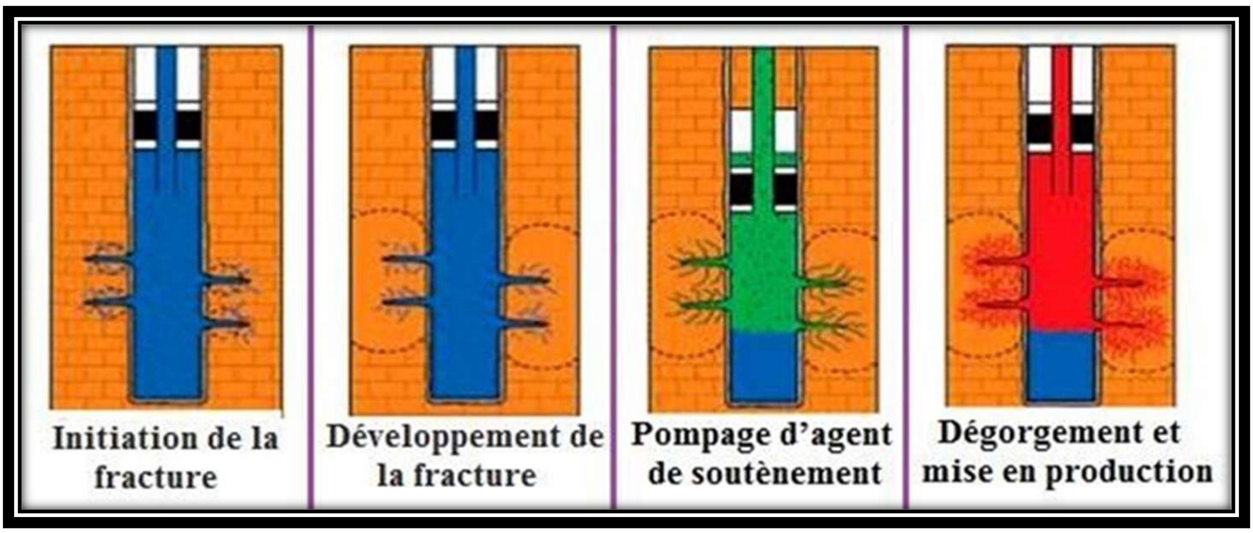


Figure II.12: Chronology of a Hydraulic Fracturing Operation.

II.3.3.3.Pressure evolution during treatment:

When pumping begins, the pressure rises until the peak:

- The peak represents the fracture initiation pressure.
- After the peak, there is a decline followed by a quasi-stable pressure, which is the propagation pressure.
- Finally, there is a pressure drop due to pumping cessation. This is followed by another decline indicating the closure pressure.

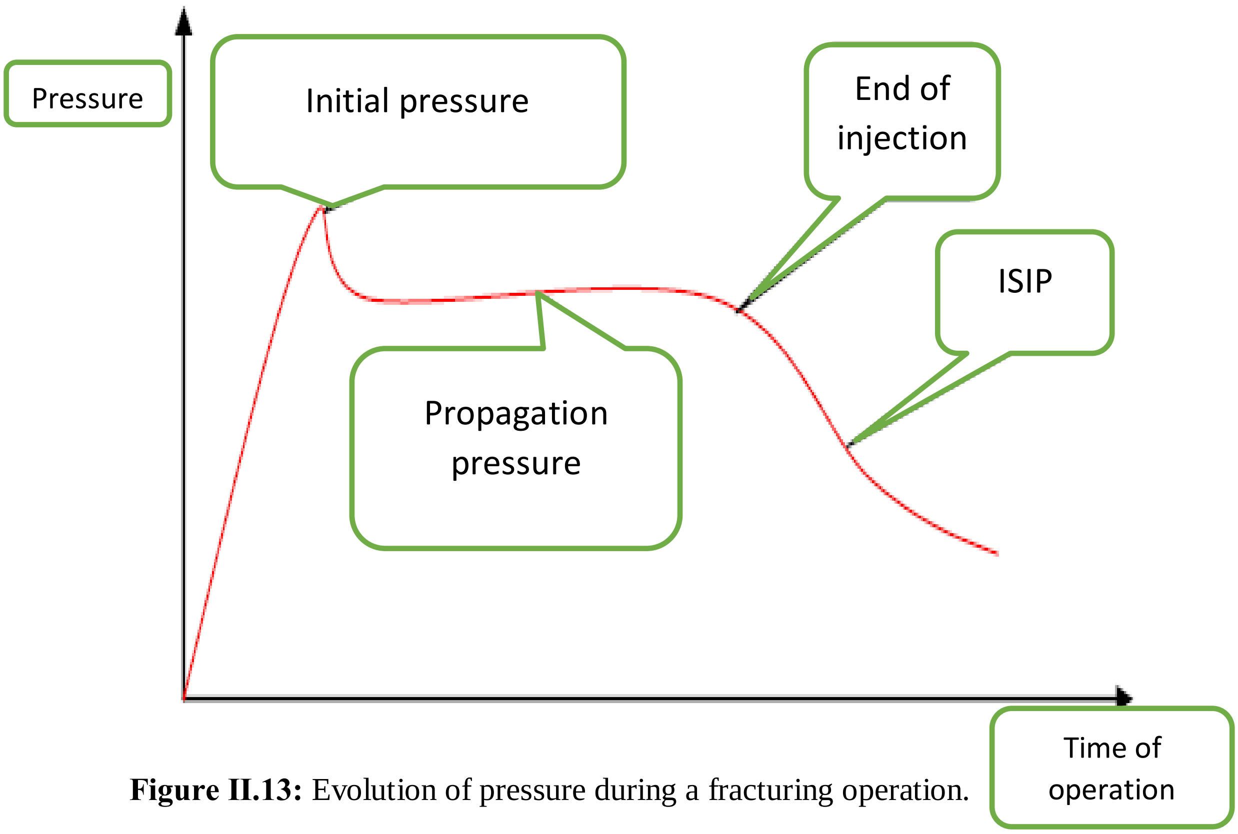


Figure II.13: Evolution of pressure during a fracturing operation.

Fracturing of the injectors well MD 757:

The decrease in injectivity of gas injector well MD 757 can arise from various factors, necessitating interventions such as hydraulic fracturing for enhancing injectivity, by creating fractures in the reservoir rock. This technique effectively addresses for formation damage, low permeability issues, and mechanical obstructions, there by optimizing fluid flow and maximizing the productivity of gas injection operations.

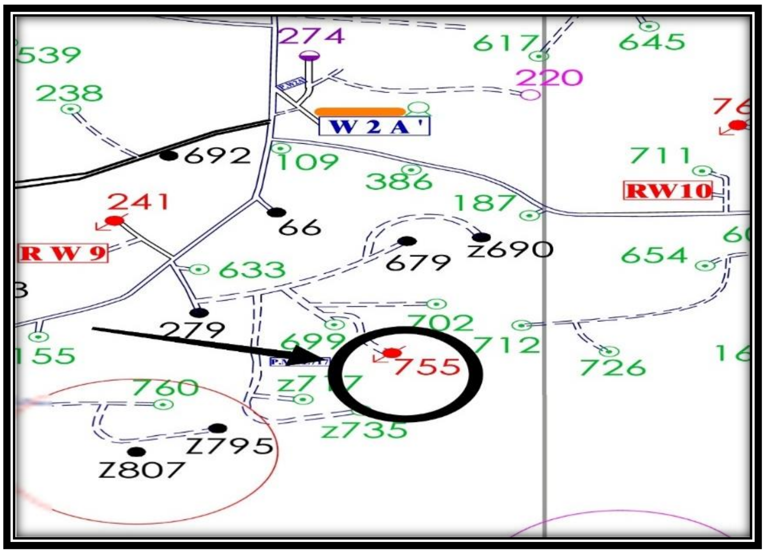


Figure II.14: MD755 location.

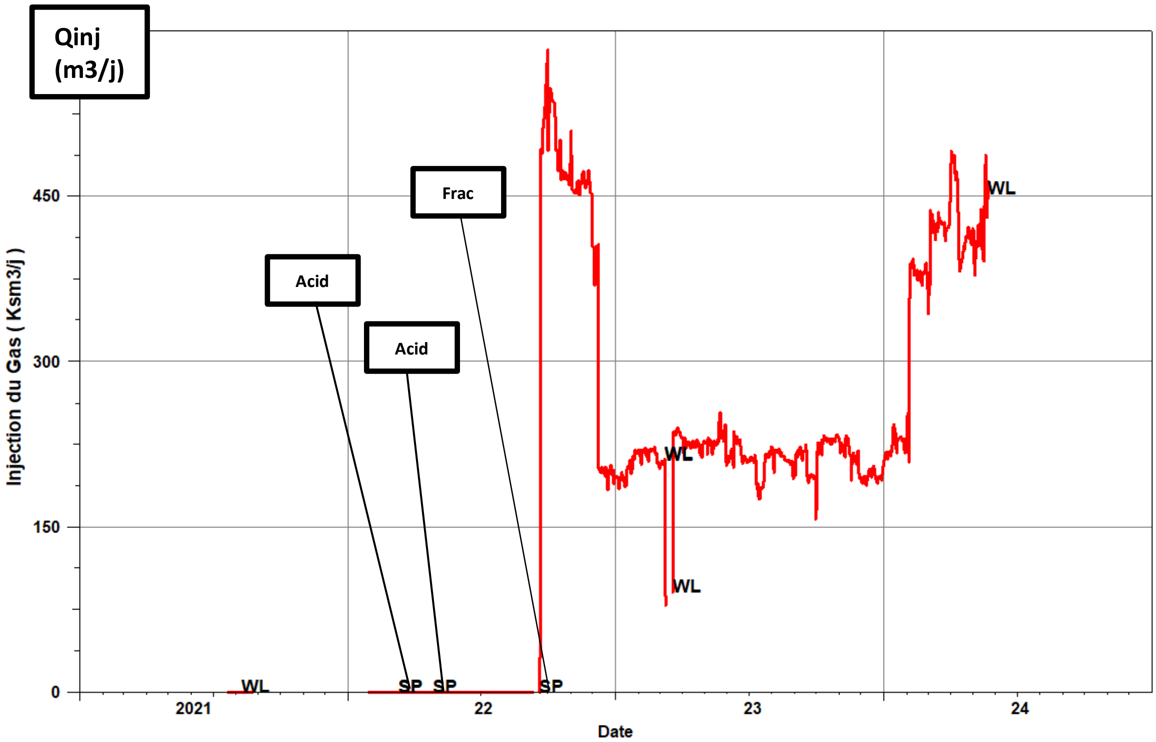


Figure II.15: the variation in injection flow before and after the hydraulic fracturing operation (MD755 case). [21]

According to the following curve, we observe that:

- In our case here, this well underwent two unnecessary acidizing operations. and required us to perform a hydraulic fracturing operation in order to restore its original flow rate.
- The success of the operation and its effectiveness are represented by the almost instantaneous increase in the injection rate.
- acid fracturing involves pumping acid at high pressure into the formation to create or enhance fractures near the wellbore. This method can bypass near-wellbore damage, increase reservoir contact, and improve injectivity by enhancing fluid pathways.
- The injectivity is an important factor that influences the efficiency, effectiveness, and sustainability of injection operations in oil production. High injectivity wells are essential for maximizing oil recovery rates, maintaining reservoir pressure, optimizing production economics, and ensuring compliance with environmental and regulatory standards. Therefore, the operation of interventions as cleaning , acidizing , fracturation increase injectivity continue to be a priority in reservoir engineering and production optimization efforts within the oil industry.

Conclusion:

The impact of gas injectors on oil production can be significant and depends on several factors, including the type of gas used, the reservoir conditions, and the types of intervention such as cleaning, acidizing and fracturing. Here are some key points to consider:

1. Gas injection is often used as a method of enhanced oil recovery. Injecting gases such as natural gas can help increase the reservoir pressure, displace oil towards production wells, and improve overall recovery rates. This process is particularly effective in mature or depleted reservoirs where primary and secondary recovery methods have already been utilized.
2. In Hassi Messaoud fields, natural reservoir pressure declines as oil is extracted. Injecting gas helps maintain or restore reservoir pressure, which in turn can sustain or even increase oil production rates over an extended period.
3. Gas injection can significantly impact oil production by improving recovery rates, maintaining reservoir pressure, and extending the productive life of oil productivity

wells. However, the effectiveness of gas injection depends on reservoir-specific conditions and project objectives, requiring careful planning and management to achieve desired outcomes.

Chapter 3

Surface facility corrosion and protection in injection wells

III.1.Problem statement:

The phenomenon of corrosion in Hassi Messaoud field poses detrimental problems to the surface installation of injection wells, corrosion in parts of this system leads to a reduction in its lifespan, and often necessitates the intervention of specialized technicians to replace or repair the faulty components. Parts such as high-pressure gas pipes may halt the injection and recovery process partially until they are replaced, which directly affects production levels. Therefore, finding possible solutions to protect these system components is an urgent necessity that must be implemented as soon as possible. In this section, we propose cathodic protection as a type that has been previously tested and proven effective in oil fields.

Figure III.1: corroded parts of the injection system

III.2.Corrosion of Above-Ground Injection Facilities:

The corrosion observed is localized on the exterior of the piping, caused by aggressive soil attack, its pH, and its salinity, combined with the mechanical effect of erosion. The equipment affected by this corrosion includes:

- Surface equipment of the wells: carbon steel sleeves located downstream of the gate valve are subjected to severe hydrodynamic conditions due to the geometric variation of the piping.

- Junctions, manifolds of gas injection wells, and various collectors.

- Corrosion is particularly evident at the weld seams and lower generators, as these are connected by welding a flange between two sleeves. The low points of the collectors, due to the relief's elevation changes, provide favorable conditions for the stagnation of the aggressive aqueous phase, and the elbows where erosion phenomena reach their maximum.

FigureIII.2: Perforation of 4’’ Pipe

III.3.Corrosion of Buried Pipelines:

Buried pipelines can undergo external corrosion due to:

- The formation of an electrochemical cell between the soil and the pipeline caused by soil heterogeneity.

- Aggressive attack from chemicals infiltrated into the subsoil, originating from drilling mud or cement discharged on the soil surface.

- The crossing of two pipelines, where one is protected and the other is unprotected, resulting in the formation of an electrochemical cell, with the unprotected pipeline becoming the anode in relation to the protected pipeline.

FigureIII.3: External Corrosion of a Buried Pipeline

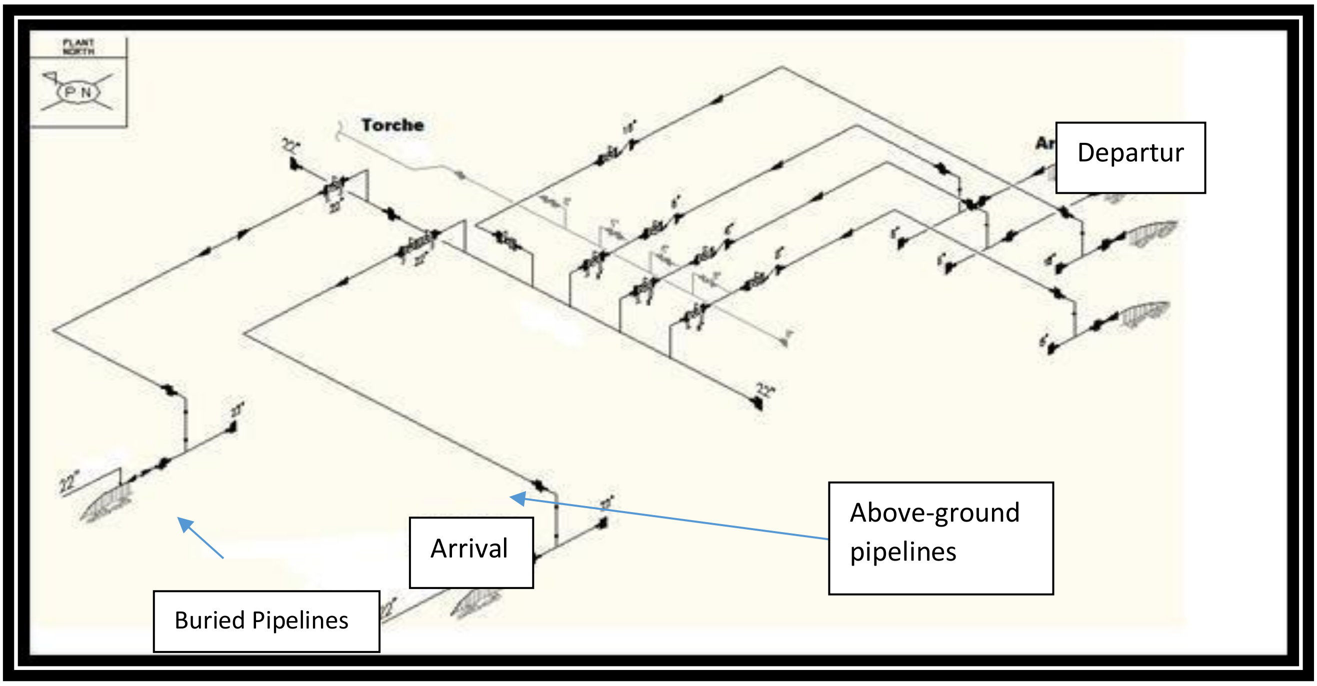


Figure III.4: The components most affected by corrosion on a manifold

III.4.Corrosion factors:

- Soil aggressiveness.
- Hydrogen potential "pH".
- salinity

III.5.Assessment of soil aggressiveness:

Soil aggressiveness plays the main role in the corrosion of certain parts of the injection well system. Where it contributes significantly to the degradation of surface equipment in contact with the ground such as manifolds and pipes. Therefore, it is necessary to find out why soil is aggressive by following several analyses:

III.5.1.Soil resistivity:

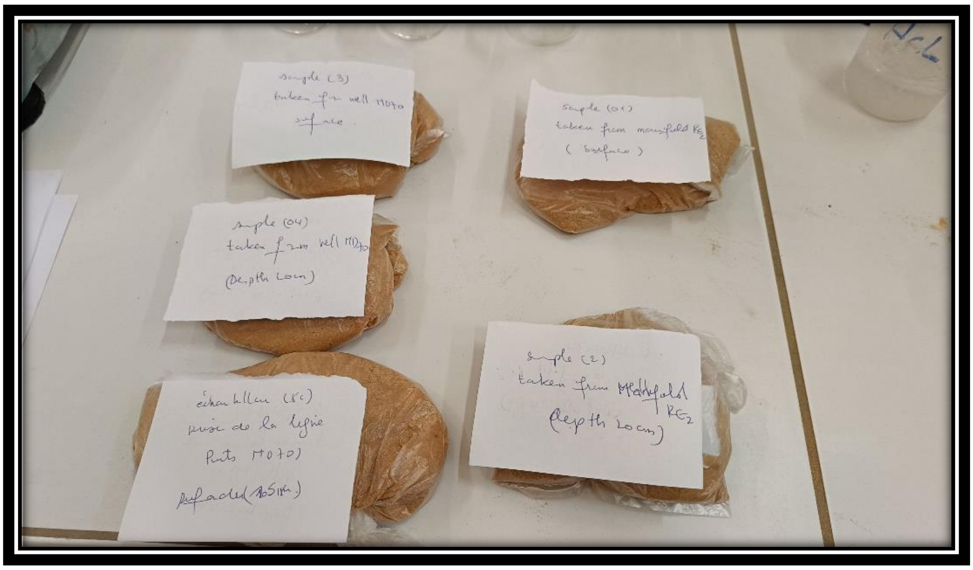
Soil resistivity is a measure of how much the soil resists the flow of electric current. The resistance of soil to the flow of electrical current, typically expressed in ohm-meters ($\Omega \cdot m$).we can measure its value by two famous methods, one of these last two called Wenner Method, this is a common method used to measure soil resistivity. It involves placing four equally spaced electrodes in a straight line on the ground and passing a current between the outer electrodes while measuring the voltage difference between the inner electrodes. **[26]**

III.5.2.Soil salinity:

Soil salinity refers to the concentration of soluble salts in the soil, Salinity is a critical factor influencing soil health, and the integrity of infrastructure such as injection well installations, The presence of soluble salts in the soil, typically measured in terms of electrical conductivity (EC), expressed in deciSiemens per meter (dS/m) or millimhos per centimeter (mmhos/cm).

III.5.3.Experimental protocol:

Five soil samples were collected from various locations around the injection wells, and the following method was employed to determinate the factors of soil aggressivity:

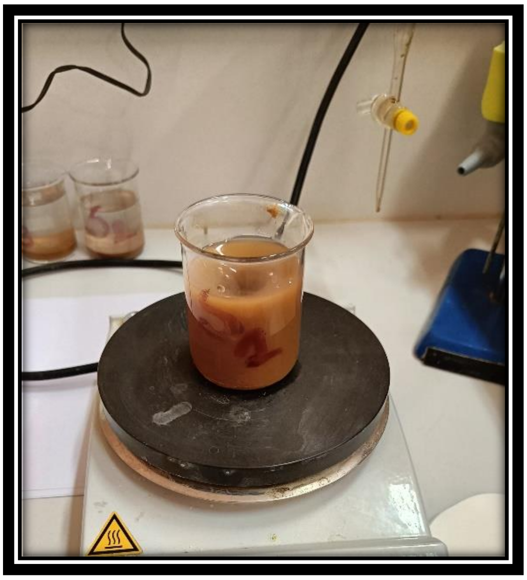


FigureIII.5: samples of soil on different locations.

- We put 20 grams of the content of each sample.
- This amount was infused with distilled water to 100 ml.
- We added a few drops of HCL (1M) to help break down the salts in the soil.

FigureIII.6: Experimental samples after diluting them in distilled water.

- After 24 hours, the agitation was applied and then filtration of these solutions, in preparation for reading the parameters.



FigureIII.7: Experimental samples after shaking and filtration.

- We use the multi parameters apparues measurements to evaluate the resistivity , salinity and pH of the samples

FigureIII.8: multi parameters measurement.

TableIII.1: Results of measurement.

	S1	**S2**	**S3**	**S4**	**S5**
Salinity	0.5	0.52	0.54	0.45	0.6
PH	9.2	8.4	8.76	9.1	9.02
Resistivity	9.43	9.89	12.3	10.89	9.46

The table III.1 presents different data of resistivity, salinity and PH for the five samples Lower resistivity (9.43 Ω·m, 9.46Ω·m, 9.89Ω·m) indicates higher conductivity, which can accelerate the corrosion process. When soil or formation fluids have low resistivity, they can facilitate the flow of electrons between metals (such as pipelines or well casings) and the surrounding environment, promoting electrochemical reactions that lead to corrosion.

Higher salinity (0.52 PSU,0.54 PSU,0.45PSU,0.6 PSU) can increase the aggressivity of soil or formation fluids towards metals. Salts act as electrolytes in aqueous environments, facilitating electrochemical corrosion processes such as galvanic corrosion, pitting corrosion, or stress corrosion cracking.

High pH (9.2, 8.4, 8.76, 9.1, and 9.02) (alkaline) environments can induce localized corrosion mechanisms such as caustic cracking or hydrogen embrittlement in susceptible metals. The combined influence of resistivity, salinity, and pH can synergistically affect soil aggressivity. Low resistivity and high salinity in acidic soils can create highly corrosive conditions that significantly degrade pipe-line and injector wells installations .in the zone of gas injection in Hassi Messaoud field

- The Cathodic protection is necessary for injectors wells facilities in aggressive soils primarily to mitigate the risk of corrosion. This system of protection creates an electrochemical environment that protects buried or submerged metal structures from corroding.
- We propose an implement installation procedure in accordance with industry standards to ensure the integrity and effectiveness of the cathodic protection system for the gas injection zone in Hassi Messaoud field.

III.6.Sizing a cathodic protection system for surface installation of injection wells:

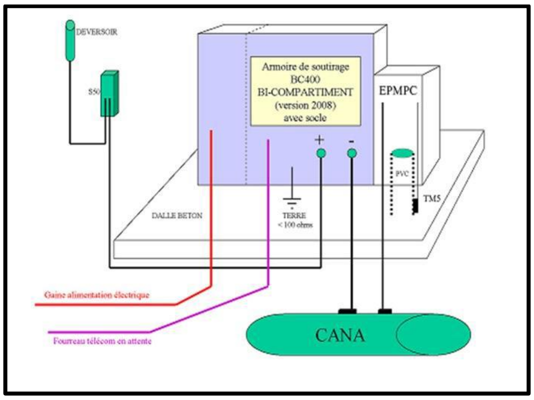
The gas injection area at Hassi Messaoud requires a cathodic protection system, According to previous experiences that have proven its effectiveness, it is preferable, especially in our case, to use the impressed current protection, as system that can be expanded in the future, powered by various types of power sources, and we opted for solar panels in our case.

III.6.1.Cathodic Protection (or Extraction) Station:

To ensure protection using this method, it is necessary to install a cathodic protection station. The role of the station is to deliver the current required for the protection of the structure. Generally, a station consists of:

- A voltage connection: from a power source.
- This electrical energy can be from a solar source (PV), thermal (thermoelectricity).
- Extraction cabinet: it includes a circuit breaker (which protects downstream electrical equipment), a meter, and a rectifier transformer. This last element regulates each time to deliver the necessary current for protection, thus being a very important element in this protection method.
- Connecting conductor to the spillway and the structure to be protected.

The design of an extraction station takes into account many factors including the location of the extraction station, the protection range of the station, the positions of the anodes, and the type of electrical source. To avoid repetition, we prefer to address the part concerning the sizing of the extraction station in the following chapter. [28]; [29].

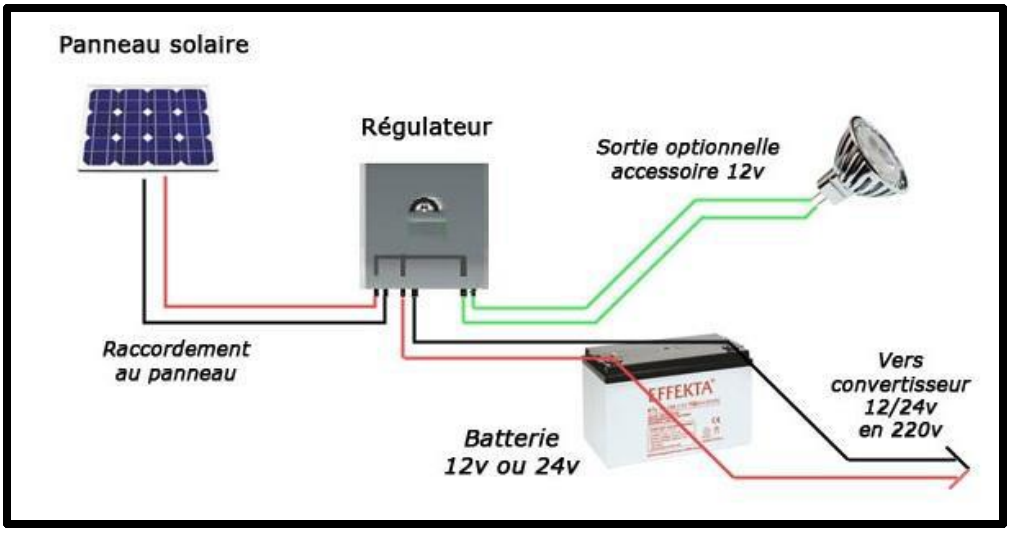


FigureIII.9: Poste de protection cathodique.

III.6.2.Providing the necessary energy by photovoltaic:

III.6.2.1.The Solar Panel:

The characteristics of the panel are generally indicated on a label attached to the back of the panel. **[30]**



FigureIII.10:photovoltaic solar installation diagram.

III.6.2.2.The Regulator:

The regulator is an electronic unit whose role is to manage the flow of current:

- Current coming from the panels for the purpose of charging the battery.
- Current coming from the battery to the consumers.

It manages the charge and discharge of the battery by disconnecting the panel when the batteries are charged or by cutting off power to the consumers when the battery is too discharged. The regulator is thus at the intersection of the entire system. It includes a blocking diode to prevent the battery from discharging into the panel during the night. Therefore, a regulator cannot be avoided. **[30]**

III.6.2.3.The Inverter:

The inverter is an electronic unit that allows the production of alternating current (220V) from direct current (12V). It is directly connected to the batteries (12 volts) and then connected to the consumers (220 volts). **[32]**

III.6.2.4.The Batteries:

The role of this component is to store electrical energy to take over during periods when the weather conditions do not allow the panels to provide this energy. An electrical battery is an electrochemical component, it consists of positive and negative electrodes composed of dissimilar alloys immersed in an electrolyte (acid). The redox reactions that govern the operation of a battery are reversible, as long as it has not been long or completely charged or too overcharged.

Generally, the batteries used here are stationary deep-cycle lead alloy batteries. They are designed to deliver a stable current for long periods while retaining their rechargeability and this over a large number of cycles (at least 400 cycles). On the market, stationary batteries are available in 2, 6, or 12 volts nominal. A battery is also characterized by its capacity expressed in ampere-hours [Ah], which is the amount of current it can provide over a specific number of hours at a reference temperature. It is important to note that nowadays, solar batteries with a lifespan of 10 years are available. **[32]**

III.6.2.5.Wiring:

It is advisable not to lengthen them under the risk of significantly reducing efficiency: adding 1 meter can drastically reduce the power of the supplied energy.
The table below indicates the minimum diameters to be respected for the wiring between:

- Regulator - panel: about 10m

- Regulator - battery: about 1m
- Regulator - distribution box: about 5m

III.6.3. Ground-Adapted Anodes :

The most suitable anodes for burial in the ground are cylindrical anodes made of high-silica iron, weighing from 1 to 80 kg, with diameters ranging from 30 to 110 mm, and lengths from 250 to 1500 mm. The anodes have iron conductors at their ends, which are connected to the cable by welding. **[33]**

Figure III.11: Ferro-silicon sacrificial anodes. **[33]**

Ferro-silicon anodes are generally shaped like cylindrical rods; the most common dimensions are shown in Table:

Tableau III.2: Dimensions of Ferro-Silicon Anodes. **[33]**

Diamètre (mm)	Longueur (m)	Masse (Kg)
38	0.915	7.5
51	1.22	19
51	1.525	23
64	1.525	35
76	1.525	50

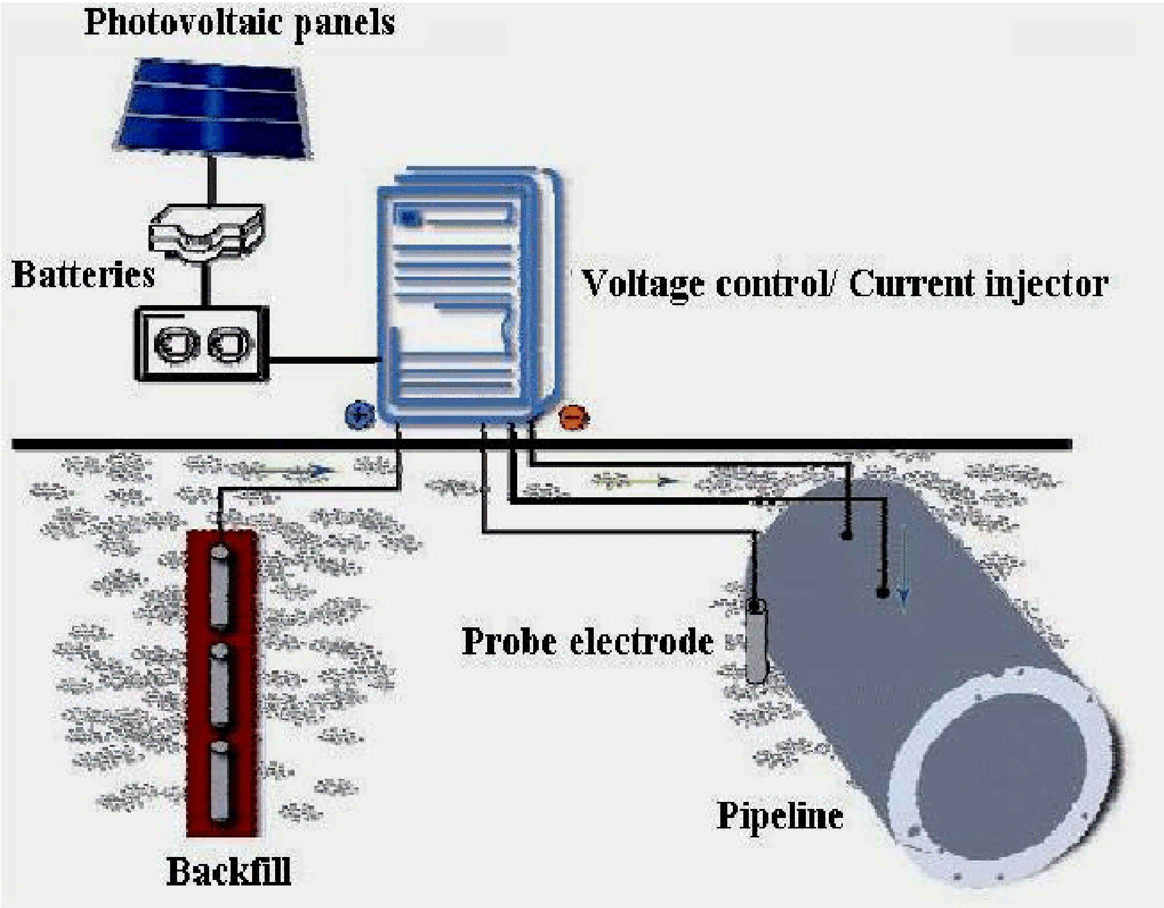


Figure III.12: summary diagram of impressed current protection powered by a photovoltaic system.

III.7.The work procedure:

We present a calculation note for the design of the cathodic protection system for a pipeline, followed by a calculation note for the sizing of the solar generator that will provide direct current to the drainage station.

III.7.1.Determination of the Insulation Resistance Value:

The average insulation value of a structure is merely an indicator of the average level of insulation of the structure. It depends on the presence of coating defects that expose the steel of the pipe, which comes into contact with the surrounding soil. Additionally, it depends on the resistivity of the soil surrounding the structure; the lower the soil resistivity, the lower the insulation resistance, and vice versa.

III.7.1.1.By Testing:

The provisional protection test, after verifying the potentials of the structure relative to the soil, will help define the value of the average insulation resistance. The average insulation resistance value of a pipeline can be calculated using the following formula: For a given section, the average insulation resistance will be:

$$R = \frac{\Delta U}{I} \times Se = \frac{\Delta U}{I} \times \pi\, D\, L \qquad \textbf{(III. 1)}$$

- **R**: Approximate average insulation value in $\Omega.m^2$
- **ΔU**: Average potential gain determined by calculating the difference between the potential of the structure with current applied (measured during the test) and the natural (spontaneous) potential of the structure in the soil before the test, or the potential with the current switched off (disconnected).
- **I** : current intensity during the test, expressed in amperes
- **Se** : external surface area of the structure to be protected, in m^2
- **D** : diameter of the pipeline in meters

III.7.1.2. By estimation:

In the absence of data collected from the test site, indicative isolation values are provided in the table below:

Table III.3: Insulation Values **[35]**

Type of Conduit	Insulation Resistance in $\Omega\cdot m^2$
Buried pipeline network with very degraded coating	500 to 1000
Mesh network of buried pipelines with type C coating	5000 to 15000
Buried steel pipeline with type C coating	5000 to 100,000
Buried steel pipeline coated with PE tape	10^4 to more than 10^5
Buried steel pipeline coated with extruded PE	10^5 to more than 10^6

Difficult installation conditions, the presence of very rocky soil, or waterlogged terrain can lower the limits set in this table.

III.7.2 Study of Cathodic Protection:

The definition of cathodic protection for a pipeline involves calculations based on parameters that need to be measured or estimated, as well as the designer's experience. The basic data for the calculation and design of cathodic protection systems are:

- The planned operational duration for the structure to be protected (years),
- Dimensional characteristics of the structure: length, diameter, thickness, etc.
- The insulation value of the coated structure and the aging coefficient of the applied coating β\betaβ,
- The soil resistivities along the route.

III.7.2.1.Cathodic Protection by Drainage:

Before determining the calculation formulas, it's essential to explain the main concepts and provide certain parameters used in the calculations **[33]**:

A.Injection Potential: The injection potential is defined as the reduction in potential required at the drainage point to achieve values at the ends of the pipeline that are below the protection thresholds (<-850 mV / Cu/CuSO4).

B.Protection Current: It is defined as the current intensity needed to be injected into the structure to ensure a reduction in potential compared to the protection criterion.

C.Longitudinal Resistance of the Pipeline: Metal structures traversed by the protection current are considered conductors, and these conductors exhibit resistance to the passage of electric current. This resistance is called longitudinal resistance and depends on the material's nature and dimensions. It is given by the following formula

Where:

$$r = \frac{\rho_a}{\pi\, e\, (D_{EX} - e)} \quad [\Omega \, . \, m^{-1}] \quad (\textbf{III}.2)$$

-r : Longitudinal resistance of the pipeline in ohms per meter (Ω/m)

-ρ_a: Resistivity of steel, which varies between 17.10^{-8} and $24.\ 10^{-8}$

- **e**:Thickness of the tube in meters (it is a function of the diameter)

-$\mathbf{D_{EX}}$: Outer diameter of the pipeline in meters.

D. Transverse Resistance of the Pipeline:

The transverse resistance R, expressed in ohm-meters (Ω·m), is the electrical resistance per meter of coated pipeline with respect to the ground. It is given by:

$$\boldsymbol{R\ trans} = \frac{\boldsymbol{R_{IS}}}{\boldsymbol{\pi\ .D_{EX}}}\ [\Omega\ .\boldsymbol{m^{-1}}] \quad \textbf{(III. 3)}$$

Where:

-**R trans** : Transverse resistance of the pipeline in (Ω·m)

-$\boldsymbol{R_{IS}}$: Insulation resistance in (Ω·m)

-$\boldsymbol{D_{EX}}$: Outer diameter of the pipeline in meters.

E. Attenuation Coefficient :

$$\boldsymbol{\alpha} = \sqrt{\frac{\boldsymbol{r}}{\boldsymbol{R}}}\ \ [\boldsymbol{m^{-1}}] \qquad \textbf{(III .4)}$$

r: longitudinal resistance of the pipe in $[m^{-1}]$

R: transverse resistance of the pipe in Ω.m

This coefficient varies from 1 to 20 x$10^{-5}\ m^{-1}$. It is inversely proportional to the insulation value: the higher the insulation value, the lower the α, and the greater the tapping range.

F. Characteristic Resistance:

The characteristic resistance of a section represents the earth resistance of a pipeline of infinite length.

$$\mathrm{Rc} = \sqrt{r * R} \quad \textbf{(III.5)}$$

G. Calculation of Protection Current:

In this case, we can use the concept of protection current density to calculate the protection current.

$$I = i.\pi.D.L \quad \textbf{(III.6)}$$

Where:

- **I**: Protection current of the network in amperes
- **i**: Current density in mA/m², calculated by the formula:

$$i = \frac{E_{REP} - E_{PROT}}{R_{is}} \quad \textbf{(III.7)}$$

Or determined from the test.

- $\boldsymbol{E_{REP}}$: Potential of the pipeline at rest (without protection) = -0.75 or 0.4 V (Cu/CuSO4)
- $\boldsymbol{E_{PROT}}$: Threshold potential of the pipeline under protection = -1 V (Cu/CuSO4)
- $\boldsymbol{R_{is}}$: An estimated value from the table in Chapter II based on the nature of the coating
- **D:** Outer diameter of the tube
- **L**: length of the tube.

H.Determination of Rail Weight:

According to Faraday's law, the consumption of: Ferro-silicon is 0.3 Kg/Amp. Year

$$\mathbf{P} = \boldsymbol{I} \times \boldsymbol{t} \times \mathbf{0.3} \quad \textbf{(III. 8)}$$

Where:

- **P** :is the weight of the rail required for a current flow I .
- **t** : is the desired lifespan of the rail (20 to 30 years).

I.Determination of Rail Length:

$$\boldsymbol{L} = \frac{\boldsymbol{P}}{\boldsymbol{Pa}} \times \boldsymbol{La} \quad \textbf{(III. 9)}$$

P: *the weight of the rail*

Pa: *the weight of anode*

La :*anode Length*

J.Calculation of Drainage Resistance:

The drainage resistance of a spillway must be calculated to be compatible with the capabilities of the continuous current generator, which provides the necessary current for the network's protection, taking into account foreseeable extensions. This resistance depends on the shape of the spillway, its dimensions, and the soil resistivity:

$$\boldsymbol{R_v = \frac{\rho_S}{2\pi}\left(\ln\frac{8L}{d} - 1\right)} \qquad \textbf{(III .10)}$$

$\boldsymbol{R_v}$: earth resistance in (Ω)
ρs: soil resistivity in (Ω·m),
L: length of the anode in (m),
d: diameter of the anode in (m).

III.7.2.1.11.Determination of the tapping power:

$$\boldsymbol{X = \frac{U \times I_S}{\eta} = \frac{R \times I_S^2}{\eta}} \qquad \textbf{(III .11)}$$

η: Efficiency of the rectifier, generally between 60% and 75%
R: Circuit resistance = ∑Ri = R1 + R2 + R3 + R4
R1: Discharge/ground resistance
R2: Pipe/ground resistance
R3: Pipe resistance
R4: Cable resistance

Calculation of **R2**: See Appendix A for the graph showing the pipe resistance as a function of the distance between the discharge point and the pipe, and according to different soil resistivities.

$$\boldsymbol{R_3 = \frac{\rho_a \times L_T}{\pi \times D_{ex} \times e}} \qquad \textbf{(III .12)}$$

$$\mathbf{R_4 = \rho \times \frac{L}{S}} \qquad \textbf{(III .13)}$$

$\boldsymbol{\rho}$ **:** The resistivity of copper is 1.68×10^{-8} ohm-meter (Ω·m).

III.8 Sizing of the Photovoltaic System:

Given a geographical location and thus meteorological data, sizing a photovoltaic generator involves balancing the satisfaction of the expressed energy demand with the installed power, both in terms of modules and batteries. The proper optimization of this combination aims to define the most economical generator in terms of acquisition and maintenance, capable of meeting the specifications.

The recommended solar generator is therefore closely linked to the input values (sunlight data, energy demand), and the generator's autonomy can be affected, for instance, by an increase in consumption during critical periods. This can be resolved thanks to the flexibility of this electricity production process.

III.8.1 Sunlight Input Data:

As an indication, the daily sunshine (irradiation) received at the optimal angle during the least favorable month of the year for some regions is recorded in the table below

Table III.4: Solar Irradiation [31]

Wilaya	Solar Irradiation (kWh/m²/day)
Bechar	3.0 - 4.5
Biskra	2.0 - 3.2
Djelfa	2.9 - 3.4
El-oued	2.9 - 3.3
Naama	2.7 - 3.8
Ouargla	2.7 - 4.7
Ghardaïa	3.7 - 4.5

III.8.2 Calculation of the energy required for the tapping station: E_n

The energy required for the tapping station is the minimum energy needed for the station to perform its function under a given power and operating time.

$$E_n = X \times t_f \qquad \textbf{(III.14)}$$

With:

$\boldsymbol{E_n}$: Energy required for the tapping station [Wh/day]

$\boldsymbol{X}$: Power of the tapping station [W]

$\boldsymbol{t_f}$: Operating time of the solar generator station [hours/day].

III.8.3 Calculation of the Energy to be Produced by the Photovoltaic Generator:

Losses are inherent in any energy conversion process. Photovoltaic systems must supply all the energy, including the energy that is lost. These losses have several sources:

- losses due to dust accumulation on the panel,
- losses (voltage drops) in the wiring and energy conditioning equipment,
- losses due to the batteries,
- meteorological uncertainty, etc.

The energy to be supplied by the photovoltaic generator is therefore given by:

$$E_f = \frac{E_n}{1-f} \qquad \textbf{(III.15)}$$

Where: $\boldsymbol{E_f}$: Energy to be supplied [Wh/day]

$\boldsymbol{f}$: Losses, estimated to be between 25% and 45% (see Appendix C1)

$\boldsymbol{E_n}$: Energy required for the tapping station [Wh/day]

In this formula, F is the fraction of energy lost. For example, if the losses are estimated to be 30%, then F = 0.30.

III.8.4 Calculate the Peak Power of the Photovoltaic Generator (PPG):

$$PP_G = \frac{E_f}{I_r} \qquad \textbf{(III.16)}$$

$\boldsymbol{PC_G}$: Peak power of the photovoltaic generator [Wc]

$\boldsymbol{E_f}$: Energy to be supplied [Wh/day]

$\boldsymbol{I_r}$: Average daily solar irradiation [kWh/m²·day].

III.8.5 Determine the Number of Solar Panels (Nps):

$$N_{PS} = \frac{PP_G}{PC_{PS}} \qquad \textbf{(III.17)}$$

III.8.6 Calculate the Required Battery Capacity (C):

$$C = \frac{E_n \times A}{D \times U} \qquad \textbf{(III.18)}$$

C: capacity of battery [Ah].

En: required energy = consumed energy [Wh].

A: battery autonomy [days].

D: deep discharge limit [%].

U: system operating voltage [V].

III.8.7 Calculation of the Number of Batteries Required:

The number of batteries needed is determined by the ratio between the chosen system voltage (the voltage at which the system's equipment operates) and the voltage provided by a single battery. The batteries are connected in series to provide the necessary voltage.

$$\boldsymbol{N_b = \frac{U}{U_b}} \qquad \textbf{(III.19)}$$

Where:

- $\boldsymbol{N_b}$: Number of batteries.
- $\boldsymbol{U}$: System operating voltage [V].
- $\boldsymbol{U_b}$: Voltage provided by a single battery [V].

III.9.Calculation of the cathodic protection system and photovoltaic system:

We have chosen the network of the gas pipelines and applied the aforementioned regulations. This study is applicable to the rest of the pipelines network.

The length of the pipelines is 9825 meters with 10” and 38123 with 6” this pipes is distributed by three manifolds RO1, RO2 and RO3, The length total is 47948 m.

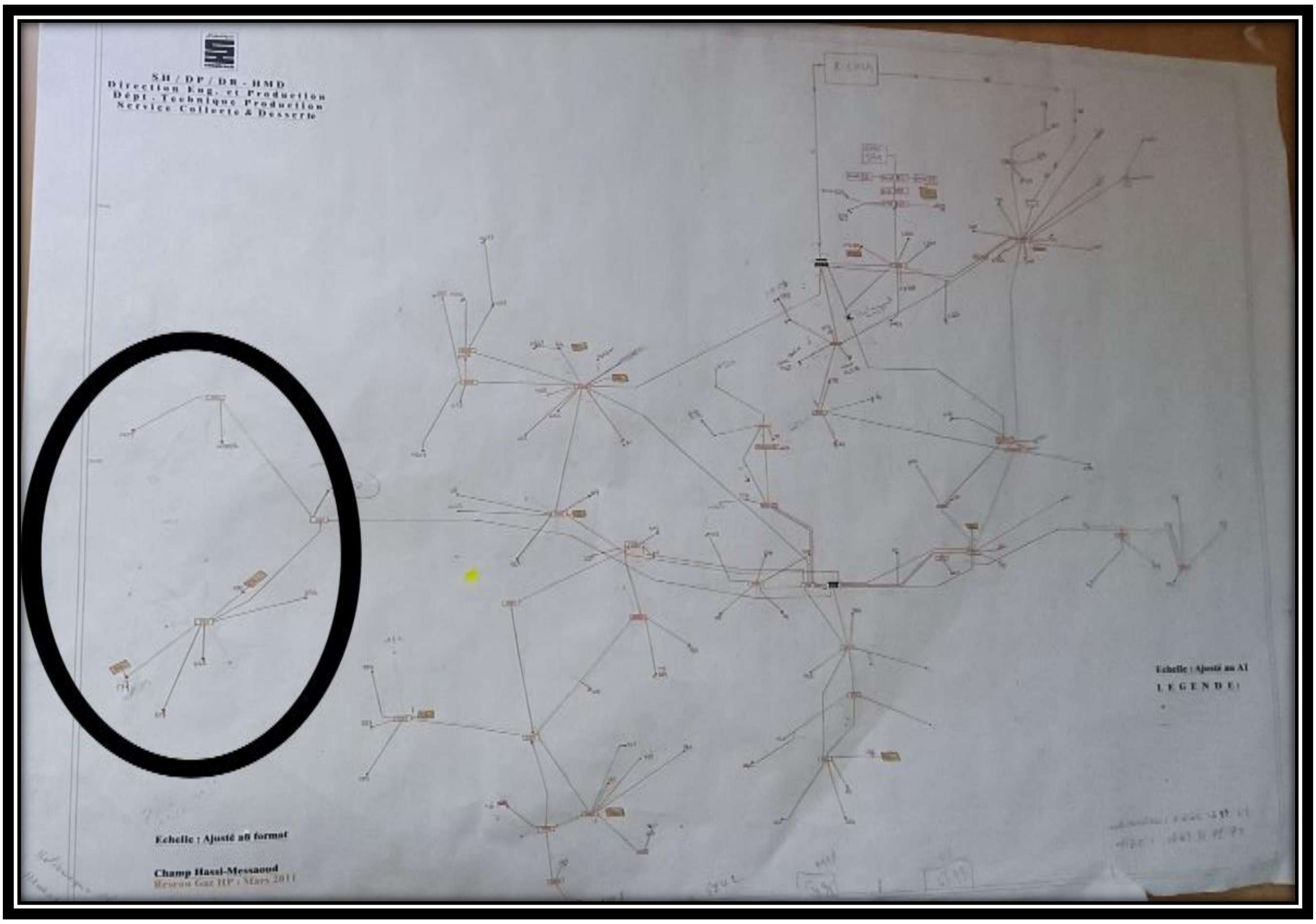


Figure III.13: practical application zone. [21]

Table III.5: System Sizing

Magnitude	Value
Insulation resistance	**900 Ω·m²**
Longitudinal resistance of the pipeline	**2.32×10^{-5} (Ω/m)**
Transverse resistance of the pipeline	**3009 (Ω)**
Attenuation coefficient	**8.78×10^{-5}**
Characteristic resistance	**0.26 (Ω)**
Number of anods	**4**
Discharge/soil resistance	**1.38 (Ω)**
Pipeline/soil resistance	**0.154 (Ω)**
Pipeline resistance	**0.11 (Ω)**
Cable resistance	**0.102 (Ω)**
Rail length	**6.1 (m)**
Cable length	**300 (m)**
Voltage	**36 (V)**

Current	**20.8 (A)**
Power of the extraction station	**548 (Wh)**
Energy required for the extraction station:	**13152 (Wh/J)**
Energy to be supplied by generator	**18788 (Wh/J)**
Peak power of the photovoltaic generator	**5368 (Wc)**
Battery capacity	**1096 (Ah)**
Number of solar panels	**36**
Number of batteries	**11 (150 Ah of each)**
Number of regulators	**1**

The Cathodic protection systems are typically calculated table III.5 based on several key results to ensure they are effectively protecting injectors well facilities from corrosion. Here are some common aspects that are evaluated:

1. **Potential Measurements**: Monitoring the electrical potential of the protected structure relative to a reference electrode (typically a silver-silver chloride electrode) i. The potential should be within the desired range to ensure effective cathodic protection.
2. **Current Output**: The amount of electrical current supplied by the cathodic protection system indicates its ability to provide sufficient protection. This is often measured in terms of amperes (Amps) or milliamperes (mA).
3. **Protection Criteria**: Various standards and specifications define criteria for cathodic protection systems. These may include maintaining the structure's potential at a specific level (e.g., -850 mV vs. $cu/cuso_4$ reference electrode) or achieving a certain current density.
4. **Coating Integrity**: Assessing the integrity of coatings (if applied) on the structure is essential. A cathodic protection system should not only prevent corrosion of exposed areas but also protect coated surfaces from potential holidays (defects in the coating).
5. **Inspection and Maintenance Records**: Regular inspections and maintenance records are essential for evaluating the long-term effectiveness of cathodic protection systems. This includes checking anode conditions, monitoring electrical parameters, and assessing the overall system performance over time.
6. **Environmental Conditions**: Monitoring environmental factors such as soil resistivity, pH levels, and temperature can also provide insights into the performance of the cathodic protection system.

Conclusion:

When corrosion affects the injectors wells or associated equipment, it can reduce the efficiency of gas injection operations. This may result in decreased pressure maintenance within the reservoir, lower injection rates, and ultimately, reduced production efficiency. To mitigate corrosion in gas injection wells, operators employ various strategies:

- Sizing Cathodic protection.
- Monitoring and Maintenance

Gas injection wells are indispensable assets in the Hassi Messaoud field, playing an important role in maintaining reservoir pressure, enhancing oil recovery, optimizing production efficiency, and supporting sustainable development practices. .However, their effectiveness can be significantly impacted by various problems, including **decrease of injectivity** and corrosion

Increasing injectivity in injector wells is important for maintaining or enhancing their ability to efficiently inject fluids into the reservoir .The operational intervention strategies used to achieve this objective include:

1. **Cleaning:** interventions by cleaning in injector wells are essential for maintaining and optimizing reservoir performance. By effectively removing obstructions and restoring fluid flow capacity, these interventions contribute to efficient oil and gas production and reservoir management.
2. **Perforation Cleaning**: Over time, perforations in the casing or liner of injector wells can become clogged with scale, debris, or formation damage. Cleaning these perforations using mechanical or chemical methods can restore or improve injectivity.
3. **Matrix Acidizing**: This technique involves pumping acid into the well to dissolve minerals and other formations that may restrict fluid flow within the reservoir rock matrix. By removing these obstructions, injectivity can be improved.
4. **Hydraulic Fracturing**: Injectors wells can be subjected to hydraulic fracturing (fracking) to create or enhance fractures in the reservoir rock. This increases the surface area through which fluids can flow, thereby enhancing injectivity.
5. **Injection Rate** Optimization: Adjusting the injection rate and pressure based on reservoir conditions and injectivity tests can optimize fluid flow into the reservoir. This ensures efficient injection without exceeding formation limits.
6. **Advanced Well Stimulation Techniques**: Utilizing advanced stimulation techniques such as nitrogen injection can improve injectivity by altering the fluid properties or enhancing reservoir rock permeability.
7. **Reservoir Management**: Proper reservoir management practices, including monitoring injection pressures, reservoir pressure profiles, and fluid compositions, are essential for maintaining optimal injectivity over the life of the well.

8. **Wellbore and Equipment Maintenance**: Regular maintenance of wellbores and injection equipment to prevent scaling, corrosion, or mechanical damage that can impair injectivity.

By implementing these operational interventions, we can effectively augment injectivity in injector wells, ensuring sustained and efficient fluid injection into the reservoir for enhanced production and reservoir management.

Protecting injector wells from corrosion is essential to maintain their integrity and longevity. We propose these operational strategies for the protection of injector wells:

1. **Material Selection**: Using corrosion-resistant materials for constructing well components such as casing, tubing, and valves can significantly reduce the risk of corrosion. Materials like stainless steel or corrosion-resistant alloys are often chosen for their durability in corrosive environments.
2. **Cathodic Protection**: Installing sacrificial anodes or impressed current systems near the wellhead or along the pipeline can provide cathodic protection. This technique helps to prevent corrosion by directing the flow of electrical current away from vulnerable metal surfaces.
3. **Monitoring and Maintenance**: Regular inspection and monitoring of well conditions, including corrosion rates, fluid chemistry, and equipment integrity, are crucial. Implementing a proactive maintenance program allows for early detection of corrosion issues and timely intervention.

By integrating these operational strategies into injector well management practices, we can effectively protect against corrosion, ensuring reliable and safe operation while extending the lifespan of injector wells in the Hassi Messaoud field.

Enhancing Economic Viability: Evaluate the economic implications of corrosion-related downtime, maintenance costs, and production losses. Identify opportunities for cost-effective interventions and operational improvements to maximize the economic return from injector wells.

- Ensure the selected coating is compatible with the fluids, temperatures, pressures, and environmental conditions encountered in injector wells.

-incorporate additional corrosion protection measures, such as sacrificial anodes or impressed current cathodic protection systems, in conjunction with the coating to enhance longevity.

-Choose coatings specifically designed for the harsh conditions encountered in injector wells, such as those resistant to corrosive fluids (e.g., brine, CO_2, H_2S) and high temperatures.
- Evaluation of the cost of the prepared coating on an industrial scale."
-Optimize reservoir management practices to maximize sweep efficiency and injection rates.

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ANNEXES :

Annuaire Panneaux Solaires (/pv/panel) / XSSP140-155M27

XSSP140-155M27

Zhejiang Wuyi Xinsheng Energy Science and Technology Co., Ltd.

Type:	Monocristallin
Gamme de Puissance:	140 ~ 155 Wp
Région :	Chine

Produit Alternatif

(/pv/panel-datasheet/Monocrystalline/30505/102279?utm_source=ENF&utm_medium=enquiry_product

FS-M315-M335-72

(/pv/panel-datasheet/Monocrystalline/30505/102279?utm_source=ENF&utm_medium=enquiry_product

Abshine

A partir de €0.285 / Wp

Matériaux Donnée STC Qualité

Type Cellule: Monocristallin

Dimension Module: 1956x992x45 mm

Poids: 23 kg

Taille Cellule: 156×156 mm

Epaisseur du Verre: 3.2 mm

Plus (/pv/panel-datasheet/Monocrystalline/3050

(/) Annuaire Entreprises (44,600) Annuaire Produits (61,600) Industrie Solaire Publicité Contact (/contact)

S'identifier (/member/login)

Inscription (/member/register)

Information de Produit **Profil d'entreprise**

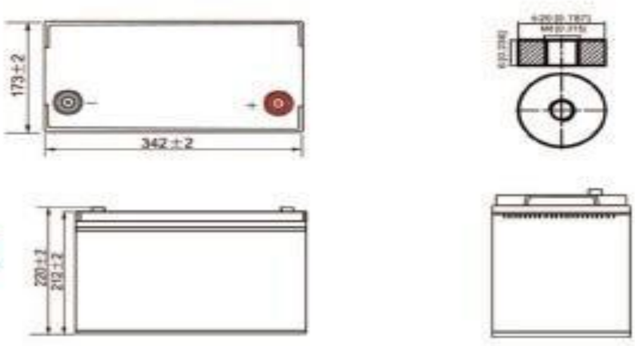
Caractéristiques du Produit

No. de Modèle	XSSP140M27	XSSP145M27	XSSP150M27	XSSP155M27
Garantie				
Garantie	10 Années			
Garantie de Puissance	10 ans à 90% de puissance sortie, 25 ans à 80% de puissance sortie			
Caractéstique Electrique (STC)				
Puissance Maximal (Pmax)	140 Wp	145 Wp	150 Wp	155 Wp
Tension à Puissance Maximal (Vmax)	27.81 V	27.97 V	28.67 V	28.99 V
Courant à Puissance Maximum (Cmax)	5.05 A	5.19 A	5.26 A	5.36 A
Tension Circuit Ouvert (Voc)	33.75 V	33.91 V	34.29 V	34.39 V
Courant Circuit Court (Isc)	5.75 A	5.79 A	5.85 A	5.88 A

https://fr.enfsolar.com/pv/panel-datasheet/Monocrystalline/23089?utm_source=ENF&utm_medium=panel_more_series&utm_campaign=enquiry_... 1/3

SOLISE

FICHE TECHNIQUE
BATTERIE 12V 100AH



CARACTERISTIQUES TECHNIQUES

Technologie : LiFePO4
Tension nominale : 12,8V
Capacité nominale : 100Ah
Energie : 1280Wh
Tension de charge maxi : 14,6V
Courant de charge standard : 50A
Courant de charge rapide : 100A
Courant de décharge continu : 100A
Courant de décharge pulse : 120A
Autodécharge : <3% /mois
Température de fonctionnement : -20°C à 60°C
Température de charge : 0 à 45°C
Nombre de cycles : 2000 à 1C 100% DOD

Connexion par vis M8
Poids : 13,5Kg
Dimensions (L x l x h) : 342mm x 173mm x 212mm
IP 56 (protection contre les projections d'eau)

Gestion de la batterie par BMS :

Protection contre les courts circuits.
Protection contre les surcharges 250A +/- 10A
Protection contre les décharges profondes tension < 8V
Protection contre les températures élevées >65°C
La protection se fait par coupure de la batterie et la reconnexion est automatique.
Equilibrage des cellules.