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(CO2 - EOR Operations in Conventional Oil Reservoirs: Lessons Learned)

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ABSTRACT

The main objective of this research is to provide basic technical information regarding the CO_2-EOR process by collecting and analyzing field data. This is study will take the advantages of Data collection, CO_2-EOR databases and surveys from different articles , technical papers, workshops presentations, book, ect… In this project we conducted Data processing, data analytics techniques, Screening criteria, descriptive statistics Selection scheme and comparative analyses.

We found that Co2 injection unsuccessful in the following conditions:

1. In high salinity wells
2. In wells containing Gas cap
3. In shallow wells

This research can be used as a manual or a guideline for engineers and workers in the oil fields through which they know when CO2 succeeds and when it fails. This research collected analyzed data from different technical aspects to investigate the best reservoir characteristics which make the CO2-EOR more successful. This research states that EOR have been found to be commercially successful where there are about 114 active commercial CO2 injection projects in US alone that together inject over 2 billion cubic feet of CO2 and produce over 280,000 BOPD. This research provided important guidelines on where and when the huff-n-puff can be used over the flooding mode and vice versa. This study pointed out some conditions where the CO2-EOR could fail.

INTRODUCTION

The oil production rate in tight oil reservoirs highly depends on enlarging a contact area between a well and the target formation, improving oil relative permeability, reducing oil viscosity and altering wettability. Recovery mechanisms related to CO2 flooding include a swelling effect, viscosity reduction, interfacial tension reduction and light components extraction .

The CO2 flooding process is regarded as a promising enhanced oil recovery (EOR) technique for tight oil reservoirs.

CO2 in either a miscible or a near-miscible condition, contributes to better oil recovery as compared to a water flooding process. Changing a well from water to gas injection, after a prolonged water cycle, can lead to a short-lived increment in production (Lake, 1989). In general, the WAG (water alternating gas) process provides higher oil recovery as compared to continuous water or gas injection .

Wettability alteration is one of the main residual oil mobilizing mechanisms during the WAG process. Although many CO2 field applications in low permeability reservoirs have been recorded as successful, a number of CO2 injection trials in tight formations have proven to be uneconomic Leena,(2008).The CO2 EOR process in tight oil reservoirs needs to be investigated in detail to set guidelines for screening candidate reservoirs and parameters. This process of injecting CO2 into existing oil fields is a well-known “enhanced oil recovery” (EOR) technique: the addition of CO2 increases the overall pressure of an oil reservoir, forcing the oil towards production wells. The CO2 can also blend with the oil, improving its mobility and so allowing it to flow more easily. The IEA’s new global database of enhanced oil recovery projects shows that around 500 thousand barrels. of oil are produced daily using CO2-EOR today, representing the oil is recovered by the injection of a material that is not originally present in the reservoir; in the case of CO2-EOR, carbon dioxide is the injected material. Several physical mechanisms enhance oil production when CO2 is introduced into the reservoir. If the technology is applied after waterflooding, the goal is to produce (extract) the mobile oil that was bypassed by water and the immobile residual oil trapped by capillary force. In the desirable case where the reservoir pressure is above the minimum miscibility pressure (MMP) and the injected CO2 and residual oil are miscible, the physical forces holding the two phases apart (interfacial tension) effectively disappears. This promotes a mass transfer (extraction/vaporization) of light and intermediate hydrocarbons.

Not so long ago, the world became very dependent on oil and gas, as the methods of oil production did not reach the required level at that time and did not obtain high returns, as huge quantities of oil remained in the pores and cracks of the springs. Ensuring the extraction of these quantities until they reached methods that gave the productive layer energy over its capacity and increased the yield of the reservoir and improved its production. Oil field development is carried out in two or three recovery stages. During primary recovery, oil is produced by natural drive mechanisms As reservoir fluids are extracted, the reservoir pressure declines, and so do oil production rates. To prolong the duration of primary production, pressure maintenance and fluid lifting techniques are employed. During secondary recovery a fluid, most commonly water, is injected not only to maintain reservoir pressure but also to displace oil toward producing wells. On average, only 30–50% of the oil is recovered after secondary recovery and 50–70% of the oil remains in the reservoir EOR is often considered a tertiary phase of recovery. The oil is recovered by the injection of a material that is not originally present in the reservoir in the case of CO_2-EOR, carbon dioxide is the injected material

In light of the increasing demand and consumption for oil, it was necessary to find secondary methods to extract the remaining oil from the primary operations. Among these methods is the CO_2 gas injection process, in which it is divided into two parts co2 huff-n-puff and co2 flowing :

- Co2 flooding: The CO_2 gas is injected in this method in small batches and with a certain percentage of the pore size, in alternating with water jets, where the mobility of CO_2 gas is reduced widely and large quantities of it are quarantined in the water. Finally, all gas and water seals are water-driven.
- CO_2 Huff-Puff It is the activation or induction of heavy pressures to movement, as several tons of CO_2 gas are injected into the well and then closed until a large portion of the CO_2 gas is dissolved in the oil. as an ultimate long-term geologic storage solution for CO_2 owing to its economic profitability from incremental oil production offsetting the cost of carbon sequestration.

Objective

1) The objective of this report is to provide basic technical information regarding the CO_2-EOR process, which is at the core of the assessment methodology, to estimate the technically recoverable oil Emphasis is on CO_2-EOR because this is currently one technology being considered.

2) Understand the mechanisms of CO_2-EOR.

3) Understand when and where CO_2-EOR succeed or fail.

4) What are the best candidate reservoirs for CO_2-EOR applications.

part 1: Screening criteria for CO_2-EOR

Different kinds of reservoirs recovery:

The first issues in definitions are about the way of enhanced oil recovery in the last of 19th century, and after sometimes and technology improvement, these definitions have been more universal. 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:

1. Primary recovery
2. Secondary recovery
3. Tertiary recovery

Primary recovery in this classification is the only use of reservoir natural energy and second recovery is also each recovery which is done after the primary recovery in order to maintain reservoir pressure which usually includes water injection or gas injection. Each mechanism which is done after the secondary recovery in order to produce the retained oil is called the tertiary recovery Today, advanced enhanced oil recovery methods are considered as the replace of 2nd and 3rd stages, based on the idea of many scientists. This classification is as follow:

1- Primary recovery : which is called as the use of all natural mechanisms in production from the reservoir and mechanisms which are formed in order to maintain the pressure in the reservoir;

2- Enhanced oil recovery in advanced ways (EOR): which are all the ways that have been done after primary recovery in order to production from the reservoirs.

3- Gas injection in order to maintain pressure

As you see in figure , gas injection is formed in gas cap center. In this kind of injection, the pressure of injective gas is relatively low and surface tension is fixed between phases. In large field, gas injection should be done in all over the reservoir, as what was said about water injection, it can create gas zones which result in pressure increase and oil drive toward the production well. It should be considered that gas injection is very effective, when the reservoir natural drive mechanism is gravity drainage mechanism. The injection of natural gas has been decreased in all over the world, because of using it as heat and fuel .

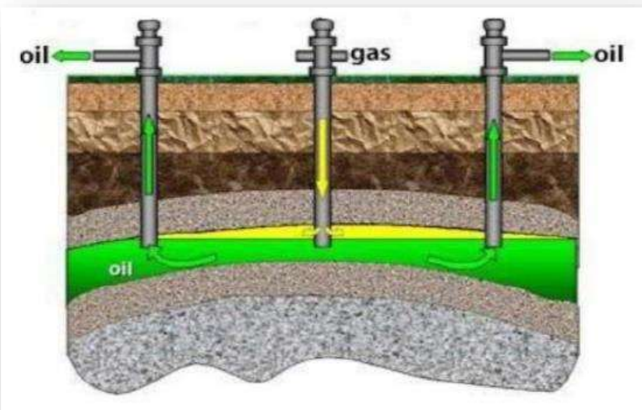

Fig.1: Gas injection in gas cap (Advanced CERT Canada Inc.)

4- Gas injection in miscible way:

Gas injection is the most widely applied EOR process for light oils. Oil recoveries for gas injection processes are usually greatest when the process is operated under conditions where the gas can become miscible with the reservoir oil. The primary objective of miscible gas injection is to improve local displacement efficiency and reduce residual oil saturation below the levels typically obtained by waterflooding. Examples of miscible gas injection are CO2.

5- CO2 injection:

The EOR technique that is attracting the most new market interest is CO2-EOR. First tried in 1972 in Scurry County, Texas, CO2 injection has been used successfully

throughout the Permian Basin of West Texas and eastern New Mexico, and is now being pursued. Until recently, most of the CO2 used for EOR has come from naturally-occurring reservoirs. But new technologies are being developed to produce CO2 from industrial applications such as natural gas processing, fertilizer, ethanol, and hydrogen plants in locations where naturally occurring reservoirs are not available. When we inject CO2 into an oil reservoir, it becomes mutually soluble with the residual crude oil as light hydrocarbons from the oil dissolve in the CO2 and CO2 dissolves in the oil. When the injected CO2 and residual oil are miscible, the physical forces holding the two phases apart (interfacial tension) effectively disappears. This enables the CO2 to displace the oil from the rock pores, pushing it towards a producing well just as a cleaning solvent would remove oil from reservoir rocks.

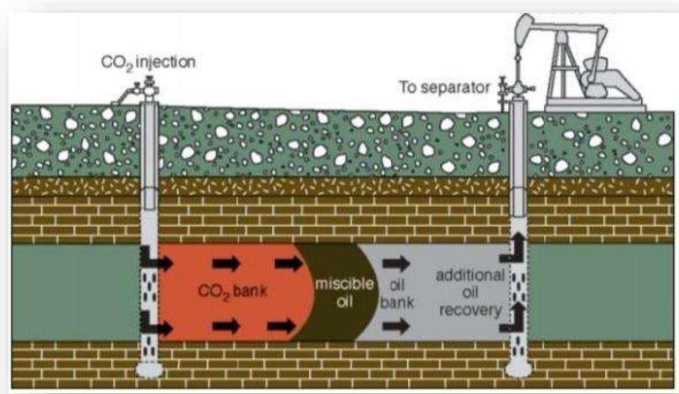

Fig. 2: CO2 injection (Advanced CERT Canada Inc)

Limitations and problems We need a good and cheap source of CO2; meanwhile, there are corrosion problems, especially if CO2 is seen in production well.

5.1 Effects of Nanoscale Pore Confinement on the CO2 Injection Process :

During CO2 flooding, the vaporizing and condensing gas drive mechanism will alter fluid compositions. In a nanopore, the molecular orientation and arrangement can be changed, resulting in a shift in the component's critical properties. In this way, the CO2 injection process in tight oil reservoirs may vary from that in conventional oil reservoirs to some extent. This section presents: the effect of nanoscale pore confinement on the CO2 injection process, the fluid properties alteration during CO2 injection and an analysis of the effect of nanoscale pore confinement on the stable and unstable CO2 displacement. Oil displacement by CO2 can develop miscibility through the extraction of light hydrocarbon components into a CO2-rich phase. In this process, a phase envelope of reservoir oil can be altered by CO2 injection; a different volume of CO2 injection results in various bubble point pressures. As shown in Figure , the bubble point pressure for reservoir oil rises as the amount of injected CO2 increases.

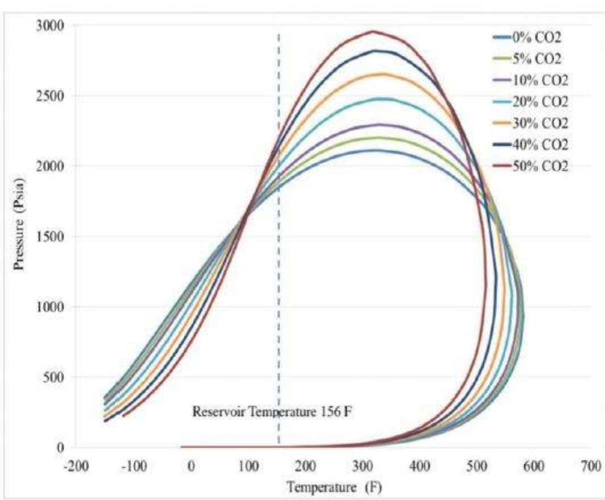

Fig.3: The Impact of CO2 Concentration on Phase Envelope (Zhang, 2015)

In the process of CO2 injection into tight oil reservoirs, the bubble point pressure is not only a function of the amount of CO2 injected but also a function of the confinement effect caused by the nature of nanoscale pores. As shown in Figure CO2 injection has a chance of enlarging the bubble point pressure; however, the confinement effect decreases the bubble point pressure and the liquid region is further expanded by the confinement effect. The oil bubble point pressure is smaller with the confinement effect than that without the confinement effect during CO2 injection.

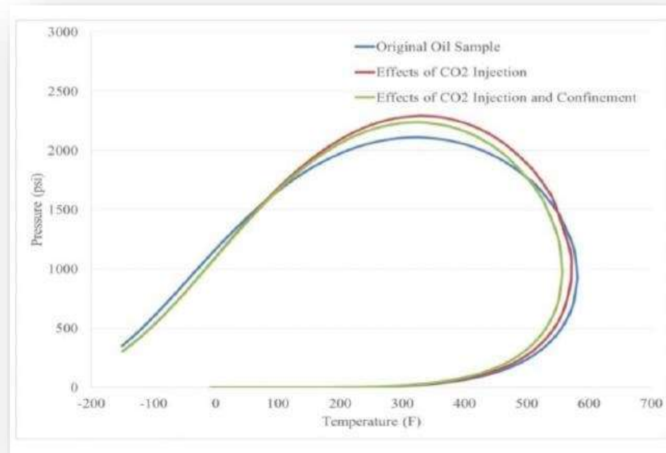

Fig.4: Phase Envelope Alteration with Effects of CO2 Injection and Confinement

5.2 Effects of Nanoscale Pore Confinement on Relative Permeability Alteration during CO2:

During CO2 flooding, a significant change in gas-oil relative permeability occurs when interfacial tension drops below 0.04 dyne/cm (Longeron, 1980).The curvature of gas-oil relative permeability can be straightened with a reduction in interfacial tension (Asar, 1988).In addition, hysteresis cannot be ignored when interfacial tension is high and the reservoir permeability is low (Henderson, 1998; Fatemi, 2013). Hysteresis is much higher for the non-wetting phase (gas) compared to that for the wetting phase (oil) (Fatemi, 2012; Fatemi, 2013). The relative permeability for a given phase is greater when its saturation is increased (Fatemi, 2012;Fatemi, 2013). The variation in the drainage and imbibition relative permeability curves is highly related to the saturation history, which can cause gas phase trapping to some extent (Land, 1971).In tight oil reservoirs, a large amount of nanoscale pores exist where the pore size is smaller than 100 nm for sandstone reservoirs and 10 nm for shale reservoirs (Nelson, 2009). Within a nanopore, the van der Waals forces and molecules orientation and arrangement can be altered to some extent (Morishige, 1997; Zara Goicoechea, 2004; Travalloni, 2010; Devegowda, 2012;Pitakbunkate, 2015). The confinement effect can cause fluid critical temperature and critical pressure shifts (Singh, 2009), resulting in an alteration in phase behavior (Teklu, 2014; Zhang,2015). Furthermore, fluid transportation varies in a nanopore when it is in a bulk state (Wu, 2015;Wu, 2016).As an interfacial tension reduction can occur during CO2 injection, gas and oil relative permeability has to be altered during CO2 injection. Nanoscale pores are extensively distributed in tight oil reservoirs, and the associated confinement effect can affect gas and oil relative permeability during CO2 injection as well. In this section, the interfacial tension of gas-oil is used to analyze the relative permeability curve with the hysteresis in a confined state. The relative permeability of gas and oil can be altered by interfacial tension reduction. The curvatures of the gas-oil relative permeability curves decrease as the interfacial tension reduces (Asar, 1988). Once the fluid system approaches miscibility, the relative permeability of both phases show linear behavior and become diagonal lines (Fatemi, 2013). As shown in Figure (5)the gas-oil relative permeability is plotted as the black dashed line; the curve tends to straighten and the wetting phase is more sensitive to the interfacial tension reduction. The intersection of the gas-oil relative permeability curves shifts to the right to some extent, corresponding to a tendency in the water wet character (Asar, 1988). With the confinement effect, the interfacial tension can be further decreased, therefore, the curvature can be further reduced as well, as shown by the blue dashed line. In addition, the number of shifts in relative permeability depends on the amount of CO2 injected and the pore size.

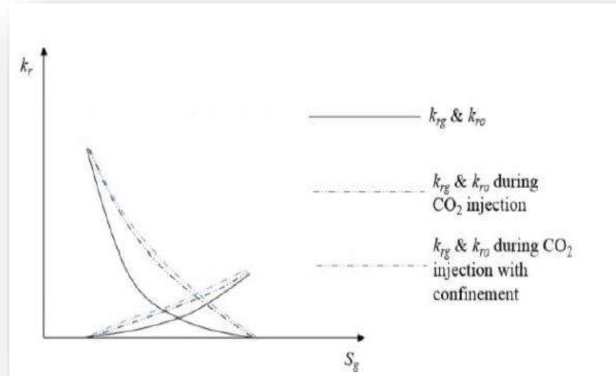

Fig.5:Relative Permeability Alteration during CO2 Injection with Confinement.

5.3 Mechanism injection gas co2 and effective

Carbon dioxide is used in improved oil recovery, where it is injected into or near oil wells, where the carbon dioxide becomes mixed with the oil. This method can increase the production of extracted oil by reducing the loss of extracted oil as a result of saturation by 23.7% over the normal methods of oil extraction. Carbon dioxide also acts as a pressure agent when buried oil melts and significantly reduces its viscosity, and changes the chemical composition of the layers, so that the oil can flow more quickly from reservoirs to wells.

The experience of Straw in 1964 was considered the first successful experiment of C02 gas injection, as the experiment showed that injection of a batch of CO2 followed by injection of water produced a greater amount of oil compared to the amount of oil produced in water alone.

Between 1980-1982 the study of CO2 injection developed, especially in Texas, where oil production began using the huge natural reservoirs of CO2 recently discovered in Mexico.

Table.1:Comparison between miscible and immiscible CO2-EOR methods

Projects	Co2 Miscible	Co2 Immiscible
Project start	Before or after water flooding	After water flooding
Project duration	Short	Long
Project scale	Small	Large
Oil production	Early (1-3y)	Late (>5-8y)
Oil recovery potential	Lower (4-12% OOIP)	Higher (up to 18% OOIP)
Recovery mechanism	Complex	Simple
Co2 storage potential	Low (0.3 tonn/bbl)	High (up to 1 tonn/bbl)

5.4 Decomposition of Co2 gas by oil:

CO2 dissolves in the oil, reducing its viscosity and increasing its volume, reducing its density. The dissolution of c02 gas in oil is easier than it is dissolved by water 4-10 times so that the CO2 gas can move from water to oil easily as it weakens in the molecular bonding forces represented by the surface tension forces (surface tension) between oil and water in the contact area and thus becomes a phase displacement act The wet, which is the water, which leads to the flow of oil from the layer towards the production wells.

5.5 Effect of C02 dissolution by petroleum on its density:

It is known that the density of the oil can be influenced by two factors when it is saturated with gas

1.Gas-dissolved by oil increases the volume of oil, which is why the density decreases when the volume of gas dissolved by oil decreases.

2. When the pressure increases, the opposite occurs, as there is a decrease in the volume of oil, which leads to an increase in its density.

5.6 The effect of dissolution of C02 by oil on the viscosity of oil:

As a general rule for hydrocarbons we find:

1. Viscosity decreases with increasing temperature

2. The viscosity increases with increasing pressure due to fluid compression

3. The viscosity decreases with the increase in the amount of gas: The dissolution of C02 by oil leads to a large decrease in viscosity, and this decrease is similar to the decrease in the viscosity of oil with increasing temperature

5.7 The possibility of applying the C02 gas injection method into the layer:

This method can be used for all oil reservoirs, regardless of their permeability, with the exception of reservoirs with very weak permeability, except for oil containing a high percentage of asphalt, as well as this method can be applied for calcareous and sandy layers and for all basic oil saturation states, as well as for cracked and sloping reservoirs.

Some of the world's gas-interchangeable water injection projects

Table 2: CO2-EOR cases in the united states of America

Layer production	Miscibility	The type of gas	Project location	Field name	Starting the project	se
Sandy	Miscible	Co2	Texas	Mead steawn	1964	1
Carbonate	Miscible	Co2	Texas	Kelly snydre	1972	2
Calcareous	Miscible	Co2	Texas	Levelland	1972	3
Dolomite	Miscible	Co2	Texas	Willard (wasson)	1972	4
Sandy	Miscible	Co2	West virginia	Rock creek	1976	5
Sandy	Im Miscible	Co2	Arkansas	Lick creek	1976	6

Table 3: CO2-EOR cases in the united states of America

Layer production	Miscibility	The type of gas	Project location	Field name	Starting the project	se
Sandy	Miscible	Co2	West viginia	Granny is creek	1976	7
Dolomite	Miscible	Co2	Texas	Slaughter estate (SEU)	1976	8
Sandy	Miscible	Co2	Oklahome	Garber	1980	9
Sandy	Miscible	Co2	Oklahome	Purdy springer NE	1980	10
Dolomite	Miscible	Co2	New mexico	Maljamar	1981	11
Carbonate	Miscible	Co2	North dakota	Little knife	1981	12

Table 4: CO2-EOR cases in the united states of America

Layer production	Miscibility	The type of gas	Project location	Field name	Starting the project	se
Sandy	se	Co2	Louisiana	Quarantine bay	1981	13
Sandy	se	Co2	Alberta ,canada	Joffer viking	1983	14
Dolomite	se	Co2	SESSAU texas	San andres	1983	15
Dolomite	se	Co2	Texas	Wasson denver	1983	16
Sandy	se	Co2	Siberia ,canada	Caroline	1984	17
Dolomite	se	Co2	New mexico	East vacuum	1985	18

Hydrocarbon miscibility

With decline in overall production levels from mature oil fields, oil companies have turned to enhanced oil recovery (EOR) techniques as a way of maximizing output. The more commonly applied technique is gas injection or miscible flooding. Miscible flooding is a commonly used term used to describe gas injection processes. This involves the displacement of oil that aids in maintaining original reservoir pressures by reducing the interfacial tension that exists between the oil and gas phases. This acts by removing the interphase between the two fluid phases, and commonly used gases include CO2,

CO2 injection methods:

CO2 gas is injected in several ways, and these methods depend on the characteristics of the reservoir to be cleared, including:

A- Continuous injection: CO2 gas is continuously injected into the layer until the percentage of gas produced with oil becomes very high and so that the process remains economical.

B- Alternating injection: CO2 gas is injected in this method in small batches and with a certain percentage of the size of the pores, in alternating with water batches, where the mobility of CO2 gas is reduced widely and large quantities of it are quarantined in the water. Finally, all gas and water seals are water-driven. Controlled in this way by the following:

1- The size of the initial plug.
2- The ratio of CO2 gas to the injected water.
3- The size of the pores.

The effectiveness of this method of injection depends on the ratio of gas to water. When the ratio of CO2 to water decreases, the probability of its penetration in front of the water decreases, and this means reducing the possibility of gas crossing into highly permeable layers in injection wells. When the ratio of gas to water increases, the effect of gravitational forces can appear due to the difference in the density of CO2 and water, and then the water will enter the lower section while the gas goes to the upper section, and thus the CO2 gas will pass into production wells through the high permeable layers. The primary factor in choosing the CO2 to water ratio is not to allow the gas to permeate into the producing wells.

C- CO2 gas injection in batches: A batch of CO2 gas is injected and pushed horizontally by a scavenging fluid, most likely water, so that it is caught in the water when its movement decreases. But when the scavenging is vertical, the expelling or propellant fluids are lighter gases than the injected CO2 gas, such as nitrogen gas.

D- Annular injection: It is the activation or induction of heavy pressures to movement, as several tons of CO2 gas are injected into the well and then we close it until a large portion of the CO2 gas is dissolved in the oil.

Problems and disadvantages of CO2 injection into the layer:

1- Deposition of paraffins and other materials (such as the deposition of salts and asphaltenes) The main cause of asphalt deposition is the occurrence of structural disturbances (the difference in the structure of phases) caused by the mixing displacement process and the sedimentation increases whenever the oil is colloidal.

2- Corrosion of metal equipment used in injection, as well as equipment of production wells, due to the formation of carbon acid. Corrosion can be avoided by using corrosion contraindications.

3- The decrease in the layer enclosure during the displacement of CO2 gas compared with the displacement in normal water due to the fact that the CO2 gas is not wetted phase.

4- CO2 gas takes the light extracts from the oil. As for the heavy ones, they remain in the layer and extract it becomes more difficult than before due to its lack of kinetic ability.

5- Loss of efficiency of productive pumps due to the leakage of CO2 gas in the annular vacuum. Therefore, it is preferable to use gas lift production.

6- Loss of a quantity of CO2 gas that remains confined within the narrow pore spaces and within the isolated areas, and this percentage may reach 75% of the total amount of CO2 injected, and this increases the cost of extracting one ton of oil using this method.

7- The transport of CO2 gas requires special conditions, as well as special tubes made of resistant mixtures, and this raises the cost of the process and thus the cost of the ton extracted in this way.

8- Deposition of salts in the layer and its decrease in permeability due to the presence of carbonic acid.

Mechanisms by miscible CO2 displacement:

1. Miscible process

Petroleum industry defines miscibility within a reservoir as that physical condition between two or more fluids that permits them to mix in all proportions without any existence of interface between them (Holm, 1986). Miscible CO2 injection is more favorable than traditional recovery methods, because it may result in producing mobile oil from matrix which is bypassed from previous water injection. Studies of immiscible and miscible CO2 flooding have shown that the latter one has a higher recovery where the results from the work done by Kulkarni and Rao in 2004 and 2005 showed 23% against 93.7% recovery for immiscible CO2 and miscible CO2 flooding, respectively (Kulkarni and Rao, 2004, Kulkarni and Rao, 2005).

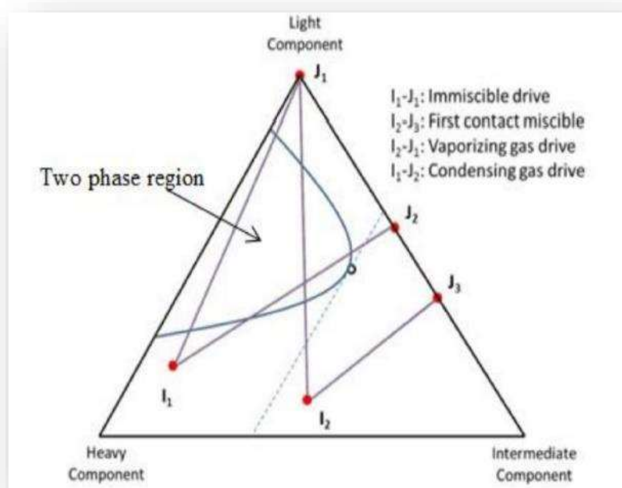

Fig. 6: The miscible ratio diagram for Co2

2. MMP To achieve a miscible displacement of oil by CO2, the average reservoir pressure needs to be greater than the Minimum Miscibility Pressure (MMP) of CO2 and the reservoir oil. The MMP is minimum pressure required to achieve miscibility for two fluids.

Part 2: Comparision between CO2-EOR Flooding Mode and Huff-n-Puff Mode

description of co2 huff n puff:

Definition of Huff-n-puff CO2 injection is an enhanced oil recovery technique that is widely used for conventional oil reservoirs and is known as cyclic injection of CO2. The CO2 Huff-Puff process is similar to cyclic steam injection. CO2 is injected into a well in a day's time, the well is shut-in for 2to 4weeks, and then the well is opened for production. The CO2 is injected at the fastest rate possible. Production. The faster that the CO2 is injected into the well, the further the CO2 will finger throughout the reservoir, thus contacting more oil. The CO2 moves through the reservoir by mostly displacing the mobile. As the CO2 soaks in the reservoir, it is mostly absorbed by the oil because the water becomes saturated with CO, very quickly. The solubility of CO2 in oil is much greater than the solubility of CO2 in water. Thus, oil can hold many times the amount of CO2 as water at reservoir conditions. The CO2 causes the oil to swell, lowers its viscosity, and reduces the interfacial tension that held the oil in the pore spaces. The swelling of the oil and lowering of its viscosity increases the relative mobility of the oil and thus primary oil is produced at faster rates. Produced at faster rates. Carbon dioxide (CO2) injection as a huff-n-puff process is a preferred approach to improve oil recovery in tight reservoirs

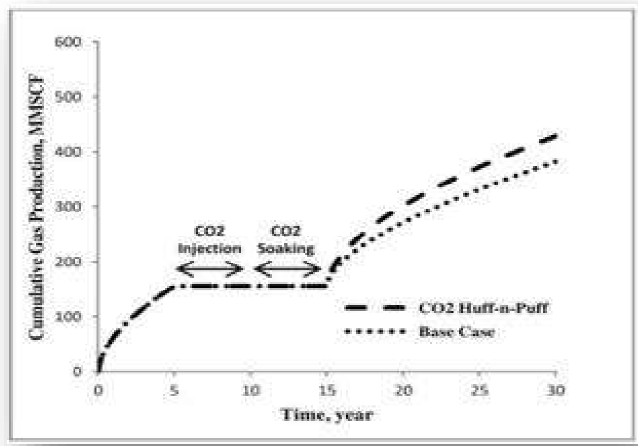

Fig. 7: Chart showing the percentage increase in output after co2 injection with the co2 huff-n-puff method

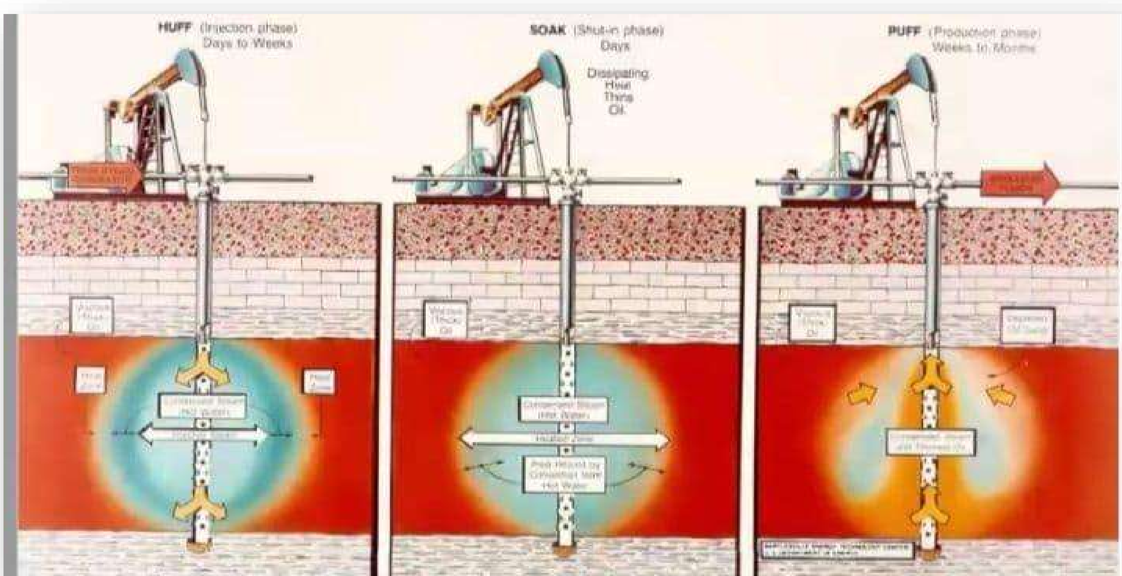

Fig. 8 : Stages of the co2 gas injection process huff-n-puff Method

description of CO_2 flooding:

Definition of Carbon dioxide (CO_2) flooding is a process whereby carbon dioxide is injected into an oil reservoir in order to increase output when extracting oil. When a reservoir's pressure is depleted through primary and secondary production, carbon dioxide flooding can be an ideal tertiary recovery method. It is particularly effective in reservoirs deeper than 2,500 Water is injected to increase the pressure of the tank until it reaches the required pressure level, then gas is injected into the oil that penetrates into it, and at the end water is injected to sweep the oil to the production areas. So the effectiveness of this method of injection depends on the ratio of gas to water. When the ratio of CO to water decreases, the probability of it penetrating into the water is reduced, which means reducing the possibility of gas crossing over. When the ratio of gas to water is increased, the effect of the gravitational forces can appear due to the difference in the density of CO gas and water, and then the water will enter the lower section while the gas goes to the upper section. The main factor in choosing the ratio of CO to the ratio of water is that the gas is not allowed to penetrate towards the producing wells.

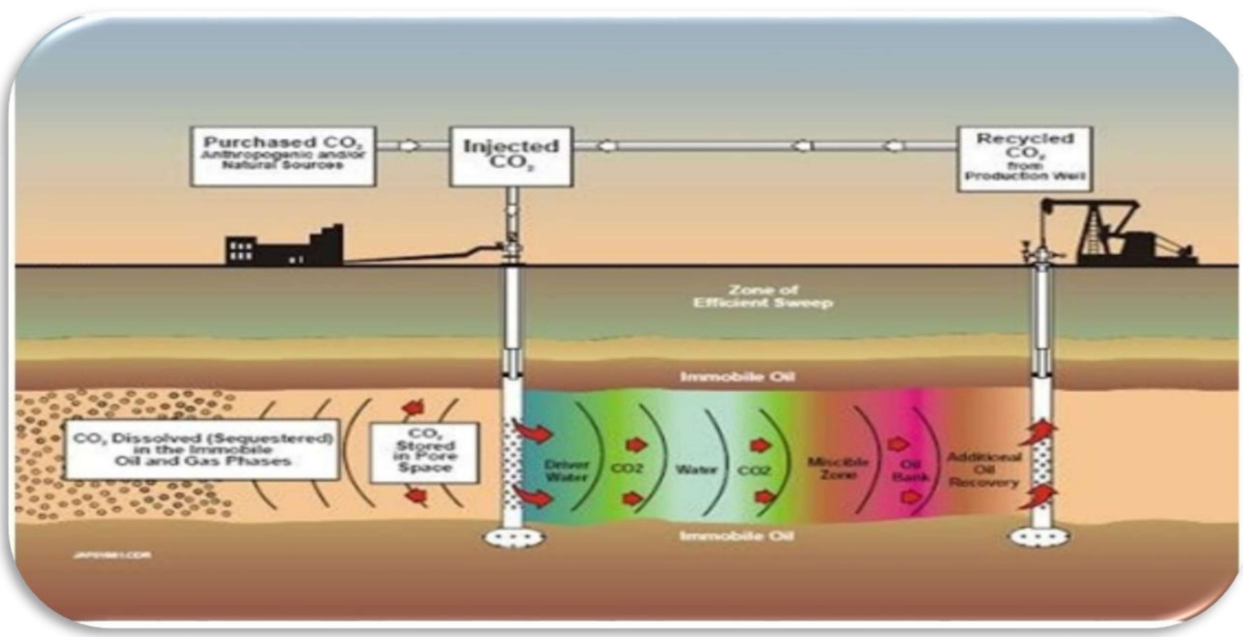

Fig. 9 : alternating injection water with Co2

Table 5 : Comparison between co2 flooding co2 huff -n-puff

From where	co2 huff -n-puff	Co2 flooding
Project success	Successful in narrow reservoirs of little thickness, little depth, and high oil saturation	It is particularly successful and effective in large reservoirs of great depth and thickness
Mechanical	Gas is injected quickly, continuously and for a short period, then the well is closed from 2 to 4 weeks forthe purpose of soaking. Then the well is opened for the purpose of production and this process is repeated periodically	A separate injection well is drilled from the production well and water is pumped into it to increase the pressure, then the gas is injected and after injection it mixes with the oil and then the water is injected to sweep the oil into the production well
Injection and production time	Short period	Long period
Used wells	The wells do not need injection, but should be injected into the same production well	It needs to drill injection wells distributed in the reservoir Often the wells are a single injector well surrounded by several producing wells, or several injector wells surrounding a central producer.
Economic cost	lower cost	Highest cost
Water injection	Uncommon	common

Table.6: Optimal properties of both methods

Reservoir Parameters	Co2 Huff-n-Puff	Co2 flooding
API	11-31%	22-37%
Oil saturation	30%	60%
Depth (M)	600-3900	< 3000
Permeability (MD)	10-2500	<300
Porosity	10-32%	<20%
Viscosities (Cp)	0.5-3000	10-15
Thicknesses (M)	> 67	< 67

Table .7: A group of fields in which a test was applied

Field	Country	Injection type	The result
Dollarhide	USA	Co2 flooding	Raising the extraction factor by about 20%
Slaughter	USA	Co2 flooding	Raising the extraction factor by about 20%
Mead Steawn	Texas USA	Co2 flooding	Raising the extraction factor by about 35%
North Gaoqian	North of Bohai Bay, China	Co2 huff-n-puff	More than 160000 tons of crude oil was recovered by Co2 within seven years
Weyburn	Canada	Co2 huff-n-puff	Store around 20 million tons of Co2 generate about 130 million barrels of oil, and extend the life of the field by over two decades
Ordos	China	CO2 huff-n-puff	Raising the extraction factor by about 30%

part 3: Performance of CO2-EOR in the Field Scale Around the Globe

Gas injection in order to maintain pressure

gas injection is formed in gas cap center. In this kind , the pressure of between injective gas is relatively low and surface tension is fixed phases. In large field, gas injection should be done in all over the as what was said about water injection, it can create gas zones ,reservoir pressure increase and oil drive toward the production which result in that gas injection is very effective, when well. It should be considered the reservoir natural drive mechanism is gravity drainage mechanism. over the world, The injection of natural gas has been decreased in because of using it as heat and fuel.

Gas injection in miscible way

Gas injection is the most widely applied EOR process for light oils. Oil gas injection processes are usually greatest when the recoveries for process is operated under conditions where the gas can become objective of miscible gas miscible with the reservoir oil. The primary reduce residual injection is to improve local displacement efficiency and oil saturation below the levels typically obtained by water flood in Examples of miscible gas injection are CO2

CO2 gas injection

new technologies are being developed to produce CO2 from industrial and applications such as natural gas processing, fertilizer, ethanol hydrogen plants in locations where naturally occurring reservoirs are not available. When we inject CO2 into an oil reservoir, it becomes mutually the residual crude oil as light hydrocarbons from the oil soluble with dissolves in the oil. When the injected CO2 dissolve in the CO2 and CO2 forces holding the two phases and residual oil are miscible, the physical enables the CO2 apart (interfacial tension) effectively disappears. This producing to displace the oil from the rock pores, pushing it towards a well just as a cleaning solvent would remove oil from reservoir rocks.

Table.8: Summary of Carbon Dioxide Projects Within United States (Koottungal, 2012). [Perm., Permeability; Temp., Temperature; NA, Not available; MD, Millidarcy, ° API, American Petroleum Institute, An Oil Gravity Measure, in Degrees; CP, Centipoise, A Measure of Oil Viscosity; ° F, Degrees Fahrenheit; ss., Sandstone; ls., Limestone; Dol., Dolomite; trip., Tripolite]

Number ofProjects	Lithology	Porosity (Percent)	MD)Perm (	Depth (Feet)	Gravity (°API)	Viscosity (CP)	TEMP. (°F)
			Miscible				
42	ss.	7-26	16-280	1600-11950	30-45	0.6-3.0	**82-257**
2	ss./ls.-dol.	10	4-5	5400-6400	35	1	**170-181**
41	dol.	7-5	2-28	4000-11100	28-42	0.6-6.0	**86-232**
12	Dol.\ls.	3-12	2-5	4900-6700	31-44	0.4-1.8	**100-139**
6	ls.	4-20	5-70	5600-6800	39-43	0.4-1.5	**125-135**
1	Dol.\trip.chert	13.5	9	8000	40	NA	**122**
7	tripolite	18-24	2-5	5200-7500	40-44	0.4-1.0	**101-123**
1				Inadequate Data			
			Immiscible				
8	ss.	17-30	30-1000	1500-8500	11-35	0.6-45	**99-198**
1	dol.	17	175	1400	30	6	**82**

Table .9: Large Carbon Dioxide Miscible Projects in the US10

Field	State	Start Date	Lithology	Depth (ft)	Oil API	Oil Production (B / D)		Injection Wells
						Total	Enhanced	
SACROC Unit	Texas	January1972	Limestone	6,700	39	31,200	29,300	414
Wasson (Denver (Unit	Texas	April 1983	Dolomite	5,200	33	34,500	28,990	537
Seminole (Main (Pay	Texas	July 1983	Dolomite	5,300	35	23,500	22,700	160
Rangely	Colombia	October 1986	Sandstone	6,000	35	15,300	11,600	262
Means (San (Andres	Texas	November 1983	Dolomite	4,300	29	10,000	8,700	284
Wasson (ODC (Unit	Texas	November 1984	D / L	5,100	34	9,230	8,440	165
North Hobbs	Namibia	March 2003	Dolomite	4,200	35	11,100	6,800	41
Salt Creek	Texas	October 1986	Limestone	6,300	39	9,200	6,800	130
West Mallalieu	Montserrat	1981	Sandstone	10,550	40	6,500	6,500	27
Anton Irish	Texas	April 1997	Dolomite	5,800	28	5,850	5,400	75
Vacuum	Namibia	February 1981	Dolomite	4,500	38	6,200	5,200	103
Cogdell	Texas	October 2001	Limestone	6,800	40	5,450	5,010	37
Postle	okalahoma	November 1995	Sandstone	6,200	36	5,000	5,000	100
Slaughter Sundown	Texas	January 1994	Dolomite	4,950	33	5,950	4,747	144
Lost Soldier	wyoming	May 1989	Sandstone	5,000	35	4,672	4,545	39
Wasson ((Willard	Texas	Jananuary 1986	Dolomite	5,100	32	4,800	4,050	203
Salt Creek	wyoming	January 2004	Sandstone	1,900	37	3,900	3,900	83

Using carbon dioxide (CO_2) in Saudi arabia :

Project Design

Given the relatively light nature of crude oils and generally high reservoir pressures in Saudi Arabia, CO_2 injection is a viable recovery method, especially in flooded reservoirs. An initial screening highlighted several good candidates for CO_2 injection. A mature, waterflooded part of a large oil field with a carbonate reservoir was selected as a candidate for CO_2 injection. Further studies were conducted for the candidate reservoir that included laboratory, feasibility, and detailed reservoir-simulation studies. This reservoir has been flooded for decades in a peripheral water-injection mode, and considerable reservoir and production data were available

Laboratory Studies

Two sets of experimental studies must be conducted for any given CO_2-EOR prospect: fluid/fluid and fluid/rock interactions. The important laboratory experiments include the minimum miscibility pressure of the crude with CO_2, swelling and fluid properties of CO_2/oil mixtures, asphaltene precipitation onset and bulk asphaltene deposition, and oil-recovery potential by use of coreflooding studies. It must be emphasized that these experiments need to be conducted at reservoir conditions with live reservoir fluids and supercritical CO_2; otherwise, the data have limited value at best.

Simulation Studies.

The reservoir selected for CO_2 injection is a Jurassic carbonate reservoir, and the area selected is in a downflank, flooded part of the field. The selected area has been on peripheral water injection for more than 50 years and has been well-waterflooded because of its proximity to the peripheral injectors. Approximately 40 MMscf/D of relatively pure CO_2 was available from a gas plant approximately 85 km from the pilot site. The slimtube data show that the minimum miscibility pressure is lower than the reservoir pressure, indicating that the CO_2 will develop a miscible displacement in the reservoir at current reservoir pressures. The main objectives of the simulation study were as follows: Carry out screening and mechanistic studies and find areas suitable for a CO_2-injection pilot. Assess the amount of CO_2 sequestered over the period of the pilot testing. Assess incremental oil recoveries associated with different modes of CO_2 injection. Optimize the pilot design within the reservoir and operational constraints.

Table 10: Characteristics of some fields in which Co_2 gas injection was applied successfully, which gave an increase in production

Reservoir Parameters	Fulmar	Gullfaks	Ekofisk
API	41	36	
Pressure (MPa)	37	31	49
Depth (M)	3000	1800	3170
Permeability (MD)	100-300	800	1(matrix)
Temperature (C°)	121	74	131
Viscosities (Cp)	0.49		
Fraction of oil remining remarks	>0.4	>0.4	0.62

Conclusion

1. *This research can be used as a manual or a guideline for engineers and workers in the oil fields through which they know when CO2 succeeds and when it fails.*
2. *This research collected analyzed data from different technical aspects to investigate the best reservoir characteristics which make the CO2-EOR more successful.*
3. *This research states that EOR have been found to be commercially successful where there are about 114 active commercial CO2 injection projects in US alone that together inject over 2 billion cubic feet of CO2 and produce over 280,000 BOPD.*
4. *This research provided important guidelines on where and when the huff-n-puff can be used over the flooding mode and vice versa.*
5. *This study pointed out some conditions where the CO2-EOR could fail.*

References

1. book Integrated Reservoir Studies for CO2-Enhanced Oil Recovery and Sequestration

2. Holm, L.W.: Status of CO2 and Hydrocarbon Miscible Oil Recovery Methods, JPT 76. 1976

3. book EOR Methods

4. Herb.L et. al. Barriers to CO2 Ehanced Oil Recovery(CO2 EOR) in Alberta. Energy and Environment Solutions, Alberta Innovates. 2013

5. CO2 EOR and storage in oil reservoir https://www.researchgate.net/publication/245277512_CO2_EOR_and_storage_in_oil_reservoir

6. CO2 storage and enhanced oil recovery 'can aid economy' https://www.bbc.com/news/uk-scotland-scotland-business-20313643

7. Co2 gas injection technology (part 6) https://emufeed.com/index.php/ar/article/6940

8.co2
https://ar.m.wikipedia.org/wiki/%D8%AB%D9%86%D8%A7%D8%A6%D9%8A_%D8%A3%D9%83%D8%B3%D9%8A%D8%AF_%D8%A7%D9%84%D9%83%D8%B1%D8%A8%D9%88%D9%86

9. book Mobility Control by CO2-foam Injection for Integrated EOR

10. Potential of CO2-EOR for Near-Term Decarbonization https://www.frontiersin.org/articles/10.3389/fclim.2019.00005/full

11. CO2-EOR really provide carbon-negative oil https://www.iea.org/commentaries/can-co2-eor-really-provide-carbon-negative-oil

12. The use of gases in the enhanced oil recovery process
https://www.oilgastoday.com/post/%D8%A7%D8%B3%D8%AA%D8%AE%D8%AF%D8%A7%D9%85-%D8%A7%D9%84%D8%BA%D8%A7%D8%B2%D8%A7%D8%AA-%D9%81%D9%8A-%D8%B9%D9%85%D9%84%D9%8A%D8%A9-%D8%A7%D9%84%D8%A7%D8%B3%D8%AA%D8%AE%D9%84%D8%A7%D8%B5-%D8%A7%D9%84%D9%85%D8%B9%D8%B2%D8%B2-%D9%84%D9%84%D9%86%D9%81%D8%B7

13. CO2-EOR/Sequestration: Current Trends and Future Horizons By Erfan Mohammadian, Badrul Mohamed Jan, Amin Azdarpour, Hossein Hamidi, Nur Hidayati Binti Othman, Aqilah Dollah, Siti Nurliyana Binti Che Mohamed Hussein and Rozana Azrina Binti Sazali Submitted: March 6th 2019Reviewed: September 5th 2019Published: November 12th 2019 https://www.intechopen.com/books/enhanced-oil-recovery-processes-new-technologies/co-sub-2-sub-eor-sequestration-current-trends-and-future-horizons

14. March 2020 In book: The Effect Evaluation of Haze Governance Policies in Hebei Province–Based on I-O Model Huimin Li ،Xiaojing Ma، (pp.13-44) Guofeng Zhang
https://www.researchgate.net/publication/339705681_Analysis_of_the_Current_Situation_of_Research_Areas

15. Volume 3, Issue 1, March 2017, Pages 68-78
https://www.sciencedirect.com/science/article/pii/S2405656116301420

16. Lorna Jennifer Mohammed-Singh ; Ashok Kumar Singhal , Steve Soo-Khoon Sim Paper presented at the SPE/DOE Symposium on Improved Oil Recovery, Tulsa, Oklahoma, USA, April 2006. Paper Number: SPE-100044-MS https://doi.org/10.2118/100044-MS

17. Energy.gov. Retrieved 2020-04-22. https://en.m.wikipedia.org/wiki/Carbon_dioxide_flooding

18. 2019 https://emufeed.com/index.php/ar/article/6940

19. Handong Huang , Fenglan Zhao , Jirui Hou https://pubs.rsc.org/en/content/articlelanding/2021/ra/d0ra09448j#!divAbstract

20. Hobson, George Douglas; Eric Neshan Tiratsoo (1975). Introduction to petroleum geology. Scientific Press. ISBN 9780901360076.

21. Walsh, Mark; Larry W. Lake (2003). A generalized approach to primary hydrocarbon recovery.

22. Organisation for Economic Co-operation and Development (1998). 21st century technologies. OECD ISBN 9789264160521. .39 صفحات Publishing

23. Donald G. Kaufman; Cecilia M. Franz (1996). Biosphere 2000: protecting our global environment. Kendall/Hunt Pub.

24. Pierantozzi, Ronald (2001). "Carbon Dioxide". Kirk-Othmer Encyclopedia of Chemical Technology. Kirk-Othmer Encyclopedia of Chemical Technology. Wiley.

25. William Emerson Brock, B. Kleidt, H. Voelker: Viewegs Geschichte der Chemie, Springer-Verlag, ISBN 3-540-67033-5, S. 72

26. Egyptian Journal of Petroleum Volume 22, Issue 2, December 2013, Pages 225-240 https://www.sciencedirect.com/science/article/pii/S1110062113000500

27. Hrvoje Galic ; Stephen John Cawley ; Simon Richard Bishop ; Frederic Gas ; Steven Todman Paper presented at the SPE Offshore Europe Oil and Gas Conference and Exhibition, Aberdeen, UK, September 2009. Paper Number: SPE-123788-MS https://onepetro.org/SPEOE/proceedings-abstract/09OE/All-09OE/SPE-123788-MS/146856

28. Chawarwan Khan, Robert Amin & Gary Madden Journal of Petroleum Exploration and Production Technology Volume 3, pages55–60(2013)Cite this article https://link.springer.com/article/10.1007/s13202-012-0044-8