Analysis on Carbon Dioxide Storage and Injection into Oil Reservoirs to Improve Extraction from Reservoirs

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Abstract
The several methods have been proposed to reduce propagation of CO₂ to increase density of carbon dioxide gas in atmosphere of earth planet e.g. CO₂ flooding for the sake of underground extraction and storage. Consuming fossil fuels has led to production of 27 billion tons of carbon dioxide throughout the world where it is followed by many adverse effects on environment. Thus, presentation of strategies for controlling and reduction of propagation of such gases is deemed as one of the foremost research preferences out of which propagation of greenhouse gases and injection of them in geological formation is one of the paramount techniques for reduction of propagation of greenhouse gases. This process is an early-efficient process that can cause reducing the great volume of dissemination of this gas through atmosphere. In this technique, CO₂ is extracted from propagation sources and transferred by pipeline to the injection site and stored in subterranean formations through injection wells. On the other hand, linking this process to oil over-extraction operation is one of the methods for making CO₂ gas storage process economic. The great volume of CO₂ is injected into the reservoir in this process that increases oil extraction and justifies totally this operation in terms of cost-effectiveness. The studies show that if CO₂ is injected into the reservoir under optimal conditions (suitable injection model and operational conditions and with CO₂ in purified mode), it not only leads to producing great amounts of oil left in reservoir, but also it can prepare the ground for storage and prevention from wasting the huge amount of this greenhouse gas. The oil over-extraction technique by CO₂ flooding is a totally well-known technology. Carbon dioxide, both in miscible and or immiscible form, can favorably affect pressure of reservoir. CO₂ causes inflation in oil in miscible form and it causes reducing viscosity of crude oil. The reduced viscosity of CO₂ is led to easier motion of oil toward the produced oil well. Similarly, the immiscible CO₂ also increases pressure of reservoir. Combination of these factors increases rate of oil extraction. The rate of increase in efficiency is at least 25% in this technique, but the real outcome is much noticeable because by injection of CO₂ gas into oil reservoirs, one of the foremost environmental pollutants is reduced. It has been discussed about method of storage and injection of CO₂ into oil reservoirs in this paper.

Keywords: Rise of oil extraction, CO₂ storage, CO₂ injection, Oil reservoirs
Introduction

Nowadays with respect to the special conditions of energy market, it is crucially important to access further to energy resources than ever. Although providing of energy from other sources is increased from the foremost energy supplies and fossil energy and especially oil (nuclear energy and recoverable energies), such a rising rate is small and at least for two subsequent decades, they will be exclusively used as complementary for hydrocarbon sources. In order to respond to ever-increasing growth trend in world demand to provide oil and gas resources, it is necessary either for discovery of and exploitation from new hydrocarbon sources or the oil and gas reservoirs to be extracted using various techniques as in situ and without utilization from the given reservoirs by over-extraction processes [1].

The rate oil extraction from oil reservoirs is averagely 15-25% in Iran. Likewise, whereas most of national reservoirs currently pass through the second half of their lifetime and thus oil extraction becomes harder so it is necessary for us to extract from them further by proposing suitable techniques [2].

Processes of efficiency and production in hydrocarbon reservoirs:

According to Fig (1), the hydrocarbon fluid is stored inside reservoir and it requires for adaption of various techniques for extraction [3].

![Fig (1): Schemata of a hydrocarbon reservoir](image)

There are several processes and techniques to extract fluid from the reservoirs.

With respect to extraction time periods, the oil extraction operation from reservoirs is divided into three general phases:
In primary recovery phase, fluid is extracted with normal pressure and or by means of artificial lifting from the reservoir. The recovery process is not usually too efficient at first extraction period and noticeable amount of producible hydrocarbon is left in reservoir [4].

The secondary recovery step includes implementation of artificial techniques i.e. water injection into subterranean table or immiscible gas injection to the upper cap. The secondary recovery mechanism is usually done after the end of primary recovery period, but in some cases it can be also done simultaneously. Flooding is assumed as one of the most common techniques of secondary recovery [5].

After extraction by means of second phase techniques, about 30-50% of oil may be also left as non-extracted residue in reservoir. Here, the oil extraction is done by the aid of third phase techniques [1].

Gas injection is one of the oldest processes of fluid injection to oil reservoirs. Execution of this method was suggested in 1864 and only a few years after drilling of DARKE well. This operation aimed to keep the pressure in reservoir and return the production to the initial conditions. After this time, method of natural gas injection and or other gases was utilized successfully in many numbers of reservoirs throughout the world and as a secondary recovery technique. The research projects of gas injection has been designed under initial conditions and for rise of immediate processing and they should be considered similar to research projects for oil over-extraction and the injected fluid should also displace oil similar to a fan by over-extraction in addition to rise of energy of reservoir and move it toward production well. Such methods are economically very suitable. Overall, gas is injected into the reservoir for two purposes.

- To keep pressure fixed
- To create an oil front and sweep it toward production wells

The gas may displace the oil as a miscible or immiscible process. The characteristics and features of oil and gas and conditions of temperature and injection pressure determine type of process. The immiscibility generally depends on pressure, temperature, oil composition and the injected fluid [6].

MUSKU (1946) showed that keeping fixed pressure might enhance the oil recovery, particularly if volumetric coefficient of oil was higher [7]. Based on the conduct experiments by ELKINS
(1969), volume of injected gas, pol viscosity and oil volumetric formation coefficient are three main factors in oil recovery processes. The further contact among the injected oil and reservoir oil may increase variations in the oil compounds and lead to further oil production. It does not seem in a huge carbonated reservoir with high permeability the injection pressure to have high effect on final oil recovery [8].

CO₂ injection in oil reservoirs is designated for rising extraction that drawn attention by industry for several years. Whereas many flooding fields approach to the end of exploitation lifetime thus CO₂ injection has been highly addressed and noticed more than ever. Usually 25-50% of oil is left in reservoirs using frequently used water and gas discharge methods.

The noticeable part of this oil may be extractable if the oil is contacted to a miscible fluid. A miscible fluid is formed upon CO₂ injection and through mixing with oil of reservoir under suitable conditions. As miscibility is realized, the capillary pressure forces, which have already caused immobility of oil, are removed and then oil can be moved toward produced wells.

The rate of rising efficiency is at least 25% in this method, but the actual result is much considerable because following to CO₂ injection into oil reservoirs, one of the foremost environmental pollutants is reduced.

The given CO₂ can be provided for injection by the emitted gases from industrial factories and oil downstream plants e.g. gas refineries, petrochemical units and fertilizer manufacturing factories. Injection of CO₂ into oil reservoirs is one of the methods for reducing pollutants e.g. CO₂.

**Physical properties of carbon dioxide**

Carbon dioxide is a colorless gas with linear molecules and bivalent bonds among carbon and two atoms of oxygen. It is non-polar substance that is compressed at temperature of -78°C and it creates a white solid material called dry ice. The liquid CO₂ may be formed only under certain pressure. It is slightly soluble in water and thereby creates weak citric acid and it is partially synthetized into bicarbonate and carbonate as well.

The solubility of CO₂ in water is added by increase in pressure and it is reduced by rising temperature and salinity. The density of bicarbonates is increased in water by injection of CO₂. This causes sedimentation around the injection well and affects negatively on oil extraction. The relative high solubility of carbon dioxide in water along with reduced pH may affect chemical properties of reservoir. This impact may vary depending on PVT conditions and properties of rock
and fluid. Due to a lot of advantages of CO₂ in terms of Enhanced Oil Recovery (EOR) versus other gases, the applicability of this gas has been increased in processes of over-extraction. Compared to injection of other solvents, some of advantages of this material include miscibility under low pressure, displacement high efficiency, providing possibility for gravitational collapse mechanism, usability for oil reservoirs under different conditions and relative MMP (Minimum Miscibility Pressure) in CO₂ injection operation. As the system accesses this pressure, the relatively high solubility will be realized. If pressure of reservoir is discharged during exploitation, the pressure of reservoir should be initially increased by water injection and then CO₂ should be injected [9].

Project of CO₂ gas capture and storage

Carbon Capture and Storage (CCS) operation is basically a CO₂ gas capture process from very big and fixed sources and it is transferred to a suitable site for injection and pumping of underground geological formations. Capturing of gas flow may be implemented by isolation processes from the produced natural gases or isolation of them from flue gases resulting from consuming fossil fuels (flue gases may result from energy supply sources e.g. power plants and chemical production factories). Likewise, the gas capture operation in power generation factories may be done through CO₂ isolation process from flue- produced gas and by means of absorbent agent e.g. amine. In addition, there are also alternative processes that can be employed for capturing CO₂ e.g. pre-combustion, combustion processes and by de-carbonization process and using oxygen instead of air. Using membranes and solid absorbent materials and corrosion may play important role in CO₂ capture. As the absorbed gas was transferred by pipeline and or by means of transportation tankers to land or offshore sites, the given site may inject the gas for storage (Today, approximately 3100km of pipeline are used for transportation of CO₂ flow with about capacity of 110MT CO₂/year. One can refer to oil and gas discharge- reservoirs, deep salt water basins, desolated coal mines as the underground reservoirs and sites ready for CO₂ Capture and Storage operation. Fig 2 indicates types of subterranean reservoirs for CO₂ gas storage.
The security and safety are assumed as important and key requirements for conducting CO₂ storage operation used in this technology. It is generally noteworthy that oil and gas industry has injected million tons of CO₂ gas into oil reservoirs and underground water basins for using in over-extraction and CO₂ gas storage operations during past decades and other uses. For example, security and safety were provided for execution of such operations due to risk management system that was invented using various information e.g. carriage specifications, revision of operation, scientific concepts and engineering experience. Nevertheless, it can be predicted more certainly that execution of CO₂ gas storage operation that is done for development in technologies led to reduced propagation of resultant gases from burning fossil fuels may present perfect perception of underground storage risks to form the basis for engineering subjects and in line with achieving reasonable security and safety.

Acid Gas Injection and EOR techniques and natural gas storage may lead to our access to valuable information and experiences concerning gas injection to underground reservoirs. At present, CO₂ gas is mainly consumed for conducting over-extraction operations in which this gas is injected to reservoir to displace left oil in reservoir and this consumption amount is about 33MT CO₂/ year. The over-extraction operations may be assumed economical provided the recovery amount of left oil in an oil field can compensate for costs of CO₂-gas supply and additional costs of gas injection. Similarly, proper use of over-extraction operations which may be economic can prepare valuable information for managing CO₂-gas underground storage. Fig (3) shows CO₂ gas injection for conducting EOR projects.

![Fig (2): A view of the existing underground reservoirs for gas storage](image-url)
Rise of density of greenhouse gases e.g. CO$_2$, CH$_4$ and N$_2$O is the most major reason for high temperature of earth planet. This increase rate has been noticeable due rise of human’s activities since time of industrial revolution. Inadvertent use of land for farming and destruction of forests are considered as the foremost reason for rising density of methane and nitrogen oxide and on the other hand increase in consuming fossil fuel is the major reason for rise of CO$_2$ density in atmosphere so that CO$_2$ density has been increased from 30PPM for the period before industrialization to 180PPM in 2005 [10]. The rate of CO$_2$ propagation will be increased due to production and consumption of energy with faster trend from growing consumption of base energy in the upcoming years. The CO$_2$ propagation rate will finally reach to 80 billion tons per year with annual uniform growth rate 1.8% between years 2000 to 2030 and this is 70% increase compared to current annual propagation rate. The 2/3 of this rate is due to consumption in developing countries and energy and transportation sectors will increase 75% in CO$_2$ propagation gas [11].

CCS is a process that comprises of CO$_2$ isolation from great CO$_2$ production sources (e.g. power plants and refineries etc.) and transport and storage of this gas in secure sites for centuries. Two foremost choices for CO$_2$ storage purpose are as follows:

- Rheological storage
- Storage at oceanic depths [12]

CO$_2$ thalassic storage includes CO$_2$ injection to the depth of ocean where carbon dioxide will be solved or create hydrates with heavier water masses and thereby CO$_2$ is thrown away from atmosphere for hundreds of years [13]. It is estimated that if this idea is operationalized, 2GT of CO$_2$ can be stored annually at depths of oceans and this can be done for 1000 years [14].
Nonetheless, CO$_2$ thalassic storage is followed by several problems e.g. lack of accurate perception of physical and chemical processes, efficiency and storage, cost, technical practicality and environmental side-effects. Injection of only a few tons of CO$_2$ may create considerable change in chemical pH condition in the given zone of ocean. As a result, injection of hundreds of GT of CO$_2$ may affect the ocean totally and this is hazardous for life of aquatic creatures [15]. Moreover, due to oceanic circulation this may be followed by legal, political and international limitations for storage at large scale. Therefore, CO$_2$ thalassic storage is only an alternative and although this choice is still practically and scientifically analyzed in few countries, it is not seriously considered in terms of economic and political dimensions. Unlike thalassic storage, currently CO$_2$ rheological storage is currently presented as the best and most early-efficient choice for reducing atmospheric pollution. This technology may be adapted according to experiences of other industries e.g. oil and gas extraction and production and natural gas storage. The CO$_2$ rheological storage comprises of CO$_2$ injection to the depth in 1km at upper layer of earth so that temperature will rise more than CO$_2$ - critical temperature, but the pressure is high enough. Carbon dioxide can be stored in oil reservoirs which cause increase in oil extraction and it can be stored in blank gas reservoirs or within underground layer of salt water. For example, total storage capacity of oil and gas reservoirs and salt water layer in Ukraine amount to 20GT of CO$_2$ and this quantity is equal to total pollutions of Ukraine for forty years [16].

**CO$_2$ storage in oil reservoirs**

The high solubility of CO$_2$ in oil (approximately 10 times greater than solubility in water) and related miscibility in oil under certain temperature, pressure and oil type are assumed as the important property of carbon monoxide (Usually light- and medium-weight oils with API >25) [17, 18].

If CO$_2$ is injected to miscibility reservoir of mixed oil and carbon dioxide, it reduces oil viscosity and moves it toward extraction wells and this property is used in CO$_2$ -EOR. Some amount of injected CO$_2$ is extracted with produced oil and it is injected again after isolation, but the major portion of injected CO$_2$ is left in reservoir and stored forever [19, 20].

Rise of oil extraction by CO$_2$ has potential for storage of very great amount of CO$_2$ pollution and at the same time causes rising oil production as well. Merging oil production rise and CO$_2$ storage includes three advantages.

- Due to extraction of CO$_2$ pollutions by means of EOR- CO$_2$, from large industrial units e.g. power plants it can provide a lot of added value. The quantity of this market is estimated
about 7000 million tons by 2030. Selling the captured CO₂ may relatively provide also costs caused by installation and performance of Carbon dioxide Capture and Storage (CCS) technology.

- The oil production by CO₂ injection with pollution is free of 70% carbon monoxide.
- CO₂ -EOR can be recovered by 39-48 billion barrels of crude oil that can economically give us lucrative profit in Iran [21].

Given the history of gas production, injection condition economic practicality, all reservoirs are not suitable for CO₂ –storage. SHAW and BASCH have posited the necessary conditions in assessment of oil reservoirs for CO₂ - storage under such circumstances.

- Evaluation of consistency between CO₂ -EOR and CO₂ -storage
- Storage and identifying suitable oil reservoirs for CO₂ -EOR
- Approximation of profit for oil production and f-storage in oil reservoirs [22]

The oil reservoirs may be continually extracted by usual methods at primary development processes and initial over-extraction even though CO₂ is injected it is probably extracted with the produced oil. Thus, it should be focused on oil reservoirs with long history of production so that only execution of EOR process will not be economic. In addition, in that case of lower permeability of reservoir, this will not affect CO₂- injection and also one should ensure from adequate potential for storage and selection of suitable reservoirs may restrict CO₂-storage with respect to all above-said factors. The conditions of reservoir should be assessed for CO₂ -EOR process after selection of suitable reservoir for CO₂-storage. Majority of injected CO₂ is placed in some cavities of reservoirs during CO₂ -EOR process as these places were already occupied by produced oil and water. Some amount of CO₂ will be solved in aqueous compound and oil. Only small amount of CO₂ enters surely in reaction with minerals. Moreover, the additional capacity of storage will result from compression of aqueous compounds, left oil and rocks in reservoirs. Due to complexity of displacement and rheological conditions such density difference in phases of water, gas and oil and homogeneity of compounds limit CO₂- storage in oil reservoirs.

**Rising oil extraction by injection of CO₂ to reservoir**

Since 1950s, oil industry has been benefited from CO₂- injection as a mechanism for rising production, but with respect to rising oil price, using CO₂ has caused growing increase in oil industry as a mechanism for rising production during recent years [23].

In this method, oil is produced by injection of carbon dioxide at ground level and alternately CO₂ gas is stored in the reservoir. This gas possesses many environmental and economic benefits. Through review on studies conducted about the conditions for execution of CO₂-EOR, it can be
concluded that this method is suitable under depth level more than 600m. Therefore, the factors of depth formation type, oil saturation, oil composition, viscosity, weight, permeation, temperature and project cost should be taken into consideration before execution of this project [24].

This technique is mostly utilized in USA reservoirs and it includes the most of CO$_2$-EOR projects in the world. According to the published papers and studies, this technique is growingly used in the world [25, 25].

![Fig 4: History of over-extraction projects using CO$_2$-injection in USA and the world [26]](image)

The CO$_2$-EOR foremost project in USA but in the world is the existing project in Permian zone at west Texas and including north New Mexico. The world greatest CO$_2$-EOR project is located in this zone. According to statistics in March 2010, about 1.6 billion cubic feet of CO$_2$ is injected to the fields of this zone per day and it produces 170000 oil barrels daily from 12 oil fields [27].

BP-SONATRACH-STAT OIL Project of Al-Jazeera has been estimated as the greatest CCS project outside Europe and North America where 230 million cubic meters of gas may be extracted in this project. CO$_2$ is derived from KRECHBA gas processing unit by means of amine and then it is condensed up to 200bar and prepared for injection into aqueous aquifer of reservoir. The injection started since 2004 and it has been predicted 1 mega tons per year and 17 mega tons throughout project [28].

There is high potential for CO$_2$-storage in oil and gas fields throughout the Middle East.

- 100-105 GT in marine oil and gas reservoirs
- 75-200 GT in land oil and gas reservoirs

One of the results of studies done by Stevens et al. has been presented about suitable sites existing in the Middle East in the following table.
Table 1: The suitable sites for CO2 storage in the Middle East [29]

<table>
<thead>
<tr>
<th>Province</th>
<th>Sequestration capacity in Gt (with Tcf in brackets)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qatar Dome</td>
<td>53 (1,000)</td>
</tr>
<tr>
<td>Zagros Fold East</td>
<td>42 (794)</td>
</tr>
<tr>
<td>Mesopotamian Foredeep</td>
<td>42 (787)</td>
</tr>
<tr>
<td>Greater Ghar Al Uplift</td>
<td>36 (684)</td>
</tr>
<tr>
<td>Rub Al Khali</td>
<td>24 (456)</td>
</tr>
</tbody>
</table>

**Design of CO2-injection**

Many factors should be noticed upon designing for CO2-injection among of which three factors are highly addressed i.e. conditions of reservoir, volume of injected mass and CO2 accessibility. Similarly, controlling high mobility and dynamics of carbon dioxide is deemed as one of the foremost issues which should be considered. Distance of these sources from injection well is another important point in all these cases. The other point is the cost which is higher than over-extraction operation cost on many occasions. Similarly, cost of distance from injection well is other given point.

The CO2 may be used as source of providing this gas in those reservoirs CO2-injection has been terminated.

The volumetric mass of injected fluid is directly proportional to number of crossing oil and CO2 phases in reservoir. Alternately, economic issues may restrict further injection of CO2. Thus, access to optimal conditions is taken into consideration. In this regard, using WGA mechanism is the best choice. The studies have shown that 1.8 million cubic feet of CO2 is necessary for production of one oil barrel.

**Criterion for CO2 injection**

Any oil reservoir includes a list of specifications and sum of these features denotes character of reservoir and quality of its behavior versus various and certain motivational methods. The problem to which an engineer is exposed including determination of higher amount these characteristics as possible and then prediction of behavior and performance of reservoir.

Among them, any characteristic is not only a determinant factor. Therefore, the determined number for a characteristic should not be assumed as a rigid boundary, but it can be an agent and sign of importance level. For example, the oil with degree (< API= 25) is usually not suitable for over-extraction by CO2-injection technique.
The same issue may not exclude automatically all reservoirs with the oil heavier than API=25 from consideration and analysis. Perhaps, there are some other favorable factors preferred to an inappropriate factor. The following criteria should be considered and addressed from suitable viewpoint:

Saturation of the residual oil is fundamentally important. If the field was treated by flooding, saturation of residual oil may fail both from technological and economic views. Saturation with range (25-30%) is often assumed as the minimum saturation level. The previous flooding may not automatically exclude the fields since the simulation studies indicate that the noticeable oil quantities may result from the flooded sands.

The large gas cape is usually unfavorable factor. If pressure of reservoir is considerably lesser than miscibility pressure, it needs to great volume of CO$_2$ to achieve miscibility. The density of CO$_2$ may exceed from gas in reservoir. Thus, in this even the potential of mixing and contact to fluid will be increased in reservoir.

This case was a tactic taken along granite agents in Weeks Island where $f$ was injected to site of GOC gas and oil contact point. The highly fractured reservoir is usually assumed as unfavorable because the fractures act such as a canal from injection site to the produced well. However these fractures are also followed serious problems for another type of studied processes at the same time.

A reliable and sufficient CO$_2$ source with rational cost is one of the most primary requirements. Due to absence of CO$_2$ sources near to many fields of world, the serious interest in nitrogen and flue gas has been very quickly pervasive as the techniques for injection of alternative gas. Horizontal permeability of reservoir rock is not considered as a critical factor, but vertical-to-horizontal permeability ratio is deemed as a very important and critical factor. Conducting a reservoir simulation study on a flooded sandstone sample came to the result that KH/KV ratio was the foremost parameter of reservoir in CO$_2$-injection process. Whereas this parameter controls CO$_2$-separation rate the relatively slim permeable regions in reservoir (15-25ft) possess technical advantages because they lessen tendency to preference of gravitational force, but the thicker areas benefit from oil volume.

Depth is important factor because the minimum miscibility pressure is usually higher than 1200PSI which requires for depth more than 2500ft so that not to exceed from facture gradient value. Also temperature is not an important factor.
The lower boundary of oil weight and gravity is located within range (25-30ft) some of which is related to this issue whether the oil is aromatic, asphaltic otherwise or not. So far viscosity of oil reservoir has been about 1cp in most of CO$_2$-projects. The pure CO$_2$ is the best choice for injection, but such a source is rarely available. Pollution of CO$_2$ with methane may increase miscibility pressure. However 5-10% of methane is tolerable. Hydrogen sulfide lowers miscibility pressure, but due to corrosion, it is followed by environmental and health hazards and unfavorable odor. Given the injection is done for oil over-extraction, the field experience with CO$_2$- injection can be summarized within limits of following considerations:

- In sandstone, lime stone, dolomite and chert
- With no depth limitation up to 10800ft
- In formations with average permeation less than 2MD
- At temperature of bottom of well up to 248f and with no restriction
- In the formation in which diameter varies 8-600ft by considering variations of heterogeneity
- In places the gravity of crude oil is 16-45 API
- Where immiscible crude oil is displaced
- In reservoirs with oil saturation within range 28-54%
- With maximum distance up to 51 Acres for any well
- When the injected fluid maximally includes 29% of hydrogen sulfide

**Analysis of an experimental sample of CO$_2$ cyclic injection in Iranian oil reservoirs**

This method is utilized in heavy-weight oil reservoirs where it is not possible to use thermal over-extraction techniques or in reservoirs in which temperature and pressure conditions are in such a way that there is no potential for extraction. The important parameters of this method include injection cycles and CO$_2$-volume used in any cycle. The f is injected to the reservoir (surrounding of produced well) in this technique (The produced and injection wells are not the same in this technique). The injection well will be closed to spend permeation time after this operation that may continue between a few hours and several days. This time may vary for a few days to weeks. One or more following operations lead to rise of oil production from reservoir during this period.

- Carbon dioxide is solved in oil and reduces oil viscosity. This issue may lessen oil motion toward the produced well.
- CO$_2$ solution in oil is led to its expansion and then causes moving toward produced well.
- Mechanism of the solved gas is capable in oil. This process is repeated for several times and efficiency of production will be reduced any time of course.
Solving of CO₂ and discharge of asphaltite takes place simultaneously during CO₂ injection and both causes reducing viscosity, but solution of carbon dioxide and discharge of asphaltite act inversely concerning changes in oil density. Carbon dioxide increases this density while discharge of asphaltite reduces density.

This test has been summarized in several phases as follows:

- Immiscible injection of hot water and hot CO₂
- Injection of CO₂ gas
- Injection of CO₂ hot gas
- Water injection
- Frequent injection of water and CO₂
- Frequent injection of hot water and hot CO₂

This experimental test aims to analysis and comparison of production efficiency rate from a fractured core using over-extraction techniques including CO₂ gas injection, CO₂ hot gas injection, water injection, frequent water and CO₂ gas injection and frequent injection of hot water and CO₂ hot gas.

It was observed after execution of CO₂-gas injection scenario that the final recovery amount included 44.6% of blank spaces in the fractured sample. Based on the conducted test, the oil recovery rate by means of frequent hot water and CO₂ hot gas injection technique is greater than in methods of frequent water and CO₂ injection, water injection, CO₂ gas injection and CO₂ hot gas injection.

The frequent water and gas injection has been employed as a suitable technique for light- and medium-weight oils, but frequent hot water and hot gas injection technique is also utilized for heavy-weight oils because this method is composed of fluid injection and thermal techniques. Temperature of water and hot gas reduces oil viscosity and surface tension. The following results can be implied of findings of this study:

- Compared to some methods e.g. frequent water and gas injection, water injection CO₂ gas injection and CO₂ hot gas injection, oil recovery rate is greater using frequent hot water and CO₂ hot gas injection method.
- Rise of temperature increases corrosion and corrosive nature of this gas is one of the problems that take place in using of CO₂ gas especially when it is heated. Of course, we will not usually encounter too problems in experimental operation but if we intend to use this gas at industrial scale, we should certainly consider this factor as well and also the gas should be free of moisture upon injection.
Due to more mobility of hot gas, it permeates mainly into the areas which have not been accessible in normal injection.

The frequent injection of hot water and CO\(_2\) hot gas process can be utilized in fractured reservoirs as a favorable oil over-extraction technique.

In addition to global need to conducting scientific studies in this field, the Iranian reservoirs also necessarily need to use practical and affordable and at the same time useful techniques to increase oil extraction from the reservoirs since only a small part of oil reservoirs can be extracted by the aid of current methods while the noticeable part of this divinely gift may be left unavailable.

With respect to gas sources e.g. CO\(_2\) (ammonia production projects) and hydrocarbon gases etc. and the existing water supplies in our country, using of frequent water and gas injection technique may be noticed for oil over-extraction and preservation of reservoirs.

**Conclusion**

CO\(_2\)-storage and injection proportional to the produced oil is assumed as the important subject in adaption of this technique. This technique is not economic in some of oil fields locating at sea because given water as an available source using water injection technique is very affordable.

Also in land-based fields, CO\(_2\)-storage tankers with the related transport costs may highly affect these costs and in this case replacement of a pipeline that can carry CO\(_2\) from production site to injection zone can reduce costs. However this is cost-consuming for long distances since the extracted gas should be CO\(_2\) output from factories not resulting from production.

Despite ease of CO\(_2\) injection, controlling this operation is very important underground. Today, adaption of new techniques e.g. magnetic photography is deemed as precious tool for controlling injection. Using advanced high-quality magnetic-photographical technique one can identify the barriers that block gas and water flow thereby to determine precise location for injection.

It is noteworthy, gas injection should be done carefully because if dynamic status is disturbed in reservoir not only production is not increased, but also the reservoirs may be damaged and their production is reduced as well.

**References:**


[27] National Energy Technology Laboratory, USA Government”Carbon Dioxid Enhance Oil Recovery” pp., 9 – 10