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A Review of Early Opportunity-Analysis on CO_2 Sequestration and Enhanced Oil Recovery for Iran

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Abstract

In recent years, greenhouse gases (GHGs) such as carbon dioxide have increased in the atmosphere and caused some concerns about climate change. The table published by International Energy Agency shows that from 1990 to 2007, Iran after China has had the highest rate of increase in carbon dioxide emission. In 1990, Iran produced a total of 175 million tons of carbon dioxide to the atmosphere while in 2007 this rate has reached to 466 million tons. Geological sequestration is one way to reduce the CO_2 content in the atmosphere. There are several options for sequestrating CO_2 in geological sinks. Mature oilfields are one of the most favorable targets for the CO_2 sequestration .Injecting CO_2 into these reservoirs can increase the amount of oil produced in addition to offsetting some of the CO_2 storage expenses. Most of the CO_2 injection aspects into the reservoirs for the purpose of Enhanced Oil Recovery have been known for decades. The economics and incentives for combined EOR and sequestration process are less clear at this time, but a first step in the development process should be to do studies in order to investigate ways for both producing oil efficiently and maximizing storage of the carbon dioxide.

This study looks at such scenarios that reduce the CO_2 emissions using the existing oil reservoirs as sink. The goal of this research is to better understand the potential for simultaneous enhanced oil recovery and CO_2 sequestration in oil reservoirs over a range of conditions.

Key words: CO_2 sequestration; Enhanced Oil Recovery; Iran

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INTRODUCTION

Since the beginning of the industrial age, atmospheric concentrations of greenhouse gases have increased significantly. Experts forecast that carbon dioxide emissions will account for about two thirds of potential global warming[1]. As Figure 1 shows measured atmospheric CO_2 concentrations for the last two hundred and fifty years have increased from 270 to 370 parts per million (ppm). It is estimated that half of this amount has occurred in the last 50 years. The increase is mainly attributed to the combustion of fossil fuels for energy production[2]. The rank of Iran in top CO_2 emitters is also shown in Table 1.

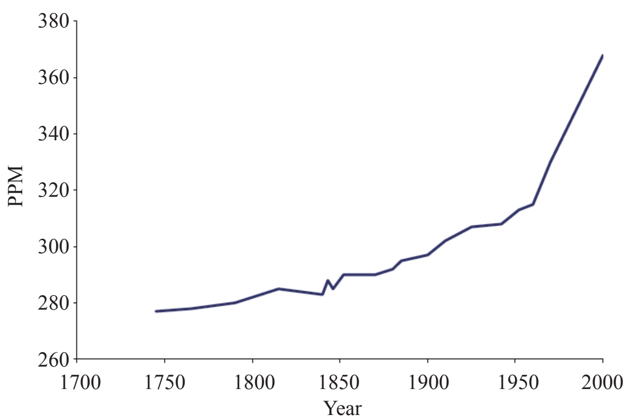

Figure 1
Atmospheric CO_2 Concentrations in the Last 250 Years[3]

Table 1
Rank of Iran in Top CO_2 - Emitters (From Wikipedia, 2007)

Rank	Country	Annual CO_2 emissions (in thousands of metric tons)	Percentage of total emissions
-	World	28,431,741	100.0 %
1	China	6,103,493	21.5 %
2	United States	5,752,289	20.2 %
3	Russia	1,564,669	5.5 %
4	India	1,510,351	5.3 %
5	Japan	1,293,409	4.6 %
6	Germany	805,090	2.8 %
7	United Kingdom	568,520	2.0 %
8	Canada	544,680	1.9 %
9	South Korea	475,248	1.7 %
10	Italy	474,148	1.7 %
11	Iran	466,976	1.6 %

One possible solution to reduce atmospheric CO_2 emissions is geologic sequestration of CO_2. This is summarized as the storage of CO_2 deep within the earth instead of releasing it to the atmosphere. According to the Kyoto protocol, underground sequestration of CO_2, accomplishes the goal of reduction of greenhouse gases emission, as oil and gas fields offer huge CO_2 storage capacities. Carbon dioxide is already injected into oil reservoirs to increase oil recovery. It has been used in enhanced oil recovery (EOR) processes since the 1970s; the traditional approach is to reduce the amount of CO_2 injected per barrel of oil produced. This minimizes the purchase cost of CO_2. For a sequestration process, however, the aim is to maximize both the amount of oil produced and the amount of CO_2 stored. Oil reservoirs are good candidates for sequestration because the physical and legal infrastructure already exists for CO_2 injection. Anthropogenic CO_2 could substitute for the naturally occurring CO_2 currently injected. Additional geologic options include deep saline aquifers, unmineable coal beds and mined salt domes[4,5].

2. CARBON CAPTURE AND STORAGE (CCS)

Carbon capture is best used at large stationary sources such as power stations and industrial plants, as shown in Figure 2. The process requires the separation of CO_2 from impurities like: acidic gases or particulates and compression for transport and underground injection. The CO_2 is transported from the source to the storage sites via pipeline or tankers.

Possible CCS strategies include storage in the deep ocean, injection into geological structures or precipitation as a solid carbonate. Geological formations are regarded as the most viable and environmentally acceptable of these options. Potential structures that have been considered in the literature are:

- Depleted oil reservoirs
- Depleted gas reservoirs
- Deep saline aquifers
- Unmineable coal beds

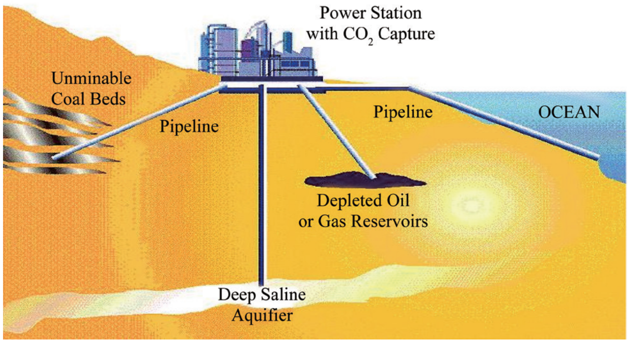

Figure 2
Typical Process of CCS, Which Shows Available Storage Sites From Power Stations[6]

We are interested in CO_2 storage in the first three systems. Injecting CO_2 into depleted oil and gas reservoirs has the primary advantage of being economically beneficial to oil and gas production companies who seek to increase their recoverable reserves[7]. CO_2 flooding is an effective tertiary recovery mechanism that uses established injection infrastructure and the vast technological experience of the oil industry to extend the profitability of many reservoir systems. While suitable formations are easily located, they have the distinct disadvantage of being inequitably distributed geographically[8]. Compared with oil and gas reservoirs, deep saline aquifers are widely distributed throughout the globe, although often have poorly characterized geology. These systems could therefore be used for the disposal of anthropogenic CO_2 in locations where there are no suitable oil or gas reservoir alternatives[6].

3. CO_2 SEQUESTRATION IN GEOLOGICAL FORMATIONS

The storage of CO_2 within geological formations was first proposed in the late 1970s[9]. However, genuine research into this area only started in the early 1990s. Since then significant progress has been made in the technologies available for predicting the fate of injected CO_2. This has allowed a large body of work to be produced and the feasibility of CO_2 disposal in several aquifers systems to be determined.

Two classical studies have been performed on structures in Norway and the Alberta Basin, Canada. The first successful CO_2 sequestration field test in a brine-bearing formation was performed in the Sleipner gas field in the Norwegian North Sea[10]. In the Sleipner project,

CO_2 was stripped from the produced natural gas and injected into a sand layer called the Utsira formation. The injection started in October 1996 and CO_2 is injected at a rate of 1 million tonnes per year. Over 10 million tonnes of CO_2 have been injected so far without any significant operational problems observed in the capture plant or in the injection well[11,12].

Another field test of CO_2 sequestration was conducted in high permeability brine-bearing sandstone of the Frio Formation beneath the Gulf Coast of Texas, USA[13]. 1,600 tonnes of CO_2 were injected 1,500 m below surface starting in October 2004, followed by monitoring and assessment.

The Weyburn field project in Canada[14] was the first to study CO_2 storage as both an enhanced oil recovery (EOR) technique and a storage method. The Weyburn project is a good example to prove that oil reservoirs are attractive candidates for subsurface CO_2 storage.

Another CCS project already in operation is in Algeria. The In Salah Gas project comprises a phased development of eight gas fields located in the Ahnet-Timimoun Basin in the Algeria Central Sahara[15]. CO_2 removed from the produced gas is injected into the formation, which provides storage of 1.2 million tonnes per year.

In the UK, a large-scale CO_2 injection project into a depleted oil field - the Miller Field, in the North Sea was planned with the purpose of CO_2 storage in addition to EOR[6]. Natural gas from the North Sea would be converted to hydrogen and carbon dioxide, using the hydrogen to make low carbon electricity and pumping the carbon dioxide back into the reservoir of the Miller field. It was announced that an extra 40 (million barrels) of oil would be produced over a 20 year period by injecting about 1.25(million tonnes/year) CO_2 into the field. However, although it has been thoroughly studied, this project was not implemented because of financial constraints[6].

Similar projects are also planned in Norway, where Shell and Statoil recently launched their plan for a project to use CO_2 captured from a large natural gas fired power plant and methanol production facility at Tjeldbergodden in Mid-Norway for enhanced oil recovery offshore at the Shell operated Draugen field and later at the Statoil operated Heidrun field[6].This so called CO_2 value chain project aims storing CO_2 underground, while at the same time achieving increased oil recovery and electricity supply. It is estimated that 2.5 million tonnes of CO_2 can be separated by the capture facility per year.

According to the Intl. Energy Agency (IEA) Greenhouse R&D Program, oil and gas reservoirs have an estimated CO_2 storage capacity of about 920 Gt while deep saline aquifers could store between 400 to 10,000 Gt[16]. This is compared to annual global CO_2 emissions of 25 Gt. Although there are significant uncertainties in these estimates, geological formations clearly have a large storage potential.

3.1 CO_2 Sequestration Simulation

Monitoring CO_2 in the reservoir during and after injection is necessary to ensure that the CO_2 is retained in the formation. Two methods for monitoring the subsurface movement of CO_2 are reservoir simulation and geophysical studies.

Reservoir simulations predict the CO_2 distribution in the system during and after injection so that effective management decisions can be made[7]. Geophysical measurement techniques such as seismic, electrical and gravity measurements provide regional, cross-well or single well mapping of the CO_2 saturation in the field. From an engineering point of view, flow simulation is imperative for the design of CO_2 sequestration schemes. Simulations allow the development of an injection strategy that maximizes the storage volume of the reservoir while minimizing the risk of leakage. This method provides engineers with predictions of the flow paths and distributions of the CO_2 within geological formations so that an efficient design can be carried out. However, in order to obtain a representative simulation of the project, detailed information on the physical and chemical mechanisms that occur during the sequestration process is necessary.

Malik and Islam (2000) provided detailed results of a comprehensive reservoir simulation study that used a fully compositional model to optimize the injection/production strategies of CO_2 in the Weyburn field, Canada. Their study indicated that horizontal injection wells were efficient for CO_2 flooding as they increased both the volume of recovered oil and the volume of CO_2 stored. The presence of contaminants in the injection gas, mainly N_2, was modeled in the system and this is believed to have resulted in the inefficient displacement of the reservoir oil due to the decrease in solubility and diffusivity of CO_2 in the hydrocarbon phase. The underlying aquifer was also shown to have a significant impact on the oil production and CO_2 storage capacity.

Krumhansl *et al*. (2002) studied geological sequestration of CO_2 in a depleted oil reservoir. They considered binary interactions between crude oil components and CO_2 using the Soave-Redlich-Kwong equation of state and the bicarbonate-rich brine's reactions with the reservoir rock. The simulation results, Figure 3 (a) - (c), indicated that the volume of CO_2 dissolved in the water was smaller than that present in its own phase and a significant decrease in permeability of the system resulted from mineral precipitation. They also built a geochemical reaction path model, which primarily focused on the impact of the increase in CO_2 pressure on the solubility of anhydrite and calcite and determined that this solubility is a strong function of the pressure. However, their simulations were only on a model with 7,168 grid blocks.

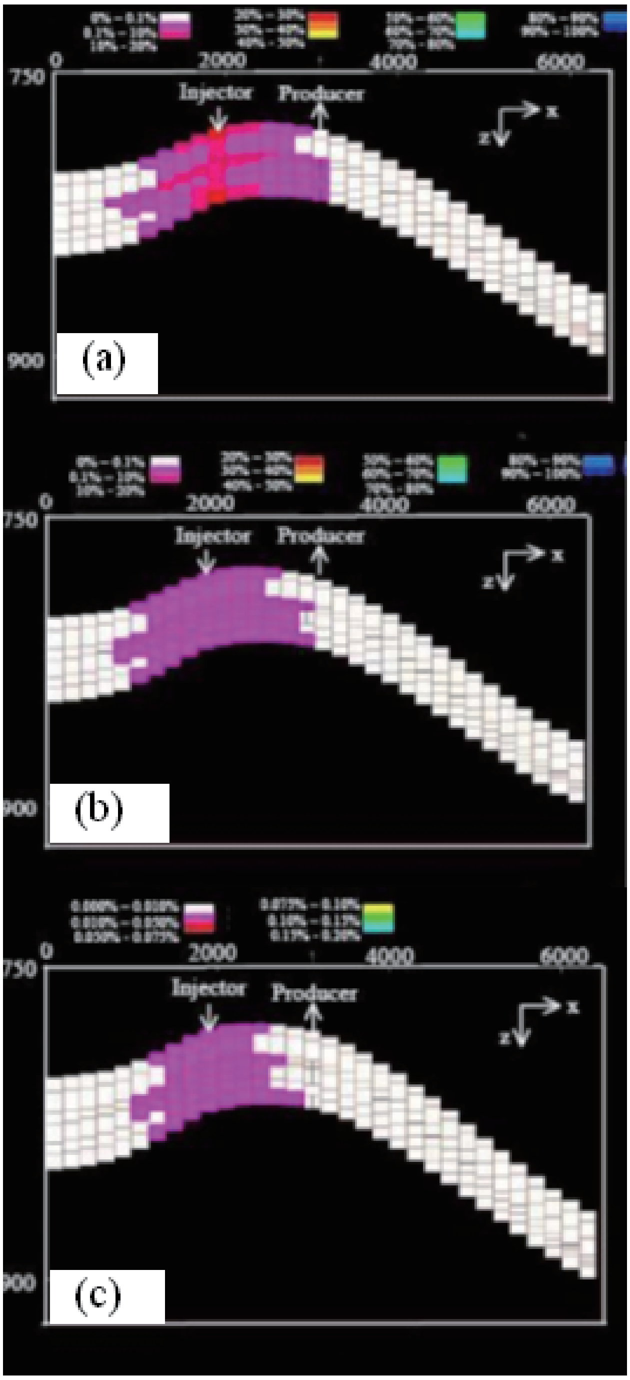

Figure 3
Distribution of (a) Gaseous CO_2 (b) Liquid CO_2 (c) Aqueous CO_2 1 Year After Injection was Stopped

Bachu *et al*. (2004) studied the effect of an underlying aquifer on the estimation of oil recovery and CO_2 storage capacity. Produced water-oil ratio and gas-oil ratio were shown to be indicative of the strength of the underlying aquifer. Through material balance analysis on 19 oil pools, if the reservoir pressure is only allowed to increase to the initial pressure, the CO_2 storage capacity is reduced on average by 3 % for a weak underlying aquifer and by 50 % for a strong underlying aquifer.

Ghomian *et al*. (2008) studied the effect of relative permeability hysteresis on both CO_2 storage and oil recovery using a compositional simulator, GEM. In their simulations, they used a modified Land's trapping model, which matched simulation results and experimental data from Jerauld *et al*. Their 2D and 3D simulation (with 16,800 grid blocks) results showed that relative permeability hysteresis has a significant effect on CO_2 storage and oil recovery during WAG injection. They also tested the influence of WAG ratio, CO_2 slug size and reservoir heterogeneity. Their economic analysis showed that there is no significant reduction of profit when CO_2 storage was maximized while oil production was not.

CONCLUSIONS AND RECOMMENDATIONS

Based on this study, it is evident that geological formations have the potential to be used for CO_2 storage and that CCS should be a part of any effort to reduce the emissions of CO_2 into the atmosphere. Despite the oil industry's considerable experience with CO_2 injection in enhanced oil recovery, a number of challenges still exist. Among these is the need for a clear understanding of the ultimate fate of the injected CO_2 to ensure that it remains trapped underground. As such, precise and accurate simulation technologies must be developed and employed to predict the transport of CO_2 underground. Recent research studies have also the limitation of inability to study fine-scale geological models.

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