Evaluation of CO\(_2\) storage potential of oil reservoirs in Ordos Basin

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Abstract. The huge impact of the emission of the greenhouse gas CO\(_2\) on the global climate and environment has caused wide concern all over the world. Deep CO\(_2\) emission reduction is the only way for sustainable development of human beings. In order to meet the urgent need of sustainable economic and social development, effective measures must be taken to achieve large-scale CO\(_2\) emission reduction. As an increasingly mature and feasible technology, CO\(_2\) geological sequestration has become one of the effective ways to achieve large-scale CO\(_2\) emission reduction. In Ordos basin as the research object, this paper documents and basic information system collect and organize data, evaluated the Ordos basin in turn CO\(_2\) enhanced oil recovery (CO\(_2\)-EOR) and CO\(_2\) sequestration potential, depleted oil reservoir and select 60 oilfield in Ordos basin CO\(_2\) sequestration potential analysis and to meet the requirements of 27 oilfield seal ratio analysis, the results showed that: Under the screening condition that the burial depth is greater than 800 m, when assuming that 60 oilfields in the Ordos basin are all used for CO\(_2\)-EOR, the CO\(_2\) sequestration potential of the reservoir is about 318.27 Mt; when 60 oilfields are all treated as abandoned reservoirs, the CO\(_2\) sequestration potential is about 1221.57 Mt. When the amount of CO\(_2\) to be sequestered is small, Huachi (Changqing) field should be preferred, and when the amount of CO\(_2\) to be sequestered is large, Jiyuan (Changqing) field should be preferred. In this paper, the evaluation results of CO\(_2\) sequestration potential of reservoir in Ordos basin are of great significance to the further development of theoretical sequestration potential evaluation and engineering planning of Ordos basin.

Keywords: Ordos basin; CO\(_2\) reservoir; Storage potential; Seal ratio.

1. Introduction
The large-scale burning of fossil fuels leads to the excessive emission of greenhouse gases, represented by carbon dioxide, into the atmosphere, which is one of the most important factors causing the sharp rise of the world temperature in the past century. Global warming may have significant negative impacts on the Earth's environment and human survival, such as the continued rise in global sea level caused by the large-scale melting of glaciers. It is estimated that the global sea level will rise over years, the original
climate balance system has been destroyed, biodiversity has been sharply reduced, and extreme disaster events are frequent. As a responsible country, the Chinese government has taken various measures to reduce carbon emissions and fulfilled its international commitments to reduce carbon emissions. In recent years, Carbon Capture and storage (CCS) technology has been widely concerned in the international community because of its great emission reduction potential. The source of CO2 includes power plant, chemical plant, cement plant and so on. CO2 storage area includes oil field, gas field and salt water layer.

Ordos Basin is the second largest sedimentary basin in China, and its natural resources are extremely rich, among which coal, natural gas and coalbed methane are the first in the actual proved resources, and petroleum proved reserves are the fourth in the country, it is the most important energy production and supply base of our country in this century. Located in the northeast of the Ordos Basin, Yulin is the main reservoir of energy resources in the basin. It is rich in coal, oil, natural gas and other energy resources, the Yulin Energy and chemical industry base planned and built in the region is the only national energy and Chemical Industry Base in China. It serves as the source of the country's west-to-east coal transportation, the hub of the west-to-east power transmission, and the hinterland of the west-to-east gas transmission, the healthy and sustainable development of the energy and chemical industry in Yulin is of great significance to the energy security of our country. However, with the rapid development of energy, chemical, coal and power industries in the region, coupled with the carbon dioxide emissions from oil, natural gas, cement, steel and other industries, resulting in a sharp increase in carbon dioxide emissions, facing enormous pressure to reduce emissions.

The issue of carbon dioxide emission reduction has become one of the biggest bottlenecks restricting the development of the energy and chemical industry in the region and directly restricting the sustainable development of the national economy (Ren Xiangkun, 2010), effective measures must be taken to achieve large-scale reduction of carbon dioxide emissions. Fan Jiqi, Li Wuguang (2011), Wu Qinghua (2012) and Zang Yaqiong (2013) have made a systematic analysis and comprehensive evaluation of the geological storage conditions of carbon dioxide in major sedimentary basins in China from different angles, many research results show that Ordos Basin is one of the most suitable geological storage sites for carbon dioxide because of its huge resource potential, high exploration degree, stable geological structure and sufficient gas source.

Therefore, this paper takes the Ordos Basin as the research object, selects 60 oil fields for comprehensive analysis, builds a reservoir CO2 potential assessment model based on the existing research, and evaluates the potential of the 60 oil fields in the Ordos Basin to implement CO2 storage to provide data basis and technical support for the design and implementation of future CO2 sequestration industrial projects in the region.

2. Geological Storage of CO2 in Oil Reservoirs

2.1. Geological Sealing in CO2-EOR Reservoirs for Enhanced Oil Recovery

In the petroleum industry, CO2 has been used for decades to enhance oil recovery in oil reservoirs. EOR (carbon dioxide enhanced oil recovery) technology. Oil Recovery is simply the proportion of oil recovered to the total reserves in the reservoir. At the end of the traditional water injection method, many crude oil will remain in the rock crevices because of capillary action, and can not flow to the production well, and the crude oil in the rock crevices can not be squeezed out with enough driving force produced by Water and hydrocarbon gas, it's a waste of oil. CO2 can improve the velocity ratio of crude oil and water, enhance the permeability of formation, remove part of reservoir pollution, extract and vaporize the light hydrocarbon gas in crude oil, and mix with oil to form a uniform phase. The residual oil in the rock crevices expands in volume and decreases in viscosity, allowing it to flow smoothly to the production well. In this way, the crude oil that could not be extracted before can be recovered successfully, and the oil recovery rate can be improved.

There are many ways to adopt co2l-eor, such as continuous CO2, CO2 and water injection alternately. The conventional primary oil recovery technology can only produce 5-40% of the original oil reserves
in the reservoir, while the secondary oil recovery using water flooding technology can increase 10-20% of the original oil reserves, the enhanced oil recovery (EOR) by CO2 injection can further increase the yield of 7-23% crude oil. In the process of applying CO2 to enhance oil recovery, part of CO2 will be discharged out of the surface along with the crude oil as the accompanying gas, and in the case of CO2 storage, the recovered CO2 needs to be separated and compressed and injected into the reservoir, finally, the geological storage of CO2 is realized.

2.2. Geological storage in abandoned reservoirs

Abandoned reservoir generally refers to the reservoir after three production, lost the ability to carry out economic exploitation. As the abandoned reservoir is the storage of the existing reservoir, the original reservoir has been certified, the relevant parameters are complete, and some oil wells and surface facilities used for oilfield development can be reused for underground gas storage, the corresponding computer software can simulate and predict the migration and capture of underground CO2, so it is the key area for CO2 disposal.

CO2 burial in abandoned oil and gas reservoirs requires a re-evaluation of the sedimentary types of the reservoirs based on the previous research around oil and gas exploration and development, the evaluation of the buried depth, thickness and three-dimensional geometry, morphology and integrity of the reservoir, as well as the physical properties and Heterogeneity of the reservoir, requires attention to the following two issues:

(1) the existence of a strong aquifer. In the process of producing oil and gas, because of the pressure, the water in the Aquifer can enter the reservoir, thus restoring the pressure and reducing the reservoir space. Similarly, if the pressure is close to the original reservoir pressure after secondary or tertiary recovery, it should not be considered for CO2 storage.

(2) the sealing horizon and wellbore of abandoned oil and gas reservoirs need to be re-marked and evaluated. In a wet environment, CO2 will corrode the cement stone, increasing the risk of leakage.

3. Calculation method of CO2 storage in reservoir

3.1. Oil field CO2-eor using CO2 to enhance oil recovery

CO2-EOR has a relatively mature experience and technology, but there is very limited public data on CO2 injection and circulation in large oil and gas fields. Using the relationship between CO2-EOR and crude oil reserves established by Stevens, this paper estimates the CO2 storage capacity of the oil fields where CO2-EOR is applied:

\[
\text{API} = \frac{141.5}{\text{SG}} - 131.5
\]

The API is a measure of the density of Petroleum and petroleum products. At present, the International Api as one of the main criteria to determine the price of crude oil. The higher the number, the lighter the oil, and the higher the price.

SG is the specific gravity (relative density of crude oil) of the oilfield, which refers to the ratio of the weight of crude oil to the weight of pure water at the same volume and temperature of 4 °C under the surface standard conditions of 20 °C, 0.1 MPA, and the specific gravity of crude oil is generally between 0.75 and 0.98.

(2) the percentage of CO2 enhanced oil recovery is % EXTRA

Stevens argues that although there are many factors affecting CO2-EOR, API weight of crude oil is closely related to the CO2-enhanced oil recovery rate of % EXTRA. The empirical relationship is derived from the EOR project of seven permian basins in the United States.

\[
\%EXTRA = \begin{cases} 
5.3\% & (API \leq 31) \\
1.3 \times API - 35\% & (31 < API \leq 41) \\
18.3\% & (API \geq 41)
\end{cases}
\]
Empirical formulas show that more CO2 is required to extract the same amount of heavy oil than is required to extract a barrel of light oil.

(3) Calculating OIPC BASED ON OOIP:

\[ \text{OOIPc} = \text{OOIP} \times C \]

Among them, OOIP represents the geological reserves of crude oil, unit is Mt. C is the contact ratio of CO2 to crude oil, 75% is used in this paper. OOIPC is the amount of crude oil that can come into contact with CO2, in the same unit as OOIP.

(4) Based on the above calculated parameters, the incremental oil recovery and CO2 storage capacity can be obtained:

\[ \text{EOR} = \frac{\text{OOIPc} \times \% \text{EXTRA}}{\text{OOIPC} \% \text{EXTRA}} \]
\[ \text{CO2} = \text{EOR} \times \text{RCO2} \]

Among them, EOR is the amount of crude oil that can be increased, and its unit is the same as OOIP. CO2 is the amount of CO2 that can be stored, that is, the storage potential of the storage, in tonnes t or Mt.

RCO2 is the typical ratio of the net injection of CO2 to the amount of oil increase, that is, the oil change rate. The unit is ton / barrel (t / bbl), or ton / ton (t / t). Many studies have given experimental or predicted data on oil change rates, generally between 2.47 - 4.12 tons CO2 / ton oil. In this paper, the intermediate value is adopted, and 3.30 tons of CO2 / ton of oil is adopted uniformly.

3.2. Abandoned oil fields

The CO2 storage capacity of abandoned oil fields is estimated using the formula used by the applied science in the GESTCO2 project:

\[ \text{CO2-depleted} = \text{OOIP} \times \text{RF}_O \times \text{FVF}_O \times \rho_{\text{CO2}} \]

Among them, OOIP and the above-mentioned formula of implementing EOR oilfield, represents the geological reserves of crude oil, unit is MT, RF is the recovery rate of crude oil, in this paper take 35%, that is, the recovery rate of 35% oilfield will be regarded as abandoned oilfield. At present, the average recovery factor of the developed oilfields in China is only 32%; FVF is the volume Coefficient of the oilfields, which is the ratio of the degassing volume per unit volume of crude oil in formation to that in surface standard conditions; CO2 is the ratio of the degassing volume per unit volume of crude oil under the conditions of temperature and pressure in the oilfields, the density of supercritical CO2, in MT / M3, and the amount of CO2-depleted that can be stored, namely the storage potential of the storage.

4. Assessment results

In this paper, 60 oil fields in Ordos Basin are selected to analyze the potential of CO2 reservoir. When all these 60 oil fields are used for CO2-EOR, the theoretical potential of CO2 storage is about 318.27 MT, and the production of crude oil can be increased by XX ton. When all oil fields are treated as abandoned reservoirs, the theoretical storage potential of CO2 is about 1221.57 Mt. The CO2-EOR storage potential and related information in Ordos Basin are shown in Table 1.

After the evaluation of theoretical CO2 storage potential, the reservoir should be further screened before CO2 geological storage. The scale of storage site is an important screening criterion. The storage point chosen must be able to accommodate CO2 generated from CO2 emission sources over a specified period of time. Based on the characteristics of more than 100 CO2-EOR projects in North America at the end of 2007, Nunez-Lopez v ET al. suggest that CO2-EOR should be used for reservoir storage ≥1mt CO2. According to the evaluation results of this paper, 27 oilfields meet the requirements, and the CO2 storage amount is about 99% of the total CO2-eor storage amount. The storage potential of the 27 fields is shown in figure 2.
### Table 1. CO2-EOR storage potential and related information in Ordos Basin

| Name of field (Oil reservoirs) | OOIP (Mt) | CO2-EOR (Mt) | CO2-depleted (Mt) |
|-------------------------------|-----------|--------------|------------------|
| Ansai (Changqing)             | 18.66     | 33.45        | 42.46            |
| Baibao (Changqing)            | 13.03     | 3.21         | 45.19            |
| Baiyanjing (Changqing)        | 0.34      | 0.65         | 40.82            |
| Changwu (Or) 2                | 0.14      | 0.05         | 40.69            |
| Chenghao (Changqing)          | 0.04      | 0.98         | 5.66             |
| Chi (Or) 1                    | 0.01      | 0.00         | 5.51             |
| Dabaantiang                   | 0.14      | 0.03         | 5.55             |
| Dashuikekeng (Changqing)      | 0.50      | 0.44         | 5.10             |
| Dingbian                      | 5.60      | 2.29         | 9.41             |
| Donghuangzhuan                | 0.12      | 0.04         | 6.84             |
| Fanjiachuan (Changqing)       | 2.19      | 1.87         | 6.70             |
| Guhechengchuan                | 0.22      | 0.06         | 6.71             |
| Hengshan                      | 0.70      | 0.22         | 6.85             |
| Heshui                        | 39.20     | 14.68        | 18.78            |
| Honghe                        | 22.92     | 5.74         | 13.74            |
| Hongjiating (Changqing)       | 0.03      | 0.93         | 5.36             |
| Huachi (Changqing)            | 0.03      | 3.42         | 8.65             |
| Huangling (Changqing)         | 24.63     | 15.18        | 20.67            |
| Huqiu (Changqing)             | 31.22     | 45.49        | 51.43            |
| Huijianshan (Changqing)       | 5.74      | 4.12         | 12.99            |
| Jianyucha (Yanchang Complex)  | 2.80      | 0.79         | 12.04            |
| Jing'an (Changqing)           | 75.45     | 49.72        | 42.69            |
| Jingbian (Yanchang)           | 0.32      | 1.11         | 32.17            |
| Jinghe                        | 0.55      | 0.07         | 31.21            |
| Jiyuan (Changqing)            | 0.70      | 45.81        | 85.04            |
| Laoshan (Yanchang Complex)    | 0.85      | 0.28         | 81.49            |
| Lihua (Changqing)             | 0.01      | 0.07         | 19.97            |
| Mafang (Changqing)            | 0.69      | 0.67         | 20.45            |
| Majiatai                      | 0.04      | 0.04         | 20.14            |
| Maling (Changqing)            | 0.75      | 8.71         | 8.09             |
| Miaoqiu                       | 0.29      | 0.04         | 8.08             |
| Miaoqiao                      | 0.05      | 0.01         | 8.01             |
| Nanliang (Changqing)          | 21.07     | 9.37         | 16.66            |
| Nanniwan (Yanchang Complex)   | 6.33      | 2.23         | 18.50            |
| Ningdong                      | 0.65      | 0.16         | 16.74            |
| Panlong (Yanchang Complex)    | 0.42      | 0.57         | 12.88            |
| Qingtingchuan (Yanchang Complex) | 1.72    | 0.56         | 12.71            |
| Qingyang                      | 0.29      | 0.11         | 12.67            |
| Suijing (Changqing)           | 0.85      | 0.11         | 12.85            |
| Wangjiachuan (Yanchang Complex)| 8.33  | 3.63         | 15.16            |
| Wangwazi (Changqing)          | 1.22      | 0.42         | 12.96            |
| Wayaozao (Yanchang Complex)   | 5.60      | 2.44         | 14.32            |
| Wu (Or) (2006) 10             | 0.07      | 0.03         | 12.60            |
| Wujiang (Changqing)           | 0.70      | 0.23         | 12.32            |
| Wuqi (Changqing)              | 11.48     | 7.58         | 8.86             |
| Xiasiwuan (Yanchang Complex)  | 1.68      | 0.52         | 9.25             |
| Xifeng (Changqing)            | 40.51     | 22.19        | 26.71            |
| Xin'anhuai (Changqing)        | 5.04      | 3.43         | 27.75            |
| Xingzhuang                   | 12.18     | 1.54         | 29.27            |
| Xiqu (Changqing)              | 0.98      | 0.25         | 25.80            |
| Yanchang (Yanchang Complex)   | 18.82     | 7.04         | 31.33            |
| Yangmian                     | 1.19      | 0.38         | 24.75            |
| Yongneng                      | 9.30      | 4.38         | 31.13            |
| Yongping (Yanchang Complex)   | 0.53      | 0.13         | 26.98            |
| Youfanzhuang (Changqing)      | 1.15      | 1.28         | 9.90             |
| Yuanchong (Changqing)         | 2.42      | 3.20         | 12.47            |
| Zhang-15 (Or)                 | 2.80      | 0.96         | 10.97            |
| Zhenbei (Changqing)           | 2.80      | 4.90         | 16.17            |
| Zhenjing                      | 0.14      | 0.03         | 15.45            |
| Zhihuo (Yanchang Complex)     | 1.60      | 0.41         | 15.93            |

| Total                         | 407.84    | 318.27       | 1221.57          |

From Table 1, it can be seen that when all the oil fields are used for CO2-EOR, the potential of CO2 theoretical storage in Jing'an Changqing Oilfield is the highest, and the potential of CO2 theoretical storage in Jingbian Yanchang Oilfield is the lowest. When all of them are treated as abandoned
reservoirs, the CO2 theoretical storage potential of Jiyuan Changqing Oilfield is the highest, and that of Fanjiachuan Changqing Oilfield is the lowest. The CO2 storage potential of 27 oilfields treated as abandoned reservoirs is much greater than that of CO2-eor.

![Fig. 1 Bar Chart of storage potential of 27 oil fields meeting the requirements](image)

From the ratio of CO2-EOR, CO2-depleted to oil reserves, Huachi Changqing Oilfield has a maximum ratio of 128.749, and Baibao Changqing Oilfield has a minimum ratio of 0.246, which indicates that under unit weight, Huachi Changqing Oil Field has more CO2 and Baibao Changqing oil field has less CO2, so Huachi Changqing oil field should be the first choice in this case.

When all the oil fields are treated as abandoned oil reservoirs, the maximum ratio of Huachi Changqing oil field is 325.319, and the minimum ratio of Heshui oil field is 0.479, which indicates that more CO2 is sealed in Huachi Changqing oil field per unit weight, the amount of CO2 in Heshui Oilfield is less, so Huachi Changqing Oilfield should be the first choice in this case.

In summary, if the distance between CO2 emission source and oil field is not considered, Huachi Changqing oil field should be preferred when the amount of CO2 to be sealed is not large, and Jiyuan Changqing oil field should be preferred when the amount of CO2 to be sealed is large. The ratios of CO2-EOR, CO2-depleted to oil reserves in 27 selected oilfields are shown in Table 2.
Table 2. Ratio information of CO2-EOR, CO2-depleted to oil reserves in 27 selected oilfields

| Name of field | Reserves (Mt) | CO2-EOR (Mt) | CO2-depleted (Mt) | CO2-EOR/reserves | CO2-depleted/reserves |
|---------------|---------------|---------------|-------------------|------------------|-----------------------|
| Ansai         | 18.66         | 33.45         | 42.46             | 1.792            | 2.275                 |
| Baibao        | 13.03         | 3.21          | 45.19             | 0.246            | 3.467                 |
| Dingbian      | 5.60          | 2.29          | 9.41              | 0.409            | 1.680                 |
| Fanjiachuan   | 2.19          | 1.87          | 6.70              | 0.374            | 0.599                 |
| Heshui        | 39.20         | 14.68         | 18.78             | 0.374            | 0.479                 |
| Honghe        | 22.92         | 5.74          | 13.74             | 0.250            | 0.599                 |
| Huachi        | 0.03          | 3.42          | 8.65              | 128.749          | 325.319               |
| Huangling     | 24.63         | 15.18         | 20.67             | 0.616            | 0.839                 |
| Huqing        | 31.22         | 45.49         | 51.43             | 1.457            | 1.647                 |
| Hujiashan     | 5.74          | 4.12          | 12.99             | 0.718            | 2.264                 |
| Jing'an       | 75.45         | 49.72         | 42.69             | 0.659            | 0.566                 |
| Jingbian      | 0.32          | 1.11          | 32.17             | 3.426            | 99.466                |
| Jiyuan        | 0.70          | 45.81         | 85.04             | 65.440           | 121.485               |
| Maling        | 0.75          | 8.71          | 8.09              | 11.537           | 10.717                |
| Nanliang      | 21.07         | 9.37          | 16.66             | 0.445            | 0.791                 |
| Nanniwan      | 6.33          | 2.23          | 18.50             | 0.353            | 2.923                 |
| Wangjiachuan  | 8.33          | 3.63          | 15.16             | 0.436            | 1.821                 |
| Wayaobao      | 5.60          | 2.44          | 14.32             | 0.436            | 2.557                 |
| Wuqi          | 11.48         | 7.58          | 8.86              | 0.661            | 0.772                 |
| Xifeng        | 40.51         | 22.19         | 26.71             | 0.548            | 0.659                 |
| Xin'anbian    | 5.04          | 3.43          | 27.75             | 0.681            | 5.07                  |
| Xingzichuan   | 12.18         | 1.54          | 29.27             | 0.126            | 2.403                 |
| Yanchang      | 18.82         | 7.04          | 31.33             | 0.374            | 1.664                 |
| Yongning      | 9.30          | 4.38          | 31.13             | 0.471            | 3.349                 |
| Youfangzhuang | 1.15          | 1.28          | 9.90              | 1.109            | 8.603                 |
| Yuancheng     | 2.42          | 3.20          | 12.47             | 1.322            | 5.153                 |
| Zhenbei       | 2.80          | 4.90          | 16.17             | 1.749            | 5.775                 |

5 Conclusion

This paper analyzes the potential of CO2 storage in the Ordos Basin and selects 60 oil fields in the Ordos Basin for the theoretical capacity analysis of CO2 geological storage. The evaluation results show that when it is assumed that all 60 oil fields in the Ordos Basin are used for CO2 -EOR, the CO2 storage potential is about 318.27Mt, and when all oil fields are treated as waste reservoirs, the CO2 storage potential is about 1221.57Mt, and the storage potential is huge. There are 27 oilfields with CO2-EOR reservoir storage capacity ≥1 Mt CO2, which meets the requirements.

The evaluation results in this article provide a basis for companies to further carry out the site selection and safety evaluation of CCS projects. However, because there is no unified method for calculating CO2 storage at home and abroad, the results of different calculation methods are different. Therefore, on the basis of establishing the calculation method of CO2 storage in reservoirs, the evaluation of the potential of CO2 storage in reservoirs is evaluated. Further research is needed.

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