Iraqi National Journal of Earth Science
www.earth.mosuljournals.com

Evaluation of Geometric Deformation Due to CO_2 Injection in Selected Reservoirs in Iraq

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Article information

Received: 17- Oct -2023

Revised: 09- Nov -2023

Accepted: 19- Nov -2023

Available online: 01- Jul- 2024

Keywords:
Deformation
Tensile
Porosity
Permeability
Carbon Dioxide

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ABSTRACT

In the last decade, the repercussions of global warming in Iraq have become more severe. Scientists recommended storing carbon dioxide as it is the most greenhouse gas resulting from fossil fuel burning. As a result of the repercussions of injection operations, problems emerged related to the failure of the reservoir's seal. This study creates a model and applies a simulation of the process of injecting carbon dioxide gas into the reservoir for a specific period. The computer modeling Software (CMG) is applied to study the distortions occurring as a result of increasing hydrostatic pressure of the pore fluids on the seal. The study results reveal that the secondary porosity is due to the fracture of the rock structure after two years of the CO_2 injection process at a rate of 200 thousand cubic meters per day into the selected reservoir. The Barton Bandel model is used to diagnose permeability variation, as it is proven that the geometric deformation in the rock structure of the seal is proportional to the permeability resulting from the failure of the seal.

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تقييم التشوه الهندسي للخزان النفطي الناجم عن حقن غاز ثاني اوكسيد الكربون في تكاوين مختاره في العراق

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معلومات الارشفة

تاريخ الاستلام: 17- اكتوبر -2023

تاريخ المراجعة: 09- نوفمبر -2023

تاريخ القبـول: 19- نوفمبر -2023

تاريخ النشر الالكتروني: 01- يوليو -2024

الكلمات المفتاحية:

التشوه الهندسي

فشل الشد

المساميه

النفاذيه

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الملخص

اصبحت تداعيات ظاهرة الاحتباس الحراري في العراق اكثر تطرفا في الاونة الاخيرة. اقترح العلماء تخزين ثاني اوكسيد الكربون في الارض باعتباره اكثر الغازات المسببه للاحتباس الحراري والناتجة عن حرق الوقود الاحفوري. نتيجة لتداعيات عمليات الحقن، سُجلت مشاكل تتعلق بفشل ختم الخزان. قامت الدراسة بتصميم نموذج ثنائي الابعاد وتطبيق محاكاة لعملية حقن غاز ثاني اوكسيد الكربون في مكمن يقع في نهر عمر لمدة محددة (10 سنوات). استخدمت النمذجة الحاسوبية (CMG) لدراسة التشوهات الناجمة عن زياده الضغط المسامي نتيجة حقن غاز ثاني اوكسيد الكربون. اثبتت الدراسة بان هنالك تولداً للمسامية الثانويه كدالة للتشوهات الهندسية بعد سنتين ونصف من بداية الحقن الذي بلغ 200 الف متر مكعب يوميا. استخدم موديل بارتون لتشخيص تغير النفاذية في الختم وباعتباره دليلاً على التشوهات الهندسية في صخور الختم بالتحديد، بالاضافة الى ايضاح العلاقة الطردية مع تداعيات فشل الختم.

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Introduction

Studying the deformation occurring in oil reservoirs is one of the priorities that has received a great attention recently, especially after the worsening problem of global warming (Alshammari et al., 2022; Al-Sudani, 2019; Masson-Delmotte, 2022; Lowe, 2009; Yang, 2015; Li, 2022; Salimzadeh, 2018). Reservoir pressure influences the oil production period. One of the oldest techniques to increase the pressure was injecting water to maintain the reservoir pressure. This technique is called enhance oil recovery. At the beginning of the stages of enhancing oil production due to reservoir pressure as a result of the depletion of oil reserves, initial recommendations were stated the necessity of increasing the reservoir pressure by injecting quantities of water to compensate the deficiency within the reservoir and to manage the production of hydrocarbons in what is known as enhanced oil recovery (EOR) (Kokal and Al-Kaabi, 2010). In later stages, this process revealed new problems related to increasing the production of water ratio with hydrocarbons (Alagorni et al., 2015). Scientists have proposed injecting carbon dioxide gas due to the advantages of low gas viscosity and high gas density, especially the supercritical phase, and what is known as a secondary enhancement of hydrocarbon production or second recovery (Dezfuli et al., 2020). The study mentions to selected formation that has a good availability of data. The most common pretended formations required data like Yammama, Nahar Umar, Umm-radhuma, and Al-Rus formations. All these formations show a similar structural geology since they come from the same basin. However, the Nahar -Umar Formation provides more data of porosity and permeability; consequently, it represents in this study as an example and to summarize the results as well.

Study Area

The study area is located in the Nasiriyah City (Fig. 1, map of Iraq). Nahar Umar Formation is one of the important oil fields in the south of Iraq, Saudi Arabia, Qatar, and Kuwait (Al-Khafaji, 2015; Buday, 1980; Steinke, 1956). The geological time refers to the end of the Jurassic and early Cretaceous as a part of the tectonic activities of the Arabian plate. The Arabian plate force created an isolated rift basin of carbonate sediments that spread between the Algaraf-basin in Iraq, the Reyad basin in the Saudi Arabia, to the southeast of the Arabian plate (Sharland, 2001).

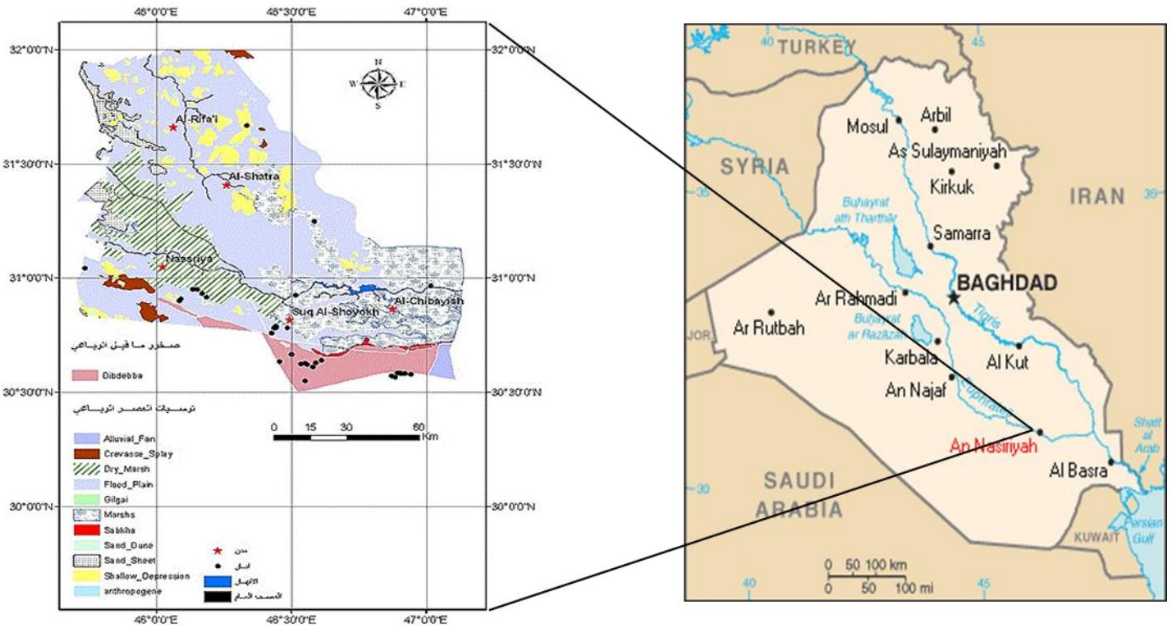

Fig. 1. The location of the study area.

Types of porosity

Porosity can be classified into two types: primary porosity, which is formed during the depositional processes of rocks, and secondary porosity is the porosity that follows the process of rock deformation, which forms by chemical, biological, and mechanical deformation (Al-Sudani, 2019; Shanmugam, 1985; Giles, 1990). Therefore, the effect resulting from the injection of fluids into the formation may cause a structural deformation that is reflected in the change of secondary porosity and permeability (Alshammari, 2019; Mohammed, 2018; Rutqvist, 2010).

Preliminary Data and Motivation

Some of the results mentioned in Previous studies (Al-Sudani, 2019; Al-Khafaji, 2015; Al-Sudani, 2019; Buday, 1980; covered many preliminary data for Nahar Umar Formation including values of rock properties, geometric characteristics, porosity, permeability, compression coefficient, Poison’s ratio, and Young's modulus (Table 1). However, no simulation studies exploit this information to guide future risks associated with global warming and improving the production of hydrocarbons, suggesting that both require this type of research since the preliminary information is sufficiently available in Nahar Umar Formation more than Yammama Formation. This study is conducted as a model that can be used in similar oil formations, taking into account the possibility of developing it in the long term.

Table 1. the coordinates of the Nasiriya Well -1 and rock properties.

Well Name	X	Y	Thickness	Porosity	Permeability
NS-1	596.655	3465.833	117	200	131

Methodology

This study can be summarized through the following basic attempts based on the available data from borehole examination and laboratory tests then applying the advanced simulation software to present the results virtually and reflecting the injection deformation at the end according to following steps:

1-Collecting data about rock and engineering information referred to previous studies.

2- Designing a simulation model using the computer modeling Software package.

3- Implementing the scenario of injecting carbon dioxide gas in the short term into one of the proposed wells that penetrate an oil reservoir in Nahar Umar Formation.

4- Interpreting the simulation results to explain the repercussions of carbon dioxide injection and its distorting effect on the structure of the cover above the oil tank.

Modeling

A two-dimensional model is designed to represent the penetration of the Nasiriyah Well NS-1 (Table 2) into Nahar Umar reservoir. Based on the standard values of both, the geometric and lithology properties available from previous studies (Al-Sudani, 2019; Alshammari et al., 2022). The study proposed creating two systems of seals to simulate the shale layers above the reservoir. The rocks above the seal place cumulative stress on the seal system according to the density and liquid content of the overburdened rocks (Fig. 2).

Table 2. Geomechanics parameters modified from CMG lab work 2023

Material Name	Density Gm/cm^3	Young's Modulus GPa	Poisson's Ratio %	Unconfined Compressibility Strength MPa
Sandstone	2.0-2.65	0.1-0.30	0-0.45	1-250
Clay	1.9-2.1	0.06-0.15	0.2-0.5	
Shale	2.3-2.8	0.4-70	0.0-0.3	2-250
High Porosity Chalk	1.4-1.7	0.5-5	0.05-0.35	4.0-15.0

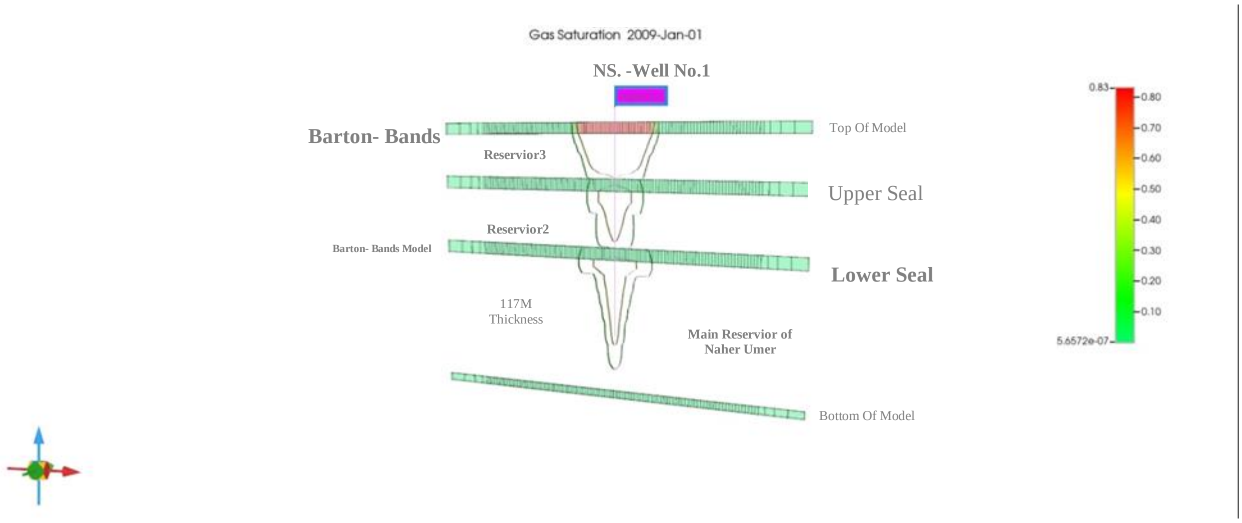

Fig. 2. The structure of the two-dimension mode showing the seal system and the expected migration of the CO_2 plume within the simulation time.

Results and Discussion

Modeling ten years of a supercritical carbon dioxide injection in the Nasiriyah well number NS-1, which is located in Nahar Umar Formation considers that CO_2 injection rate 400,000 cubic meters per day with a maintenance pressure 51710 KPa. The injection rate covered the first half of the simulation time (first five years) only, while the second half of the simulation time detected the fate of CO_2 plume migration and the repercussion of seal deformation. The simulation shows an interesting result.

Both the reservoir and the seal respond against carbon dioxide injection. However, the research focuses on the importance of the deformations occurring in the seal as a factor leading to the failure of the underground storage system at all. During the injection period (the first five years), the hydrostatic pore pressure (HPP) started to increase from the initial condition value of 51710 KPa in year 2010 to reach the critical point after 31 months (Fig. 3). The effective normal stress (ENS) is the weight of the overburdened rock above the seal at a 3400-meter depth, above the seal's system force downward against the (HPP) (Fig. 4). A critical point an equilibrium status occurs between the (HPP and ENS) in august year 2022. Then a tensile failure occurs due to fracturing the seal when the pore pressure exceeds the effective normal stress (Fig. 4).

On the other hand, the deformation on the seal system is reflected by creating a secondary porosity called fracture porosity started change from the original value 20% to reach 25% at the end of simulation period in year 2010 (Fig. 5). Implications of geometric deformation of rocks did not stop at this point, the simulation show that permeability value has been changed from the initial condition value 5 mD to the new value 235 mD (Figs. 6,7). These values allow the CO_2 plume to migrate through the seal system to the upper part of the simulation model which considered the atmosphere.

The Barton band model examined the distribution of the permeability variation due to the geometric deformation of the seal system failure. As a result of permeability variation in the seal, the BBM shows a clear response exactly in the fracture of the seal where CO_2 plumes are forward up to the overburdened rock due to the Buoyancy property of differential densities (Fig. 2).

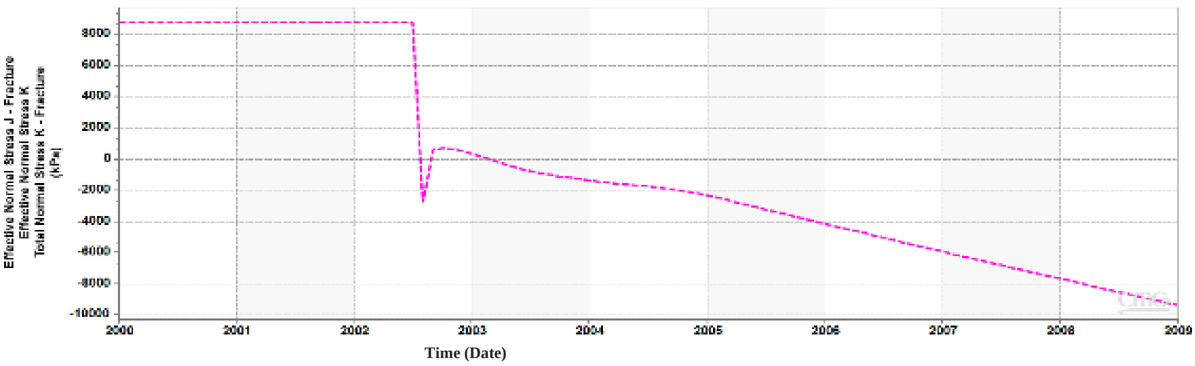

Fig. 3. Showing the relation between the time and the effective normal stress for the period 10 years a rapped drop occurs after 31 months of simulation starting point the CO_2 plume penetrating the fractured seal.

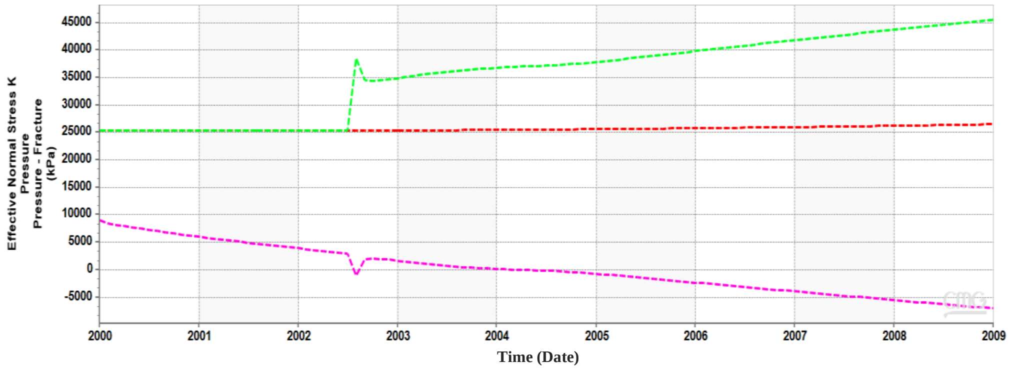

Fig .4. The relation between the ENS, pressure, and fracture pressure showing increasing reservoir pressure against constant fracture pressure at the seal. When the ENS becomes less than the pore pressure, the rapture occurs at the 18 th month of starting simulation period.

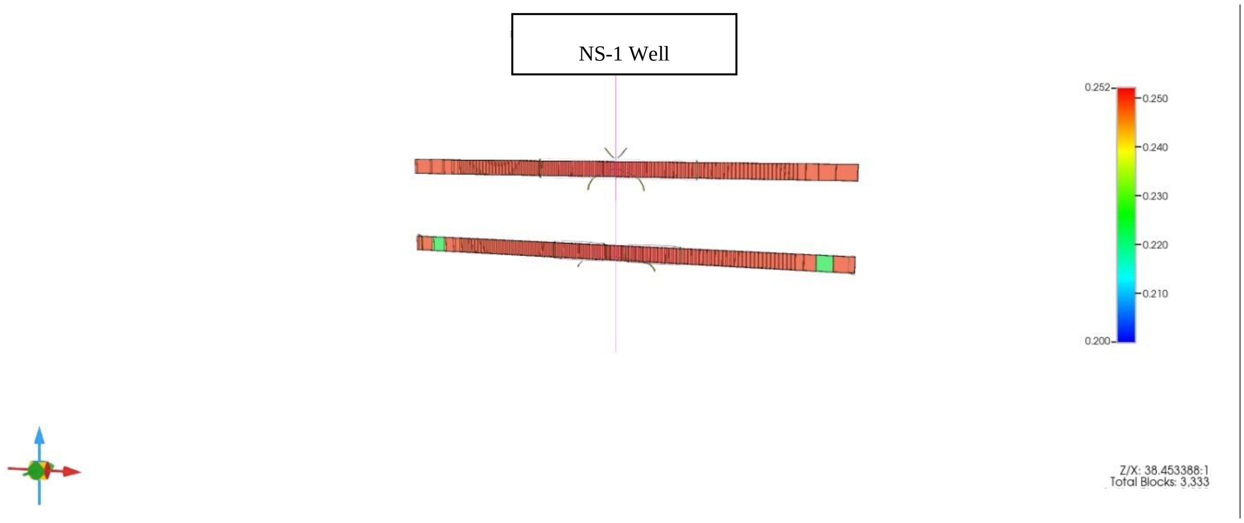

Fig. 5. Showing the progress of porosity variation during ten years of the injection period. The figure shows increasing the porosity value at the fractured area to 0.25.

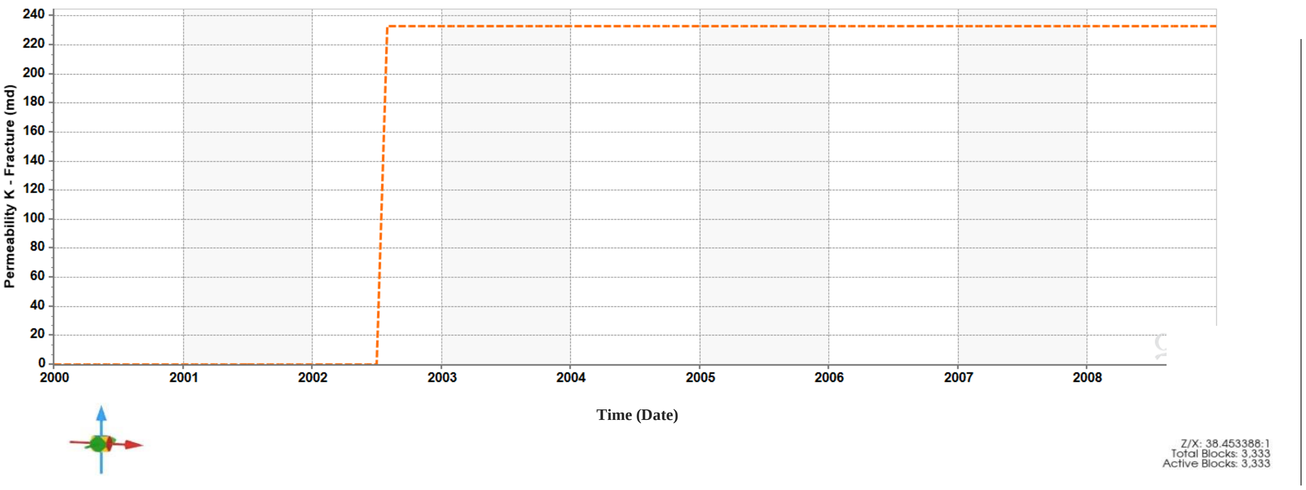

Fig. 6. The permeability value of the seal jumped from the minimum value to 240 mD after the fracture

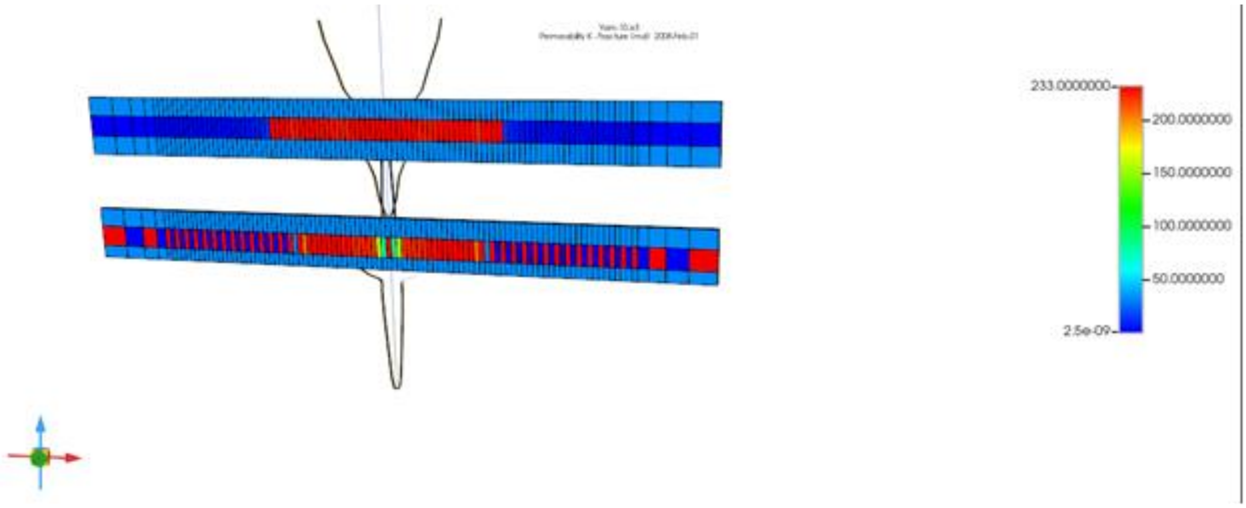

Fig. 7. Showing the seal system. The red color indicates the permeability at the fracture part of both seals proportional with the fractured parts under the injection area.

Conclusion

In summary, after 31 months of the super-critical CO_2 injection. The lower seal has been affected by fracturing caused by increasing the pore pressure and decreasing the ENS. The CO_2 penetrates the second reservoir to reach the upper seal and repeating the same scenario rapidly. The repercussion of this fracturing is the deformation in the seal presented as creating new values of permeability and porosity. The numerical calculation shows that the CO_2 plume varies from the supercritical phase to the gas, dissolved, aqueous phases according to the lithological, structural, and initial conditions of Nahar Umar Formation (fig. 9; Table 3). This study considers a pilot project and can be developed for a similar reservoir especially in Iraq, since the global worming phenomena have shown an interesting effect in the last years.

Table 3. Showing the fate of injected carbon dioxide for ten years of simulation.

CO_2 Storage Amounts in Reservoir -----	Moles	kg
Gaseous Phase	= 0.00000E+00	0.00000E+00
Liquid Phase	= 0.00000E+00	0.00000E+00
Supercritical Phase	= 4.64657E+10	2.04495E+09
Trapped Sg < Sgc / Hysteresis	= 6.94253E+09	3.05541E+08
Dissolved in Water	= 9.40129E+09	4.13751E+08

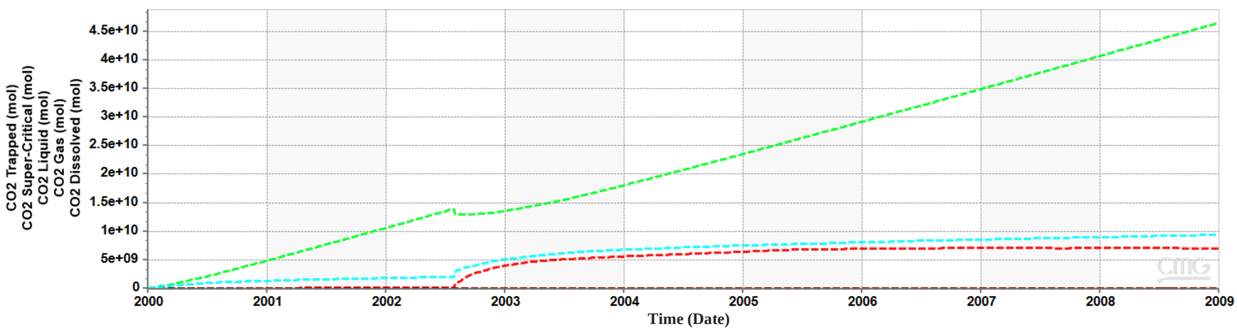

Fig. 9. Showing the fate of CO_2 within the 10 years simulation period. The first five years represents the injection period, while the second five years show the remind of the CO_2 migration through the seal system. CO_2 varies from the super critical phase to trapped, gaseous, liquid, and dissolved phase depending on the reservoir structure properties.

Acknowledgment

I would like to thank the Computer Modeling Group Limited for their support and for granting the CMG software to the University of Mosul under License Number U-3741 in 2023.

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Appendix

$$\sigma'_m = \frac{1}{3}\sigma'_{ii} = \frac{1}{3}(\sigma'_{11} + +\sigma'_{22} + \sigma'_{33})$$

σ'_1 : Maximum principle effective stress
σ'_3 : Minimum principle effective stress

p : Pressure

T : Temperature

V_b : Current bulk volume

V_p : Current pore volume

α : Biot's number

β : Volumetric thermal expansion coefficient of pore volume

σ_m : Mean total stress

$$\varphi^*_{n+1} = \varphi^*_n + c_n^{\,0}(p_{n+1} - p_n) + c_n^{\,1}(T_{n+1} - T_n)$$

Where,

$$c_n^{\,0} = (c_0 + c_2 a_1)_n$$

$$c_n^{\,1} = (c_1 + c_2 a_2)_n$$

$$a_1 = \Gamma\left\{\frac{2}{9}\frac{E}{(1-\nu)}(c_b - c_r)\right\}$$

$$a_2 = \Gamma\left\{\frac{2}{9}\frac{E}{(1-\nu)}\beta\right\}$$

E:	Young's modulus
c_b:	Bulk compressibility
c_r:	Solid rock compressibility
v:	Poisson's ratio
Γ:	Boundary constrained factor
n:	Time level n
n+1:	Time level n+1

These coefficients are calculated in the geomech module.

$$\frac{k}{k_0} = \exp(C_{n1}\varepsilon_V)$$

Where,

K_0 : Initial permeability

C_{n1} : Parameter for each rock type

ε_V : Volumetric strain