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Investigation of the effect of the Reservoir Rock Compressibility on Oil Recovery Factor during Gas Injection

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Keywords:
Reservoir Rock Compressibility
Reservoir Simulation
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ABSTRACT

A type of EOR, secondary production includes water flooding and gas injection. Normally, gas is injected into the gas cap and water is injected into the production zone to sweep oil from the reservoir. A pressure-maintenance program can begin during the primary recovery stage, but it is a form of enhanced recovery. The main purpose of this report is to investigate the effect of the reservoir rock compressibility on oil recovery factor during gas injection. The problem statement of this study is firstly, as the reservoir oil and gas production under primary conditions, causes the reservoir pressure to decline. Secondly, A gas injection is required to re-energize or "re-pressurize" the reservoir. The main objective of this project is to investigate the effect of the reservoir fluid densities on oil recovery factor during gas injection. By using ECLIPES Software, we model the data and find out the best prediction of gas injection that is suitable for the available field data. It is proven that the optimum oil production is by injection a high amount of injection rate. The highest increase in percentage of the total gas production is when an injection of 54 MMSCF is 0.58 %. The higher the compressibility value of the rock, will give the higher the rate of oil and gas production. The relationship between oil rate, gas rate, pressure, and oil recovery factor are directing the compressibility of rocks is a direct relationship.

دراسة تأثير انضغاطية الصخور المكمنية على عامل استخلاص الزيت أثناء حقن الغاز

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الملخص

نوع من أنواع الاستخلاص المعزز للنفط (EOR)، يتضمن الإنتاج الثانوي بغمر المياه وحقن الغاز. عادة، يتم حقن الغاز في غطاء الغاز ويتم حقن الماء في منطقة الإنتاج لإزاحة النفط من الخزان. يمكن أن يبدأ برنامج صيانة الضغط أثناء مرحلة الاسترداد الأولية، ولكنه شكل أو استرداد محسّن. الغرض الرئيسي من هده الورقة هو التحقيق في تأثير انضغاطية صخر المكمن على عامل استخلاص الزيت أثناء حقن الغاز. تتضمن مشكلة هذه الدراسة فى أولاً، حيث ينتج المكمن النفط والغاز في ظل الظروف الأولية، مما يقلل من ضغط المكمن. ثانيًا، يلزم حقن الغاز لإعادة تنشيط الخزان أو "الضغط عليه". الهدف الرئيسي من هذا المشروع هو دراسة تأثير كثافة سائل المكمن على معامل استخلاص النفط أثناء حقن الغاز. باستخدام برنامج ECLIPES، نقوم بنمذجة البيانات ومعرفة أفضل تنبؤ لحقن الغاز المناسب للبيانات والمجالات المتاحة. ثبت أن الإنتاج الأمثل للزيت يتم عن طريق الحقن بكمية عالية من معدل الحقن. أعلى زيادة في النسبة المئوية لإجمالي إنتاج الغاز هي عندما حقنة 54 مليون قدم مكعب هي 0.58٪. كلما زادت قيمة انضغاط الصخور، كلما ارتفع معدل إنتاج النفط والغاز. العلاقة بين معدل النفط ومعدل الغاز والضغط وعامل استخراج النفط التي توجه انضغاط الصخور هي علاقة مباشرة.

الكلمات المفتاحية:
انضغاط صخور الخزان
محاكاة الخزان استخراج النفط
حقن الغاز
معامل الاسترداد النفطي.

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Introduction

The downward displacement of oil by gas injection in a reservoir result in very high oil recovery efficiencies [1]. The success of this technique stems from the continuity of the oil phase provided by the bulk films of oil in all pore space invaded by the gas under conditions of positive oil spreading coefficients and the gravity stabilized oil bank moving toward the production well. Gas injection is a common EOR method for increasing oil recovery factor. It is an economical method, especially in cases where the injection gas for such gas injection project is easily available [2]. Gas injection has become one of the most investigated methods for enhanced oil recovery in unconventional reservoirs. [3]. In the common methods of water and gas injection, high and unsuitable mobility ratio within the injected fluid and the oil in the reservoir leads to viscose fingering and reduction of sweep efficiency [4]. Pressure maintenance by gas injection in gas cap is one of the well-established methods for improving the ultimate recovery [5]. Hydrocarbon gas injection is one of the major EOR methods. Hydrocarbon gas has some similar properties with the oil in reservoir, which has no damage to the formation [6]. Normally, gas is injected into the gas cap and water is injected into the production zone to sweep oil from the reservoir as shown in the figure 1. A pressure-maintenance program can begin during the primary recovery stage, but it is a form or enhanced recovery.

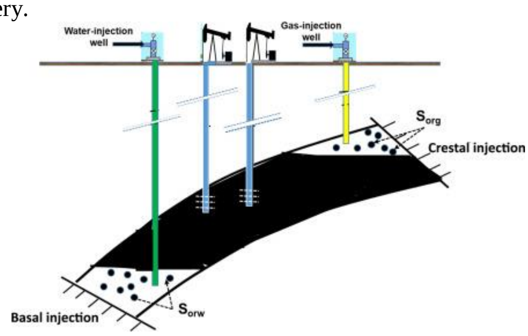

Fig. 1: Gas Injection & Water Injection

Research Objectives: The objective of this study is:

1. The main objective of this project is to investigating the effect of the reservoir rock compressibility on oil recovery factor during gas injection.
2. By using ECLIPES Software program, we model the data and find out the best prediction of gas injection that is suitable for the available data and field.

Research Problem Statement: The problem statement of this study is:

1. As the reservoir produces oil and gas under primary conditions, which lowers the pressure of the reservoir.
2. A gas injection is required to reenergize or "pressure up" the reservoir.

Eclipse Software: It has been recognized that an efficient way of understanding and possibly resolving these problems arise on this study is by using a reservoir simulation which is ECLIPSE. Reservoir simulation is a combination of physics, mathematics, reservoir engineering and computer programming. It is to develop a tool to predict reservoir performance under various operating conditions.

RESERVOIR PROPERTIES:

Relative Permeability: Figure 2 and 3 show data obtained from a laboratory test conducted on a reservoir core saturated with crude oil and initial connate water. The crude is displaced from the core by immiscible gas and water. In reservoir simulation using a black oil simulator, the laboratory-generated relative permeability must be adjusted to account for the interaction and mixing that are taking place between the injected gas and oil.

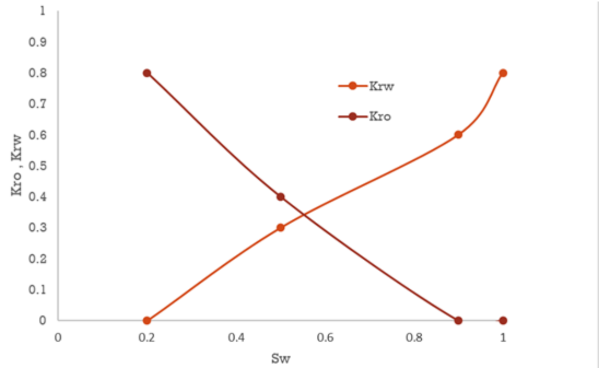

Fig. 2: Water/Oil Saturation Functions

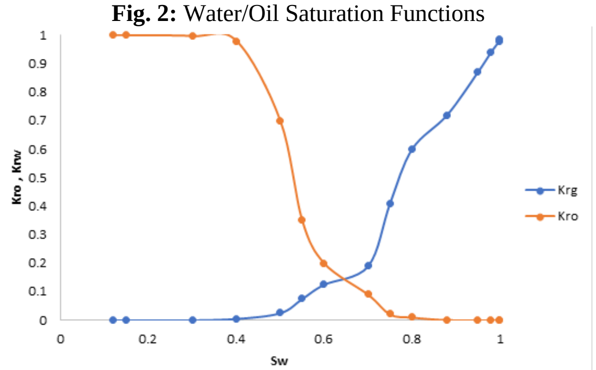

Fig. 3: Gas/Oil Saturation Functions

Initial Reservoir Properties: Next table shows that the reference depth of the well is 3280, and through it the pressure and temperature of the well are measured. The contact of water with oil 3937, and it is defined as the highest depth in the reservoir and the depth of the oil. The contact of water with oil 3937, and it is defined as the highest depth in the reservoir and the depth of the oil. Gas in oil 3280, and it is defined as the minimum level in the tank, its contact and depth. The initial tank temperature is 70 degrees.

Table 1:Initial Reservoir Properties

Datum Depth	3280	ft
Pressure at Datum Depth	3000	psi
WOC Depth	3937	ft
GOC Depth	3280	ft
Initial Reservoir Temperature	70	C

Reservoir Fluid Properties: It is plays a key role in the design and optimization of injection and production strategies and surface facilities for efficient reservoir management as shown in the Table 2.

Table 2: Reservoir Fluid Properties

Oil Density	50.805	Ib/ft3
Water Density	62.808	Ib/ft3
Gas Density	0.055439	Ib/ft3

Reservoir Rock Properties: The reservoir rock contains pores and throats, creating flow path and an accumulating system for hydrocarbon and also consist of a sealing mechanism for prohibiting hydrocarbon penetration to surface layers. Table 3 shows the reservoir properties of this reservoir.

Table 3: Reservoir Rock Properties

X permeability	100 md
Y permeability	100 md
Z permeability	10 md
Porosity	0.2
Rock Properties	3.65E-06

Field Wells: Table 4 shows the number of wells that have been drilled, which were seven production wells and three gas injection wells. The first well was drilled in 2022 and the last well was drilled in 2024. In August 2024, gas injections began.

Table 4: Field Wells

Production Well Name	Start Production Date
P101	01-Nov-22
P102	01-Mar-23
P103	01-May-23
P104	01-Aug-23
P105	01-Nov-23
P106	01-Feb-24
P107	01-May-24
Injection Well Name	**Start Injection Date**
I108	01-Aug-24
I109	01-Nov-24
I110	01-Feb-25

RESERVOIR MODEL:

Well Location Model: Figure 4 shows the distribution of the locations of the injection wells and the production wells.

Initial Gas Saturation Map: Figure 5 shows the percentage of gas saturation from the lowest value to the highest value in the first layer. Where the least saturation was 12% and the most saturation was 63%, which indicates the percentage of gas saturation before production.

Initial Oil Saturation Map: Figure 6 shows the percentage of oil saturation from the lowest value to the highest value. Where the least saturation was 24% and the most saturation was 76%, and this explains the percentage of oil saturation before production in the first layer.

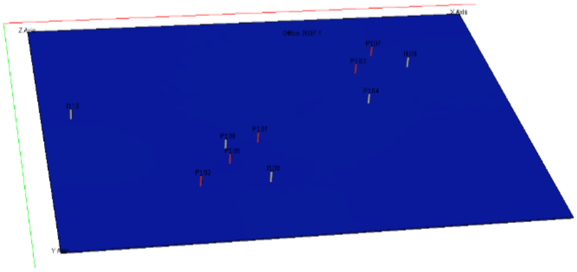

Fig. 4: Well Location Model

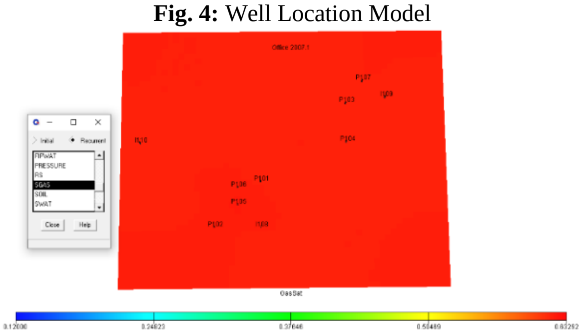

Fig. 5: Initial Gas Saturation Map

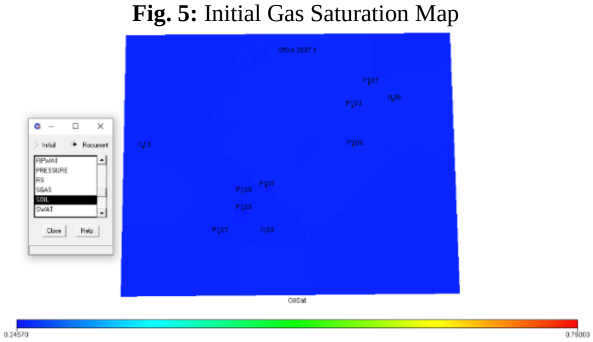

Fig. 6: Initial Oil Saturation Map

Initial Water Saturation Map: Figure 7 shows the percentage of water saturation from the lowest value to the highest value. It also shows the percentage of water saturation before production in the first layer, which is 12%, because the percentage of water is low, because there is no mechanism for pushing water.

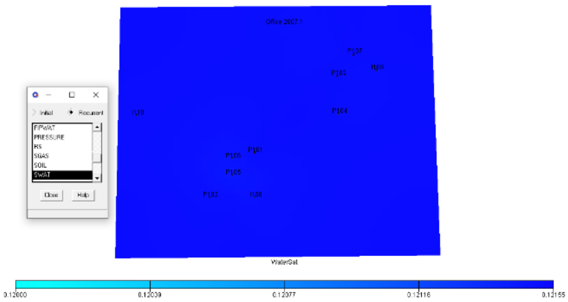

Fig. 7: Initial Water Saturation Map

PRIMARY RECOVERY:

Table 5 shows the start date of production for seven wells, the beginning of production from 1-11-2022 to 1-5-2024, and the end of production for seven wells on 11-12-2060.

Table 5: Base Case at Primary Recovery

Start Production Date	Production Well Name	Status	End Date
01-Nov-22	P101	Open	11-Dec-60
01-Mar-23	P102	Open	11-Dec-60
01-May-23	P103	Open	11-Dec-60
01-Aug-23	P104	Open	11-Dec-60
01-Nov-23	P105	Open	11-Dec-60
01-Feb-24	P106	Open	11-Dec-60
01-May-24	P107	Open	11-Dec-60

Field Oil and Gas Production Rate at Primary Recovery: Figure 8 shows the amount of oil produced from 2022 to 2060 through several wells. The figure shows that the x-axis represents the time from 1-11-2022 to 11-12-2060, and the y-axis represents the amount of oil production per day for seven wells. We notice from this figure that the amount of increased production decreases after a period of time. Also, Figure 8 shows the amount of gas production in the reservoir in X axis that represents the time from 1-1-2022 to 1-1-2060, and the y-axis represents the amount of gas production in the field that is 62000 MSCF\DAY.

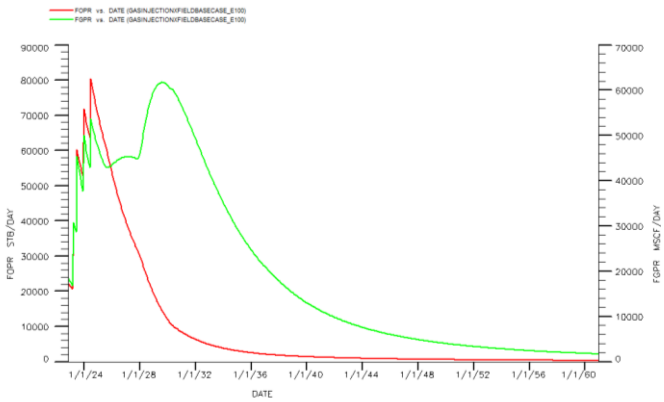

Fig. 8: Field Oil Production and Field Gas Production Rates Vs. Time at Primary Recovery

Field Oil Recovery Factor, Water Cut, and Pressure Vs Time at Primary Recovery: Figure 9, x axis represents time and the y axis represents the amount of original oil production, which is 50%. This figure shows the pressure in the reservoir decreases with the passage of time, and then gas is injected until the pressure increases. Also, Figure 9 shows that in the x axis it represents the time from 1-11-2022 to 11-12-2060 and in the y axis it represents the pressure at the beginning of production 3000 and after a period of time has there been a decrease in pressure. Also, Figure 9 shows the percentage of water in the field. The x axis represents the time from 1-11-2022 to 1-1-2060, and the y axis shows the amount of water production in the field. Through the figure, the water production rate is 20%.

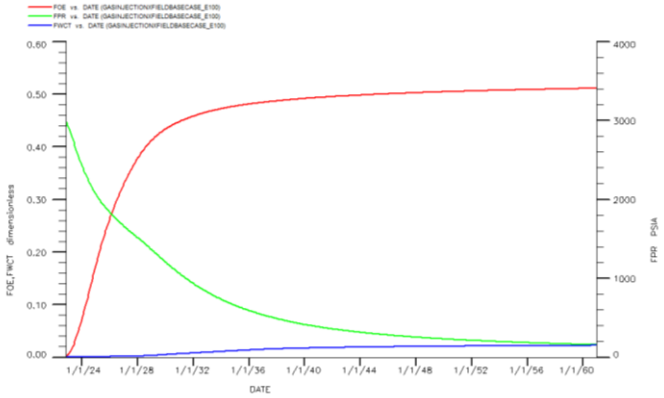

Fig. 9: Field Oil Recovery Factor, Water Cut, and Pressure Vs Time at Primary Recovery

SECONDARY RECOVERY:

Gas Injection: Table 6 shows the amount of gas injection in the field, where then choose 12 cases to find out the best gas injection rate, case #1, then inject 1500000 SCF/DAY, in case #12, then inject 18,000,000 SCF/DAY for each injection well. Through these tests, the best gas injection rate is known. into the injection wells

Table 6: Gas Injection Rates

NO	Well SCF-DAY	Total SCF-DAY
Case#1	1500000	4500000
Case#2	3000000	9000000
Case#3	4500000	13500000
Case#4	6000000	18000000
Case#5	7500000	22500000
Case#6	9000000	27000000
Case#7	10500000	31500000
Case#8	12000000	36000000
Case#9	13500000	40500000
Case#10	15000000	45000000
Case#11	16500000	49500000
Case#12	18000000	54000000

Field Oil Production Rate at Gas Injection: This figure shows the amount of oil production increase when gas is injected, where the axis represents the time from 1-11-2022 to 1-1-2060, and the y-axis represents the amount of oil production when gas is injected.

Field Oil Recovery Factor at Gas Injection: This figure shows the total oil production from the reservoir when the gas is injected, in the x axis representing the time from 1-11-2022 to 1-1-2060.

Field Pressure Factor at Gas Injection: This figure shows the pressure in the reservoir and its impact on gas injection .Through this figure, we notice when the amount of gas injection increases, the pressure increases gradually, the x-axis represents the time from 1-11-2022 to 1-1-2060, and the y-axis represents the pressure in the field.

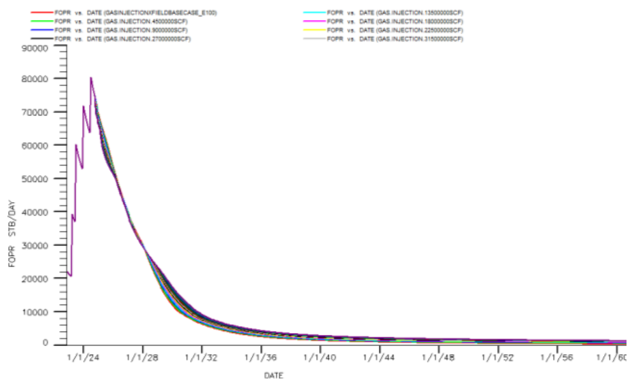

Fig. 10: Field Oil Production Rate Vs. Time at Gas Injection

Field Water Cut at Primary Recovery Gas Injection: This figure determines the amount of water produced. The more the amount of gas injection increases, the amount of water decreases. The x axis represents the groups from 1-11-2022 to 1-1-2060.

Field Gas Production Rate at Gas Injection: This figure shows the amount of gas production in the field in relation to time, as the amount of gas production increases from the year 2024 to the year 2060.

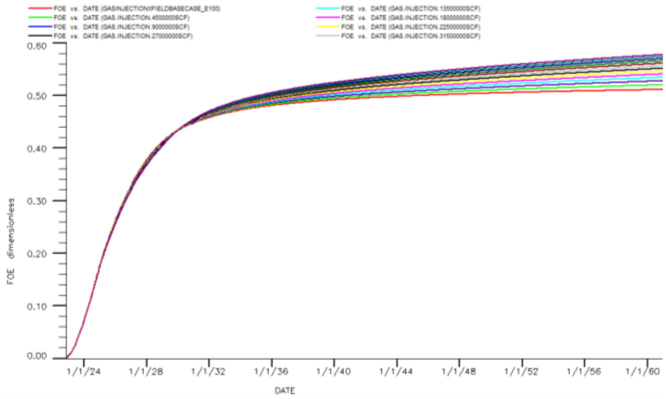

Fig. 11: Field Oil Recovery Factor Vs. Time at Gas Injection

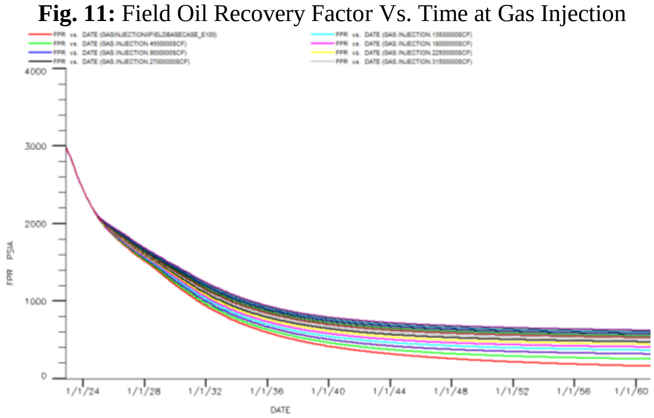

Fig. 12: Field Pressure Vs. Time at Gas Injection

Oil Saturation at Gas Injection: This figure shows the percentage of oil saturation when injecting gas. From this figure, we notice a saturation rate from 0% to 76%, and the saturation percentage decreases when producing oil.

Gas Saturation at Gas Injection: This figure shows the percentage of gas saturation when injecting gas, and the percentage of saturation from 12% to 97%, and the percentage of gas saturation increases when injecting gas.

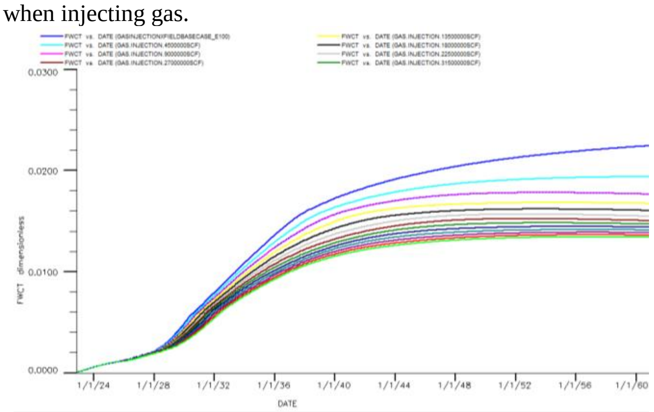

Fig. 13: Field Water Cut Vs Time at Gas Injection

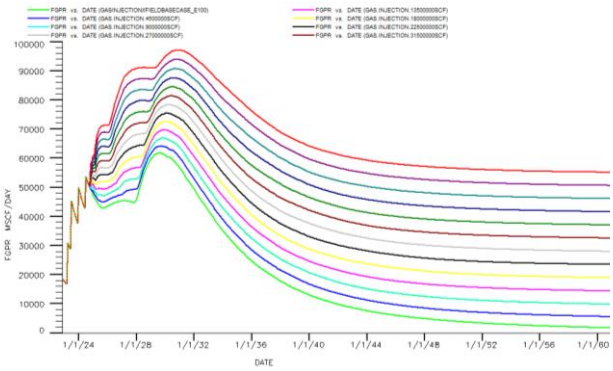

Fig. 14: Field Gas Production Rate Vs. Time at Gas Injection

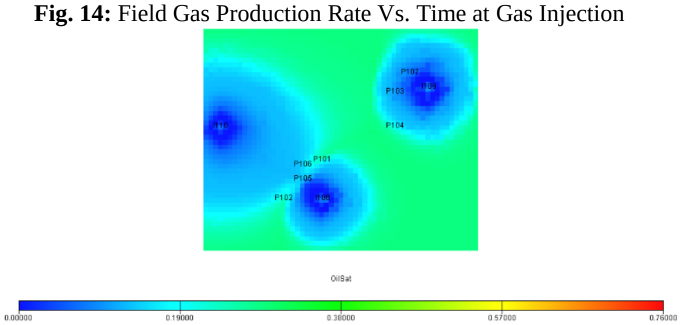

Fig. 15: Oil Saturation Mao at 2070 at Gas Injection

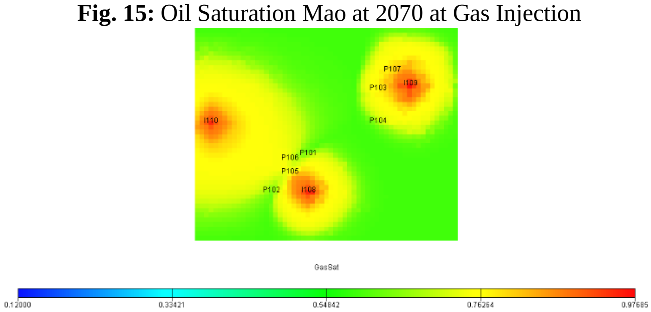

Fig. 16: Oil Saturation Mao at 2070 at Gas Injection

Water Saturation at Gas Injection: This figure shows the percentage of water saturation when injecting gas and from 12% to 12%, we notice from this figure that the water saturation does not increase due to the gas injection.

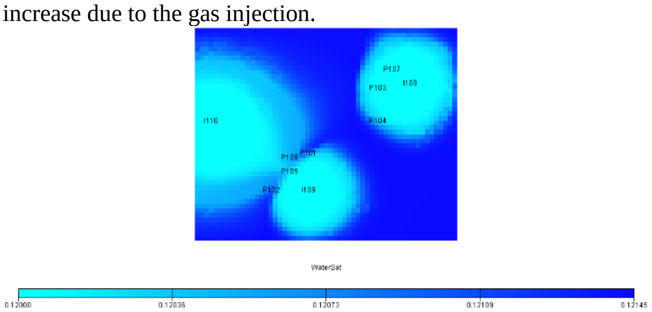

Fig. 17: Oil Saturation Mao at 2070 at Gas Injection

ROCK COMPRESSIBILITY RESULTS:

Field Oil Production Rate at different Rock Compressibility: Figure 18 shows the rate of oil production when rocks are compressed in four different solutions. The x-axis represents the time from 1-11-2022 to 1-12-2060. The Y axis represents the rate of oil production under the compressibility effect of rocks. The red color represents the first case (3 * 10 ^-6), indicating that the lowest value of compressibility of rocks. The green color represents the fourth case (6*10^-6), the highest value of compressibility of rocks as shown in the table 7. The lower the compressibility value of the rock, the lower the value of the oil production rate. The higher the compressibility value of the rock, the higher the rate of oil production.

Table 7 :Rock Compressibility

Cases	Case#1	Case#2	Case#3	Case#4
Rock Compressibility	0.000003	0.000004	0.000005	0.000006

Field Gas Production Rate at different Rock Compressibility: Figure 19 shows the rate of gas production when rocks are compressed in four different solutions. The x-axis represents the time from 1-11-2022 to 1-12-2060. The y axis represents the rate of gas production under the compressibility effect of rocks. The green color represents the first case (3 * 10 ^-6), indicating that the lowest value of compressibility of rocks. The violet color represents the fourth state (6*10^-6), the highest value of compressibility of rocks. The lower the compressibility value of rocks, the lower the rate of gas production. As the compressibility value of the rock increases, the rate of gas production increases.

Field Oil Recovery Factor at different Rock Compressibility: Figure 20 shows the oil recovery factor when the rock is compressed in four different solutions. The x-axis represents the time from 1-11-2022 to 1-12-2060. The Y axis represents the oil recovery factor under the compressibility effect of rocks. The red color represents the first case (3 * 10 ^-6), indicating that the lowest value of compressibility of rocks. The green color represents the fourth case (6*10^-6), the highest value of compressibility of rocks. The lower the compressibility value of the rock, the lower the value of the oil recovery factor. As the compressibility value of the rock increases, the oil recovery factor increases.

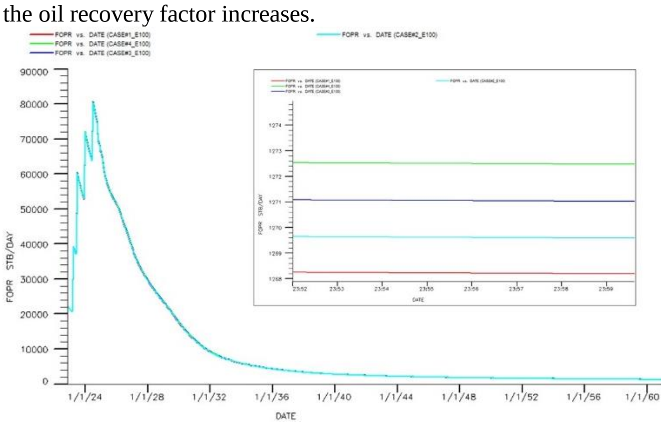

Fig. 18: Field Oil Production Rate at different Rock Compressibility

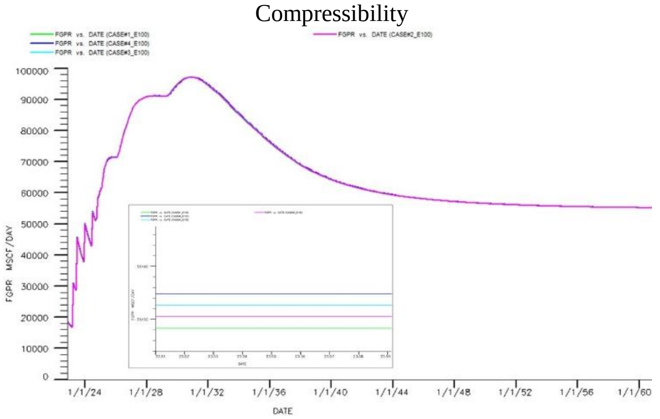

Fig. 19: Field Gas Production Rate at different Rock Compressibility

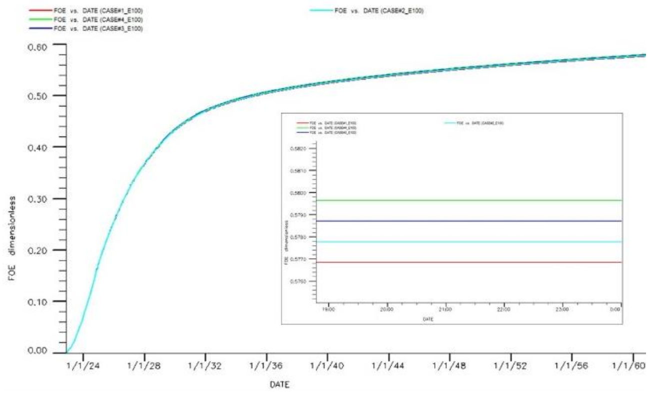

Fig. 20: Field Oil Recovery Factor at different Rock Compressibility

Field Pressure at different Rock Compressibility: Figure 21 shows the field pressure when rocks are compressed in four different solutions. The x-axis represents the time from 1-11-2022 to 1-12-2060. The y-axis represents field pressure under the compressibility of rocks. The red color represents the first case (3 * 10 ^-6), indicating that the lowest value of compressibility of rocks. The green color represents the fourth case (6*10^-6), the highest value of compressibility of rocks. Whenever the compressibility value of rocks decreases, the value of field pressure decreases, and whenever the compressibility value of rocks increases, the field pressure increases.

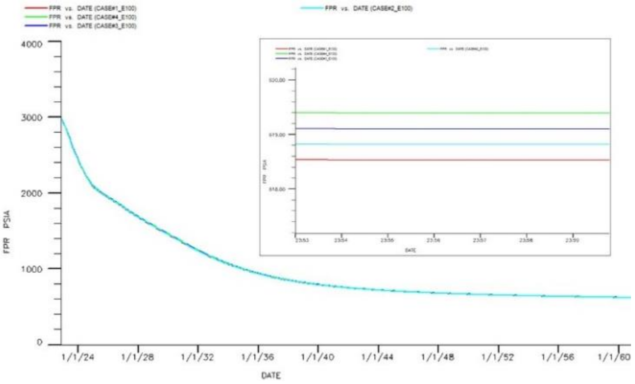

Fig. 21: Field Pressure at different Rock Compressibility

Field Water Cut at different Rock Compressibility: Figure 22 shows (field water cut) when rocks are compressed in four different solutions. The x-axis represents the time from 1-11-2022 to 1-12-2060. The y-axis represents the water cut at the compressibility effect of rocks. The violet color represents the first case (3 * 10 ^-6), indicating that the lowest value of compressibility of rocks. The blue color represents the fourth state (6*10^-6), the highest value of compressibility of rocks. Whenever the compressibility value of rocks decreases, the water cut value decreases, and whenever the compressibility value of rocks increases, the water cut increases.

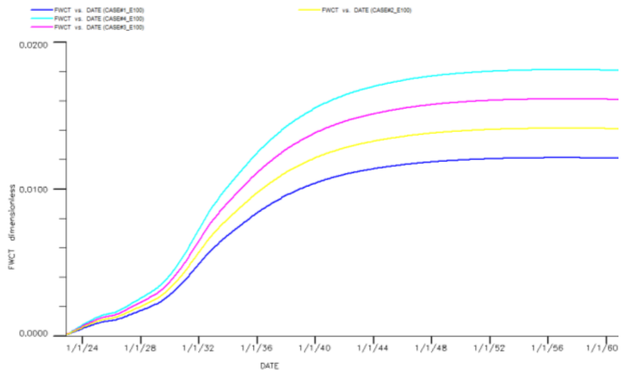

Fig. 22: Field Water Cut at different Rock Compressibility

Field Water production rate at different Rock Compressibility: Figure 23 shows the amount of water produced when rocks are compressed in four different solutions. The x-axis represents the time from 1-11-2022 to 1-12-2060. The Y axis represents the amount of water produced by the compressibility effect of rocks. The violet color represents the first case (3 * 10 ^-6), indicating that the lowest value of compressibility of rocks. The blue color represents the fourth state (6*10^-6), the highest value of compressibility of rocks. The lower the compressibility value of the rocks, the lower the value of the amount of water produced. As the compressibility value of the rock increases, the amount of water produced increases.

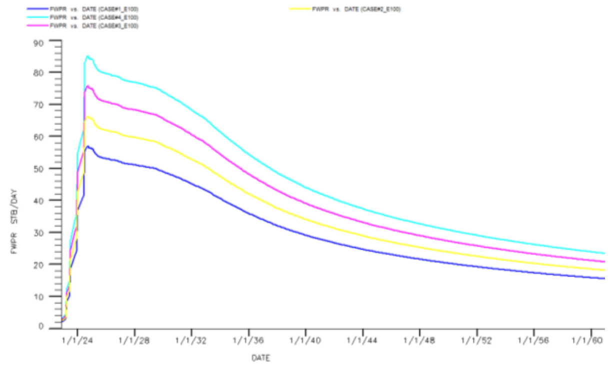

Fig. 23: Field Water Cut at different Rock Compressibility

Field Water Production Total at different Rock Compressibility: Figure 24 shows the total amount of water produced when rocks are compressed in four different solutions. The x-axis represents the time from 1-11-2022 to 1-12-2060. The Y axis represents the total amount of water produced by the compressibility effect of rocks. The violet color represents the first case (3 * 10 ^-6), indicating that the lowest value of compressibility of rocks. The blue color represents the fourth state (6*10^-6), the highest value of compressibility of rocks. The lower the compressibility value of the rocks, the lower the value of the total amount of water produced. As the compressibility value of the rocks increases, the total amount of water produced increases.

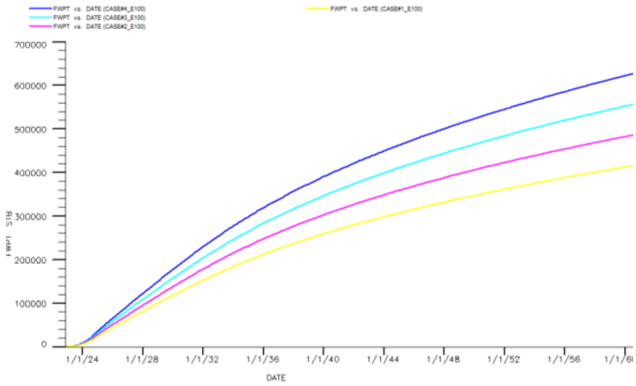

Fig. 24: Field Water Production Total at different Rock Compressibility

Field Gas Production Total at different Rock Compressibility: Figure 25 shows the total gas production when rocks are compressed in four different solutions. The x-axis represents the time from 1-11-2022 to 1-12-2060, and the y-axis represents the total gas production at the impact of compressibility of rocks. The pink color represents the first case (3 * 10 ^-6), indicating that the lowest value of compressibility of rocks. The green color represents the fourth state (6*10^-6), the highest value of compressibility of rocks. The lower the compressibility value of the rocks, the lower the value of the total gas production. The higher the compressibility value of the rocks, the greater the value of the total gas production.

Oil Saturation at different Rock Compressibility: Figure 26 shows the percentage of oil saturation. It is noticed that at the side of the injection wells of (108,109,110) the presence of the blue color as a result of the gas entrainment ranging from 0% to 76%. It is also notices that the more we increase the gas injection, the less oil saturation percentage becomes.

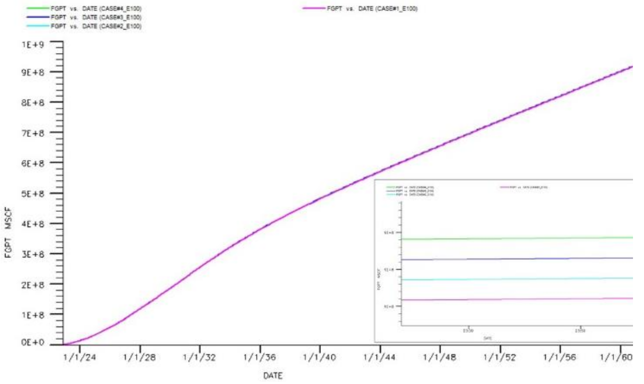

Fig. 25: Field Gas Production Total at different Rock Compressibility

Water Saturation at different Rock Compressibility:

Figure 28 shows the percentage of water saturation. It is noticed that at the side of the injection wells of (108,109,110), the percentage of water saturation is less as a result of the increase in gas injection, it is on (Scale12%). It is also noticed that the more gas is injected, the lower the water saturation rate.

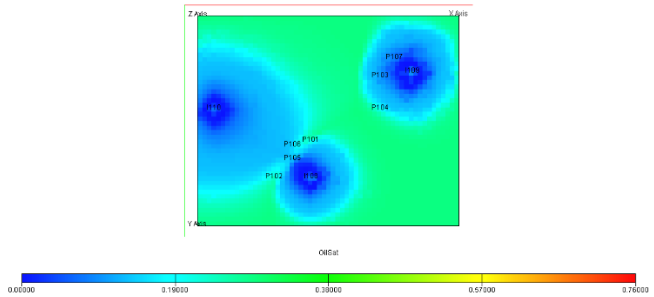

Fig. 26: Oil Saturation at different Rock Compressibility

Gas Saturation at different Rock Compressibility: Figure 27 shows the percentage of gas saturation, and we notice in the injection wells (108,109,110) in the sides of the wells, the color is red as a result of increased gas injection, and usually the red color represents the (97% Scale) The more gas is injected, the higher the gas saturation rate.

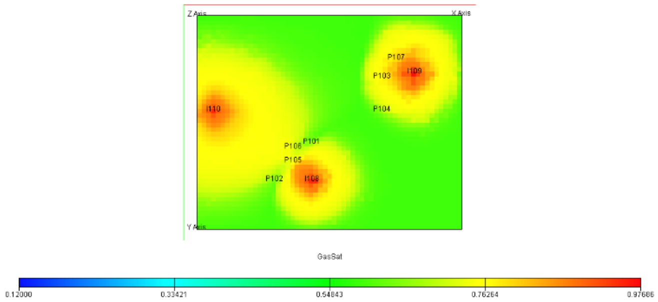

Fig. 27: Gas Saturation at different Rock Compressibility

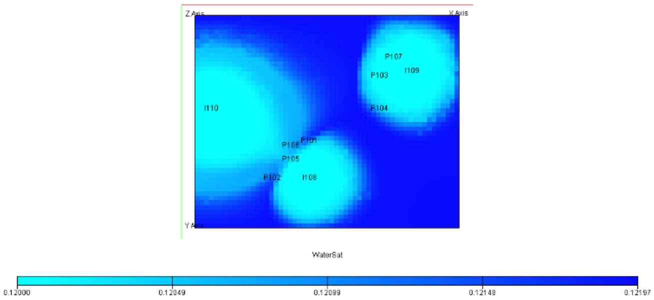

Fig. 28: Water Saturation at different Rock Compressibility

Comparison of Rock Compressibility Results: Table 8 shows the final results of the effect of compressibility of rocks for the four cases of: oil recovery factor, total amount of produced oil production, total amount of produced gas production, field pressure, water cur, and amount of produced water production.

Table 8: Comparison of Rock Compressibility Results

CASE	CASE#1	CASE#2	CASE#3	CASE#4
FOE	0.577	0.578	0.579	0.580
FOPT	146727760	147216350	147704850	148193870
FGPT	920216700	920764610	921312260	921861310
FPR	618.529	618.812	619.102	619.390
FWCT	0.012	0.014	0.016	0.018
FWPT	418007	488662	559476	630438

Comparison of Oil Recovery Factor at different Rock Compressibility: From the figure below, it is clear that the relationship between the oil recovery factor and the compressibility of rocks is a direct relationship. First case #1 (0.577). Second case #2 (0.578). Third case #3 (0.579). Fourth case #4(0.580).

Comparison of Field Oil Production Total at different Rock Compressibility: From the figure below, it is clear that the relationship between the total amount of oil produced and the compressibility of rocks is a direct relationship. First case #1 (146727760). The second case #2 (147216350). The third case #3 (147704850). Fourth case #4 (148193870).

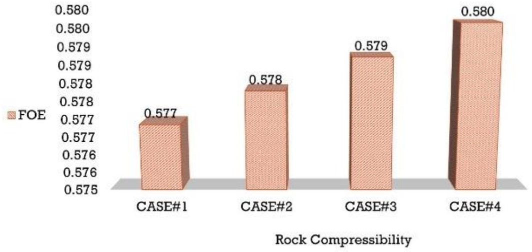

Fig. 29: Comparison of Oil Recovery Factor at different Rock Compressibility

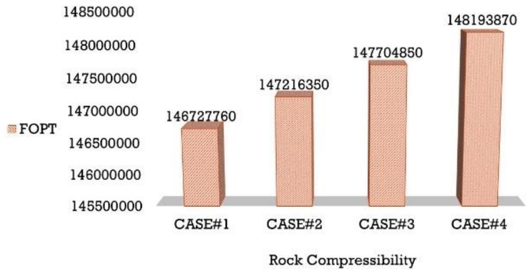

Fig. 30: Comparison of Field Oil Production Total at different Rock Compressibility

Comparison of Field Gas Production Total at different Rock Compressibility: From the figure below, it is clear that the relationship between the total amount of gas produced and the compressibility of rocks is a direct relationship. First case #1 (920216700). The second case #2 (920764610). The third case #3 (921312260). Fourth case #4 (921861310).

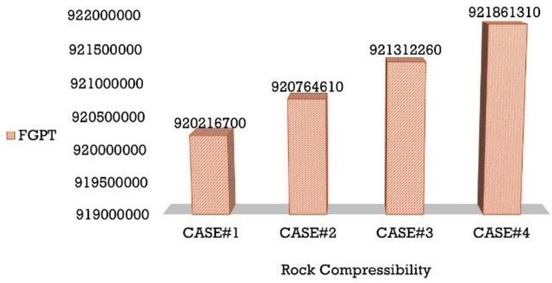

Fig. 31: Comparison of Field Gas Production Total at different Rock Compressibility

Comparison of Field Pressure at different Rock Compressibility: From the figure below, it is clear that the relationship between field pressure and rock compressibility is direct. First case #1 (618,529). Case #2 (618,812). The third case #3 (619.102). Case #4 (619,390).

Comparison of Field Water Cut at different Rock Compressibility: From the figure below, it is clear that the relationship between water cut and compressibility of rocks is a direct relationship. First case #1 (0.012). Second case #2 (0.014). Third case #3 (0.016). Fourth case #4(0.018).

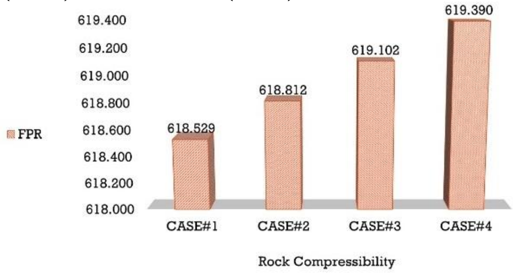

Fig. 32: Comparison of Field Pressure at different Rock Compressibility

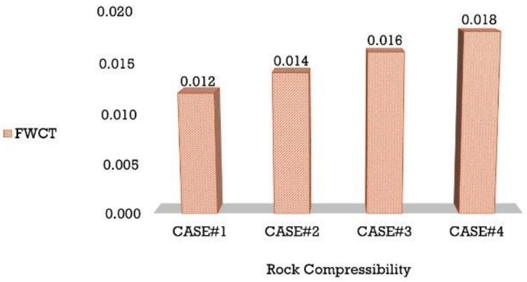

Fig. 33: Comparison of Field Water Cut at different Rock Compressibility

Comparison of Field Water Production Total at different Rock Compressibility: From the figure below, it is clear that the relationship between water production and the compressibility of rocks is a direct relationship. First case #1 (0.012). Second case #2 (0.014). Third case #3 (0.016). Fourth case #4(0.018)

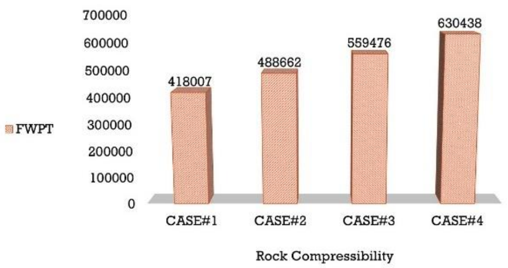

Fig. 34: Comparison of Field Water Production Total at different Rock Compressibility

CONCLUSION AND RECOMMENDATIONS:

In this study, it is proven that CO2 injection has successfully enhanced the gas recovery. This study focuses on the effect of different value of CO2 injection rate and rock compressibility to the oil production. It is proven that the optimum oil production is by injection a high amount of injection rate. The highest increase in percentage of the total gas production is when an injection of 54 MMSCF is 0.58 %. Not only that, a study of effect of different rock compressibility. The conclusion of this study is:

1. The higher the compressibility value of the rock, will give the higher the rate of oil production.
2. As the compressibility value of the rock increases, the rate of gas production will be increases.
3. The lower the compressibility value of the rock, will give the lower the value of the oil recovery factor.
4. Whenever the compressibility value of rocks decreases, the value of field pressure will decrease.
5. When the compressibility value of rocks decreases, the water cut value will decreases, and whenever the compressibility value of rocks increases, the water cut increases.
6. As the compressibility value of the rock increases, the amount of water produced is increases.
7. The lower the compressibility value of the rocks, the lower the value of the total gas production.
8. From this study, the relationship between oil rate, gas rate, pressure, and oil recovery factor are directing the compressibility of rocks is a direct relationship.

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