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FMH606 Master's Thesis 2023

Process Technology

Computational Study of CO2 Injection for Enhanced Oil Recovery and Storage

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www.usn.no

Course: FMH606 Master's Thesis, 2023

Title: Computational Study of CO2 Injection for Enhanced Oil Recovery and Storage

Number of pages: 31

Keywords: EOR, CMG, oil production, well, reservoir, CO2 injection, water injection.

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Summary:

After a while of oil production from reservoir, pressure of reservoir will be decreased, and the rate of production will be decreased too as a result some oil will remain in the reservoir.

One of the main problems is choosing the best method for having better production.

The solution for increasing the reservoir pressure is injecting a fluid into the reservoir by a new well. It can be steam or gas or any other fluid. Different valves can be used in the well such as ICD or AICV. And, by decreasing the viscosity which affects directly on the mobility of oil and production rate. One of the best software which is effective for simulating the reservoir is CMG which is used in this thesis too.

As a conclusion, by increasing the injection of fluid in long period, more production can be achieved. And ICD can store more gas in the reservoir in compared to openhole which is so effective for environmental issues.

Preface

I want to thank my supervisors for guiding me in this thesis and the USN university for giving me the chance of studying MSc of process technology.

Porsgrunn, 2023

Ashkan Azimirad

Contents

1 Introduction

In this thesis EOR is going to discuss which is a process for production more oil from reservoir. In this method $CO_2$is injected to the reservoir and by this action, the pressure of reservoir will be increased, and the viscosity of oil will be decreased as the result the production of oil will be increase.

This process will be held after the primary and secondary recovery. Usually in the primary recovery 10% of the whole oil of the reservoir can be produced and in the secondary recovery 20 to 40 %. But in the tertiary recovery can be produce up to 60% oil.

On the other hand, there are some challenges in using this process, economic challenges.

The drop in oil prices has a significant impact on the production of enhanced oil, the cost of oil and the supply of CO_2 have a significant impact on the economics of CO_2-EOR projects. One of the biggest expenses for a CO_2 EOR project is CO_2 purchases.

HSE requirements challenging is one of the main challenges because according to the environmental rules no hazardous liquid must be poured into the ocean, so the remaining oil distribution is another challenge. Placing and number of wells is so vital. the quantity of production wells and injection wells are limited and there is Installation limitation and the cost of money and expensive. [1]

So, we want to see and compare different methods for increasing oil production.

2 Theory

2.1.1 Wettability

Altering wettability is a successful strategy for increased oil recovery. The wettability alteration aims to make the rock more water-wet by changing its wetting condition. The wettability is influenced by a number of elements, such as pressure, temperature, rock composition, brine, crude oil, and so on. [2]

2.1.2 Capillary Pressure

Capillary pressure is the variations in pressure between two immiscible fluids in contact at the curved interface of a tiny capillary tube. Wetting phase pressures and nonwetting phase pressures are used to express the pressure differential. [3]

The fractional flow of water will increase due to the capillary pressure gradient, which lowers frontal water saturation, increases frontal velocity, and ultimately lowers oil recovery. [4]

2.1.3 Porosity and Permeability

Any rock or loose sediment has the qualities of porosity and permeability. Both depend on how many, how big, and how connected the rock's openings are. In fact, a rock's porosity is a gauge of how well it can contain a liquid. In mathematics, it is the open area within a rock divided by the volume of the entire rock (solid and space). The ease with which a fluid can pass through a porous substance is measured by its permeability. Even though a rock has many pores, it won't be permeable if the pores are not connected. [5]

2.1.4 Oil saturation

oil saturation is the highest amount of dissolved water which that oil can keep. The saturation can be affected by different parameters, one of the main parameters is temperature, by increasing the temperature the saturation point will decrease which is shown in Figure 1. [6]

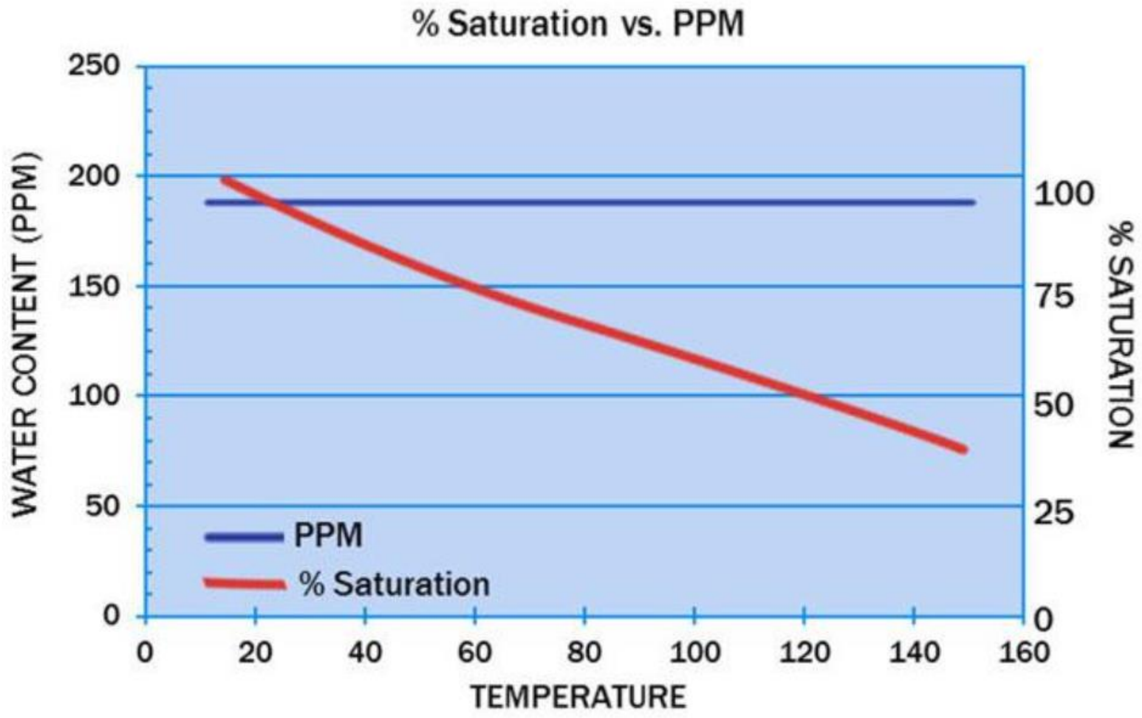

Figure 1 Saturation and temperature [6]

2.1.5 Relative Permeability to Water at S_{orw}

By increasing the permeability, the relative permeability to water will increase too. And there is a direction relation between these two. [7]

2.2 Mechanism *of EOR*

After injection of CO_2 into the reservoir oil there are two kinds of conditions, miscible and immiscible. It relates to pressure and temperature and composition of oil in our reservoir oil. The minimum pressure that CO_2 can be mixed into the oil is defined as a minimum miscibility pressure (MMP). If the pressure of reservoir oil is less than MMP there can be an immiscible situation otherwise, miscible CO_2 into oil.

Mixing the CO_2 into the oil is not happening instantaneously. By injecting the CO_2 into the reservoir, the CO_2 starts to dissolve into the oil and vice versa. Eventually one single phase is formed by passing time. *[8]*

Generally, when our pressure is under the MMP or heavy oil (having a high density and viscosity) can be seen immiscible CO_2 into oil. In comparison to miscible case, immiscible case has less efficient in oil production.

2.3 CO2 injection process

For performing EOR, CO_2 is needed, which is usually gotten by CO_2 captured plant, they are transported to the well by truck, train, or pipelines. CO_2 is needed to be compressed and have a supercritical state which it can be reached at temperatures more than 31.1 centigrade and pressures more than 7.38 MPa. By this specification our CO2 has the mobility as same a gas and density close to liquid phase. After production of oil, due to the decreased pressure, CO_2 starts detaching in the oil and it can be collected and reused in the same process.

Depends on the reservoir, vertical or horizontal well can be added. [8]

2.4 ICD

ICD is abbreviation of Inflow Control Device, which is mainly formed of two sections, one is housing and the other is nozzles Figure 2. The main formula for calculating the pressure drop is as equation 2-1 . [9]

$$\Delta P = \frac{\rho}{2}(\frac{q_v}{AC_d})^2$$

2-1)

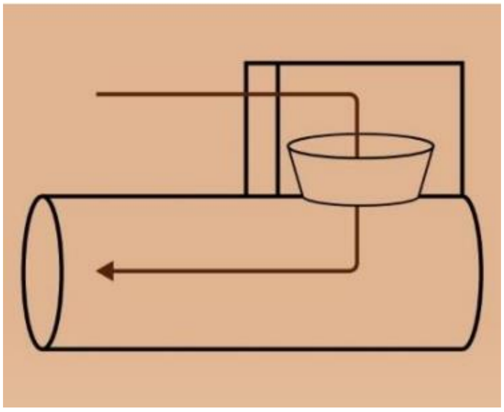

Figure 2 ICD [9]

drag coefficient is a parameter which is representative of resistance an objective in the flow and is shown by C_d. Based on Figure 2.whatever the density of fluid is more the pressure drop will be more too. ICD can help in production of oil when there are water and oil, but in gas situation will not get a good result and this can be known as a disadvantage of ICD. [9]

3 Simulation

One of the best software for simulating the reservoir is CMG which has its own advantages.

One of the most advantages of CMG is its different options which gives the user for simulating different situations in reservoir and user friendly.

By using CMG, production of oil can be simulated in different kind of reservoirs and different parameters can be defined in the software such as the saturation of oil, gas, water etc. also well can be defined as an injection or production and the well can be shut in or open also.

3.1 CMG

CMG software looks like as Figure 3. On the left side there is a section for selecting the file and on the right side there is a section for selecting the module that is needed. There are some different modules such as STARS, IMEX & GEM, in this report STARS is going to be used because ICD are going to be used in the well. Also, some other options such result which is for seeing the plots & result of simulated case, CEDIT which is for editing the simulation by coding and BUILDER which is so useful for editing and simulating the case in that atmosphere.

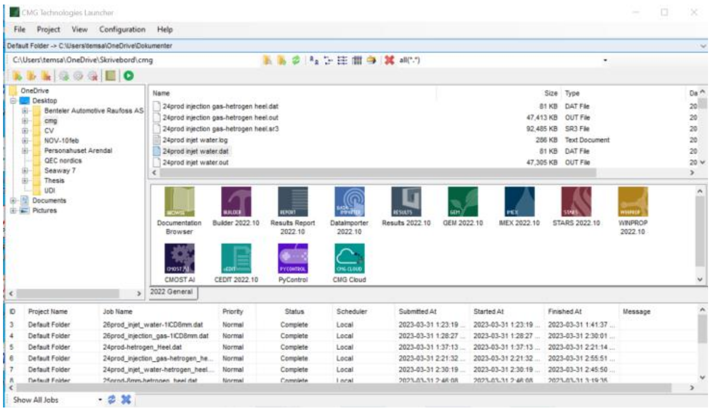

Figure 3 CMG

3.1.1 BUILDER section

The BUILDER is shown in Figure 4. On the left side there are some options that at the end of the simulation must have a green tick on them. Because this version of software is an academic version and not a full version, it has some limitations. The maximum grid which can be used is 10000 grids. In the Reservoir section on the left side the Cartesian grid 20 in X direction, 19 for Y & Z direction are selected. Due to the limitation of number of grids, the grids near wells are smaller than other grids so the sensitivity beside wells are more than the rest of reservoir.

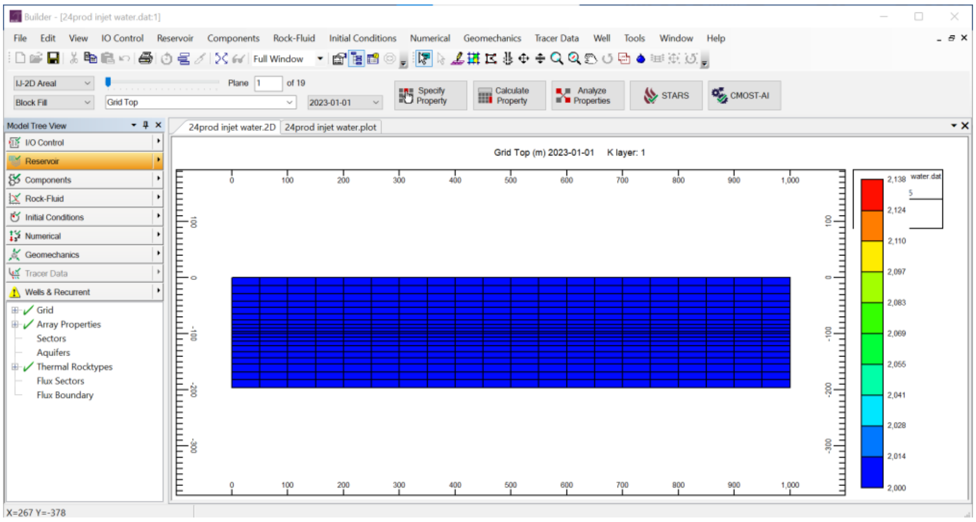

Figure 4 BUILDER

The next section is Components, which were defined by PVT file, the plots, viscosity, density, and relative permeability are shown here. Which are shown by Figure 5, Figure 6, Figure 7, Figure 8, Figure 9, Figure 10, Figure 11, Figure 12, Figure 13, Figure 14.

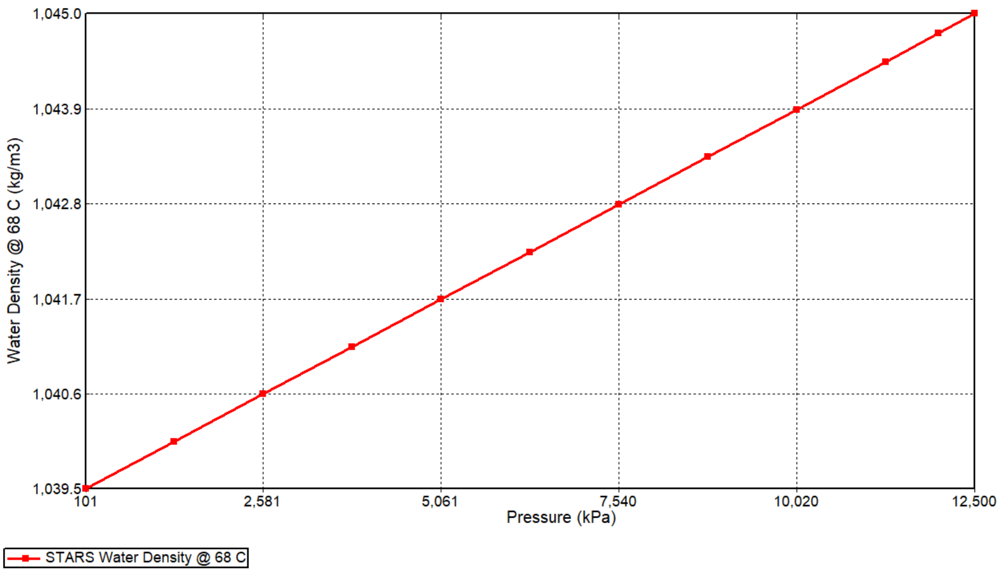

Figure 5 Water density

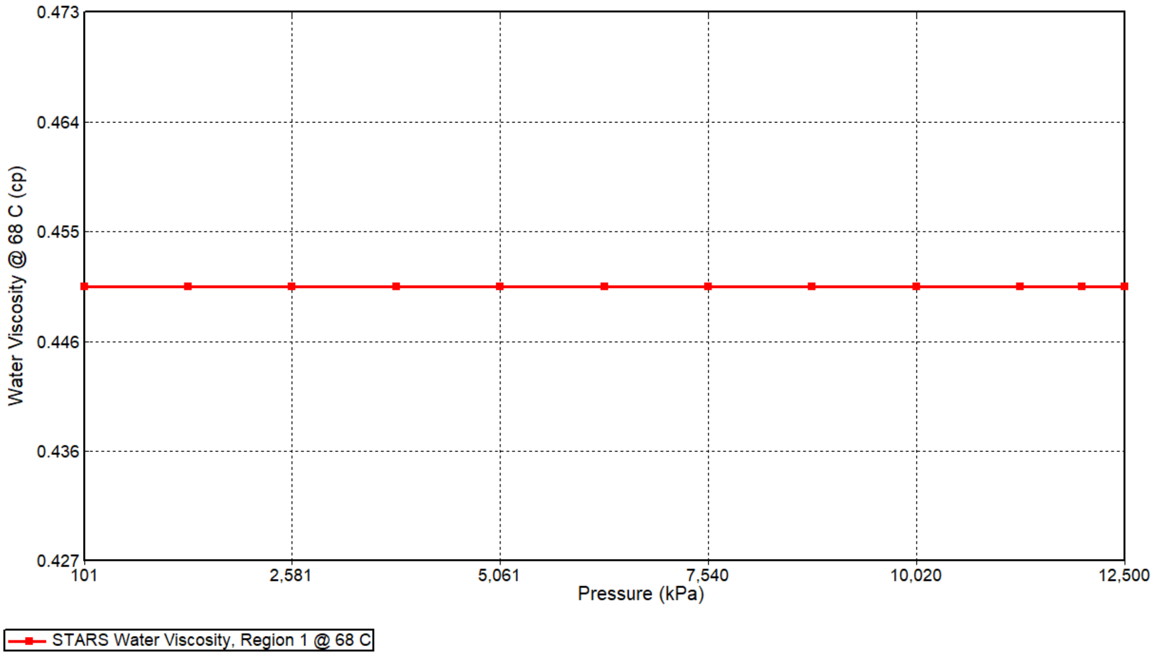

Figure 6 Water viscosity

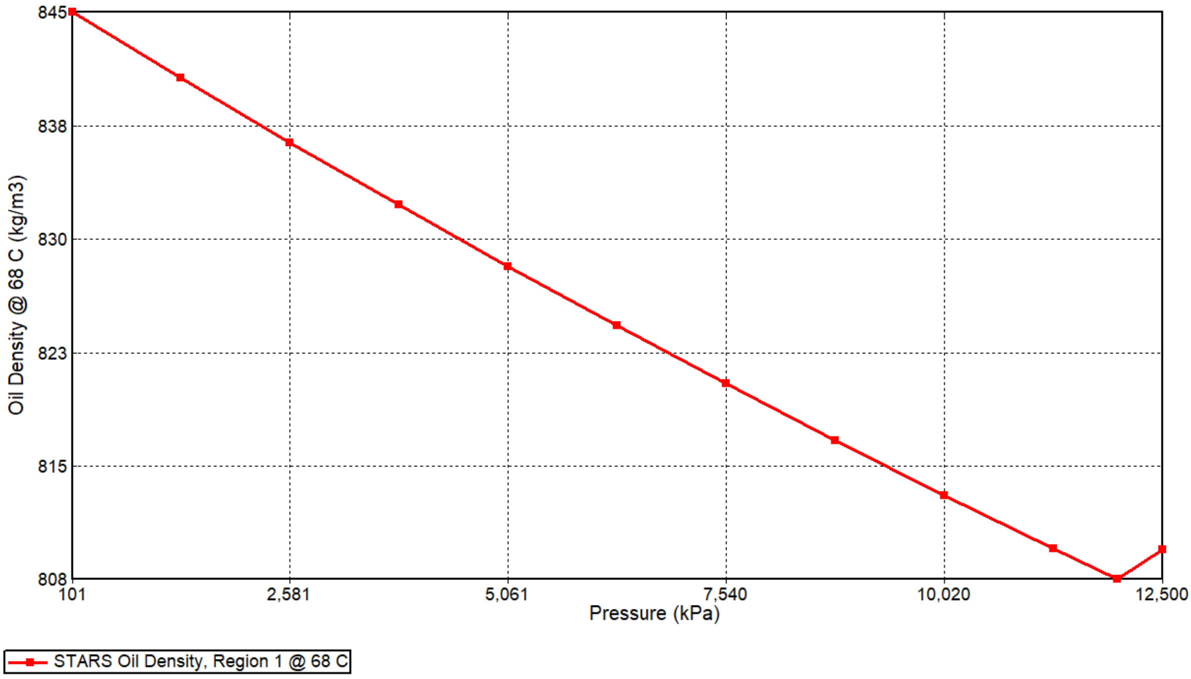

Figure 7 Oil density

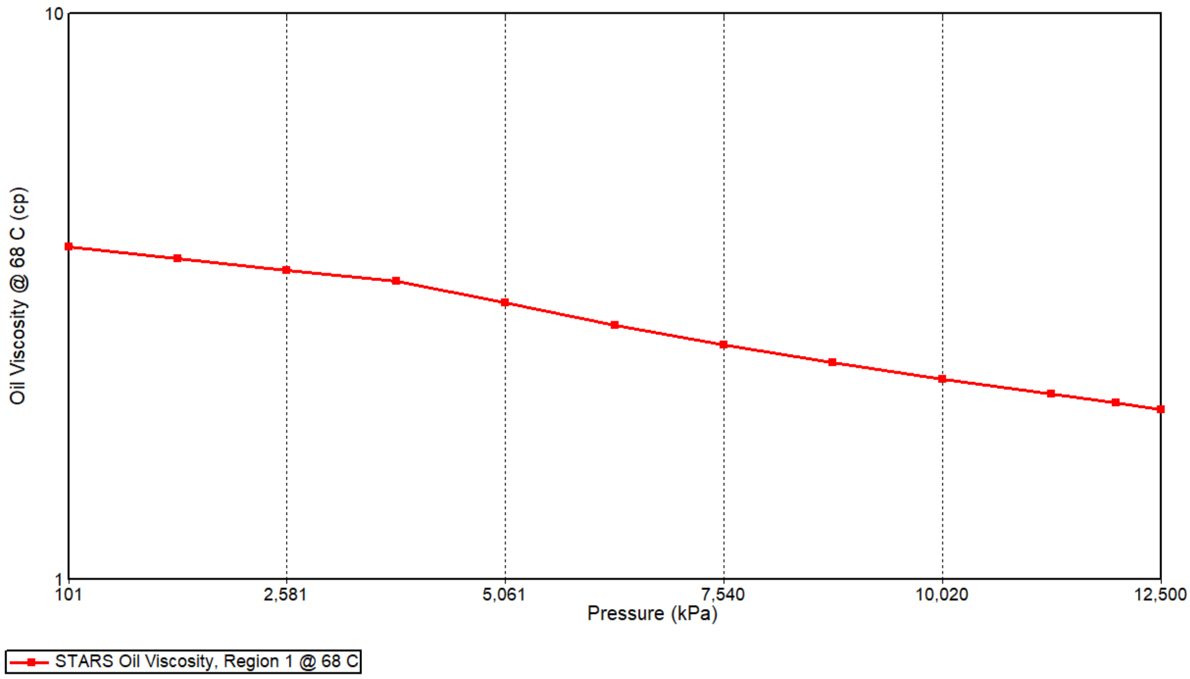

Figure 8 Oil viscosity pressure

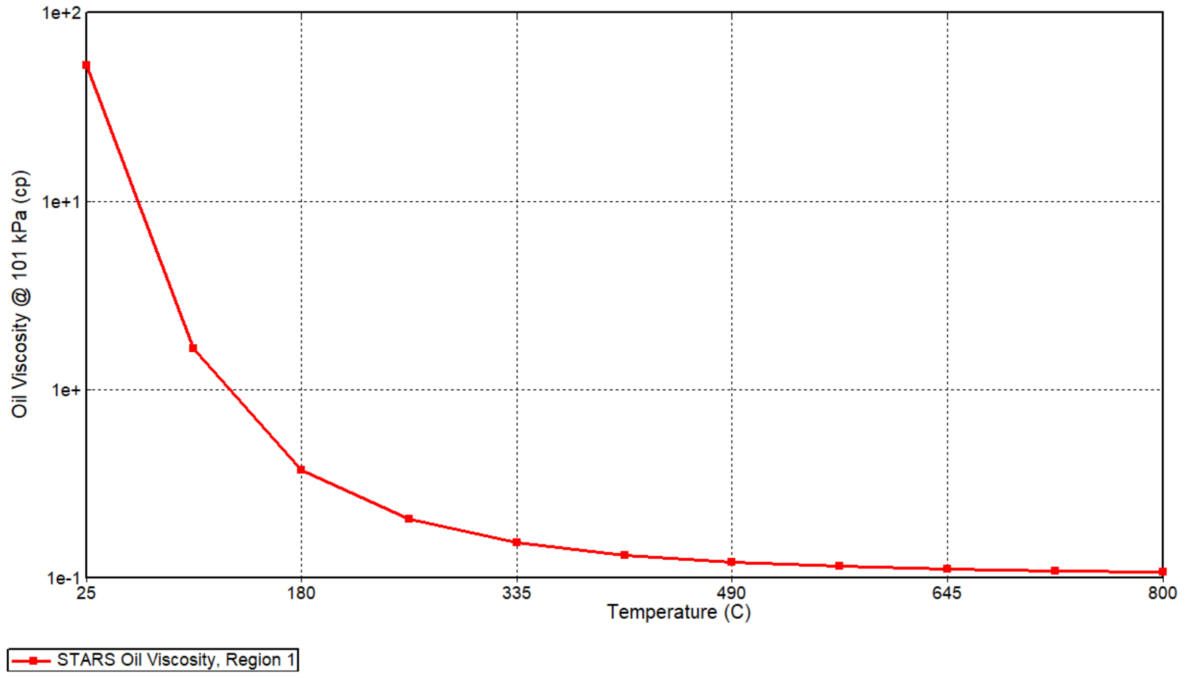

Figure 9 Oil viscosity

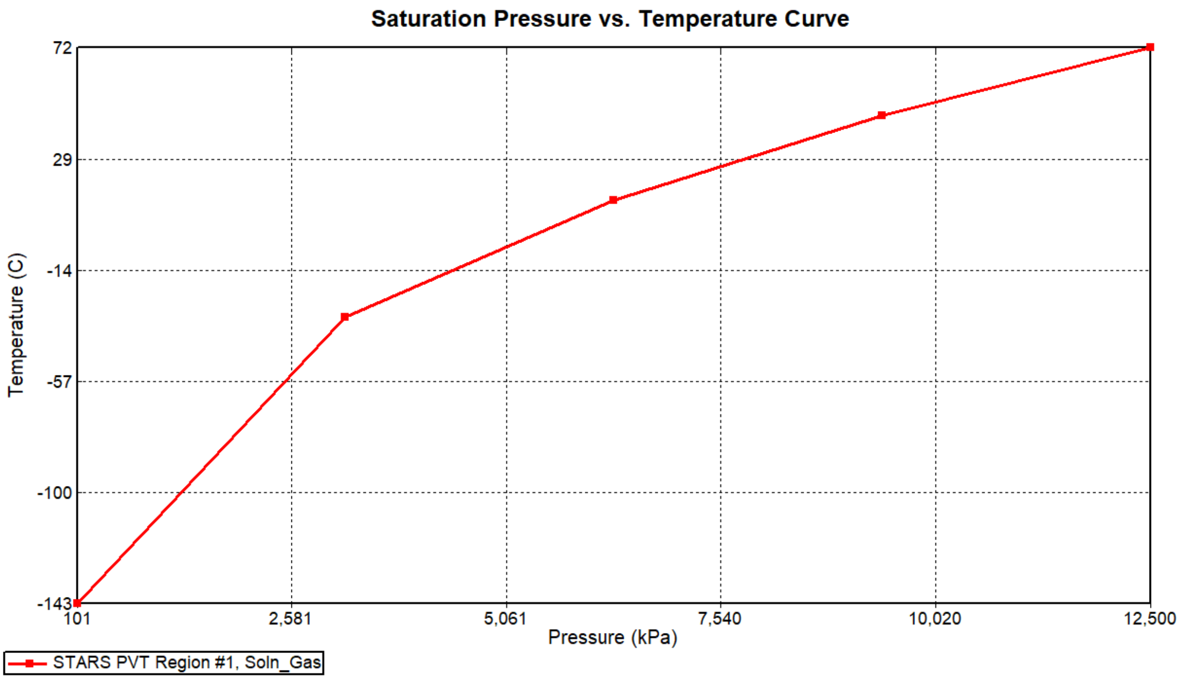

Figure 10 PVT

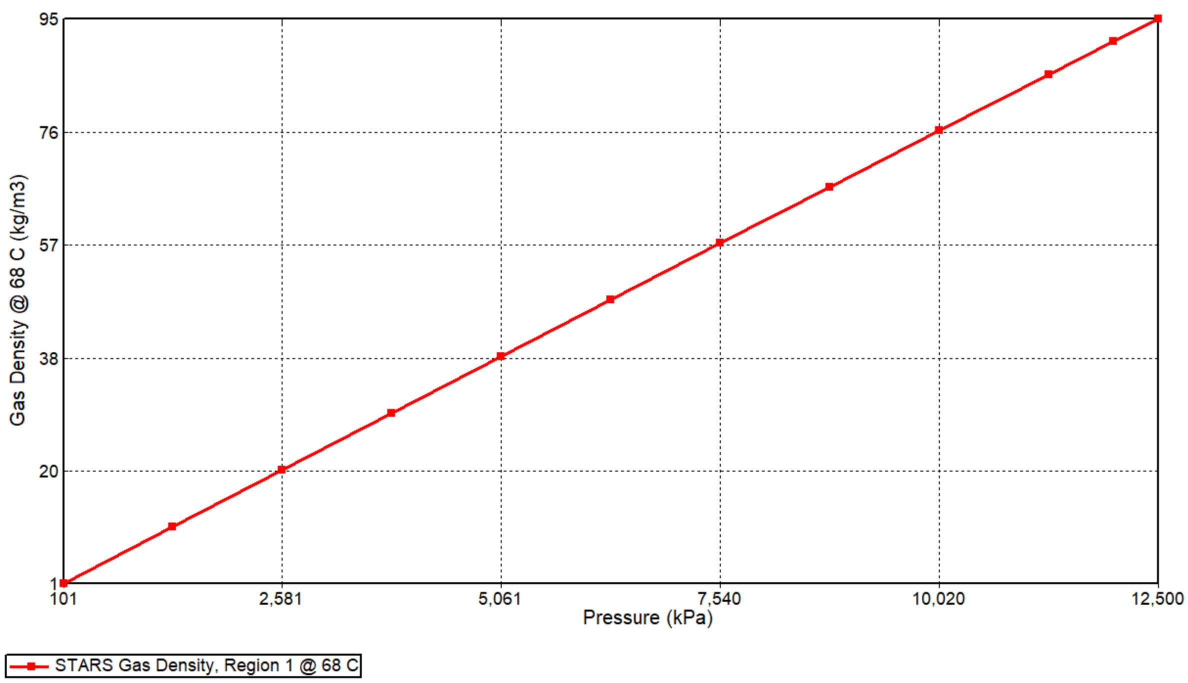

Figure 11 gas density

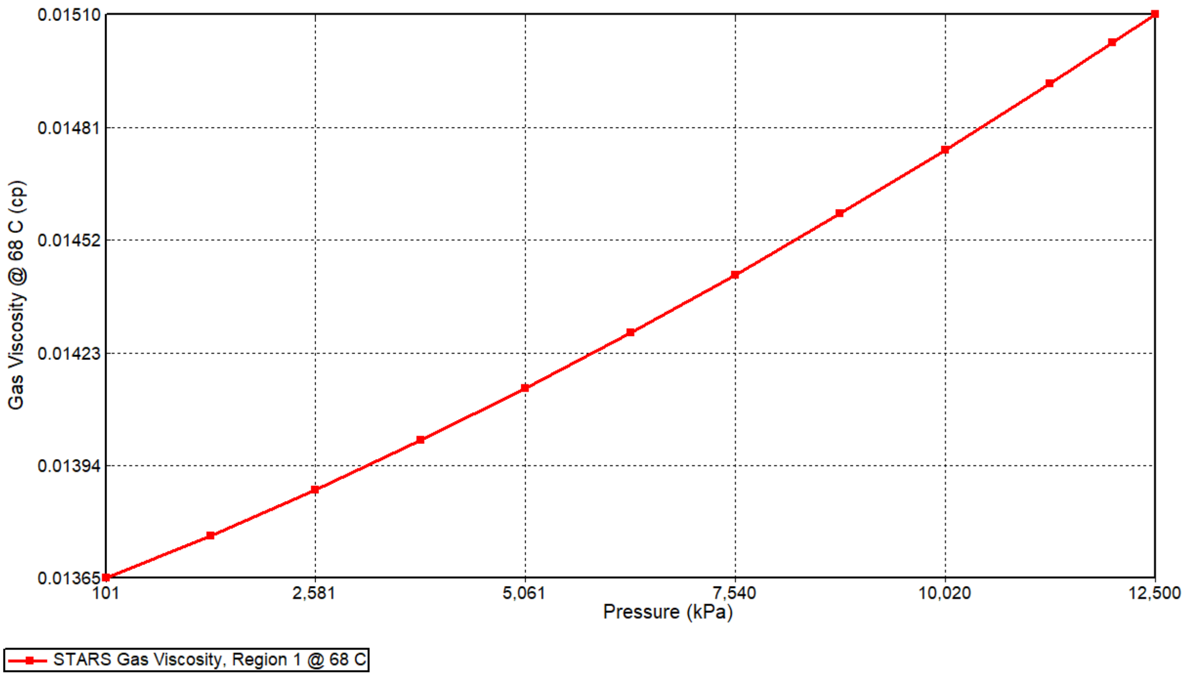

Figure 12 Gas viscosity

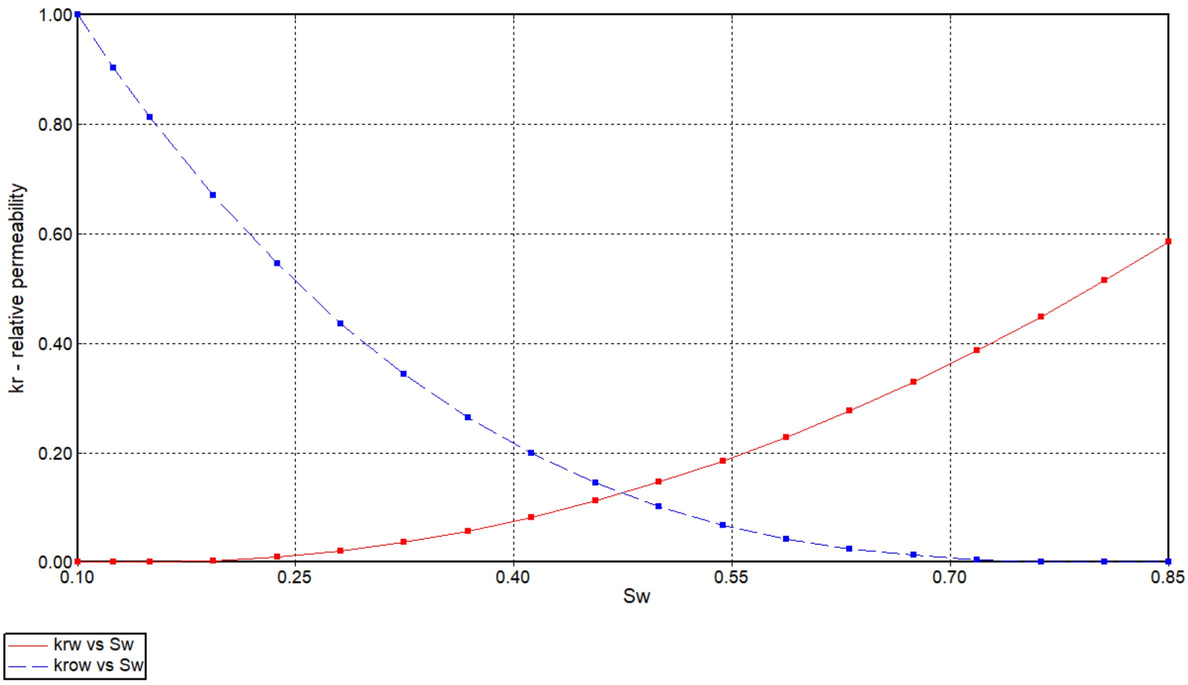

Figure 13 Relative permeability Sw

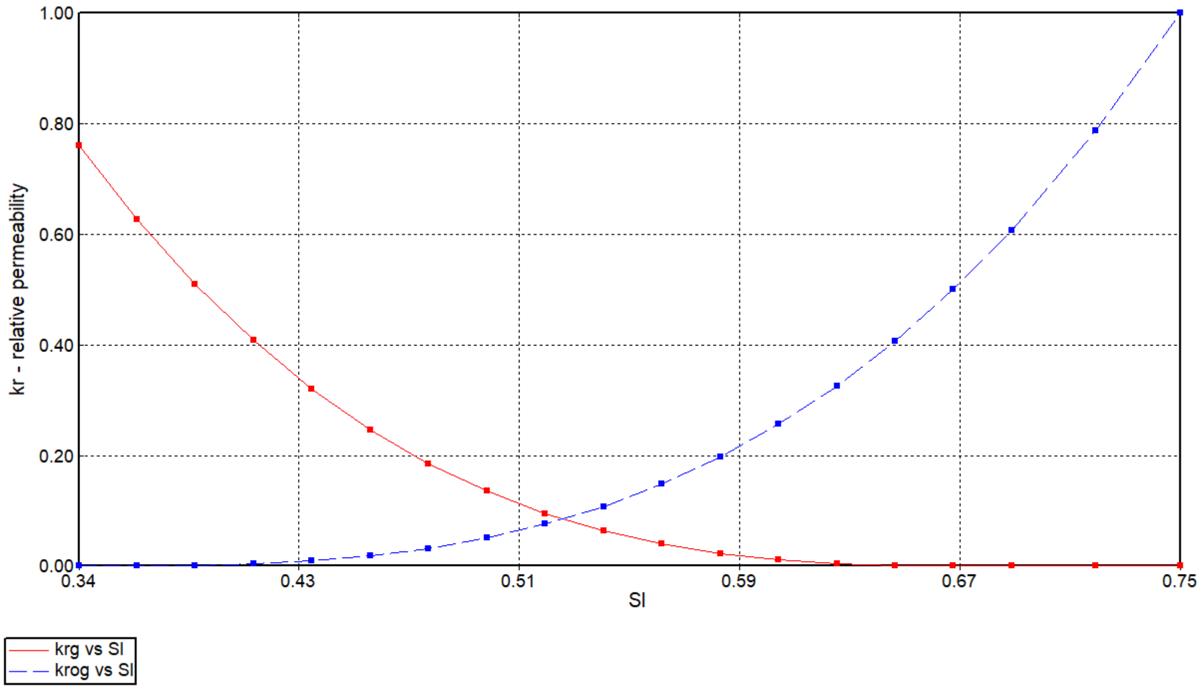

Figure 14 Relative permeability Sl

The Rock Fluid section, the relative permeability and the type of the rock can be determined.

The other section is Initial Conditions which some parameters such as depth for output pressure, water oil contact depth and gas oil contact depth can be defined.

In the last option on the left column, there is Wells & Recurrent which is for defining production well, injection wells, adding AICV, ICD, closing the well, duration of production (which is five years in this case), constraint, limitation value of production (1000 cubic meter per day) and injection (400 cubic meter per day) fluid, bottom hole pressure BTP (min is 10000kPa in this case) etc.

On the top side of the software there is a section Specify Property which is for determining different parameters such as grid top (2000m in this case), grid Thickness (which is 10m and between 2 wells are 3m), porosity (0.3), permeability I (2000md), permeability j (2000md),permeability k (250md), oil saturation (100% from layer 1 to 15), water saturation(100% from layer 15 to 19), gas saturation (0% for whole the case), temperature (68°C), pressure (12500 kPa from layer1 to 18 and 12600 kPa for layer 19) etc. the distance between injection and production well is 15m.

After setting all the parameters the final case can be shown by Figure 15, Figure 16. Finally, the case can be run and get the results.

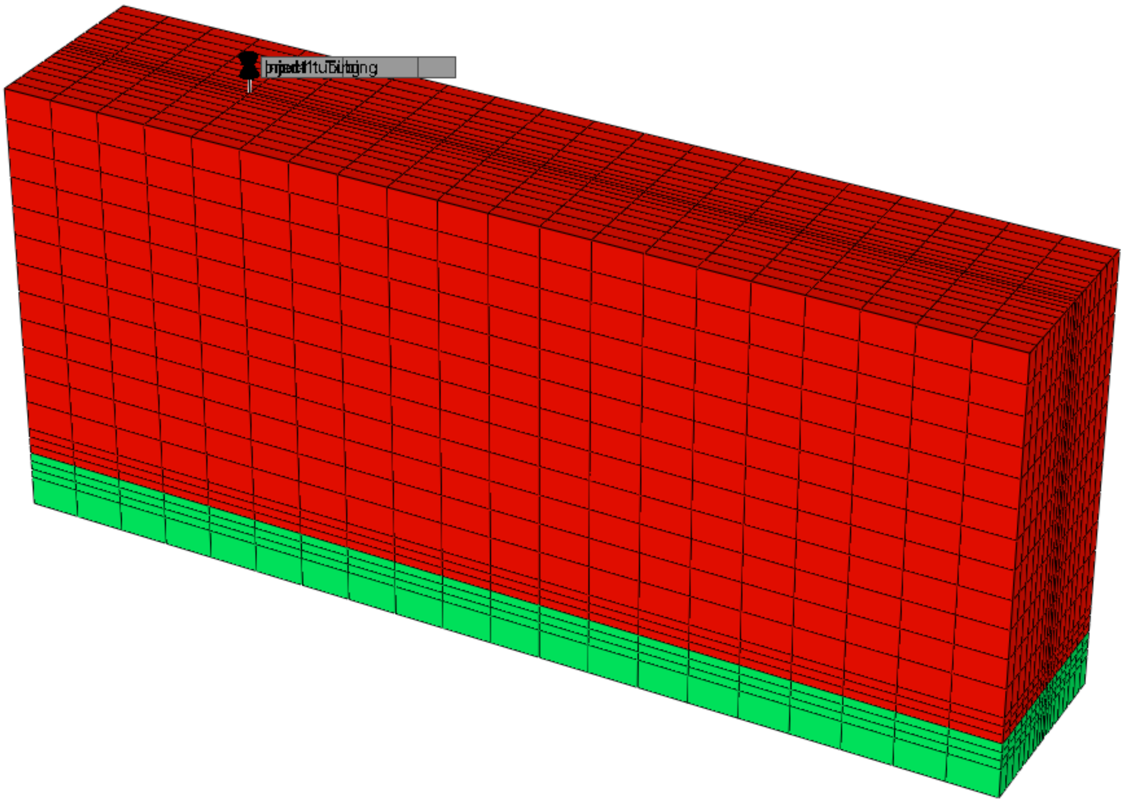

Figure 15 Final simulation of one case 3D

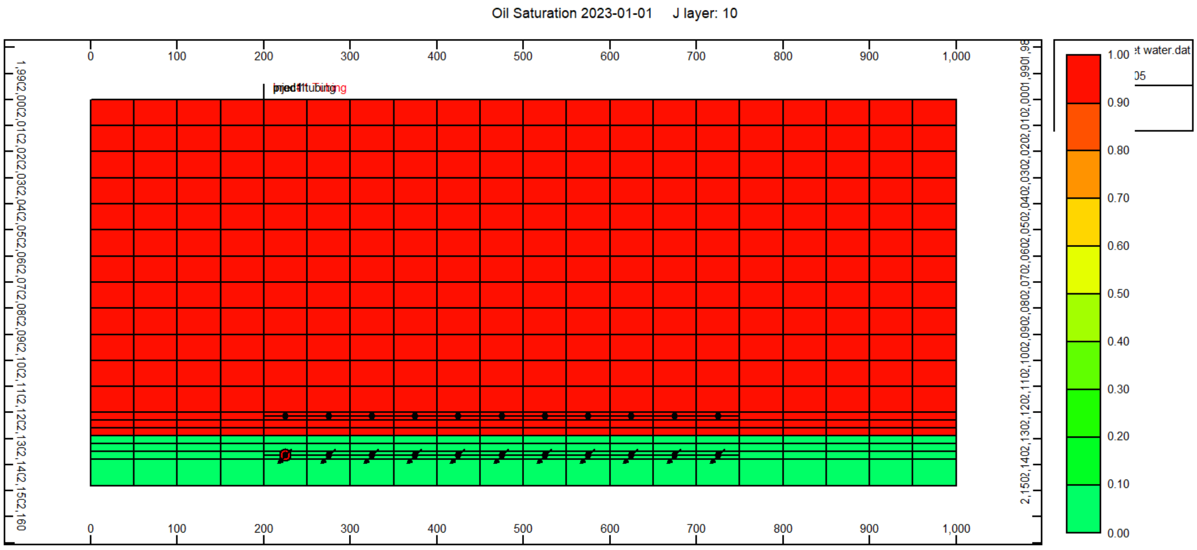

Figure 16 Final simulation of one case-IK-2D X sec

4 Results and discussion

In this thesis different conditions are simulated, there are some common parameters among them and some different. In general, two main cases are discussed, homogeneous and heterogeneous. And each case is divided into well with ICD (diameter of 2.5mm) and well without ICD (diameter of 8 mm which is considered as an open hole). Also, injection of water and gas (CO_2) are implemented and see the result and effects of them on oil production. Duration of production is 5 years for all the cases. The maximum volume fluid injection for gas is 600 m^3/day and for water is 400 m^3/day See Figure 17.

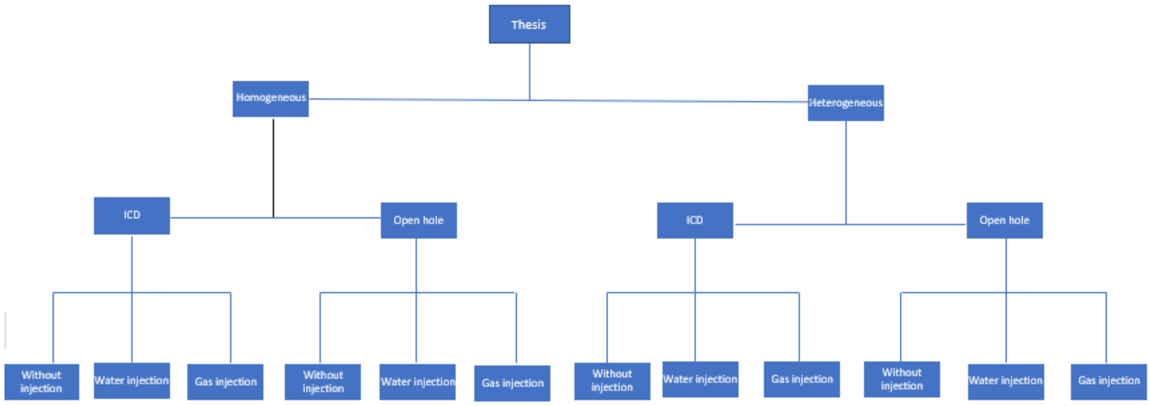

Figure 17 investigated cases.

The maximum limitation for oil production is 1000 cubic meters per day and this parameter is set for all the cases. In the case of ICD, 11 sections of the well are designed for ICD and in each section 4 ICD are located. Different cases are compared with each other, and the related oil production plots and profiles are shown in this thesis.

In the homogenous and heterogenies cases which well has ICD, oil production in three cases, production without any injection, production with water injection and gas injection is shown by Figure 18 and Figure 19Figure 18Figure 19. Oil production can be increased by injection of fluid and the best result can be taken by injection of water then gas and the last is no injection. By injection of gas the oil production can last one year more than no injection case, and by injection of water, oil production can last longer.

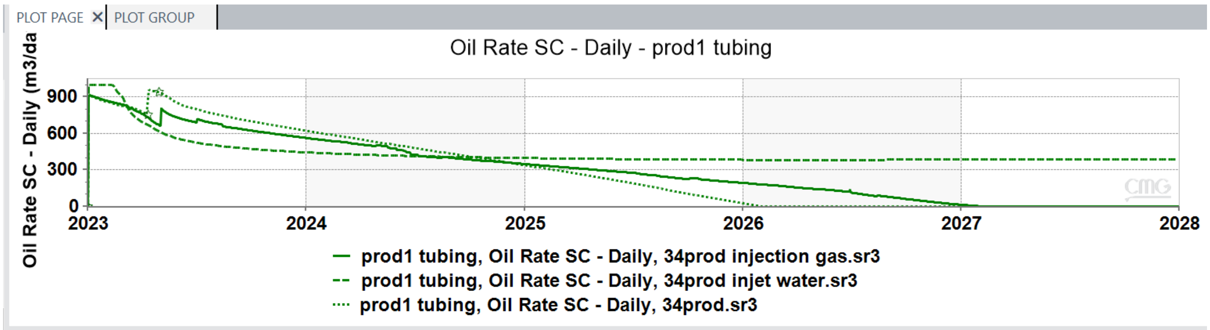

Figure 18 Oil rate with ICD in homogeneous in three cases

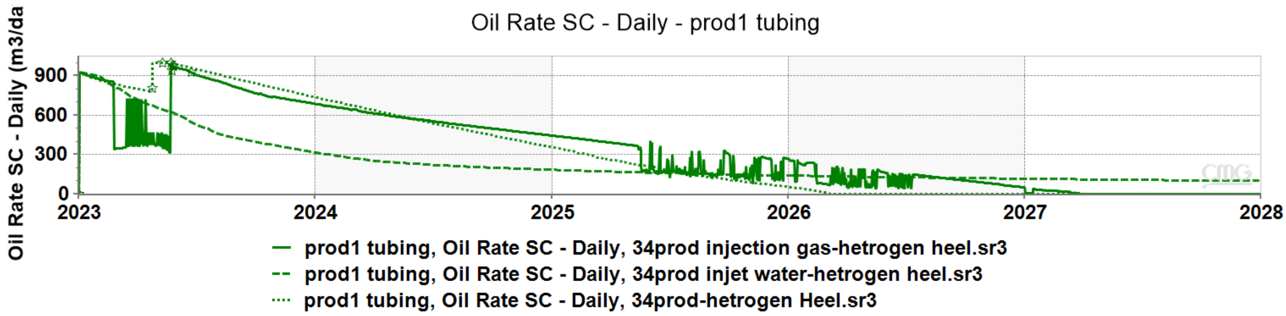

Figure 19 Oil rate, with ICD in heterogeneous in three cases

In the homogenous and heterogenies cases which wells do not have ICD (ICD with bigger diameter which are considered as an open hole) in all three cases, with water and gas injection and no injection are compared with each other and the oil. Initially the oil production is high in no injection then gas then water injection in both homogenous and heterogenies cases, but after 1.5-year oil production in the homogenous changes and the oil production in water injection increases more than gas injection. See Figure 20, Figure 21.

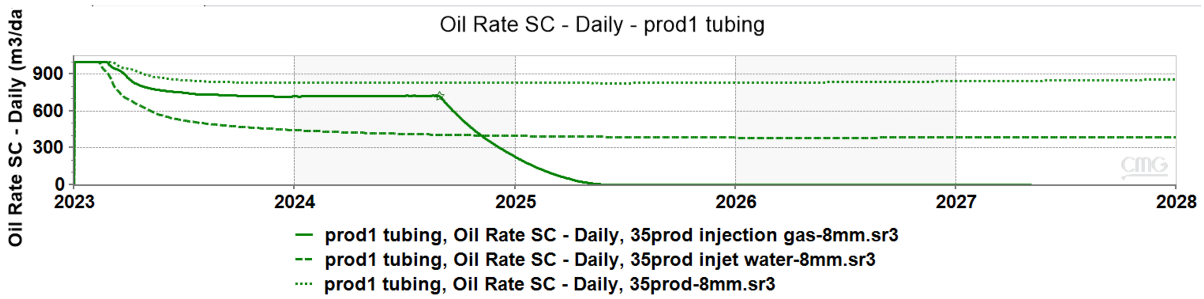

Figure 20 Oil rate with open hole in homogeneous in three cases

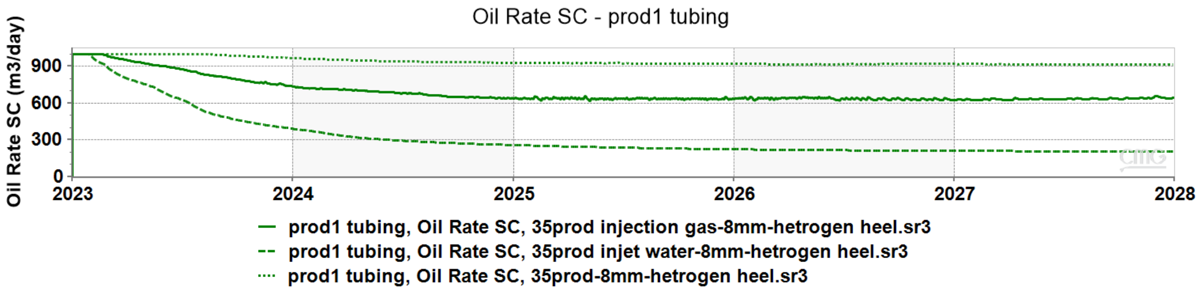

Figure 21 Oil rate with open hole in heterogeneous in three cases

In this section oil production in homogeneous and heterogeneous with ICD in wells, in three case of injection is going to be discussed. In case of no injection & gas injection nearly equal production can be seen, but in case of water injection better oil production can be seen in homogeneous case. Also, by injection of water, oil production can be produced longer than other injections. See Figure 22, Figure 23, Figure 24

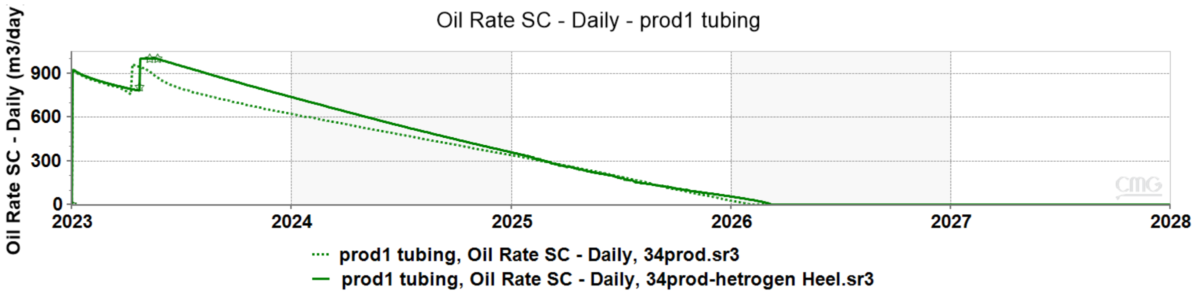

Figure 22 Oil production ICD, homogeneous and heterogeneous no injection

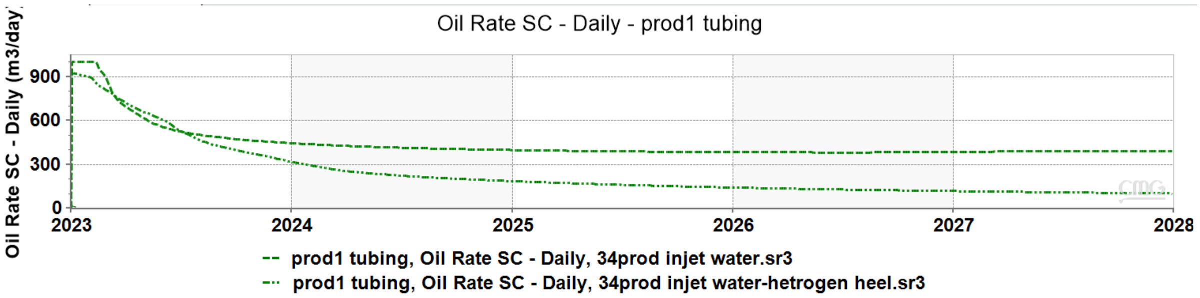

Figure 23 Oil production ICD, homogeneous and heterogeneous water injection

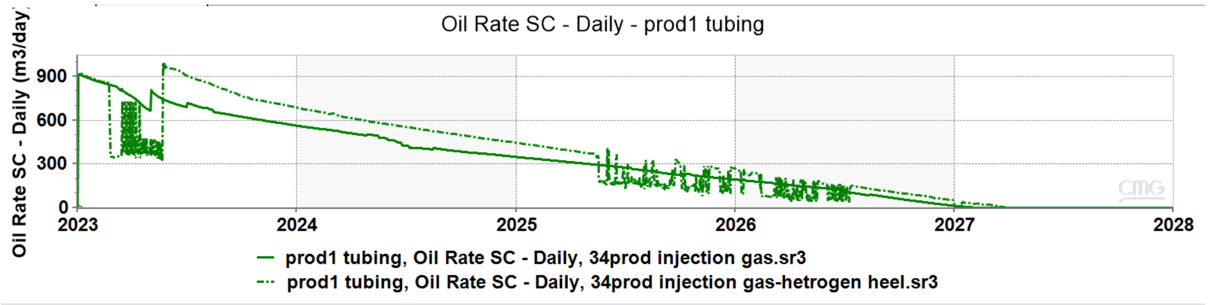

Figure 24 Oil production ICD, homogeneous and heterogeneous gas injection

In this section heterogenous and homogeneous reservoir with open hole well in three different injections (no injection, gas & water injection) is going to be discussed.

In case of no injection, nearly the same production is reached but heterogenous is a bit better than homogeneous. In water injection case, homogenies have a better result than heterogeneous reservoir. And in the last case, gas injection into the heterogeneous reservoir has a better result than homogeneous. In gas injection in open hole wells in homogeneous well the oil production finishes after 2.3 years. See Figure 25, Figure 26, Figure 27.

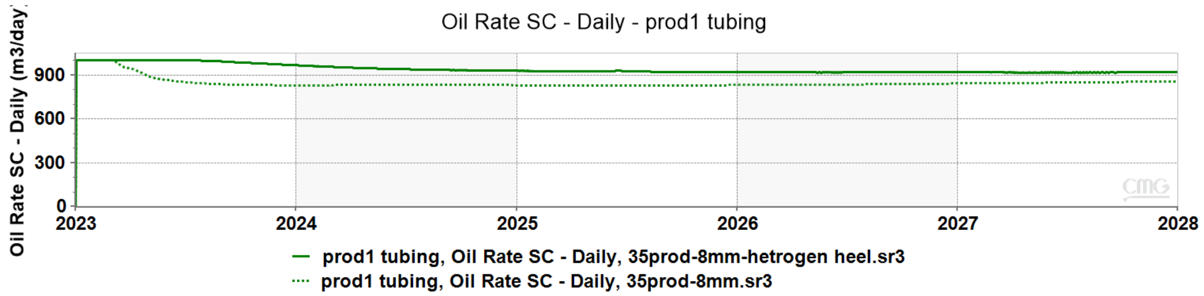

Figure 25 Oil production open hole, homogeneous and heterogeneous no injection

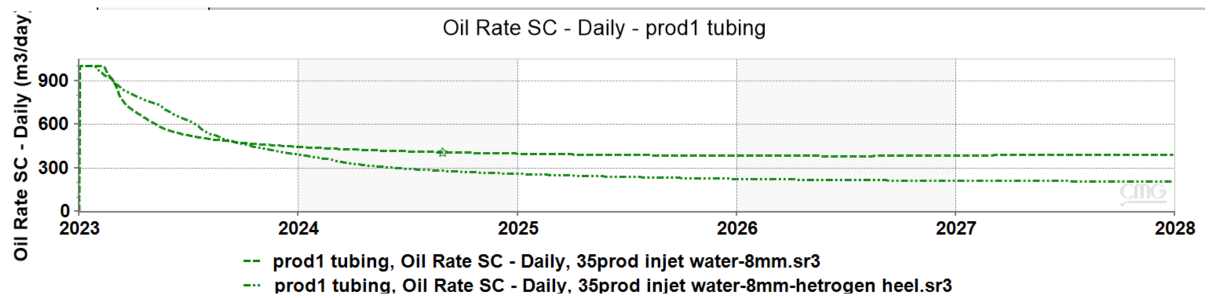

Figure 26 Oil production open hole, homogeneous and heterogeneous water injection

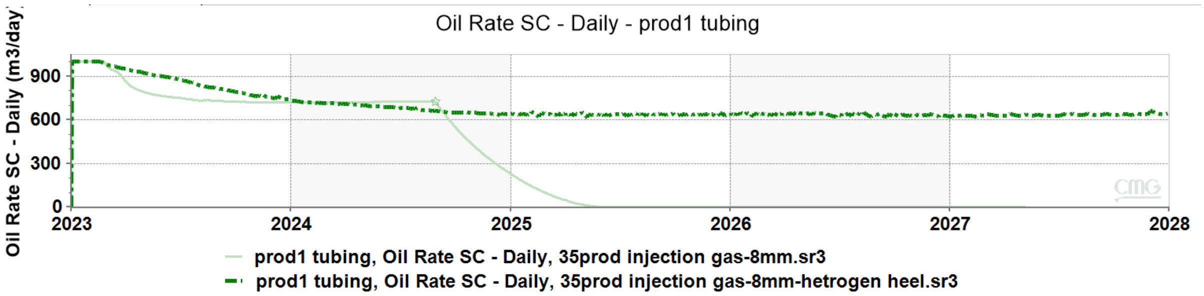

Figure 27 Oil production open hole, homogeneous and heterogeneous gas injection

based on Table 1, Table 2, Figure 28, Figure 29 best oil production can be achieved by no injection with high diameter ICD (open hole).

Table 1 Cumulative oil based on increasing & cumulative gas.

	Homogeneous reservoir	**Cumulative oil (m^3)**	**Cumulative gas (m^3)**	**Heterogeneous reservoir**	**Cumulative oil (m^3)**	**Cumulative gas (m^3)**
1	no injection well openhole	1.541e+06	5.044e+07	no injection well openhole	1.714e+06	5.545e+07
2	water injection ICD	797121	3.046e+07	gas injection well openhole	1.264e+06	4.706e+07
3	water injection openhole	797121	3.047e+07	gas injection well ICD	612781	2.430e+07
4	injection gas with ICD	559927	2.300e+07	water injection openhole	588753	2.401e+07
5	gas injection well openhole	534065	2.148e+07	no injection well with ICD	586382	2.275e+07
6	no injection well with ICD	528134	2.049e+07	water injection ICD	436818	1.819e+07

Table 2 Cumulative oil based on comparing cases & cumulative gas.

	Homogeneous reservoir	**Cumulative oil (m^3)**	**Cumulative gas (m^3)**	**Heterogeneous reservoir**	**Cumulative oil (m^3)**	**Cumulative gas (m^3)**
1	no injection well openhole	1.541e+06	5.044e+07	no injection well openhole	1.714e+06	5.545e+07
2	water injection ICD	797121	3.046e+07	water injection ICD	436818	1.819e+07
3	water injection openhole	797121	3.047e+07	water injection openhole	588753	2.401e+07
4	gas injection well openhole	534065	2.148e+07	gas injection well openhole	1.264e+06	4.706e+07
5	injection gas with ICD	559927	2.300e+07	gas injection well ICD	612781	2.430e+07
6	no injection well with ICD	528134	2.049e+07	no injection well with ICD	586382	2.275e+07

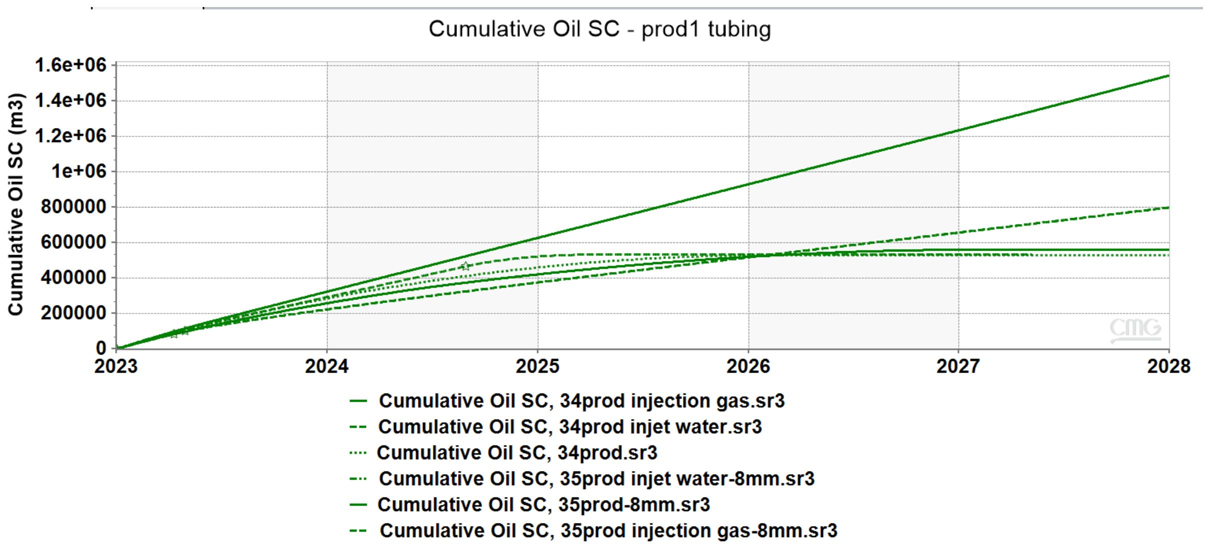

Figure 28 cumulative oil homogeneous

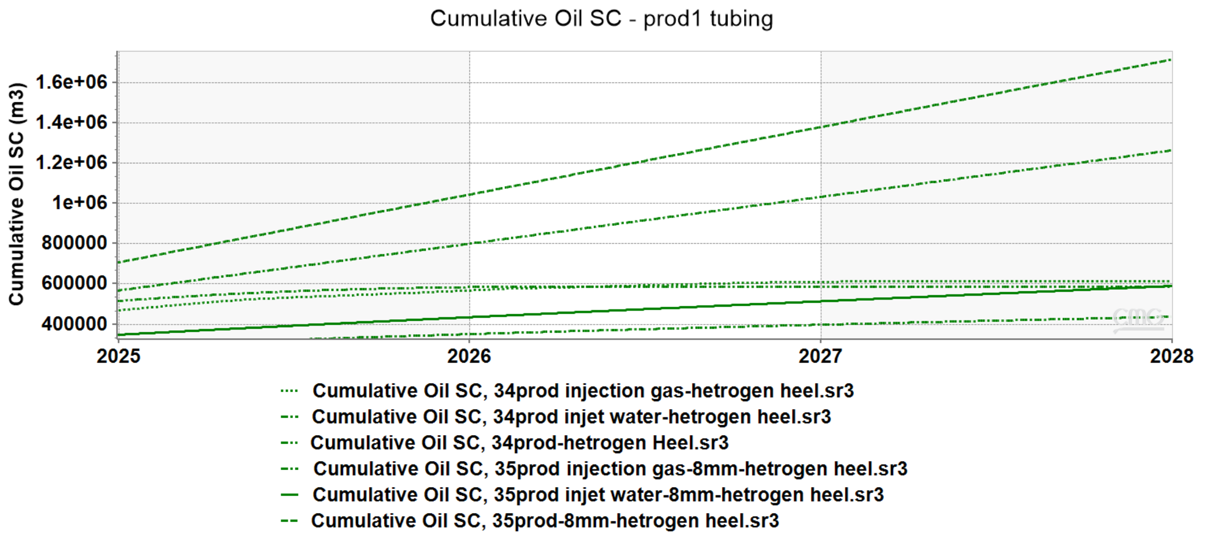

Figure 29 cumulative oil heterogeneous

by changing the grid thickness in z direction (from 5 to 10 m) between injection well and production well from 15 meters to 50 meters and changing the maximum injected fluid to 350 m^3/day for water and gas in the heterogenies and homogeneous reservoir the result changes. And the maximum limitation for oil production is still 1000 cubic meters per day. By using ICD valve less gas can be produced in compared to openhole valve. See Table 3, Table 4, Figure 30, Figure 31.

Table 3 Cumulative oil based on increasing.

	Homogeneous reservoir	**Cumulative oil (m^3)**	**Cumulative gas (m^3)**	**Heterogeneous reservoir**	**Cumulative oil (m^3)**	**Cumulative gas (m^3)**
1	no injection well openhole	1.82241e+06	5.997e+07	no injection well openhole	1.82224e+06	6.014e+07
2	water injection ICD	1.510e+06	5.619e+07	gas injection well openhole	1.821094e+06	6.270e+07
3	water injection openhole	1.510e+06	5.619e+07	water injection openhole	1.397e+06	5.334e+07

4	gas injection well ICD	747619	2.935e+07	water injection ICD	1.136e+06	4.500e+07
5	gas injection well openhole	741772	2.886e+07	gas injection well ICD	802575	3.096e+07
6	no injection well with ICD	662214	2.560e+07	no injection well with ICD	676098	2.613e+07

Table 4 Cumulative oil based on comparing cases.

	Homogeneous reservoir	**Cumulative oil (m^3)**	**Cumulative gas (m^3)**	**Heterogeneous reservoir**	**Cumulative oil (m^3)**	**Cumulative gas (m^3)**
1	no injection well openhole	1.82241e+06	5.997e+07	no injection well openhole	1.82224e+06	6.014e+07
2	water injection ICD	1.510e+06	5.619e+07	water injection ICD	1.136e+06	4.500e+07
3	water injection openhole	1.510e+06	5.619e+07	water injection openhole	1.397e+06	5.334e+07
4	gas injection well openhole	741772	2.886e+07	gas injection well openhole	1.821094e+06	6.270e+07
5	gas injection well ICD	747619	2.935e+07	gas injection well ICD	802575	3.096e+07
6	no injection well with ICD	662214	2.560e+07	no injection well with ICD	676098	2.613e+07

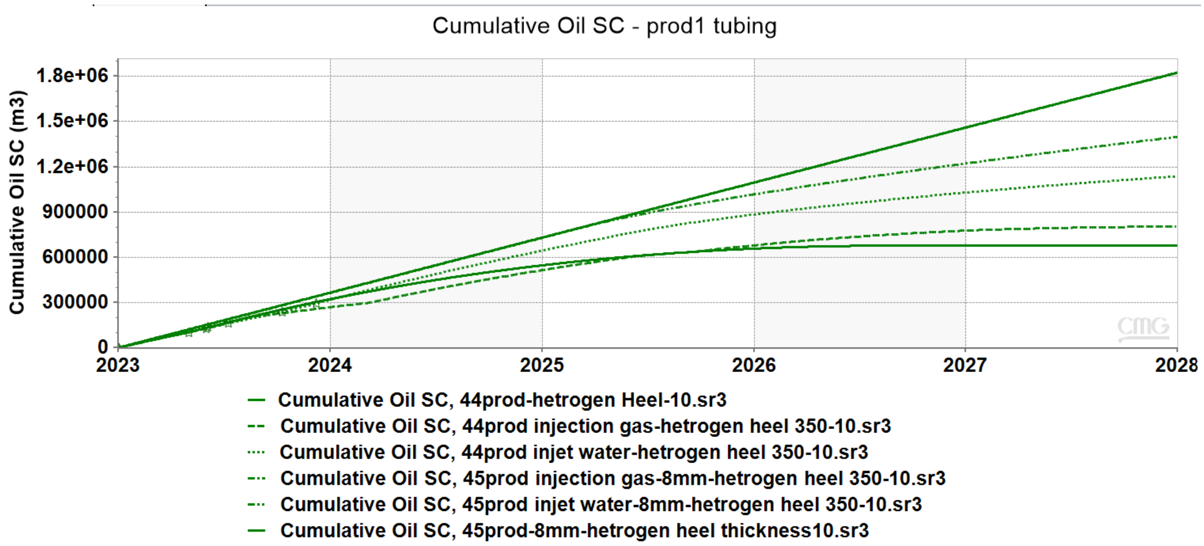

Figure 30 cumulative oil heterogeneous

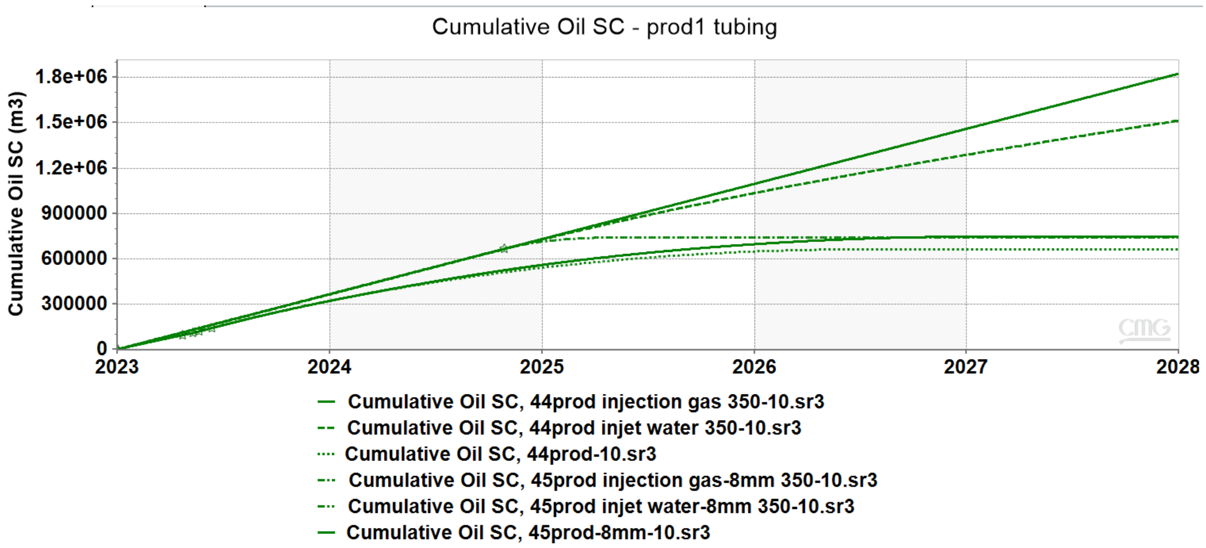

Figure 31 cumulative oil homogeneous

In homogeneous case result are not a very good one so we focus more on heterogeneous case and by increasing the duration of production to 2045 and also increasing the CO_2 injection rate from 350 to 2000 m^3/day, finally more oil can be reached by gas injection in compared to no-injection in heterogeneous reservoir with open hole (ICD with high diameter 8mm) see Table 5, Figure 32, Figure 33.

Table 5 cumulative oil and gas

	Heterogeneous reservoir	Cumulative oil (m^3)	Cumulative gas (m^3)
1	gas injection well openhole	4.787e+06	3.72e+08
2	no injection well openhole	4.695e+06	3.42e+08

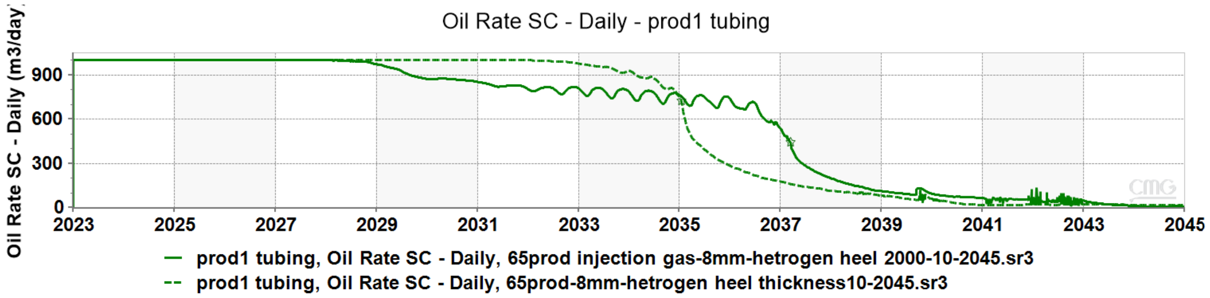

Figure 32 oil rate heterogeneous, gas and no-injection

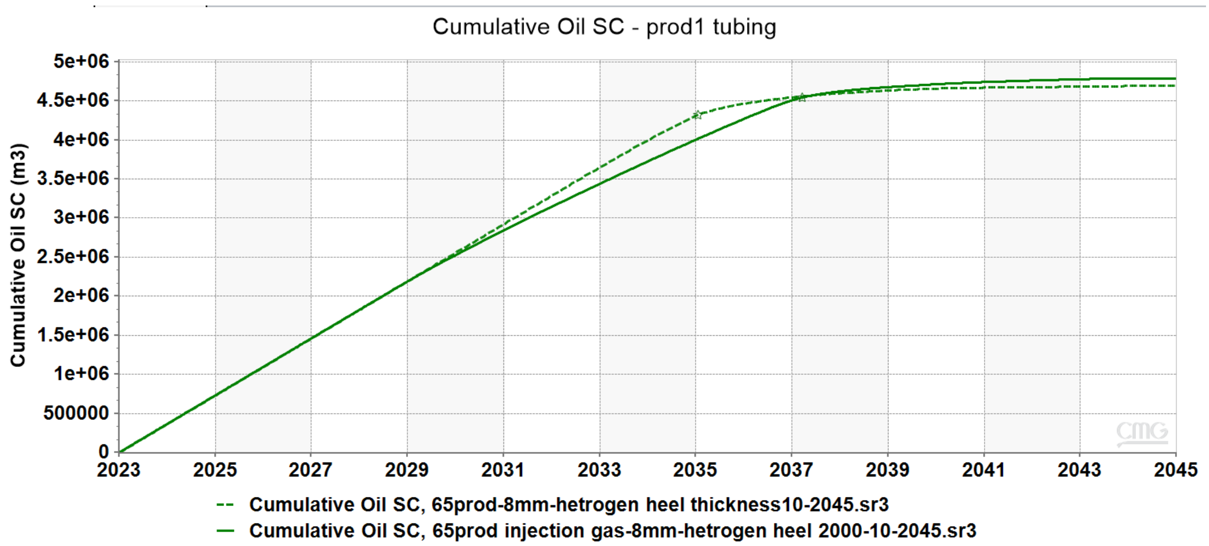

Figure 33 cumulative oil heterogeneous gas and no-injection

To reduce the cost of production, gas can be injected in the middle of production, so the gas is injected in 2029 and better result can be achieved in compared to no-injection, but still less than injection of CO_2 from the first. Injecting the gas in the middle of production in compared to no-injection can store more gas in the reservoir and more oil production too. See Table 6, Figure 34Figure 34.

Table 6 cumulative oil & gas heterogeneous

	Heterogeneous reservoir	Cumulative oil (m^3)	Cumulative gas (m^3)
1	gas injection (from the first) well openhole	4.787e+06	3.72e+08
2	gas injection well openhole in starts from Nov2029	4.759e+06	3.42e+08
3	no injection well openhole	4.695e+06	3.59e+08

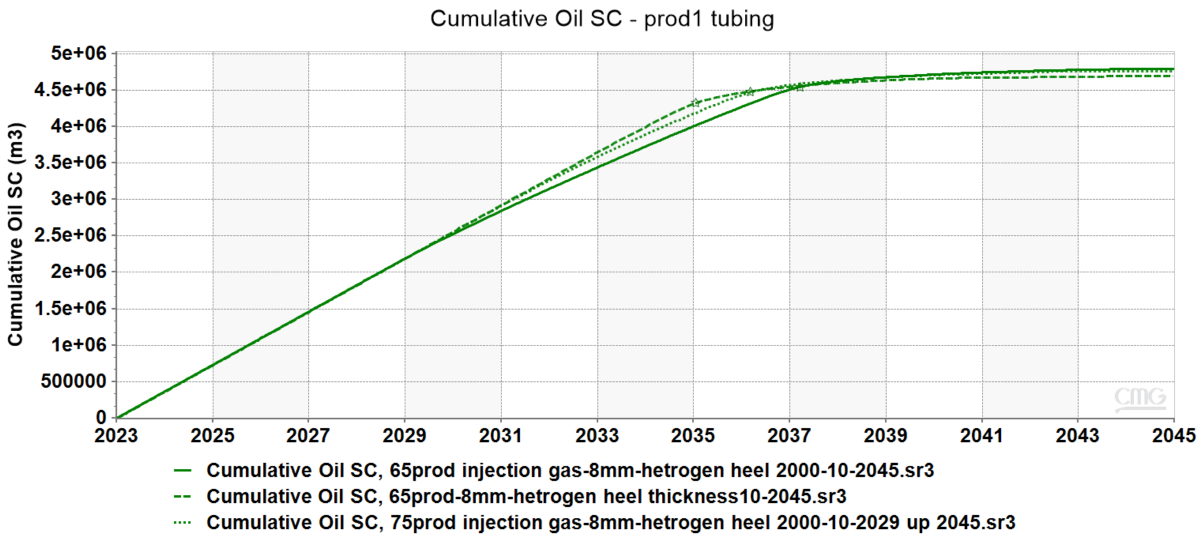

Figure 34 cumulative oil heterogeneous

So now one output from these simulations is injecting the gas in during of our production, can reach better production than no injection.

Now, injecting CO_2 in the middle of production can be tested on no-injection and gas injection in heterogeneous reservoir with open hole well, maximum 3000 m^3/day oil production, maximum 1200 m^3/day fluid injection from 2023-2028 and injection of gas will be started at Nov 2024. By injecting the CO_2 the efficiency of oil production will be increased and less gas will be produced which means that more gas is stored in reservoir. See Figure 35, Table 7.

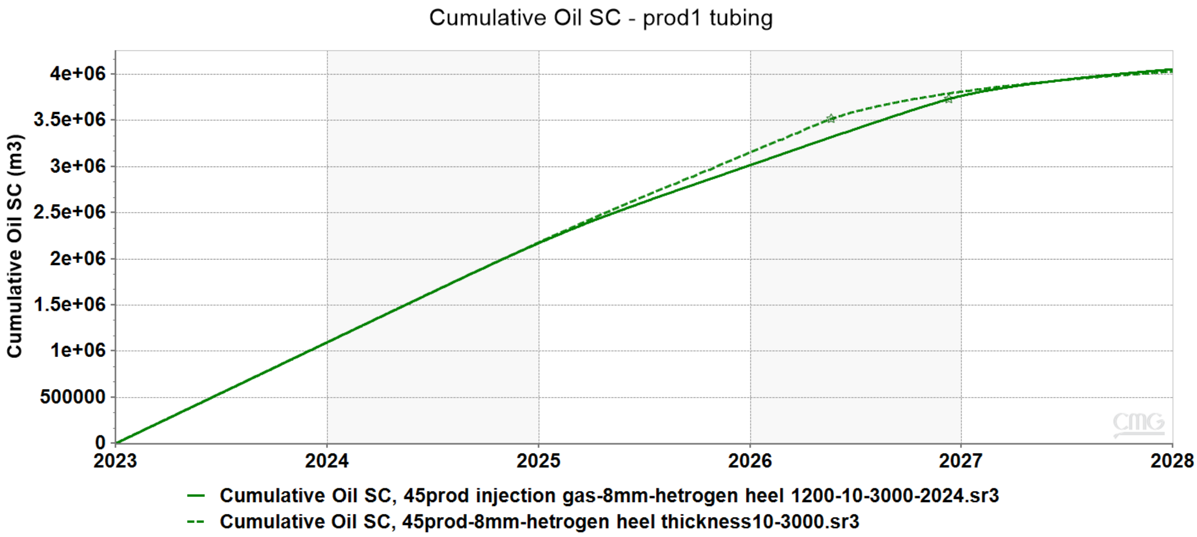

Figure 35 cumulative oil heterogeneous

Table 7 cumulative oil heterogeneous

	Heterogeneous reservoir	**Cumulative oil (m^3)**	**Cumulative gas (m^3)**
1	gas injection well openhole in starts from Nov2024	4.049e+06	1.97e+08
2	no injection well openhole	4.025e+06	2.52e+08

5 Conclusion

In general, oil production is discussed in this thesis and different injections were tried to implement in two kinds of reservoirs and EOR method, homogeneous and heterogeneous. ICD is used in both injection and production wells. By simulating 12 cases and getting the result of them the best and most effective solution can be selected.

At first, the best oil production can be reached in no-injection than injection CO_2 but by modifying other parameters such grid thickness, maximum CO_2 injected, still the production in CO_2 injection is lower than no-injection. By increasing the duration of production from 5 years to 22 years and increasing the CO_2 injection from 350 to 2000 m^3/day finally more oil can be produced from gas injection method than no-injection method.

But due to the consideration of cost of this production, in another case, gas is injected in 2029 (not from the start of production) and the result shows that better production can be achieved than no-injection method but still less than CO_2 -injection method which was injected from the first of production and as the result more money can be saved by this method.

And, in case of environmental view, better gas storage can be achieved by ICD in compared to openhole, and if the start of injection gas is from the middle of production, more CO_2 can be stored in the reservoir in compared to injection $CO_2$from the first or no-injection case.

As a conclusion in long time production, by EOR method and injecting CO_2 from the start of project, more oil can be produced than no-injection and CO_2-injection (start injection in the during the production) but it cost more money, so it is recommended that CO_2 injection starts in during the production and more CO_2 can be saved in the reservoir which is so beneficial for environment.

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