Compositional Grading and its Effects on Optimization of a CO_2 Injection Project; A Case Study

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Abstract

In any comprehensive reservoir study the first step is an accurate assessment of the spatial distribution of the fluid components in both horizontal and vertical directions. Compositional grading, which refers to variation in fluid composition with depth, has been observed in many reservoirs. In most cases, the oil density and heavy components composition increase with depth while methane and other light components composition decrease with depth. Such a compositional grading can have a significant influence on various aspects of reservoir development. When considering gas injection, one must be aware that compositional effects (such as the development of miscibility) change with depth.Although there are numerous studies about compositional grading and all authors emphasized that variation of composition makes variation of miscibility condition, but all of them try to formulate this phenomenon based on the thermodynamic approach to reach to a proper model in order to predict composition and other reservoir fluid properties along the reservoir column, and there is a lack of attention to its effects on gas injection.In this work one of the southwest Iranian oil reservoirs was selected. The reservoir under study was a low shrinkage undersaturated oil reservoir with the oil API gravity of 30. Two simulation models of CO_2 injection for enhanced oil recovery (EOR) process were prepared, one with considering compositional grading, and the other for uniform fluid condition. Two models were compared and the effect of compositional grading on optimum injection rate and recovery factor was studied. Considering compositional grading results in a more realistic but more complex simulation model, and simulation run time would increase, but because of the drastic difference between the results of the two cases, it cannot be ignored.

Keywords:compositional grading, enhanced oil recovery, carbon dioxide, optimization, fielddevelopment, reservoir simulation

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ISBN ۹۷۸-۶۰۰-۶۷۲۰-۰۰-۵

1 Introduction

The compositional grading phenomenon refers to the variation of fluid composition with depth in a reservoir. As depth increases, the mole fraction of light components decreases, density increases and gas oil ratio (GOR) decreases. Near critical oils and volatile fluids exhibit the largest compositional grading effects while black oils have the least variation in properties with depth. Compositional grading is less if the system is highly undersaturated[1].

Numerous examples of petroleum reservoirs with significant compositional gradients can be found in the literature. Most of them report decreasing methane content and solution gas oil ratio with increasing depth, but increasing amount of heptane and heavier components. The variation of composition with depth generates variations in otherreservoir fluid properties, such as density, molecular weight, and saturation pressure. It is desirable to determine the importance of these effects as early as possible. Compositional gradients are particularly important in thick reservoirs or reservoirs with large structural relief [2, 3 and 4].

This phenomenon is not only in oil reservoirs, but also is reported in gas reservoirs too. GhawarKhuff is one of huge gas reservoirs which compositional grading is observed. In this reservoir all hydrocarbon components, including heavy ends, decrease in composition with depth. But the non-hydrocarbon gases, hydrogen sulfide, carbon dioxide, and nitrogen all increase in composition with depth. Condensate gas ratio (CGR) and dew point pressure decreases with depth [5].

Assessment of compositional grading is important in calculation of initial hydrocarbons in place (stock-tank oil and surface gas), prediction of gas-oil contact, design of surface production requirements, design of immiscible gas and water injection processes (variation in mobility ratio with depth), design of developed miscible gas injection processes (variation in miscibility conditions with depth), initialization of reservoir simulators, and consideration of production alternatives. These factors can have significant economic impacts on field development [6].

In gas injection projects, compositional effects such as miscibility development, saturation pressure, and other fluid properties change as the depth increases. While compositional grading effects are more considerable in volatile oils, they may influence the field development in reservoirs with heavier oils as well.An example is a North African field in which strong grading in stock-tank oil gravity and a related variation in reservoir oil viscosity have been observed. In this case, the presence of highly viscous oil near the oil/water contact has forced production from updipand would be a serious obstacle for downdipwater injection [1].

Although there are numerous studies about compositional grading and all authors emphasized that variation of composition makes variationof miscibility condition, but all of them try to formulate this phenomenon based on the thermodynamic view to reach to a proper model in order to predict composition and other reservoir fluid properties along the reservoir column, and there is a lack of attention to its effects on gas injection.

1.1 Compositional Grading Theory and Models

Calculation of the compositional variations of the reservoir fluid with depth is usually based on the assumption that the mass flux of all the components is equal to zero and the system is in a "stationary" state [7] in the absence of convection.

To satisfy the condition of zero component net flux, a balance of driving forces or flux equations is used. The driving forces considered include chemical energy, gravity, and thermal gradient. The general equation to be satisfied, for all but one component is:

$$\sum_{k=1}^{n-1}\left(\frac{\partial \mu_i}{\partial X_k}\right)\nabla X_k = F_{Gi} - F_{Ti}\frac{\nabla T}{T} \qquad (1)$$

Where μ_i is the chemical potential of component i,X_k is the mole fraction of other components, T is temperature, $F^g{}_i$and $F^T{}_i$ are the gravitational segregation force and the thermal force of the component irespectively[8].

Gravitational force usually results in maximum compositional variation, while thermal diffusion tends to mitigate the gravitational segregation [8].

Based on the assumptions the most important compositional grading models are isothermal and thermal models. Isothermal model considers the gravity chemical equilibrium condition and ignore the temperature variation while thermal model incorporate the effect of the geothermal temperature gradient and thermal diffusion as well. These models give the pressure, temperature and composition at reference depth and calculate composition and other fluid properties at specified depths [6 and 8].

2 Simulation Approach

To investigate the effect of compositional grading on a gas injection project and optimum injection rate, one of the Iranian southwest oil reservoirs with the oil API gravity of 30 was selected. The thickness of the reservoir was 500 ft and the net to gross (NTG) ratio was 0.673. It was produced under natural depletion mechanism for all of its lifetime. Because of nearby power plants, this is a good candidate for CO_2 injection. There is some evidence such as saturation pressure change and variation in oil formation volume factor (FVF) with depth which approve the existence of composition variation through the reservoir column. Effect of compositional gradient on saturation pressure and reservoir pressure is shown is figure (1).

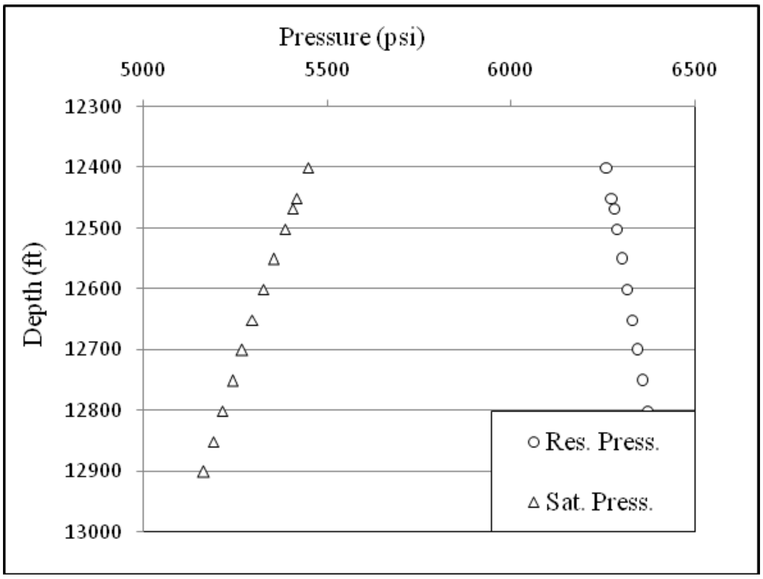

Figure 1.The effect of compositional grading on saturation and reservoir pressure

A full compositional reservoir simulation model was prepared with accurate petrophysical, geological, and PVT data. History matching with 30 years of production and

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pressure data was then conducted to confirm the validity of the simulation model. This model was used to simulate the uniform composition case with the considering composition of the datum depth (12468 ft). Then the compositions at other depths were calculated and imported into the model. For this purpose the isothermal compositional grading model is used to simulate the case of compositional grading in the reservoir. Isothermal compositional grading model is known to be the best model to predict the fluid composition through the reservoir column for Iranian oil reservoirs [9]. Finally, the two models were compared and the effect of compositional gradient on optimum gas injection rate was studied.

2.1 Gas Injection

In a gas injection project, variations of compositional effects such as miscibility development with depth must be taken into consideration [1]. Although different parameters such as the amount of the total injected gas and optimum injection rate, injection well bottom hole pressure and generally the field pressure, miscibility, etc., are influenced if the compositional grading model is used in the gas injection simulation studies, we only deal with the optimum injection rate and recovery factor as these are affected by all the other parameters.

For this purpose, a simulation model with two wells were prepared so that one of the two wells in the reservoir is considered as an injection well, and the other well is assumed to be a production well. 50-year production-injection scenario for CO_2 injection is conducted.

3 Sensitivity Analyses

Somesortofsensitivityanalysis was done uponinjectionratetosee itsimpactonreservoiroil recovery factorandplateauenhancementbyincreasingthe recoveryduration.Theresultsofsensitivityanalysison two cases, with and without considering compositional grading, for production rate of 2500 (STB/Day) willbe described in thefollowingsections which arethesimulation results.

3.1 Considering Compositional Grading

InthiscaseeightdifferentCO$_2$injectionratesof10,11, 14, 16, 18, 20, 22and 24 (MMscf/Day) aretested. As it is clear from the figures (2) and (3), by increasing the injection rate the field oil recovery factor and plateau time increased till injection rate of 20 (MMscf/Day), but because of the injection well constraints such as maximum pressure limit, the maximum operational rate of injection is 11 (MMscf/Day) which is the optimum injection rate. This is shown in figure (4).If there was no operational limits on controlling the injection rate like the uneven patterns in figure (4), injection rate of 20 (MMscf/Day) would be the optimum injection rate.

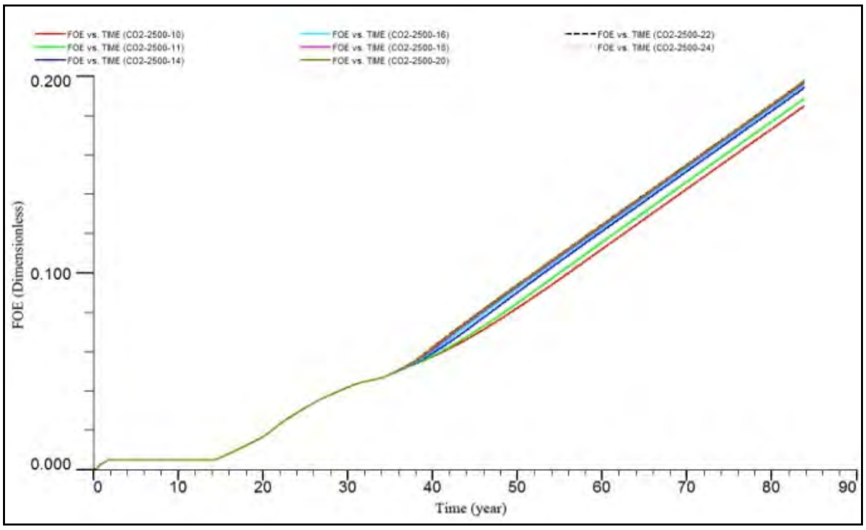

Figure 2.Effect of injection rate on field oil recovery factor

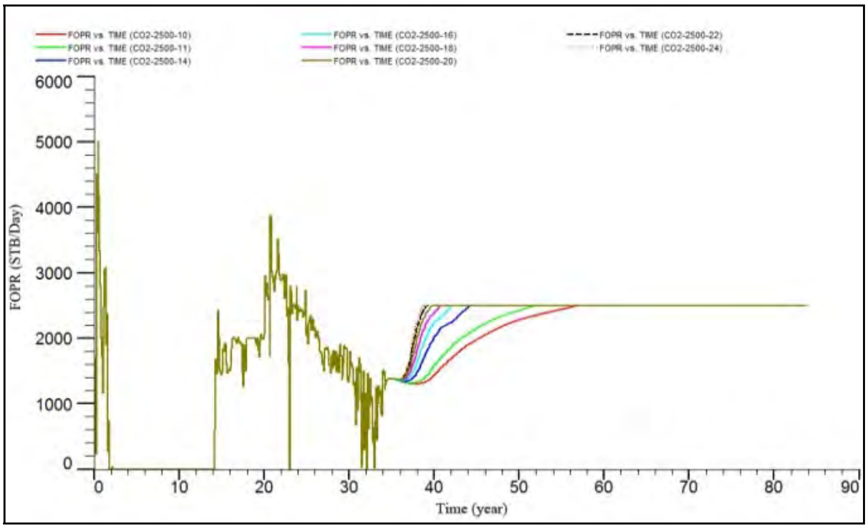

Figure 3.Effect of injection rate on plateau time

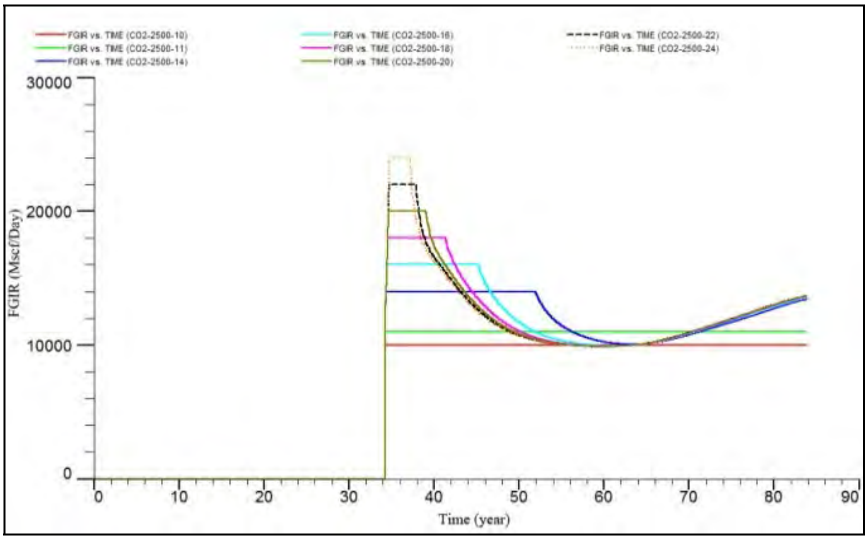

Figure 4.Effect of injection well constraints on injection rate

3.2 Uniform Composition

In this case eight different injection rates of 8, 9, 10, 11, 14, 16, 18 and 20 (MMscf/Day) are tested. Like the previous case, as it can be seen in figures (5) and (6), by increasing the injection rate, the field oil recovery factor and plateau time increasedtill injection rate of 14 (MMscf/Day), but because of operational limits of handling the injection rate, as it is clear in the figure (7) the optimum injection rate is 9 (MMscf/Day). Theoretically if there was no obstacle on injection rate, like the uneven patterns in figure (7), the optimum rate would be 14 (MMscf/Day).

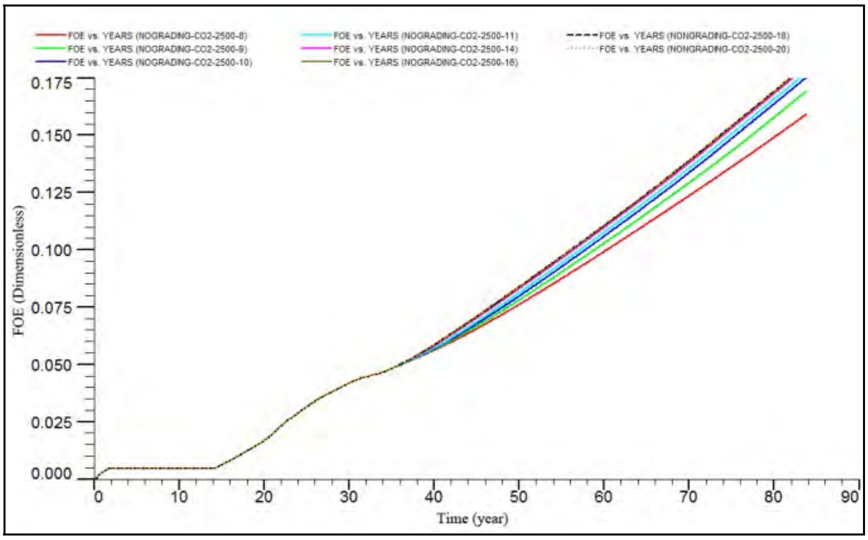

Figure 5.Effect of injection rate on field oil recovery factor

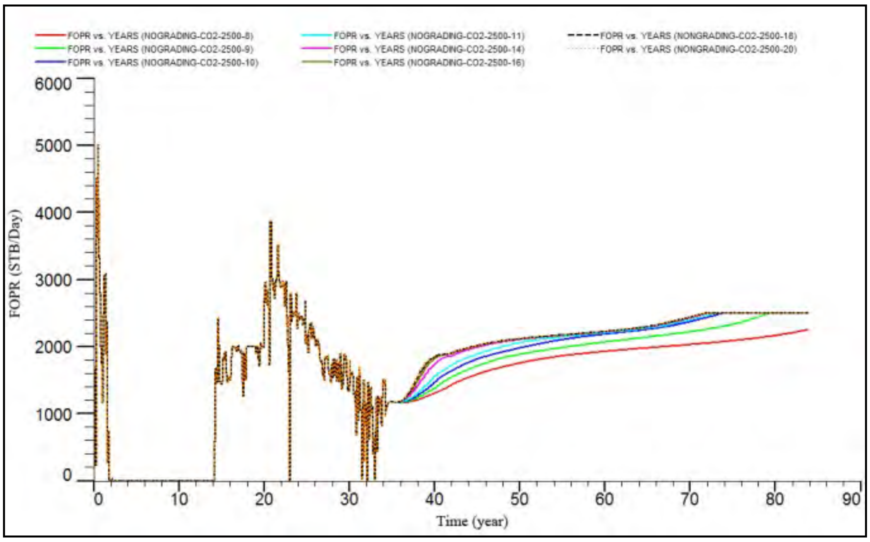

Figure 6.Effect of injection rate on plateau time

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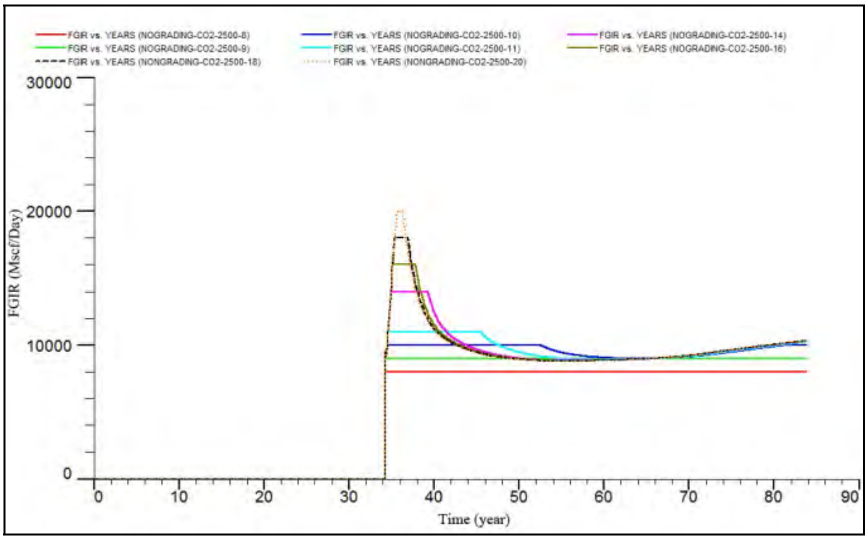

Figure 7.Effect of injection well constraints on injection rate

3.3 Compositional Grading versus Uniform Composition

It is shown that considering compositional grading affects the optimum injection rate. But in order to completely clarify the drastic difference between the two cases, it is better to compare two cases in field oil recovery factor and the plateau time at optimum injection rates.

In figure (8) the difference between the two models in field oil recovery factor at operational optimum rates is shown. As it is clear from figure (8), thefinal oil recovery factor difference for two cases is about 2 percent.

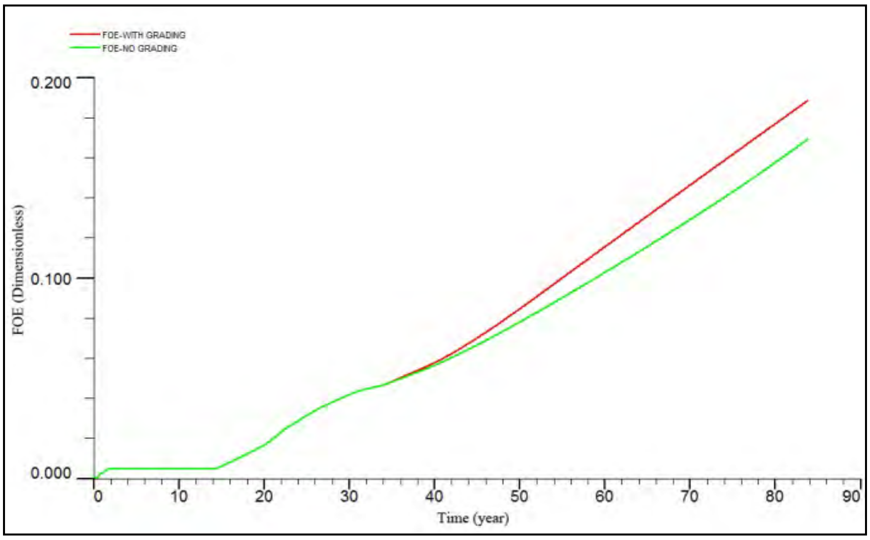

Figure 8.Comparison between oil recovery factor in optimum injection rate of two cases

Plateau time of two cases is shown in figure (9). This is clear that when compositional grading is considered the plateau time is increased rapidly and leads to a long time constant production rate.

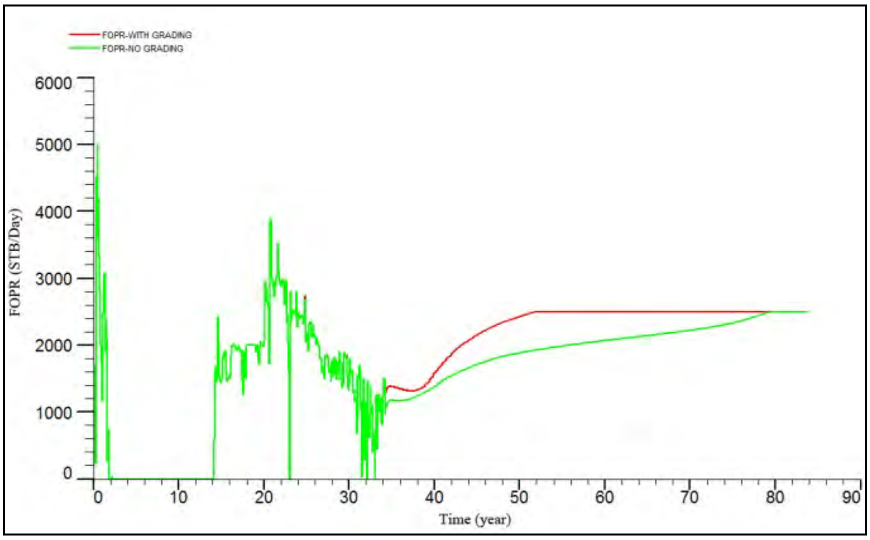

Figure 9.Comparison between oil production plateau at optimum rate of two cases

Conclusions

1) Considering compositional grading results in a more realistic simulation model.

2) By taking compositional grading into consideration the complexity of the model rises and simulation run time would increase, but because of the drastic resultant difference, it cannot be ignored.

3) Even if there was no operational constraint on gas injection, the optimum injection rate would be different in both cases.

4) The case under this study was a low shrinkage oil reservoir. The error due to considering uniform composition fluid could be much higher for volatile oil reservoirs.

5) While the reservoir thickness and the NTG ratio are relatively small, the saturation pressure change along the reservoir column is noticeable.

Nomenclature

CGR = condensate gas ratio

FVF = formation volume factor

F^g_i= gravitational segregation force of the component i

F^T_i= thermal force of the component i

GOR = gas oil ratio

NTG = net to gross

T = temperature

X_k= mole fraction of component k

μ_i = chemical potential of component i

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