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To cite this article: Chen Taoping *et al* 2019 *IOP Conf. Ser.: Earth Environ. Sci.* **242** 022034

IOP Conf. Series: Earth and Environmental Science **242** (2019) 022034 doi:10.1088/1755-1315/242/2/022034

Non-homogeneous Influence the Effect of CO_2-N_2 Compound Flooding in Ultra-low Permeability Reservoir

Chen Taoping, ZhaoBin, Bi Jiaqi, Sun Wen

Enhanced Oil and Gas Recovery Key Laboratory of Ministry of Education, Northeast Petroleum University, Daqing 163318, China

Abstract. Affected by reservoir rhythmicity, permeability contrast and length-thickness ratio, using carbon dioxide-nitrogen compound flooding in ultra-low permeability non-homogeneous reservoir will influence the oil recovery. Based on the experimental core model, a series of targeted models are established by changing the correlation parameter by numerical simulations. The results shows that, the higher heterogeneity, the lower oil recovery in reservoir, the less carbon dioxide injection should be needed to achieve the maximum recovery; because of the gravitational differentiation and fluid exchange between the oil layers, using carbon dioxide-nitrogen compound flooding in non-interbedded positive rhythm reservoir will have a better recovery than positive rhythm of interbedded reservoir, negative rhythm of interbedded reservoir and negative rhythm reservoir without interbed; when the permeability contrast is a constant, the larger length-thickness ratio, the later the gas breakthrough and the higher oil recovery.

1. Introduction

As of 2014, the EOR production by carbon dioxide flooding in the USA has already reached to the 1371×10^4 t, which accounted for 93% in the world at reference [1-3]. For the past few years, in China, over eight billion tons oil-geology reserves which belong to the low permeability and ultra-low permeability reservoir have been proved up. For these reservoir, water flooding development is a difficult way but could be a better way to inject carbon dioxide. Carbon dioxide flooding pilot experiments have already achieved a good effect like Daqing, North China, Jilin in China at present. In Zhongyuan Oil Field, fluid physical parameters during the carbon dioxide multiply contact the oil by the way of numerical simulations at reference [4]. Supercritical carbon dioxide miscible flooding experiment had been done at reference [5]. The result shows that, in miscible conditions, carbon dioxide can be hold back through the miscible zone. Because water can have a bad influence on miscible condition during the water alternating gas flooding, the slug should be adjusted.

Foreign gas in carbon dioxide can have much impact on the minimum miscible pressure at reference [6]. The oil minimum miscible pressure had been measured by slim-tube experiment. The result can combine with the empirical formula then provide guidance to the field production at reference [7]. Reference [8] indicated that carbon dioxide slug ＋ nitrogen flooding can improve the oil recovery and shorten the development cycle. Because of the diffusion and dispersion between the carbon dioxide and nitrogen, in order to avoid it, the carbon dioxide slug needs a certain length. Dynamic variation of oil component content during the carbon dioxide slug + nitrogen compound flooding in slim tube model had been simulated by the way of numerical simulations. The result indicates that 0.3 PV carbon dioxide can prevent the diffusion and dispersion between the carbon dioxide and nitrogen at reference [9]. Reference [10] indicated that in non-homogeneous model, carbon dioxide can breakthrough the oil during the carbon dioxide flooding. Because the actual reservoir has non-homogeneity. The research of carbon dioxide - nitrogen compound flooding in non-homogeneous ultra-low permeability reservoir model will be done through the way of numerical simulations. The result can provide guidance to the experiment.

2. Non-homogeneous model

The non-homogeneous physical model was established by CMG numerical simulation software, like the Figure 1. The lower permeability is $3\times10^{-3}\mu m^2$, porosity is 10%; The higher permeability is $9\times10^{-3}\mu m^2$, porosity is 10.2%; The permeability contrast is 3; Formation temperature is 90°C; Grid partitioning: 100 grids in *i* direction; Grid spacing is 0.0025m in *j*， *k* direction.

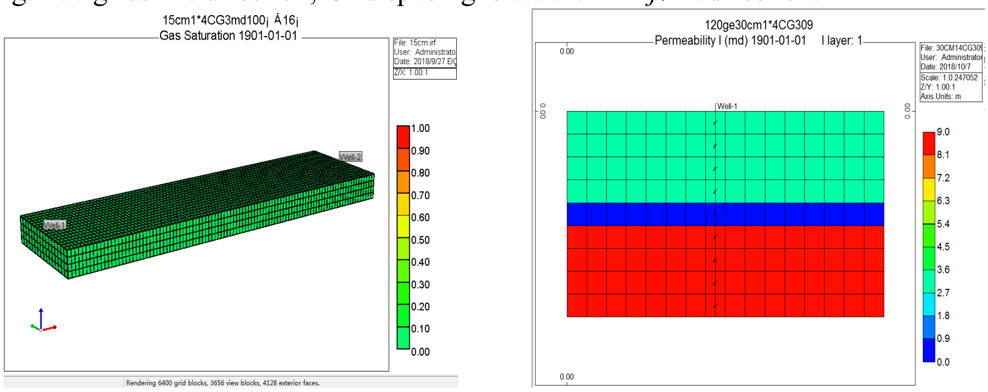


Figure 1. Non-homogeneous model

3. Permeability contrast & reservoir rhythm

The relation curve between the carbon dioxide slug + nitrogen compound flooding in 4 different kinds of permeability contrast with different reservoir rhythm and the carbon dioxide injection (PV) have been stimulated by CMG in model's length-thickness ratio 30. The results are shown in Figure 2, Figure 3.

Figure 2 is the relation curve between the oil recovery in carbon dioxide–nitrogen compound flooding and carbon dioxide injection (PV) in positive rhythm reservoir. The result shows that when the permeability contrast is a constant, the higher carbon dioxide injection, the higher oil recovery is, then till the steady. When the permeability contrast has been changed, the oil recovery will also be changed. As the permeability contrast increased, the oil recovery will decrease from 45.2% to 32.1%, but the oil recovery curves' rule is consistency. Meanwhile as the permeability contrast decrease, the properties of the upper and lower two oil layers tend to be consistent; the carbon dioxide injection (PV) in the maximum oil recovery will be changed from 0.25 PV to 0.5 PV. The result shows that, reservoir thickness will influence the carbon dioxide slug's size when the oil recovery is the maximum.

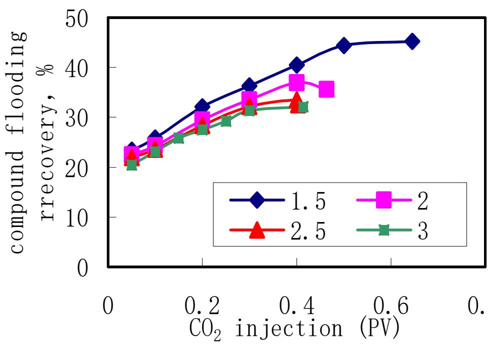


Figure 2. Positive rhythm recovery curve

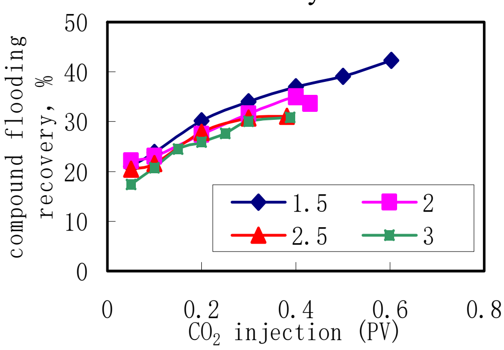


Figure 3. Negative rhythm recovery curve

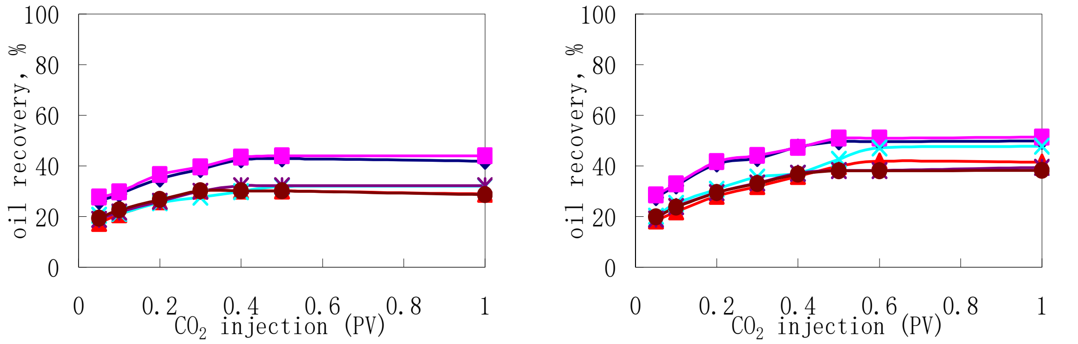
Figure 3 is the relation curve between the oil recovery in carbon dioxide–nitrogen compound flooding and carbon dioxide injection (PV) in negative rhythm reservoir. The result shows that as the permeability contrast increased, the oil recovery is decreased and the rule is same with the positive rhythm reservoir model; the difference is negative rhythm reservoir model have a lower oil recovery than positive rhythm reservoir model. The oil recovery by carbon dioxide + nitrogen compound flooding will decreased as the permeability contract increased; the number will be changed from 42.3% to 30.8% and the carbon dioxide injection (PV) will increased from 0.25 PV to 0.6 PV, when the oil recovery is the maximum.

Contrast Figure 2 and Figure 3, when the model length-thickness ratio is 30 and the permeability contrast is 3, The positive rhythm reservoir model's maximum oil recovery is 32.1% and the number is 30.8% in negative rhythm reservoir model; When the permeability contrast decreased to the 1.5, the number is 45.2% in positive rhythm reservoir model and the number is 42.3% in negative rhythm reservoir model. Easy to figure out, as the permeability contrast decreased, the oil recovery will increase then the carbon dioxide injection (PV) when the oil recovery is the max; when the permeability contrast is common, positive rhythm reservoir model will have a better oil recovery than negative rhythm reservoir model.

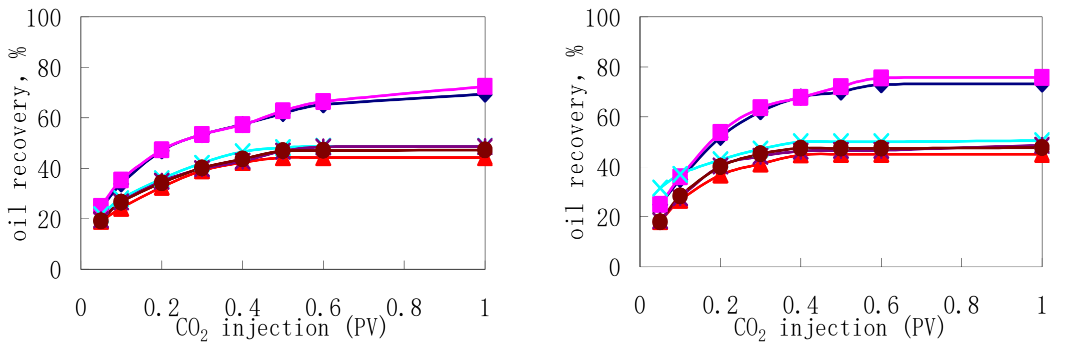
4. Length-thickness ratio

In order to research how to influenced between the carbon dioxide maximum slug in compound flooding, the ultimate oil recovery and length-thickness ratio in non-homogeneous model, take the permeability contrast 3 as an example and consider 4 situations: different permeability with impervious break (309, 903) and different permeability without impervious break (39, 93) then changed the models' length, the maximum effective slug size and ultimate oil recovery in carbon dioxide–nitrogen compound has been simulated in different length –thickness ratio non-homogeneous reservoir model. Meanwhile, for convenient comparison, Single layer homogeneous model with the permeability $3\times10^{-3}\mu m^2$ and $9\times10^{-3}\mu m^2$ also be simulated in Figure 4.

From Figure 4, the result shows, as the carbon dioxide injection (PV) increased the oil recovery increased then steady when it reached the maximum and the rule is the same in different length-thickness ratio model; The different is as the length-thickness ratio increased, the oil recovery also increased, the results indicated that, model's length-thickness ratio can make the benefit to the oil recovery.

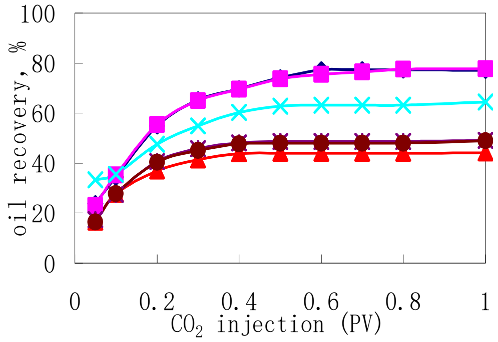


(a) Length-thickness ratio 30 **(b)** Length-thickness ratio 50

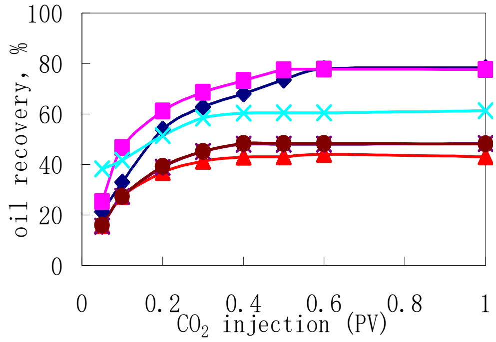


(c) Length-thickness ratio 100 **(d)** Length-thickness ratio 200

IOP Conf. Series: Earth and Environmental Science **242** (2019) 022034 doi:10.1088/1755-1315/242/2/022034



(e) Length-thickness ratio 500



(f) Length-thickness ratio 750

permeability distribution

9 3 93 39 903 309

Figure 4. The relation curve between CO_2 PV and ultimate recovery in different length–thickness ratio non-homogeneous model

From Figure 4, the result shows, as the carbon dioxide injection (PV) increased the oil recovery increased then steady when it reached the maximum and the rule is the same in different length-thickness ratio model; the different is as the length-thickness ratio increased, the oil recovery also increased, the results indicated that, model's length-thickness ratio can make the benefit to the oil recovery. In Figure 4, two kinds of different permeability homogeneous model which are $3\times10^{-3}\mu m^2$ and $9\times10^{-3}\mu m^2$; when the length–thickness ratio increased, the curve regulation are same to the non-homogeneous models' curve but the oil recovery over it in common. It indicated that model homogeneity is benefit for carbon dioxide–nitrogen compound flooding. Two oil recovery curve of different permeability homogeneous model has been compared and it is easy to find that when the length–thickness ratio under the 100, the model which permeability is $3\times10^{-3}\mu m^2$ will have a higher recovery; When the length–thickness ratio over the 100, the recovery tends to be same but the oil recovery in model which permeability is $3\times10^{-3}\mu m^2$ will slightly higher than the model which permeability is $9\times10^{-3}\mu m^2$ and the value is 2%~3% in common which indicated that the lower permeability, the more benefit for the gas flooding.

According to the Figure 4, the curves of the maximum injection of pure carbon dioxide (PV) and the ultimate oil recovery between the model length–thickness ratio can be done. Such as Figure 5 and Figure 6.

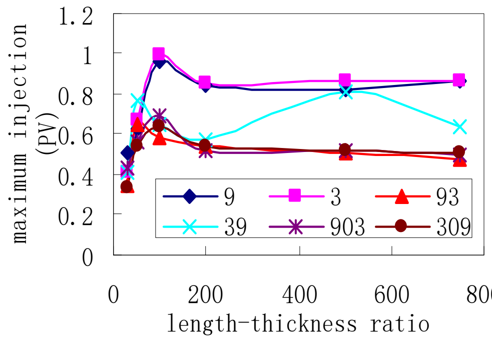


Figure 5. the maximum injection of pure carbon dioxide (PV) with the length–thickness ratio

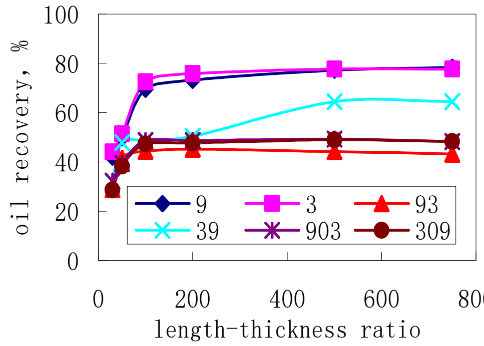


Figure 6. the ultimate oil recovery by CO_2 flooding with the model length–thickness ratio

According to the Figure 5, in non-homogeneous model, when the length–thickness ratio under the 100, the maximum injection of carbon dioxide (PV) is increased as the length–thickness ratio higher; when the length–thickness ratio over the 100, the carbon dioxide injection (PV) reach to the maximum value then the value come to small; When the length–thickness ratio reach to the 100, the value reaches to steady. In Figure 6, different kinds of models have a same rule. When the length–thickness ratio under the 100, the higher length–thickness ratio, the better oil recovery is; when the length–thickness ratio over the 100, the oil recovery tend to steady. It is easy to see, the higher length–thickness ratio, the better oil recovery to be. By comparing Figure 5 and Figure 6, it also can see they have the same rule which can proved that the ultimate oil recovery by carbon dioxide flooding is closely related to the maximum injection (PV). The remarkable fact is that, in positive rhythm model without impervious break, because of the gravitational differentiation and fluid exchange between the oil layers, the higher length –thickness can easy to get the higher oil recovery. Meanwhile, the oil recovery in non-homogeneous model is under the homogeneous model. It can be seen by comparing the results of a series models' calculation. The oil recovery of non-homogeneous model with impervious break is increased as the length–thickness increased, when the length–thickness over the 100, there is little change in oil recovery. When the length–thickness is a constant, in non-homogeneous model with the impervious break, the oil recovery curves have nothing to do with the rhythm. For the non-homogeneous model without impervious break, When the length–thickness over the 100, There is little change in oil recovery and the curve rule is the same with the non-homogeneous model with impervious break. But there is some little different when the length–thickness is a constant. The oil recovery which model with impervious break will lower than the non-homogeneous model without impervious break; It is due to the in positive rhythm model, the upper formation's permeability is lower than the lower formation. Carbon dioxide will priority to enter the lower formation and impel. Meanwhile, under the influence of gravitational differentiation, the carbon dioxide in lower formation will easy to permeate the upper formation and drive then it will achieve a better oil recovery. That is the reason why the positive rhythm models have a greater recovery than negative rhythm mode in carbon dioxide–nitrogen compound flooding. It is easy to see the fluid exchange between the oil layers has a positive effect on oil recovery.

According to Figure 4 to Figure 6, because of the gas diffusion in flooding, the greater length–thickness will cost more time than the smaller length–thickness, the oil recovery also be better. When the length–thickness under the 100, increasing the length-thickness ratio appropriately is a good way to enhance the oil recovery and when it over the 100, the influence is little; because of the gravitational differentiation and fluid exchange between the oil layers, the positive rhythm without impervious break will have a better oil recovery than other 3 kind of non-homogeneous models; when the length-thickness ratio is small, it will influence the steady of carbon dioxide slug flooding and it will be hard to influence when the length-thickness ratio reach to a special value.

5. Conclusion

(1) In carbon dioxide–nitrogen compound flooding, as the permeability contrast increasing the oil recovery decreased; the injection of carbon dioxide decreased when it reached to the maximum recovery.

(2) Because of the gravitational differentiation, the positive rhythm without impervious break will have a better oil recovery than other 3 kind of non-homogeneous models.

(3) Because of the gas diffusion in flooding, the greater length–thickness will cost more time than the smaller length–thickness, the oil recovery will also be better.

Acknowledgement

Thanks to the 13th Five-Year national major projects (2017ZX05009-004)"Feasibility study of composite gas to improve CO_2 gas flooding in low permeability-extra low permeability reservoir"support.

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