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**Research Article**

# Optimization of injection parameters for air foam profile control in low permeability oil field

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**Abstract:** In view of the high water cut, effect of strong anisotropy, low water drive spread coefficient and injected water channeling of M block in A oil field, some research on the technology of M block air foam profile control was done. On the basis of 3D geological model, method of numerical simulation and controlling variate method and input-output ratio used as an economic evaluation index were chosen to optimize the injection parameters affecting the effect of profile control. The research showed that, air foam profile control technology can significantly improve the output of M block. On the same time, to M block in A oil field, the optimal injection parameters for injection were: the foaming agent volume was 0.5PV, the foaming agent injection rate was $13m^3/d$, foaming agent concentration was 0.3%, the foaming agent injection cycle was 25d, gas injection rate was $40m^3/d$, gas-liquid ratio was 3:1.
**Keywords:** air foam profile control; injection parameters optimizing; numerical simulation; gas injection rate; gas-liquid ratio.

## INTRODUCTION

The pore structure of low permeability reservoir is complex, with fine throats and fractures usually. Also the heterogeneity of formation is serious. Previous development experience shows that the water absorption capacity of low permeability reservoir is low with high water injection pressure[1-4]. Water drive direction is also difficult to control and it is easy to crack or along the high permeable channels into the wells, thus found an inefficient circulation. Therefore, this kind of water flooding reservoir has some characteristics like has small affected area, low displacement efficiency and low recovery rate. The injection pressure of gas injection development is not high and viscosity reduction is good, but it is prone to gas channeling, so the spread area is small and the development effect is poor. Polymer flooding has a large spread area, higher cleaning efficiency.

The air foam flooding technology has the advantage of two kinds of technology of gas drive and polymer flooding. The oxygen in the air can react with the crude oil in the formation which is called low temperature oxidation reaction. During this reaction, some oxides are created such as CO and $CO_2$, which can reduce the viscosity of crude oil. Foam can significantly improve the sweep efficiency and displacement efficiency. Its mechanism is: horizontally, large pores have low oil saturation after long displacement, so foam is not easy to eliminate bubbles, which can give the foam strong sealing ability. In small pores which can not be washed for a long time have high oil saturation, so the foam is easy to eliminate bubbles and the foam has low plugging capacity. Therefore, the displacement of the system flows along the small pore, increasing the sweep coefficient. Vertically, foam can weakening the effect of gravity override on gas, which can raise the vertical sweep coefficient; foaming agent is actually a kind of surface active agent, which has the functions to reduce the interfacial tension of oil and water and improve the displacement efficiency.

### Block overview

The contract legal of M block in A oil field is sheet sand and the block mainly developed near EW cracks. The area that has oil is $3.2km^2$, and the depth of main reservoir is 1244m, and the average effective thickness is 7.2m, the effective porosity is 17.7%, the average permeability is $35\times10^{-3}\mu m^2$, and the permeability variation coefficient is 0.6, initial oil saturation is 54%, so the reservoir is middle hole low permeability reservoir. In the formation condition, the crude oil viscosity is 5.7 mPa·s, crude oil density is $0.853g/cm^3$, volume coefficient is 1.1, the original formation pressure is 13MPa, reserves abundance is $25.7\times10^4t/km^2$.

M block in A oil field was first developed in 2007, up to now, it has 5 horizontal wells, which produce 25.59t liquid per day, 4.3t oil per day, and comprehensive moisture content is 83.2%. Cumulative oil production is $2.84\times10^4$t, and mining degree is 6.88%. There are 12 water injection wells and water injection rate is $87m^3/d$, cumulative water injection is $10.47\times10^4m^3$. Till now, 2 wells without water, the water content of the 3 wells are 88.54%, 75.14%, 84.88%. The block has a high water content at present which is severely affected by heterogeneity. So this paper that on the basis of fine 3D geological modeling, uses numerical simulation and control variable method to optimization of injection parameters affecting the effect of air foam flooding, so as to guide the field practice and improve the oil recovery rate.

**Fine 3D geological modeling**

This paper is based on the structural features and reservoir properties of M block in A oil field, using Petrel to found fine 3D geological model, figure 1. After geological reserve fitting by CMG, a fitting method that gradually refine from the whole to the part is used to fit the formation average pressure, cumulative oil production, single well oil production and single well water cut in M block and achieve the required accuracy requirements.

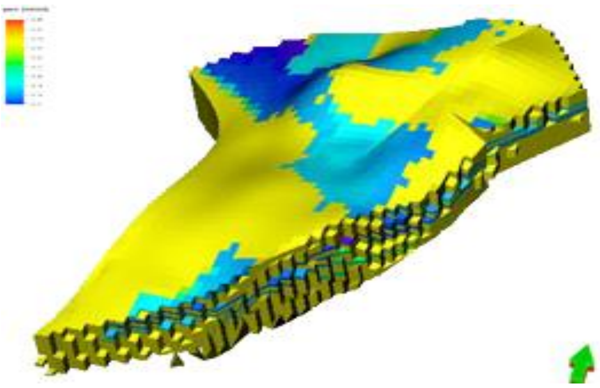

**Fig-1: Fine 3D geological model of M block**

**Injection parameters for air foam profile control optimizing**

Considering execution and the corrosion of the pipelines[4], the air and foaming agent were alternately injected. Therefore, it is necessary to optimize the injection parameters. According to the geological and practical characteristics of M block, the optimized injection parameters include: the foaming agent volume, the foaming agent injection rate, foaming agent concentration, foaming agent concentration the foaming agent injection cycle, gas injection rate, gas-liquid ratio.

***Foaming agent volume***

The volume of foam is affected directly by the foaming agent volume, and the foam volume affects the oil displacement in the end. The control variable method was adopted in the design of the optimized project (the same below), and the five injection projects were: 0.2PV、0.3PV、0.4PV、0.5PV and 0.6PV, and predicted cumulative oil production in the next 5 years and calculated the input-output ratio. The results of simulation are shown in Figure 2.

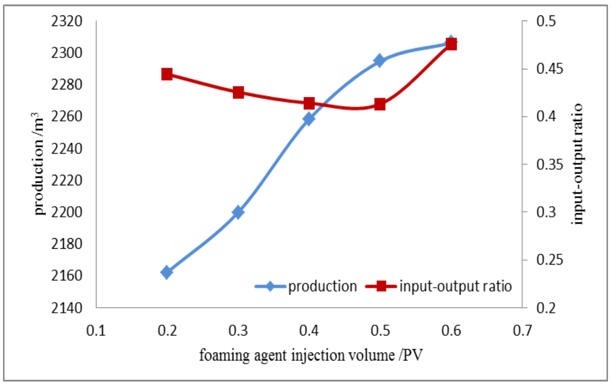


**Fig-2 :Relationship between the amount of foaming agent and the amount of oil production and input output ratio**

Figure 2 shows that the amount of oil produced increases with the increase of the amount of foaming agent. When the amount of injection is less than 0.5PV, changing the amount of injection has a great effect on oil production, and the input and output ratio is gradually reduced as well. When the amount of injection is more than 0.5PV, the effect made by amount of injection on oil production is very small, and the input-output ratio is gradually increased. So the optimal amount of injection for this area should be 0.5PV.

***Foaming agent injection rate***

The foaming agent injection rate directly affects the sweep coefficient, so it has have a certain impact on drive results. Make the Foaming agent volume 0.5PV. Five different foaming agents injection rates were designed such as $5m^3/d$, $9m^3/d$, $11m^3/d$, $13m^3/d$, $15m^3/d$ and predicted cumulative oil production in the next 5 years and calculated the input-output ratio. The results of simulation are shown in Figure 3.

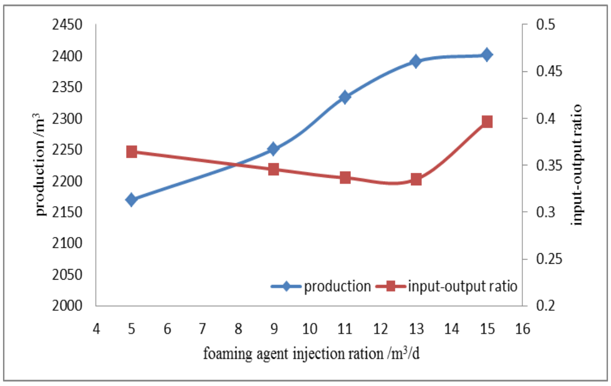


**Fig-3: Relationship between the injection rate of foaming agent and the amount of oil production and input output ratio**

Figure 3 shows that the cumulative oil production increased with the increase of foaming agent injection rate. When the injection rate is less than $1.3m^3/d$, the increase of oil production rate increases with the increase of injection rate, and input-output ratio reduces gradually. When the injection rate is more than 13m$^3$/d, the increase of cumulative oil production gets small. But with continuous increase in injection rate, the input output ratio increases. So the optimal injection rate of the foaming agent is 13m$^3$/d.

### *Gas injection rate*

Gas injection rate affects the foaming degree and sweep area, so it has effect on the final drive. Adjust the injection amount of foaming agent 0.5PV, foaming agent injection rate 13m$^3$/d. Five different gas injection rates were: 10m$^3$/d, 20m$^3$/d, 30m$^3$/d, 40m$^3$/d, 50m$^3$/d and then predict cumulative oil production in the next 5 years and calculated the input-output ratio. The results of simulation are shown in Figure 4.

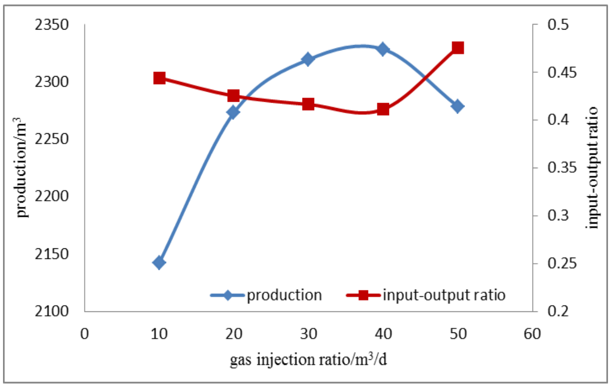


**Fig-4: Relationship between gas injection rate and input output ratio**

Figure 4 shows that with the increase of gas injection rate, the cumulative oil production shows a trend of first increasing and then decreasing. So there is an optimal value (40m$^3$/d). When the gas injection rate is more than 40m$^3$/d, the amount of oil production drops sharply. Input-output ratio rises sharply. Therefore, the optimal gas injection rate for this block is 40m$^3$/d.

### *Foaming agent concentration*

Foaming agent concentration has an effect on the stability of foam, which has a great influence on effect of profile control and flooding. The injection amount of foaming agent is 0.5PV, foaming agent injection rate is 13m$^3$/d, and gas injection rate is 40m$^3$/d. Five different foaming agent concentration values were 0.1%, 0.3%, 0.5%, 0.7% and 0.9%. And then predicts cumulative oil production in the next 5 years and calculated the input-output ratio. The results of simulation are shown in Figure 5.

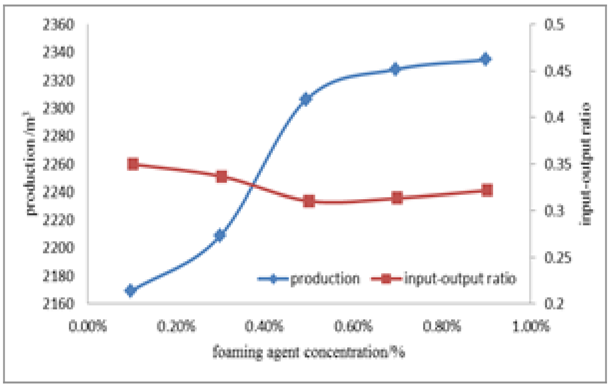


**Fig-5:Relationship between foaming agent concentration and the oil production and input output ratio**

Figure 5 shows that, with the increase in the concentration of foaming agent, the increase of oil production is first large and then small. When the foaming agent concentration changes before 0.3%, the increase of the amount of oil production is larger, input-output ratio is gradually reduced. When concentration of foaming agent is more than 0.3%, with the concentration increasing, the increase of oil production gets small, the input output ratio increases slowly. So, the best foaming agent concentration in this area is 0.3%.

### *Gas-liquid ratio*

Gas-liquid ratio has an effect on resistance coefficient, which affects effect of profile control and flooding. The injection amount of the foaming agent is 0.5PV, the injection rate of the foaming agent is 13m$^3$/d, the gas injection rate is 40m$^3$/d, and the foaming agent concentration is 0.3%. Set five different gas-liquid ratio, respectively 1:2, 1:1, 2:1, 3:1 and 4:1. And then predicts cumulative oil production in the next 5 years and calculated the input-output ratio. The results of simulation are shown in Figure 6.

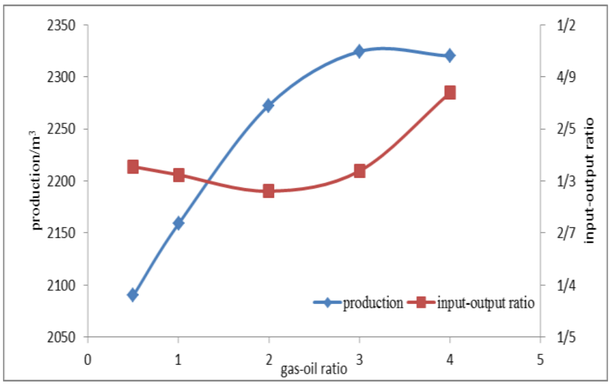


**Fig-6: Relationship between gas-liquid ratio and the oil production and input output ratio**

Figure 6 shows that, with the increase of gas-liquid ratio, the amount of oil production increases firstly and then decreases. That is, there is an optimal value (3:1), when the gas-liquid ratio exceeds 3:1, then the gas-liquid ratio increases, and the amount of oil production reduces gradually. In the same time, the input-output ratio increased sharply, so the block for optimal gas-liquid ratio is 3:1.

***Foaming agent injection cycle***

Foaming agent injection cycle affects the bubble degree, which directly affects effect of profile control and flooding. The injection amount of the foaming agent is 0.5PV, the injection rate of the foaming agent is $13m^3/d$, the gas injection rate is $40m^3/d$, the foaming agent concentration is 0.3% and the gas-liquid ratio is 3:1. Set five different injection cycles, which are 10d, 15d, 20d, 25d, and 30d. And then predicts cumulative oil production in the next 5 years and calculated the input-output ratio. The results of simulation are shown in Figure 7.

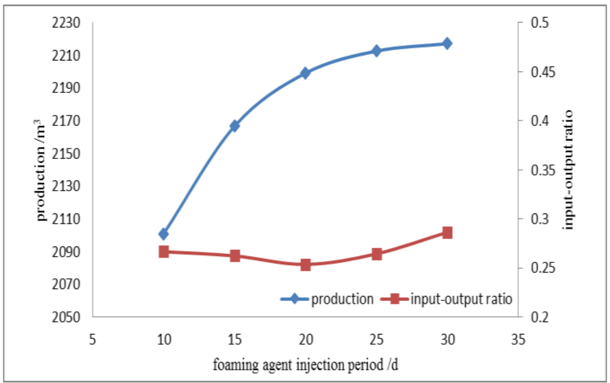


**Fig-7 :Relationship between the foaming agent injection cycle and the amount of oil production and input output ratio**

Figure 7 shows that, with the increasing of the foaming agent injection cycle, the cumulative oil production is on the rise. When the injection cycle of the foaming agent changes before 25d, the amount of oil production increases, and the input output ratio decreases gradually. When the period is more than 25d, the cumulative oil production tends to a constant value, and the input output ratio increases gradually. Therefore, the best foaming agent injection cycle for this area is 25d.

**CONCLUSION**

The results show that the air foam profile control technology can significantly improve the production of M block. Through the simulation calculation and parameter optimization of the actual geological model of M block in A oilfield, according to the calculation results of input output ratio, the parameters of injection parameters are determined: the injection amount of the foaming agent is 0.5PV, the injection rate of the foaming agent is $13m^3/d$, the foaming agent concentration is 0.3%, the foaming agent injection cycle is 25d.

There is an optimizing value of gas injection rate, when it is more than the best value, the amount of oil production dropped significantly, so the gas injection rate has a large effect on oil production. According to the simulation results of the actual geological model of the M block, the best value of gas injection rate for the M block is $40m^3/d$.

Gas-liquid ratio also exists an optimum value :3:1, so, field operation should be avoided when gas-liquid ratio is more than 3:1.

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