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Optimization of Injection Parameters for Profile Control and Flooding in an Oilfield during High Water Cut Period

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Abstract

In order to improve the effect of water control and oil stabilization during high water cut period, a mathematical model of five point method well group was established with the high water cut well group of an Oilfield as the target area, the variation law of water cut and recovery factor of different injection parameters was analyzed, and the optimization research of injection parameters of polymer enhanced foam flooding was carried out. The results show that the higher the injection rate, the lower the water content curve, and the higher the oil recovery rate. As the foam defoamed when encountering oil, when the injection time was earlier than 80% of water cut, the later the injection time was, the better the oil displacement effect would be. When the injection time was later than 80% of water cut, the later the injection time was, the worse the oil displacement effect would be. The larger the injection volume, the lower the water content curve and the higher the recovery rate. After the injection volume exceeded 0.2 PV, the amplitude of changes in water content and recovery rate slowed down. The optimal injection parameters of profile control agent for high water content well group in Oilfield A were: injection rate of 15 m^3/d, injection timing of 80% water content, and injection volume of 0.2 PV.

Keywords

High Water Cut Period, Profile Control, Injection Rate, Injection Timing, Injection Volume

1. Introduction

After the oilfield enters the high water cut stage, the development contradiction intensifies, the seepage channels develop, the water channeling is severe, and the development effect continues to deteriorate (Liu et al., 2023; Zhang et al., 2023a; Bai, 2023). In order to achieve water control and stable oil production during the high water content period, it is necessary to carry out profile control and displacement control on the high water content well group to achieve balanced displacement (Ju et al., 2023; Zhang et al., 2023b, 2023c; Friedmann et al., 1991). The injection parameters are controllable factors in the production process, and the injection parameters vary depending on the specific situation of the oilfield (Falls et al., 1986; Kovscek et al., 1993; Kovscek et al., 1994; Kovscek et al., 1997). Foam profile control and flooding technology has been applied in the oilfield for many years, and has the characteristics of "defoaming when encountering oil and stabilizing when encountering water". It has made considerable progress in water plugging and profile control, fracturing and acidizing, oil displacement, etc., and has obvious economic benefits (Bertin et al., 1998; Zhao et al., 2008; Du et al., 2009; Li, 2009). According to the reservoir characteristics and well pattern form of high water cut well group in Oilfield A, this problem establishes a five point well group model, draws water cut and recovery ratio curves under different injection parameters according to the simulation results, analyzes the change law, optimizes the injection parameters of foam profile control and flooding system, and provides technical support for improving the effect of water control and oil stability of profile control and flooding measures in high water cut oilfields.

2. Model Parameter

A five point well group model is established to simulate polymer enhanced foam flooding, taking the high water cut well group of an oilfield as the target area. The model parameters are shown in **Table 1**.

3. Influence of Injection Rate on Foam Flooding Effect

The injection rate affects the injection intensity, fluid flow rate, foam volume and foam viscosity of foam flooding, and then affects the oil displacement effect of foam flooding. Five schemes are designed here, and the displacement effects of polymer enhanced foam flooding at injection rates of 5 m^3/d, 10 m^3/d, 15 m^3/d, 20 m^3/d and 25 m^3/d are calculated respectively. The formula of foam agent is: polymer concentration is 1200 mg/L, surfactant concentration is 0.25 wt%, and gas-liquid ratio is 1:1.

Table 1. Model parameter table.

parameter	value	parameter	value
permeability (10^{-3} μm^2)	47.3	surfactant concentration (wt%)	0.25
porosity (%)	22.7	polymer concentration (mg/L)	1200
model dimension (m × m × m)	200 × 200 × 3.7	gas-liquid ratio	1:1
oil saturation	0.69	oil viscosity (mP·s)	5.8
well network form	five-spot	——	——

Basic plan: Inject water at a rate of 15 m³/d until the water content reaches 98%.

Scheme 1: In the early stage, water drive to 80% of water content. At the injection rate of 5 m³/d, transfer polymer enhanced foam oil displacement system, with injection volume of 0.2 PV, and then water drive to 98% of water content.

Scheme 2: In the early stage, water drive to 80% of water content. At the injection rate of 10 m³/d, transfer polymer enhanced foam oil displacement system, with injection volume of 0.2 PV, and then water drive to 98% of water content.

Scheme 3: In the early stage, water drive to 80% of water content. At the injection rate of 15 m³/d, transfer polymer enhanced foam oil displacement system, with injection volume of 0.2 PV, and subsequent water drive to 98% of water content.

Scheme 4: In the early stage, water drive to 80% of water content. At the injection rate of 20 m³/d, the polymer enhanced foam oil displacement system is transferred, with the injection volume of 0.2 PV, and the subsequent water drive to 98% of water content.

Scheme 5: In the early stage, water drive to 80% of water content. At the injection rate of 25 m³/d, the polymer enhanced foam oil displacement system is transferred, with the injection volume of 0.2 PV, and the subsequent water drive to 98% of water content.

Draw the curves of water content and oil recovery over time based on the simulation results (as shown in **Figure 1** and **Figure 2**). Plot the curve of water content changing with PV number here.

It can be seen from the figure that when the injection rate is less than 15 m³/d, the decline degree and opening width of the "groove" of the water cut curve increase rapidly with the increase of the injection rate, that is, the longer the effective period of the foam, the corresponding recovery factor increases rapidly, and the oil displacement effect is significantly enhanced. However, when the injection rate is greater than 15 m³/d, the decline degree and opening width of the

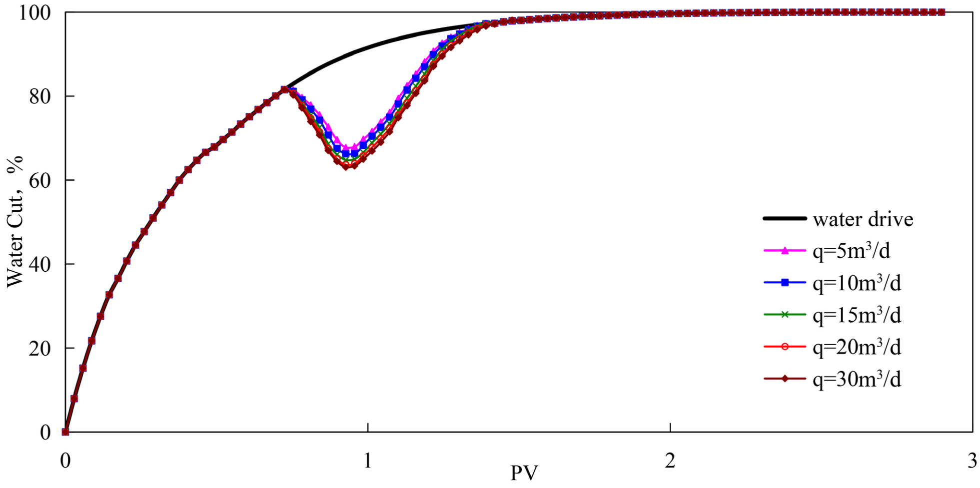

Figure 1. Water content variation curve at different injection rates.

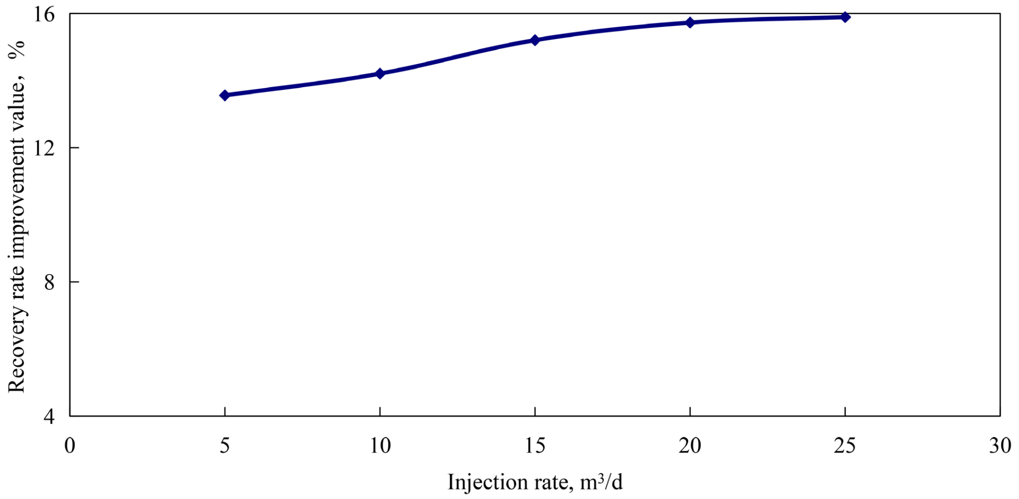

Figure 2. Recovery rate variation curve at different injection rates.

"groove" of the water cut curve no longer change significantly with the increase of the injection rate, The increase in oil recovery rate has significantly slowed down.

The greater the injection speed of foam, the greater the amount of foam generated at the same time, the higher the foam concentration, the greater the sweep efficiency of foam flooding, the wider the sweep range, and the oil displacement efficiency within the sweep range will also increase. However, because foam has the shear thinning feature, with the increase of injection speed, the shear rate will increase, and the viscosity of foam will decrease. The combined effect of the two causes the increase of foam oil removal effect to slow down, the incremental recovery rate decreases. Therefore, the injection rate of 15 m^3/d at the inflection point of the recovery curve is selected as the optimal injection rate.

4. Influence of Injection Timing on Foam Flooding Effect

Foam has the characteristics of "defoaming when encountering oil and stabilizing when encountering water" in the formation. Early implementation of polymer enhanced foam flooding is not conducive to the formation of stable foam, and late implementation will miss the best opportunity for reinjection. Six groups of schemes are designed here. Based on the determination of injection mode and injection period, the displacement effects of polymer enhanced foam flooding with water cut of 60%, 70%, 80%, 90% and 98% are calculated respectively. The formula of foam agent is: polymer concentration is 1200 mg/L, surfactant concentration is 0.25 wt%, and gas-liquid ratio is 1:1.

Basic plan: Inject water at a rate of 15 m^3/d until the water content reaches 98%.

Scheme 1: In the early stage, water drive to 60% of water content, and at the injection rate of 15 m^3/d, transfer polymer enhanced foam oil displacement system, with injection volume of 0.2 PV, and then water drive to 98% of water content.

Scheme 2: In the early stage, water drive to 70% of water content. At the injection rate of 15 m^3/d, the polymer enhanced foam oil displacement system is transferred, with the injection volume of 0.2 PV, and the subsequent water drive to 98% of water content.

Scheme 3: In the early stage, water drive to 80% of water content. At the injection rate of 15 m^3/d, transfer polymer enhanced foam oil displacement system, with injection volume of 0.2 PV, and subsequent water drive to 98% of water content.

Scheme 4: In the early stage, water drive to 90% of water content, and at the injection rate of 15 m^3/d, transfer polymer enhanced foam oil displacement system, with injection volume of 0.2 PV, and then water drive to 98% of water content.

Scheme 5: In the early stage, water drive to 98% of water content. At the injection rate of 15 m^3/d, the polymer enhanced foam oil displacement system is transferred, with the injection volume of 0.2 PV, and the subsequent water drive to 98% of water content.

Draw curves of water content and recovery rate changes based on simulation results (as shown in **Figure 3** and **Figure 4**).

As can be seen from the figure, after the polymer is converted to strengthen the foam oil displacement system, the water cut curve will appear "groove", and its shape is related to the injection time. Before the water content reaches 80%, the later the injection time is, the greater the decline degree of "groove" will be. After the failure of foam flooding, the water cut will rise more slowly, the width of "groove" will be larger, and the recovery factor will increase gradually, indicating that the foam oil displacement effect is more obvious. However, when the injection time is later than 80%, the decline degree of the "groove" of the water cut curve becomes smaller, the water cut rises faster after failure, the width of the

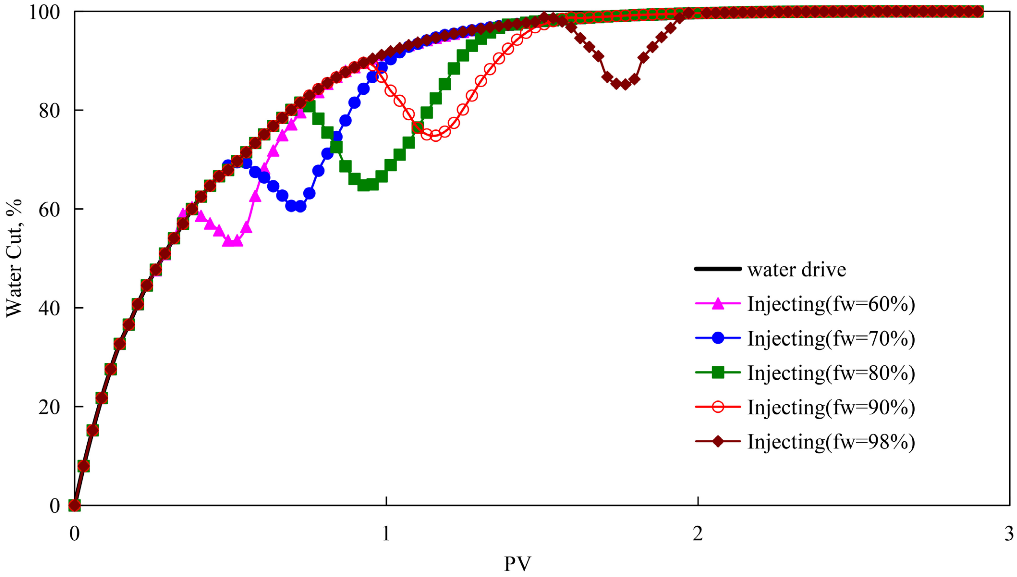

Figure 3. Water content change curve at different injection times.

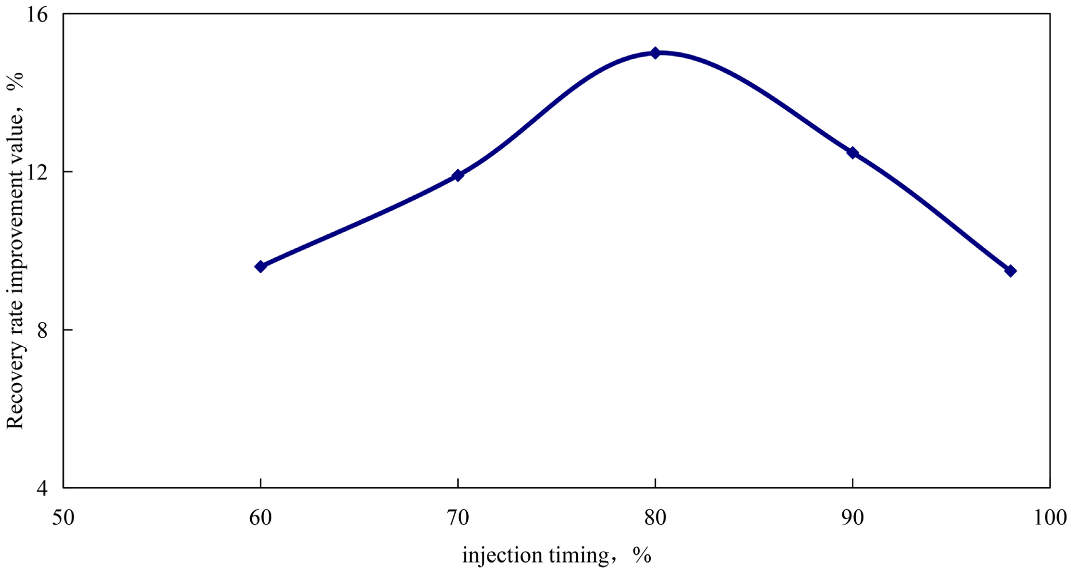

Figure 4. Recovery rate variation curve at different injection timing.

"groove" mouth is smaller, the increase in oil recovery decreases, and the foam displacement effect becomes weaker.

Foam has the characteristics of defoaming when encountering oil and being stable when encountering water. When the water content is low, the oil saturation in the formation is high. The defoaming speed of foam when encountering oil is high, which is not conducive to the formation of stable foam. When the water content is high, the oil saturation in the formation decreases, the defoaming speed of foam when encountering oil decreases, and gradually forms stable foam. The total amount of foam increases, and the plugging ability of the formation increases accordingly, So the "groove" of the moisture content curve will be wider and deeper. However, it is not advisable to implement foam flooding too late, because the best injection opportunity will be missed too late, resulting in complete flooding of production wells. The low water cut period is short after polymer enhanced foam is injected, and the water cut increases rapidly after the measure fails.

In summary, the injection timing should not be too early or too late, and the optimal injection timing is to take a water content of 80%.

5. Influence of Injection Volume on Foam Flooding Effect

The greater the injection volume of foam is, the better the oil recovery is. However, considering well pattern, economy and other factors, the injection volume should be a reasonable value. Five groups of schemes are designed here. On the basis of the determination of injection mode and injection period, the displacement effects of polymer enhanced foam flooding are calculated respectively when the injection amount is 0.1 PV, 0.15 PV, 0.2 PV, 0.25 PV and 0.3 PV. The formula of foam agent is: polymer concentration is 1200 mg/L, surfactant concentration is 0.25 wt%, and gas-liquid ratio is 1:1.

Basic plan: Inject water at a rate of 15 m³/d until the water content reaches 98%.

Scheme 1: In the early stage, water drive to 80% of water content. At the injection rate of 15 m³/d, the polymer enhanced foam oil displacement system is transferred, with the injection volume of 0.1PV, and the subsequent water drive to 98% of water content.

Scheme 2: In the early stage, water drive to 80% of water content, and at the injection rate of 15 m³/d, transfer polymer enhanced foam oil displacement system, with the injection volume of 0.15 PV, and the subsequent water drive to 98% of water content.

Scheme 3: In the early stage, water drive to 80% of water content. At the injection rate of 15 m³/d, transfer polymer enhanced foam oil displacement system, with injection volume of 0.2 PV, and subsequent water drive to 98% of water content.

Scheme 4: In the early stage, water drive to 80% of water cut. At the injection rate of 15 m³/d, the polymer enhanced foam oil displacement system is transferred, with the injection volume of 0.25 PV, and the subsequent water drive to 98% of water cut.

Scheme 5: In the early stage, water drive to 80% of water content. At the injection rate of 15 m³/d, transfer polymer enhanced foam oil displacement system, with injection volume of 0.3 PV, and then water drive to 98% of water content.

Draw curves of water content and recovery rate changes based on simulation results (as shown in **Figure 5** and **Figure 6**).

It can be seen from **Figure 5** and **Figure 6** that when the injection amount is less than 0.2 PV, the decline degree and opening width of the "groove" of the water cut curve increase rapidly with the increase of the injection amount, that is, the longer the effective period of the foam, the corresponding recovery factor increases rapidly, and the oil displacement effect is significantly enhanced. However,

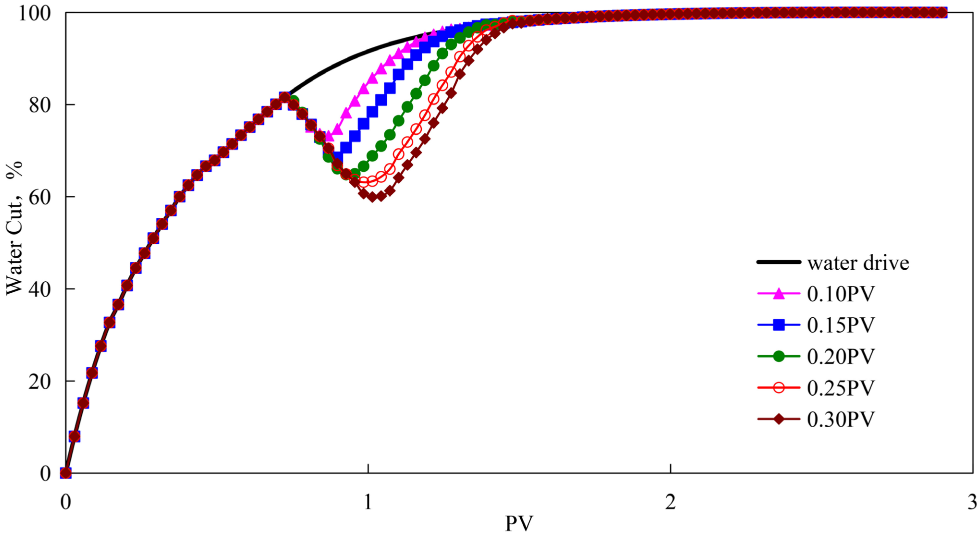

Figure 5. Water content change curve for different injection volume.

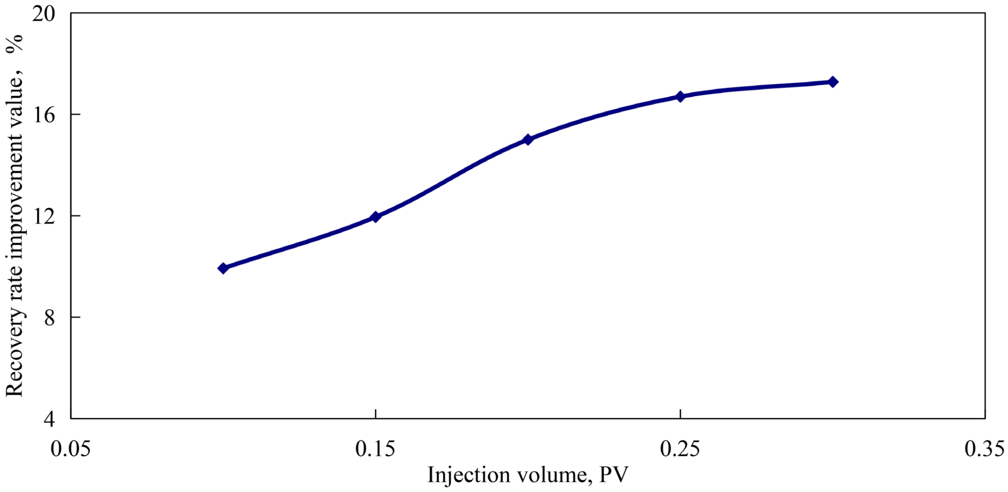

Figure 6. Recovery rate variation curve with different injection volume.

when the injection amount is greater than 0.2 PV, the decline degree and opening width of the "groove" of the water cut curve no longer change significantly with the increase of the injection amount, the increase in oil recovery rate has significantly slowed down.

The greater the injection amount of foam, the greater the sweep efficiency of foam flooding, the wider the sweep range, and the oil displacement efficiency within the sweep range will also increase. However, for a certain size of well pattern, the well pattern control degree is certain, and the sweep efficiency of foam cannot increase indefinitely. When the sweep efficiency reaches a certain value, the increase will slow down, leading to a smaller increase in oil recovery. Considering economic factors, excessive injection volume will inevitably lead to increased development costs. Therefore, taking into account factors such as well network and economy, the optimal injection volume is selected as 0.2 PV at the inflection point of the recovery curve.

6. Conclusion

1) The higher the injection rate, the lower the water content curve, and the higher the recovery rate. After the injection rate exceeds 15 m^3/d, the amplitude of changes in water content and recovery rate slows down.

2) As the foam will defoam when encountering oil, when the injection time is earlier than 80% of water cut, the later the injection time is, the better the oil displacement effect will be. When the injection time is later than 80% of water cut, the later the injection time is, the worse the oil displacement effect will be.

3) The larger the injection volume, the lower the water content curve and the higher the recovery rate. After the injection volume exceeds 0.2 PV, the amplitude of changes in water content and recovery rate slows down.

4) The optimal injection parameters of foam profile control and flooding system in oilfield A are: injection rate is 15 m^3/d, injection timing is 80% water cut, and injection volume is 0.2 PV.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Bai, J. (2023). Development and Performance Evaluation of Salt-Tolerant Foam Flooding System. *Contemporary Chemical Industry, 52,* 981-984.

Bertin, H. J. et al. (1998). Development of a Bubble Population Correlation for Foam Flow Modeling in Porous Media. *SPE Journal, 3,* 356-362. https://doi.org/10.2118/52596-PA

Du, Q. J., Hou, J., Li, Z. Q., Wang, Y. D., & Chen, Y. M. (2009). A Mathematical Model of Polymer Enhanced Foam Flooding. *Chinese Journal of Computational Physics, 26,* 872-877.

Falls, A. H., Gauglitz, P. A., Hirasaki, G. J. et al. (1986). Development of a Mechanistic Foam Simulator: The Population Balance and Generation by Snap-Off. *SPE Reservoir Engineering, 3,* 884-892.

Friedmann, F., Chen, W. H., & Gauglitz, P. A. (1991). Experimental and Simulation Study of High-Temperature Foam Displacement in Porous Media. *SPE Reservoir Engineering, 6,* 37-45. https://doi.org/10.2118/17357-PA

Ju, Y., Li, W. T., Zhang, C. X., Zheng, X. L., Du, R. F., Dong, H. C., & Wang, Y. F. (2023). Study on Compatibility of “Sealing Channeling + Composite Foam Drive” and Reservoirs. *Contemporary Chemical Industry, 52,* 1925-1930.

Kovscek, A. R., Patzek, T. W., & Radke, C. J. (1993). Simulation of Foam Transport in Porous Media. In *SPE Annual Technical Conference and Exhibition*. Society of Petroleum Engineers.

Kovscek, A. R., Patzek, T. W., & Radke, C. J. (1994). Mechanistic Prediction of Foam Displacement in Multidimensions: A Population Balance Approach. In *SPE/DOE Improved Oil Recovery Symposium*. Society of Petroleum Engineers.

Kovscek, A. R., Patzek, T. W., & Radke, C. J. (1997). Mechanistic Foam Flow Simulation in Heterogeneous and Multidimensional Porous Media. *SPE Journal, 2,* 511-526. https://doi.org/10.2118/39102-PA

Li, N. (2009). *Study on EOR Technology of Air foam Flooding in Gudong Oilfield.* Master’s Thesis, China University of Petroleum.

Liu, G. C., Cao, R. B., Yan, W., Liu, H. B., Liang, G. L., & Fan, Y. (2023). Calculation Method and Its Application of Reservoir Dominant Flow Path Parameters after Polymer Flooding. *Petroleum Geology & Oilfield Development in Daqing, 42,* 90-98.

Zhang, C. Q., Li, C., Su, Y., Yang, Z. C., & Wu, D. M. (2023a). Application of Deep Profile Control and Flooding Technology for Control Water and Stabilize Oil Production at Mature Offshore Oilfield. *Petrochemical Industry Application, 42,* 21-24.

Zhang, G. H., Deng, J. F., Zhang, Z. J., Wang, X. R., & Wei, S. (2023b) New Technology and Field Practice of Injection Concentration Optimization and Adjustment of Chemical Flooding in Offshore Oilfield. *Journal of Chengde Petroleum College, 25,* 10-14.

Zhang, H., Wang, Q., Xia, X., Gou, W., & Song, Q. (2023c) Studying on the Reservoir Heterogeneity Controlling on Air Foam Flooding Injection Effect—A Case Study of the Chang-6 Oil Formation in the Ganguyi Oilfield, Ordos Basin. *Geological Review, 69,* 375-382.

Zhao, J., Xu, K. Q., & Ye, J. (2008). Study of High Stability Aqueous Base Foam. *China Surfactant Detergent & Cosmetics, 38,* 365.