Determination of adsorption parameters in numerical simulation for polymer flooding

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Abstract. A study on the determination of adsorption parameters for polymer flooding simulation was carried out. The study mainly includes polymer static adsorption and dynamic adsorption. The law of adsorption amount changing with polymer concentration and core permeability was presented, and the one-dimensional numerical model of CMG was established under the support of a large number of experimental data. The adsorption laws of adsorption experiments were applied to the one-dimensional numerical model to compare the influence of two adsorption laws on the historical matching results. The results show that the static adsorption and dynamic adsorption abide by different rules, and differ greatly in adsorption. If the static adsorption results were directly applied to the numerical model, the difficulty of the historical matching will increase. Therefore, dynamic adsorption tests in the porous medium are necessary before the process of parameter adjustment in order to achieve the ideal history matching result.

1. Introduction

Polymer flooding has the advantage of increasing aqueous phase viscosity, increasing sweep efficiency and reducing the mobility ratio of oil and water[1], and polymer flooding is more efficient than traditional water flooding in the heterogeneous reservoir[2]. The parameters of polymer flooding numerical simulation mainly includes viscosity, adsorption, accessible pore volume, permeability reduction factor and diffusion coefficient[3]. And the amount of adsorption has the greatest influence on historical matching in all the parameters[4]. However, the law of Langmuir model is the most commonly used in the numerical model[5, 6], but the adsorption law in polymer flooding experiment does not follow the law of Langmuir because of the existence of inaccessible pore volume and specific surface area[7-9]. Therefore, it is necessary to determine the optimal adsorption data in numerical simulation.

In this paper, experiments of polymer static adsorption and dynamic adsorption were conducted to determine the adsorption law. And the numerical simulation result is matched with the experiment result, which can lower the level of difficulty of history matching significantly.

2. Experimental Section

2.1. Polymer Static Adsorption

Experimental Procedure.
Mix 1 gram sand and 5 gram polymer solution of different concentrations and put the mixture in an ampulla bottle, then oscillate the mixture for 12 hours to reach the adsorption equilibrium state. Then, spectrophotometric should be used to determine the concentration of the solution. The standard curve

of the polymer solution was shown in **Figure 1**. The equation to compute static adsorption amount are given as follows.

$$\delta = \frac{m_0 - m_1}{m}$$

（1）

where δ =static adsorption amount; m_0 =polymer mass before adsorption in solution; m_1 =polymer mass after adsorption in solution; m =the dry weight of sand.
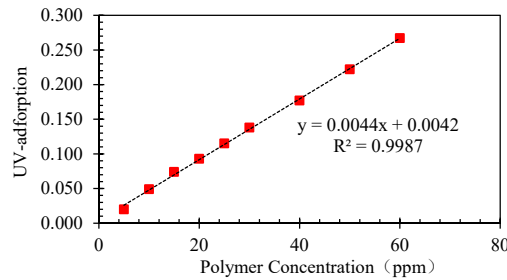

Figure 1. A standard curve of polymer solution.

2.2. Polymer Dynamic Adsorption

Experimental Procedure.
Dynamic adsorption amount was evaluated with a set of core-flooding test, as shown in **Figure 2.** The procedure for dynamic adsorption core flooding experiment is as follows:

    a) The cores were made by the mixture of sand and epoxide-resin glue.

    b) The cores were saturated with brine and testing the permeability of cores.

    c) Flooding polymer solutions with 0.1ml/min flow rate which concentration was 500ppm, 1000ppm, 2000ppm until the polymer concentration of effluent liquid equals to the concentration of the polymer that was flooded in.

    d) Flooding brine with the same flow rate until there is nearly few polymer effluent at the outlet of the cores.

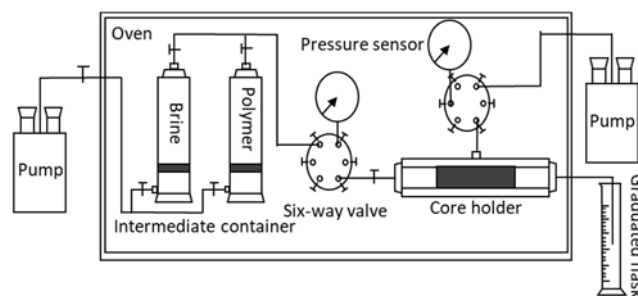   e) Computing dynamic adsorption amounts according to the formula 2.

Figure 2. Picture of dynamic adsorption test device.

$$\delta = \left(c_0 V_0 - \int_{i=1}^{n} c_i V_i \right) / m$$

（2）

Where δ =dynamic adsorption amount; $c_0 V_0$ =flooding polymer mass; $c_i V_i$ =polymer mass of each effluent sample; m =the dry weight of the core.

3. Results and Discussion

3.1. Polymer Static Adsorption

As the **Figure 3** shown, static adsorption amount increases with the increase of polymer concentration, and the adsorption equilibrium occurs at the concentration of 1200 ppm of the polymer solution. The time of adsorption equilibrium **(Figure 5)** is around 3-4 hours, and negative correlation occurs between the percentage of concentration reduction and polymer concentration (**Figure 4**). The adsorption law of Langmuir can be found from **Figure 3** because the quantity of adsorption site on the sand surface is limited and the acrylamide molecules which have been adsorbed on sand surface repulse dissociative molecules.
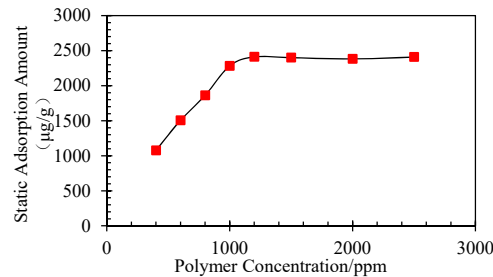

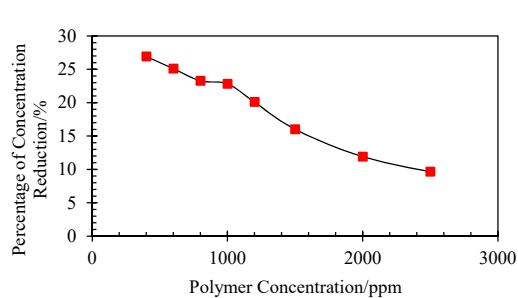**Figure 3.** The static adsorption results of polymer on the sand.

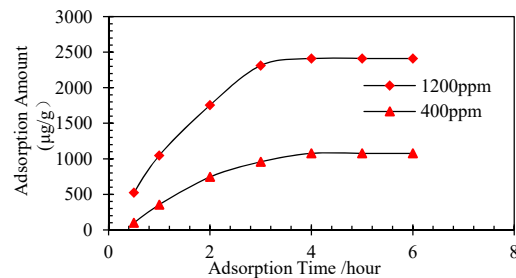**Figure 4.** The concentration loss results of polymer on the sand.

Figure 5. The adsorption time results of polymer on the sand.

3.2. Polymer Dynamic Adsorption

Dynamic adsorption amount has two parts, one is the polymer molecules that have been adsorbed on the pore throat of the porous medium; the other is the retention polymer molecules that were entrapped by microfine throats. As the **Figure 6** shown, the dynamic adsorption amount is negatively correlated with the water permeability of the core. The larger core permeability, which means the larger size of pore and throat, can reduce the probability that acrylamide molecules are entrapped by the throat. Besides, the higher polymer concentration, the larger dynamic adsorption amount. Increasing the polymer concentration will increase the probability that acrylamide molecules are entrapped by the throats, which will eventually increase the dynamic retention amount. On the other hand, as the **Figure 3** shown, the adsorption amount will rise with the increase of polymer concentration. Hence, it is the synergistic reaction of retention and adsorption that increases the dynamic adsorption amount.
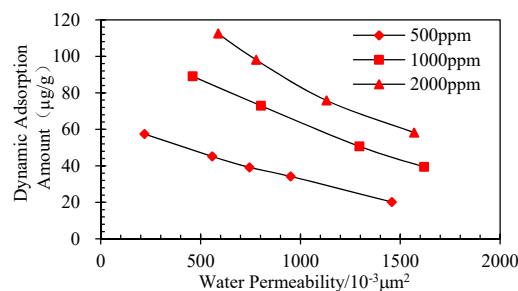
Figure 6. The test result of dynamic adsorption.

4. Simulation Result

In the laboratory, the polymer flooding experiment was conducted to get the elution curve of polymer flooding. Meanwhile, the data of the viscosity of the polymer solution, the accessible pore volume of the core, the permeability reduction factor of the core and the diffusion coefficient of polymer solutions were obtained by a large number of experiments. Then based on these data, the one-dimensional model was constructed using CMG software.

Besides, the data of static and dynamic adsorption were applied to the same model respectively. As the **Figure 7** shown, the curves of polymer relative concentration of elution fluid have a similar shape. It will be about 0.5 pore volume for the polymer to be found at the outlet of the core if the dynamic adsorption data was applied to CMG, and the curves of experiment and dynamic adsorption simulation result coincide well. But it will be about 0.25 pore volume later to test the effusion of polymer if the static adsorption data was used, which means the dynamic adsorption data is more accurate than the static adsorption data to be applied to numerical simulation. By contrasting **Figure 3** and **Figure 6**, the polymer adsorption amount in the porous medium is far less than the static adsorption amount. There are two reasons: The existence of inaccessible pore volume including nonconductive pores and the pores inhabited by intrinsic irreducible fluid reduces the contact area of acrylamide molecules and the porous medium. What's more, the specific surface area in the porous medium is far less than it in quartz sand.
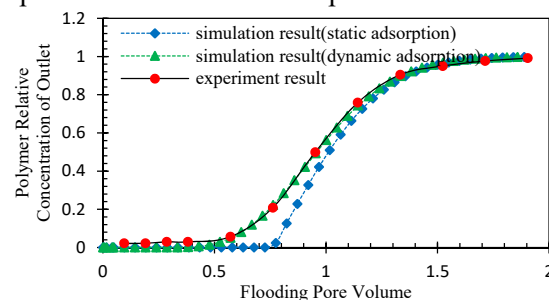

Figure 7. Matching results of numerical simulation

5. Conclusion

On the basis of experiments and numerical simulation, the law of static and dynamic adsorption of the polymer was determined. The static adsorption follows the law of Langmuir. The dynamic adsorption amount increases with the increase of polymer concentration and the decrease of core permeability, and the dynamic adsorption amount was 20-100 times less than static adsorption. Therefore, using dynamic adsorption law in polymer numerical simulations will lower the difficulty of history matching, and the parameters of polymer adsorption applied to numerical simulations should be obtained by core flooding experiments.

References

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