

# A Study on the Evaluation Method of the Configuration Effect of Polymer Solution

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**Abstract.** Through analyzing the effect of configuration process on polymer solution, this study is to comprehensively evaluate the configuration effect of polymer solution from the aspects of its viscosity loss and mixing uniformity. It also puts forward a kind of evaluation coefficient with regard to the mixing uniformity of polymer solution and establishes an evaluation method of the configuration effect of polymer solution. The on-site experiment has proved that this method has accurate evaluation result with simple operation, and it is suitable to be promoted in the oil industry, and it provides a criterion for the design of the configuration process of polymer solution and the equipment selection.

## 1 Introduction

As the application and research of the enhanced oil recovery technology of polymer flooding and ASP flooding has become increasingly mature, the configuration effect of polymer solution has direct effect on the actual production recovery rate of oil field. At present, the evaluation of configuration effect of polymer solution in the oil industry mainly aims at two aspects: viscosity loss rate and mixing effect of the polymer solution. But these two methods have certain limitations. They cannot fully reflect the configuration effect of polymer solution.

The conventional evaluation method of the configuration effect mostly adopts sampling analysis method to carry out the evaluation. The sampling analysis method is mainly to take samples in different locations at the same time or take samples for multiple times in the same position at a specified time interval, and then carry out viscosity analysis and calculate viscosity loss rate of the polymer solution samples. Although the principle of sampling analysis is simple, the field practicability still needs to be improved, and the contingency of the measurement result data is strong. It is unable to use apparatus to directly measure the mixing effect of the mixing unit on the polymer solution. Currently the main evaluation methods are: sampling measurement and numerical simulation analysis. Sampling measurement method is mainly to take samples in multiple positions of measurement area at the same time, test sample viscosity, and calculate the non-uniformity of the viscosity in each position of the measurement area; At present, some scholars have put forward an online measurement method, which is to evaluate the mixing effect by detecting the fluid mass

and volume flow within a unit time. Numerical simulation analysis method is the most widely applied method at present: i.e. to establish mixing unit numerical model based on computational fluid mechanic theory, and carry out multiphase flow numerical simulation to the flow field inside the mixing unit through engineering fluid simulation software (such as CFX、Fluent) and analyze the mixture distribution situation in the flow field. By summarizing the aforesaid existing evaluation method of the configuration effect of polymer solution, we can see that it is able to effectively solve the evaluation problems of the configuration effect of polymer solution in the actual production of the oil field through putting forward evaluation methods that are convenient for the on-site operation and with accurate evaluation result. The evaluation method introduced in his study is based on image processing method. It carries out analysis by using CCD image acquisition, and at the same time measures the viscosity of polymer solution in the configuration process, and performs accurate evaluation to the configuration effect of the configuration device of polymer solution.

## 2 The study on mixing effect

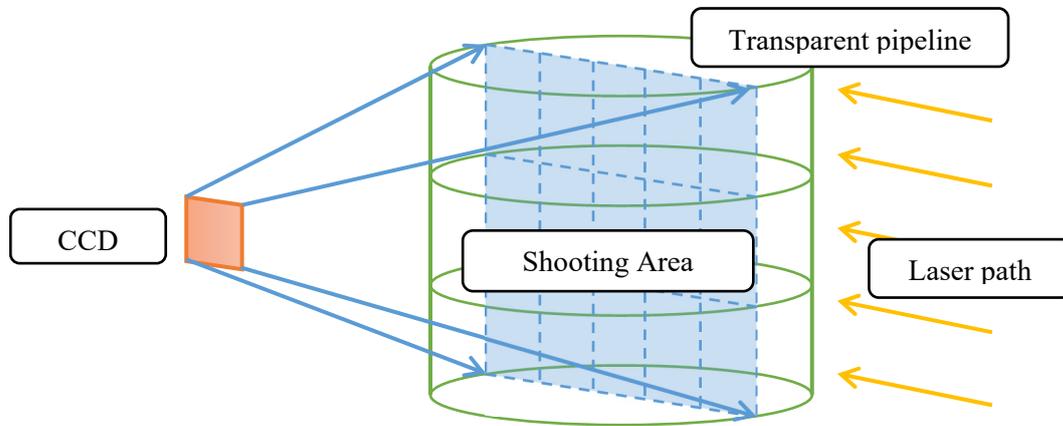
### 2.1 The evaluation method of mixing effect

This evaluation method aims at the study of the mixing effect in the configuration process of polymer solution, introduces the concept of statistics—discrete degree of data, and puts forward a new parameter, namely mixing non-uniformity. The method of measuring the mixing non-uniformity in the polymer solution configuration process is to analyze and evaluate the mixing effect in the flow field through image processing approach. The

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specific method is to: configure the tracer particles and polymer dry powder together, and capture images of posterior flow field of mixing unit based on CCD camera (charge coupled device camera). The mixing effect of the fluid in the flow field can be reflected by analyzing the particle distribution in the image. Capture images of posterior transparent pipeline of polymer mixing

configuration process by using CCD camera. Take n photos at the moment of  $j_1, j_2, \dots, j_n$  respectively with the same time interval  $\Delta t$ , and select photos taken at a certain moment  $j_n$ . The number of tracer particles in the whole photo area is X:



**Fig.1** Schematic diagram of the experimental device of mixing effect evaluation

The number of tracer particles in each area is  $x_1, x_2, \dots, x_n$ . Take this data as a collection and analyze the data distribution situation in it. The division of the areas in the flow field needs to comply with the basic principle of sampling analysis, i.e. the statistical test of parameters requires that the sample size must be large enough. Generally, the sample size is  $n \geq k+1$ . When  $n \geq k+1$ , parameter estimation can be obtained. But when n is too small, the quality of parameter estimation is not good; in addition, some following works necessary for establishing model cannot be carried out. For example, the statistical test of parameters requires that the sample size must be large enough, and z test cannot be applied when  $n < 30$ ; t test is the most common method for testing the significance of variables. Experience shows that t distribution is stable and the test is effective when  $n - k \geq 8$ . Therefore, according to general experience, the basic requirement of model estimation can only be met when  $n \geq 30$  or  $n \geq 30(k+1)$ .

## 2.2 Mixing non-uniformity

The discrete degree of data is an important feature of data distribution. It reflects the degree of each stain value away from its central value. The larger the discrete degree of data, the less the measured value of the centralized trend can represent the reorganized data; the smaller the discrete degree, the more it can represent. According to different data types, the measured values used for describing the discrete degree of data mainly are variation ratio, interquartile range, variance and standard deviation. Moreover, there are range, mean difference and discrete coefficient used for measuring relative discrete degree. Through the feature analysis of the data distribution and the mixing process of polymer solution configuration, it is knowable that the discrete degree of data distribution  $\sigma_{\max}$  can reflect the mixing non-uniformity of the polymer solution configuration.

Suppose we select a simple random sample with capacity of  $n_i$  from the  $i^{\text{th}}$  collectivity to make  $\bar{x}_i$  as the sample mean of the  $i^{\text{th}}$  collectivity:

$$\bar{x}_i = \frac{\sum_{j=1}^{n_i} x_{ij}}{n_i} \quad (1)$$

$n_i$ —Sample size of the  $i^{\text{th}}$  collectivity;  $x_{ij}$ —The  $j^{\text{th}}$  observation value of the  $i^{\text{th}}$  collectivity; Non-uniformity X in a single area is:

$$X = \frac{x_{ij}}{\bar{x}_i} \quad (2)$$

If the mixture is uniform,  $x_{ij} = \bar{x}_i$ , the range of random variables is concentrated on the expected value  $E(X)=1$ :

$$\sigma^2 = D(X) = E[X - E(X)]^2 \quad (3)$$

$$\sigma = \sqrt{D(X)} = \sqrt{\frac{1}{n_i} \sum_{j=1}^{n_i} (x_{ij} - \bar{x}_i)^2} \quad (4)$$

$$\sigma_{\text{mix}} = \bar{\sigma} = \frac{\sum_{j=1}^{n_i} \sigma_{ij}}{n_i} \quad (5)$$

The value  $\sigma_{\text{mix}}$  calculated can represent the discrete degree of tracer particle distribution of piped fluid in each area during the whole testing process, and it can also indicate the mixing effect of piped liquid. Namely the larger the  $\sigma_{\text{mix}}$  is, the greater the fluctuation of the whole number set, the greater the discrete degree of the particle quantities of the inner pipe in each area at different moments, the less uniform the liquid mixed in the pipe.

### 3The study on the evaluation method of configuration effect of polymer solution

#### 3.1A study on viscosity loss of polymer

The polymer solution used in the oil industry, such as some hydrolyzed polyacrylamide (HPAM), has charged groups. These groups can have strong interaction with dipolar water molecules through hydrogen bond and form bound water around macromolecule. At the same time, due to the electrostatic repulsion between the charged groups, the polymer molecular are more stretch and the volume of the random coils becomes larger so that the inner friction force of the molecular motion is increased so as to increase the viscosity of water.

When the polymer solution is under shearing and stretching of mechanical force, macromolecular endures sufficiently large shearing stress so that the molecular chain ruptures. Because the relative molecular mass of polymer is large, the activation energy of molecular bond secondary valence force and molecular motion far outweighs chemical bond energy, and under the mechanical force, chemical bond may lead to rupture so that the degradation of macromolecular chains may occur. Polyacrylamide solution is a kind of liquid which is very sensitive to shear. The viscosity of the solution is decreased with the increase of shear rate. Under low shear rates, the polymer molecules get close to each other, and the liquid exhibits a high viscosity. Under the action of shearing, the curled thread ball gets straightened and oriented, which is conducive to the mutual sliding between polymer molecules, so that the viscosity decreases. With the increase of the shear rate, it is easier for the polyacrylamide molecules to get straightened and oriented so that the flow resistance is reduced so as to decrease the viscosity greatly.

The viscosity loss rate of the polymer solution can be expressed by  $\Delta\mu$ , the specific expression is:

$$\Delta\mu = \frac{\mu_0 - \bar{\mu}}{\mu_0} \times 100\% \quad (6)$$

$\Delta\mu$ —Viscosity loss rate;  
 $\mu_0$ —Initial viscosity;  
 $\bar{\mu}$ —to measure viscosity mean value.

During the preparation process of polymer solution, because the viscosity loss caused by mechanical shearing occurs in various mechanical devices, the agitator, filter, static mixer, flow meter, valve, infusion pump, infusion pipe will produce mechanical shear to polymer solution, leading to viscosity loss in different degrees. During the whole process of mixing, transporting through valve and gate, and flowing to the nearby stratum, mechanical degradation of polymer may occur, resulting in a decrease of solution viscosity, and the viscosity loss rate is between 10%~50%. Mechanical degradation is a process that the molecular structure is destroyed due to the chemical reaction of polymer chain caused by the input of mechanical energy. There are many ways for mechanical degradation of polymer, such as the stirring, extrusion, granulation, grinding and so on in the process

of polymerization, as well as PAM is stirred, pumped and injected in solution state, and high-speed shearing, friction and extensional flow and so on in porous medium.

#### 3.2The evaluation method and model establishment

Due to the uncertainty of sampling analysis, viscosity loss rate  $\Delta\mu$  and mixing non-uniformity  $\sigma_{mix}$  are given measurement error coefficients. The measurement error coefficient of viscosity loss rate and the measurement error coefficient of mixing non-uniformity are  $\xi_\mu$ ,  $\xi_\sigma$  respectively. The formulas for solving the two coefficients are: the measurement error coefficient of viscosity loss rate, in which,  $\xi_\mu$  is measurement uniformity of viscosity loss ratio;  $\mu_{min}$ ,  $\mu_{max}$  are the minimum and maximum viscosity respectively, with the unit of  $mPA \cdot s$ ; the measurement error coefficient of mixing non-uniformity, in which,  $\xi_\sigma$  is measurement uniformity of viscosity loss ratio;  $\sigma_{min}$ ,  $\sigma_{max}$  are the minimum and maximum mixing non-uniformity respectively.

Because the viscosity loss rate and the mixing non-uniformity of the polymer solution show a positive correlation with the configuration effect of the polymer solution I, then the evaluation model is established by using the product method. In consideration of using the product method to establish model, when one factor is 0, the value of another factor has no significance for the result, and there is a certain range for the viscosity loss rate and mixing non-uniformity during the actual production, so the two factors are given a constant respectively. The evaluation model obtained is:

$$I_A = [K_a + (\Delta\mu \times \xi_\mu)] \times [K_b + (\sigma_{mix} \times \xi_{mix})] \quad (7)$$

In which,  $K_a$ ,  $K_b$  are constants; the values of  $K_a$ ,  $K_b$  are obtained from the combination with the actual production experience of oil field, in which,  $K_a$  is determined by viscosity loss rate,  $K_b$  is determined by mixing non-uniformity. In this study, combined with the actual production experience in Daqing Oilfield, the parameter values of coefficients  $K_a$ ,  $K_b$  are: when  $\Delta\mu \leq a, K_a = 1, \Delta\mu > a, K_a = 0.75$ ; coefficient  $K_b$  is obtained from  $\sigma_{min}$ , when  $\sigma_{min} \leq b, K_b = 1$ , when  $\sigma_{min} > b, K_b = 0.75$ .

### 4The field application for the evaluation method of the configuration effect of polymer solution

#### 4.1The experimental method and process

The mother liquid (or Sanyuan mother liquid) in the station enters into the testing device. After being transported by triplex plunger pump, it is fully mixed in the static mixer with the water from water tank according to a certain proportion. The waste liquid of the test enters into the sewage pond in the test station. During the whole testing process, we can have a more direct understanding of the static mixing effect by using a high-speed video

camera to capture the motion state of the fluid (adding tracer particles in water). The setting of parameters and the control of process equipment are completed by central control system. The control of light source and high-speed camera are completed by synchronous control system. Image acquisition and analysis are completed by image processing system.

To evaluate the configuration effect of polymer solution of static mixer unit, the specific experimental procedure is:

1. Configure polymer mother liquid in the maturation tank of polymer solution, and add tracer particles. The maturation time is 2h;

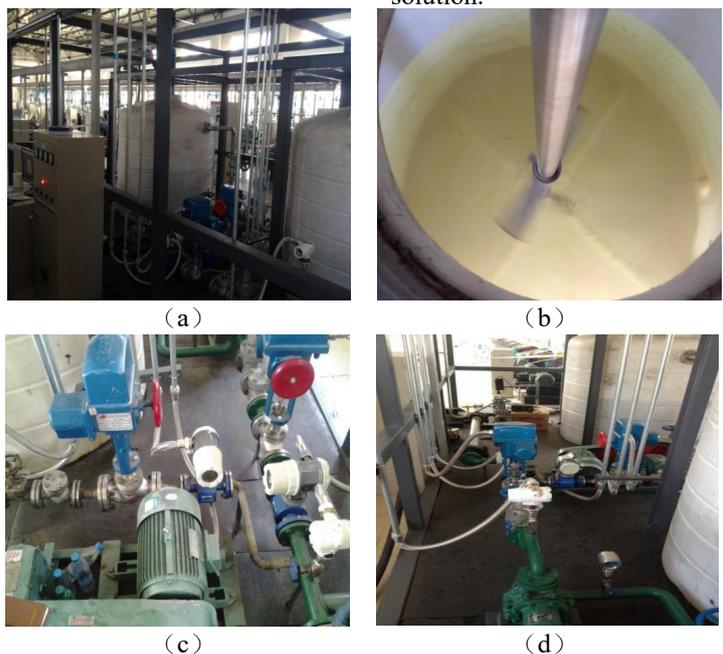
2. Open the plunger pump, adjust to the target flow, inject the polymer solution after maturation into static mixer;

3. Take samples at the both ends of the outlet and inlet of the static mixer; test and measure the viscosity of polymer solution;

4. Open the centrifugal pump without closing plunger pump; adjust to the target flow, and inject water into static mixer;

5. Wait until it becomes smooth and stable; use CCD camera to shoot photos of back-end flow field of static mixer at the same time interval;

6. Input the photos to the computer and post-process them to calculate the mixing non-uniformity of polymer solution.



**Fig. 2** The evaluation device of the configuration effect of polymer solution

**4.2 Experimental data and analysis (Take the evaluation of the configuration effect of polymer solution of static mixer unit for example)**

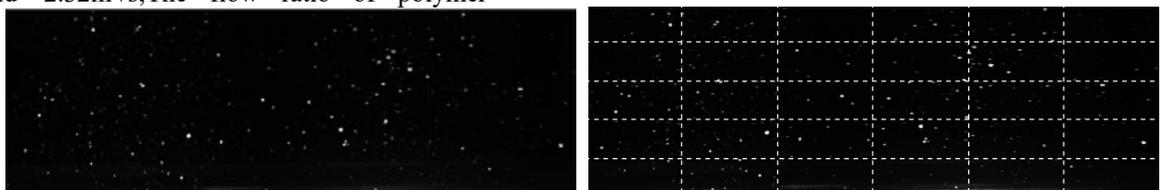
**(1) Experimental conditions**

The L/D ratio of the stirring paddle of stirring tank—1:3;The maturation time of stirring tank—2h;The length of static mixer—1.5m;Injection flow of polymer mother fluid—2.32m<sup>3</sup>/s;The flow ratio of polymer

mother fluid and water—1/1;Inlet pressure of static mixer—0.95MPa.

**(2) The evaluation on the configuration effect of polymer solution with different static mixers**

Firstly, take the evaluation on the mixing effect of A type static mixer that is commonly used in the oil industry for example; the photos taken are as follows.The flow field is divided into 6×5=30 areas with the same size;



**Fig. 3** A photo taken on the spot after the area was divided

Through the calculation of measurement result, the parameter value are obtained,  $K_a=1, K_b=0.75$ ; bring the calculation result into the evaluation equation, and calculate the configuration effect of polymer solution of static mixture unit.

Calculate the configuration effect of polymer solution of B-type static mixture according to the same steps, and

we can obtain:  $I_B \approx 3.791, I_A < I_B$ . By comparing the configuration effect of two static mixtures, it is knowable that the configuration effect of polymer solution of A-type static mixture is better than that of B-type static mixture. Therefore, it is recommended to choose A-type static mixture under such working environment. Through the experiment, measurement, and the further analysis

and calculation to the experimental result, the evaluation method put forward in this study can effectively determine the optimization of the configuration process of polymer solution, providing a high-efficient and accurate method for the design and model selection of the oil industry in the future.

(3)The evaluation on the configuration effect of polymer solution of static mixture with different injections

**Table. 1** The configuration effect of static mixture under different flows

Inlet flow of static mixture /( $m^3/h$ )	Mean measured viscosity of inlet fluid of static mixture /(mpa.s)	Mean measured viscosity of outlet fluid of static mixture /(mpa.s)	Mean mixture non-uniformity	Measurement error of mixing non-uniformity /%	Configuration effect of polymer solution / $I_{CE}$
2.32	43.7	42.4	3.491	79.2	3.600
4.31	44.8	41.7	5.673	82.5	5.460
6.66	44.2	39.3	6.817	80.8	6.808

By analyzing the experimental data and calculation result and comparing the configuration effect of polymer solution under different flows, we can find that as the increase of the inlet flow, the viscosity loss caused by static mixture unit and the mixing non-uniformity are increased. This is because as the increase of the flow, the mixing time of the aqueous phase and the polymer solution in the mixer combination is further shortened, while the liquid phase moves more intensely in the mixer, and even leads to the partial back mixing, which weakens the mixing effect. With the continuous increase of the flow, the solution is also increased continually through the press drop at the both ends of the mixture combination. This is because after the increase of the flow, the liquid phase moves more intensely in the mixer combination, and the internal unit of the mixer combination is more effective in blocking the fluid, resulting in the increase of pressure drop.

The evaluation method of the configuration effect of polymer solution put forward through this study can effectively optimize the process parameters of polymer solution preparation and provide an effective evaluation method for the future study and design of the configuration process of the polymer solution.

## 5 Conclusion

This study has established an evaluation method for the configuration effect of the polymer solution, comprehensively evaluated it from the viscosity loss and the mixing uniformity of the polymer solution, and considered the contingency of the sampling analysis. This method has accurate measurement results with good operability and safety, and it is worth to be promoted in the oil industry; This study has put forward evaluation coefficients with regard to the mixing uniformity of the polymer solution, made use of numerical analysis method, and complied with the principles of sampling analysis, analyzed the normal distribution situation of the data in a set, and expressed the mixing non-uniformity of the fluid in the test area by calculating discrete degree of data in a set; This study has analyzed the viscosity loss

Adjust the inlet flow amount and calculate the configuration effect of polymer solution of static mixture unit under different flows by using the same static mixture. Measure the result according to the experimental requirement, and the experimental results are as follows:

mechanism of the polymer solution and, in the combination of the mixing process, described the relationship between the viscosity loss and the mixing uniformity of the polymer solution in the configuration process of the polymer solution in the oil industry. The main factor that affects the viscosity loss and the mixing non-uniformity of polymer is mechanical shearing, i.e. the larger the mechanical shear, the greater the viscosity loss of polymer solution, the lower the mixing non-uniformity. Combined with the index in the oil industry, the evaluation method put forward through this study provides an effective method for the process parameter design of the polymer solution configuration and the equipment selection in the oil industry.

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