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## The Performance of Polymer Solution Added with Viscosity Stabilizer and the Evaluation of Its Oil Displacement Efficiency in Daqing Oilfield

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### Abstract

Aiming at the low viscosity of polymer solution, which is compounded with fresh water but diluted with produced water, and at the problems concerning oil displacement efficiency, an onsite test on polymer solution with viscosity stabilizer (PSVS) is carried out. As a result, it has great and guiding significance to the application and popularization of viscosity stabilizer by studying the performance of polymer solution with viscosity stabilizer and its influence on oil displacement efficiency. In this paper, aiming at two different kinds of polymer solutions among which one is compounded with fresh water but diluted with fresh produced water and the other with aerated produced water, two laboratory evaluative tests concerning viscosity stabilization, anti-shear stability, fluidity, and absorbability of polymer solution as well as its oil displacement efficiency are done. The results of onsite application of PSVS are traced and analyzed.

The viscosity stabilization of the polymer solution adding with viscosity stabilizer becomes much better than that of the normal polymer solution. The resistance and the residual resistance factors, the static oil sand adsorption rate and the dynamic core adsorption rate of the solution are all increased markedly. The working viscosity and oil displacement efficiency are improved markedly as well. In comparison with the polymer solution diluted with fresh produced water, the polymer solution diluted with aerated produced water is much better in terms of viscosity stabilization. Comparing with the normal polymer solution with viscosity stabilizer before sheared, the polymer solution which is sheared before adding with viscosity stabilizer performs obviously better in terms of viscosity stability. In contrast to the adjacent block

injected with normal polymer solution, the block under onsite flooding test with injection of PSVS features that the average injection pressure increases slightly but keeps steady, the recovery speed of the average monthly water cut of production wells slows down, the thickness of the absorptive layers increases, and the periodic recovery rate improves as well.

**Key words:** Polymer solution; Viscosity stabilizer; Daqing oilfield

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### INTRODUCTION

At present in Daqing Oilfield, the method of oil displacement usually adopts polymer solution of produced water diluted with fresh water. To solve the problem of low viscosity of polymer solution diluted with produced water, which affects the oil displacement efficiency, Daqing Oilfield carried out onsite experiments by adding viscosity stabilizer to polymer solution in September, 2006. The viscosity stabilizer is capable of restraining the polymer's degradation and stabilizing the viscosity of polymer solution, hence proving favorable to enhancing the oil displacement efficiency of polymer solution with produced water<sup>[1,2]</sup>. Therefore, the tracking and the analysis of numerous indoor research and onsite experiments, inquiring into the performance of polymer solution with viscosity stabilizer (PSVS) and its effects on oil displacement, is both theoretically and practically significant for applying and popularizing the technology of adding viscosity stabilizer to polymer solution. For

the time being, the PSVS technology is still at the stage of indoor and onsite experimentation<sup>[3,4]</sup>. To compare the two kinds of polymer solutions, one diluted with fresh water, the other diluted with aerated water, this paper evaluates the performance of PSVS and the indoor oil displacement experiment on drill core, thus it tracks and analyzes the onsite effects of PSVS application. This paper compares and analyzes the viscosity stability, anti-shear stability, fluidity, absorbability and oil displacement efficiency of PSVS and the normal polymer solution. It also calibrates the average injection pressure of the wells in the experiment block applied with viscosity stabilizer. The recovery speed of the average monthly water cut of production wells, the working viscosity, the laws of the fluctuating oil layer absorption profiles and periodic recovery rate are provided as well. Thus it sets a firm theoretical foundation of applying and popularizing the PSVS technology.

## 1. THE MECHANISM OF VISCOSITY STABILITY OF POLYMER SOLUTION

### 1.1 Oxide Sterilization<sup>[5]</sup>

In the water produced from oil well, there are a large amount of sulfate-reducing bacteria (SRB), iron bacteria (IB), total growth bacteria (TGB) among many other kinds of bacteria. Those bacteria, reproducing themselves voluminously, corrode the casing, the tubing, the pumps and other surface equipments. The SRB in particular is infamous for its severe damage on the molecular chain of polymer, which deteriorates the stability of polymer solution's viscosity. Oxygen can restrain the protein compounding within the bacteria, reducing their growth and even sterilize them, in a way to safeguard the molecular chain of polymer from being damaged. Accordingly, the polymer solution diluted with aerated water features increased oxygen content which, in

sterilizing the bacteria, enhances the stability of polymer solution.

### 1.2 The Effect of Carbon Free Radical<sup>[6]</sup>

The polymer in the solution, under condition of 45°C, is partially disintegrated to generate carbon-centered free radicals. They have enough survival duration both in the aerated water and the fresh produced water, causing deterioration such as molecular bond break and reducing the polymer viscosity. The viscosity stabilizer, when added, can reduce the growth of carbon free radicals and thus prevent molecular bond break induced by carbon free radicals, realizing the function of stabilizing the polymer solution viscosity.

### 1.3 The Association of Chemical Bond<sup>[7]</sup>

The polymer molecule group is usually found in chain structure. However, it coils up when the negative electric charges at its surface are neutralized by the positive electric charges in highly mineralized water in the polymer solution. With stabilizer added, the association its stabilizing ingredient exerts together with the amide group's hydrogen bond and the hydrophobic group within the polymer itself leads to increased hydrodynamic scope of the molecular bond and strengthened inter-chain twisting and internal friction. Thus, the viscosity and the stability will be enhanced for the polymer solution of the produced water.

### 1.4 Performance Evaluation of Viscosity Stabilizer in Polymer Solution

The polymers applied in the experiment are those of high, middle and low molecular weight manufactured by Daqing Chemistry and Refinery Company. Their specifications are shown in Table 1 while the qualities of fresh water and used water for the experiment are illustrated in Table 2.

**Table 1**  
Specifications of the Polymers for the Experiment

Type	Solid content (%)	MW (10,000)	Hydrolysis (%)	Viscosity (mPa·s)	Filtering factor	Insoluble (%)	Granularity rate(%)	
							≤0.2mm	≥1.0mm
HMW	89.54	3060	24.5	46.5	1.2	0.10	1.1	2.6
MMW	89.53	1550	23.9	42.9	1.5	0.004	0.4	0.9
LMW	89.77	330	25.1	10.7	1.2	0.01	0.0	1.9

**Table 2**  
**Water Quality Calibration**

Type	PH value	Ca <sup>2+</sup> (mg/L)	Mg <sup>2+</sup> (mg/L)	Mineralization (mg/L)	Floating solid (mg/L)	Oil content (mg/L)	Polymer concentration (mg/L)
Used water	7.41	20.04	4.86	4985.70	7.0	2.9	316
Fresh water	8.28	20.04	9.74	357.27	0.4	/	/

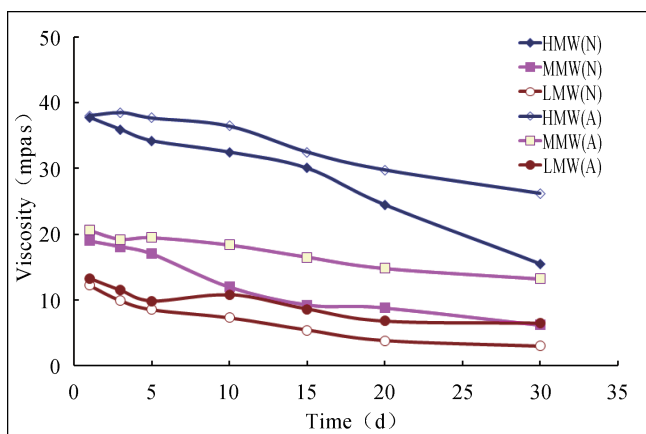
**1.4.1 Stability**

The 5000mg/L polymer solutions compounded with fresh water are to be diluted to the level of 1200mg/L with fresh produced water and aerated water respectively, the content of viscosity stabilizer being 120mg/L. They are calibrated in terms of viscosity change by time before and after the addition of viscosity stabilizer into the polymer solutions.

Fig.1A and Fig.1B show the data of viscosity stability of viscosity stabilizer/ polymer solutions with aerated water and fresh water. Both the Tables illustrate that the polymer solutions, no matter that of fresh produced water or that of aerated water, when added with viscosity stabilizer, feature slight rise in the initial viscosity of different molecular weights and better long-term stability. For the polymer solutions compounded with fresh water and added with viscosity stabilizer, the viscosity retention rates of high, middle and low molecular weight on the thirtieth day are 56.0%, 49.0% and 30.2% respectively, increas-

ing by 22.3%, 26.1% and 12.3% respectively over those without viscosity stabilizer; for the polymer solutions compounded with aerated water and added with viscosity stabilizer, the viscosity retention rates of high, middle and low molecular weight on the thirtieth day are 68.9%, 64.1% and 48.9% respectively, increasing by 27.9%, 31.5% and 24.3% respectively over those without viscosity stabilizer.

Table 3A and Table 3B also show that the polymer solution compounded with aerated water enjoys a slightly higher viscosity in the initial stage and better long-term stability than that compounded with fresh water. On the thirtieth day, the polymer solutions, with viscosity stabilizer added, of high, middle and low molecular weight have viscosity retention rates at 68.9%, 64.1% and 48.9% respectively, higher by 12.9%, 18.1% and 18.7% than those of the polymer solutions compounded with fresh produced water.

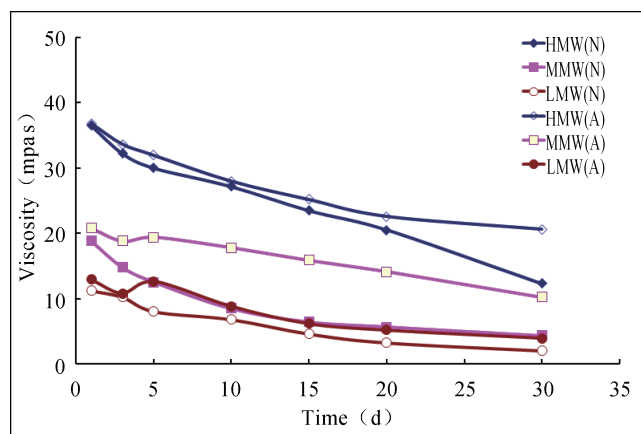


**Figure 1A**  
**The Stability Data of Viscosity Stabilizer/ Polymer Solution (Aerated Water)**

**1.4.2 Anti-Shear Performance**

The 5000mg/L polymer solutions compounded with fresh water are to be diluted to the level of 1200mg/L with fresh produced water and aerated water respectively, the content of viscosity stabilizer being 120mg/L either before or after the shear. They are calibrated in terms of viscosity change by time before and after the addition of viscosity stabilizer into the polymer solutions.

Table 4 shows the data of viscosity stability of polymer solutions compounded with aerated water and fresh



**Figure 1B**  
**The Stability Data of Viscosity Stabilizer/ Polymer Solution (Fresh Produced Water)**

water, with viscosity stabilizer added either before or after the shear. It can be found from Table 4 that the polymer solutions, no matter compounded with fresh or aerated water, have better viscosity if sheared before added with viscosity stabilizer than the case when added with viscosity stabilizer before sheared. On the sixtieth day, the retention rates stand at 75% and 76% for the polymer solutions compounded with fresh produced water and aerated water respectively, as sheared first and then added with viscosity stabilizer, higher by 8% and 28% respectively than those

added with viscosity stabilizer first and then sheared. For this reason, the location of viscosity stabilizer for onsite addition should be close behind the shearing equipment. Also it can be found that the viscosity on the sixtieth day is

higher than that on the thirtieth day, so to say, along with the addition of viscosity stabilizer, the viscosity stability of polymer solution is on the rise.

**Table 4**  
**The Viscosity Stability Data of Polymer Solutions Before and After the Addition of Viscosity Stabilizer**

	Polymer solution type	Polymer solution viscosity(mPa.s)						Retention rate (%)
		0d	3d	7d	15d	30d	60d	60d
Fresh	33% shear before adding stabilizer	36.7	32.6	27.2	26.7	23.4	27.7	75
	Adding stabilizer before 33% shear	36.4	32.5	25.7	21.3	23.0	24.7	68
Aerated	20% shear before adding stabilizer	43.2	37.0	36.3	34.1	30.5	33.0	76
	Adding stabilizer before 20% shear	43.4	30.6	27.9	26.7	22.1	20.7	48

### 1.4.3 Fluidity

The physical specifications of drill core are shown in Table 5 below. First the drill core is cleared of saturated strata water before injected with produced water by 4PV~5PV, the pressured recorded; then it is injected with polymer solution by 4PV~5PV; finally injected with fresh water by 4PV~5PV, also the pressured recorded. For the experiment, the injection speed is 0.3mL/ min, pressure recording interval 20min, the concentration of viscosity stabilizer 120mg/L, and the polymer solution is 5000mg/L mother liquid compounded with fresh water, which is diluted to the level of 1000mg/L.

Table 6 shows the calibration results of resistance (The mobility ratio of injected water to polymer solution during the polymer flooding) and residual resistance factors (The

mobility ratio of injected water before to after the polymer solution seeping through the rock) of polymer solutions, of both middle and high molecular weight, with the addition of viscosity stabilizer. According to Table 6, the viscosity stabilizer bears markedly on the fluidity characteristics of polymer solution, which, when added, gives rise to evident enhancement of resistance and residual resistance factors of the polymer solutions. The resistance and residual resistance factors of HMW polymer solution are respectively 15.0 and 5.3; those of MMW polymer solution are 8.4 and 5.1. Comparing with the polymer solution without viscosity stabilizer, the former factors increase by 3.7 and 4.0 while the latter ones increase by 3.0 and 4.0 respectively.

**Table 5**  
**Physical Factors of Drill Core**

No.	Length (cm)	Diameter (cm)	Dry wt (g)	Wet wt (g)	Geometric bulk (cm <sup>3</sup> )	Pore volume (cm <sup>3</sup> )	Porosity (%)	Air permeability (10 <sup>-3</sup> μm <sup>2</sup> )
4-4	9.33	2.54	76.6	90.1	47.3	13.5	28.6	275.3
4-7	9.20	2.54	76.5	90.1	46.6	13.6	29.2	2716
5-3	9.93	2.54	80.0	94.0	50.3	14.0	27.8	2813
5-4	9.94	2.54	79.8	93.8	50.4	14.0	27.8	2640

**Table 6**  
**Resistance and Residual Resistance Factors**

No.	Permeability (10 <sup>-3</sup> μm <sup>2</sup> )	Sample	Pressure/ (0.1MPa)			Resistance factor	Residual resistance factor
			Water flooding	Polymer flooding	Later water flooding		
4-4	2753	MMW normal	0.0102	0.055	0.011	5.4	1.1
4-7	2716	HMW normal	0.0096	0.108	0.012	11.3	1.3
5-3	2813	MMW + stabilizer	0.0103	0.087	0.053	8.4	5.1
5-4	2640	HMW + stabilizer	0.0105	0.157	0.056	15.0	5.3

#### 1.4.4 Absorbability

The 1000mg/L polymer solution of MMW and HMW, prepared in proportion of 20:1, (the 5000mg/L mother liquid compounded with fresh water is diluted with aerated water to the level of 1000mg/L), is put into a plugged flask together with oil sand from Daqing Oilfield, evenly mingled then, and placed in 45°C water of constant

temperature to be surged for 24 hours before sent for centrifugal separation. The upper clear liquid is tested in terms of polymer concentration and then come under calculation of static absorption of polymer on the oil sand in accordance with the difference between initial and balanced concentration, the equation being as follows:

$$\text{static absorption (mg/g)} = \frac{\text{polymer mass before absorption(mg)} - \text{that after absorption(mg)}}{\text{oil sand mass(g)}}$$

Table 7 shows the calibration results of static absorption experiment on MMW and HMW polymer solutions before and after the addition of viscosity stabilizer. According to Table 7, the viscosity stabilizer affects evidently the static absorption of polymer on

oil sand, which increases after the addition of viscosity stabilizer, standing at 1.2mg/g and 4.6mg/g for MMW and HMW polymer solutions respectively, higher by 0.5mg/g and 2.94mg/g than those without viscosity stabilizer.

**Table 7**  
**Test Result of Polymer Static Absorption**

Sample	Oil sand mass (g)	Polymer concentration (mg/L)		Static absorption (mg/g)
		Before absorption	After absorption	
MMW normal	10	1000	965	0.70
MMW+ stabilizer	10	1000	940	1.20
HMW normal	10	1000	917	1.66
HMW+ stabilizer	10	1000	770	4.60

The dynamic absorption and fluidity experiments, conducted simultaneously, aim at calibrating the difference between the injection and outflow amounts of

polymer mass and the drill core mass and calculating the dynamic absorption amount.

$$\text{dynamic absorption (mg/g)} = \frac{\text{Injection polymer mass (mg)} - \text{outflow polymer mass (mg)}}{\text{Drill core mass(g)}}$$

Table 8 shows the calibration results of the dynamic absorption experiment on MMW and HMW polymer solutions both before and after the addition of viscosity stabilizer. According to Table 8, the viscosity stabilizer affects evidently the dynamic absorption of polymer on drill

core, which increases after the addition of viscosity stabilizer, standing at 0.31mg/g and 0.42mg/g for MMW and HMW polymer solutions respectively, higher by 0.12mg/g and 0.13mg/g than those without viscosity stabilizer.

**Table 8**  
**Test Result of Polymer Dynamic Absorption**

Sample	Air permeability rate of drill core (10 <sup>-3</sup> μm <sup>2</sup> )	Polymer concentration (mg/L)		Core mass (g)	Dynamic absorption (mg/g)
		Injection	Outflow		
MMW normal	2813	1000	388	79.99	0.19
MMW+ stabilizer	2454	1000	325	75.63	0.31
HMW normal	2640	1000	340	79.79	0.28
HMW+ stabilizer	2753	1000	263	76.56	0.41

## 2. OIL DISPLACEMENT EVALUATION OF VISCOSITY STABILIZER/ POLYMER SOLUTION

The model by size of 4.5cm×4.5cm×30cm, a man-made drill core made of epoxy quartz sand, is divided vertically into three layers of the top, the middle and the bottom, of 1.5cm in thickness for each layer, the permeability at 1000mD, 350mD and 150mD respectively. The experiment oil is compounded with the crude oil in Daqing Oilfield and kerosene, the viscosity at about 10mPa.s in temperature of 45°C. The polymers are those of MMW and HMW manufactured by Daqing Chemistry and Refinery Company, and their specifications are shown in Table 1. The water for the experiment are fresh water and the produced water from the Water Injection Station

in Daqing Oilfield, their qualities shown in Table 2.

Table 9 shows oil displacement experiment on MMW and HMW polymer solutions in purpose of enhancing recovery rate both before and after the addition of viscosity stabilizer. According to Table 9, the viscosity stabilizer affects evidently the oil displacement effects of polymer; with the addition of viscosity stabilizer, the working viscosity and recovery rate are enhanced markedly. Those of HMW polymer solution through water and then polymer flooding are 26.5mPa.s and 24.4% respectively; those of MMW polymer solution are 13.5mPa.s and 17.2%. Comparing with data of solutions without viscosity stabilizer, the working viscosity and recovery rate of HMW polymer solution through water and then polymer flooding enhance by 10.7mPa.s and 8.5% respectively; those of MMW polymer solution through water and then polymer flooding by 7.5mPa.s and 7.5% respectively.

**Table 9**  
**Data of Oil Displacement Experiment on Polymer Solutions Before and After the Addition of Viscosity Stabilizer**

No.	Content	Working viscosity (mPa·s)	Oil saturation (%)	Recovery rate (%)		Enhanced recovery rate (%)
				Water flooding	Polymer flooding	
1	Water flooding to 92% + 0.57PV polymer flooding (MMW)+ later water flooding to 98%	6.0	70.8	38.8	54.2	9.7
2	Water flooding to 92% + 0.57PV polymer flooding (MMW + viscosity stabilizer)+ later water flooding to 98%	13.5	71.5	38.1	61.7	17.2
3	Water flooding to 92% + 0.57PV polymer flooding (HMW)+ later water flooding to 98%	15.8	71.3	38.7	60.4	15.9
4	Water flooding to 92% + 0.57PV polymer flooding (HMW + viscosity stabilizer)+ later water flooding to 98%	26.5	71.6	38.4	68.9	24.4

## 3. ANALYSIS OF ONSITE APPLICATION OF VISCOSITY STABILIZER

From September 2006, Daqing Oilfield conducted the experiment of injecting viscosity stabilizer in the target block, covering 27 injection wells and 16 central production wells. The specific effects are shown as follows:

### 3.1 Stable Injection Pressure

From the average injection pressure in the experiment block, it slightly increases and keeps stable after the addition of viscosity stabilizer. Of the 27 wells, the average injection pressure stands at 12.55MPa before the addition of viscosity stabilizer and at 12.88MPa half a year after, a level evenly kept ever since. Thus that is a rise of 0.33MPa.

### 3.2 Decreased Recover Speed of the Average Water Cut

Comparing with the adjacent blocks without the injection of viscosity stabilizer, the experiment block after the injection, witnesses decreased recover speed of the average monthly water cut of the central production wells. Within one year after the injection of viscosity stabilizer, the recover speed of the average monthly water cut of the central production wells enhances by 0.16%. The adjacent block without the injection, the same speed enhances by 0.27%.

### 3.3 Slight Increase in the Viscosity of Liquid from Production Wells

Of the central production wells in the experiment block, the viscosity slightly increases after the injection of viscosity stabilizer. In the initial stage after the injection of viscosity stabilizer in the experiment block, the viscosity of the central production wells stands at 2.58mPa.s and rises to 2.74mPa.s in seven month and keeps stable at 2.8mPa.s, an increase of 0.22mPa.s.

### 3.4 Slight Increase in Periodic Recovery Rate and Absorption Thickness

Comparing with the adjacent blocks without the injection of viscosity stabilizer, the experiment block after the injection witnesses a slight increase of recovery rate and absorption of the oil layers in the central production wells. The periodic recovery rate of the experiment stands at 1.32%, an increase of 0.14%, and the absorption thickness covers three extra layers.

## CONCLUSIONS

(1) The polymer solution with viscosity stabilizer added obviously performs better in terms of viscosity stability than that without. The same is true of the polymer solution diluted with aerated water, comparing with that diluted with fresh produced water. So is the case with solution sheared before the addition of viscosity stabilizer, comparing with that added with viscosity stabilizer before being sheared.

(2) Comparing with the normal polymer solution without viscosity stabilizer, that with the stabilizer features marked increase in resistance and residual resistance factors, static absorption of the oil sand and dynamic absorption of the drill core.

(3) As evident in the oil displacement experiment, the polymer solution with the addition of viscosity stabilizer after water flooding performs better than the normal polymer solution, with recovery rate increased by about 8.0%.

(4) Comparing with the adjacent blocks without the injection of viscosity stabilizer into the normal polymer solution, the experiment block after the injection witnesses first slightly increased and then stabled injection pressure in the injection wells, and decreased recover speed of the average monthly water cut, higher viscosity, larger thickness of the oil layers and increased periodic recovery rate

of the central production wells in the experiment block.

(5) When the molecule weight of the polymer solution is compatible with the pore structure of the reservoir and formation plugging does not occur, the greater the polymer solution concentration and viscosity, the better the polymer flooding effects. But an optimum concentration value exists to make the oil production enhanced by per ton polymer solution the highest. Under our research condition, the optimum concentration value of polymer solution ranges between 1500 and 2000 mg/L.

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