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Studies on the Scaling of High Pressure and Low Permeability Oil Reservoir Water Injection Well

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Abstract

Injection wells scaling and scale inhibitor were studied in this paper, in consideration of the severe scaling problem of a high pressure injection wells in low permeability reservoirs. The result shows that the injected water contains some scale ions, such as carbonate calcium and magnesium ions. It also demonstrates that the main component of the scale is calcium carbonate, while the scale at bottom hole contains more silicon dioxide. Besides, the scaling of water injection wells mainly appear in the lower parts of the well and its thickness along the well increases rapidly. The indoor experiments of anti-scaling agent indicate that the anti-scaling agent is of good performance in scale prevention and its best concentration is 15 mg/L. In addition, it is also found that the scale inhibiting efficiency of scale inhibitor 2 is higher when the injected water is at low temperature, while scale inhibitor 1 shows better performance when the temperature of injected water is over 75 ℃.

Key words: High pressure and low permeability oil reservoir; Water injection well; Scaling; Scale inhibitor

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INTRODUCTION

With the rapid development of exploration and exploitation of petroleum in China, the proportion of low permeability reserves in the new proven reserves is more and more, about more than 70% of the proven reserves is the low permeability reserves. The lithology is dense in the low permeable oil fields, high seepage resistance, pressure conduction ability is poor, usually lack of natural energy, the oil well natural capacity is poor. When the exploration of petroleum rely on the natural energy, the initial formation pressure and the production drop quickly, a recovery efficiency is very low, and difficult to recover. In order to improve development benefit, waterflood development is the main exploitation of low permeability oilfield[1-4]. Because of low permeability and the small pore radius, the request of injection water quality is high, but some water injection development of low permeability, the quality of injection water exceeds bid because of suspended solids and oil content, and the poor compatibility of injected water with formation water. Injected water contains a lot of Ca^{2+}, Mg^{2+}, SO_4^{2-}, CO_3^{2-} scale-forming ions, and with the comprehensive effect of the temperature and pressure change when the water is injected in formation, injection Wells generate the scale. At the same time there are corrosive substances in injected water, so there are different degrees of corrosion problems. Injection well corrosion and scaling reduced the water flooding efficiency, cause jams, and bring great harm to the production. In order to effectively prevent the injection Wells corrosion and scaling, study on the scaling of high pressure and low permeability oil reservoir water injection well is important[5-8].

In recent years, many researchers has made some important research results on the injection well antiscale. By the oil field injection well scale analysis, in the process of waterflooding scale types mainly include carbonate scale, sulfate scale and iron compounds scale, and so forth[9-10]. The research results show that: the basic reason of carbonate scale is the injected water containing a lot of scale ions lead to precipitation; sulfate scale formation is mainly due to the two incompatible water mixture, formation water contain a lot of scale cation, injected water contain SO_4^{2-}, leads into sulfate scale in near wellbore zone; iron compounds scale mainly include FeS, FeO, Fe_2O_3, and so forth. the main source of scale is the production of wellbore and equipment. In general the influence factors can be divided into geological factors and external factors. Geological factors is mainly refers to the porosity of the formation, rock mineral composition, and the properties of formation water. External factors mainly refer to the chemical characteristics of injection water[11-13].

1. WATER INJECTION WELLS SCALING ANALYSIS ON SITE

1.1 Water Injection Well Conditions

The scaling in a water injection well of Shengli oil field is analyzed, some information of the water injection well is shown in Table 1. The water quality analysis report is shown in Table 2.

Table 1
Parameters of the Water Injection Well

Name	Parameters
Total depth	3,317.73 m
Artificial bottom hole	3,374 m
Nitride tubes (*Φ*73)	348
Water injection pressure	30 MPa
Tubing pressure	13 MPa
Casing pressure	12 MPa
Daily average water injection	29.167 m^3/d

Table 2
Water Quality Analysis Report

Sample name		Injected water		Sampling spot		Water injection station	
Test standard		SY/T 5523-2000		SY/T5329-94		HJ/ZY2003-A0-01	
Analysis item		ρ (B)/(mgL^{-1})	c (1/zB^{Z-})/(mmolL^{-1})	Analysis item		ρ (B)/(mgL^{-1})	c (1/zB^{Z+})/(mmolL^{-1})
Anion	F^-	0	0	Cation	Li^+	0	0
	Cl^-	20,948.81	590.940		Na^+	12,816.53	557.483
	Br^-	0	0		NH_4^+	0	0
	NO_2^-	0	0		K^+	48.58	1.242
	NO_3^-	0	0		Mg^{2+}	95.56	7.861
	SO_4^{2-}	0	0		Ca^{2+}	607.30	30.304
	OH^-	0	0		Sr^{2+}	190.95	4.359
	CO_3^{2-}	0	0		Ba^{2+}	159.92	2.329
	HCO_3^-	823.71	13.499		Fe	16.00	0.859
Total		21,772.52	604.439	Total		13,934.83	604.439
pH			7.4	ρ (SS)(mg/L)			52.4
ρ (oil)(mg/L)			1.6	ρ (Sulfide)(mg/L)			0
ρ (dissolved oxygen)(mg/L)			0.07	ρ (CO_2)(mg/L)			0.0
Mineralization ρ (∑B)/ (mgL^{-1})			35,707.35	Permanent hardness ρ ($CaCO_3$)/ (mgL^{-1})			1234.57
Total alkalinity ρ ($CaCO_3$)/ (mgL^{-1})			675.63	Temporary hardness ρ ($CaCO_3$)/ (mgL^{-1})			675.63
Total hardness ρ ($CaCO_3$)/ (mgL^{-1})			1,910.20	Negative hardness ρ ($CaCO_3$)/ (mgL^{-1})			0

1.2 Water Injection Wells Scaling Situation

It is found that there is severe scaling in the water injection pipe, which is taken out from the well after two years and a half water injection. Figure 1 shows the scaling in water injection pipe.

From the wellhead to the 1,000 meters depth, there is only a very thin layer of reddish-brown scale cinder in the inner wall of the tube. The pipe wall is smooth after getting rid of this thin layer of scale cinder and there is no obvious corrosion. From 1,000 m to 1,700 m, the inner wall of the tube becomes rough. The massive scale area and black corrosion area shows discontinuous distribution.

Scale layer appears at 1,700 m depth, which is duck-egg blue and about 0.2 mm thick. After getting rid of the scaling layer, it is found that there is a small amount of bronzing corrosion products below the scale and the inner wall of the tube is rough.

Over 1,800 m depth, the scale thickness increases with the increase of the well depth. The scale is a dense thin layer, which is about 0.7 mm - 0.8 mm thick. It has duck-egg blue smooth surface and contains a bit of black impurities. Under-deposit corrosion can be found after getting rid of the scaling layer.

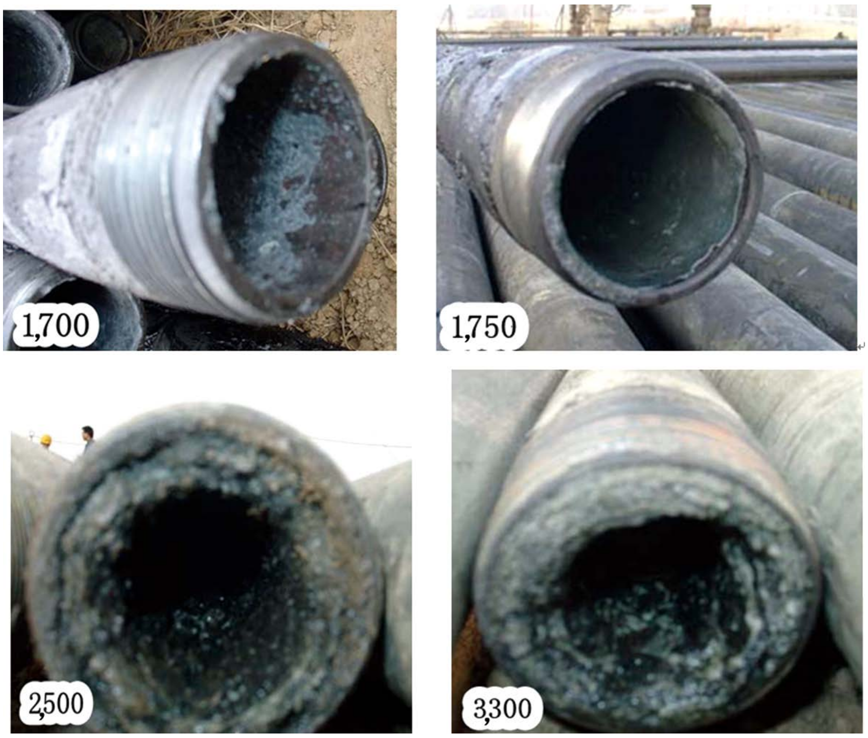


Figure 1
The Scaling in Water Injection Pipe at Different Well Depth

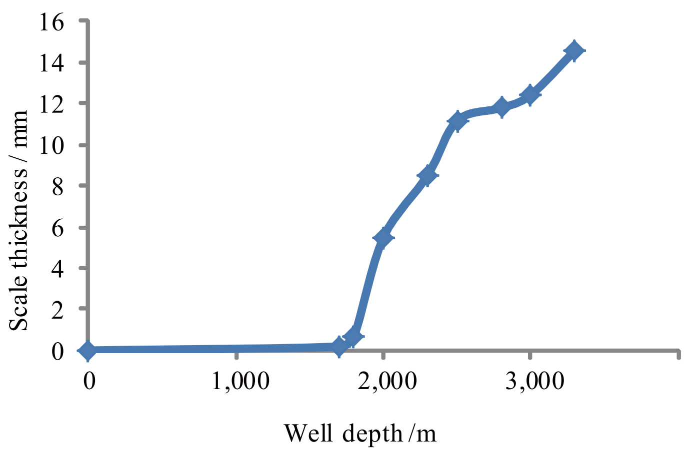


Figure 2
The Change of Water Injection Pipe Scale Thickness With the Increase of Well Depth

Over 2,000 m depth, the scale obvious thickening and about 5 mm - 6 mm thick on average, which is duck-egg blue and black staggered distribution. Moreover, under-deposit corrosion is more serious.

2,300 m depth, the scale thickness is 8 mm - 9 mm.

2,500 m depth, the scale thickness is 11.17 mm on average.

2,800 m depth, the scale thickness is 11.78 mm on average.

3,000 m depth, the scale thickness is 12.42 mm on average.

3,300 m depth, the scale thickness is 14.58 mm on average.

The scaling trend of water injection well can be get from the above data, as shown in Figure 2.

1.3 Component Analysis of the Scale in Water Injection Well

Take the scale at 1,800 m, 2,500 m and 3,200 m well depth as samples for XRD analysis. The spectrum diagram is respectively shown in Figure 3, Figure 4, Figure 5. Table 3 shows the result.

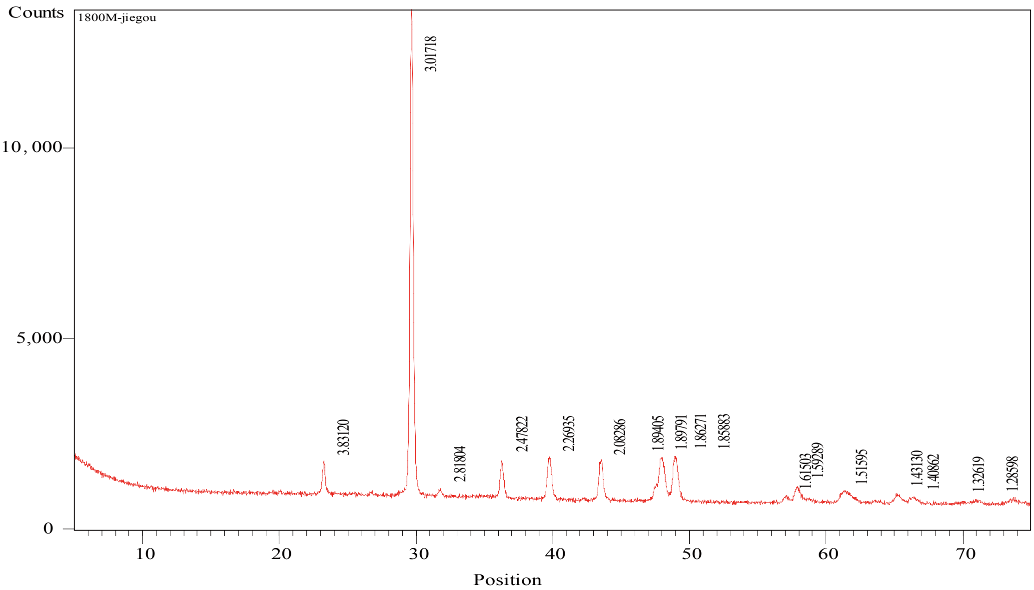


Figure 3
The XRD Spectrum Diagram of the Scale at Well Depth of 1,800 m

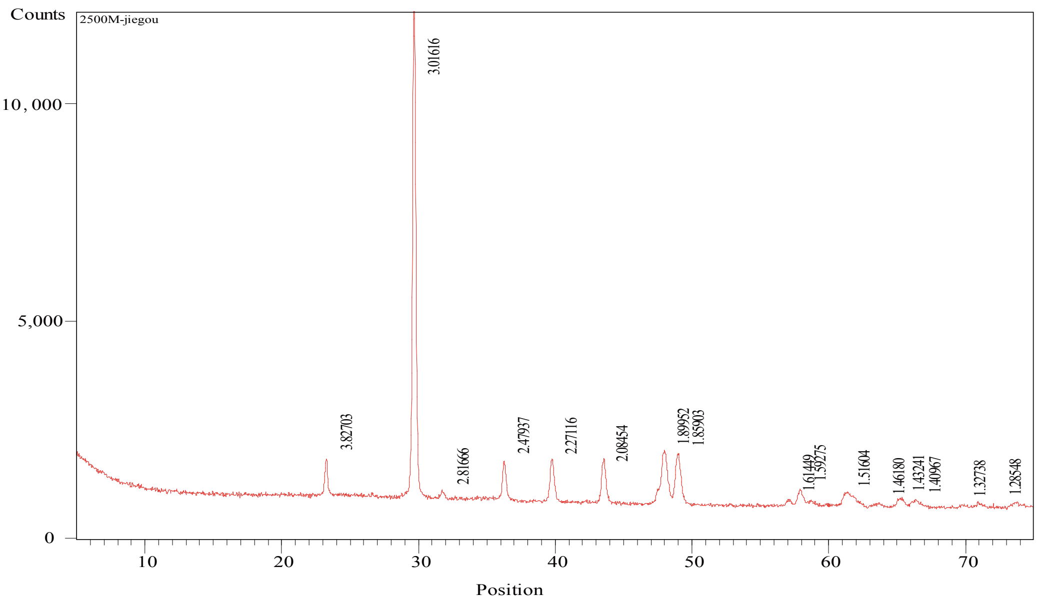


Figure 4
The XRD Spectrum Diagram of the Scale at Well Depth of 2,500 m

Table 3
The Results of Scale Sample Analysis

Sampling location	Composition analysis results	Proportion
1,800 m	$(Mg_{0.06}Ca_{0.94})CO_3$, mainly in the form of calcite	95%
2,500 m	$(Mg_{0.1}Ca_{0.9})CO_3$	95%
3,200 m	$(Mg_{0.06}Ca_{0.94})CO_3$	61.17%
	SiO_2	38.83%

It can be found that the scale in this well is mainly composed by $(Ca,Mg)CO_3$ and the scale at 1,800 m exits mainly in the form of calcite. Besides, the scale at the location near bottom is the mixed phase of $(Ca,Mg)CO_3$ and SiO_2. SiO_2 may be the impurities in formation sandstone.

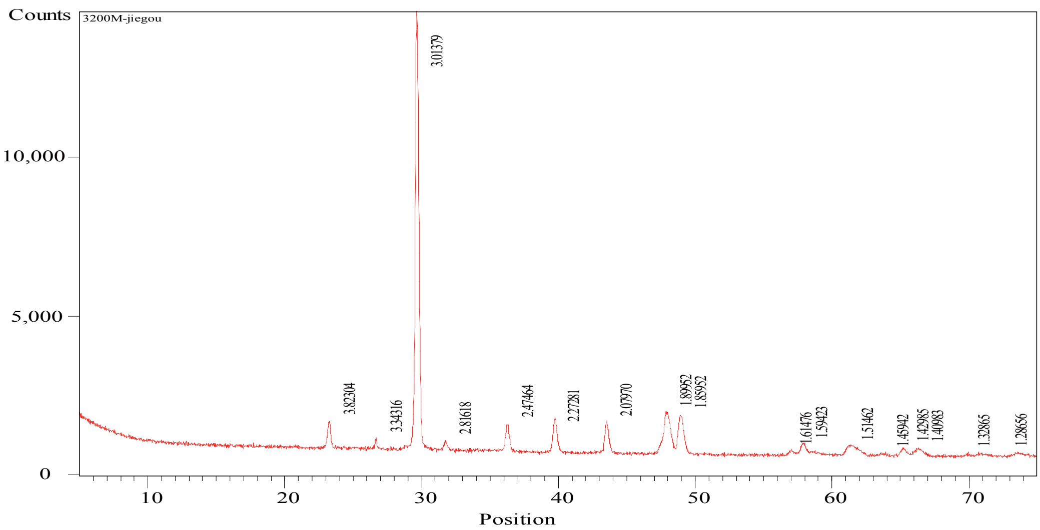


Figure 5
The XRD Spectrum Diagram of the Scale at Well Depth of 3,200 m

2. EXPERIMENT RESEARCH OF SCALE INHIBITOER USED IN SCALE PREVENTION

By water analysis of injection water, it's found that the main scaling ion is CO_3^{2-}, Ca^{2+} and Mg^{2+}. The $CaSO_4$ scaling don't format for the lack of SO^{2-}. It's certain that 95% percent of scaling is $CaCO_3$ via the component analysis of injection well scaling. In addition, the scaling also contain a small amount $MgCO_3$, no Sulphate scaling. Considering the serious scaling of injection well, the analysis of scaling and the scale prevention technology by far, it's effective to add scale inhibitor into injection wellbore. So, the two kinds of selected scale inhibitors is evaluated in experimental condition, aiming at providing guidance of scale prevention in injection wellbore with high pressure and low permeability

2.1 The Method of Scale Inhibitor Assessment

One basic index in scaling assessment is the efficiency of scale inhibitor used in scale prevention. The method used to test the scale inhibitor efficiency in lab is sediment weight method.

Under the same conditions, the scale inhibitor is added in water samples. The number of precipitation amount of scaling can be used to measure the efficiency of scale inhibitor. Generally the better the scale inhibitor is added, the less amount sediment format.

In precipitation test, changing the experimental conditions with one kind of water or mixing two incompatible water, the mixing ratio of precipitation depends on the largest precipitation of blank samples.

Scale-preventing efficiency is calculated by the following formula

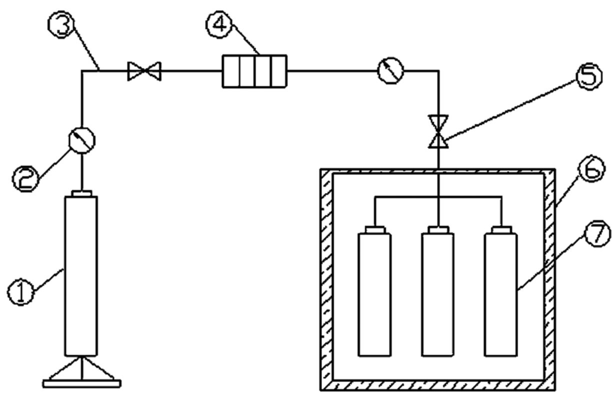
Scale-preventing efficiency (%) = $[(g_0-g)/g_0] \times 100\%$

The formula: g_0 - the amount of blank sample precipitation, g;

g - the amount of sample precipitation after added scale inhibitor, g;

The advantages of precipitation method are simple, more intuitive, but for some scaling produce sticky wall situation will affect the accuracy of the test.

2.2 Experimental



1. Hand cranking high pressure metering pump; 2. Pressure gauge; 3. High pressure line; 4. High pressure apparatus of piston cylinder type; 5. Needle valve; 6. Thermostat container; 7. High pressure apparatus.

Figure 6
Injection Wells Scaling Simulation Device

The material of injection pipes is custom-made to be standard coupons. Using the device as shown in Figure 6 simulates the injection wells environment. The high-pressure vessel filled with water samples from the injecting water station. In order to evaluate the efficiency of scale inhibitor, respectively, add varying amounts and different types of scale inhibitors to the high pressure vessel under the same conditions. The treated coupons were placed in different water samples, then seal the vessel and boost the pressure to injection wells pump station value (30 MPa), at a predetermined temperature soak some time. Due to the scale, the coupon have a mass difference before and after immersion, that is, the scaling amount under that condition, and then use the scaling amount in check test to calculate the scale-preventing efficiency. By simulating scaling in injection well under different conditions further evaluation about scale inhibitor efficiency is made.

2.3 Results and Discussion

Use injection wellbore scaling simulating device to test the efficiency of two kind scale inhibitors, Stone Chemical (scale inhibitor 1) and Easters Chemical (scale inhibitor 2).

(a) Test conditions: 30 Mpa, 50 ℃, test the two scale inhibitor efficiency in different concentration.

Figure 7 shows that in the medium pressure of 30 MPa, temperature is 50 ℃, the two kinds of scale inhibitors have good performance, scale-preventing efficiency increases with the rise of scale inhibitor concentrations and leveled off at 15 mg/L. The scale inhibitor 1 maximum scale-preventing efficiency is around 70%, the scale inhibitor 2 is about 80%.

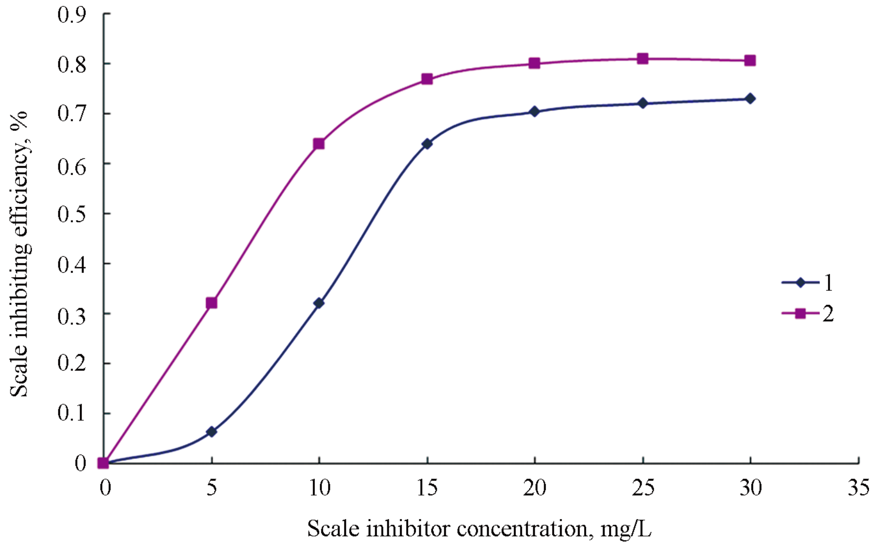


Figure 7
The Relationship Between Scale Inhibiting Efficiency and Scale Inhibitor Concentration (50 ℃)

(b) Test conditions: 30 Mpa, 90 ℃, test the two scale inhibitor efficiency in different concentration.

Figure 8 shows that, in the medium pressure is 30 MPa, temperature 90 ℃, compared with the case when lower temperature 50 ℃, the scale-preventing efficiency changes with the concentration is almost same. When the concentration of scale inhibitor reach 15 mg/L, the scale inhibitor 1 maximum scale-preventing efficiency peak at 65% and the scale inhibitor 2 peak at 50%, that is the difference. It's indicted that the scale inhibitor 1 scale inhibitor scale-preventing efficiency have little change in the experimental temperature, The scale inhibitor 2 is opposite, as the temperature increases, scale-preventing efficiency is reduced.

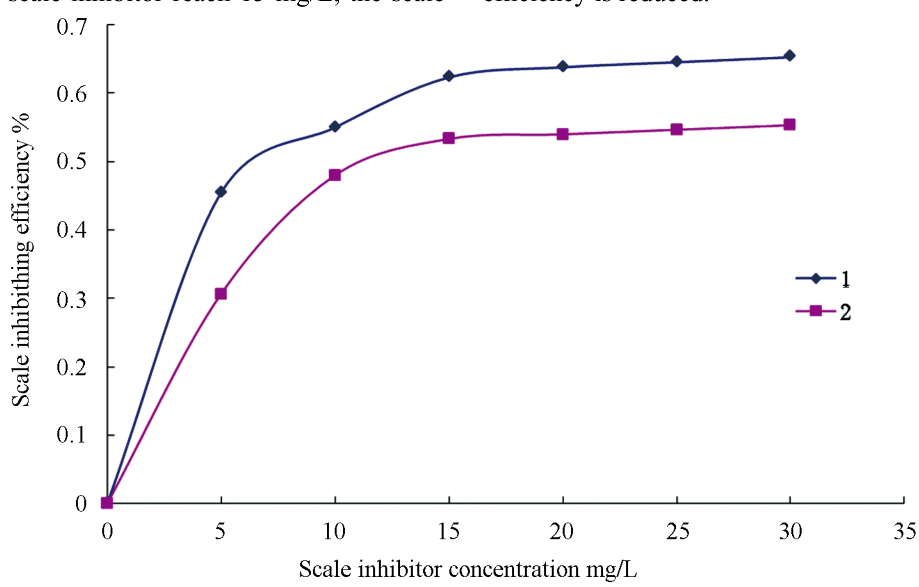


Figure 8
The Relationship Between Scale Inhibiting Efficiency and Scale Inhibitor Concentration (90 ℃)

(c) Test conditions: 30 Mpa, scale inhibitor concentration: 20 mg/L (scale inhibiting efficiency maximum), research on temperature effect on the scale inhibiting efficiency.

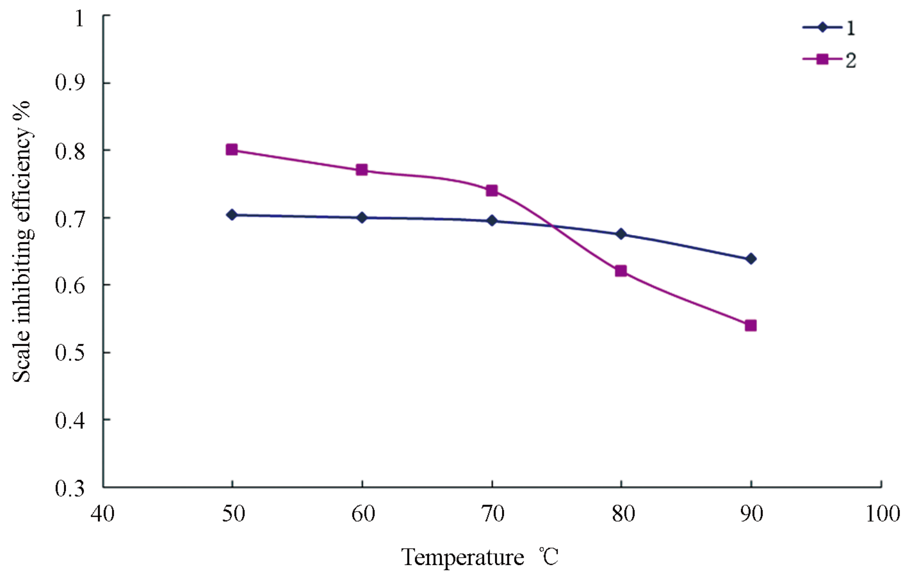


Figure 9
Temperature Effect on the Biggest Scale Inhibiting Efficiency

As is shown in Figure 9, Temperature has less effect on the scale inhibitor 1. The biggest scale inhibiting efficiency of scale inhibitor 2 reduce quickly with the temperature increases. When temperature is less than 75 ℃, The biggest scale inhibiting efficiency of scale inhibitor 2 is greater than the biggest scale inhibiting efficiency of scale inhibitor 1, after more than 75 ℃, high temperature make the scale inhibiting efficiency of scale inhibitor 2 decrease, the biggest scale inhibiting efficiency is lower than scale inhibitor 1. So the scale inhibitor should choose by temperature of the injection water. At low temperature, scale inhibitor 2 is better, at high temperature, scale inhibitor 1 is better.

CONCLUSION

(a) The research on the well scaling of high pressure low permeability reservoir shows that scaling is not obvious if well depth is no deeper than 1,800 m, however, the scale thickness increases rapidly from 1,800 m well depth. Besides, water quality analysis results demonstrate that the injected water contains large amounts of carbonate calcium and magnesium ions. The analysis on scale components indicates that the scale is mainly composed by calcium carbonate whose content is as much as 95% and it also contains a small amount of magnesium carbonate. In addition, the scale will contain more silicon dioxide at the location near the bottom hole.

(b) scale inhibitor can be used to prevent the serious scaling in the water injection wells of high pressure low permeability reservoir. The indoor evaluation of two kinds of scale inhibitor demonstrates that both of them show good anti-scaling performance and their best concentration is 15 mg/L. Besides, scale inhibitor 2 has high scale inhibiting efficiency at low water temperature, but its scale inhibiting efficiency degrades with the increase of temperature and its scale inhibiting efficiency becomes lower than scale inhibitor 1. Therefore, scale inhibitor 1 shows better anti-scaling performance at high temperature.

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