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Research on Indoor Experimental Technology of ultra-high Temperature Acidizing Corrosion Inhibitors Containing N-Heterocyclic Quaternary Ammonium Salts

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Keywords: ultra-high temperature; corrosion inhibitor; N heterocyclic quaternary ammonium salt

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Temperature Acidizing Corrosion Inhibitors Containing N-Heterocyclic Quaternary Ammonium Salts

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Abstract: In the process of acidizing operation, especially in ultra-high temperature wells, metal components such as wellbore tubing and surface equipment are severely corroded by acid fluids, leading to operational challenges in oilfield production. At present, the addition of corrosion inhibitors is one of the most effective methods to mitigate metal corrosion. Pyridine residues, quinoline quaternary ammonium salts, aldehyde ketone amine condensates, acetylenic methyl ammonia and imidazoline corrosion inhibitors have been widely studied in the industry. Among them quaternary ammonium salts are widely used in oilfield production due to their excellent corrosion resistance, low toxicity and good water solubility. However, their limited heat resistance makes them unsuitable for ultra-deep exploration wells or scientific research wells. This study focuses on N-heterocyclic quaternary ammonium salt-based corrosion inhibitors (alkyl quinolinium quaternary ammonium salts), which can withstand temperatures up to 200°C, meeting the requirements of ultra-high temperature wells.

Keywords: ultra-high temperature, corrosion inhibitor, N heterocyclic quaternary ammonium salt

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1. Introduction

Acidizing is an important measure to increase production of oil wells and injection of water wells, and has been widely used in petroleum industry. However, the acid used in acidizing process will cause serious corrosion to pipelines and equipment, and also cause potential damage to formations. In order to reduce acid corrosion and ensure the success of acidizing operation, the most economical and effective method is to add high efficiency acidizing corrosion inhibitor to acidizing fluid. In recent years, with the increasing demand of deep wells, ultra-deep wells and sulfur-bearing oil and gas fields, ultra-high temperature acidizing corrosion inhibitors are urgently needed to solve the corrosion problem in high temperature and acidic environment in oil and gas exploitation.

At present, the commonly used acidizing corrosion inhibitors mainly include quaternary ammonium salts, Mannich bases and imidazolines. Imidazoline corrosion inhibitors have excellent corrosion inhibition performance for medium carbon steel in hydrochloric acid, etc. Mannich base corrosion inhibitors have been paid much attention to as corrosion inhibitors suitable for concentrated hydrochloric acid medium under high temperature conditions due to their good corrosion inhibition performance. Mannich base is a class of corrosion inhibitors with excellent performance and is widely used as corrosion inhibitors for concentrated hydrochloric acid at high temperature in acidizing operations. However, these inhibitors are only effective for certain acids and are often less effective for other acid types.

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With the increasing requirements for acid corrosion inhibitors, common acidizing corrosion inhibitors have the disadvantages of easy coking, stratification and unstable dissolution and dispersion at high temperature, which may cause further damage to the formation. Single Mannich alkali corrosion inhibitor is difficult to achieve ideal corrosion inhibition effect when used alone due to its molecular structure and other problems. At present, the research and development direction of acidizing corrosion inhibitors is to develop new, environmentally friendly, high temperature and concentrated acid resistant long-term corrosion inhibitor compound system; the high temperature acidizing corrosion inhibitors developed by relevant experts are mainly composed of multi-component corrosion inhibitors and synergists, especially amines, quaternary ammonium and alkynes compound corrosion inhibitors are widely used in order to achieve high performance and more extensive application range.

Based on the above knowledge, this paper evaluates the performance of quaternary ammonium salt corrosion inhibitors synthesized from different raw materials by optimizing the synthesis route, obtains the best corrosion inhibitor, and studies its corrosion inhibition mechanism. In order to solve the problem of corrosion inhibitor's solubility in acid, the proper solvent, dispersant and surfactant were selected. In order to further improve the performance of corrosion inhibitor, synergistic agent was compounded, and finally the ultra-high temperature corrosion inhibitor which could resist 200 °C was obtained.

2. Materials and Methods

2.1. Alkylpyridine quaternary ammonium salt was synthesized by alkylation reaction with alkylpyridine and benzyl chloride as raw materials. The main reaction is as follows:

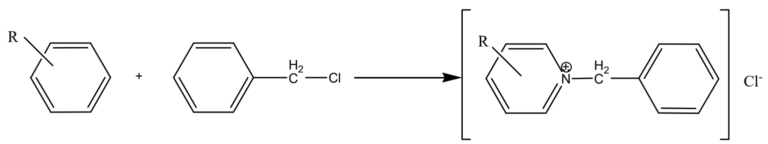

Figure 1. Reaction formula for synthesis of alkyl pyridine benzyl quaternary ammonium salts.

2.2 Alkylquinoline quaternary ammonium salt is synthesized by alkylation reaction with alkyl quinoline and benzyl chloride as raw materials. The main reaction is as follows:

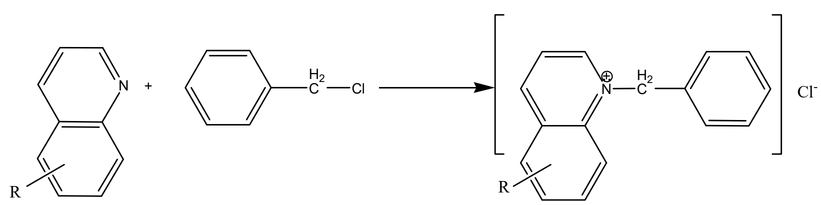

Figure 2. Reaction formula for synthesis of alkyl quinoline benzyl quaternary ammonium salts.

2.3 Alkylpyridine and chloromethyl naphthalene were used as raw materials to synthesize alkylpyridine quaternary ammonium salts. The main reactions are as follows:

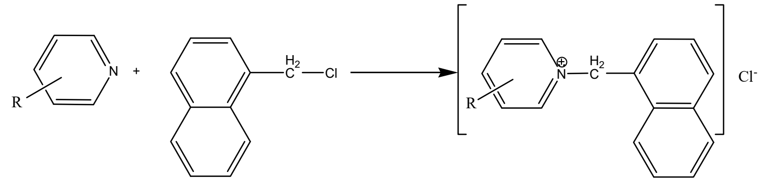

Figure 3. Reaction formula for synthesis of alkyl pyridine naphthylmethyl quaternary ammonium salts.

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2.4 Alkyl quinoline quaternary ammonium salt is synthesized by alkylation reaction with alkyl quinoline and chlorohydrin as raw materials. The main reaction is as follows:

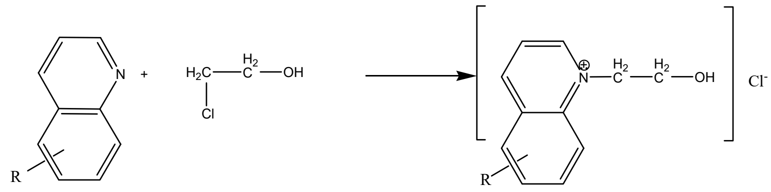

Figure 4. Reaction formula for synthesis of alkyl quinoline hydroxyethyl quaternary ammonium salt.

3. Results and Discussion

3.1. Study on Corrosion Inhibition Mechanism of Alkyl Quinoline Quaternary Ammonium Salt

Figure 5 shows the polarization curves of N80 carbon steel at 90°C and 15%HCl after adding alkyl quinoline quaternary ammonium salt with varying concentrations [1–9]. The parameters obtained by fitting the polarization curves are shown in Table 1.

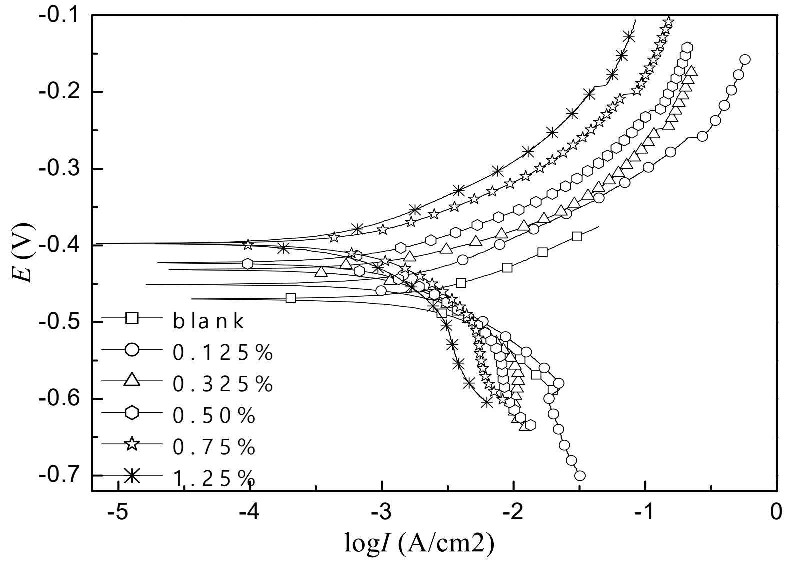

Figure 5. Polarization curves of N80 carbon steel in 15% HCl with different concentrations of alkylquinoline quaternary ammonium salts at 90°C.

Table 1. Polarization curve fitting results of N80 carbon steel at 90°C in 15% HCl containing different concentrations of alkyl quinoline quaternary ammonium salts.

Concentration (mol/L)	Corrosion potential (V)	Anode Tafel Slope (mV)	Cathode Tafel Slope (mV)	corrosion current Density (A/cm²)	inhibition efficiency (100%)
0	-0.47	79.0	84.0	2.0×10^{-2}	--
0.0050	-0.45	80.4	119.1	2.3×10^{-3}	88.5
0.0125	-0.43	60.3	125.4	1.6×10^{-3}	92.0
0.0200	-0.42	64.5	110.3	1.1×10^{-3}	94.5
0.0300	-0.40	65.9	106.4	8.6×10^{-4}	95.7
0.0500	-0.39	67.0	103.8	5.2×10^{-4}	97.4

The potentiodynamic scanning results showed that although the inhibition result of alkyl quinoline quaternary ammonium salt was not as good as that of Mannich base quaternary ammonium salt under the same conditions, alkyl quinoline quaternary ammonium salt also had good

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inhibition effect in 90°C and 15%HCl, and the inhibition effect was more obvious with the increase of alkyl quinoline quaternary ammonium salt concentration. It was also found that the Self-corrosion potential of N80 steel increased with the addition of alkyl quinoline quaternary ammonium salt, which indicated that alkyl quinoline quaternary ammonium salt was a corrosion inhibitor mainly of anodic inhibition type.

According to the Flory-Huggins isothermal equation $\log[\frac{\theta}{C}] = \log K + x\log(1-\theta)$, the adsorption isotherm fitting results are shown in Figure 6 [10–16], and the x value obtained is 1.45. The results show that the adsorption of quinoline quaternary ammonium salt on carbon steel surface is a single molecule adsorption film, and theoretically 1 quinoline quaternary ammonium salt molecule replaces 1.45 water molecules.

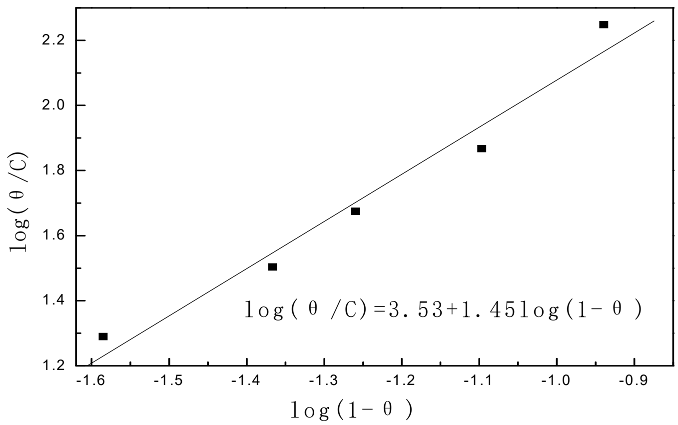

Figure 6. Flory-Huggins adsorption isotherm of alkylquinoline quaternary ammonium salts on N80 carbon steel surface in hydrochloric acid solution.

The following figure shows the AC impedance of N80 carbon steel after adding different concentrations of alkyl quinoline quaternary ammonium salt to 15%HCl at 90°C[17–24].

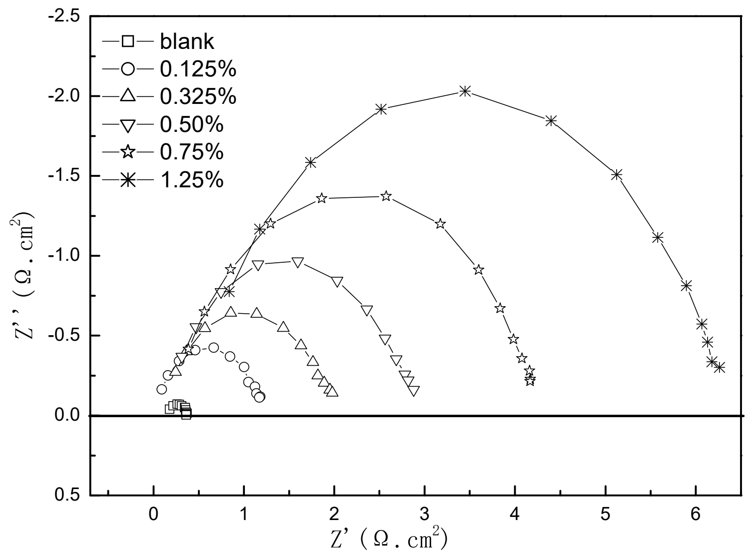

Figure 7. AC impedance spectra of N80 carbon steel at 90°C in 15% HCl containing different concentrations of alkyl quinoline quaternary ammonium salts.

The AC impedance spectrum of this system is fitted using the equivalent circuit shown in the figure below [25–27].

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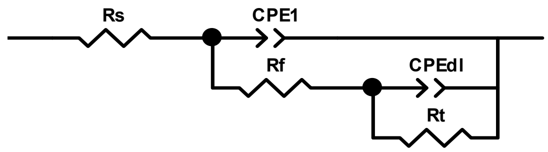

Figure 8. AC impedance spectrum equivalent circuit diagram.

Rs, Rf, and Rt in the equivalent circuit of Figure 8 are solution resistance, film resistance, and charge transfer resistance, respectively. CPE1 and CPEdl are constant phase angle elements related to interface capacitance and electric double layer capacitance, respectively. See Table 2 for fitting results of each component.

Table 2. AC impedance spectrum fitting results of N80 carbon steel in hydrochloric acid solution containing different concentrations of alkyl quinoline quaternary ammonium salts.

Concentration (mol/L)	Rs (Ω.cm²)	CPE1-T (F/cm²)	CPE1-P	Rf (Ω.cm²)	CPE1-T (F/cm²)	CPE1-P	Rt (Ω.cm²)
0	0.25	9.15e-4	0.98	0.16	7.25e-4	0.71	0.13
0.0050	0.18	1.52e-4	0.63	1.11	5.71e-5	0.83	1.12
0.0125	0.41	3.83e-4	0.62	1.54	1.45e-4	0.81	1.74
0.0200	0.29	2.9e-4	0.69	2.79	1.32e-4	0.83	2.58
0.0300	0.27	3.4e-4	0.73	4.25	2.2e-4	0.79	3.76
0.0500	0.30	4.12e-4	0.70	6.71	2.51e-4	0.79	5.65

AC impedance results show that film resistance and charge transfer resistance increase obviously after adding alkyl quinoline quaternary ammonium salt, especially charge transfer resistance Rt, which can reflect the level of corrosion difficulty. The larger the transfer resistance, the more difficult the corrosion is to proceed and the lower the corrosion rate [28–34]. AC impedance fitting results show that the charge transfer resistance of electrode increases significantly after adding alkyl quinoline quaternary ammonium salt, and the charge transfer resistance increases gradually with the increase of alkyl quinoline quaternary ammonium salt concentration, which further indicates that alkyl quinoline quaternary ammonium salt has obvious inhibition effect on corrosion of N80 carbon steel in hydrochloric acid solution, and the inhibition effect becomes more obvious with the increase of alkyl quinoline quaternary ammonium salt concentration.

Figure 9 (a) and (b) are polarization curves of N80 steel in 15%HCl solution and 15%HCl solution containing 0.05mol/L alkylquinoline quaternary ammonium salt at different temperatures respectively. See Table 3 for fitting results.

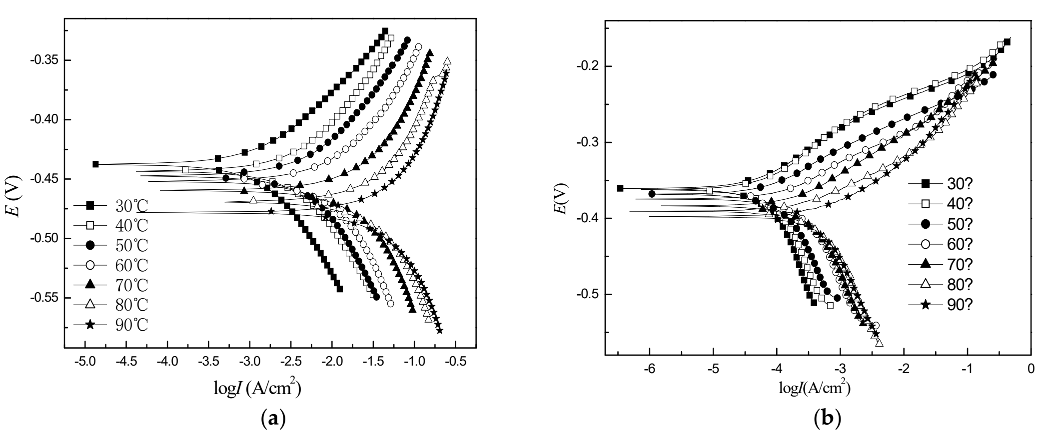

Figure 9. Polarization curves of N80 carbon steel at different temperatures (a) 15%HCl (b) 15%HCl containing 0.05mol/L alkylquinoline quaternary ammonium salt.

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Table 3. Polarization curve fitting parameter results of N80 steel in different solutions at different temperatures.

Corrosion inhibitor concentration (mol/L)	Temperature (K)	Corrosion potential (mV)	Anode Tafel Slope (mV)	Cathode Tafel Slope (mV)	Corrosion current Density (A/cm^2)
	303.2	-438.5	68.4	100.7	3.5×10^{-3}
	313.2	-443.4	75.0	89.2	4.8×10^{-3}
	323.2	-447.5	71.4	94.8	7.2×10^{-3}
	333.2	-452.2	73.3	91.6	8.7×10^{-3}
	343.2	-459.1	75.8	88.0	1.1×10^{-2}
	353.2	-469.1	80.0	83.0	1.7×10^{-2}
0	363.2	-477.9	80.3	82.6	1.9×10^{-2}
	303.2	-360.7	62.5	116.9	5.98×10^{-5}
	313.2	-362.0	67.2	103.4	7.28×10^{-5}
	323.2	-368.1	62.1	118.3	1.01×10^{-4}
	333.2	-374.6	63.9	112.4	1.92×10^{-4}
	343.2	-383.6	61.5	120.5	2.61×10^{-4}
0.050	353.2	-390.5	51.8	189.9	3.72×10^{-4}
	363.2	397.7	54.9	157.5	5.20×10^{-4}

From the polarization curve test results, with the increase of temperature, the self-corrosion current continuously increases, thus it is inferred that the corrosion reaction may coincidence the Arrhenius equation [35–42], and its expression can be expressed as follows:

$$I_{corr} = A\exp(-\frac{E_a}{RT}) \tag{1}$$

wherein, Icorr--corrosion current density value, A/cm^2;

A --Arrhenius predigital factor, A/cm^2;

Ea-activation energy of reaction process, J/mol.

The logarithm of the above formula was used to perform linear fitting with ln (Icorr) and 1/T values in the fitting results of polarization curves, and the slope and intercept of the fitted line were used to calculate the preexponential factor and reaction activation energy values [43–47].

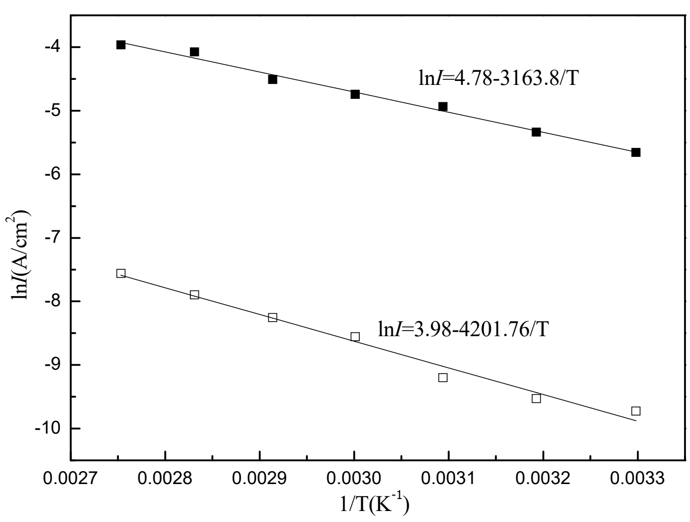

Figure 10. $\ln I_{corr}$-1/T curves for N80 carbon steel in different solutions.

The preexponential factor and reaction activation energy in blank solution and solution added with corrosion inhibitor calculated by slope and intercept of fitting straight line are shown in Table 4 respectively.

Table 4. Pre-exponential factors of corrosion reaction of N80 steel in different solutions, i.e., reaction activation energy.

Concentration (mol/L)	Pre-exponential factor A (A/cm^2)	Activation energy Ea (J/mol)
0	4.78	2.6×10^4
0.0056	3.98	3.5×10^4

3.2. Primary Screen of Quaternary Ammonium Salts Containing N Heterocyclic Rings

The quaternary ammonium salts obtained from the reaction of alkyl pyridine and chloromethyl naphthalene were eliminated due to their poor acid solubility. The quaternary ammonium salts obtained by reaction of alkyl pyridine with benzyl chloride, alkyl quinoline with benzyl chloride and alkyl quinoline with chloroethanol were preliminarily screened.

3.2.1. Evaluation of Corrosion Inhibition Performance of Quaternary Ammonium Salts Obtained by Reaction of Alkyl Pyridine and Benzyl Chloride at Low Temperature

Table 5. Corrosion Inhibition Performance of Alkyl Pyridine Benzyl Quaternary Ammonium Salt.

Acid temperature (°C)	Acid concentration (100%)	Inhibitor concentration (%)	Corrosion rate ($g/m^2 \cdot h$)
60	15%HCl	0.5	4.5
60	12%HCl+3%HF	0.5	3.8
60	multi-hydrogen acid	0.5	2.9
90	15%HCl	1	3.5
90	12%HCl+3%HF	1	3.1
90	multi-hydrogen acid	1	2.7

3.2.2. Evaluation of Corrosion Inhibition Performance of Quaternary Ammonium Salts Obtained by Reaction of Alkyl Quinoline and Benzyl Chloride at Low Temperature

Table 6. Corrosion Inhibition Performance of Alkyl Quinoline Benzyl Quaternary Ammonium Salt.

Acid temperature (°C)	Acid concentration (100%)	Inhibitor concentration (%)	Corrosion rate ($g/m^2 \cdot h$)
60	15%HCl	0.5	2.8
60	12%HCl+3%HF	0.5	2.1
60	multi-hydrogen acid	0.5	1.5
90	15%HCl	1	2.3
90	12%HCl+3%HF	1	1.9
90	multi-hydrogen acid	1	1.2

3.2.3. Evaluation of Corrosion Inhibition Performance of Quaternary Ammonium Salts Obtained by Reaction of Alkyl Quinoline and Chloroethanol at Low Temperature

Table 7. Corrosion Inhibition Performance of Alkyl Quinoline Hydroxyethyl Quaternary Ammonium Salt.

Acid temperature (°C)	Acid concentration (100%)	Inhibitor concentration (%)	Corrosion rate ($g/m^2 \cdot h$)
60	15%HCl	0.5	5.2
60	12%HCl+3%HF	0.5	4.3
60	multi-hydrogen acid	0.5	4.1
90	15%HCl	1	4.1
90	12%HCl+3%HF	1	3.9
90	multi-hydrogen acid	1	3.3

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From the above experiments, it can be found that quaternary ammonium salt obtained by reaction of alkyl quinoline and benzyl chloride has the best corrosion inhibition performance.

3.2.4. Evaluation of the Performance of Alkyl Quinoline Quaternary Ammonium Salts of Compound Propargyl Alcohol at High Temperature

Dimethylformamide, isopropanol and synergist propargyl alcohol were added to the synthesized alkyl quinoline quaternary ammonium salt to obtain high temperature acidification corrosion inhibitor. Corrosion inhibitors of different concentrations are added to different acid solutions at different temperatures, and the corrosion inhibition effect after compounding is evaluated in high pressure equipment. See Table 8 for more details.

Table 8. Corrosion Inhibition Performance of Alkyl Quinoline Quaternary Ammonium Salt Combined with Propargyl Alcohol.

Acid type	inhibitor concentration	temperature (°C)	pressure (Atmospheric pressure)	corrosion rate g/ $(m^2 \bullet h)$	Remark
multi-hydrogen acid	2%	120	160	7.5	specimen brightness
	3%	140	160	12.2	specimen brightness
	4%	160	160	18.7	specimen brightness
15%HCl	2%	120	160	12.8	specimen brightness
	3%	140	160	18.6	specimen brightness
	4%	160	160	21.2	specimen brightness
12%HCl+3%HF	2%	120	160	9.4	specimen brightness
	3%	140	160	14.3	specimen brightness
	4%	160	160	17.2	specimen brightness

The test results show that the corrosion inhibitor has a very good inhibition performance on multi-hydrogen acid, 15% HCl and mud acid when the temperature is up to 160°C.

3.2.5. Performance of Alkyl Quinoline Quaternary Ammonium Salt after Compounding Propargyl Alcohol and Cuprous Iodide at 180°C

Dimethylformamide, isopropanol and synergist propargyl alcohol are added to the synthesized quinoline quaternary ammonium salt to obtain inhibitor agent A, cuprous iodide is agent B, two formulations A、B are used to form ultra-high temperature acidification corrosion inhibitor, ultra-high temperature acidification corrosion inhibitor of different concentrations is added to different acid solutions at different temperatures, and the corrosion inhibition performance after compounding is evaluated in oil pressure equipment. See Table9 for more details.

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Table 9. Corrosion Inhibition Performance of Alkyl Quinoline Quaternary Ammonium Salt Combined with Propargyl Alcohol and Cuprous Iodide.

Acid type	Inhibitor concentration	Temperature (°c)	Pressure (atmospheric pressure)	Corrosion rate G/ (m^2 • h)	Remark
multi-hydrogen acid	3%	140	160	10.6	After alcohol and acetone wipe, the test piece is bright
	4%	160	160	16.1	
	4.5%	180	160	23.2	
15%HCl	3%	140	160	15.4	
	4%	160	160	19.2	
	4.5%	180	160	26.1	
12%HCl+3%HF	3%	140	160	11.9	
	4%	160	160	17.8	
	4.5%	180	160	24.7	

The experimental results show that alkyl quinoline quaternary ammonium salt mixed with propargyl alcohol and cuprous iodide has very good corrosion inhibition performance on polyhydrogen acid, 15% HCl and mud acid at 140-180°C.

At the same time, it was found that the quaternary ammonium salt of alkyl quinoline mixed with propargyl alcohol and cuprous iodide would precipitate after being placed in acid solution for a period of time. It is proposed to improve its dispersion performance by adding dispersant.

3.3. Improvement of Acid Solubility of Alkyl Quinoline Quaternary Ammonium Salts

Change dosage of dispersant and emulsifier in corrosion inhibitor, and select different emulsifier and dispersant to study the acid solubility change of quinoline quaternary ammonium salt, see Table 10 for more details.

Table 10. Alkyl quinoline quaternary ammonium hydrochloride solubility.

Acid liquor	Inhibitor concentration	Formula	Acid- solubility
multi-hydrogen acid	5%	30% quaternary ammonium salt +50% alcohol +20% OP-10	precipitation
		30% quaternary ammonium salt +60% alcohol +10% peregal	precipitation
		30% quaternary ammonium salt +50% isopropyl alcohol +20% OP-10	precipitation
		30% quaternary ammonium salt +60% isopropyl alcohol +10% peregal	homogeneous solution
15%HCl	5%	30% quaternary ammonium salt +50% alcohol +20%	precipitation

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		OP-10	
		30% quaternary ammonium salt +60% alcohol +10% peregal	precipitation
		30% quaternary ammonium salt +50% isopropyl alcohol +20% OP-10	precipitation
		30% quaternary ammonium salt +60% isopropyl alcohol +10% peregal	homogeneous solution
mud acid	5%	30% quaternary ammonium salt +50% alcohol +20% OP-10	precipitation
		30% quaternary ammonium salt +60% alcohol +10% peregal	precipitation
		30% quaternary ammonium salt +50% isopropyl alcohol +20% OP-10	precipitation
		30% quaternary ammonium salt +60% isopropyl alcohol +10% peregal	homogeneous solution

The problem of poor acid solubility of corrosion inhibitor can be solved by adding dispersant and emulsifier reasonably.

3.3. Improved Temperature Resistance of Alkyl Quinoline Quaternary Ammonium Salt Corrosion Inhibitor

3.3.1. Corrosion Inhibition Performance at 160-190°C

The corrosion inhibition performance of alkyl quinoline quaternary ammonium salt with improved acid solubility after compounding propargyl alcohol and cuprous iodide is evaluated as shown in Table 11.

Table 11. Corrosion Inhibition Performance of Alkyl Quinoline Quaternary Ammonium Mixed with Propargyl Alcohol and Cuprous Iodide after Improving Acid Solubility.

Acid type	Inhibitor concentration	Dispersant concentration	Temperature (°c)	Pressure (atmospheric pressure)	Corrosion rate G/ (m² • h)	Remark
multi-hydrogen acid	4%	5%	160	160	41.6	specimen brightness
	4.5%	5%	180	160	62.8	specimen brightness
	5%	5%	190	160	76.2	relatively bright

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15%HCl	4%	5%	160	160	59.1	specimen brightness
	4.5%	5%	180	160	76.9	relatively bright
	5%	5%	190	160	83.7	Slight blackening
12%HCl+ 3%HF	4%	5%	160	160	48.6	specimen brightness
	4.5%	5%	180	160	71.4	relatively bright
	5%	5%	190	160	79.4	Slight blackening

3.3.2. See Table 12 for Corrosion Inhibition Performance at 200°C

Table 12. Corrosion Inhibition Performance of Alkyl Quinoline Quaternary Ammonium at Ultra-High Temperature.

Acid type	Inhibitor concentration	Dispersant concentration	Temperature (°c)	Pressure (atmospheric pressure)	Corrosion rate G/ (m²• h)	Remark
multi-hydrogen acid	5.5%	7%	195	160	78.8	Slight blackening
	5.5%	7%	200	160	82.1	Slight blackening
15%HCl	5.5%	7%	195	160	90.2	Slight blackening
	5.5%	7%	200	160	94.5	Slight blackening
12%HCl+ 3%HF	5.5%	7%	195	160	84.2	Slight blackening
	5.5%	7%	200	160	88.5	Slight blackening

3.3.3. Corrosion Inhibition Performance at High Temperature in the Presence of Partial Hydrogen Sulfide

Part of sodium sulfide solid is added into the autoclave, so that sodium sulfide reacts with acid solution to produce hydrogen sulfide gas, and the corrosion inhibition performance of corrosion inhibitor in the presence of hydrogen sulfide is evaluated as shown in Table 13.

Table 13. Corrosion Inhibition Performance of Alkyl Quinoline Quaternary Ammonium in the Presence of Hydrogen Sulfide.

Acid type	Inhibitor concentration	Dispersant concentration	Temperature (°c)	Pressure (atmospheric pressure)	Corrosion rate G/ (m² •h)	Remark
multi-	5.5%	7%	195	160	79. 1	Slight

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hydrogen acid						blackening
	5.5%	7%	200	160	82. 6	Slight blackening
15%HCl	5.5%	7%	195	160	93. 7	Slight blackening
	5.5%	7%	200	160	96. 1	Slight blackening
12%HCl+ 3%HF	5.5%	7%	195	160	86. 7	Slight blackening
	5.5%	7%	200	160	89. 1	Slight blackening

The test results show that the corrosion inhibitor has good corrosion resistance to hydrogen sulfide, and the corrosion inhibition performance will not be affected when hydrogen sulfide exists in the system.

3.3.4. Inhibitory Performance of Ultra-High Temperature Acidizing Corrosion Inhibitor Under Dynamic Condition

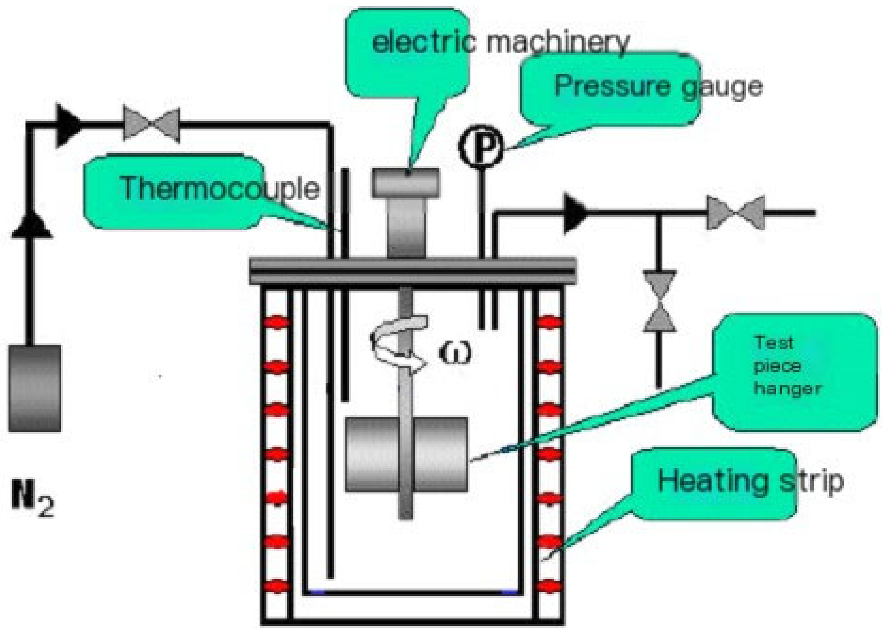


Figure 11. Corrosion inhibitor evaluation device under high temperature dynamic conditions.

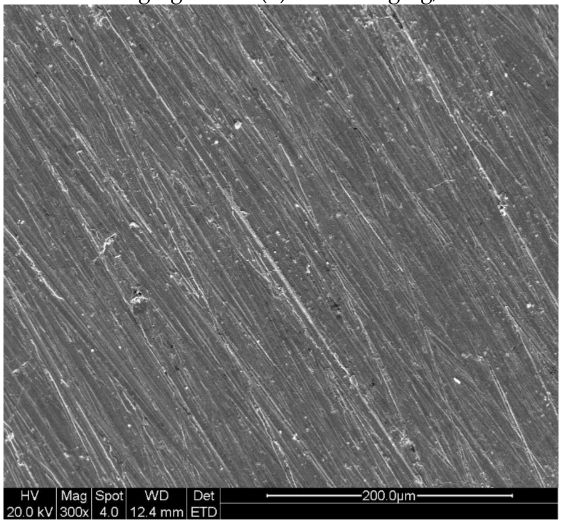
Table 14. Corrosion Inhibition Performance of Quinoline Quaternary Ammonium Salt under High Temperature Dynamic Conditions.

Acid type	Inhibitor concentration	Dispersant concentration	Temperature (°c)	Pressure (atmospheric pressure)	Corrosion rate G/ (m^2.h)	Remark
multi-hydrogen	5.5%	7%	195	160	82. 4	Slight blackening

acid	5.5%	7%	200	160	87. 8	Slight blackening
15%HCl	5.5%	7%	195	160	98. 1	Slight blackening
	5.5%	7%	200	160	99. 3	Slight blackening
12%HCl+ 3%HF	5.5%	7%	195	160	89. 2	Slight blackening
	5.5%	7%	200	160	93. 4	Slight blackening


(a) Untreated surface after hanging


(b) After hanging, the surface is cleaned with acetone.



(c) electron micrograph

Figure 12. 200°C, mud acid +5.5% corrosion inhibitor, N80 steel hanging for 4 hours.

The test results show that the corrosion inhibitor still has good corrosion inhibition performance under dynamic condition.

4. Conclusions

(1) The potentiodynamic scanning results show that although under the same conditions, alkyl quinoline quaternary ammonium salt is a kind of corrosion inhibitor mainly of anodic inhibition type;

(2) AC impedance results show that alkyl quinoline quaternary ammonium salt has obvious inhibition effect on corrosion of N80 carbon steel in hydrochloric acid solution, and the inhibition

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effect becomes more obvious with the increase of alkyl quinoline quaternary ammonium salt concentration.

(3) The fitting results of polarization curves show that the preexponential factor of corrosion reaction decreases and the activation energy of corrosion reaction increases after adding alkyl quinoline quaternary ammonium salt, and finally the corrosion rate is inhibited.

(4) The experimental results show that the compound quaternary ammonium salt of alkyl quinoline has very good corrosion inhibition performance in polyhydrogen acid, 15%HCl and mud acid at 180 - 200 °C, and has good corrosion resistance to hydrogen sulfide when hydrogen sulfide exists in the system.

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