

HIGH TEMPERATURE CORROSION INHIBITION PERFORMANCE OF IMIDAZOLINE AND AMIDE

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ABSTRACT

Imidazoline and its precursor, amide, are very effective inhibitor intermediates and are widely used in formulating the corrosion products for application in the oil and gas industries. Their high temperature corrosion inhibition performance was evaluated and compared. Our results show that imidazoline and amide offer poor to moderate high temperature/pressure (300 °F/3,000 psig) inhibition performance, respectively, with amide giving a better thermos stability. Yet, both give excellent, comparable inhibition performance at a moderate temperature of 150 °F. These chemistries can provide up to 90% effectiveness at the high temperature, if the inhibitor concentration is very high.

Keywords: Corrosion Inhibitor, Inhibition, Imidazoline, Amide, High Temperature/Pressure, Performance Evaluation.

INTRODUCTION

The application of corrosion inhibitors to a producing oil or gas field system is one of the most common means of corrosion control. Corrosion inhibitors used in the oil producing industry are, in general, formulated with the following ingredients: active inhibitor intermediate(s), carboxylic acid or dimer-trimer acid, demulsifier and/or surfactant in aromatic solvent, and alcohol.

The inhibitor intermediate is the active component contributing to corrosion protection in the formulation. Almost all active inhibitor intermediates used in the oil and gas industry are nitrogen-containing compounds. These compounds are excellent inhibitors because of the free pair electrons in nitrogen atoms that can be adsorbed on a metal surface and their hydrocarbon chain to form hydrophobic film on the surface, thus providing inhibition.¹⁻⁵ Different inhibitor intermediates can often be manufactured from the same raw materials by varying the reacting conditions such as temperature or raw materials ratios. Because raw materials used in the reaction are generally low cost and not pure, the resultant inhibitor intermediates are, therefore, not high purity products and are oftentimes a mixture of reaction products.

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Although there are many active inhibitor intermediates on the market, they are based on a few generic types of chemistries, namely, imidazoline, amide, amidoamide and amine. When these compounds are formulated into commercial products, their inhibition performance varies depending on how the products are put together, but not by a significant degree as long as the chemistry of the intermediate is similar. These amine-based corrosion inhibitors are known not to have high temperature inhibition performance with the upper limit temperature of about 300°F, yet no such data is available in the literature.

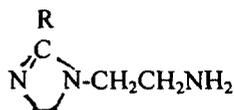
It is in our interest to develop high performance corrosion inhibitors for high temperature and high shear flow application. A high performance corrosion inhibitor which improves performance and film life at high temperature and high shear will increase reliability of corrosion inhibition and less reliance on expensive corrosion resistant alloy thus reducing capex as well as opex. In order to establish the baseline data for current commercial products, we conducted a high temperature performance evaluation for the most effective inhibitor intermediates, namely, imidazoline and amide. Amide is a precursor of imidazoline during the manufacturing process and the conversion process from amide to imidazoline is not a chemical reaction that can be easily controlled to obtain 100% conversion to imidazoline. The degree of conversion varies among vendors. Amide is a solid wax while imidazoline is a viscous, free flow compound which makes it easier for formulating a corrosion product in comparison to amide. Thus, the imidazoline intermediate used for product formulation is, in fact, a mixture of imidazoline and the amide and their ratio can vary from 1:1 (50% conversion) to 9:1 (90% conversion) depending on the manufacture's process.

Separation of amide and imidazoline is not an easy task and is unnecessary because amide is also an excellent corrosion inhibitor. Amide is also a hydrolyzed product of imidazoline under normal operating conditions.⁶⁻⁷ The fact that imidazoline is a mixture may be more beneficial to overall inhibition by providing a synergistic inhibition effect. Therefore, establishing the inhibition performance of amide is very desirable. If the amide performs as well as that of imidazoline, the effect of amide on the performance of the resultant imidazoline will be minimal and the quality control for manufacturing imidazoline intermediate will be less of a concern.

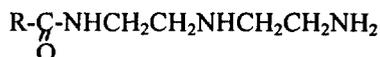
The objective for this investigation was to obtain the baseline performance data at high temperature/pressure for an imidazoline and its precursor amide through the conventional weight loss method. This paper summarizes and compares the inhibition performance of imidazoline and amide at high temperature and high pressure (300 °F and 3,000 psi), together with performance testing under normal conditions of 150 °F. A commercial tall oil imidazoline, which is a reaction product of tall oil fatty acid and diethylenetriamine at 1:1 mole ratio, and its precursor amide were obtained from a chemical vendor.

Experimental

Inhibitor Intermediates Evaluated. Two inhibitor intermediates used in this study were obtained from a chemical vendor through private communication. They are designated as HJC_I3238, an imidazoline and its amide precursor, HJC_A196. They are the reaction product of tall oil fatty acid and diethylenetriamine at 1:1 mole ratio and the percent conversion from amide to imidazoline is about 65% according to the vendor. This suggests that HJC_I3238, an imidazoline, in fact, contains 35% amide, namely HJC_A196. The molecular structures of imidazoline and amide are shown below:



Imidazoline (HJC_I-3238)



Amide (HJC_A196)

Characteristics of Imidazoline and Amide. Amide is generally a waxy solid and is less dispersible than the corresponding imidazoline. Imidazoline is a free flow, viscous liquid and is easier to handle in formulating products. In fact, this is one reason that the chemical reaction is carried out at a higher temperature to produce imidazoline by chemical vendors. For chemical vendors, blending products from solids is more difficult and costly than blending from liquids. Note that imidazoline can be hydrolyzed to the corresponding amide under the proper conditions as reported in the literature.⁶⁻⁷ This can be noted on many imidazoline-based products which show amide precipitate after long standing in storage.

Since no attempt is carried out by the manufacturer to separate the imidazoline and amide, key questions regarding quality control of manufacturing these intermediates are: (1) How important is the degree of conversion from amide to imidazoline on the performance of the resultant product, (2) Is imidazoline more effective than amide or vice versa. If the inhibition performance of amide and imidazoline are comparable, the quality control of imidazoline manufacturing will become less a concern. For inhibition performance, recent literature⁸ reported that amide gave better inhibition performance than imidazoline. That report showed that it requires smaller amide inhibitor concentration to give a constant corrosion rate of 2 mpy. There are very few literature reports on the direct comparison of performance between amide and imidazoline. The performance of these chemicals at high temperature is not available.

Formulations for Inhibition Testing. To facilitate the performance evaluation, these two inhibitor intermediates are formulated with acetic acid in isopropyl alcohol and water at 25% active as shown in Table 1. HJC-A is formulated with 25% imidazoline, HJC_I3238, and HJC-B is formulated with 25% amide, HJC_A196. A 25% active inhibitor concentration is comparable to that of the commercial products. Thus, the inhibitor concentration tested based on these formulations will be comparable to that of the concentration used in the commercial corrosion inhibitor product.

Inhibitor Performance Evaluation

The evaluation of the inhibitor performance at high temperature (300 °F) and high pressure (3,000 psig) conditions was conducted at a commercial testing lab in Houston, Texas. In order to have a direct comparison of the high temperature results, inhibitor performance at a lower temperature of 150 °F was also conducted using the conventional wheel test. Two formulated products, HJC-A and B were evaluated according to the test conditions described below. For high temperature and high pressure testing, inhibitors were tested at higher concentrations, namely, 100, 400, 1,000 PPM of the formulated samples as opposed to 10, 25, and 100 PPM used in the conventional wheel test. Since the commercial products are formulated with the active inhibitor concentration between 15-30% active, the inhibitor concentration used in the test is, therefore, comparable to that of the recommended treatment concentration of the commercial products. The test conditions for the continuous wheel test and the high temperature high-pressure test are shown in Table 2. The test procedures employed by the testing lab are described as follows:

Continuous Wheel Test at 150 °F. This is a conventional weight loss method. The method is used to evaluate the inhibitor performance simulating continuous treating in the field. The test is designed to be relatively simple and inexpensive, yet give results which can be duplicated. The test is conducted as follows:

- The synthetic brine (5% NaCl) is prepared and purged with carbon dioxide.
- The desired amount of inhibitor is placed into each juice bottle followed by a pre-weighed mild steel shimstock coupon (¼" x 3" x 0.005"). Triplicates are conducted at each inhibitor concentration or the blank.
- The juice bottles are then purged with carbon dioxide and the desired amount of brine and kerosene are metered into the juice bottles.
- The juice bottles are then capped and placed on the Corrosion Wheel Tester for the desired time interval. The Corrosion Wheel Tester rotates at 30 RPM.
- After the desired time interval has elapsed, the bottles are removed from the Corrosion Wheel Tester, coupons removed from bottles, cleaned, re-weighed, and percent protection calculated.

Continuous Treatment High Temperature/High Pressure Wheel Test. As the name implies, the test is a modification of the continuous wheel test. The pre-weighed test coupons are placed in the stainless cell containing test fluids and are pressurized with the desired gas mixtures at the test temperature. Inhibitors are added to the cells before pressurization. The autoclave cells are placed in a wheel cabinet and rotated for a certain time at the desired temperature. After the test exposure, the coupons are cleaned in 15% inhibited hydrochloric acid, rinsed in water, acetone, dried and re-weighed. The tests are conducted as follows:

- The synthetic brine is prepared and purged with nitrogen.
- The desired amount of kerosene, corrosion inhibitor and a pre-weighed corrosion coupon (1/2"x 3"x 1/16") with a 9/32" hole are placed in the pressure vessel, and the vessel is sealed.
- The pressure vessel is then placed on a manifold and a vacuum is applied to the pressure vessel.
- The desired amount of brine is then introduced into the pressure vessel under vacuum. The pressure is then adjusted to the desired value utilizing the desired gas mixture and a gas intensifier.
- The pressure vessel is checked for any leaks. The pressure vessel is then placed on the Corrosion Wheel Tester for the desired time interval and temperature. The Corrosion Wheel Tester rotates at 10 RPM.
- After the desired time interval has elapsed, the vessels are cooled, removed from the Corrosion Wheel Tester, and dismantled. The corrosion coupon is removed from the vessel, cleaned, re-weighed, and the corrosion rate and percent protection calculated.

Calculation of Inhibitor Efficiency and Corrosion Rate. The percent protection and corrosion rate are calculated from the weight loss according to the following equations:

$$\text{Percent Protection, \%P} = \frac{W_{(\text{blank})} - W_{(\text{inh})}}{W_{(\text{blank})}} \times 100 \quad (1)$$

$$\text{Corrosion Rate, MPY} = \frac{W_{(\text{inh, blank})} * 534}{D * A * T} \quad (2)$$

where

- $W_{(\text{blank})}$ = Weight loss of blank in mg
 $W_{(\text{inh})}$ = Weight loss of inhibited coupon in mg
 D = Density of the steel coupon in gm/cc, 7.86 g/cc for mild steel
 A = Area of coupon in square inches
 T = Time of exposure in hours
 MPY = Mils per year

RESULTS AND DISCUSSION

To determine the effect of time on corrosion rate and inhibition performance, coupons were pulled at three exposure times, namely 4, 24, and 72 hours. We understand that the 4-hour exposure time is much too short for the weight loss method to give a reliable weight loss reading. However, the data will still be useful for establishing the performance profile though the data uncertainty is large. Results from the testing lab include two, three-inhibitor concentrations and three exposure times in triplicate at both high temperature/high pressure and lower temperature. The data are good with acceptable reproducibility and only a few bottles were contaminated with oxygen. When inhibitors were tested at a concentration greater than 400 PPM under high temperature/high pressure, emulsion was created for both chemicals. Note that the volume capacity in the pressure bomb was only 40 ml as opposed to 180 ml in the conventional wheel test. This is not unexpected because amide and imidazoline are nitrogen-containing compounds which are known emulsifiers. The emulsion problem observed here may be controlled by the addition of a proper demulsifier or surfactant in the formulation and was not the concern here. Results are summarized and discussed below.

The Effect of Temperature on Blank Corrosion Rate

Table 3 shows the effect of temperature on blank weight loss and corrosion rate at various exposure times with the plots shown in Figures 1 and 2. As expected, the blank coupon weight loss increases with increased exposure time and the corrosion rate calculated using Equation 2 decreases with increasing exposure time at both temperatures investigated here. The decreasing corrosion rate with the exposure time is due to the corrosion product formed on the surface which gives a certain degree of corrosion protection, thus, the corrosion rate decreases with time.

As shown in Table 3, the blank corrosion rate increases with increasing temperature. The blank corrosion rates at 150 °F and 300 °F are between 80-40 mpy and 235-24 mpy respectively at the exposure time of 4-72 hours. Figure 2 shows that the effect of temperature on corrosion rate at the short exposure time of 4 hours is much more than that at longer exposure times. At 4 hours exposure, the high temperature corrosion rate at 300 °F/3,000 psig is about 4 times higher than that at 150 °F, however, after 72 hours exposure, the temperature effect on corrosion rate is not observed. The results suggest that the corrosion product formed at high temperature is more protective than that obtained at low temperature. Note also that the corrosion rate after 4 hours exposure at 150 °F is lower than that of 24 hours. This may be due primarily to the uncertainty of the weight loss data obtained at the 4-hour exposure time. The results suggest that 4-hours exposure is too short a time to give a reliable weight loss for corrosion rate measurement.

Comparing the Inhibition Performance of Imidazoline and Amide

Inhibition Performance at 150 °F. Table 4 summarizes the results of the wheel test for imidazoline and amide at 150 °F, together with their inhibition efficiency. Plots are shown in Figures 3-6. In general, results show that in the presence of inhibitors, the corrosion rate decreases and inhibition efficiency increases with increasing inhibitor concentration at all exposure times. At short exposure time, such as 4 hours, all inhibitors show inhibition protection in the range between 50-80% depending on inhibitor concentration. However, when the exposure time increases to 24 hours, all inhibitors give high inhibition performance, with percent protection between 89-96%. In increasing the exposure time to 72 hours, no further increase in performance is observed. Results suggest that the inhibitor performance can be evaluated with 24 hours exposure time, and these inhibitors maintain high performance at 150 °F over long exposure time, and 4 hours exposure time is definitely too short for the weight loss experiment.

As for the effect of inhibitor concentration, the performance increases with increasing inhibitor concentration between 10-25 ppm concentration. As shown in Figures 4 and 6, increasing inhibitor concentration from 25 ppm to 100 ppm shows no further increase in inhibitor performance at 24 and 72 hours exposure. Results suggest that the minimum inhibitor concentration to give the maximum protection for these two inhibitors are about 25 ppm of the formulations used here, namely HJC-A & B. Overtreating with higher inhibitor concentration provides no further benefit. It is recommended that the performance profile for each inhibitor be established so that the minimum inhibitor concentration for maximum protection can be determined for optimizing chemical treatment cost-effectively.

Imidazoline versus Amide Performance at 150 °F. Results in Table 4 also show that there is no significant difference in performance between imidazoline and amide studied here. At inhibitor concentration of 25 ppm (HJC-A & B) or higher, both imidazoline and amide give practically the same inhibition performance with 95% protection or higher. At low inhibitor concentration of 10 ppm, imidazoline seems to give a slightly better performance than amide with percent protection of ~95% for imidazoline and 89% for amide after 24 hours exposure. This may be attributed to the solubility difference between these two compounds as described above under the experimental section. Imidazoline is more dispersible than amide in the test fluids.

High Temperature Inhibition Performance at 300 °F/3,000 psig. Table 5 summarizes the results of high temperature/high pressure wheel test for imidazoline and amide inhibitors, together with their inhibition efficiency. The data are plotted as shown in Figures 7-10. Inhibitor concentrations tested here were purposely increased from 10-100 ppm to 100-1,000 ppm to ensure that inhibition performance of intermediates can be detected and differentiated in this high temperature, high pressure test.

In general, results obtained at high temperature/high pressure are very similar to those at 150 °F. Again, in the presence of inhibitors, corrosion rate decreases and inhibition efficiency increases with increasing inhibitor concentration at the constant exposure time. At a very short exposure time of 4 hours, both imidazoline and amide show practically the same

performance, giving inhibition protection in the range between 75-88% and 70-85% for imidazoline and amide respectively at inhibitor concentration of 100-1,000 ppm. Increasing the exposure time to 24 hours, no increase in inhibition performance was observed for both inhibitors. In fact, a slight decrease in performance was observed for imidazoline at low inhibitor concentration of 100 ppm, giving 56% percent protection at 24 hours exposure time. Further increasing the exposure time to 72 hours, a decrease in inhibition performance was observed, especially at low inhibitor concentration. For imidazoline, the percent protection decreases from 89% to 59% at 400 ppm inhibitor concentration, and a decrease from 78% to 46% protection for amide at 400 ppm.

Results suggest that both inhibitors evaluated here do not have acceptable high temperature performance and high temperature chemical stability as indicated by the reduced inhibition performance at long exposure times at 400 ppm inhibitor concentration. To compensate for poor performance at high temperature, an increase in inhibitor concentration is an alternative way to maintain the high inhibition performance. For example, inhibitor concentration at 1,000 ppm gives the acceptable 90% protection for imidazoline. Yet, at 400 ppm inhibitor concentration, the percent protection for imidazoline is only 59%. For amide, the inhibition efficiency increases from 46% at 400 ppm to 83% at 1,000 ppm at 72 hours exposure time.

Performance of Imidazoline and Amide at 300 °F. Results in Table 5 show that there is a difference in high temperature performance for imidazoline and amide studied here depending on inhibitor concentration and exposure time. At low inhibitor concentration of 100 ppm (HJC-A & B), the imidazoline and amide give practically the same inhibition performance with ~75% protection after 4 hours exposure. The inhibition performance increases to ~87% by increasing inhibitor concentration to 400 ppm and no further improvement in performance is observed at higher inhibitor concentration of 1,000 ppm. As reported by the testing lab, emulsions were observed at inhibitor concentration of 400 ppm and higher in the high temperature/high pressure testing which may affect the experimental data quality.

As shown in Figures 8 and 10, the high temperature performance is very much concentration dependent. At high inhibitor concentration of 1,000 ppm, the performance is independent of exposure time between 4-72 hours; however, with the maximum percent protection of only about 90%. At low inhibitor concentration of 100 ppm, the effect of exposure time on performance was observed indicating poor thermostability of these two inhibitors. Amide seems to have a slightly better thermostability than imidazoline, maintaining about 70% inhibition after 72 hours exposure. While for imidazoline, the inhibition efficiency decreases from 72% at 4 hours exposure to 38% after 72 hours. The hydrolysis of imidazoline to amide may contribute to the poor thermostability of imidazoline observed here. At moderate inhibitor concentration of 400 ppm, the temperature effect was observed at longer exposure time of 72 hours for both inhibitors. The inhibition efficiency of imidazoline and amide reduced from ~86% at 4-24 hours exposure to 60% for imidazoline and 46% for amide.

Results indicate that both imidazoline and amide again give comparable high temperature performance but with reduced inhibition efficiency. The minimum inhibitor concentration to give the maximum performance at high temperature is in the range of 1,000 ppm for continuous treatment application. This is about 40 times greater than that required of the same treatment at 150 °F. Amide seems to have a better overall high temperature stability or inhibition efficiency as shown in Table 5.

Effect of Temperature on Inhibition Efficiency

Table 6 summarizes the effect of temperature on inhibition performance for imidazoline and amide. In order to have direct comparison, the performance of inhibitor concentration at the same concentration of 100 ppm was compared in spite of a slight difference in testing methodology. The differences were the coupon type, size, and the test fluid volume (180 ml at 150 °F and 40 ml for 300 °F). Figure 11 shows the comparison of corrosion rate for imidazoline and amide at 150 °F and 300 °F. Figure 12 compares the effect of temperature and time on performance. At 100 ppm inhibitor concentration of the formulation HJC-A (imidazoline) and HJC-B (amide), the exposure time affects the inhibition performance at different temperatures. When the data was collected after 4 hours exposure, the effect of temperature on inhibition performance was minimal, giving essentially the same range of protection, for example, 78% to 75% for imidazoline at 150 °F and 300 °F respectively, and 82% to 70% for amide.

In increasing the exposure time to 24 hours, an increasing temperature effect on inhibition performance was observed, with more negative effect on imidazoline. At 150 °F, both imidazoline and amide gave 95% inhibition and at 300 °F, the percent inhibition is reduced to 56% and 83% for imidazoline and amide respectively. A further reduction in

inhibition efficiency by temperature increase was observed with increasing exposure time. Both inhibitors gave 96% protection after 72 hours exposure at 150 °F, and showed only 38% and 72% inhibition efficiency for imidazoline and amide respectively at 300 °F. Again, imidazoline seems to have more negative effect in inhibition by temperature increase than amide.

Figure 12 also shows that imidazoline and amide can provide as high as 95% inhibition at 150 °F while at 300 °F, the maximum protection is 83% for amide after 24 hours exposure and only 75% inhibition for imidazoline after 4 hours exposure. The high temperature performance became worse when the exposure time increased, giving only 38% protection for imidazoline and 72% for amide.

Results confirm that the most effective corrosion inhibitor intermediates-based commercial products (imidazoline and amide) do not have high temperature performance. An inhibitor product which gives high inhibition performance at a normal treatment concentration of 25 ppm would give a reduced inhibition performance at higher operation temperature and wouldn't provide the protection needed. As shown in Table 6, increasing inhibitor treatment concentration significantly by a factor of 40 times (from 25 ppm to 1,000 ppm) can improve the inhibition performance, but with a limited and lower efficiency. Thus, it is not a viable way for corrosion control. Besides, high treating dosages can create chemical compatibility problems with other production chemicals or oil/water emulsion problems which affect the oil/water separation and water quality. Consequently, the need for developing inhibitor intermediates for high temperature corrosion inhibition is obvious and certain.

CONCLUSIONS

- Imidazoline and amide do not give high inhibition efficiency at high temperature of 300 °F/3,000 psig with amide having slightly better high temperature stability. For example, both compounds give a greater than 95% inhibition efficiency at 150 °F and only 38% efficiency for imidazoline and 72% for amide at 100 ppm and 72 hours exposure (Table 6).
- High temperature inhibition performance of imidazoline and amide can be improved by increasing the inhibitor concentration; however, with limited inhibition efficiency. In this study the efficiency of imidazoline and amide increases from 60% to 90% and 46% to 83%, respectively, with increasing inhibitor concentration from 400 ppm to 1,000 ppm after 72 hours exposure (Table 5). A high inhibitor concentration can affect oil/water separation downstream and water quality for reinjection or discharge overboard.
- The minimum inhibitor concentration needed to give the maximum protection for imidazoline and amide is temperature dependent. The concentration that is required for imidazoline and amide at the high temperature of 300 °F is about 40 times that at 150 °F. At 150 °F, a minimum of 25 ppm inhibitor concentration is needed to give 95% maximum protection; it needs 1,000 ppm to give a maximum of 90% protection at 300 °F/3,000 psig.
- Imidazoline and amide show practically comparable inhibition performance. However, at high temperature, amide seems to have a slightly better performance, indicating better long-term thermostability.
- Inhibition performance for both imidazoline and amide increases with increasing inhibitor concentration and then levels off. There is no further performance benefit once the minimum inhibitor concentration is reached.
- Blank corrosion rate increases with increasing temperature. However, after long exposure time, the corrosion rate at high temperatures becomes lower due to the better protected film formed at high temperature (Figure 2).

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Table 1 Inhibitor Formulations Used in this Study

Formulated Product	Intermediate	Chemical Component	% Concentration by weight
HJC-A	HJC-I3238 (Imidazoline)	HJC-I3238	25.0%
		acetic acid	7.5%
		water	5.0%
		IPA	62.5%
HJC-B	HJC-A196 (Amide)	HJC-A196	25.0%
		acetic acid	7.5%
		water	5.0%
		IPA	62.5%

Table 2 Test Conditions for Inhibitor Evaluation Used by Testing Lab

Test Conditions	Cont. Treatment Wheel Test	Cont. High T/High P Wheel Test
Temperature	150°F	300°F
Pressure	Atmospheric	3000 psig
Acid Gas	Saturated Carbon Dioxide	
Gas Composition		2.99% CO ₂ + 97.01% Methane
Liquid Volume	180 ml	40 ml
Liquid Composition	90% Brine (5% NaCl)+ 10% Kerosene	90% Brine (5% NaCl)+ 10% Kerosene
Exposure Time	4, 24 and 72 hours	4, 24 and 72 hours
Type Coupon	Sand blasted mild steel Shimstock	Sand blasted mild steel
Coupon Size	1/4"x 3"x 0.0005"	1/2" x 3" x 1/16" with 9/32" hole
Coupon Area	1.53 in ²	3.31 in ²
Concentration (HJC-A & B)	10, 25, 100 ppm (i.e. 2.5 , 6.25 , 25 ppm active Cl)	100, 400, 1000 ppm (i.e. 25, 100, 250 ppm active Cl)

Table 3 The Effect of Temperature on Blank Corrosion Rate at Various Exposure Times

Temperature	Time, hr	wt loss, mg	mpy
150°F	4	5.5	61.3
	24	45.6	84.3
	72	67.6	41.6
300°F	4	47.2	242.0
	24	83.4	71.3
	72	85.9	24.5

Table 4 Summary, Results of Inhibitor Performance by Continuous Wheel Tests at 150 ° F

Time, Hour	Conc., ppm	HJC-A, Imidazoline			HJC-B, Amide		
		Wt. Loss, mg	mpy	% Protection	Wt. Loss, mg	mpy	% Protection
4 hrs	0	5.5	61.3		5.5	61.3	
	10	2.1	22.9	62.7	2.5	27.7	54.8
	25	1.6	17.7	71.1	1.9	20.7	66.3
	100	1.2	13.3	78.3	1	11.1	81.9
24 Hrs	0	45.6	84.3		45.6	84.3	
	10	2.4	4.4	94.8	5.2	9.5	88.6
	25	1.8	3.4	96.0	2.5	4.6	94.6
	100	2.3	4.2	94.9	2.0	3.8	95.5
72 hrs	0	67.6	41.6		67.6	41.6	
	10	5.1	3.1	92.5	24.0	6.8	83.8
	25	2.4	1.5	96.4	3.3	2.1	95.1
	100	2.8	1.7	95.9	2.2	1.4	96.7

Table 5 Summary, Results of Inhibitor Performance by Wheel Tests at 300 ° F and 3000 psig

Time, hour	Conc., ppm	HJC-A, Imidazoline			HJC-B, Amide		
		Wt. Loss, mg	mpy	% Protection	Wt. Loss, mg	mpy	% Protection
4	0	47.2	242.0		47.2	242.0	
	100	11.7	60.0	75.2	14.2	72.6	70.0
	400	5.6	28.9	88.1	6.4	32.6	86.5
	1000	5.8	29.9	87.7	7.1	36.4	85.0
24	0	83.4	71.3		45.6	71.3	
	100	36.4	31.3	56.2	14.7	12.6	82.7
	400	9.5	8.1	88.8	18.6	15.9	78.1
	1000	8.2	7.0	90.4	10.0	8.5	88.3
72	0	85.9	24.5		85.9	24.5	
	100	53.4	15.2	37.9	23.8	6.8	72.3
	400	35.2	10.0	59.0	46.0	13.1	46.4
	1000	8.8	2.5	89.7	14.7	4.2	82.9

Table 6 Effect of Temperature on Corrosion Rate and Inhibition Efficiency

Temperature	Corrosion Rate, mpy								
	4 Hours			24 Hours			72 Hours		
	Blank	HJC-A	HJC-B	Blank	HJC-A	HJC-B	Blank	HJC-A	HJC-B
150 °F	61.3	13.3	11.1	84.3	4.2	3.8	41.6	1.7	1.4
300 °F	242.0	60.0	72.6	71.3	31.1	12.6	24.5	15.2	6.8
% Protection									
150 °F		78.3	81.8		94.9	95.5		95.9	96.7
300 °F		75.2	70.0		56.2	82.7		37.9	72.3

Figure 1 Blank Weight Loss at Various Exposure Time

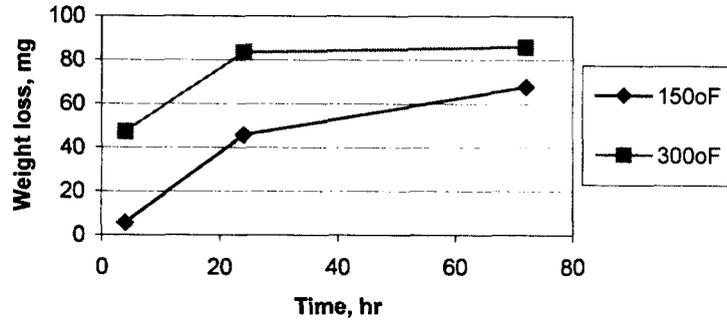


Figure 2 Blank Corrosion Rate at Various Exposure Time

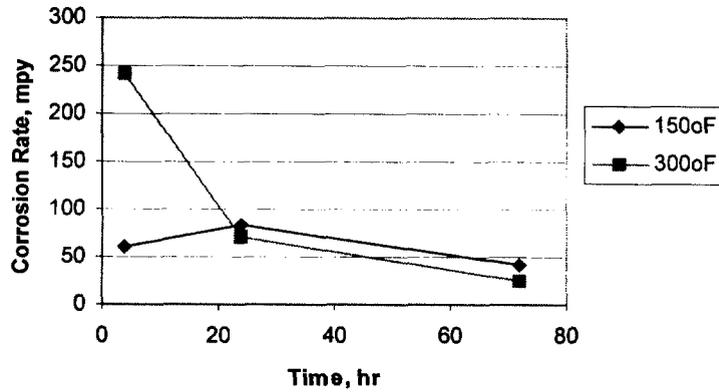


Fig. 3 Corrosion Rate vs Cl Concentration & Time at 150°F for HJC-A, Imidazoline

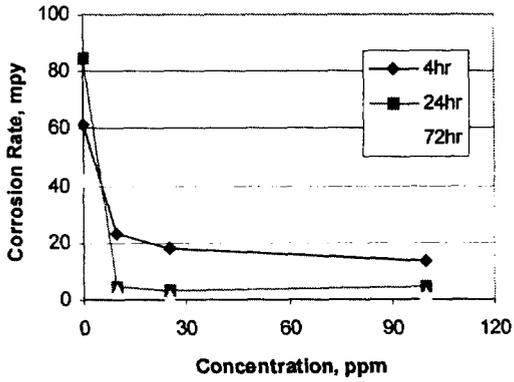


Fig. 4 % Protection vs Cl Concentration & Time at 150 °F for HJC-A, Imidazoline

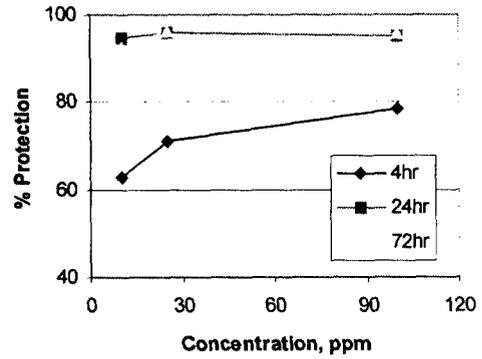


Fig. 5 Corrosion Rate vs Cl Concentration & Time at 150°F for HJC-B, Amide

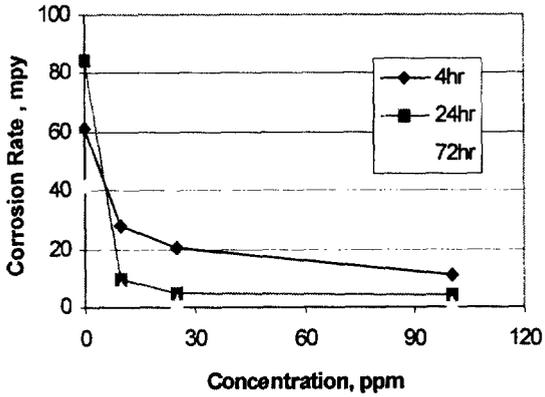


Fig. 6 % Protection Vs Cl Concentration & Time at 150°F for HJC-B, Amide

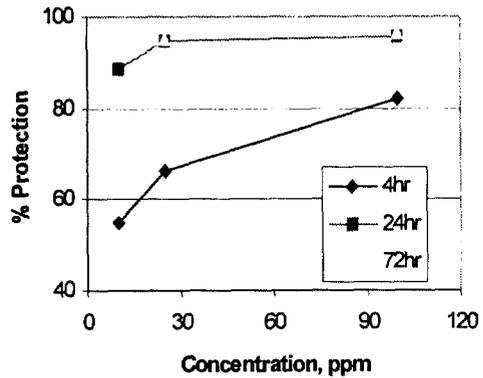


Fig. 7 Corrosion Rate Vs Cl Concentration, Time at 300°F/3000 psig for HJC-A, Imidazollne

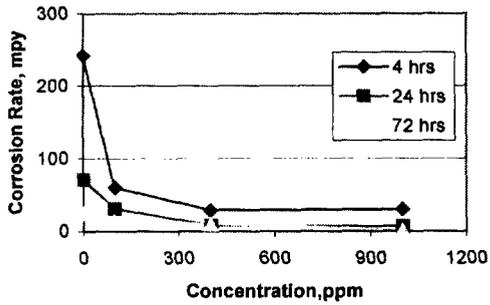


Fig. 8 % Protection vs Concentration, Time at 300 °F/3000 psig for HJC-A, Imidazollne

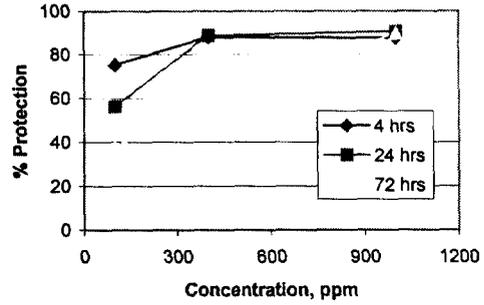


Fig. 9 Corrosion Rate Vs Cl Concentration, Time at 300°F/3000 psig for HJC-B, amide

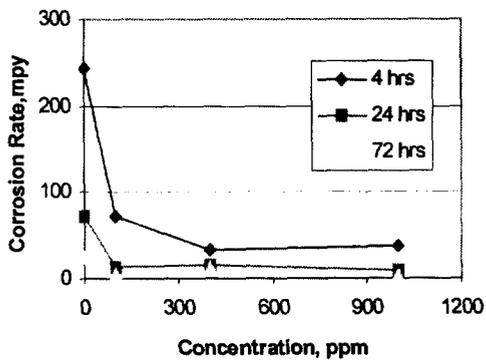


Fig. 10 % Protection vs Concentration, Time at 300 °F/3000 psig for HJC-B, Amide

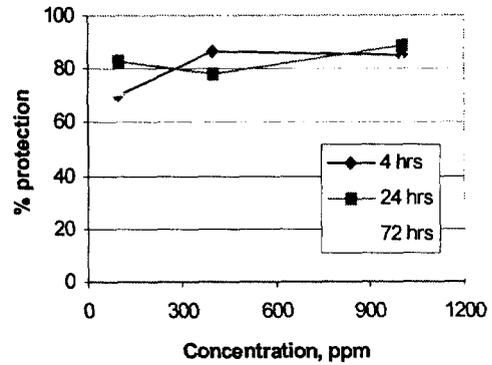


Fig. 11 Effect of Temperature on Corrosion Rate at 100 ppm Cl Concentration

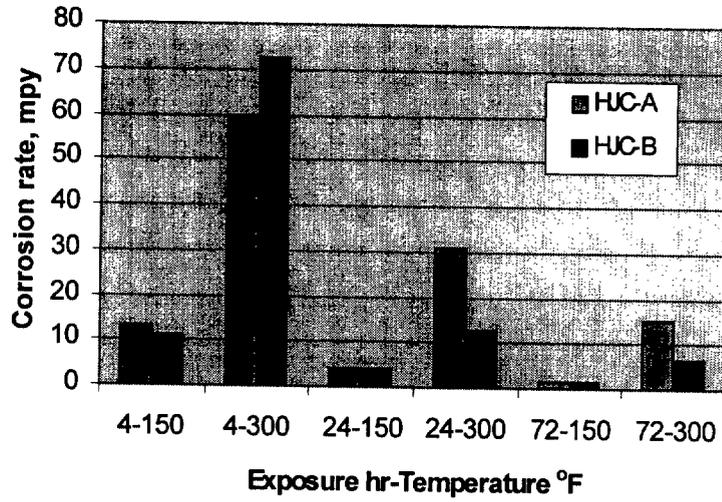


Fig. 12 Effect of Temperature on %Protection at 100 ppm Cl Concentration

