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(72) Inventeurs/Inventors:

Fong, Dodd W., US;  
Khambatta, Binaifer S., US

(73) Propriétaire/Owner:

NALCO CHEMICAL COMPANY, US

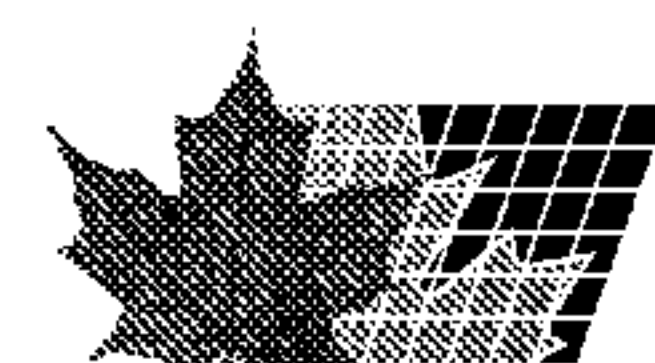
(74) Agent: SMART & BIGGAR

(54) Titre : POLYMERES CONTENANT DE L'ACIDE HYDROXAMIQUE ET SERVANT D'INHIBITEUR DE LA  
CORROSION

(54) Title: HYDROXAMIC ACID CONTAINING POLYMERS USED AS CORROSION INHIBITORS

(57) **Abrégé/Abstract:**

Hydroxamic acid containing low molecular weight polymers have been found to be excellent corrosion inhibitors for iron and steel alloys in contact with industrial waters. When the waters contain hardness ions, such as calcium, magnesium, and mixtures thereof, the waters are preferably treated with combinations of the hydroxamic acid containing polymers and scale inhibiting/dispersing polymers, which polymers do not contain hydroxamic acid functional groups. The hydroxamic acid containing polymers, as well as the combination of hydroxamic acid and scale inhibiting/dispersing polymers may also both be formulated with other corrosion inhibitors.



ABSTRACT

Hydroxamic acid containing low molecular weight polymers have been found to be excellent corrosion inhibitors for iron and steel alloys in contact with industrial waters. When the waters contain hardness ions, such as calcium, magnesium, and mixtures thereof, the waters are preferably treated with combinations of the hydroxamic acid containing polymers and scale inhibiting/dispersing polymers, which polymers do not contain hydroxamic acid functional groups. The hydroxamic acid containing polymers, as well as the combination of hydroxamic acid and scale inhibiting/dispersing polymers may also both be formulated with other corrosion inhibitors.

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INTRODUCTION

The inhibition of corrosion of iron and steel alloys in contact with industrial waters is extremely valuable. Corrosion difficulties cause immense costs and failure if corrosion of iron and steels in contact with industrial waters is not inhibited or prohibited.

The history of treatment of waters in contact with iron alloys and steels is extensive. Waters have been treated with inorganic components, such as chromate salts, but chromates have been found to be injurious to the environment, and these treatments have fallen out of favor.

Waters have been treated with inorganic or organic phosphates and phosphonates to inhibit corrosion. These materials are often expensive and must be formulated with other ingredients to provide optimal results.

The use of organic polymers, particularly relatively low molecular weight polymers have been found useful in inhibiting under scale corrosion particularly of iron and mild steels in contact with industrial waters where the polymers are primarily used as anti-scalants, prohibiting scale formation of hardness constituents in the waters such hardness scales including calcium carbonate, hydroxyapatite, calcium hydroxide, magnesium carbonates, magnesium phosphates, magnesium hydroxides and mixed magnesium and calcium scales. When the surface of the iron or steels are scaled, this provides for environments enhancing corrosion under the formed scale. Polymeric treatment of these waters prohibit or inhibit scale formation and, therefore, provide some relief in terms of enhanced corrosion rates in the presence of the scales, or below the scale.

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In fact, some low molecular weight polymers have been found to be corrosion inhibitors in and of themselves, either in the presence or absence of hardness in the water. these corrosion inhibiting polymers have been primarily  
5 carboxylate containing polymers of relatively low molecular weight, and are often synthesized with monomers that are oleophilic in nature, such monomers including methyl and ethylacrylate.

It is important to note that although polymers  
10 which are useful as anti-scalants for hardness scales are also sometimes corrosion inhibitors, not all anti-scalant polymeric substances are necessarily corrosion inhibitors. In some cases materials which are anti-scalants, in fact, induce a higher rate of corrosion. This is particularly  
15 true in the absence of hardness species, such as calcium and magnesium.

#### Objects of the Invention

It is, therefore, an object of this invention to provide for a method of inhibiting corrosion of iron and  
20 mild steels in contact

with industrial waters by treating the waters with polymers containing hydroxamic acid functionality.

It is another object of this invention to treat industrial waters with polymers having a molecular weight ranging from about 2,000 to about 50,000, which polymers contain at least one mole percent of a hydroxamic acid mer unit distributed randomly throughout the polymeric structure.

It is another object of this invention to treat these industrial waters in contact with iron and steels, particularly mild steels, with a combination of polymers, which combination contains a scale inhibiting and/or dispersing polymer which does not contain hydroxamic acid functional groups and a hydroxamic acid containing polymer.

Finally, it is an object of this invention, to treat these industrial waters with an effective corrosion inhibiting amount of either a corrosion inhibiting polymer containing hydroxamic acid functionality, or a combination of a carboxylate containing scale inhibiting and/or dispersing polymer and the hydroxamic acid containing polymer, said polymer combination being within the weight ratio of approximately 10:1 to 1:10 and said combination being added to the industrial waters so as to provide from 1 to 200 parts per million, based on waters treated, of the hydroxamic acid polymer.

Previous Disclosures

Polymers containing hydroxamic acid functional groups have been known in the art. For example, A. J. Domb, in an article entitled "The synthesis of poly(hydroxamic acid) from poly(acrylamide), which article appeared in Journal of Polymer Science: Part A: Polymer Chemistry, Vol. 26, 2623-2630 (1988), taught the synthesis of polyhydroxamic acids in either gel or water soluble forms by reacting polyacrylamides with hydroxylamine and basic aqueous solutions at room temperature. Domb's polymers contained 70 percent hydroxamic acid groups, less than 5 percent carboxylic acid groups, and 25 percent unreacted amide groups. These polymers exhibited high affinity for ferric ion and for Cupric ion in a pH range of from 1 to 5 with extremely high complexing or binding rate.

Normally, materials which exhibit very high complexing capabilities often enhance corrosion rates, for example, ethylenediamine tetracetic acid (EDTA), when added to industrial waters at high concentrations, have been demonstrated to enhance the rate of corrosion of iron and mild steels in contact with the EDTA containing waters.

The Domb article emphasizes the use of these polyhydroxamic acid polymers in terms of biopolymer research, since the polymers also possess anticoagulant and urease inhibitory activity. The article suggested the use of the polymers as ion exchanges resins but did not suggest any use as anti-corrosion treatments.

In addition to the article above, various amide and/or carboxylate polymers modified by the reaction with hydroxylamine have also been taught in the following series of U.S. patents:

1. U.S. 2,959,574, Woodbury, reacts copolymers of acrylonitrile and acrylamide with hydroxylamine to form copolymeric amidoxime compositions, which are taught to be useful as sedimentation or flocculating agents, for ore and industrial waste treatment, in mineral treatment, as coating compositions in film forming for producing wrapping materials, as thickeners, as protective colloids, in an adhesive formulations and as drilling mud additives. There is no teaching of the use of Woodbury's materials to inhibit corrosion of iron and steels in contact with industrial waters.
2. U.S. patent 4,532,046, Meunier, et. al., teaches a method to eliminate scaling of alkaline earth compounds from aqueous media by adding a treatment agent comprising of water soluble hydroxamic acid containing polymer. Again, there is no

teaching in Meunier in regard to the corrosion inhibition of iron or steels in contact with industrial waters. Meunier emphasizes the use of his polymers in sea waters as anti-scaling agent to prevent precipitation of alkaline earth salts or to limit the increase and the size of the crystals of alkaline earth precipitating salts, thereby inhibiting scale formation on surfaces in contact with sea waters.

3. U.S. patent 4,767,540, Spitzer, et. al. teaches the use of hydroxamic acid containing polymers to reduce suspended solids in Bayer processing streams. The Bayer process treats raw bauxite ores and recovers therefrom aluminum trihydrate which is later treated to recover aluminum and to make alumina products. The Bayer process runs at very high caustic and very high dissolved solid levels and requires settling and filtration to remove iron oxides and other contaminants. Again, there is nothing in the Spitzer teachings related to corrosion control by treating industrial waters with hydroxamic acid polymers to inhibit corrosion of iron and steels in contact therewith.
4. U.S. patent 4,536,296, Vio, teaches the use of clay based water drilling or completion muds, which muds are formulated with low molecular weight polymers or copolymers containing hydroxamic acids or thiohydroxamic acid groups. This patent teaches the use of his polymeric compositions to form

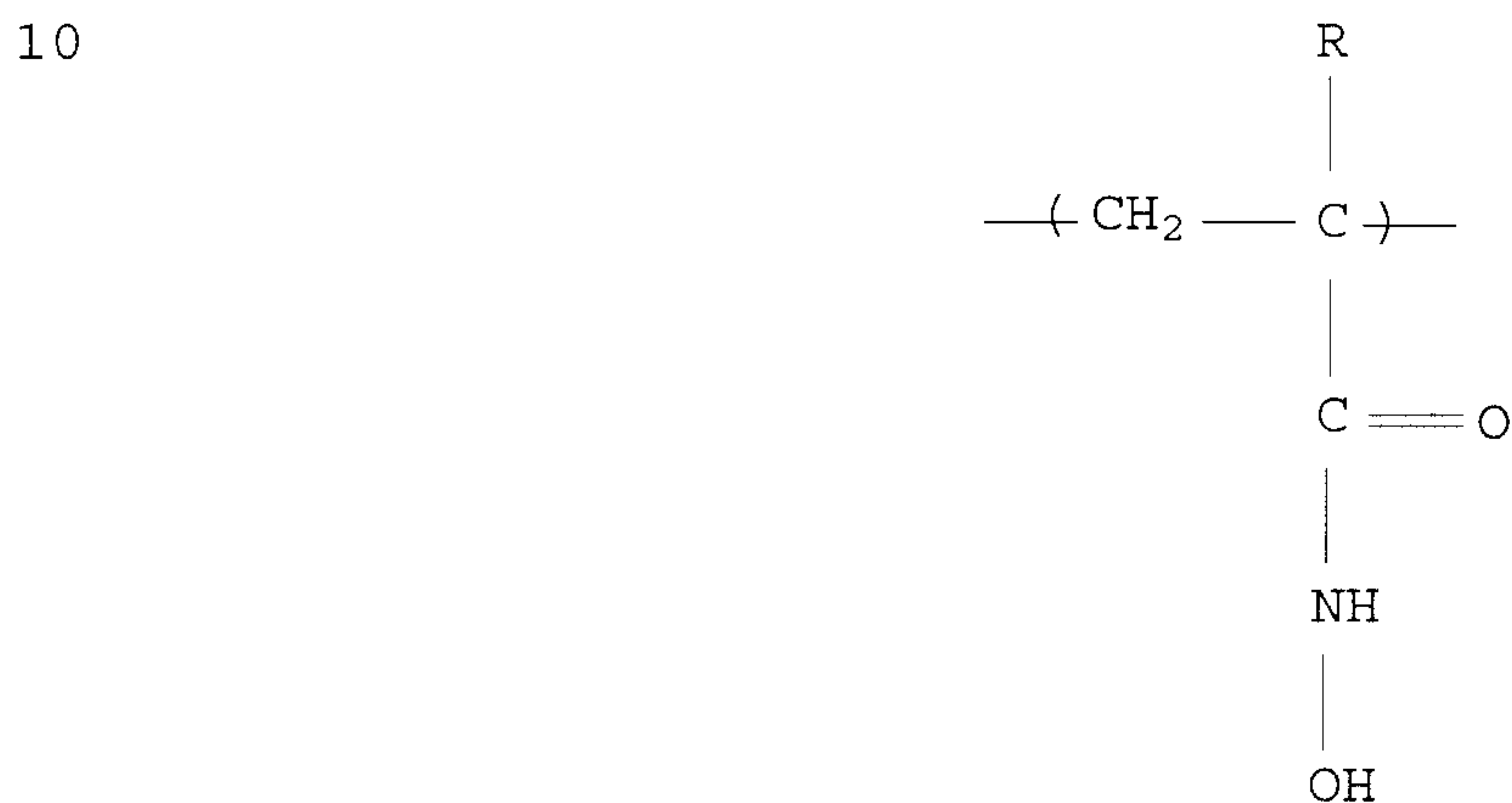
extremely stable complexes with transition metals thereby contributing to dispersancy in the drilling muds. The polymers are taught to be effectively absorbed on particles of clay through the aluminum, calcium, magnesium, iron and other cations present in the clay providing significant plugging or fluid loss effect when used as "dispersion additives". Again, no teaching is contained in this patent relative to the use of these type of hydroxamic acid polymers as corrosion inhibitors in industrial waters.

5. U.S. patent 4,810,296, Guerro, et. al., teaches the use of hydroxamic acid/ acrylamide polymers and copolymers for retarding set times in cement slurries. The use of hydroxamated polymers in hydraulic cement slurries is unrelated to the use in industrial waters to prevent or inhibit corrosion of iron or steels in contact with those waters.
6. U.S. patent 4,868,248, Sparapany, et. al. This patent teaches a method of synthesizing polyhydroxamic acid polymers from polyacrylic acids. Again, there is no teaching within this patent for the use as a corrosion inhibitor in industrial waters to protect iron ore steels against corrosion in contact with the industrial waters.

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THE INVENTION

We have invented a method of inhibiting corrosion of iron and mild steels in contact with industrial waters, which method comprises treating said waters with an  
 5 effective corrosion inhibiting amount of a water soluble polymer having a weight average molecular weight ranging from about 2,000 to about 50,000, said polymer containing at least one mole percent of a hydroxamic acid mer unit having the structure:



wherein R is individually chosen from hydrogen, methyl, and mixtures thereof.

In our method of inhibiting corrosion of iron and mild steels in contact with industrial waters, it is  
 20 preferable that our polymer has a molecular weight ranging from about 2,500 to about 25,000 and contains from about 1.0 to about 30 mole percent, preferably about 4.0 to about 30, of the above described hydroxamic acid mer unit.

It is most preferred that the industrial waters be  
 25 treated with polymers having a molecular weight in a range of about 5,000 to about 15,000 and that the polymer contains anywhere from about 2.0 to about 14, more preferably from

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about 4.0 to about 14, mole percent of the hydroxamic acid mer unit.

When referring to the hydroxamic acid mer unit, we mean to include its presence along with the presence of any  
5 of its water soluble salts, for example, alkali metal salts, alkaline earth metal salts, ammonium salts, protonated amine salts, or quaternary amine salts.

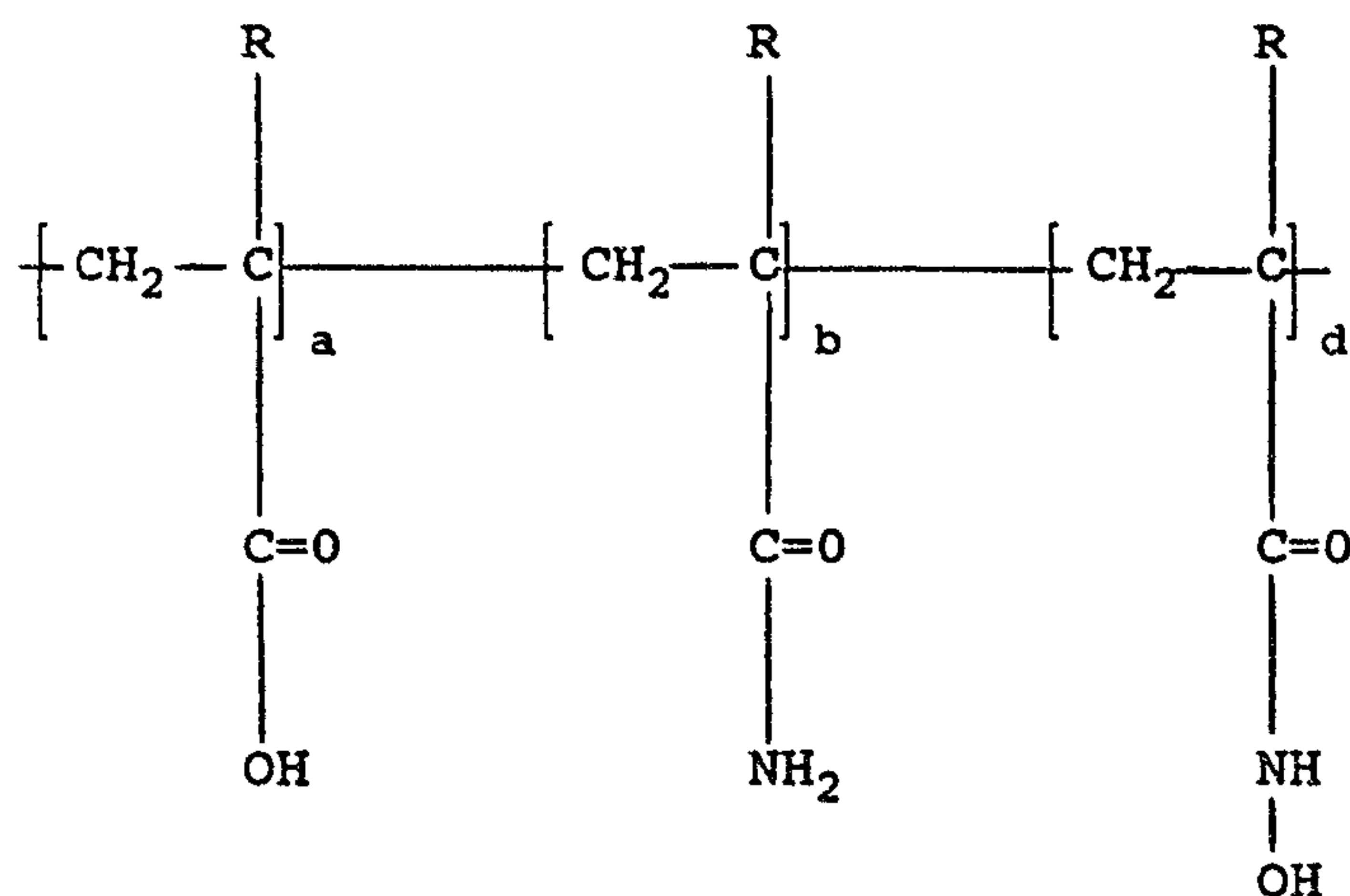
In the practice of our invention, the most effective corrosion inhibiting amount of the polymers used  
10 to treat the waters in contact with iron and steels ranges between about 1 to about 200 parts per million polymer, based on the weight of the waters treated, preferably between about 2 and 100 parts per million polymer, based on the weight of waters treated, and most preferably ranging  
15 between about 3 and about 50 parts per million polymer, based on the weight of the waters treated.

The most preferred polymers are copolymers or terpolymers which contain at least one mole percent hydroxamic acid mer unit, preferably from 1 - 30 mole  
20 percent hydroxamic acid mer unit, wherein the polymer also contains monomers or repeating mer units derived from monomers chosen from the group consisting of acrylic acid, methacrylic acid, acrylamide, methacrylamide, sulfonated monomers, such as 2-acrylamido-2-methylpropanesulfonate,

N-sulfomethylacrylamide, N-sulfoethylacrylamide, sulfonated styrenes, vinyl sulfonates, maleic anhydrides, itaconic acids, hydroxypropylacrylates, hydroxyethylacrylate, N-t-butylacrylamide, and the like.

It is particularly preferred to use copolymers, terpolymers, or above containing, in addition to the hydroxamic acid repeating mer unit, mer units obtained by polymerization of acrylic acid, methacrylic acid, acrylamide, methacrylamide, and the like.

The most preferred polymers containing hydroxamic acid mer units are the polymers that have the structure:



wherein R is chosen at each occurrence from hydrogen, methyl, and mixtures thereof, and a, b, d have the following relationships:

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1) The sum of  $a + b + d$  is sufficient to provide a molecular weight between about 2,000 to about 35,000;

2) The ratio,  $d/(a+b+d)$  ranges from about 0.30 to about 0.01;

5           3) The ratio,  $b/(a+b+d)$  ranges from about 0.3 to about 0.0;

4) The ratio,  $a/(a+b+d)$  ranges from about 0.99 to about 0.40.

Most preferably, the hydroxamic acid polymers  
10 above are those polymers wherein R is H and a, b, and d have the following relationships:

1) The sum  $(a+b+d)$  is sufficient to provide a molecular weight ranging from 2,500 to 25,000 more preferably 2,500 to 15,000;

15           2) The ratio,  $d/(a+b+d)$ , ranges from about 0.14 to about 0.02;

3) The ratio,  $b/(a+b+d)$ , ranges from about 0.30 to about 0.01;

4) The ratio,  $a/(a+b+d)$ , ranges from about 0.97 to  
20 about 0.56;

and further wherein the polymer is used at from 1 or 2 to 100 ppm polymer, based on the weight of the water being treated.

The ratio of  $d/(a+b+d)$  may be about 0.04. The  
25 ratio of  $a/(a+b+d)$  may be about 0.94.

As can be seen above, the most preferred polymers are polymers which contain acrylic acid or methacrylic acid, and optionally contain acrylamide or methacrylamide, along with the repeating mer unit containing the hydroxamic acid functional group. Again, the acidic mer units in the polymers described above may be present as their salts, as earlier described.

Although, as will be seen, and as taught in the prior art, the use of hydroxamic acid containing polymers as scale inhibitors is known, these polymers are not preferred scale inhibitors.

However, the hydroxamic acid polymers of this invention may be used in combination with other polymers, which polymers are dispersing and/or scale inhibiting polymers.

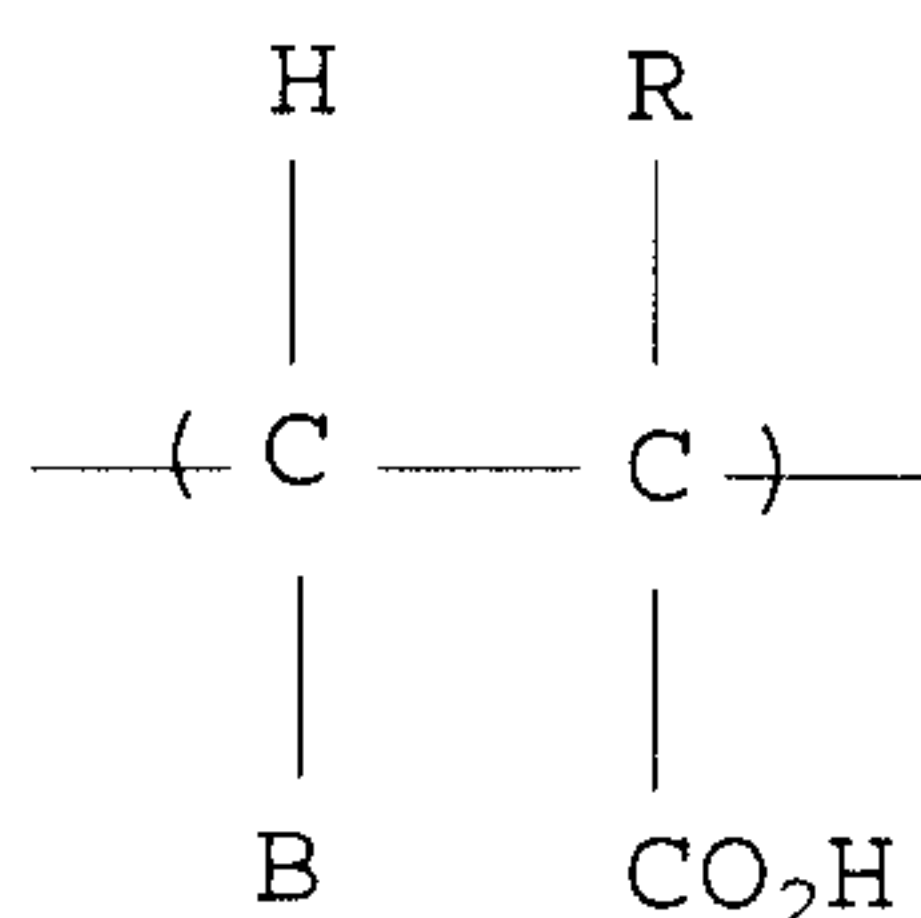
#### Combination Treatment

When practicing our method of inhibiting corrosion of mild steels and iron in contact with industrial waters containing hardness ions, it is preferred to add to the hydroxamic acid polymer treatments a scale inhibiting or dispersant polymer, or which polymer does not contain hydroxamic acid functional groups. These polymers are primarily water soluble polymers having a molecular weight between 1,000 and 50,000 and containing carboxylate functionality, said polymers again being free of hydroxamic acid

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functional groups, and said carboxylate functionality obtained from the presence in the polymer of repeating mer units, often randomly distributed, having the structure:

5



wherein R is hydrogen, methyl, or mixtures thereof; B is hydrogen,  $-\text{CO}_2\text{H}$ ,  $-\text{CH}_2\text{CO}_2\text{H}$ , or mixtures thereof; said polymers also containing from 0 to 50 mole percent of at least one of the monomers chosen from the group consisting of acrylamide, methacrylamide, hydroxypropylacrylates, hydroxyethylacrylate, N-tertiary-butyl-acrylamide, N-sulfomethylacrylamide, N-sulfoethylacrylamide, AMPS, sulfonated styrene, vinyl sulfonates, itaconic acids, and the like. These scale inhibiting/dispersant polymers are exemplified primarily by polymers that contain acrylic acid or methacrylic acid or both. These acrylic acid or methacrylic acid polymers may be homopolymers, copolymers, or terpolymers of above, but it is preferred that the polymer contains either acrylic acid, methacrylic acid, maleic anhydride, itaconic acid, or some carboxylate containing monomer unit said monomer unit or combination of monomer units being at least 50 percent of the molar ratios of total monomer used in the synthesis of these polymers.

The scale inhibiting and/or dispersing polymer, when used in combination with our hydroxamic acid containing polymers, are preferably used within the weight ratio of scale inhibitor/dispersant polymer to hydroxamic acid polymer ranging between about 10 to 1 to about 1 to 10, preferably from about 5 to 1 to about 1 to 5. When the combination of polymers are used, the combination is normally added to the water such that the addition of the combination will provide from 1 to 200 parts per million of the hydroxamic acid containing polymer, based on the weight of the waters being treated.

The most preferred scale inhibiting/dispersant polymers are homopolymers of acrylic acid, methacrylic acid, or maleic anhydride and copolymers containing either acrylic acid, or methacrylic acid, or both, which copolymers also contain at least one of the monomers chosen from the group consisting of acrylamide, methacrylamide, maleic anhydride, hydroxypropylacrylates, hydroxyethylacrylate, N-tertiary-butyl-acrylamide, 2-acrylamido-2-methylpropanesulfonate, sulfomethylacrylamide, sulfoethylacrylamide, sulfonated styrene, vinyl sulfonate, itaconic acid, and N-hydroxypropylacrylamide. These polymers normally contain at least 40 mole percent of acrylic acid, methacrylic acid, or mixtures thereof with the remainder of the polymer containing at least one of the monomer units (or mer units) mentioned above.

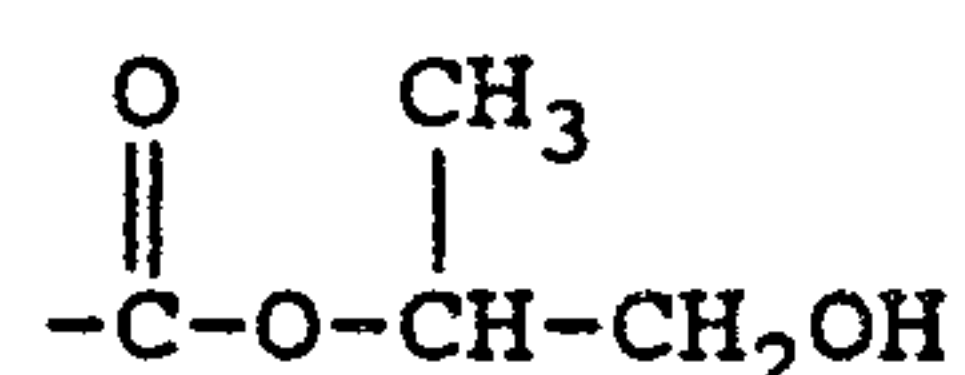
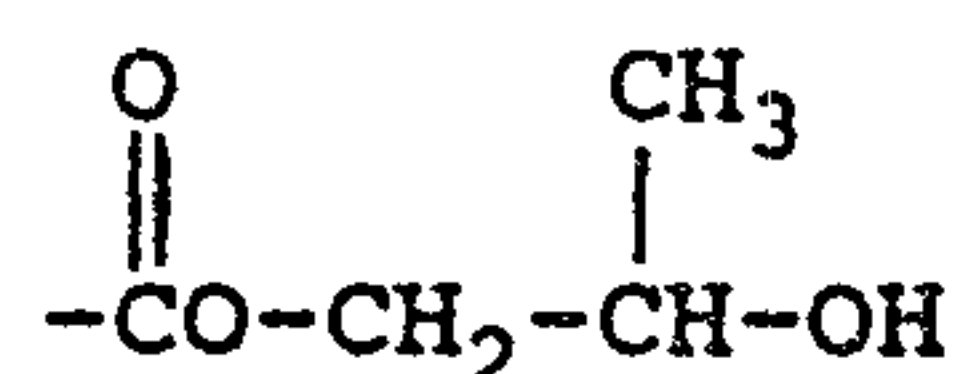
Other monomers may also be used with these polymers containing acrylic acid, methacrylic acid, or maleic anhydride, itaconic acid, and the other monomers as above. Other monomers may include acrylonitrile, methyl acrylate, ethyl acrylate, and the like, but since these monomers are primarily hydrophobic and not hydrophilic, the content of the hydrophobic monomer normally is limited to less than 10 mole percent, and preferably less than 5 mole percent in these polymers.

The water soluble dispersing and/or scale inhibiting polymers have a molecular weight ranging from 1,000 to 50,000, preferably from 2,500 to about 35,000, and most preferably to about 3,000 to about 25,000.

When the scale inhibiting/dispersant polymers are used, they may be used with the hydroxamic polymers either singly, or they may be used themselves in combinations. The combinations may include any of the polymers derivable from the definitions above but are preferably used in combinations containing homopolymers of acrylic acid, homopolymers of methacrylic acid, copolymers of acrylic acid with at least one monomer chosen from the group consisting of methacrylic acid, acrylamide, methacrylamide, the hydroxypropylacrylates, N-t-butylacrylamide, 2-acrylamido-2-methylpropane sulfonic acid, sulfomethylacrylamide, sulfoethylacrylamide, and itaconic acid; and copolymers of maleic anhydride with at least one of the monomers chosen from the group

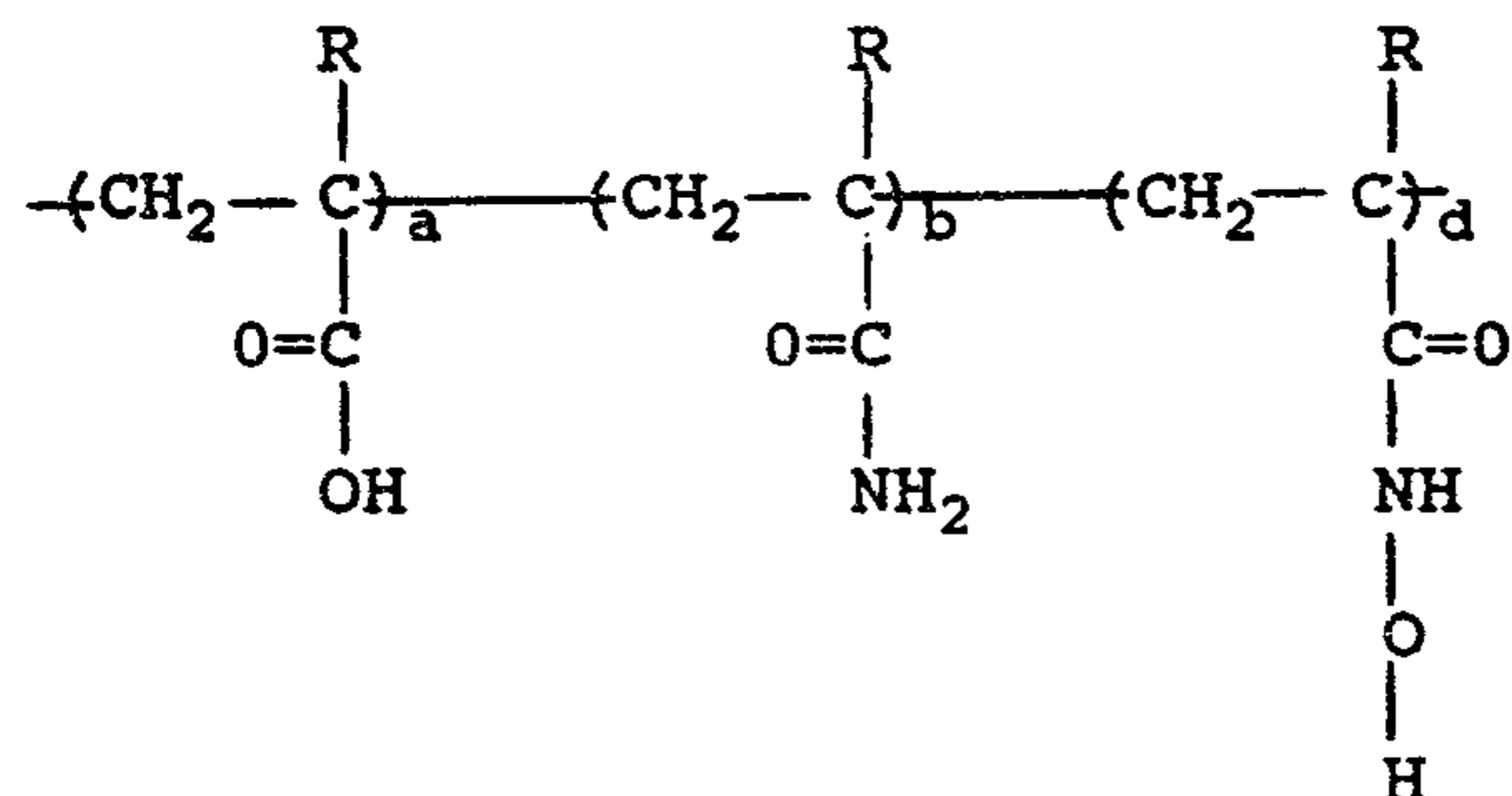
consisting of acrylic acid, methacrylic acid, vinyl sulfonate, styrene sulfonate, itaconic acid, and the like.

By the terms, hydroxypropylacrylates, we mean any structure obtained by the reaction of acrylic acid with propylene oxide leading to ester groups having the formulas:



or mixtures thereof.

When used in combination with scale inhibiting/dispersing polymers, i.e. A polymers, the hydroxamic acid containing polymer, i.e. B polymer, is preferably the terpolymer described above, which terpolymer has the structure:



Wherein R is chosen from the group consisting of hydrogen, methyl, or mixtures thereof and the following relationships exist:

- 1) the sum,  $(a+b+d)$ , is sufficient to provide for a molecular weight ranging from 2,000 - 50,000;
- 2) the ratio,  $a/(a+b+d)$ , ranges from 0.99 to 0.40;
- 3) the ratio,  $b/(a+b+d)$ , ranges from 0.30 to 0.0;
- 4) the ratio,  $d/(a+b+d)$ , ranges from 0.01 to 0.30;

As before, the acidic mer units, containing either carboxylic acids, or hydroxamic acids, or both, may be present as their salts, or mixtures thereof.

When these mixtures are used, the group A polymers, that is the scale inhibiting/dispersing polymers, and the group B polymers, that is the hydroxamic acid containing polymers, are used within the weight ratio ranging from 10:1 to 1:10, preferably 5:1 to 1:5. As before when the combination is used, the combination is preferably added to waters containing hardness ions, such as calcium, magnesium, and the like, so-called "hard waters", so as to provide from about 1 to about 50 parts per million of the hydroxamic acid polymers in the hard waters, based upon the weight of the hard waters treated.

Other Corrosion Inhibitors

In addition to the use of the hydroxamic acid polymers of this invention to inhibit corrosion, it is anticipated that these polymers may be used also in combination with known inhibitors for corrosion of iron and steel in contact with industrial waters. These inhibitors include orthophosphate, organophosphates, phosphonates, polyolphosphate esters, tolyltriazole, and mixtures thereof. They can also include zinc ions, inorganic chromates nitrite/nitrate salts and other species shown to protect iron and steel alloys from corrosion when these iron and steel materials are exposed to industrial waters.

When other corrosion inhibitors are used, it is preferred to use orthophosphate or orthophosphate sources, organophosphonates, such as 1, 2, 4-tri-carboxy-2-phosphonobutane (often referred to as PBTC) and HEDP, (1-Hydroxyethylidene) bis-phosphonic acid or the so called Dequest<sup>®</sup> product.

The hydroxamic acid polymers of this invention may, in fact, be substituted partially or completely for the normal organophosphonate corrosion inhibitors known in the art. When completely substituted for the organophosphonate, the hydroxamic acid polymers of this invention can be as effective in inhibiting corrosion as the organophosphonates. When partially substituted

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Dequest<sup>®</sup> is a registered trademark of Monsanto

for the organophosphonates, the formulation containing a mixture of the organophosphonates with the hydroxamic acid polymers of this invention, particularly when in the presence of the scale inhibiting/dispersant polymers, provides not only superior corrosion protection, but also excellent scale protection.

To exemplify our invention, we provide the following experimental information.

#### Experiments

In the experiments below, several tests were performed. These tests are summarized as follows:

##### Saturation Ratio Test

A test solution is prepared by adding calcium, magnesium, inhibitor test polymer and bicarbonate to deionized water. Initial concentrations of the salts should be: 360 ppm  $\text{Ca}^{+2}$ , 200 ppm  $\text{Mg}^{+2}$ , 500 ppm  $\text{HCO}_3^-$  (all as  $\text{CaCO}_3$ ) and 5, 10, or 15 ppm of inhibitor test polymer as polymer actives/solids. The temperature is maintained at 140° F (60° C); the solution is stirred at all times, and the pH is continuously monitored. The solution is titrated with dilute NaOH at a constant rate. With the addition of NaOH, the pH of the test solution slowly increases, then decreases slightly, and increased again. The maximum pH, prior to the slight decrease at

precipitation, is the breakpoint pH. A mineral solubility computer program is then used to calculate the calcium carbonate supersaturation ratio based on test conditions at the breakpoint pH. This supersaturation ratio is related to the calcium carbonate inhibition performance. The test procedure is repeated for different inhibitor solutions and dosages. All precipitated calcium carbonate must be removed from the test apparatus with dilute HCl prior to the next test run.

#### Calcium Carbonate Inhibition Test

Calcium, magnesium, test polymer inhibitor and bicarbonate is added to deionized water to prepare a test solution with 360 ppm  $\text{Ca}^{+2}$ , 200 ppm  $\text{Mg}^{+2}$ , 500 ppm  $\text{HCO}_3^-$  (all as  $\text{CaCO}_3$ ) and 5, 10 or 15 ppm inhibitor as actives/solids. An initial sample of the test water is collected for calcium analysis by atomic absorption. The test temperature is maintained at 140° F (60° C). Using dilute NaOH, the pH of the solution is slowly increased to 9.0, and maintained during the two hour duration of the test. At the conclusion of the test, a small sample of the solution is filtered (0.45 um) and the calcium concentration is determined by atomic absorption. The remainder of the unfiltered sample is allowed to settle, undisturbed for 24 hours, at room temperature. Water is then collected from the top of the flask after 24 hours and analyzed for calcium. The % inhibition and % dispersancy are calculated in the following manner:

$$\% \text{ inhibition} = \frac{\text{ppm Ca}^{+2} \text{ filtered}}{\text{ppm Ca}^{+2} \text{ initial}} \times 100$$

$$\% \text{ dispersancy} = \frac{\text{ppm Ca}^{+2} \text{ unfiltered, settled}}{\text{ppm Ca}^{+2} \text{ initial}} \times 100$$

#### Electrochemical Test

Both the Tafel plots and linear polarization resistance tests are conducted in the same water chemistry and conditions. The test solution for the electrochemical corrosion cell is prepared by adding calcium, magnesium, various inhibitors, and bicarbonate to deionized water to obtain 360 ppm  $\text{Ca}^{+2}$ , 200 ppm  $\text{Mg}^{+2}$ , 440 ppm  $\text{HCO}_3$  (all as  $\text{CaCO}_3$ ). Temperature is maintained at 120° F and the solution is aerated throughout the test period. The pH is uncontrolled. A standard three electrode cell is assembled for the polarization studies. Pre-polished mild steel specimens were used as the rotating working electrode, at a speed of 500 rpm. All potential measurements are made against a saturated calomel reference electrode. Two graphite rods are used as the counter electrode. Polarization resistance measurements are conducted within  $\pm 20$  mV of the corrosion potential at a scan rate of 0.1 mV/sec. Tafel plots are performed by polarizing the mild steel specimen at 250 mV cathodically and anodically from the corrosion potential.

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The Saturation Ratio calculation is described in a paper entitled, "Computerized Water Modeling in the Design and Operation of Industrial Cooling Systems" presented at the 41<sup>st</sup> Annual Meeting at the International Water Conference in  
5 Pittsburgh, Pennsylvania, October 20-22, 1980.

The Saturation Ratio test is dependent on the formation of scale above a certain critical pH. Consequently, sodium hydroxide is added to the test solution to increase the pH and supersaturate the test water until the breakpoint pH is  
10 achieved. Nucleation and crystal growth occur during test period. The breakpoint pH is used in a computer program described in the paper above to calculate the saturation ratio values. This value is simply an index for predicting the tendency toward calcium carbonate precipitation. The computer  
15 program calculates the saturation ratio based on water composition, operating conditions, temperature, breakpoint pH, cycles of concentration, and acid pH control. The program also compensates for temperature, ionic strength and ion pairing effects. The greater the saturation ratio, the better the  
20 polymer is a scale inhibitor.

The calcium carbonate inhibition test is often referred to as the "Stir and Settle Test". This test provides information such as percent inhibition and dispersancy for a particular scale control agent. Inhibition describes the  
25 ability to limit the formation of

scaling salts such as calcium carbonate by preventing calcium carbonate growth. Dispersancy characterizes the ability of a chemical to prevent the settling of particulates over extended time periods. Performance is determined by measurement of the atomic absorption of calcium, and the higher the percent inhibition and percent dispersancy, the better the polymer is as a scale inhibitor.

The electrochemical test provide for measurement of Tafel plots and linear polarization resistance data to measure corrosion inhibition activity. This activity is reported as a corrosion rate, and the lower corrosion rate, the better the polymer is as a corrosion inhibitor.

Representative of the polymers of this invention are the polymers described in Table 1.

TABLE 1

| <u>Polymer</u> | <u>Composition (mole %)</u>                                                                                   | <u>**Estimated Molecular Weight</u> |
|----------------|---------------------------------------------------------------------------------------------------------------|-------------------------------------|
| 1              | 94 mole % acrylic acid 6 mole %<br>(CH <sub>2</sub> - CH)<br> <br>O=C—NHOH                                    | 6,000 - 7,000                       |
| 2              | 90 mole % acrylic acid 10 mole %<br>(CH <sub>2</sub> - CH)<br> <br>O=C—NHOH                                   | 6,000 - 7,000                       |
| ***3           | 100% acrylic acid<br>(Backbone polymer)                                                                       | 6,000 - 7,000                       |
| 4              | 89% acrylic acid<br>5% acrylamide<br>6% hydroxamic mer unit*                                                  | 12,000 - 13,000                     |
| 5              | 70% acrylic acid<br>19% acrylamide<br>11% hydroxamic mer unit                                                 | 12,500 - 13,500                     |
| 6              | 53% acrylic acid<br>18% acrylamide<br>29% hydroxamic mer unit                                                 | 12,700 - 13,700                     |
| 7              | 83% acrylic acid<br>9% acrylamide<br>8% hydroxamic mer unit                                                   | 12,500 - 13,500                     |
| ***8           | 50 - 60% acrylic acid<br>14 - 20% sulfomethyl-<br>acrylamide<br>20 - 36% acrylamide                           | 18,000 - 19,000                     |
| ***9           | 55 - 65% acrylic acid<br>15 - 25% methacrylic acid<br>10 - 30% N-t-butylacrylamide                            | 15,000 - 16,000                     |
| ***10          | Polyacrylic acid homopolymer<br>neutralized with sodium<br>hydroxide                                          | 4,000 - 7,500                       |
| ***11          | Copolymer of acrylic acid<br>and the isopropyl ester of<br>acrylic acid (ester content<br>from 6 - 10 mole %) | 4,000 - 7,500                       |

### Other Abbreviations

PBTC - 1, 2, 4 - tri-carboxy-2-phosphono-butane

HEDP - (1-Hydroxyethylidene) bis-phosphonic acid

\* Hydroxamic mer unit =  $\text{-(CH}_2\text{---CH)-}$   
 $\quad \quad \quad |$   
 $\quad \quad \quad \text{O=C---NHOH}$

**\*\* Molecular weight is estimated weight average molecular weight as determined by gel permeation chromatography using polystyrene sulfonate standards**

\*\*\* Polymers 3, 8, 9, 10, and 11 are representative of "scale inhibiting/dispersing polymers"

Using the listed polymers, various tests were performed to determine saturation ratios, percent inhibition, and percent dispersancy in the so called "Stir and Settle" tests, and electrochemical screening tests for corrosion inhibition and determination of corrosion rates.

The water chemistry and test conditions, as well as the results are presented in the following Tables II, III, and IV.

TABLE II  
Saturation Ratio Test

Water Chemistry / Conditions:

360 ppm Ca/200 ppm Mg/500 ppm HCO<sub>3</sub> (as CaCO<sub>3</sub>)  
Temperature: 60° C, Stir rate: 300 rpm  
Titrant: 0.10 Normal NaOH  
Dosage: 5, 10 and 15 ppm actives  
Standard Deviation of Saturation Ratio: ± 6.6  
Saturation ratio of blank: 3.0

| <u>Polymer</u> | <u>Saturation Ratio</u> |               |               |
|----------------|-------------------------|---------------|---------------|
|                | <u>5 ppm</u>            | <u>10 ppm</u> | <u>15 ppm</u> |
| 1              | 40.9                    | 128.9         | 130.7         |
| 2              | 43.4                    | 97.1          | 124.7         |
| 3              | 97.1                    | 125.9         | 131.9         |
| 4              | 46.4                    | 112.3         | 127.9         |
| 5              | 62.3                    | 106.0         | 127.9         |
| 6              | 36.8                    | 53.9          | 76.9          |
| 7              | 62.3                    | 106.0         | 118.6         |

TABLE III

## Stir and Settle Test

Water Chemistry / Conditions:360 ppm Ca / 200 ppm Mg / 500 HCO<sub>3</sub> (as CaCO<sub>3</sub>)

Temperature: 60° C, Stir Rate: 250 rpm

Titrant: 0.10 Normal NaOH, pH: 9.0 for two hours

Blank: 0.6% inhibition, 1.3% dispersancy

Polymer

## Saturation Ratio

|                 | <u>5 ppm</u> | <u>10 ppm</u> | <u>15 ppm</u> |
|-----------------|--------------|---------------|---------------|
| 1 % inhibition: | 39.6%        | 53.1%         | 61.4%         |
| % dispersancy:  | 40.2%        | 59.3%         | 75.8%         |

TABLE IV

**Electrochemical Screening Test for Mild Steel Corrosion Inhibition of Several Hydroxamic Acid Containing Polymers**

Water Chemistry / Conditions:

360 ppm Ca / 200 ppm Mg / 440 HCO<sub>3</sub> (as CaCO<sub>3</sub>)  
 Temperature: 120° F, pH: uncontrolled, air agitation,  
 Unpolished Mild Steel specimen, 30 minute delay time, 500 rpm  
 Standard deviation of corrosion rate:  $\pm 0.345$  mpy

Polymer Combination:

- (A). 20 ppm inhibitor, 0 ppm PBTC, 15 ppm Polymer 8  
 (B). 10 ppm inhibitor, 10 ppm PBTC, 15 ppm Polymer 8  
 (C). 10 ppm inhibitor, 10 ppm PBTC, 15 ppm Polymer 9

| <u>Polymer<br/>Inhibitor</u> | <u>Corrosion Rate (mpy)</u> |            |            |
|------------------------------|-----------------------------|------------|------------|
|                              | <u>(A)</u>                  | <u>(B)</u> | <u>(C)</u> |
| 1                            | .18                         | 3.96       | 1.53       |
| 2                            | 1.84                        | 1.39       | 0.95       |
| 4                            | 0.38                        | .84        | 1.98       |
| 5                            | .50                         | .34        | 1.81       |
| 6                            | 3.13                        | .88        | .79        |
| 7                            | 2.24                        | .76        | 1.04       |
| Blank*                       | 8.63                        | .98        | 1.92       |

Other Combinations:

20 ppm Polymer 2, 10 ppm PBTC, 10 ppm Polymer 8: 0.75 mpy  
 15 ppm Polymer 2, 5 ppm PBTC, 15 ppm Polymer 8: 1.39 mpy  
 20 ppm Polymer 5, 0 ppm PBTC, 15 ppm Polymer 10: 0.57 mpy (avg)  
 20 ppm Polymer 5, 0 ppm PBTC, 15 ppm Polymer 11: 1.03 mpy

Other Combinations:

10 ppm Polymer 5 10 ppm Polymer 11, 15 ppm Polymer 8: 0.34 mpy

10 ppm Polymer 5, 10 ppm Polymer 10, 15 ppm Polymer 8: 0.73 mpy

10 ppm Polymer 5: 6.0 mpy

20 ppm Polymer 5: 1.75 mpy

15 ppm Polymer 11: 1.27 mpy

15 ppm Polymer 10: 2.71 mpy (avg)

Blank\*\*: no inhibitor: 31.05 mpy

\* Contains no hydroxamic acid polymer, but contains other treatments as listed

\*\* Contains no treatment

Summary

The test results above show clearly that the hydroxamic polymers of this invention can be used to inhibit corrosion of steels in contact with industrial waters, either alone or particularly in combination with hardness reactive polymers, such as the carboxylate containing polymers described above. Also, the hydroxamic acid polymers by themselves or in combination with hardness reacting polymers inhibit corrosion of iron and steel in contact with industrial waters when present in those industrial waters, either with or without other known corrosion inhibitors.

Also as can be seen from the results in Table IV, the hydroxamic acid polymers can substitute for organophosphonates when used in combination with phosphonates or when used alone in the absence of these organophosphonate corrosion inhibitors.

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CLAIMS:

1. A method of inhibiting corrosion of iron and steel alloys in contact with industrial waters containing hardness ions the method comprising the step of:

5 adding to said waters a corrosion inhibiting amount of water soluble polymer having from about 1.0 to about 30 mole percent of hydroxamic acid mer unit having the structure:



wherein R is selected from the group consisting of H, CH<sub>3</sub> and mixtures thereof, and from about 40 to about 99 mole percent acrylic acid mer unit, and wherein the polymer has a  
15 molecular weight ranging from about 2,000 to about 50,000.

2. The method of claim 1 wherein the water soluble polymer has from about 4.0 to about 30 mole percent hydroxamic acid mer unit and from about 40 to about 96 mole percent acrylic acid mer unit.

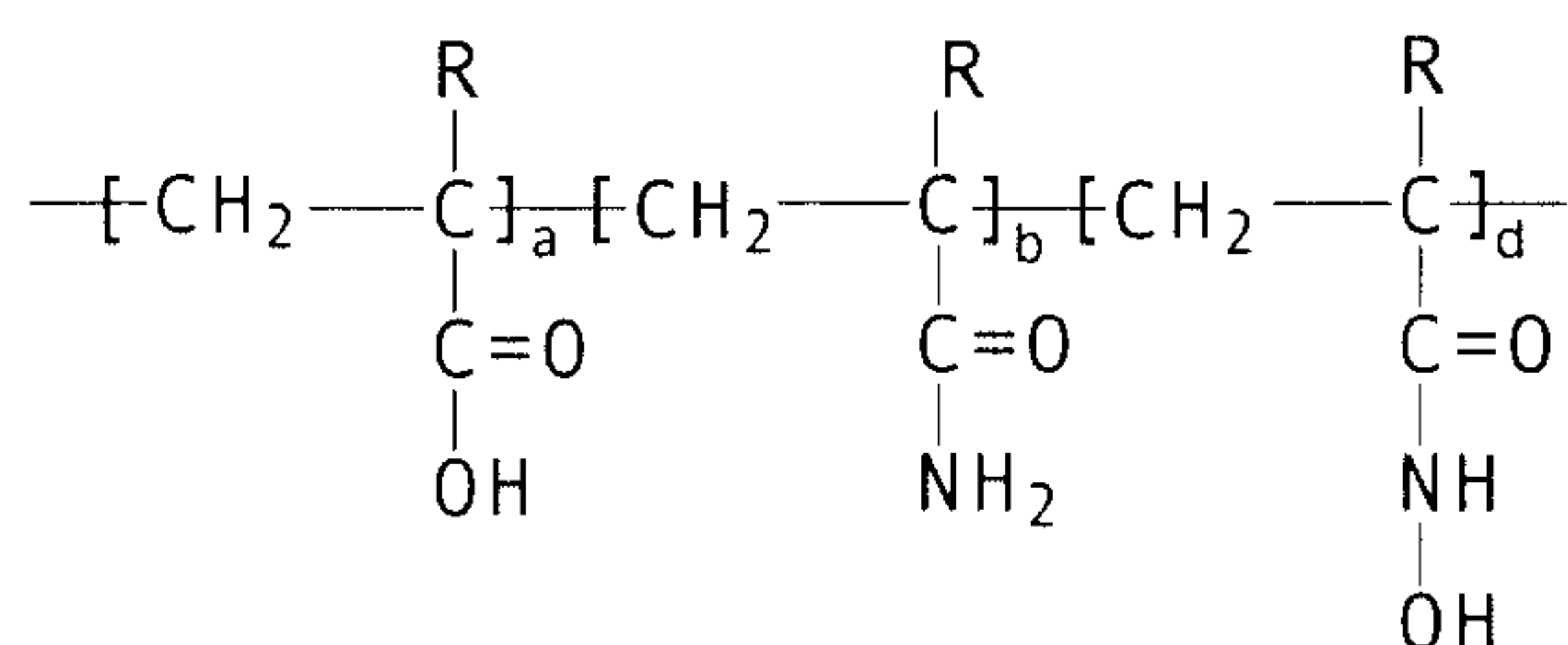
20 3. The method of claim 1 wherein the polymer has a molecular weight of from about 5,000 to about 25,000 and contains from about 2.0 to about 14 mole percent of the hydroxamic acid mer unit.

4. The method of claim 3 wherein the polymer has a  
25 molecular weight of from about 5,000 to about 25,000 and contains from about 4.0 to about 14 mole percent of the hydroxamic acid mer unit.

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5. The method of any one of claims 1-4 wherein the amount of polymer added to the aqueous system ranges between about 1 and 200 parts per million of polymer, based on the weight of waters treated.

5 6. The method of any one of claims 1-5 wherein the polymer has the structure:



10

wherein R is selected from the group consisting of H, CH<sub>3</sub> and mixtures thereof; and wherein a, b and d have the following relationships:

(1) The sum of a + b + d is sufficient to provide  
15 a molecular weight between about 2,000 to about 35,000;

(2) The ratio, d/(a + b + d) ranges from about 0.30 to about 0.01;

(3) The ratio, b/(a + b + d) ranges from about 0.3 to about 0.0; and

20 (4) The ratio, a/(a + b + d) ranges from about 0.99 to about 0.40.

7. The method of claim 6 wherein R is hydrogen and a, b and d have the following relationships:

(1) The sum (a + b + d) is sufficient to provide a  
25 molecular weight ranging from 2,500 to 15,000;

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(2) The ratio,  $d/(a + b + d)$ , ranges from about 0.14 to about 0.02;

(3) The ratio,  $b/(a + b + d)$ , ranges from about 0.30 to about 0.01;

5 (4) The ratio,  $a/(a + b + d)$ , ranges from about 0.97 to about 0.56;

and further wherein the polymer is used at from 2 to 100 ppm polymer, based on the weight of the water being treated.

8. The method of claim 6 or 7 wherein:

10 the ratio  $d/(a + b + d)$  has a lower value of about 0.04; and,

the ratio  $a/(a + b + d)$  has an upper value of about 0.94.

9. A method of inhibiting corrosion of iron and steel  
15 alloys in contact with industrial waters containing hardness ions, which method comprises the step of treating said hardness ion containing waters with a combination of the following polymers:

(a) water soluble scale inhibiting polymers having  
20 a molecular weight between 1,000-50,000 and containing carboxylate functionality, the polymers being free of hydroxamic acid functional groups, the polymers being comprised of mer units having the structure:



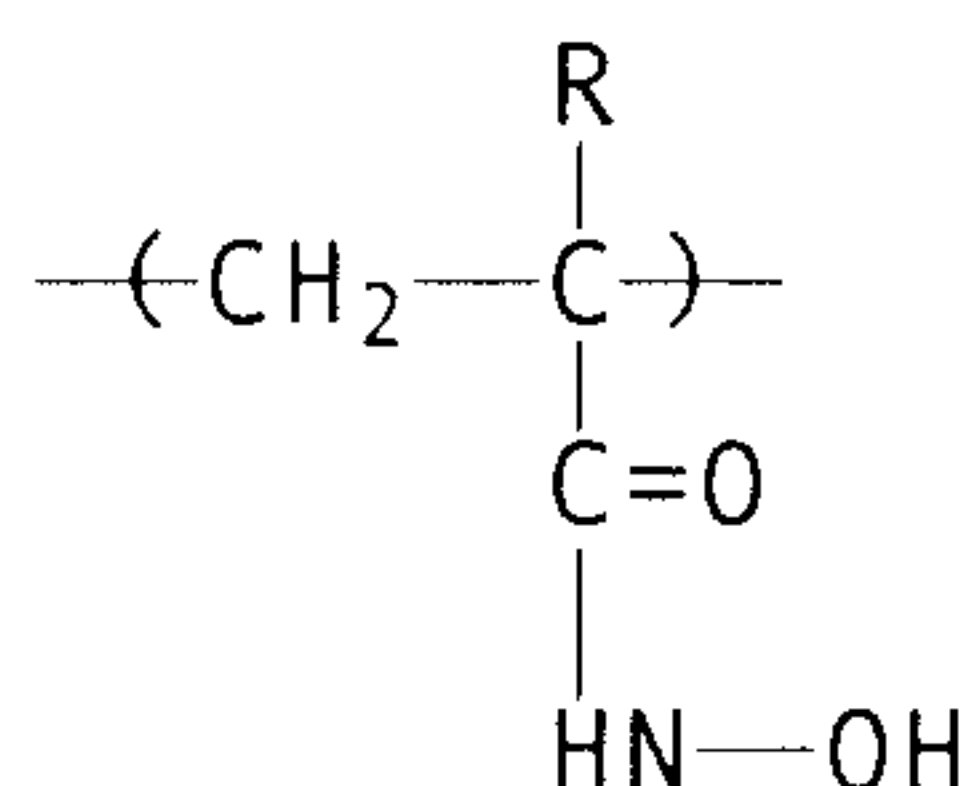
wherein:

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R is H, CH<sub>3</sub>, or mixtures thereof;

B is H, -CO<sub>2</sub>H, -CH<sub>2</sub>CO<sub>2</sub>H or mixtures thereof; and

(b) a water soluble polymer having a molecular weight between 2,000-50,000 and containing from about 1.0 to about 30 mole percent of a hydroxamic acid mer unit having the structure:



10 wherein R is chosen from the group H, CH<sub>3</sub>, and mixtures thereof, and from about 40 to about 99 mole percent acrylic acid mer unit; and

wherein the weight ratio of the two polymers is between about 10:1 to about 1:10.

15 10. The method of claim 9 wherein the water soluble polymer has from about 4.0 to about 30 mole percent of a hydroxamic acid mer unit and from about 40 to about 96 mole percent acrylic acid mer unit.

11. The method of claim 9 or 10 wherein the water  
20 soluble polymers having a molecular weight between 1,000-50,000 and containing carboxylate functionality further comprise from 0 to 50 mole percent of a monomer selected from the group consisting of acrylamide, methacrylamide, 2-acrylamido-2-methylpropane sulfonic acid,  
25 hydroxypropylacrylates, hydroxyethyl acrylate, N-t-butylacrylamide, N-sulfomethylacrylamide, N-sulfoethylacrylamide, sulfonated styrene, vinyl sulfonate,

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isopropyl ester of acrylic acid, itaconic acid and mixtures thereof.

12. The method of any one of claims 9-11 wherein:

the polymers of (a) are chosen from homopolymers  
5 of acrylic acid, methacrylic acid, and maleic anhydride, and  
from copolymers of acrylic acid with at least one of the  
monomers chosen from the group consisting of methacrylic  
acid, maleic anhydride, acrylamide, methacrylamide,  
hydroxypropylacrylates, N-t-butylacrylamide, sulfonated  
10 styrene, vinyl sulfonate, and itaconic acid; and the  
polymers of (b) further comprise about 0.0 to about 30 mole  
percent of at least one of the monomers chosen from the  
group consisting of acrylamide and methacrylamide; and  
further wherein the ratio of the two polymers ranges from  
15 5:1 to about 1:5.

13. The method of any one of claims 9-12 further  
comprising the step of adding other corrosion inhibitors  
selected from the group consisting of orthophosphate, 1-  
hydroxyethylidene bisphosphonic acid, 1,2,4-tri-carboxy-2-  
20 phosphono-butane, tolyltriazole, zinc salts, chromate salts,  
nitrite/nitrate salts, and polyphosphate.

14. The method of any one of claims 9-13 wherein the  
water soluble polymer (b) further comprises from about 0.0  
to about 30 mole percent of a monomer selected from the  
25 group consisting of acrylamide, methylacrylamide, and  
mixtures thereof.

15. The method of any one of claims 9-14 wherein the  
combination of (a) and (b) polymers are added to hard waters  
so as to provide from 1-50 ppm of (b) polymers, based on  
30 hard waters treated.