

# NOTE

## Structure of a Complex of Iron(III) with a Crosslinked Copolymer of 1-( $\beta$ -Acrylamidoethyl)-3-hydroxy-2-methyl-4(1H)-pyridinone and *N,N*-Dimethylacrylamide

### INTRODUCTION

Chelation is of great significance in many chemical and biomedical systems such as the isolation of  $\text{Fe}^{3+}$  or  $\text{Al}^{3+}$ ,  $\text{Ga}^{3+}$  and actinides,<sup>1-3</sup> the treatment of iron overload,<sup>4-6</sup> and the inhibition of bacterial growth.<sup>7-9</sup> Recently, some of us reported the synthesis and properties of several iron(III) chelating resins with immobilized natural or synthetic iron(III) chelators.<sup>10</sup> One of these resins (AHMP-DMAA) was prepared by the copolymerization of 1-( $\beta$ -acrylamidoethyl)-3-hydroxy-2-methyl-4(1H)-pyridinone (AHMP) and *N,N*-dimethylacrylamide (DMAA) in the presence of a crosslinking agent.<sup>10</sup> The structures of the monomer AHMP and of the AHMP-DMAA resin are represented in Figure 1. This resin exhibits a high affinity and selectivity for iron(III) and was found to be chemically stable and reusable. The resin has been used in the removal of iron from iron-binding proteins, milk, wine, or beer,<sup>11</sup> for the inhibition of bacterial growth,<sup>12</sup> and for iron detoxification of poisoned human plasma.<sup>13</sup> Furthermore, the stability constant of its iron(III) complex was determined recently, and was found to be even higher than that of the corresponding monomer complex.<sup>14</sup>

Although the AHMP-DMAA resin can be effectively applied for iron(III) chelation, the structure of the resin-iron(III) complex so far has been unknown. Iron binding studies with soluble iron(III) chelating ligands containing the same groups as present in AHMP, showed that a ligand/iron(III) ratio of 3 is observed at a pH range of 5-11, with an octahedral coordination around the iron(III) ion.<sup>9,15-17</sup> However, it is possible that differences occur in the coordination mode for the soluble iron(III) chelate and the resin-iron(III) complex. This article describes the results of a study about the coordination structure using infrared spectroscopy (IR), electron paramagnetic resonance (EPR), and diffuse reflectance spectroscopy (electron spectroscopy).

### EXPERIMENTAL

#### Materials

AHMP was synthesized as described earlier.<sup>9</sup> AHMP-DMAA resin was prepared by the reverse-suspension polymerization of AHMP and DMAA using *N,N*-ethylenebis-acrylamide (EBAA) as a crosslinking agent.<sup>10</sup> Iron(III) citrate monohydrate and  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  were used as purchased from Janssen and Merck, respectively.

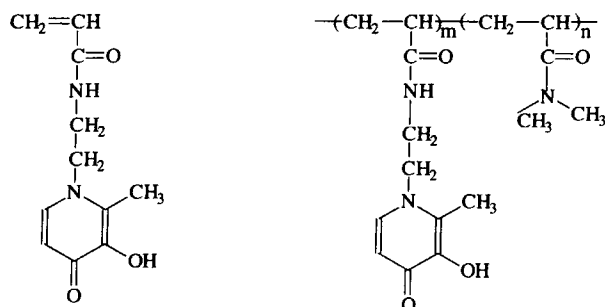
#### Preparation

**Iron(III)-Monomer Chelate.** AHMP (2.0 mmol, 444 mg) dissolved in 9 mL of methanol was mixed with a solution of  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  (0.667 mmol, 180 mg) in 1 mL of water, and the pH was adjusted to 8.0 with 1.0M NaOH (about 5 mL). The reaction took place at room temperature overnight, and the solution was evaporated, resulting in a red solid that was washed with 20 mL of hot ethanol. The product obtained (90 mg) was used without further purification.

**Iron(III)-Resin Complex.** Iron(III) citrate monohydrate (267.0 mg) was dissolved in 500 mL of phosphate buffered saline (PBS, pH 7.4). The pH of the solution was adjusted to 6.8 and the final iron(III) concentration was 1.78 mM. AHMP-DMAA resin (191.6 mg) was added to 50 mL of the iron citrate solution and the mixture was rotated for 24 h at room temperature. The iron-loaded resin was collected by filtration, washed with distilled water ( $3 \times 20$  mL) to remove uncomplexed metal, and dried at 60°C in a vacuum for 24 h.

#### Measurements

**Iron(III) Chelating Capacity.** In a stoppered vessel were placed 96 mg of the dry resin and 25 mL of the iron(III) citrate solution, and the mixture was rotated for 24 h at



**Figure 1** Schematic structures of monomer AHMP and AHMP-DMAA resin.

25°C. The iron-loaded resin, washed with distilled water ( $3 \times 20$  mL), was added to 25 mL of 1M HCl for desorption of iron(III). The mixture was rotated for 24 h at 25°C, and the amount of iron desorbed into the solution was measured with a Perkin-Elmer Zeeman 5000 atomic absorption spectrophotometer (AAS). For the resin an iron(III) chelating capacity of 146  $\mu\text{mol/g}$  was found. The AHMP ligand density of the resin was 460  $\mu\text{mol/g}$ , which means a value of 3.15 to 1 for the AHMP ligand density/iron(III) chelating capacity ratio.

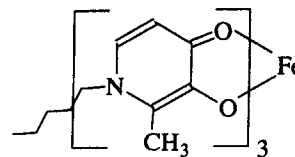
IR spectra of the chelating materials and iron complexes were recorded on a Bio-Rad FTS-60 FTIR spectrophotometer using KBr pellets. Diffuse reflectance FTIR spectra were recorded on a Bruker IFS 113v, equipped with a blocker device and an MCT detector. EPR spectra were performed at X-band frequencies at room temperature and 77 K on a Jeol Jes-RE2X ESR spectrophotometer equipped with a JEOL-Espirit 330 data system.

## RESULTS AND DISCUSSION

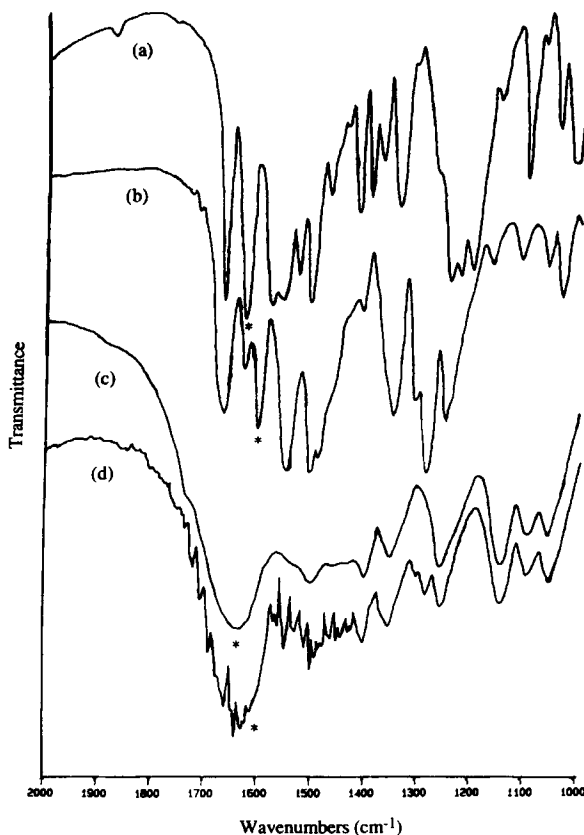
Figure 2 shows the IR spectra of the monomer, the monomer-iron(III) chelate, the resin, and the resin-iron(III) complex in the region of 2000–1000  $\text{cm}^{-1}$ . In the IR spectrum of the monomer, the band at 1630  $\text{cm}^{-1}$  (assigned as the C=O stretching vibration of the ring<sup>18</sup>) shifted toward 1600  $\text{cm}^{-1}$  in the monomer-iron(III) chelate, which indicates a metal to oxygen bonding, in agreement with literature reports.<sup>16,19</sup> The resin, as expected, exhibits much broader bands, but the band at 1640  $\text{cm}^{-1}$  is likely to contain  $\nu_{\text{C}=\text{O}}$  character. In the iron(III)-resin complex a similar broad band (with small spikes) at 1630  $\text{cm}^{-1}$  is found, for which the same shift to lower frequency is seen, suggesting a similar type of coordination. Although the yield was low for the preparation of the monomer-iron(III) chelate (14%), it is reasonable to assume that also in the isolated product the AHMP ligand to iron(III) ratio was 3 to 1, as observed in aqueous solution.<sup>9</sup>

Apart from the information obtained from the IR spectra, it should be noted that for the AHMP ligand density/iron(III) chelating capacity ratio of the resin, a value of

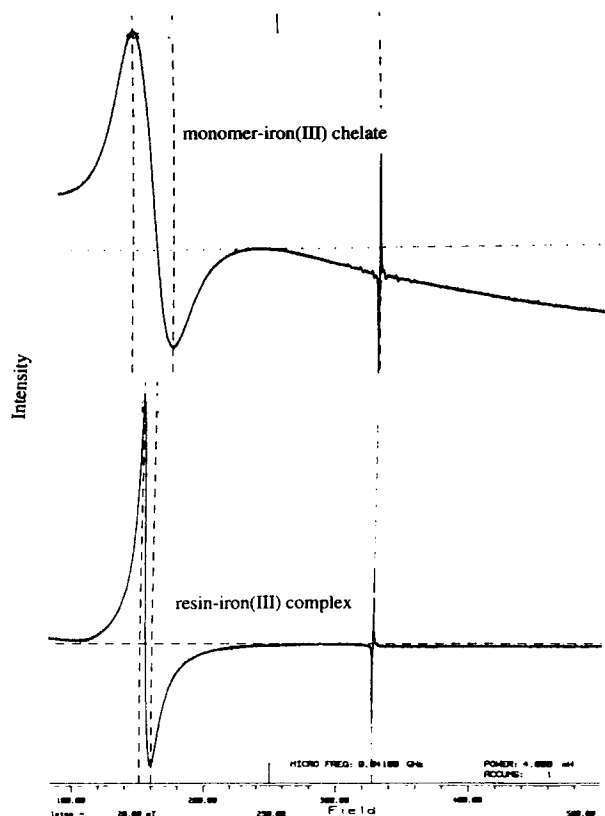
3.15 was calculated, which indicates that approximately three AHMP ligands form a complex with one iron(III) ion. Thus the general structure of the resin-iron(III) complex may be assigned as given below.



EPR spectra for the resin-iron(III) complex and the monomer-iron(III) chelate were measured and are shown in Figure 3. The EPR spectrum of the resin-iron(III) complex at 77 K showed a single sharp resonance at  $g = 4.3$  (Fig. 3), which is typical of an  $\text{Fe}^{3+}$  high-spin rhombic splitting. At room temperature this band is broader, and in addition there is no evidence for any low-spin signals at  $g = 2$ , which at most indicates a very low concentration of such species. Under the same conditions the spectrum of the monomer-iron(III) chelate (Fig. 3) was almost identical both in  $g$  value and line width with those of the resin-iron(III) complex, which in fact suggests the same coordination structure in the two types of complexes.

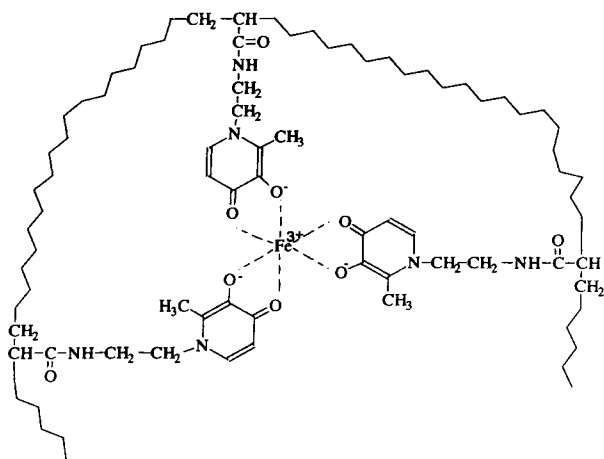


**Figure 2** (a) IR spectra of the free monomer, (b) the monomer-iron(III) chelate, (c) the free resin, and (d) the resin-iron(III) complex.



**Figure 3** EPR spectra of the resin-iron(III) complex and the monomer-iron(III) chelate at 77 K.

Based on the X-ray crystal structures of iron(III) chelates with 1-alkyl-3-hydroxy-2-methyl-4(1H)-pyridinones (analogues of AHMP) reported previously,<sup>16,20</sup> the rhombic signals at  $g = 4.3$  can be assigned to high-spin iron(III) ions in distorted octahedral structures.



**Figure 4** Proposed structure for the resin-iron(III) complex.

In the solid-state diffuse reflectance spectra a strong absorption is observed at 590–600 nm for both the resin-iron(III) complex and the monomer-iron(III) chelate. This absorption is assigned to ligand-iron(III) charge-transfer bands in the distorted rhombic structures, and strongly indicates the same Fe(III) geometry for both cases.

Given the striking similarities between the IR, EPR, and ligand field spectra for both the solid polymeric and the low-molecular weight Fe(III) species, we can accept similar geometries for both cases, in agreement with octahedral geometry. Thus, a structure for the resin-iron(III) complex is proposed (Fig. 4) in which the iron(III) ion is coordinated in an octahedral arrangement of six oxygens from three AHMP ligands.

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