

Influence of the magnetically treated 3% sodium chloride solution on the corrosion of iron

A. CHIBA, WEN-CHANG WU, A. TERASHITA

Department of Materials Chemistry, Faculty of Engineering, Yokohama National University, 156, Tokiwadai, Hodogaya-ku, Yokohama 240 Japan

It has been shown experimentally that the rest potentials of a commercial iron wire are changed when conducting solutions are made to circulate through a magnetic treatment device that uses a magnetic field. The test solution used magnetically treated 3% NaCl solution and a flow rate of 40, 110 and 220 ml min⁻¹. The magnetic treatment accelerated or inhibited the dissolution of the iron wire. Most magnetic effects were influenced by the relation between flow rate and magnetic flux density. The effect of the magnetic treatment disappeared after about 3 weeks.

1. Introduction

Many magnetic water-treatment devices are now commercially available and much data have been reported on these devices. It has been experimentally shown that voltage and currents are produced with a magnetohydrodynamical generation theory when conducting solutions are made to flow through a water-treatment device. The magnitude of the voltages and currents were found to vary with the solution flow rate according to the well-known laws of physics [1]. The magnetic field is known to have the following effects: (1) the adhesion of fur was prevented; (2) old fur was removed; (3) the corrosion of metals was inhibited; (4) plants grew, (5) the occurrence of water algae was reduced; (6) water was cleared, with cohesion and sedimentation in a colloid water system; (7) positive control of scaling in water was claimed; (8) drinking water became smoother tasting. However, the effectiveness of the magnetic treatment is known to vary widely depending on the quality of the water.

Much equipment and many facilities are applied for water in factories and buildings. The progression of corrosion causes holing of metals, with scale adhesion and a decrease in their thermal efficiency. Water control is thus very important in these plants. In general, washing by the brushing and reagent treatment methods is used, but the reagents are very expensive for application over a fairly long period, and are uneconomical in view of the amounts consumed. Magnetically treated water addresses these points; however, the effects of an external magnetic field on anticorrosive systems have not been appraised clearly. Na⁺, Cl⁻ ions and H₂O were included in a 3% NaCl solution, their susceptibilities being -5.0×10^{-6} , -2.6×10^{-5} and -1.3×10^{-5} cm³ mol⁻¹, respectively [2–4]. The 3% NaCl solution is affected by the magnetic field. The influence of a magnetic field on the dissolution and corrosion of metals [5–12] in various solutions has been reported.

When a conducting fluid flows through a magnetic field, the total electric field vector, E_T , may be calculated using Equation 1

$$E_T = E_S + E = E_S + (VB) \quad (1)$$

where E is the electric field vector induced by a fluid flow, V is the fluid flow vector, and B is the magnetic field vector. The term E_S refers to any static electric field present in the absence of a fluid flow. Because the vector, E , is determined from a vector cross-product, its magnitude will be greatest whenever the flow vector, V , and the magnetic field vector, B , are orthogonal to each other [1]. Generally, the effect of a magnetic field has been considered to be the Lorentz force. The Lorentz force on an individual ion can be expressed as Equation 2.

$$F = q(E + VB) \quad (2)$$

where F is the Lorentz force vector on an ion, q is the electric charge. The influence of Lorentz force can be treated as the Hall effect. The Hall voltage, V_H , can be expressed as

$$V_H = (R_H/d) (IB) \quad (3)$$

where R_H is the Hall constant, I is the current, d is the thickness of metal. The Hall effect was considered to be negligible in the case of 3% NaCl solutions.

In the present work, the rest potentials of iron wire were measured in 3% NaCl solution with and without a magnetic field, and the effect of the magnetic field was examined.

2. Experimental procedure

The commercial iron wire (purity 99%, 1 mm diameter) was cut to 5 cm lengths for the experiments. The surface of the wire was polished with emery cloth down to 2000, immersed for 1 min in 1 mol dm⁻³ HCl solution, and attached to the centre of a glass tube (5 mm) as shown in Fig. 1. 150 ml test solution was

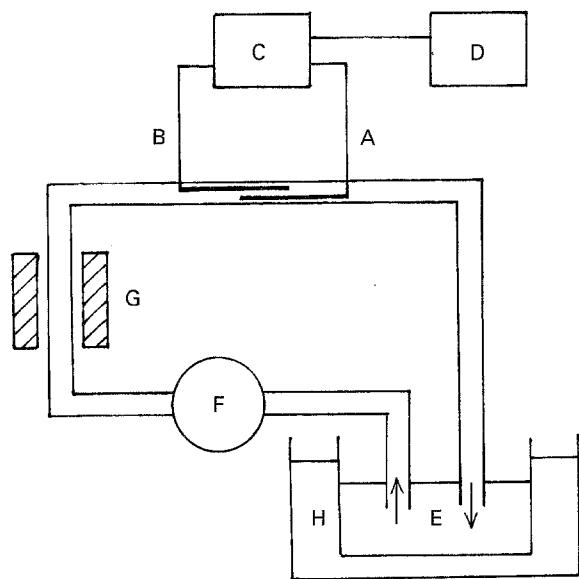


Figure 1 Schematic diagram of the magnetic treatment equipment. A, Iron wire; B, Ag/AgCl electrode; C, potential difference meter; D, recorder; E, 3% NaCl solution; F, pump; G, magnet; H, constant-temperature water bath.

flowed at a constant rate by a variable speed pump, and maintained at 298 K, and the rest potentials were measured. After a given period of time, the iron wire was removed from the solution. Fe^{2+} and Fe^{3+} ion concentrations in the test solution were measured using absorption spectrometry. 5 ml test solution was sampled and mixed with 5 ml $0.2 \text{ mol dm}^{-3} \text{ CH}_3\text{COOH}$ – $0.2 \text{ mol dm}^{-3} \text{ CH}_3\text{COONa}$ to adjust the pH level to 6, and further mixed with 5 ml 1% hydrochloric hydroxylamine, mixed with 5 ml 0.25% *o*-phenanthroline, and distilled water to make the final solution volume of 25 ml. This final solution was left undisturbed for 30 min at 298 K. The Fe^{2+} ion concentration was then measured. The Fe^{3+} concentration in the solution was determined as the difference between the total iron ion concentration, determined by adding a hydrochloric hydroxylamine, while the Fe^{2+} ion concentration was determined without the addition of hydrochloric hydroxylamine.

The magnetic treatment device was made with a samarium–cobalt magnet by covering with stainless steel. The distance between the magnetic poles was 6 mm.

The magnetic treatment device was posited as shown in Fig. 1. The direction of fluid flow was orthogonal to the magnetic line of force. The magnetic flux density was measured with a Gauss meter (model 3254, Yokogawa Electric) at the position of the iron wire.

3. Results and discussion

3.1. Voltage and current measurements [1]

It was considered that voltage and current were generated within the device according to Equation 1, and affected the corrosion. Two platinum wire electrodes (1 mm diameter \times 5 cm) were used instead of iron wire and a Ag/AgCl electrode in the magnetic field.

The potential differences were measured using a high-impedance digital multimeter. Potential differences were not observed at 40, 110 and 220 ml min^{-1} in 0.6 T magnetic flux density. The current was measured by placing a known resistor (10Ω) between the electrodes. The voltage drop across the resistor was measured using a high-impedance digital multimeter and the current was calculated from Ohm's law. No current differences were observed at 40, 110 and 220 ml min^{-1} in 0.6 T magnetic flux density, nor were differences in conductivity observed. It was concluded that no property changes of the test solution were obtained.

The rest potential of the iron wire in 3% NaCl solution was measured for 5 days in the absence of a fluid flow and magnetic field. The rest potential shifted in the noble direction and reached -610 mV versus Ag/AgCl after 24 h. After the rest potential reached -580 mV versus Ag/AgCl, it was shifted in the based direction, and finally reached about -680 mV versus Ag/AgCl after 5 days. This potential (-680 mV versus Ag/AgCl) was estimated to be the equilibrium potential in 3% NaCl solution.

3.2. Magnetically treated 3% NaCl solution

Fig. 2 shows the influence of flow rate on the rest potentials of iron wire when 3% NaCl solution was flowed at 40, 110 and 220 ml min^{-1} through a magnetic field of 0.6 T. The rest potentials shifted in the noble direction with time, and reached -550 mV versus Ag/AgCl. The required times to reach -550 mV were shorter as the flow rate decreased, in the order $40 < 110 < 220 < 0 \text{ ml min}^{-1}$. It was concluded that dissolution of iron wire was accelerated in this period. Thereafter, the rest potentials shifted slowly to the base direction and reached -680 mV versus Ag/AgCl.

The first corrosion product on the surface was pale blue in colour after the start of measurements, and was speculated to be $\text{Fe}(\text{OH})_2$. This product, $\text{Fe}(\text{OH})_2$, was converted to a mixture of α - FeOOH , γ - FeOOH and Fe_3O_4 with time. The proportion of γ - FeOOH tended

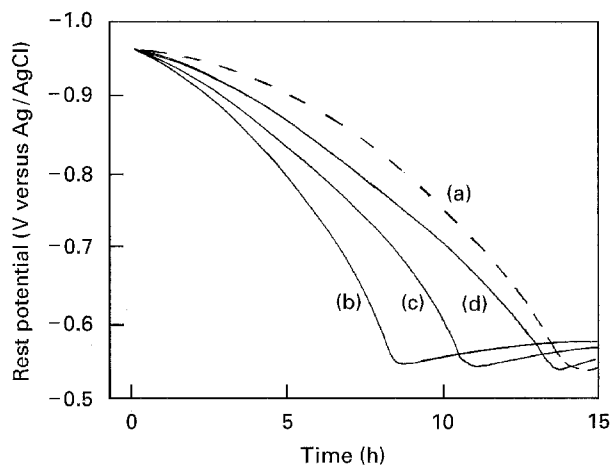


Figure 2 Influence of flow rate on the rest potential. Flow rate: (a) steady state, (b) 40 ml min^{-1} , (c) 110 ml min^{-1} , (d) 220 ml min^{-1} magnetic flux density 0.6 T.

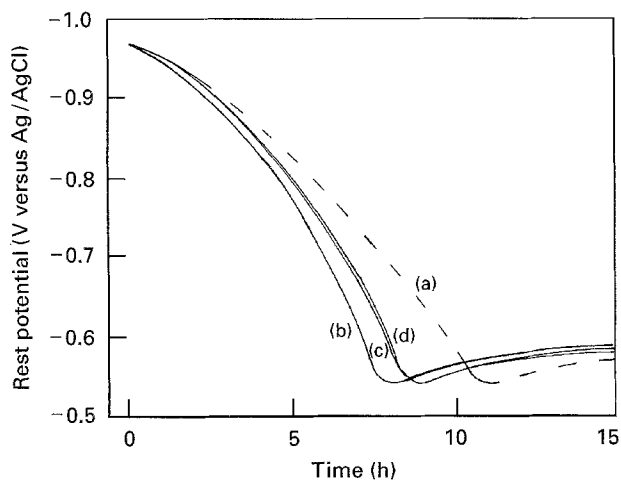


Figure 3 Influence of magnetic flux density on the rest potential. Magnetic flux density: (a) 0 T, (b) 0.2 T, (c) 0.4 T, (d) 0.6 T; flow rate 40 ml min^{-1} .

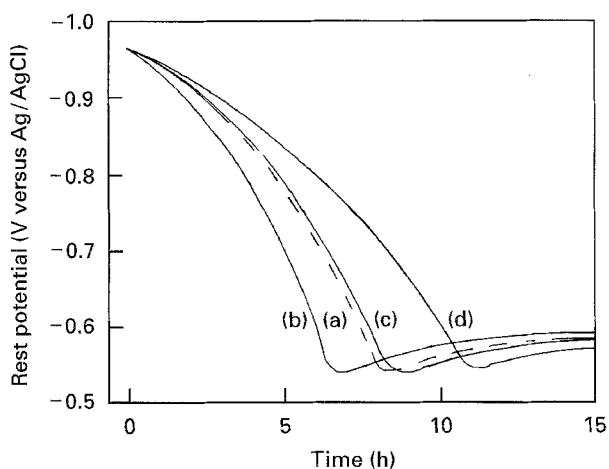


Figure 4 Influence of magnetic flux density on the rest potential. Magnetic flux density: (a) 0 T, (b) 0.2 T, (c) 0.4 T, (d) 0.6 T; flow rate 110 ml min^{-1} .

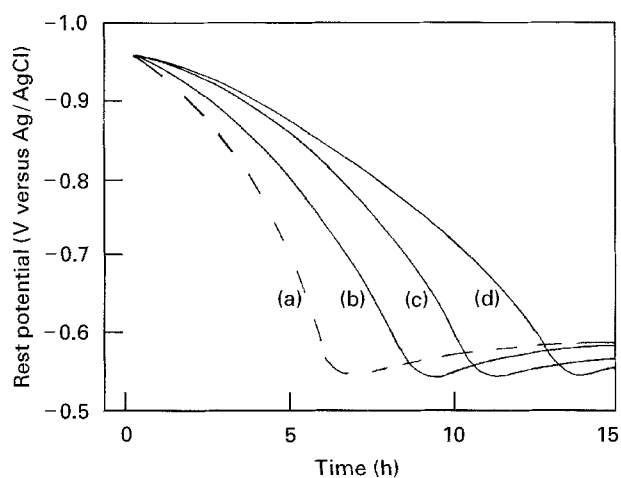


Figure 5 Influence of magnetic flux density on the rest potential. Magnetic flux density: (a) 0 T, (b) 0.2 T, (c) 0.4 T, (d) 0.6 T; flow rate 220 ml min^{-1} .

to decrease, while the ratio of $\alpha\text{-FeOOH}$ and Fe_3O_4 increased before the rest potential reached -550 mV versus Ag/AgCl . After the rest potential reached -550 mV versus Ag/AgCl , Fe_3O_4 changed to $\gamma\text{-Fe}_2\text{O}_3$. Electrochemical and chemical reactions occur-

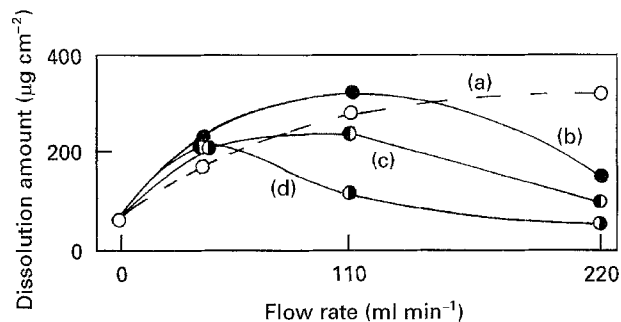


Figure 6 Influence of flow rate on the dissolution amount of iron wire after immersion for 24 h. Magnetic flux density: (a) 0 T, (b) 0.2 T, (c) 0.4 T, (d) 0.6 T.

red during the formation of rusts, and the surface of the iron wire became covered with a passive film.

Figs 3–5 shows the influence of the magnetic flux density on the rest potential. At a flow rate of 40 ml min^{-1} , the required time to reach -550 mV versus Ag/AgCl was shorter in comparison with that without a magnetic field. The required times were in order of magnetic flux density of $0.2 < 0.4 = 0.6 < 0 \text{ T}$. At a flow rate of 110 ml min^{-1} , the required time to reach -550 mV versus Ag/AgCl was shorter with 0.2 T and longer with 0.4 and 0.6 T ($0.4 < 0.6 \text{ T}$). At a flow rate of 220 ml min^{-1} , the required time to reach -550 mV versus Ag/AgCl was longer with increasing magnetic flux density. It was concluded that the most efficient magnetic field effects were influenced by the relation between magnetic flux density and fluid rate.

Fig. 6 shows the influence of flow rate and magnetic flux density on the dissolution amounts of the iron wire after 24 h. Fe^{2+} ions were not detected in the test solutions in all tests. The dissolved amounts increased with increasing flow rate without a magnetic field. When 0.2 T magnetic flux density was applied, the amounts dissolved increased at flow rates of 40 and 110 ml min^{-1} , and decreased at a flow rate of 220 ml min^{-1} . On application of 0.4 T magnetic flux density, the amounts dissolved increased at a flow rate of 40 ml min^{-1} , and decreased at flow rates of 110 and 220 ml min^{-1} , however, for 0.6 T, the amounts increased at a flow rate of 40 ml min^{-1} , and decreased at 110 and 220 ml min^{-1} . At 220 ml min^{-1} , the amounts dissolved were reduced compared with that without a magnetic field, and in the order $0.2 > 0.4 > 0.6 \text{ T}$. The data correspond to the rest potentials in Figs 3–5. It was concluded that magnetic field effects become larger as the liquid flow rate increases.

3.3. Iron wire in the magnetic field

Fig. 7 shows the influence of magnetic flux density on the rest potentials at 110 ml min^{-1} flow rate for an iron wire subjected to a magnetic field. The required time to reach -550 mV was shorter, in order of $0.4 < 0.6 < 0.2 < 0 \text{ T}$. The magnetic field had an effect on both the 3% NaCl solution and the iron wire, as seen from data in Figs 4 and 7.

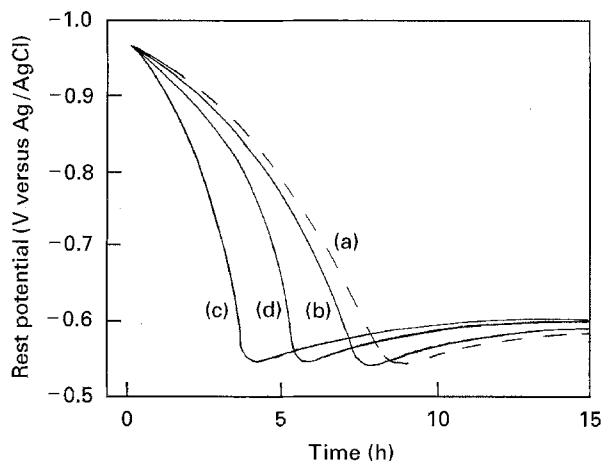


Figure 7 Influence of magnetic flux density on the rest potential when a magnetic field was applied to iron wire. Magnetic field: (a) 0 T, (b) 0.2 T, (c) 0.4 T, (d) 0.6 T; flow rate 110 ml min^{-1} .

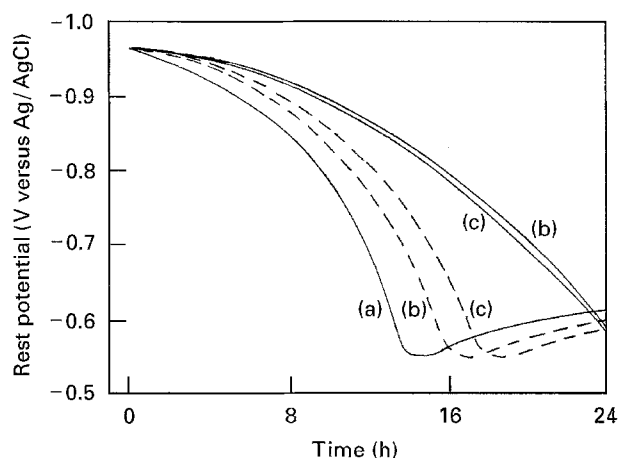


Figure 8 Influence of magnetic treatment on the rest potential. (a) No-magnetic treatment, (b) 3% NaCl solution with magnetic treatment for 24 h, (c) 3% NaCl dissolved in magnetically treated (24 h) water (3% NaCl solution). (---) Immediately after magnetic treatment, (—) 12 days after magnetic treatment.

3.4. Memorization of magnetic field effects
Sample solutions were left at room temperature after magnetic treatment. The effects of magnetically treated 3% NaCl solution and untreated 3% NaCl solution which was prepared with magnetically treated water ($0.5 \mu\text{S cm}^{-1}$), were determined. Magnetical treatment was applied for 24 h at a flow rate of 110 ml min^{-1} . Fig. 8 shows the rest potentials in the steady state. The times required to reach -550 mV versus Ag/AgCl were longer compared with those of non-magnetic treatment: the required time in magnetically treated 3% NaCl solution was longer compared with that of the 3% solution which was prepared with magnetically treated water. However, the time required was shorter compared with that of 3% NaCl solution which was prepared with magnetically treated water after 12 days. After 3 weeks, the rest potentials were at the same level as that in non-magnetically treated solutions.

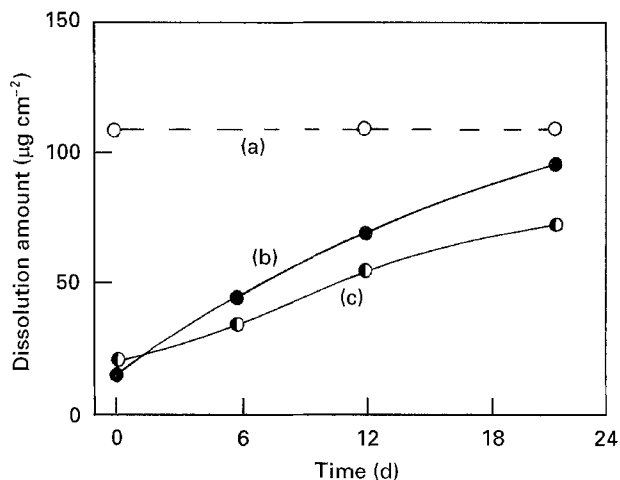


Figure 9 Influence of the time left to stand on the dissolved amounts of iron wire after immersion for 24 h. (a) 0 T, (b) 3% NaCl solution with magnetic treatment for 24 h, (c) 3% NaCl dissolved in magnetically treated (24 h) water.

Fig. 9 shows the dissolved amounts of iron wire immersed in 17 ml sample solution at a steady-state for a day. The amount of iron wire dissolved in magnetically treated solutions was reduced compared with that in non-magnetically treated solution. In magnetically treated solutions, the dissolved amounts increased with increasing immersion time. Dissolution amounts in magnetically treated 3% NaCl solution were larger compared with 3% NaCl solution prepared with magnetically treated water. The magnetic effects of both solutions disappeared after 3 weeks.

4. Conclusion

Magnetic effects were found on both iron wire and the solution. The magnetic treatment of 3% NaCl solution accelerated or inhibited the dissolution of the iron wire. The formation of Fe_3O_4 was found to be accelerated. The magnetic effects disappeared after about 3 weeks. The most efficient condition was related to the magnetic flux density and flow rate of solution. This work suggests a possible connection between the magnetic treatment of water and inhibition of corrosion.

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