

Anti-fouling by Controlling Electric Charges on the Metal Pipe

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Abstract. The electrical characteristics of metal pipe and CaCO_3 particles in aqueous solution were investigated and a new method for anti-fouling by connecting the metal pipe with the ground was developed. The results showed that the detected electric current between the metal pipe and the ground decreased with the large-scale CaCO_3 particles adhered on the inner surface of the metal pipe. The thickness of CaCO_3 scale reduced about 44% by connecting the metal pipe with the ground.

1. Introduction

Metal pipe is often used for the transportation of aqueous solution such as in the running water and heat exchanger system [1-3]. In the using process, the metal pipe is often fouled by the adhesion of ions contained in the aqueous solution. The fouling will increase the pressure drop inside the metal pipe and then weaken its application performance [4, 5].

Many ways with physical and chemical methods have been carried out for solving the fouling problem, such as adding dispersing or chelating agents, reverse osmosis method, anti-scale magnetic treatment (AMT) and electric anti-fouling (EAF) technology [6, 7]. In the fouling, calcium carbonate (CaCO_3) is the main constituent of scale, and its nucleation, growth and precipitation have been previously studied through laboratory experiment [8, 9]. However, little attention has been devoted to the electrical characteristics of the CaCO_3 particles in the aqueous solution and the metal pipe, and this may be an important factor for investigating the behaviour of the fouling formation due to the electrostatic force between them [10, 11].

About the electrical characteristics of solid particles in aqueous solution [12], there is a widespread theory of electric double layer, and it shows that an electric double layer exist in the interface of solid-liquid phase, and the layer on the liquid side consists of compact layer and diffusion layer, respectively [13]. In study, the electric double layers both generate in the surfaces of the CaCO_3 particles and the metal pipe when they contact with the aqueous solution. Along with the flow of the aqueous solution in the metal pipe, charges in the diffusion layer will be took away from the electric double layer [14], and this will make the CaCO_3 particles and the metal pipe both charged. If the charges on the CaCO_3 particles and metal pipe are opposite, they will attract each other. However, if the redundant charges on the metal pipe are induced away, the electrostatic attraction between the metal pipe and CaCO_3 particles will reduce and then the fouling behaviour will be effectively controlled.

Therefore, we designed a new method to reduce the fouling by controlling the electric charges on the metal pipe. The mechanism of fouling on the metal pipe was also discussed.



2. Experimental

The experimental system used in here is shown in Figure 1 (a), which comprised of the water tank, circulation pump, inlet valve, flow meter, the test metal pipe, outlet valve, and measuring instrument. The metal pipe was connected to the ground in two ways: the first one was always keeping the connection state in the whole experiment process and the other one was connected only in the measurement process of electric current in a very short time.

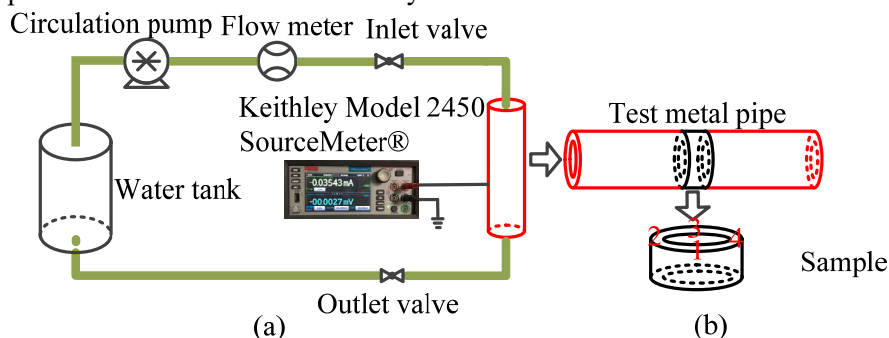


Figure 1. Schematic diagram of the experimental setup (a) and the position used for the SEM (b).

City water (20 liters, ion content shown in Table 1) were added into the water tank first, and then it was circulated by starting the pump, and the flow rate was controlled at 5 L/min by the inlet valve. In order to provide a more favorable condition for fouling on the test metal pipe, 5.50 g of CaCl_2 and 5.30 g of Na_2CO_3 were added into the city water inside the tank to form aqueous solution, and a large number of CaCO_3 particles were precipitated in the saturated aqueous solution because of the reaction between the added CaCl_2 and Na_2CO_3 . After the aqueous solution containing the CaCO_3 particles was run in the experimental system for a certain period, the electric current formed between the metal pipe and the ground was measured. The case of keeping the connection state in the whole experiment process was marked as GND, and for the connection in only current measurement process, it was marked as BLANK.

After running for 10 days, the experimental system was stopped, and then the metal pipe was taken off. A part of the metal pipe was cut along the radial direction as the sample, and the isometric four points around the sample were randomly chosen (shown in Figure 1 (b)) for scanning electron microscope (SEM) observation.

Table 1. Ions content of the city water (mg/L).

	K^+	Ca^{2+}	Na^+	Mg^{2+}	Al^{3+}	Fe^{3+}	Mn^{2+}	Cl^-
Content	24.98	63.20	30.96	15.70	<0.01	0.01	<0.01	56.30

3. Results and Discussion

The changes of current in Figure 2 indicated that the metal pipe was truly charged in the circulation process, and the redundant charges on the inner surface of the metal pipe would be induced away by connecting the metal pipe to the ground. It was noted that the electric current in both cases decreased with the increase of the running time from the first day to the tenth day, however, the current values were very different between them. In the BLANK case, the current value changed rapidly, and decreased from the value of $38.07 \mu\text{A}$ in the first day to the value of $19.53 \mu\text{A}$ in the tenth day (decreased about 48.7 %); for the GND case, however, the current decreased from $38.10 \mu\text{A}$ in the first day to $29.46 \mu\text{A}$ in the tenth day, which only changed approximately 22 %.

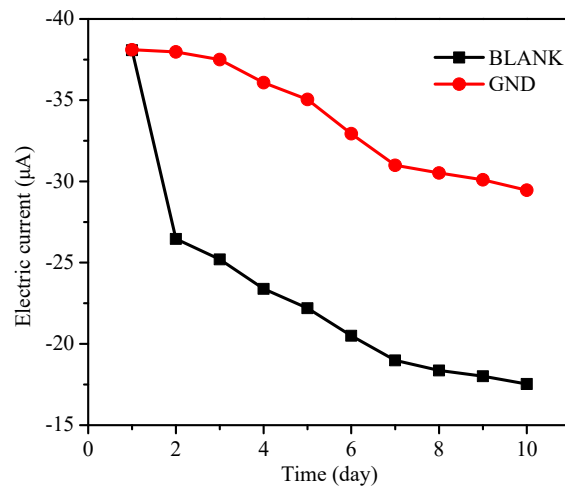


Figure 2. Change in the electric current with the running time.

Figure 3 shows the SEM micrographs of the cross-sectional microstructure of the metal pipe (a) Blank and (b) GND. The thicknesses of the fouling obtained by the measurement using the SEM micrographs were shown in Table 2. The average value of the thickness of the fouling was 55.3 μm in the GND case, it decreased about 44 % if compared to that of the Blank case (99.4 μm).

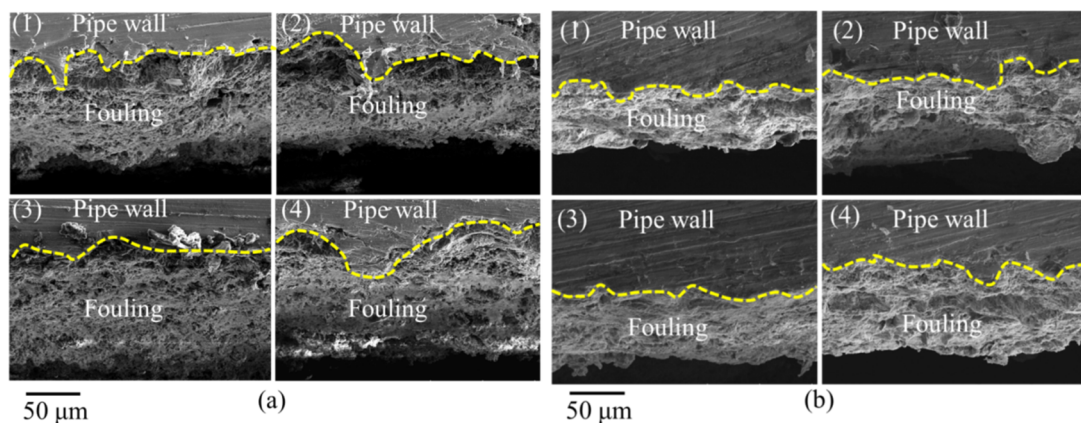
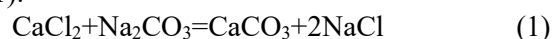


Figure 3. SEM micrographs of the cross-sectional microstructure of the metal pipe (a) BLANK and (b) GND.

Table 2. Thickness of the fouling on the inner surface of metal pipe

	Thickness of fouling/μm				Average value/μm
	1	2	3	4	
BLANK	101.4	80.2	113.4	102.6	99.4
GND	50.6	41.2	54.8	74.6	55.3

When the CaCl_2 and Na_2CO_3 were added into the city water, the reaction between them would occur immediately and the CaCO_3 particles would precipitate in the aqueous solution according to the reaction as shown in Equation (1).



The generated CaCO_3 particles were suspended in the aqueous solution and flowed with the aqueous solution. The corresponding Reynolds number (Re) of the flowing aqueous solution would be calculated by the Equation (2).

$$Re=(vd)/\mu \quad (2)$$

Where v and μ are the velocity and the kinematic viscosity coefficient of the aqueous solution, respectively; d is the inner diameter of the metal pipe. In this study, v , μ and d are 0.16 m/s, $1.01 \times 10^{-6} \text{ m}^2 \cdot \text{s}$ and $2.6 \times 10^{-2} \text{ m}$, respectively. The Reynolds number calculated by using the above parameter was about 4040 and it indicated that the flow state in this experimental condition was turbulent.

The collision and separation occurred continually between the CaCO_3 particles and the inner surface of the metal pipe in turbulent flow. Once the electrostatic attraction between the CaCO_3 particles and the metal pipe was greater than the shear force formed by the friction of the aqueous solution with the metal pipe, the CaCO_3 particles would adhere on the metal pipe. With the precipitation of the CaCO_3 particles on the metal pipe, the detected electric current between the metal pipe and the ground would reduce due to the insulativity of CaCO_3 scale (Figure 2). By contrasting with the thicknesses of the fouling formed in the cases of BLANK and GND (Figure 3), it was obvious that the thicker the insulative CaCO_3 scale was, the less the charge was conducted to the ground.

According to the well-known model of the electric double layer [15, 16], the surfaces of CaCO_3 particles and the metal pipe both generate electric double layers when they contacted with the aqueous solution. On the basis of the metal/liquid interface corrosion reaction model [17, 18], the electric charges attached to the inner surface of the metal pipe were negative. The polarity of electric charges attached to the surface of CaCO_3 particles, however, was dependent on some factors. According to other researchers results [19, 20], the isoelectric point (IEP) of CaCO_3 could be changed in a wide range of pH value from 8 to 11. In the most case of city water and including the case in this study, the pH of water/aqueous solution was basically about 7, which implied that the surface charges of CaCO_3 particles were positive. At the same time, we respectively used the electrophoretic deposition method and streaming current method to identify the polarity of CaCO_3 particles and metal pipe when connect with water solution again. The results consisted with the above researchers, i.e. the CaCO_3 particles and metal pipe carried positive and negative charges, respectively.

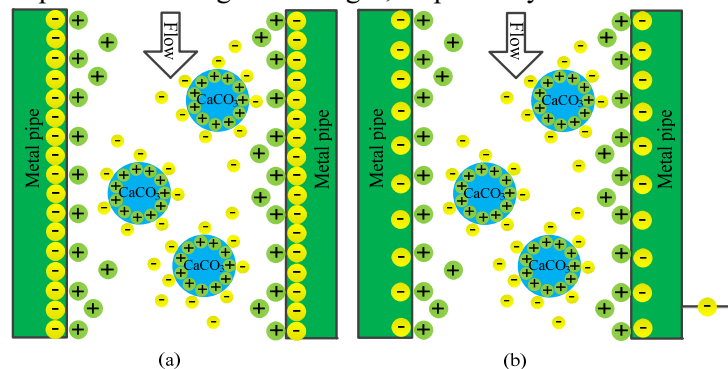


Figure 4. Electrical characteristic of the metal pipe and the CaCO_3 particles (a) without and (b) with the ground.

When the CaCO_3 -containing aqueous solution circulated in the metal pipe, a part of charges in the diffusion layers were taken away by the flow, which made the redundant charges aggregate at the surfaces of the metal pipe and CaCO_3 particles. In other words, the metal pipe and CaCO_3 particles were negatively and positively charged, respectively. Therefore, they would attract each other due to the electrostatic force. Based on the analysis above, the electrical characteristics of the metal pipe and CaCO_3 particles were shown in Figure 4 (a).

When the outer surface of the metal pipe connected to the ground (Figure 4 (b)), the redundant electric charges on the inner surface of the metal pipe induced away [21], and the electrostatic attraction between CaCO_3 particles and metal pipe decreased. In this situation, the fouling attached to the inner surface of the pipe reduced (Figure 3), it indicated that the electrical characteristic of the metal pipe has considerable effect on the anti-fouling.

4. Conclusions

The electrical characteristics of CaCO_3 particles and the metal pipe were investigated with a new method proposed for anti-fouling by connecting the pipe with the ground. From the results of the present study, the following conclusions can be drawn:

1. The metal pipe was charged by the separation of electric double layer due to the relative motion with aqueous solution, and the redundant charges on metal pipe would be induced away by connecting the metal pipe with the ground.
2. The adhered fouling on metal pipe would hinder the transfer of charges due to the insulativity of CaCO_3 particles.
3. The CaCO_3 fouling behaviour on the metal pipe was suppressed by inducing the redundant charges of the metal pipe away, which was attributed to the electrostatic attraction between the CaCO_3 particles and the inner surface of the metal pipe was reduced.

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