ASSESSMENT ON COMPATIBILITY BETWEEN COOLANT AND TYPICAL MATERIALS IN ENERGY TOWER

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Coolants are used in the energy tower cooling system for heat transfer. Due to the corrosive nature of the coolants, they would corrode with the metal in the cooling system. This will reduce the service life of the energy tower. In order to ensure the long-life operation of the equipment in the energy tower, the corrosion compatibility between the materials in the circulation system of energy tower and the coolants should be confirmed. H65 copper alloy, 3003 aluminum alloy and AISI 1020 steel are commonly used in energy tower cooling circuits. In this paper, the corrosion behavior of these three materials in six typical commercial coolants was studied. The experimental results indicated that the alliances between H65 and YH6830, 3003 and BL3500, AISI 1020 steel and HG3500 or YH6830 were optimal to control the corrosion.

Keywords: Energy tower, Coolant, Corrosion, Typical Materials

1. Introduction

Total energy consumption of buildings in China has increased rapidly in recent years, accounting for about 30% of total energy consumption, energy consumption of air conditioning is a major proportion. Developing new technology for energy utilization to reduce building energy consumption is attracted extensive attention [1,2]. Energy tower application has been widely developed in south China in recent years. In energy tower, coolant with freezing point below 0°C is applied to take heat from the air. The advantage of energy tower mainly lies in its simple structure, less restriction of regional environment and environmental protection. Obviously, energy tower has a good application prospect [3,4,5,6].

In the loop system of energy tower coolant should be used. Coolant is a intermediate medium used to transfer the cooling capacity in the indirect cooling system [7]. After the coolant is cooled by the refrigerant in the evaporator, it is sent into the cooling equipment to absorb the heat of cooled object, and then returned to the evaporator to be cooled again. Repeated in this way, the heat of the

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cooled object is transmitted to the evaporating refrigerant to achieve the purpose of refrigeration [8]. In the energy tower, coolant can be collected, transported, dissipated, and continuously cooled. Strong heat transfer ability, small pipeline pressure loss and the requirement of low power driving pump are the basic properties of coolant [9,10,11]. At present, the commonly used coolant is divided into liquid, gas, solid, or liquid-solid mixture according to the state of matter. Compared with refrigerants such as freon and ammonia, the coolant is generally more environmentally friendly [12, 13].

Due to corrosion of coolant to the energy tower circuit system, the service life of energy tower circuit system may be greatly reduced [14]. Meanwhile perforation leakage or corrosion product deposition induced by corrosion could also decrease the cooling efficiency. Therefore, during energy tower construction, the compatibility of selected material of loop system and selected coolant should be considered. Unfortunately, up to now, the inadequate corrosion data of typical loop system material in commercial coolant could not provide enough support [15, 16].

In this paper, the corrosion behaviors of three kinds of typical loop system materials, H65 copper alloy, 3003 aluminum alloy and AISI 1020 steel in six commercial coolants were investigated through electrochemical measurements and corrosion tests. This research could effectively assess the compatibility between the selected materials and coolants and provide reasonable instruction during selection of loop system material and coolant in energy tower construction.

2. Preparations of experiments

2.1 Experimental materials and devices

Six commonly used commercial coolants provided by Sinopec were selected for experimental research; the coolants were numbered by BF2354 (white powder,), HG3500 (yellow block), BK3000 (white block), BL3500 (liquid), YH6830 (liquid), ZP3682 (liquid) respectively. The selected experimental materials were H65 copper alloy, 3003 aluminum alloy and AISI 1020 steel (Fig.1). Since the energy tower is mainly used in southern China, the minimum temperature in the region is above -15°C in these areas. In high temperature weather, the temperature in the cooling circuit will not exceed 15°C. Therefore, the corrosion test temperature was selected at 15°C, 10°C, 0°C, -10°C and -15°C. The experimental equipment mainly includes electronic balance (FA2204B), Ivium stat electrochemical workstation, cryogenic coolant circulating pump, far infrared drying oven, ultrasonic cleaner, platinum electrode (auxiliary electrode), Ag/AgCl electrode (reference electrode).

(a) Cu H65 (b) Al 3003 (c) 1020 steel
Fig.1 Three kinds of materials and sample morphology in the experiment

2.2 Experimental procedure

The coolant solid was prepared into solution with deionized water according to the proportion listed in Table 1.

Table.1

Mass fraction ratio of coolant solution

Coolant/deionized water	BF	HG	BK	BL	YH	ZP
Ratio（g/g)	0.23:1	0.35:1	0.30:1	0.35:1	0.68:1	0.36:1

Before polarization measurements, copper H65, aluminum 3003 and AISI 1020 steel were cut into small plate samples. The size of the samples were controlled at 10mm × 10mm × 2mm. Then the samples were polished with 400Cw to 2000Cw water-proof abrasive paper to bright, the effective working area was $1cm^2$. After polished, the samples were rinsed with deionized water, then deoiled in acetone, degreased by ethanol, and dried with N_2, finally the non-working surface was sealed with epoxy resin. The electrochemical tests were carried out by Ivium stat electrochemical workstation (Ivium Technologies BV, the Netherlands). Three-electrode system was applied during the polarization measurements, a platinum plate electrode served as the auxiliary electrode, a Ag/AgCl electrode served as the reference electrode. The test mediums were the coolant aqueous solution provided in Table 1.

During corrosion immersion tests copper H65, aluminum 3003 and AISI 1020 steel were cut into small plate samples (the size was controlled at 50mm×50mm×2mm). Three parallel samples were used in each corrosion test. The samples were successively polished to bright with 400Cw to 2000cw water-proof abrasive paper, then rinsed by deionized water, deoiled in acetone by ultrasonic cleaning, degreased by ethanol, and dried with N_2 to constant weight (recorded weight). The treated samples were immersed in aqueous coolant solution at different temperatures (15°C, 10°C, 0°C, -10°C, -15°C) for 30 days, the surface changes of samples were observed regularly during the experiments. At the end of the experiment, the samples were taken out, the corrosion products on the surface of the sample were removed in acetone by ultrasonic cleaning, and the weight loss was recorded. The weight loss (or weight gain) corrosion rate of the samples was calculated by Eq.1.

$$V = \frac{W_1 - W_2}{At} \tag{1}$$

Here $V[g / m^2 h]$ denotes the corrosion rate, $W_1[\mathrm{g}]$ represents the mass before immersion, $W_2[\mathrm{g}]$ represents the mass after immersion and surface treatment, $A[\mathrm{m}^2]$ represents the exposed area of the specimen, and $t[h]$ indicates the immersion time.

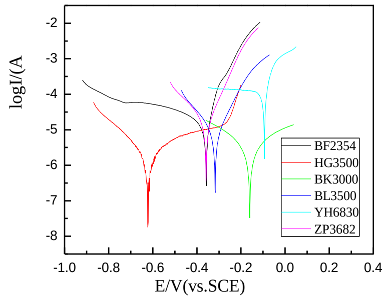
3. Results and discussion

3.1 Electrochemical testing of three metals in aqueous coolant solution at different temperatures

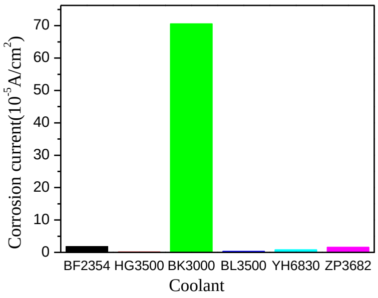
3.1.1 Polarization curve and corrosion current in coolant aqueous solution at 15°C

Fig.2 showed the measurement results of polarization curves and corrosion current analysis fitting results of three kinds of metals in aqueous solutions of six kinds of coolants at 15°C. The polarization curves in Fig.2 showed that the three metals exhibit active dissolution of the metal after the initial anodic polarization. Corrosion process controlled by electrochemical steps and the polarization current continued to rise as the potential increases. Due to the displacement reaction of metal ions to hydrogen ions, there were obvious cathode and anode Tafel regions in the polarization curve, and the slope of the Tafel region can indicate the magnitude of the electrode reaction resistance.

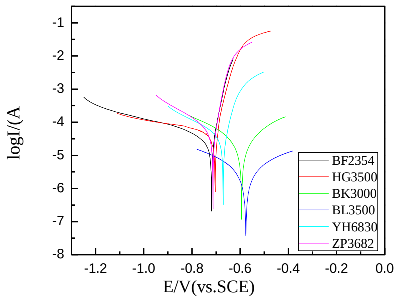
According to the polarization curve, the corrosion currents of the three materials in different aqueous solutions of coolant can be fitted. It can be seen from Fig.2 that copper H65 was the most corrosion-resistant in HG3500 coolant solution and the corrosion current was lower than **Error! Reference source not found.**10^{-6}A/cm^2**Error! Reference source not found.**, the least resistant to corrosion in BK3000 coolant solution, corrosion current was about 70×10^{-5}A/cm^2**Error! Reference source not found.**. Aluminum 3003 was the most corrosion-resistant in BL3500 coolant solution, the corrosion current was about 5×10^{-6}A/cm^2, least resistant to corrosion in ZP3682 coolant solution; maximum corrosion current was about 8×10^{-5}A/cm^2. AISI 1020 steel was the most resistant to corrosion in BL3500 coolant solution, the corrosion current was about 1×10^{-6}A/cm^2. It was the least resistant to corrosion in the BK3000 coolant solution and had a maximum corrosion current of about $2.5\times10^{-5}A/cm^2$.



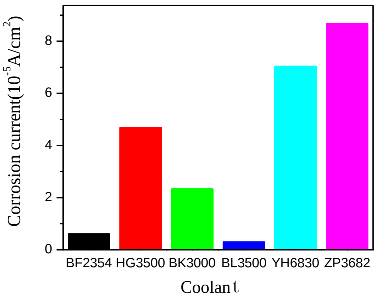
(a) Polarization curves of H65 copper alloy at 15 °C in six coolants



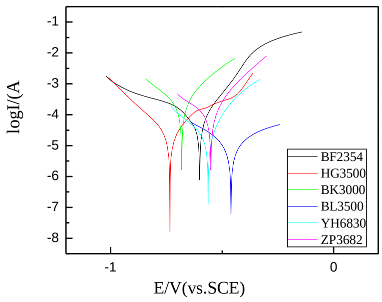
(b) Fitting corrosion current of H65 copper alloy at 15 °C in six coolants



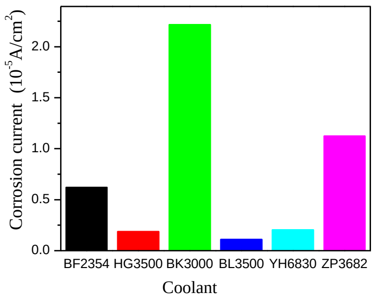
(c) Polarization curves of aluminum 3003 at 15 °C in six coolants



(d) Fitting corrosion current of aluminum 3003 at 15 °C in six coolants



(e) Polarization curves of AISI 1020 steel at 15 °C in six coolants

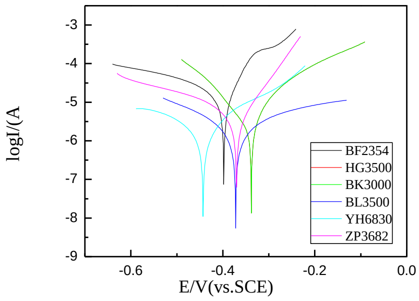


(f) Fitting corrosion current of AISI 1020 steel at 15 °C in six coolants

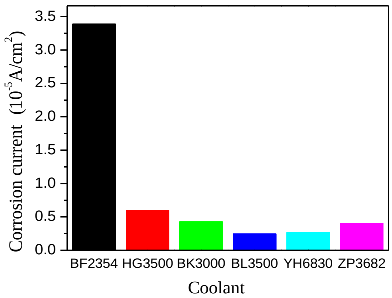
Fig.2 Comparison of polarization curve and corrosion current of three kinds of metals in different coolants at 15 °C

3.1.2 Polarization curve and corrosion current in coolant aqueous solution at 10°C

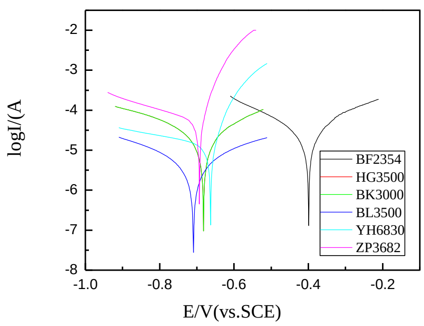
Fig.3 showed the measurement results of polarization curve measurement and corrosion current analysis fitting of three kinds of metal in the water solution of six kinds of coolants at 10°C. According to the polarization curve and the corrosion current fitting results, copper H65 was most resistant to corrosion in BL3500 coolant solution, the corrosion current was 2.5×10^{-6}A/cm^2, it was the least resistant to corrosion in BF2354 coolant solution, and the maximum corrosion current was 3.4×10^{-5}A/cm^2. Aluminum 3003 was the most resistant to corrosion in BL3500 coolant solution, with a corrosion current of 5×10^{-6}A/cm^2, it was the least resistant to corrosion in ZP3682 coolant solution, and the maximum corrosion current was about 11×10^{-5}A/cm^2. AISI 1020 steel was the most resistant to corrosion in BL3500 coolant solution, and the corrosion current was 0.8×10^{-6}A/cm^2. It was the least resistant to corrosion in the BF2354 coolant solution and had a maximum corrosion current of 4.5×10^{-6}A/cm^2.



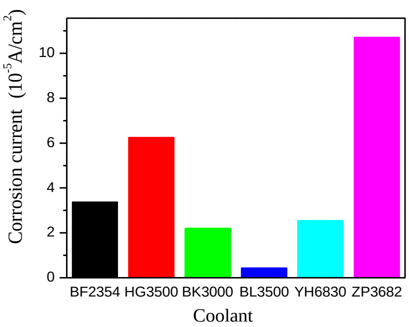
(a) Polarization curves of H65 copper alloy at 10 °C in six coolants



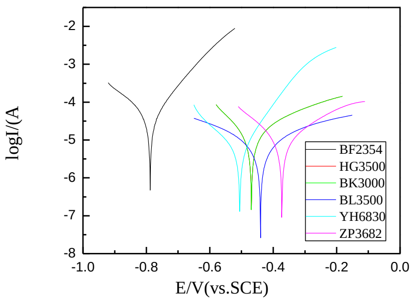
(b) Fitting corrosion current of H65 copper alloy at 10 °C in six coolants



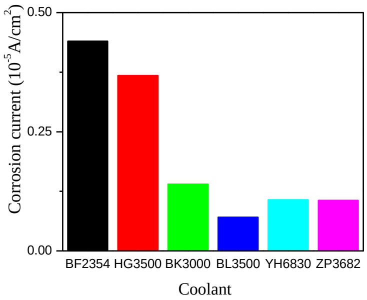
(c) Polarization curves of aluminum 3003 at 10 °C in six coolants



(d) Fitting corrosion current of aluminum 3003 at 10 °C in six coolants



(e) Polarization curves of AISI 1020 steel at 10 °C in six coolants

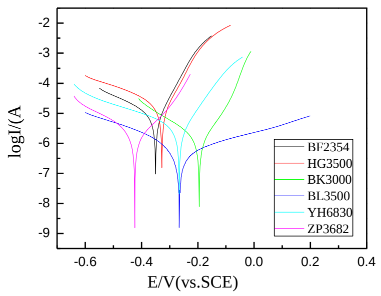


(f) Fitting corrosion current of AISI 1020 steel at 10 °C in six coolants

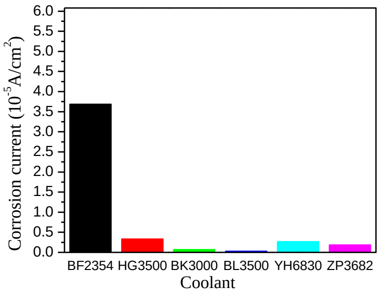
Fig.3 Comparison of polarization curve and corrosion current of three kinds of metals in different coolants at 10 °C

3.1.3 Polarization curve and corrosion current in coolant aqueous solution at 0°C

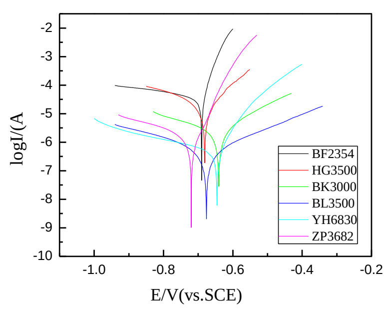
Fig.4 showed the measurement results of polarization curve measurement and corrosion current analysis fitting of three kinds of metal in the water solution of six kinds of coolants at 0°C. According to polarization curve and corrosion current fitting results, copper H65 was the most resistant to corrosion in BL3500 coolant solution, the corrosion current was less than 1×10^{-6}A/cm^2 and it was the least resistant to corrosion in BF2354 coolant solution, the maximum corrosion current was 3.75×10^{-5}A/cm^2. Aluminum 3003 was the most resistant to corrosion in BL3500 coolant solution, the corrosion current was less than 10^{-6}A/cm^2 and it was the least resistant to corrosion in BF2354 coolant solution, the maximum corrosion current was 8×10^{-5}A/cm^2.



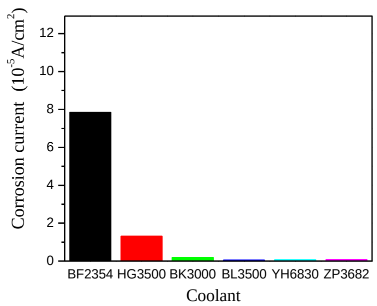
(a) Polarization curves of H65 copper alloy at 0 °C in six coolants



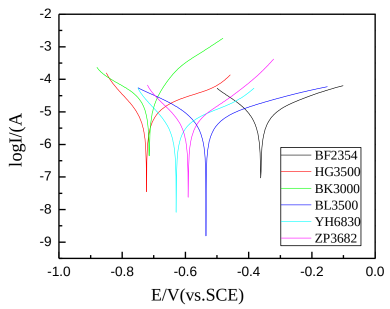
(b) Fitting corrosion current of H65 copper alloy at 0 °C in six coolants



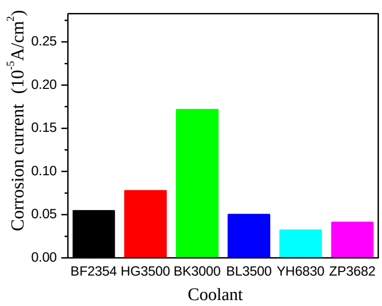
(c) Polarization curves of aluminum 3003 at 0 °C in six coolants



(d) Fitting corrosion current of aluminum 3003 at 0 °C in six coolants



(e) Polarization curves of AISI 1020 steel at 0 °C in six coolants



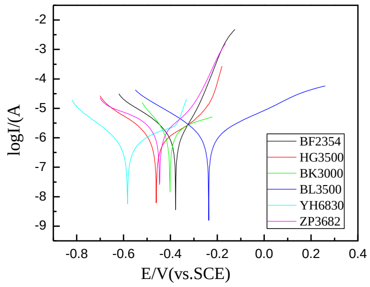
(f) Fitting corrosion current of AISI 1020 steel at 0 °C in six coolants

Fig.4 Comparison of polarization curve and corrosion current of three kinds of metals in different coolants at 0 °C

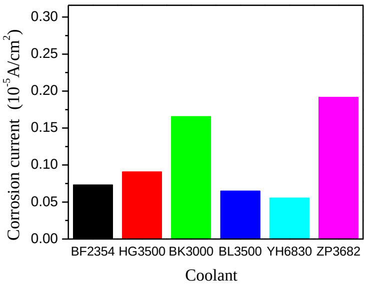
AISI 1020 steel was the most resistant to corrosion in YH6830 coolant solution, the corrosion current was 0.4×10^{-6}A/cm^2 and it was the least resistant to corrosion in BK3000 coolant solution, the maximum corrosion current was 1.75×10^{-6}A/cm^2.

3.1.4 Polarization curve and corrosion current in coolant aqueous solution at-10°C

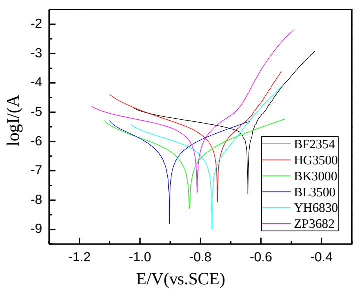
Fig.5 showed the measurement results of polarization curve measurement and corrosion current analysis fitting of three kinds of metals in the water solution of six kinds of coolants at -10°C. According to polarization curve and corrosion current fitting results, copper H65 was the most resistant to corrosion in YH6830 coolant solution, the corrosion current was 0.5×10^{-6}A/cm^2 and it was the least resistant to corrosion in ZP3682 coolant solution, the maximum corrosion current was 2×10^{-6}A/cm^2. Aluminum 3003 was the most resistant to corrosion in YH6830 coolant solution, the corrosion current was $0.02\times10^{-5}A/cm^2$ and it was the least resistant to corrosion in BF2354 coolant solution, the maximum corrosion current was $0.32\times10^{-5}A/cm^2$.



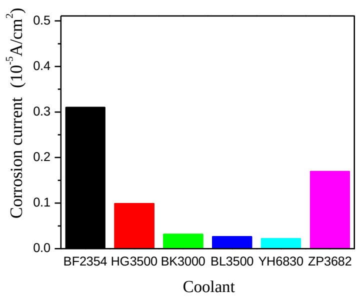
(a) Polarization curves of H65 copper alloy at -10 °C in six coolants



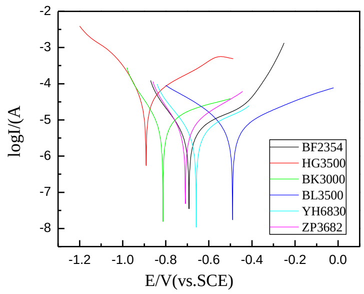
(b) Fitting corrosion current of H65 copper alloy at -10 °C in six coolants



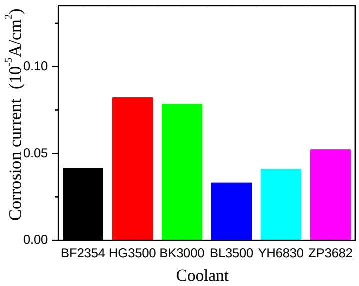
(c) Polarization curves of aluminum 3003 at -10 °C in six coolants



(d) Fitting corrosion current of aluminum 3003 at -10 °C in six coolants



(e) Polarization curves of AISI 1020 steel at -10 °C in six coolants



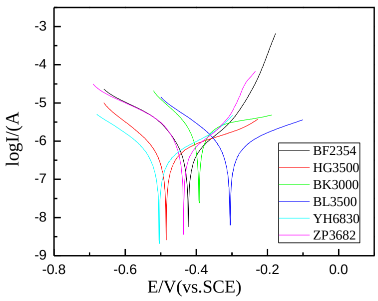
(f) Fitting corrosion current of AISI 1020 steel at -10 °C in six coolants

Fig.5 Comparison of polarization curve and corrosion current of three kinds of metals in different coolants at -10 °C

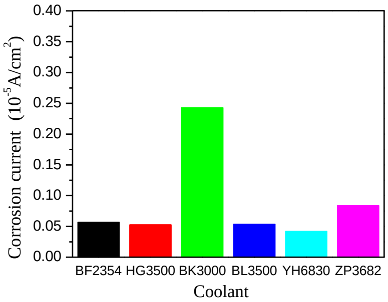
AISI 1020 steel was the most resistant to corrosion in BL3500 coolant solution, the corrosion current was 0.03×10^{-5}A/cm^2 and it was the least resistant to corrosion in HG3500 coolant solution, the maximum corrosion current was 0.08×10^{-5}A/cm^2.

3.1.5 Polarization curve and corrosion current in coolant aqueous solution at -15°C

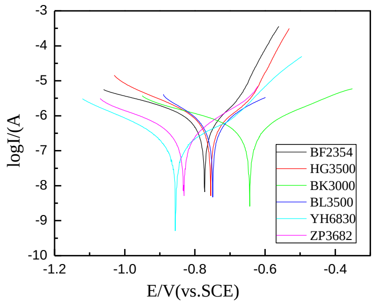
Fig.6 showed the measurement results of polarization curve measurement and corrosion current analysis fitting of three kinds of metals in the water solution of six kinds of coolants at -15°C.



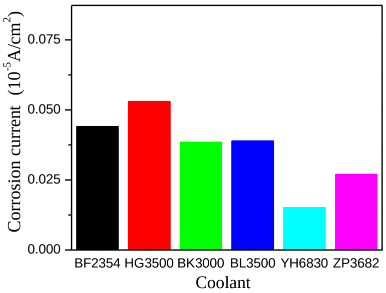
(a) Polarization curves of H65 copper alloy at -15 °C in six coolants



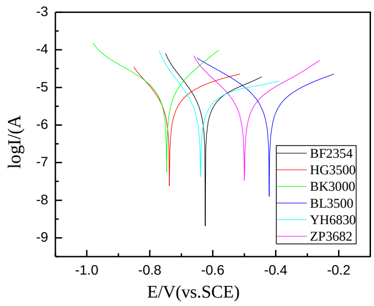
(b) Fitting corrosion current of H65 copper alloy at -15 °C in six coolants



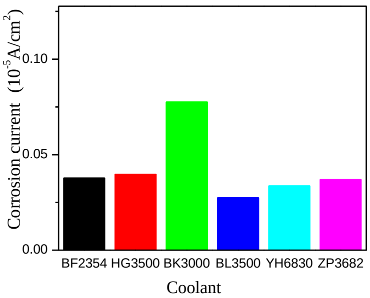
(c) Polarization curves of aluminum 3003 at -15 °C in six coolants



(d) Fitting corrosion current of aluminum 3003 at -15 °C in six coolants



(e) Polarization curves of AISI 1020 steel at -15 °C in six coolants



(f) Fitting corrosion current of AISI 1020 steel at -15 °C in six coolants

Fig.6 Comparison of polarization curve and corrosion current of three kinds of metals in different coolants at -15 °C

According to polarization curve and corrosion current fitting results, copper H65 was the most resistant to corrosion in YH6830 coolant solution, the corrosion current was 0.04×10^{-5} A/cm^2 and it was the least resistant to corrosion in BK3000 coolant solution, the maximum corrosion current was 0.25×10^{-5} A/cm^2. Aluminum 3003 was the most resistant to corrosion in YH6830 coolant solution, the corrosion current was 0.02×10^{-5}A/cm^2 and it was the least resistant to corrosion in HG3500 coolant solution, the maximum corrosion current was 0.053×10^{-5} A/cm^2. AISI 1020 steel was the most resistant to corrosion in BL3500 coolant solution, the corrosion current was 0.03×10^{-5}A/cm^2 and it was the least resistant to corrosion in BK3000 coolant solution, the maximum corrosion current was 0.075×10^{-5} A/cm^2.

According to the results of electrochemical measurements, it can be concluded that H65 copper alloy, 3003 aluminum alloy and AISI 1020 steel had good compatibility with BL3500 and YH6830. The corrosion current of three kinds of materials in these two-coolant solution is low. In order to verify the above results, the corrosion soaking tests of these three materials in six kinds of coolants were carried out.

3.2 Corrosion results and analysis of three kinds of materials immersed in six kinds of coolant aqueous solutions

The samples of three kinds of materials were immersed in six kinds of coolants for 30 days, then removed from the surface corrosion products and weighed after cleaned and dried. The weightlessness and temperature curves of the three kinds of materials in the six kinds of coolants were calculated according to the weight loss, as shown in Fig.7, 8, 9. It can be seen from Fig 7, 8 and 9, the corrosion rates of the three materials in the six coolants were all below 0.1×10^{-3}g/h, only the corrosion rates of the AISI 1020 steel in the ZP3682 coolant were above 2.8×10^{-3} g/h. Therefore, the compatibility between AISI 1020 steel and ZP3682 coolant was poor, and the two should not be matched.

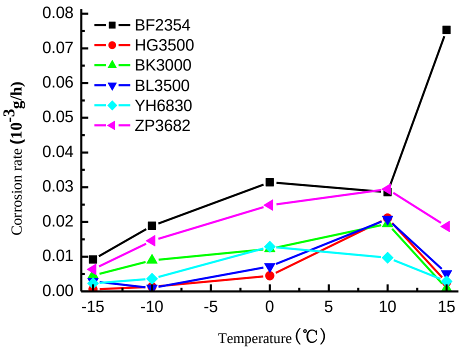


Fig.7 The average corrosion rate-temperature curve of H65 in six coolants

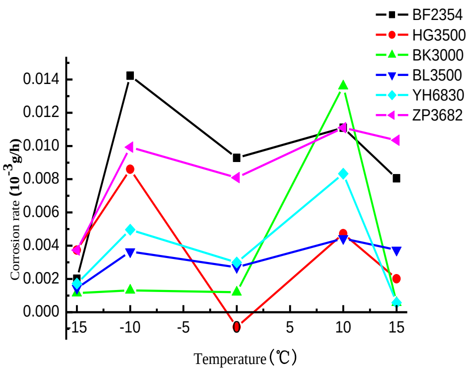


Fig.8 The average corrosion rate-temperature curve of 3003 in six coolants

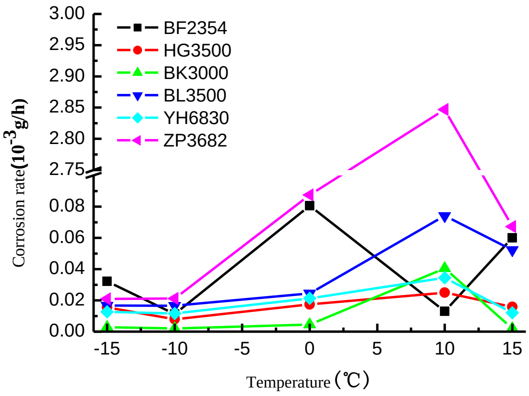


Fig.9 The average corrosion rate-temperature curve of AISI 1020 steel in six coolants.

The corrosion results of H65 copper alloy showed that H65 can maintain a relatively low corrosion rate in HG3500, BK3000, BL3500 and YH6830 coolant, among which the corrosion rate in YH6830 coolant was the most stable.

The corrosion analysis of 3003 aluminum alloy showed that aluminum alloy maintained a low corrosion rate at different temperatures in the six coolants, with the maximum corrosion current smaller than 0.015×10^{-3}g/h. Therefore, aluminum alloy had a good compatibility with the above coolants, in which the corrosion current was relatively stable at different temperatures in BL3500 coolant. The compatibility between 3003 aluminum alloy and BL3500 coolant was the best, which can maintain a low corrosion current when used together.

The corrosion current of AISI 1020 steel in six kinds of coolants was different, especially in ZP3682, where the corrosion rates were extremely high. Only three kinds of coolants, HG3500, BK3000 and YH6830, had good compatibility, among which the corrosion current was the most stable and low in the solution of HG3500 and YH6830.

Based on the above electrochemical test results and corrosion test analysis, the results of the two experiments are in good agreement. At present, there is a lack of research on corrosion between metals and coolants commonly used in energy towers. The experiments in this paper provided reference for the selection of metal materials and coolants used in energy towers.

4. Conclusions

Due to its own inertia, H65 copper alloy can maintain a relatively low corrosion current in the six selected coolant, among which the corrosion compatibility with YH6830 coolant was the best.

Due to the presence of oxide film on the surface of 3003 aluminum alloy, the corrosion current of the six selected coolants can be kept lower than that of copper alloy H65, among which 3003 aluminum alloy and BL3500 coolant were the best.

Due to the serious corrosion problem caused by improper selection of coolants, it was necessary to pay special attention to the corrosion compatibility between the materials and the coolants when selecting AISI 1020 steel as the material for the coolant loop, and HG3500, YH6830 coolants should be used as far as possible in the AISI 1020 steel.

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