Study of the corrosion of stainless steel with fatty acid/paraffin/graphite composite phase change materials

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Abstract. The corrosion performance of phase change materials on stainless steel was studied using single fatty acid, fatty acid/paraffin mixed phase change materials and fatty acid/paraffin/graphite composite phase change materials as corrosion media. The results show that the corrosion of fatty acid, paraffin and graphite composite phase change materials to stainless steel is very small; among them, stearic acid series of phase change materials are the least corrosive and can be used as the ideal energy storage medium for stainless steel phase change heat storage and heat exchange devices.

1. Introduction

China is rich in industrial waste heat resources, but due to its intermittent and unstable characteristics, the recovery and utilization of industrial waste heat is affected. Phase change heat storage technology is the most effective way to solve the contradiction between energy supply and demand in time and space. Using phase change heat storage and exothermic device, continuous heat output and utilization can be realized through the heat storage and exothermic process of phase change material, and the selection of phase change material is the key problem.

In addition to the phase change temperature, latent heat of phase change and thermal conductivity of the phase change material, the corrosiveness of the phase change material to the material used in the device is also an important consideration in the selection of the phase change material used in heat storage and exchanger devices.

Bao Zelong [1] et al. used molten chloride salt as a phase change heat storage medium and tested the corrosion of the material with three Fe-Cr-Ni alloys of 201, 304 and 321, and found that under constant temperature corrosion conditions, the partial pressure of oxygen in the molten salt was low and the corrosion caused by the specimens was mainly due to the occurrence of electrochemical interaction. Chen Hongxia [2] et al. briefly described the corrosion of condensate droplets, the corrosion of bubbles and the formation process and corrosion mechanism of multiphase flow corrosion and other related studies around the gas-liquid phase change heat process, and summarized the relevant prediction models, corrosion influencing factors and corrosion protection issues in the phase change heat process. Li Ao [3] and others studied the effect of phase change cycle parameters on the corrosion resistance of 304 stainless steel superplastic stainless steel, and found that the corrosion resistance increased with the amount of deformation. Cao Hailian [4] et al. addressed the corrosion of metallic materials by molten eutectic NaCl-MgCl₂ as phase change material and found that the Al content can play a protective role at lower levels, while higher levels exacerbate corrosion. Zhao [5] et
al. studied the corrosion behaviour of aluminium 1060 in hydrated salt phase change material (PCM) melts and found that the oxide film formed under neutral conditions has the most dense and corrosion resistant, with the dissolution of the oxide/aluminium accelerating as the ambient pH shifted outwards from 7. Cellat K [6] et al. evaluated the thermal and corrosion behaviour of fatty acid mixtures as phase change materials [PCM] for concrete used in building energy efficiency. ostr M [7] et al. used the weight method to determine the weight change of phase change materials on metal samples based on the calculation of corrosion rates. Browne M C [8] et al. investigated the compatibility of phase change materials (PCM) with various materials in thermal energy storage applications using immersion corrosion methods and made recommendations for using PCM to reduce their corrosion behaviour or mitigate it. vasu A [9] et al. reviewed the compatibility of the most commonly used phase change materials with several major vessel materials and found that stainless steel was the most compatible of these vessel materials, on the other hand, aluminium was found to be corrosive when used with brine mixtures.Pem A [10] et al. tested four commercial phase change materials (PCM) against three commonly used metals (stainless steel, aluminium and copper) to assess the degree of corrosion of each pair.Zhaowen [11] et al. found that stainless steel 304L and carbon steel C20 had good corrosion resistance to LiNO₃/KCL-EG composites with good corrosion resistance, while brass H68 was not suitable as a vessel material for the composite PCM.

In this paper, the corrosion performance of single fatty acid, fatty acid/paraffin mixed phase change materials and fatty acid/paraffin/graphite composite phase change materials on stainless steel is investigated. The corrosion properties of various phase change materials to stainless steel were analyzed through experimental tests and corrosion tests, so as to select suitable phase change materials for stainless steel phase-change heat storage and heat transfer device.

2. Experimental methods

2.1. Preparation of composite phase change materials and experimental specimens

The data on the thermal storage properties of the phase change materials prepared for the corrosion experiments are shown in Table 1. The 304 stainless steel used for the experiments was a rectangular steel sheet of 10cm x 5cm x 0.2cm. Mass ratios were carried out to make a mixed phase change material by mixing fatty acid/paraffin wax at 1:1 and a composite phase change material by mixing fatty acid/paraffin wax/graphite at 2:1:1.

The fatty acids, paraffin and graphite are mixed in a beaker, heated with an alcohol lamp and stirred with a glass rod to melt and mix well. Remove the lamp, cool and solidify to produce a fatty acid/paraffin/graphite phase change mixture for use.

| No. | Phase materials | Phase change temperature/℃ | Latent heat of change/(J·g⁻¹) |
|-----|-----------------|-----------------------------|-----------------------------|
| 1   | Lauric acid     | 42.8                        | 222.3                       |
| 2   | Stearic acid    | 67.4                        | 239.9                       |
| 3   | Myristic acid   | 52.7                        | 217.6                       |
| 4   | Palmitic acid   | 61.0                        | 241.0                       |
| 5   | Decanoic acid   | 30.5                        | 151.1                       |
| 6   | Paraffin wax    | 66.0                        | 180.2                       |

2.2. Experimental procedure

A constant temperature water bath (HH series digital display thermostatic water bath, Jiangsu Kexi Instruments Co., Ltd.) was used to heat the phase change material during the experiment. The steel pieces were placed in each phase change material solution and the corrosion experiments were carried out. During the experiments, the stainless steel pieces were removed from the phase change material every hour using forceps. The surface of the 304 stainless steel was wiped clean of the phase change...
material residue, weighed on an electronic balance and the data recorded.

2.3. Experimental data collation methods
The corrosion rate is calculated to determine the corrosiveness of the phase change material to the stainless steel. The corrosion rate of phase change material to stainless steel was calculated. Corrosion rate can be expressed in terms of the phase change material on the corrosion of stainless steel, can visually show the strength of the phase change material corrosion. Corrosion rate is calculated according to the following formula:

$$K = \frac{M}{TA}$$  \hspace{1cm} (1)

Where: $K$ - corrosion rate, mg/(m²-h).
$M$ - the change in mass of the corroded material, mg.
$T$ - corrosion process time spent, h.
$A$ - Corroded material and phase change material contact area, m².

3. Results and Discussion

3.1. Corrosive properties of single fatty acids on 304 stainless steel
The corrosion performance of five single fatty acids on 304 stainless steel is shown in Table 2 and Figure 1.

| Phase change materials | Time (h) | Steel sheet weight (g) | Corrosion rate (mg/ (m²-h)) |
|------------------------|----------|------------------------|----------------------------|
| Lauric acid            | 9        | ≈0.006                 | 63                         |
| Stearic acid           | 9        | <0.001                 | 10                         |
| Palmitic acid          | 9        | ≈0.002                 | 21                         |
| Nutmeg acid            | 9        | ≈0.001                 | 10                         |
| Decanoic acid          | 9        | ≈0.002                 | 21                         |

Fig.1 Corrosion curve of fatty acid on 304 stainless steel
As can be seen from the graph: several fatty acids corrode 304 stainless steel at a very slow rate of mass loss of the steel sheet, and the fatty acids have very little corrosive effect on 304 stainless steel. In contrast, lauric acid is the most corrosive to stainless steel and stearic acid the least.

### 3.2. Corrosion of 304 stainless steel by mixed fatty acid/paraffin phase change materials

The corrosive properties of the fatty acid/paraffin mixture on 304 stainless steel are shown in Table 3 and Figure 2.

| Phase change materials | Time (h) | Steel sheet weight change (g) | Corrosion rate (mg/(m²·h)) |
|------------------------|----------|------------------------------|-----------------------------|
| Lauric acid/paraffin   | 9        | ≈0.002                       | 21                          |
| Stearic acid/paraffin  | 9        | ≈0.002                       | 21                          |
| Palmitic acid/paraffin | 9        | ≈0.003                       | 31                          |
| Myristic acid/paraffin | 9        | ≈0.002                       | 21                          |
| Decanoic acid/paraffin | 9        | ≈0.003                       | 31                          |

![Fig.2 Corrosion curve of fatty acid/paraffin mixed phase change material on 304 stainless steel](image)

As can be seen from the graphs: the fatty acid/paraffin mixture is very weakly corrosive to stainless steel and the steel sheet loses mass at a small rate during the corrosion process. In contrast, the Palmitic acid/Paraffin and decanoic acid/paraffin mixtures are slightly more corrosive to stainless steel than the other ones, but there is no significant difference.

### 3.3. Corrosion of 304 stainless steel by fatty acid/paraffin/graphite composite phase change materials

The corrosion performance of the fatty acid/paraffin/graphite mixture on 304 stainless steel is shown in Table 4 and Figure 3.
Table 4 Corrosion rate of fatty acid/paraffin wax/graphite on 304 stainless steel

| Phase change materials | Time (h) | Steel sheet weight change (g) | Corrosion rate (mg/ (m²·h)) |
|------------------------|----------|-------------------------------|-------------------------------|
| Lauric acid/paraffin wax/graphite | 9 | ≈0.002 | 21 |
| Stearic acid/paraffin wax/graphite | 9 | ≈0.003 | 31 |
| Palmitic acid/paraffin wax/graphite | 9 | ≈0.004 | 42 |
| Myristic acid/paraffin wax/graphite | 9 | ≈0.006 | 63 |
| Decanoic acid/paraffin wax/graphite | 9 | ≈0.004 | 42 |

Fig.3 Corrosion curve of fatty acid/paraffin/graphite composite phase change material on 304 stainless steel

As can be seen from the graphs: the fatty acid/paraffin/graphite composite phase change material remains weakly corrosive to stainless steel, with the steel sheet decreasing in mass at a small rate during the corrosion process. In contrast, corrosive lauric acid/paraffin/graphite < stearic acid/paraffin/graphite < capric acid/paraffin/graphite ≈ palmitic acid/paraffin/graphite < myristic acid/paraffin/graphite.

3.4. Comparison of the corrosiveness of three types of phase change materials
A comparison of the corrosion rates of stainless steel for three types of phase change materials - single fatty acid, mixed fatty acid/paraffin and fatty acid/paraffin/graphite composite phase change materials - is shown in Table 5.

Table 5 Comparison of corrosion performance of three types of phase change materials on stainless steel

| Phase change | Lauric acid | Stearic acid | Palmitic acid | Nutmeg acid | Decanoic acid |
|--------------|-------------|--------------|---------------|-------------|---------------|

From the table we can see that, with the exception of lauric acid, a single fatty acid is the least corrosive to stainless steel, increasing in corrosiveness with the addition of paraffin, and then even more with the addition of graphite. Lauric acid, on the contrary, becomes less corrosive with the addition of other additives. Of the phase change materials formed by the different fatty acids, the stearic acid series is the least corrosive.

### 4. Conclusion

Experiments were carried out to test the corrosion of fatty acids, mixed fatty acid/paraffin phase change materials and composite phase change materials of fatty acids/paraffin/graphite against 304 stainless steel. After analysis of the experimental data, the following conclusions were drawn.

1. The corrosiveness of single fatty acids on 304 stainless steel is in the order of stearic, myristic, capric, palmitic and lauric acids from small to large, but the difference is not significant.

2. Fatty acid/paraffin wax mixed phase change materials on 304 stainless steel from small to large order of corrosion is lauric acid/paraffin wax, stearic acid/paraffin wax, myristic acid/paraffin wax, palmitic acid/paraffin wax, decanoic acid/paraffin wax, but the difference is not obvious.

3. Fatty acid/paraffin/graphite composite phase change materials on 304 stainless steel from small to large in the order of lauric acid/paraffin/graphite, stearic acid/paraffin/graphite, capric acid/paraffin/graphite, palmitic acid/paraffin/graphite, myristic acid/paraffin/graphite.

4. The single fatty acid is the least corrosive to 304 stainless steel, the addition of paraffin slightly increases the corrosiveness of 304 stainless steel, and then the addition of graphite forms a composite phase change material that is again more corrosive to 304 stainless steel compared to the first two.

5. Fatty acids and their addition of paraffin and graphite to form a composite phase change material on 304 stainless steel corrosion are relatively low, the highest corrosion rate of about 63mg/(m²-h), the use of 304 stainless steel production phase change heat storage heat exchange device is feasible, will not cause significant corrosion and affect the use.

6. Stearic acid series on the corrosion of stainless steel is the smallest, can be used as a phase change heat storage heat exchange device in the most ideal choice of materials.

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