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Failure analysis of electric-heater tube for heat-storage tank

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ABSTRACT

This paper presents an investigation of a failure of the 316L stainless steel electric-heater tube in a heat-storage tank. Visual examination was performed to discover the characteristics of the fracture zone. The fracture appearance and the ingredient analysis of the filler material were examined using scanning electron microscopy and X-ray diffraction. Also, the region that is susceptible to corrosion was identified using an electrochemical method. From those investigations, the surface defects that were caused by improper die finish during drawing process acted as the initiation points of the corrosion process. The influent water changes the filler material from magnesia to magnesium hydroxide, which causes the volume expansion. The failure of tube occurred due to the combination of the pitting corrosion on the external surface and internal pressure from the volume expansion of the filler.

1. Introduction

The district heating system collectively supplies steam or hot water from a heat-production plant to users through pipelines [1–3]. Especially, the heat-storage tank of thermal-energy storage systems facilitates the provision of the hot water that is produced by the heat-production system to the users of the district heating system. And it also stores the unused heat so that it can be provided for the users when it is needed [4,5]. The hot water that is stored in the heat-storage tank is maintained at approximately 90–98 °C using the electric-heater tube bundle that is shown in Fig. 1. The material of the electric-heater tube is austenitic stainless steel and its specifications are φ14 × 1.24 t. The electric-heater tube is manufactured using a drawing process for which the heating coil and the filling material are placed inside a manufactured tube, and this is followed by a tube reduction process that is carried out to eliminate the empty space. Magnesia (MgO) is used as the filler material, and its role comprises the following actions: (1) It transfers the heat of the heating coil inside the tube to the outside of the tube for the maintenance of the water temperature in the heat-storage tank. (2) It acts as an insulator by preventing the current flow in the heating coil that is inside the tube from escaping.

Several studies have been performed on the failures of various storage-tank types regarding this heating system. Krishnadev et al. reported that the cause of the brittle fracture of the transformer storage tank is the vulnerability of the weld metal to crack propagation under the dynamic loading condition [6]. Also, Trebuňa et al. studied the failure of the hot water storage tank roof that is due to high decreases of the steam pressure above the surface during increases of the water discharge from the tank [7]. In high temperature environments, a failure of the electric-heater tube makes it difficult to operate a heat-storage tank, which causes a loss of the heat energy [8,9]. Thus, it is important to identify the cause of the failure and to prepare counter-measures.

The purpose of this paper is an analysis of the causes of the failure of the electric-heater tube in the heat-storage tank for the purpose of operational safety. This paper describes the metallurgical investigation that was carried out on a ruptured electric-heater

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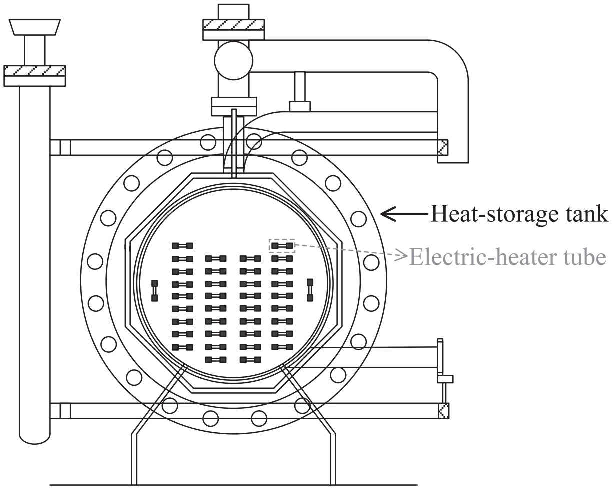

Fig. 1. Schematic diagram of the structure of heat-storage tank.

tube including a visual examination, optical microscopy (OM), scanning electron microscopy (SEM), and X-ray diffraction (XRD). Also, the potentiodynamic-polarization (PD) test, one of the electrochemical measurements, was conducted.

2. Experimental methods and operating environment

2.1. Background of operating environment and tube material

Since the failure of materials can be affected by the environment, an analysis of the environment in which the materials are used is one of the important factors in the identification of the failure causes. Therefore, the water analysis of a heat-storage tank for an electrical-heater tube was conducted, and the results are presented in Table 1. Also, inductively coupled plasma optical emission spectrometry (ICP-OES) was performed to confirm the tube material. The results are shown in Table 2, and the tube material was identified as the 316L-grade stainless steel.

2.2. Experimental methods

Visual examinations of the ruptured electrical-heater tube in both the as-received and the pickled states were performed both outside and inside the fracture zone, and the photographic data were taken to record the features of the failure. Also, the electrical-heater tube was cut for macroscopic and microscopic examinations. Optical microscopy was used to confirm the surface conditions of the used and the unused electrical-heater tubes. The field emission scanning electron microscopy (FE-SEM, JSM-7600F, JEOL) was used to analyze the characteristics of fracture surface and the progress of the fracture. Also, the X-ray diffraction (XRD, D8 ADVANCE, Brucker) was used to analyze the internal filling materials of the damaged electrical-heater tube and corrosion product. The potentiodynamic polarization (PD) test was performed using EG&G PAR VMP2 potentiostat/galvanostat by constructing a three-electrode electrochemical system. The details of the three-electrode electrochemical system consisting of a tube specimen, two pure

Table 1
Analysis of water in heat-storage tank.

	pH	Conductivity (μS/cm)	Ca^{2+} (mg/L)	Mg^{2+} (mg/L)	Fe ion (mg/L)	NO_2^- (mg/L)	SO_4^{2-} (mg/L)	Cl^- (mg/L)
District heating water	7.6	33.8	0.03	0	0	0	0	3.8

Table 2
Chemical composition of the electric-heater tube (wt%).

Composition	C	Mn	P	S	Si	Cr	Ni	Mo	N	Fe
Tube	0.03	1.73	0.022	0.008	0.38	16.34	11.04	2.01	0.08	Balance
316L STS	Max. 0.03	Max. 2.00	Max. 0.045	Max. 0.030	Max. 0.75	16.00–18.00	10.00–14.00	2.00–3.00	Max. 0.10	Balance