Parametric study of Adsorption dehumidification according to the various adsorbents for performance enhancement of nuclear plant steam turbine

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***Keywords : adsorption dehumidification, adsorbent, Isotherm properties, relative humidity**

1. Introduction

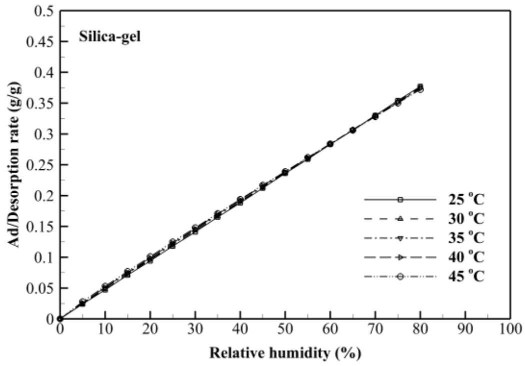
In order to reduction of wetness loss and enhancement of safety in nuclear plant steam turbine, the humidity control technology is necessary. The mature dehumidification system is operated based on the compressor system. However the mature dehumidification system requires the high electric energy consumption for operating the compressor. Therefore, the development of low-energy consuming technology for humidity control system is attracting attention to save the energy and cost. The adsorption dehumidification system can control the humidity of environment with the porous materials, namely, adsorbents. In addition, the adsorption dehumidification system is the thermal-driven process for adsorption and desorption, thus it can be operated with the one-tenth of electrical energy which is for operating the mature dehumidification system. Generally, the re-generation of the adsorbents is occured at under adsorbent temperature of 60 °C thus it can be operated with the low quality energy sources such as the waste heat, solar-, and geothermal energies. Therefore, application of adsorption dehumidification system can result in energy savings and cost savings. The adsorption dehumidification system is highly depending on the performance of the adsorbents. The performance of adsorbent can be estimated with the cycle time for saturation of adsorbent and the adsorption heat. The higher cycle time for saturation of adsorbent means that the higher amount of moisture removal. In addition, it can decrease the number of mode change for adsorption and desorption processes. Moreover, the generation of lower adsorption heat during the adsorption process means that lower cooling energy is required during the process. In this study, the performance evaluation of dehumidification system with three different adsorbents regarding the cycle time for saturation of adsorbent and adsorption heat was conducted at various relative humidities.

2. Result and discussion

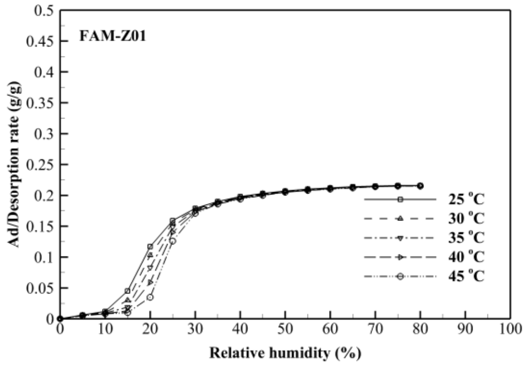
To evaluate the heat from the exothermic reaction according to the type of adsorbents, three different adsorbents were employed such as silica-gel, FAM-Z01, and aluminum fumarate. The adsorption heat of adsorbents can be shown in Table. 1 [1-4]

Table 1. Adsorption heat of three different adsorbents

	Silica-gel	FAM-Z01	Aluminum Fumarate
Adsorption heat (kJ/kg)	2,800	3,109	2,780



(a)



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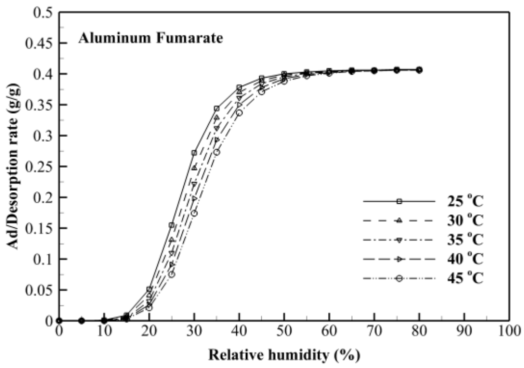

(c)

Fig. 1. Isotherm graphs of three different adsorbents (a) Silica-gel, (b) FAM-Z01, and (c) Aluminum fumarate

The isotherm graph of adsorbent can be shown in figure 1. The different shape of isotherm graph can be seen in the figure 1. The silica-gel has a linear-shape of isotherm graph. However, the FAM-Z01 and aluminum fumarate has the S-shape of isotherm graphs. As you can see that each adsorbent has a different max adsorption and desorption rate. The aluminum fumarate has a lagest adsorption and desorption rate among the three different adsorbents. The equations of ad/desorption rate for three different adsorbents with respect to the temperature of adsorbent and relative humidity can be shown as follows. The equations (1)-(3), (4)-(5), and (6)-(8) are for silica-gel, aluminum fumarate, and FAM-Z01, respectively [1-4].

The equations of ad/desorption rate for three different adsorbents with respect to the temperature of adsorbent and relative humidity can be shown as bellows:

$$q^* = A(T_S)\cdot[P_S(T_W)P_S(T_S)]^{B(T_S)} \quad (1)$$

$$A(T_S) = A0\cdot T_S + A1\cdot T_S^2 \quad (2)$$

$$B(T_S) = B0\cdot T_S + B1\cdot T_S^2 \quad (3)$$

$$q^* = q^{\max}K(P/P_S)^m / \left[1+(K-1)(P/P_S)^m\right] \quad (4)$$

$$K = \alpha\exp[(Q_{st}^* - h_{fg})] \quad (5)$$

$$q^* = \beta K_H\left(P/P_0\right) + (1-\beta)q_m(K_S P/P_0)^{1/n} / 1-(K_S P/P_0)^{1/n} \quad (6)$$

$$K = K_0\exp(-\Delta H/RT) \quad (7)$$

$$n = A + B/T \quad (8)$$

Figure 1 presents the ad/desorption rates according to the relative humidity. The silica-gel has the maximum adsorption and desorption rate approximately 0.45, however, the required relative humidity for adsorption is slightly higher than others. Although the isotherm characteristics of aluminum fumarate according to the temperature looks well matching with the dehumidification system, the performance of dehumidification system is not only depending the isotherm characteristic but also the adsorption heat of adsorbent. The generation of adsorption heat issues when the adsorption phenomena proceeds at the porous adsorbent. It can decrease the adsorption rate of the adsorbent and also increae the temperature of the outlet air.

In this section, the numerical study of the proper adsorption time for three different adsorbents was conducted to investigate the proper adsorbent for the dehumidification system based on adsorption process. The aimed amount of moisture removal in humid air was 0.006 kg/kg. The air flow rate was 0.5 kg/s. The 50%, 60%, and 70% of humid air were employed and the dry-bulb and wet-bulb temperatures were 27 and 19.5°C, 27 and 21.2°C, and 27 and 22.8°C, respectively. The absolute air humidity was 0.013, 0.015, and 0.018 at 50%, 60%, and 70% of relative humidity, respectively. The weight of each adsorbent was 4kg. As shown in figure 1,

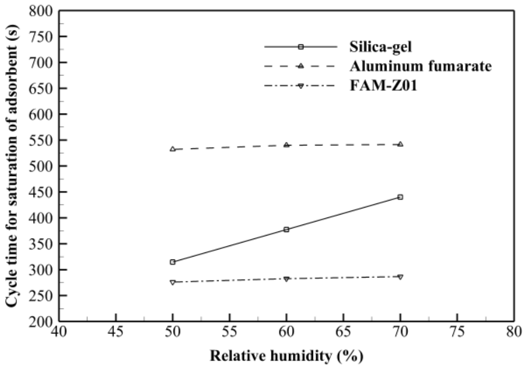

Fig. 2. Cycle time for saturation of adsorbent for three different adsorbents

the higher adsorption rate of each adsorbent can be seen at the higher relative humidity.

Figure 2 shows the cycle time for saturation of adsorbent for three different adsorbents. The adsorption and desorption rate increases with an increase in the relative humidity as shown in the figure 2. When the aluminum fumarate and FAM-Z01 were employed, the cycle time for saturation of adsorbent asymptotically increase as an increase in the relative humidity. This is because the isotherm graphs of aluminum fumarate and FAM-Z01 are S-shape. Meanwhile, the cycle time for saturation of adsorbent for silica-gel linearly increases according to the relative humidity because the isotherm graph is linear shape. The maximum cycle time for saturation of adsorbent was 541s when the aluminum fumarate was employed with the relative humidity of 70%. This is because the aluminum fumarate shows the highest adsorption and desorption rate around 0.406 kg/kg at the relative humidity of 70%. It means that the aluminum fumarate can remove the more moisture during the cycle time and it is the most proper adsorbent for adsorption dehumidification system among the three different adsorbents.

In order to investigate the cooling load due to the adsorption heat, the adsorption heat was estimated by the numerical study. The adsorption heats of each adsorbent during the saturation of adsorbents were 8.4, 8.34, and 9.33 kW at the silica-gel, aluminum fumarate, and FAM-Z01, respectively. Through this study, we reveal that the aluminum fumarate requires lowest cooling energy to remove the adsorption heat. This definitely shows the aluminum fumarate is the most proper adsorbent regarding the cooling load and cycle time.

3. Conclusion

In this study, we tried to reveal numerically the most proper adsorbent for the adsorption dehumidification system among the three different adsorbents such as silica-gel, aluminum fumarate, and FAM-Z01. The performance evaluations of the adsorbents were conducted regarding the cycle time for saturation of adsorbent and the adsorption heat. The comparison study regarding the cycle time for saturation of adsorbent and the adsorption heat were conducted at the various condition of humid air with three different adsorbents. As a result, we reveal that the cycle time for saturation of adsorbent increased linearly as an increase in the relative humidity when the silica-gel was employed as adsorption agent due to its linear isotherm characteristic. Meanwhile, we also revealed that when the aluminum fumarate and FAM-Z01 were employed, the cycle times for saturation of adsorbent slightly increase with an increase in the relative humidity due to its S-shape isotherm characteristic. Through this study, we revealed that the aluminum fumarate is the most proper adsorbent for improving adsorption dehumidification system. Among the three different adsorbents, the aluminum fumarate has the highest cycle time for saturation of adsorbent around 541s and the lowest adsorption heat around 8.34 kW.

ACKNOWLEDGEMENT

This work was supported by the Korea Evaluation Institute of Industrial Technology (KEIT) and Ministry of Trade, Industry & Energy (MOTIE) of the Republic of Korea (No. 20018410).

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