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Moisture removal system using adsorbent for a better cold start of FCVs

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Abstract

In this study, a new method is suggested to improve the cold start characteristics of FCVs (Fuel Cell Vehicles). To avoid freezing, the moisture is removed from the fuel cell system by using an adsorbent as soon as an FCV is turned off. Experiments have been performed to verify this concept and evaluate the efficiency of water removal and regeneration characteristics. In the moisture removal phase, the time required to remove the water droplets from the solenoid valve was measured for various operation conditions. In the regeneration phase, the time for the regeneration was measured and the overall performance was evaluated in detail.

Keywords: Cold start; Fuel cell vehicle; Adsorbent; Moisture removal

1. Introduction

Improving cold start characteristics is essential for satisfactory operation of fuel cell vehicles [1, 2]. If an FCV is turned off and left in a cold environment, the moisture remaining in the fuel cell system can be frozen into ice. Especially, this causes a serious problem to the solenoid valves used in the fuel cell system because the disk and the valve seat stick together. In order to move the valve again, the ice should be melted with heat which is generally generated by electricity. To overcome this problem, a new method is suggested in this study. It removes the moisture from the fuel cell system before the FCV is turned off. The moisture removal in this study circulates hot air which makes the remaining water in the fuel cell system evaporate. Then, the moisture in the air is removed as it passes through the absorbent such as silica gels [3].

After adsorbing enough moisture, the adsorbent should be regenerated for the next adsorption phase. In an FCV this regeneration process can be performed by using the heat from the operation of the fuel cell system.

To evaluate the characteristics of water removal and regeneration, an experimental setup was designed and manufactured. In the adsorption phase, the time required to remove the water droplets from the solenoid valve was measured for various air temperatures and flow rates. In the regeneration phase the time for the regeneration was measured and the overall performance was evaluated in detail.

2. Moisture Removal

2.1 Experimental setup and method

Fig. 1 shows the solenoid valve tested in this study. The sites of water droplets formed are also indicated. Most of the water formed in the fuel cell system flows

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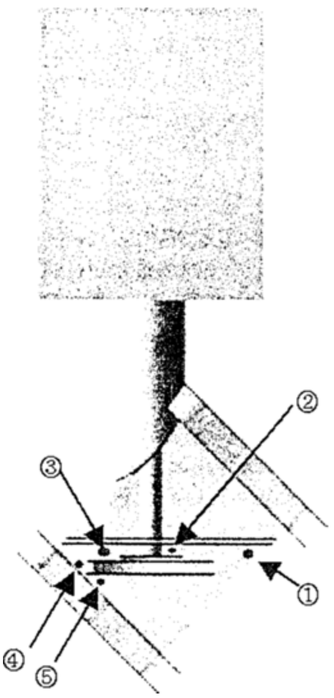


Fig. 1. Solenoid valve tested.

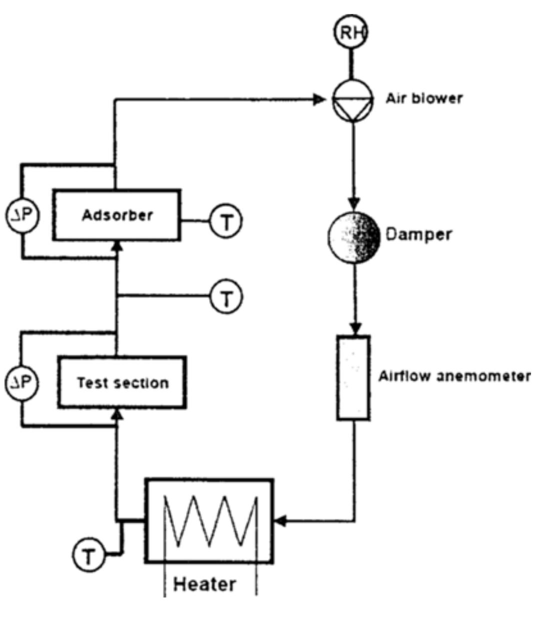


Fig. 2. Moisture-removal system.

down and drains by gravity when the system is turned off, but a small amount of water remains as droplets. In cold weather these droplets freeze into ice and cause a difficulty in starting. The valve used in our

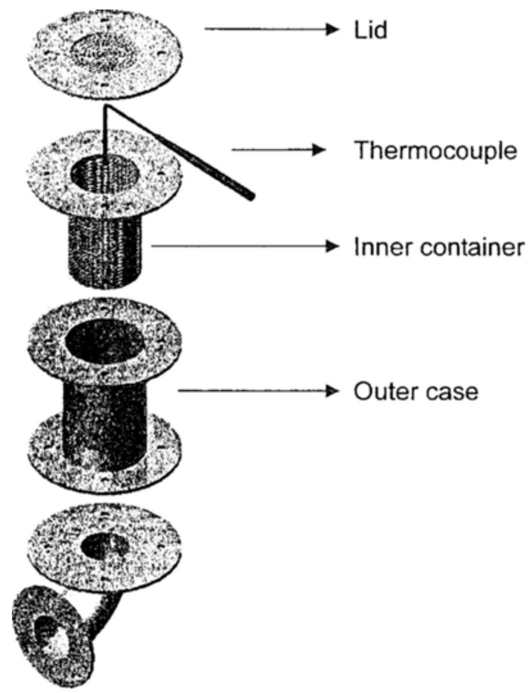


Fig. 3. Schematics of the absorber.

experiment has an inside diameter of 35 mm and a stroke of 5 mm. The disk made of silicon has a diameter of 25.4 mm.

Figure 2 shows the experimental apparatus used for the moisture removal phase. The system can remove the moisture from the test section (solenoid valve) by using the adsorbent. The air blower circulates the air through the moisture removal system. The flow rate of the circulating air is adjusted with a damper, and it is measured by an accurate anemometer. Then, the air is heated, and enters the test section. The hot air removes the moisture in the wetted test section. The air leaving the test section has high moisture content, which is reduced in the absorber.

The connecting pipes in the experimental apparatus are made of acryl to check the remaining moisture on the surface inside the solenoid valve. The adsorber is made of stainless steel and filled with the adsorbent. The adsorber is comprised of an outer case and an inner container as shown in Fig. 3. The inner container with a diameter of 50 mm and a height of 72 mm is made of finely perforated metal plate and has a function to distribute the air flow evenly through the adsorbent. The adsorbent used in our experiment is alumina silica gel (Neo Sun, Keuk-Dong Chemicals) and the amount of 100 g in dry

Table 1. Physical properties of the adsorbent.

Bead Diameter	2.4 ~ 4.75 mm
Al_2O_3	15%
SiO_2	85%
Surface Area	550 ~ 600 m^2/g
Static Absorption @ 50% RH	25 wt%
Static Absorption @ 90% RH	38 wt%
Total Pore Volume	0.43 ~ 0.45 cc/g
Bulk Density	720 ~ 780 g/L
Crush Strength	15 ~ 20 kg

condition was charged in the absorber. The characteristics of the adsorbent are summarized in Table 1.

To wet the inside of the valve, some water was supplied to the upper side of the solenoid valve, and it was flushed with the start of the experiment. Most of the flushed water flowed down and drained, but a small amount of water remained on the surface of the valve as droplets. The patterns of droplet locations were not identical, but they showed some trend. The locations observed repeatedly in the experiments are shown in Fig. 1.

As the water evaporated from the droplets, they became smaller and disappeared finally. An endoscope was installed to observe the droplets and determine the time when the last droplet disappears.

Pressure drops were measured at the test section and the adsorber with an accurate manometer which can read the pressure difference of 0.1 Pa.

The experiment was started with the dry adsorbent, and the first run continued until all the droplets in the solenoid valve disappeared perfectly. After the time for the first run was measured, water was flushed again and the next run started. In this manner, three consecutive runs were carried out for a given operation condition (air temperature and velocity). After these 3 runs, a new series of experiments was conducted by using new dry adsorbent.

2.2 Experimental results

Figure 4 shows the droplets formed inside the valve. Since the droplet which disappears at the end determines the moisture removal time, the location of the last droplet is important. It was observed that the position of the last drop changed a little however, the droplet at ③ in Fig. 1 disappeared lastly in most cases.

Figure 5 shows the moisture removal time for

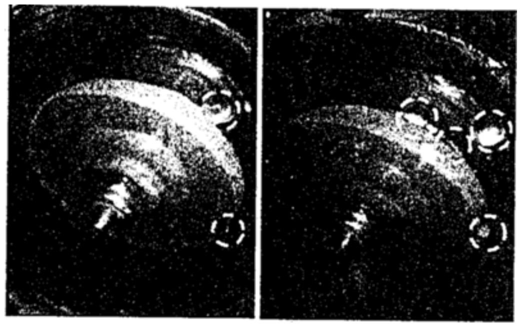


Fig. 4. Position of remaining droplet inside the valve.

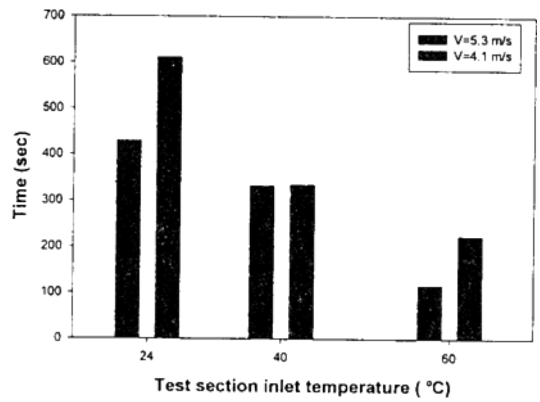


Fig. 5. Moisture removal time.

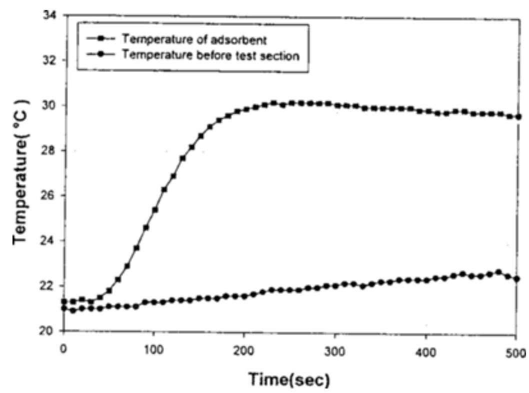


Fig. 6. Temperature variation of air and adsorbent.

different operation conditions. The bars in the graph indicate the average value for 3 consecutive runs described above. The average moisture removal time decreased as the inlet air temperature of test section is higher. Also, it is reduced with increasing air velocity. The increase of saturation pressure of water due to high temperature and the higher mass transfer coefficient due to high velocity made the mass transfer active. One interesting result is that there was no significant difference among the times required for 3 consecutive runs which are indicated in parentheses in seconds. The time for the first run had been expected to be shorter than that of the second or the third one because the adsorbent already absorbed the moisture after the first experiment, and lost the adsorption capability. However, it turned out that there was no significant difference. This result indicated that the adsorbent kept the adsorption capability at least for 3 runs.

Fig. 6 shows an example of the temperature change of the adsorbent and air with time. As the adsorbents absorbed the moisture, adsorption heat was generated. It was measured that the temperature of adsorbents was higher than the inlet air temperature by 7~10 K during the adsorption process.

3. Regeneration of The Adsorbent

3.1 Experimental setup and method

After adsorbing enough moisture, the adsorbent should be regenerated for the next operation. Fig. 7 shows a schematic diagram of the experimental apparatus for the regeneration phase. In the regeneration phase the absorber used in the moisture removal phase has the function of regeneration (desorption). The air is heated in the heater, and it regenerates the adsorbent passing through the desorber. In the regeneration phase the air is not circulated but discharged to the environment. Since acryl pipes cannot stand high temperature, the connecting pipe between the heater and the desorber was replaced with a stainless steel pipe.

Before the experiment was started for regeneration, the adsorbent of 100 g was kept in a container to be saturated with water vapor. This process took about 2~3 days. When the adsorbent was fully saturated, it was filled in the desorber and the regeneration experiment was conducted.

After the adsorbent was heated for a given time, it was taken out from the desorber, and its weight was measured by using a precision balance as quickly as possible to avoid any heat loss during the measurement. Then, the adsorbent was charged back to the desorber and the regeneration carried on. Table 2 shows the experimental conditions for the regeneration experiment. Although the initial mass of all the dry adsorbent samples was exactly 100 g, the saturated samples weighed 118~124 g. The difference is thought

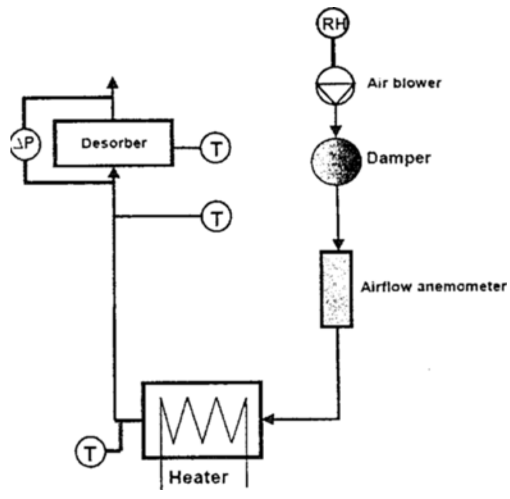


Fig. 7. Diagram of regeneration experiment.

Table 2. Experimental conditions for regeneration.

Classification	Contents
Inlet temperature	22~25 ℃
Velocity of inlet air	2.48 m/s 3.85 m/s 4.53 m/s
Regenerating temperature	80~120 ℃
ΔP at desorber	0.04 mmAq at 2.48 m/s 0.05 mmAq at 3.85 m/s 0.09 mmAq at 4.55 m/s

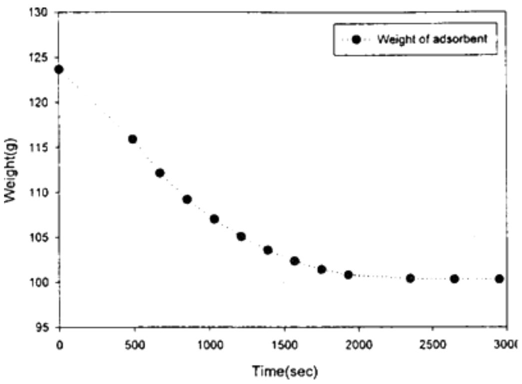
ought to be due to different positions of the adsorbent samples in the saturation container.

The regeneration temperature was maintained constantly by the on/off control of the heater. The generation temperature was kept lower than 130 ℃, since degradation (change of the color) had been observed in the preliminary test if the regeneration temperature exceeded 150℃.

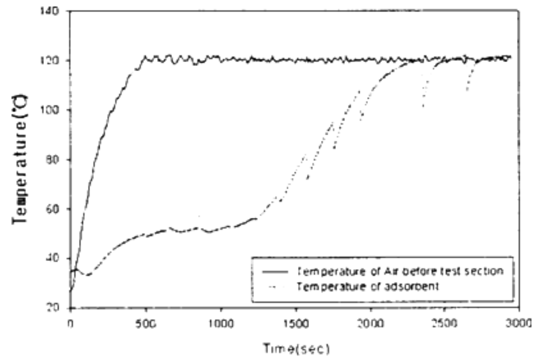
3.2 Experimental results

Fig. 8 is an example of the experimental data. It can be seen that regeneration takes place easily at the beginning, but its rate becomes slower as the adsorbent temperature approaches to that of the hot air. Several sudden drops of the adsorbent temperature are observed because of the measurement processes described above.

Since the regeneration rate becomes slower and slower as the mass approaches the initial mass (100 g), reaching the initial mass takes very long or may not



(a) Change of weight at V=3.85 m/s, T=120℃, Δ P=0.05 mmAq



(b) Change of perature at V=3.85 m/s, Δ P=0.05 mmAq

Fig. 8. Weight and temperature variations of the adsorbent. (T=120℃, V=3.85 m/s)

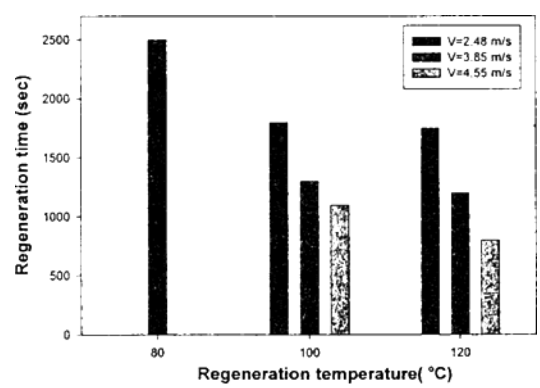


Fig. 9. Effect of air temperature and velocity on regeneration time.

be possible. Therefore, the regeneration time was defined as the time required to reach 1 % of the moisture content in the adsorbent (101 g of the adsorbent).

Fig. 9 shows how the regeneration time is influenced by the air temperature and velocity. As expected, the regeneration time is shorter for higher temperature and higher velocity. There was no significant difference in the regeneration time between 100℃ and 120℃, but it increased significantly at 80℃. Considering this, the air temperature of around 100℃ is recommended for the adsorbent used in this study. Concerning the velocity of the air, it is recommended that higher velocity should be used if a pressure drop is allowed.

4. Conclusion

In this study, a new method was suggested to remove the moisture from the solenoid valve by using adsorbent. Experiments were performed to verify this concept and evaluate the characteristics of water removal and regeneration.

The droplets from the inner surface of a solenoid valve could be removed by using 100g of alumina silica gel. The moisture removal time was less than 10 minutes, and it decreased as the temperature and velocity of air increased.

In the regeneration phase, the adsorbent was dried until it reached 1 % of moisture content. The regeneration rate was fast at the beginning, but it slowed down as temperature of the adsorbent approached that of the hot air. The time required for the regeneration of the adsorbent was in the range of 10~40 minutes, and it decreased with increasing air temperature and velocity. However, the difference was not much between 100 and 120℃ of air temperature.

Since the time required for the moisture removal and regeneration is in a practical range, it is expected that the new concept of moisture removal with adsorbent can be successfully applied to FCVs.

Nomenclature

P : Pressure, mmAq
T : Temperature, °C
t : Time, s
V : Velocity, m/s

Acknowledgements

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