# THE EXPERIMENTAL INVESTIGATION OF THE DUAL EVAPORATOR TYPE ADSORPTION CHILLER

*Takahiko Miyazaki, Assistant Professor, Tokyo University of Agriculture and Technology, (Koganei-shi, Tokyo 184-8588, Japan);*
*Yuya Tani, Student, Tokyo University of Agriculture and Technology, (Koganei-shi, Tokyo 184-8588, Japan);*
*Yuki Ueda, Associate Professor, Tokyo University of Agriculture and Technology, (Koganei-shi, Tokyo 184-8588, Japan);*
*Atsushi Akisawa, Professor, Tokyo University of Agriculture and Technology, (Koganei-shi, Tokyo 184-8588, Japan);*

**Abstract:** The improvement of the coefficient of performance (COP) and the reduction of the chiller size are required for the adsorption chiller. The authors have proposed the dual evaporator type adsorption chiller (DEAC) to improve the cooling perfomrance. The chiller is consisted of two evaporators and a condenser as well as three adsorbers. The evaporation-adsorption process occurs at two different pressure levels, which results in the extension of the adsorbate concentration change between the adsorption and the desorption. The experimental study of the dual evaporator type adsorption cycle was performed to reveal the performance improvement by the DEAC. The improvement of the performance indices due to the two staged evaporation-adsorption was confirmed by experimental measurement. The COP of the dual evaporator type adsorption chiller was compared with that of the conventional adsorption chiller. The results showed the advantages of the dual evaporator adsorption chiller over the conventional adsorption chiller.

**Key Words: adsorption chiller, experiment, coefficient of performance**

## 1 INTRODUCTION

The utilization of waste heat is essential to enhance the energy efficiency of the systems that are driven by fossil fuels. The adsorption chillers enable the use of relatively low temperature waste heat around 60-80 $^{o}$C. The heat of this temperature level can be converted into the heat at temperature levels lower than the ambient, which increases the usage of the waste heat.

The major advantages of the adsorption chiller with silica gel-water combination are the low driving temperature and the use of natural refrigerant. On the other hand, the COP of the adsorption chiller is lower than that of the absorption chiller with lithium bromide water solution driven at 90 $^{o}$C. In addition, the reduction of the chiller size is imperative to expand the application field of the adsorption chiller. Therefore, the main objectives of our research on the adsorption chiller are the improvement of the COP and the increase of the cooling power per adsorbent mass.

The authors have proposed a novel adsorption chiller, called the Dual Evaporator type Adsorption Chiller (DEAC), and its performance was predicted by simulation (Miyazaki et al. 2010). It was shown that a large improvements in COP and specific cooling capacity were achieved by the DEAC compared with a conventional, two-bed adsorption chiller. The current study is to conform the performance improvements by experimental set up. In this paper, the results of the experimental study on the concept of the dual evaporator adsorption cycle are reported, and the cooling performance of the dual evaporator adsorption cycle was compared with that of the conventional adsorption cycle.

## 2 THE DUAL EVAPORATOR TYPE THREE-BED ADSORPTION CHILLER

### 2.1 The structure and the operation of the DEAC

The DEAC consisted of three adsorbers, two evaporators and a condenser as depicted in Fig.1. The two evaporators work at different pressure levels corresponding to the evaporation temperature, which results in the extension of the adsorbate concentration change between the adsorption and desorption processes.

The chilled water flows in series through the higher pressure evaporator and the lower pressure evaporator. Therefore, the temperature difference between the inlet and outlet of the chilled water ($\Delta T$) is larger than that of conventional chillers. The $\Delta T$ is usually 5 $^{o}$C for the conventional chiller, while it is about 10 $^{o}$C for the DEAC. The large $\Delta T$ has a positive effect on the energy savings of large scale systems such as district heating and cooling plants because the pumping power of the chilled water distribution can be reduced.

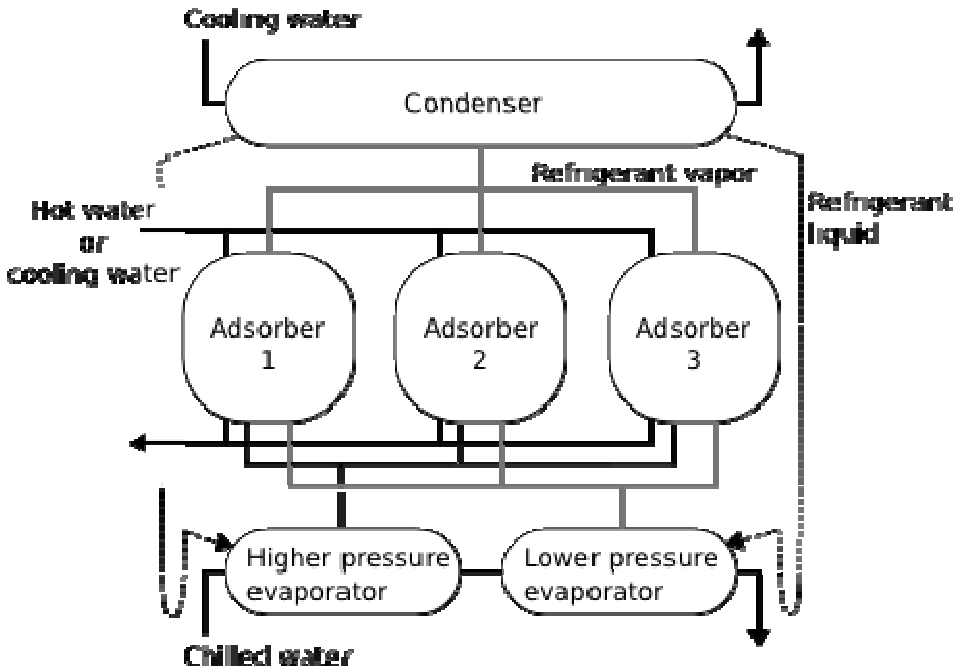


**Figure 1: The schematic of the DEAC.**

The operation of the DEAC is illustrated by Fig.2. A cycle of the DEAC consists of five processes, namely, desorption, pre-cool, lower pressure adsorption, higher pressure adsorption, and pre-heat. Three adsorbers carry out these processes out of phase.

The adsorber is connected with the lower pressure evaporator during the lower pressure adsorption process, and the connection is changed to the higher pressure evaporator when the process is switched to the higher pressure adsorption process. Because the relative pressure of the refrigerant vapor increases by switching of the process from the lower pressure to the higher pressure, the adsorbent can adsorb more refrigerant.

One of the features of the DEAC is the shorter desorption time compared with the adsorption time. The desorption time is about one-third of the total cycle time. The adsorption cycle can maintain a useful working range of adsorbate concentration change between the desorption and the adsorption by this cycle time configuration because the mass transfer speed during desorption is much higher than that during adsorption.

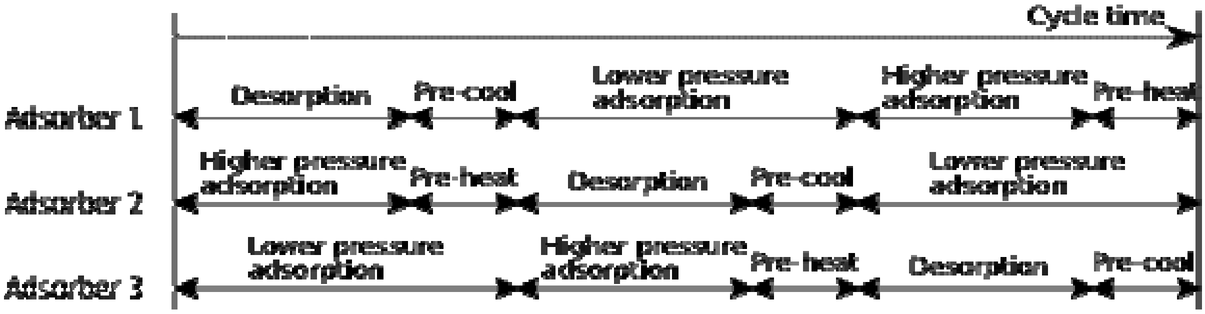


**Figure 2: The operation of the DEAC.**

## 2.2 The P-T diagram of the DEAC

In Fig.3, the adsorption cycle of the DEAC with the temperature range from 30 °C to 75 °C is depicted on the P-T diagram. The lower pressure adsorption process is performed at around 1kPa, which corresponds to the evaporation temperature of around 8 °C. Then, the adorber switches the connection to the higher pressure evaporator, and the higher pressure adsorption process is carried out. The evaporation temperature in the higher pressure evaporator is around 14 °C and the vapor pressure is around 1.6 kPa.

In the case of the conventional adsorption cycle, which works under the same adsorbent temperature range, the maximum adsorbate concentration is approximately 0.17 kg/kg. On the other hand, the maximum adsorbate concentration is extended to 0.25 kg/kg by the DEAC. It is clear that the increase in the adsorbate concentration change enhances the cooling effect of the adsorption cycle.

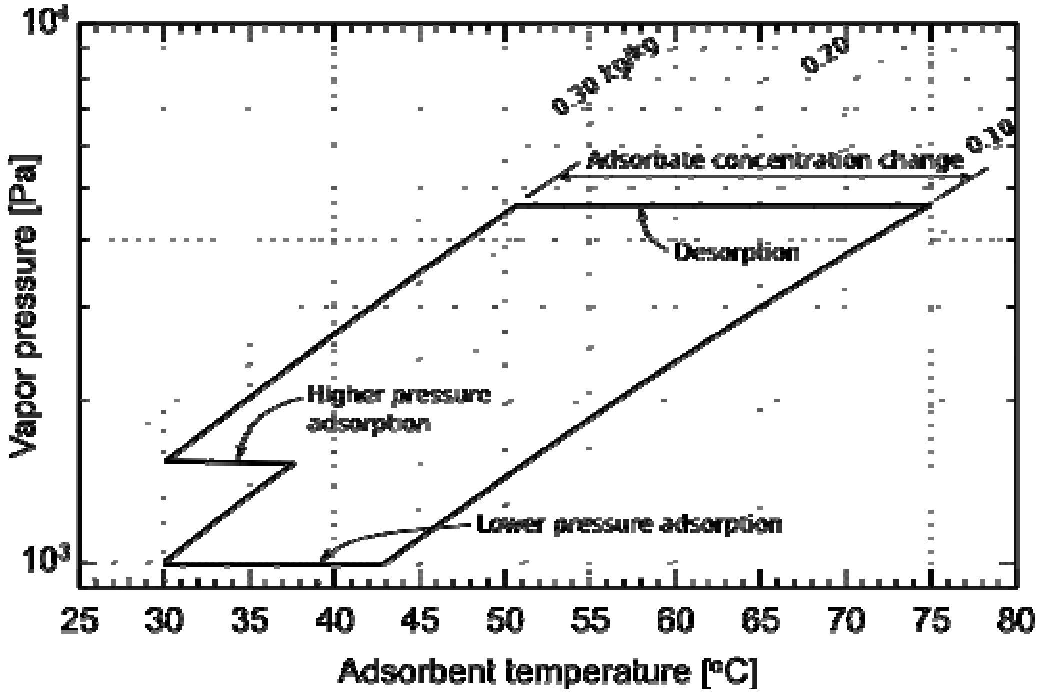


**Figure 3: The adsorption cycle of the DEAC.**

## 3 EXPERIMENTAL SET UP

The adsorption cycle of the DEAC shown in Fig.3 was tested by using an adsorption heat exchanger. The adsorbent is a low temperature regeneration type zeolite and the refrigerant is water. The experimental apparatus is illustrated in Fig.4. The hot water inlet temperature was 80 $^{o}$C, the cooling water inlet temperature was 30 $^{o}$C, and the chilled water inlet temperature to the higher pressure evaporator was 20 $^{o}$C. Because of the one-bed configuration, it was not possible to operate both of the evaporators simultaneously. Therefore, the inlet temperature of the chilled water to the lower pressure evaporator was determined as the average of the outlet temperature of the chilled water from the higher pressure evaporator after sufficient cyclic operations. The inlet and outlet temperatures of the heat transfer fluids were measured by the Pt resistance thermometers.

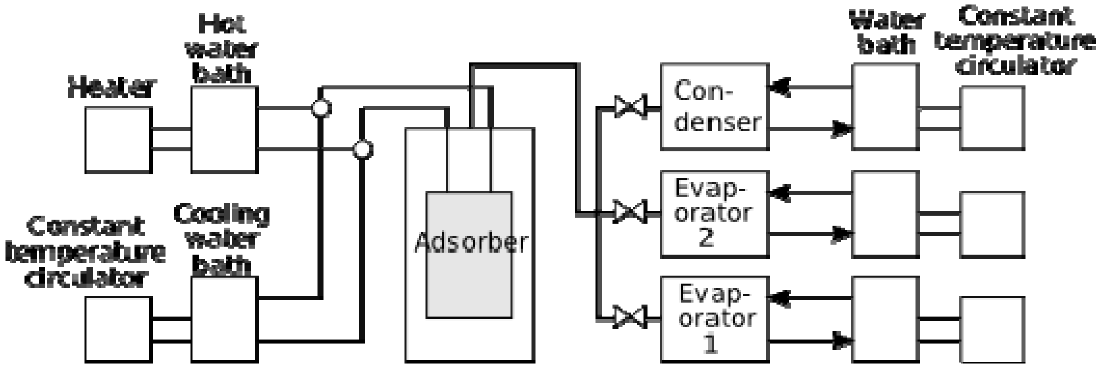


**Figure 4: The experimental apparatus.**

## 4 EXPERIMENTAL RESULTS

The cyclic operation of the system was performed until the system achieved the cyclic steady state. The cycle time settings of the DEAC cycle and the conventional cycle are given in Table 1. As shown in Fig.2, the lower pressure adsorption time of the DEAC is equal to the sum of the pre-cooling time and the higher pressure adsorption time.

**Table 1: The cycle time settings of the experiment**

| Cycle | Pre-heat | Desorption | Pre-cool | Lower pressure adsorption | Higher pressure adsorption |
|---|---|---|---|---|---|
| DEAC | 600 s | 600 s | 600 s | 1200 s | 600 s |
| Conventional | 600 s | 600 s | 600 s | 600 s | - |

### 4.1 The temperature profiles

The inlet and outlet temperature of the adsorber is depicted in Fig.5. The heat transfer fluid to the adsorber was the hot water during the time 0 s to 1200 s, and it was the cooling water from 1200 s to 3600 s. It was shown that the adsorber temperature was kept near the cooling water temperature through the lower pressure adsorption.

The heat added or removed to or from the adsorber by the heat transfer media was calculated from the temperature difference between the inlet and the outlet. That was about 560 kJ during the pre-heat and desorption and was about 600 kJ during the pre-cool and adsorption. The error in the heat balance was acceptable.

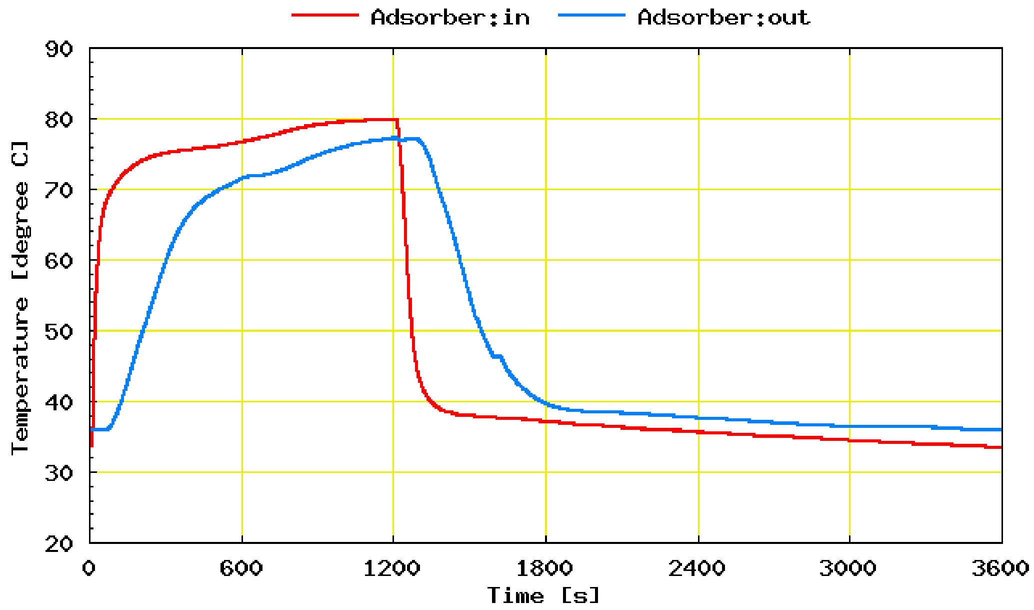


**Figure 5: The inlet and outlet temperatures of the adsorber.**

The temperature profiles of the heat transfer media to the condenser and the evaporators are shown in Fig.6. When the desorption process started at 600 s, the outlet temperature from condenser was increased because of the condensation heat of the desorbed refrigerant. After that, the cooling effect was observed in the lower pressure evaporator, and then in the higher pressure evaporator. It was confirmed that the adsorber worked by two-staged adsorption processes as expected.

The heat input and output with regard to the condenser and the evaporators were calculated, and they were about 55 kJ for the condenser, and 30 kJ for the sum of the evaporators, respectively. The difference between the condenser and the evaporators were large, but it would be caused by a low performance of the evaporators. The optimization of the evaporator design is required.

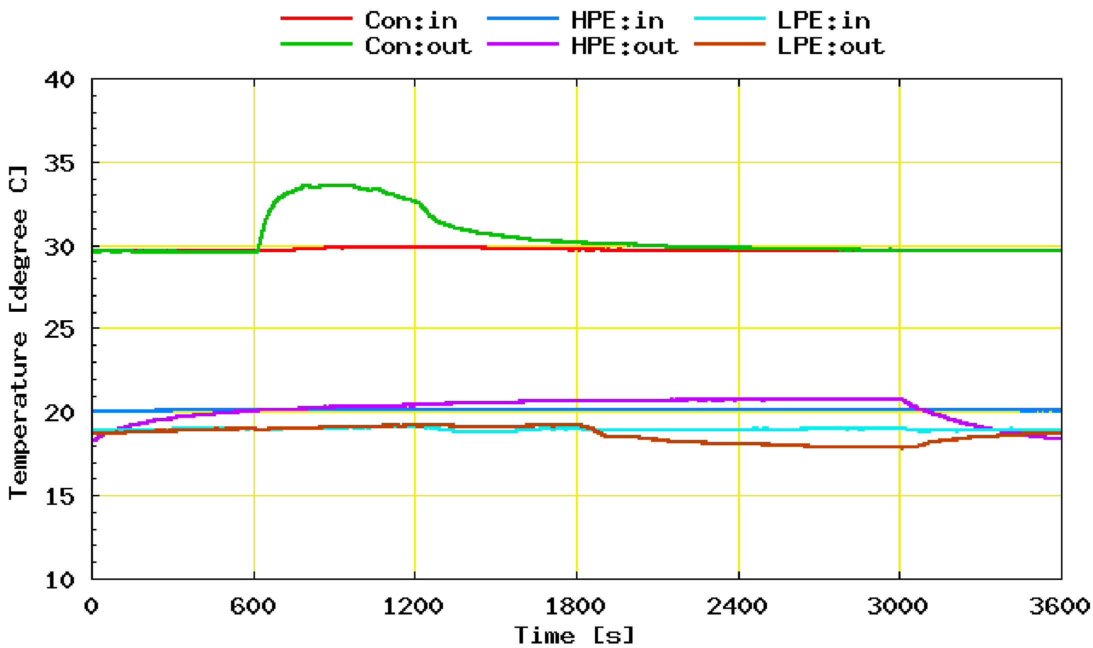


**Figure 6: The inlet and outlet temperatures of the condenser and the evaporators.**

In addition to that, the cooling effect obtained by the evaporator was much smaller than the heat added to the adsorber during the pre-heat and desorption processes. This result in a very low COP of the system. One of the reasons of the low COP would be that the desorbed refrigerant vapor was condensed in the adsorber and it was absorbed during the adsorption period. In other words, the most of the adsorbed refrigerant did not contribute to the cooling effect of the evaporator. The improvement in the insulation of the adsorber would be a method to solve this problem.

### 4.2 The comparison with the conventional cycle

The conventional cycle operation was performed using the adsorber, the condenser, and one of the evaporator. The same problems as in the case of the DEAC cycle caused a low COP of the cycle. The measured data of the inlet and outlet temperature are reliable, however. Table 2 shows the experimental COP and the cooling effect of both cycle. The comparison between the DEAC cycle and the conventional cycle revealed that the cooling effect of the DEAC cycle was about 3.8 times of that of the conventional cycle. In terms of the COP, the DEAC cycle had a higher COP by the factor of 3.4.

**Table 2: The COP and cooling capacity of the DEAC and the conventional cycles**

| Cycle | COP | Cooling effect [kJ] |
|---|---|---|
| DEAC | 0.054 | 30.2 |
| Conventional | 0.016 | 7.8 |

## 5 CONCLUSIONS

The performance of the DEAC was examined by experimental apparatus using one adsorber. It was confirmed that the adsorption cycle of the DEAC could be achieved by appropriate configuration of heat source temperatures. The results showed that the COP of the DEAC was 3.4 times higher than that of the conventional cycle under the given operation conditions. On the other hand, it was revealed that some problems of the experimental set up caused very low COPs of both DEAC and conventional cycles. The improvements in the experimental apparatus, as well as the optimization of the operation conditions would be the future work.

## 6 REFERENCES

Miyazaki T., A. Akisawa, and B.B. Saha 2010. “The performance analysis of a novel dual evaporator type three-bed adsorption chiller,” *International Journal of Refrigeration*, Vol. 33, pp. 276–285.