Development of Shallow and Multiple Stratification Type Thermal Storage Tanks

by IWATA Yoshimi, MORI Fukashi, KITANO Hiroaki, SAGARA Kazunobu

1 Electric Power Research & Development Center, Chubu Electric Power Co., Inc.
   Kitasekiyama20-1, Odaka-cho, Midori-ku, Nagoya, 459-8522 Japan
   e-mail: Iwata.Yoshimi@chuden.co.jp, Fukashi.Mori@chuden.co.jp

2 Department of Architecture, Mie University, Kamihama-cho 1515, Tsu, Mie, 514-8507 Japan
   e-mail: kitano@arch.mie-u.ac.jp

3 Department of Architectural Engineering, Graduate School of Engineering, Osaka University,
   Yamadaoka 2-1, Suita, Osaka, 565-0871 Japan
   e-mail: sagara@arch.mie-u.ac.jp

KEY-WORDS
Cold storage, Water, Stratification, Parallel, Feasibility

ABSTRACT

The purpose of this paper is to present the development of a temperature stratified type of thermal storage tank with a high thermal storage performance composed of parallel-connected tanks with a shallow water depth of 1.5 to 2 meters, which can be installed in the double slab space under the basement of medium rise buildings. In order to achieve this object, the inflow/outflow port which enables the flow rate of port to be almost equal with one another was developed, and the effect of connecting hole through tank partition on canceling stored heat imbalance which is attribute to parallel connection of tanks was studied.

1. INTRODUCTION

Electric power companies in Japan are putting efforts into popularizing an air-conditioning system with water thermal storage which can shift their electric power demands from daytime to nighttime. This system stores cold water or warm water which is required for space cooling or heating during the daytime in the form of sensible heat energy in thermal storage tank, and discharges it during the daytime. Among water thermal storage systems which are used in air-conditioning systems and are effective in leveling power demand, there are generally two types; the connected complete mixing tank type and the temperature stratified type. Recently, it is trying to design the parallel type of temperature stratified thermal storage tank having its own inlet and outlet because of its high storage performance. Though it is difficult to keep the balance of input/output water flow rate and stored heat in each tank, the connecting holes through partition between tanks are useful to keep the balance of stored heat.

The purpose of this paper is to explain the development of a temperature stratified type of thermal storage tank with a high thermal storage performance, composed of parallel-connected tanks with a water depth of around 1.5 to 2 meters, which can be installed in the underground double slab space in a medium rise building.

As the first stage, in order to overcome the problem of imbalance of stored heat in each tank caused
by unbalancing of the inflow and outflow rate, a study was conducted to obtain relatively simple inflow and outflow ports and a simplified calculation method to enable balancing of the inflow and outflow rate and securing satisfactory temperature stratification.

After a series of experimental studies using a model tank, a parallel type of temperature stratified thermal storage tank was applied in an actual building to verify the effect of connecting hole on solving the imbalance. And, it was found that in case of stored heat imbalance about 20% or less, this imbalance was canceled by installing appropriate connecting holes at tank partition due to water density difference in both sides of tank partition.

2. VERIFICATION OF THE THERMAL STORAGE BALANCE IN AN ACTUAL SYSTEM

2.1 Outline of the building, heat source facility and temperature measurements

The outline of building and heat source facility are summarized in Table 1, and Photo 1 shows a photograph of the Gifu Building. The designing of this thermal storage system was conducted at about the same time that the experimental study in which even small size of connecting hole was found to have the enough canceling effect. However, the size of connecting holes installed in this building was relatively large in order to ensure that the imbalance of stored heat would surely canceled though the inflow/outflow port was similar type to one used in experimental study. Fig. 1 shows a schematic drawing of the developed temperature stratified type of thermal storage tank connected in parallel and having shallow water depth. Fig. 2 shows the outline of plan and arrangement of piping, diffusers, and connecting holes. Fig. 3 shows the details of connecting holes, and Fig. 4 shows the details of diffusers.

Table 1. Outline of the building and the heat source facility

<table>
<thead>
<tr>
<th>Building name</th>
<th>Chubu Electric Power Company, Gifu Building</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total floor area</td>
<td>24,097 m²</td>
</tr>
<tr>
<td>Structure</td>
<td>Steel frame building, one floor underground, 11 floors above ground</td>
</tr>
<tr>
<td>Completion date</td>
<td>March 2001</td>
</tr>
<tr>
<td>Heat source facility</td>
<td>Multi-tank parallel type temperature stratified type thermal storage tank</td>
</tr>
<tr>
<td></td>
<td>Water depth, 1.5 m, Utilized temperature difference, 10°C</td>
</tr>
<tr>
<td></td>
<td>Cold, warm water tank, thermal storage tank A 259 m³</td>
</tr>
<tr>
<td></td>
<td>Cold-water tank, thermal storage tank B 309 m³, Thermal storage tank C 191 m³</td>
</tr>
<tr>
<td></td>
<td>High efficiency water-cooling screw chiller 1 unit</td>
</tr>
<tr>
<td></td>
<td>Cooling capacity, 580 Mcal/h Heating capacity, 619 Mcal/h</td>
</tr>
<tr>
<td></td>
<td>Air-cooled type heat pump chiller 1 unit</td>
</tr>
<tr>
<td></td>
<td>Cooling capacity, 258 Mcal/h, warming capacity, 322 Mcal/h</td>
</tr>
</tbody>
</table>

Photo 1  Photograph of the Gifu Building
As shown in Fig. 3, connecting holes of 600 mm in diameter were installed at the left and right side of tank partition, and the upper hole was arranged near the water surface and the lower hole was arranged near tank bottom. Then as an idea, the main diffuser pipes were passed through the center of the connecting holes to decrease the number of openings in the tank partition.

Fig. 1 Schematic drawing of temperature stratified type of thermal storage tank connected in parallel and having shallow water depth

Fig. 2 Plan drawing of thermal storage tank and arrangement of piping, diffuser and connecting holes

Fig. 3 Installation of connecting holes and diffusers
In order to monitor the stored heat balance of thermal storage tanks B and C which have different total tank capacities and piping respectively in this system, temperature sensors were installed at a total of 4 points at 300 mm intervals in the vertical direction of Point b and Point c (see Fig. 2) Also in order to study the situation of the stored heat balance at both end tanks of the same piping, 31 temperature sensors were installed at 50 mm intervals in the vertical direction in the end tanks a-1 tank and a-8 tank of thermal storage tank A composed of 8 tanks.

### 2.2 Verification of stored heat balance in different thermal storage tanks

Photo 2 shows the inside of the temperature stratified type of thermal storage tank installed in the Gifu Building, and Photo 3 shows the details of diffusers.
In order to study the effects of connecting holes on stored heat balance in actual buildings, the flow rate was adjusted so that the flow rate of thermal storage tank B and of thermal storage tank C would become unbalanced.

Fig. 5(a) shows the flow rate balance of thermal storage tanks B and C at the time of thermal storing and thermal discharging as the number of water replacements. The number of water replacements here is defined as a ratio of the integrated flow rates into thermal storage tank B and thermal storage tank C to their respective volume, and it is identical to the dimensionless charged heat into the respective tanks. Fig. 5 (b) shows the temperature response at 4 points of 300 mm, 600 mm, 900 mm, and 1,200 mm height from the tank bottom in thermal storage tanks B and C.

From these results, it can be seen that any difference is hardly observed between the temperature response at the various heights at thermal storing or discharging and that the stored heat balance has been kept by the effect of the connecting hole, even though there is an imbalance of 20% or more between thermal storage tanks B and C.

2.3 Verification of stored heat balance in the end tanks of the same piping

Fig. 6 compares the transition of temperature profile at the time of thermal storage of the two end tanks (a-1 tank and a-8 tank) of thermal storage tank A. Though the a-1 tank and the a-8 tanks are the most distant tanks in the thermal storage tank A composed of 8 tanks, their temperature profiles roughly show the same movement and it can be seen that the stored heat balance is also maintained between the two end tanks of the same piping. Furthermore, the volume efficiency of this thermal storage tank was obtained from the temperature profile and it was found to be a high efficiency of approximately 90%.

As shown in Fig. 2, in this temperature stratified type of thermal storage tank connected in parallel, even if each inflow/outflow port can realize an uniform flow rate, there is still a possibility that the stored heat will not come into equilibrium because the volume of each parallel tank is not identical.

Consequently, it may be said that even if inflow/outflow ports which enable the uniform flow rate are installed, the installing of connecting holes is essential to assure the stored heat balance. However, from the point of building structural strength, it is obvious that the size of connecting hole is better to be as small as possible because it is installed by digging through the tie beam of underground double slab space. The development of design method for the optimum connecting holes is an issue which must to be solved hereafter.
2. CONCLUSION

The results obtained in this study are summarized to serve as a conclusion.

1) The inflow/outflow port which enables the flow rate of port to be almost equal with one another was developed. This inflow/outflow port is composed of port attached a perforated tube and small branch pipe connected to larger main pipe which is passed horizontally inside the tank. And, it was confirmed that this port is useful to balance the inflow and outflow flow rates and to secure a good temperature stratification.

2) A verification study for the stored heat balance of an actual system with a temperature stratified type of thermal storage tank connected in parallel and having a depth of 1.5 meter was conducted, and it was confirmed that the stored heat balance was maintained between tanks with different piping and between the end tanks of the same piping by the effect of the connecting hole even when the flow rate balance was insufficient.

3) By installing connecting holes in tank partition, it became possible to cancel the unbalance of stored heat of a certain extent. But, even in such cases, mixing by the flow through the connecting hole cannot be avoided. Therefore, it is necessary to equalize the flow rate at the inflow/outflow ports of each tank to secure a high thermal storage performance.

4) Though this is the first time that a temperature stratified type of thermal storage tank with a shallow water depth of 1.5 meters was applied to an actual building, the volume efficiency of this thermal storage tank was found to be a high efficiency rate of approximately 90%.

From these results, it was verified that the temperature stratified type of thermal storage tanks connected in parallel and having shallow water depth tanks can be applied to the double slab space of medium rise building basements. It is hoped that the results of this study will serve to spread and promote the temperature stratified type of thermal storage tank having a high thermal storage performance and the air-conditioning system with thermal storage which can contribute to the leveling of electric power demand.

References
