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Study on heat storage performance of a single hot water tank with heat insulation board as thermocline layer

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ABSTRACT
The mixing of cold and hot fluids caused by inlet and outlet or natural convection in a heat strorage tank, interfere with temperature stratification will reduce the thermal performance of the heat storage tank. In this paper, a method of installing movable heat insulation board in a single tank heat storage is proposed. The temperature field of heat storage tank equipped with heat insulation board and traditional heat storage tank is simulated and analyzed. Results show that under static conditions, the mixing of cold and hot fluids in the traditional single tank will lead to rapid heat transfer, which is the main factor the maximum fluid temperature. The heat insulation board can prevent mixing, so as to ensure the heat storage system maintains higher exergy. The thermal performance of the heat storage tank can be improved by selecting materials with low thermal conductivity to make heat insulation board.
Keywords: sing tank, heat storage, thermocline, exergy, heat insulation board

NONMENCLATURE

Abbreviations	
TES	Thermal Energy Storage
Symbols	
c_p	Specific Heat, kJ/(kg·K)
g	Acceleration of Gravity, m/s^2
H	Height,m
κ	Kinetic Energy
f	Fluid
ϕ	Diameter,m
T	Temperature, K
t	Time, s
λ	Thermal Conductivity, W/(m·K)
ρ	Density, kg/m^3
μ	Dynamic Viscosity, kg/(m·s)
β	Thermal Expansion Coefficient,1/K
$\vec{u}$	Velocity Vector

1. INTRODUCTION

Thermal energy storage (TES) technology can solve the mismatch between energy supply and demand, improve the utilization efficiency of renewable energy and fossil energy, and provide a feasible technical path for a greater proportion of renewable energy consumption under the background of carbon neutralization[1]. TES technology is mainly divided into sensible heat storage, latent heat storage and chemical reaction heat storage. Sensible heat storage technology is to change the temperature of heat storage materials to realize heat storage and release[2]. The technology is relatively mature, with a wide range of materials and low cost. It is widely used for heat storage and cold storage. Sensible heat storage system with water as thermal storage medium has two forms: single tank heat storage and double tank heat storage. The double tank heat storage system stores the cold and hot fluids in two single tanks respectively. Although there is no mixing of cold and hot fluids, in practical use, the working medium volume in the tank can only reach half of the design volume at most, and the equipment investment cost is high. The single tank heat storage system stores the cold and hot fluids in the same tank, uses the density difference between fluids to produce stratification under the action of gravity, and generates a thermocline temperature layer at the junction to reduce the mixing of cold and hot fluids and realizing heat storage. The solar seasonal water-pit heat storage system is also an application of this technology[3]. Aristides M. Bonanos et al. [4] proposed a new algebraic solution of thermocline energy storage tank and verified it. Jan Marti et al. [5] improved the exergy efficiency and materials of a thermocline packed bed thermal energy storage system based on cost optimization. Zhaoyu He et al.[6] studied the heat storage performance of traditional single water tank and water tank with paraffin filled bed. The results show that the stratification performance of phase change water storage tank is not as good as that of traditional single tank water storage tank, but the thermal efficiency is higher. Based on the perforated baffle, Wanruo Lou et al.[7] proposed a method to solve the problem of uneven flow distribution in a single tank thermocline storage system. In the traditional single tank, the inlet / outlet will lead to strong mixing of cold and hot fluids, interfere with temperature stratification, and reduce the thermal performance of the tank. In this paper, a method of installing movable heat insulation board in a single tank heat storage is proposed, so as to maximize the separation of cold and hot fluids in the heat storage tank, prevent mixing, and make the heat storage system have higher thermal efficiency.

2. NUMERICAL APPROACH

2.1 Modeling

The research object is a traditional single tank heat storage and a single tank with the same geometric parameters installed with a heat insulation board. The structure of the tank is shown in Fig. 1, and the dimensions are shown in Tab.1.

Tab.1 Structural parameters of heat storage tank

	ϕ	H
tank	1.5	2.4
heat insulation board	1.5	0.02

Based on symmetry, in order to reduce the amount of calculation, the heat storage tank can be simplified and one quarter of the tank body can be selected for simulation.

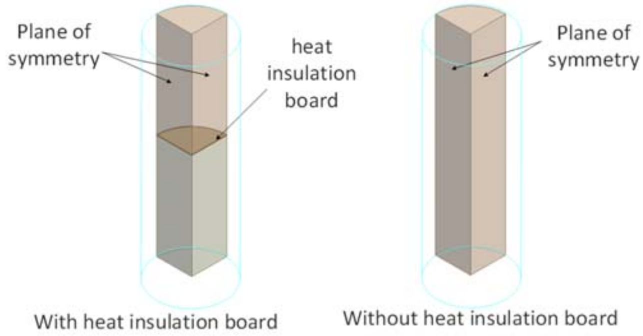

Fig.1 Structural diagram of single tank heat storage

The corresponding grid division is shown in Fig. 2. Special grid densification is carried out for all near wall areas involved in heat exchange.

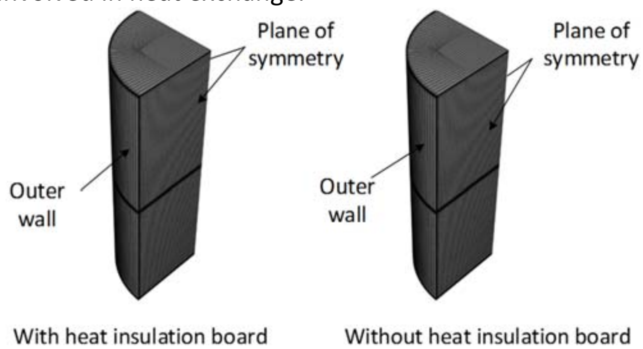

Fig.2 Mesh for simulation

In order to improve the calculation accuracy and reduce the calculation time, the independence of the number of grids is tested. The section at z = 1.211m from the bottom of the heat storage tank is taken as the monitoring surface, and the average temperature of the section after 2000 seconds of operation is taken as the comparison object to test the independence of the models with different number of grids. The results are shown in Figure 3.

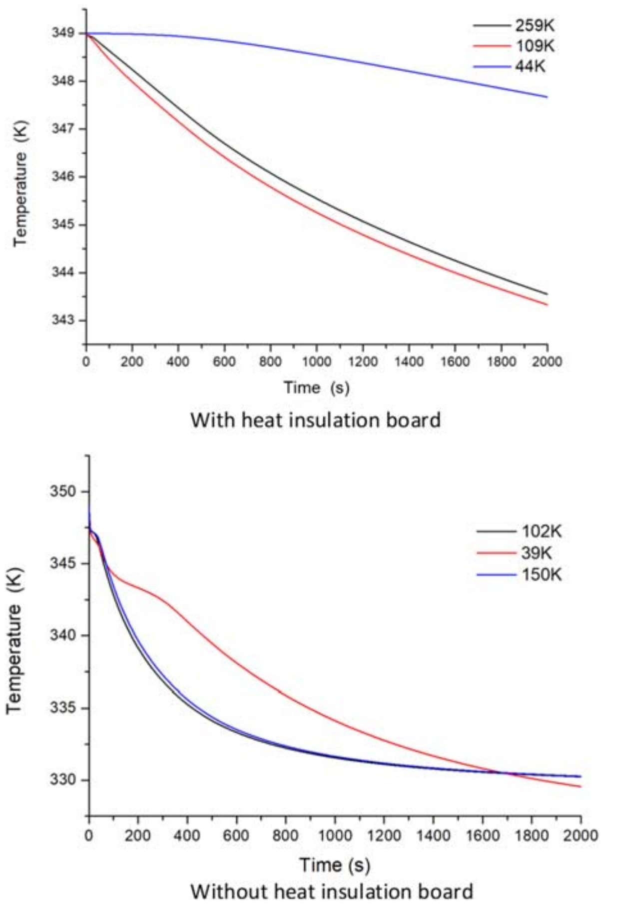

Fig.3 Mesh independent verification

It can be seen from the above results that for the heat storage tank, when the number of grids is greater than 102K, increasing the number of grids will not affect the simulation results. For the heat storage tank with a heat insulation board, when the number of grids is greater than 109K, increasing the number of grids will not affect the simulation results. On the premise of ensuring the accuracy, in order to further reduce the amount of calculation. The monitoring area is established at 1.211m of 102K and 109K grids with different time steps to detect the average temperature of the section after 2000s. The results are shown in Fig.4.

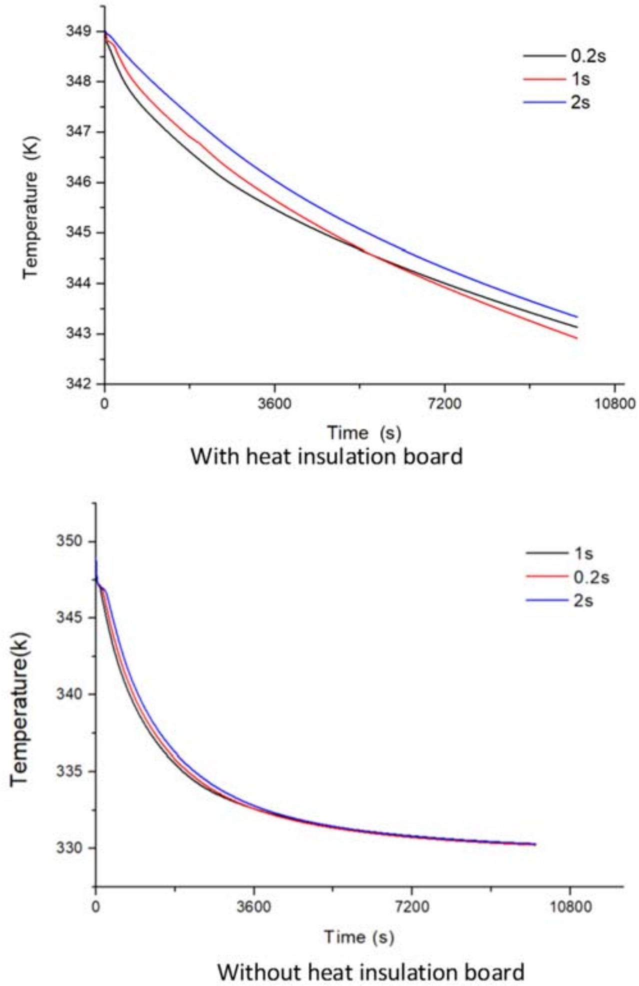

Fig.4 Time step independent verification

According to the results, when the step size of the two heat storage tanks is less than 1s, it will not affect the simulation results. Therefore, 1s is selected as the time step in the following analysis.

2.2 Mathematical model

The governing equation in the fluid region can be expressed as:

$$\frac{D\rho_f}{Dt} + \rho_f \nabla \cdot \vec{V} = 0 \tag{1}$$

$$\rho_f \frac{D\vec{V}}{Dt} = -\nabla p + \mu_f \nabla^2 \vec{V} + \vec{F} + (\mu_f + \lambda)\nabla(\nabla \cdot \vec{V}) \tag{2}$$

$$\rho_f c_{P,f} \frac{DT_f}{Dt} = \rho_f c_{P,f}\left[\frac{\partial T_f}{\partial t} + (\vec{V} \cdot \nabla) T_f\right] = \nabla \cdot (\kappa_f \nabla T_f) + \beta_f T_f \frac{Dp}{Dt} + \mu_f \Phi \tag{3}$$

Boussinesq approximation assumes a linear relationship between density and temperature, and ignores its change in the continuity equation. $\rho_f = \rho_{fi}[1 - \beta_f(T_f - T_{fi})]$. The boundary condition is rigid and there is no slip on the wall. The upper and lower surfaces and side walls conduct heat transfer with the environment. In order to simplify the calculation, the heat transfer coefficient between the tank and the outside world is taken as 2W / (m^2·K)[8]. The physical properties of materials involved in the calculation are shown in Tab.2.

Tab.2 Physical properties of materials

	ρ	c_p	λ
tank	8030	0.5	16.2
heat insulation board	700	2.3	0.2

3. RESULTS AND DISCUSSION

In the initial state, the temperature of the hot fluid in the upper part of the heat storage tank is 349K, the temperature of the cold fluid in the lower part is 309K, and the external ambient temperature is 300K. The temperature distribution in the tank at different times is shown in Fig. 5.

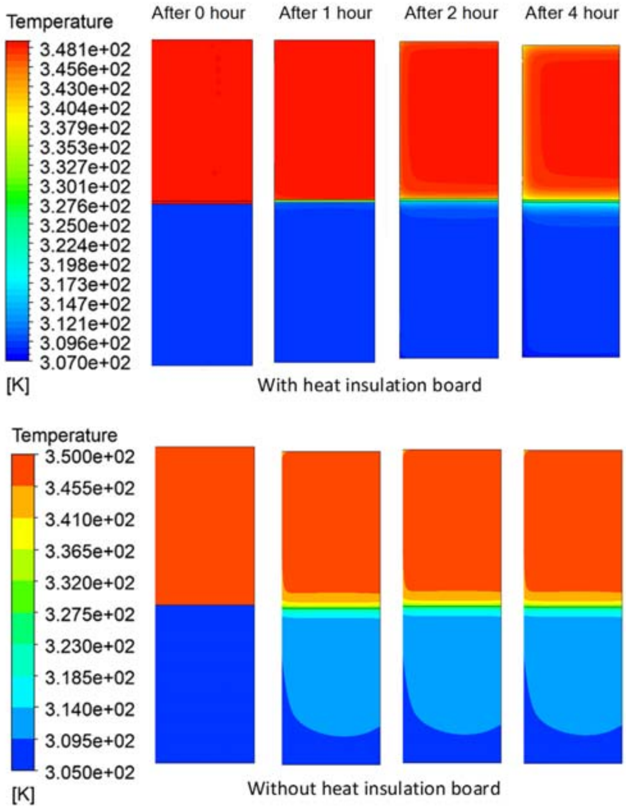

Fig.5 Temperature field in heat storage tank over time

According to the temperature field in Fig. 5, the existence of thermocline layer in the heat storage tank has become the core area for heat exchange of cold and hot fluids. With the increase of time, the thickness of the thermocline layer increases gradually, and the volume proportion of it in the heat storage tank increases gradually. At the same time, due to the convective heat loss on the surface of the heat storage tank, the near wall temperature is lower, and there is an intermediate depression in the thermocline layer. Compared with the traditional heat storage tank without heat insulation board, the existence of heat insulation board prevents the mixing between cold and hot fluids, and significantly reduces the thickness growth rate of the thermocline layer.

In order to clearly show the change of thermocline layer, the temperatures at the heights of 1.15m, 1.18m, 1.2m, 1.22m and 1.25m on the central axis are selected as the monitoring points, and the results are shown in Fig. 6.

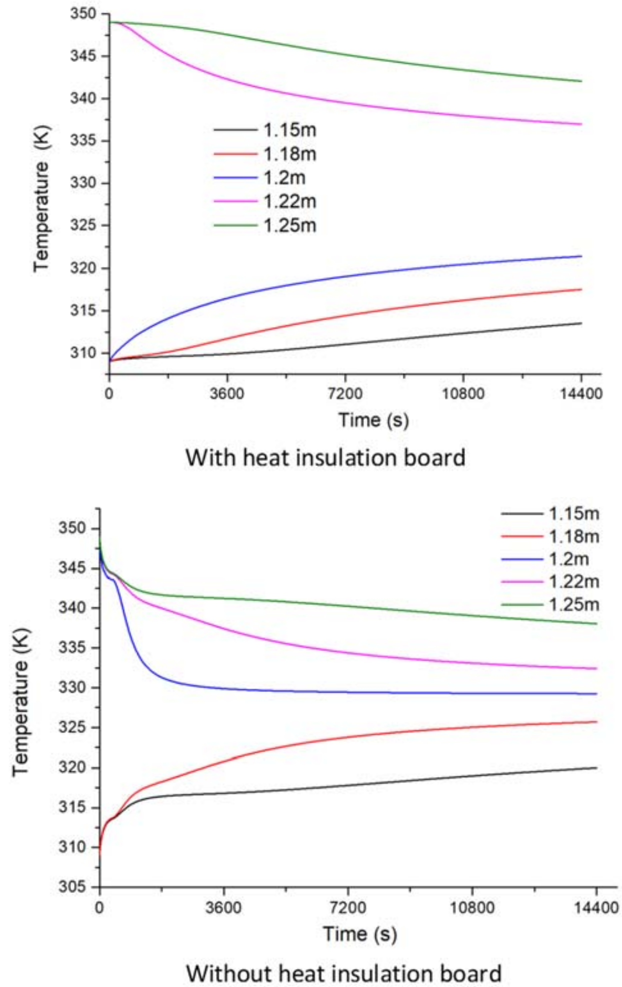

Fig.6 Temperature changes at five monitoring locations in the tank

According to the temperature changes at different monitoring points in Fig.6, the heat insulation board inhibits the violent mixing of cold and hot fluids. Therefore, the temperature gradient at the thermocline layer of the traditional single tank heat storage is smaller than that of the heat storage tank with heat insulation board.

4. CONCLUSIONS

The temperature field of heat storage tank equipped with heat insulation board and traditional heat storage tank is simulated and analyzed. The main conclusions are as follows.

1) Under static conditions, the mixing of cold and hot fluids in the traditional single tank will lead to rapid heat transfer, which is the main factor the maximum fluid temperature. The heat insulation board can prevent mixing, so as to ensure the heat storage system maintains higher exergy.

2) The thermal performance of the heat storage tank can be improved by selecting materials with low thermal conductivity to make heat insulation board.

ACKNOLEDGEMENT

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Initial conditions:

$u=0$, $T_{hot}=363K$, $T_{cold}=303K$, $T_a=283K$