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Simulation on Phase Change Thermal Storage Panel based on Capillary Network

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Abstract

Storage technology has the advantage to solve the problem of the not matching in time and space of energy's supply and demand, making it an effective way to the rational use of resources and reducing environmental pollution. What is used in this paper is a regular flat phase change heat storage module packaging with capillary network and phase change material. In this paper, the software Fluent was used to simulate the impact factors and the ways to enhance heat transfer in the process of phase change. The simulation result indicates that: 1、During the melting process, because of the influence of natural convection, the top of phase change regional melts faster, the temperature contour ramp to top. 2、The higher the horizon is, the temperature contour is more stable. 3、Natural convection play different role in the melting and solidification process, which accelerated melting rate in the melting process, and slowed down in solidification. The surface temperature of phase change thermal storage panel will be maintained at 26.5 ℃, within the limits of human body comfort and is able to improve the air temperature within a certain space.

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Keywords: Phase change thermal storage panel; Phase change heat transfer; Numerical simulation

1. Introduction

Production energy consumption take 20.3% while life energy consumption take 79.7% in rural energy consumption of china. The traditional Kang heating system take a large proportion in life energy consumption, the

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integrated thermal efficiency of traditional Kang heating system is less than 45%, and the average daily indoor temperature of rural building is less than 5℃[1]. To improve the thermal environment of rural building, the phase change thermal storage panel based on capillary network were proposed in this paper.

Phase change materials(PCM) were applied to energy storage and heat preservation, physical state and chemical composition of PCM will change during the phase change process, it absorb heat from environment while melting, and release heat to environment while solidification, this part of energy is called latent heat[2]. The first passive solar house of world was built in Massachusetts by Dr.Maria Telkes [3]. Shapiro et al. put PCM into plasterboard, and it's heat storage capacity is 350KJ/m^2 [4]. Oak ridge national laboratory in the United States have simulated on phase change wallboard, the results indicated that the selection of heating equipment can be reduced to 66% in the similar climate types of Tennessee state and 50% in similar climate types of Denver state [5]. Zhang Hongji studied on phase change heat transfer system, Zhang Yinping et al. researched on improving heat storage capacity of PCM and it's working conditions [6-10]. Kang Yanbing came to the general rule of ventilation at night of phase change heat storage system by simulation and experimental testing [11]. Feng Guohui et al. picked a mixture of two kinds of fatty acids of PCM and developed phase change wallboard [12]. Yan Quanyin et al. have done experimental research on phase change temperature and latent heat of few kinds of paraffin and polyols [13,14].

Nomenclature

PCM	phase change materials
Kang	a heatable brick bed (in north china)
AC	air condition

2. Change Thermal Storage Panel

In this paper, phase change thermal storage panel was proposed to ensure thermal comfort of human body, PCM of 30 phase change temperature and capillary network were packaged in this panel. The trunk main of capillary network can be linked to heat source like solar water heating system or boiler. The capillary network can take full advantage of unstable heat source like solar water heating system as heating terminal. While the water temperature is more than 30℃, heat will be stored. The application of phase change thermal storage panel can reduce the environment pollution caused by burning of fossil fuels. For the northern rural residents of China, the phase change thermal storage panel can be combined to Kang to ensure the local temperature of bed surface. And it can also be applied in the south of China without central heating to reduce the cost of AC and enhance the thermal comfort of human body.

The phase change thermal storage panel is made up of three parts: the shell structure to package PCM and capillary network、the PCM and the capillary network. The structure of phase change thermal storage is shown in Fig1.

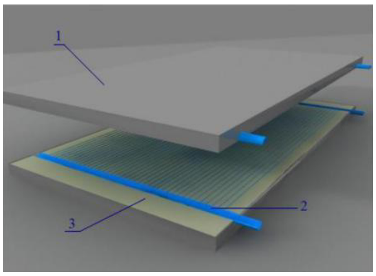

Fig. 1. structure schematic diagram of Phase Change Thermal Storage Panel

According to medical research, the metabolism of human body cell is in direct proportion to environment temperature when it's under 39℃. And human body cell will be damaged during 39-40℃ for 1 hour, will be dead during the temperature of 40-41℃ for 1 hour. Considering the physiology and thermal comfort of human body, the temperature of phase change thermal storage panel should not be too high or too low. The highest temperature should be under 40℃, the lowest temperature should be above 24℃.The mixture of heptadecane and 48# paraffin were used in this paper, the phase change temperature is during 17-49℃[15], According to experience when the temperature of hot water flow past capillary network is during 30-50, it can satisfy the demand of the phase change thermal storage panel.

3. Simulation

3.1. Physical model

The phase change thermal storage panel is rectangular, PCM were packaged between shell structure and capillary network. The left、right、front and back side of shell structure were consider as adiabatic. The hot water flow past capillary network and conduct heat to PCM by heat conduction, PCM begin to melt.

Because of the temperature difference of the flow direction and the direction of PCM's thickness, and the volume change during the melting progress, the effect of natural convection can't be ignored. Heat transfer of PCM happened because the temperature difference of X direction and Y direction by heat conduction. The heat transfer of Z direction can be ignored. The direction of X and Y of hot water flow past capillary network can be ignored too. For the sake of analysis, the following hypothesis are made to physical model .(1)The PCM is isotropous.(2)The thickness and thermal resistance of capillary network can be ignored.(3) The specific heat、heat conductivity coefficient and density of PCM are invariable, and will not change by temperature variation.(4)The hypothesis of Boussinesq is accepted.According to the hypothesis above, one capillary was picked as object of study, shown in Fig2.

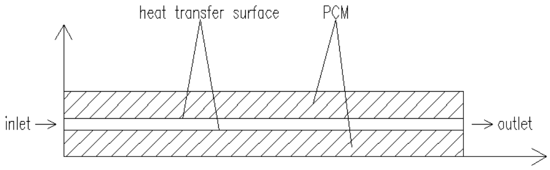

Fig. 2. the selection of computational cell

The object of study is symmetrical, the area of left side and right side can be ignored compare to the surface, can be considered as adiabatic. The lower surface can also be considered as adiabatic when the phase change thermal storage panel was put in a bed. But it can't be considered as adiabatic when the phase change thermal storage panel was put in a Kang.

3.2. Results and analysis of simulation

As shown in Fig2, the height of computational cell is 30mm, the diameter of capillary is 1600mm, the temperature of PCM in the beginning is less than 25℃, the temperature of hot water is 5℃ more than PCM, the velocity of hot water is 0.1m/s.The parameters of water in the Fluent database are selected, the parameters of PCM are shown in table1:

Table 1. Phase change material properties.

parameters	PCM
Density(kg/m^3)	770
Specific heat(j/kg • k)	2500
Heat conductivity coefficient in solidification(w/m • k)	0.296

Heat conductivity coefficient in liquid(w/m・k)	0.15
The starting point for melting(K)	308
Latent heat(j/kg)	230000
Dynamic viscosity(kg/m・s)	0.03
expansivity(1/k)	0.001

The Solidification/Melting model was applied to analyze for several working condition. One of the working condition was analyzed. The operational aspect of this working condition are: the beginning temperature of PCM is 10℃, the inlet water temperature is 40℃, the velocity of hot water is 0.1m/s.

Modling and meshing were made to one capillary according to Fig2. The type of meshing is quadrangular and pave, the separation distance is 1mm. The inside part are defined as fluid region, the outside part are defined as PCM region. The meshing are shown in Fig3.

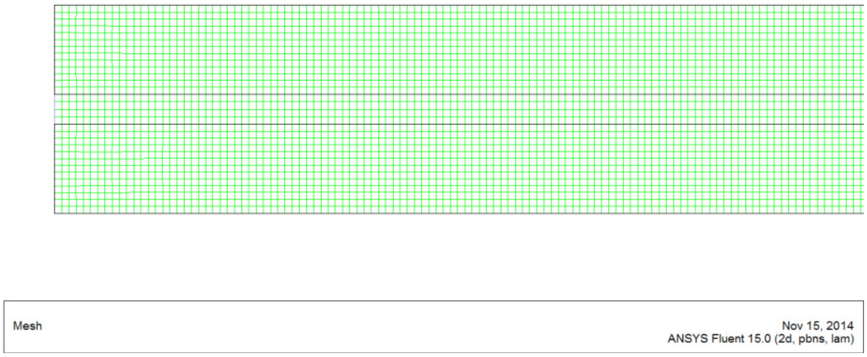

Fig. 3. amplification of computational grid.

The meshing file was lead to fluent15.0, the solver was selected as 2D, implicit and unsteady state. The Solidifiaction/Melting model was applied to simulate the process of phase change. Second-order upwind difference scheme was applied in energy and momentum equation. Pressure gradient of discrete items was PRESTO, SIMPLE algorithm was applied in pressure and velocity coupling. Relaxing factor remained tolerant. The solidus and liquidus were set as 308K, coefficient of cubical expansion was 0.001 1/K, the phase-transiton temperature and the temperature of hot water were set, the inlet was selected as velocity inlet and the outlet as outflow, no information was put in coupling boundary. The initial temperature was set in PATCH, time step was 0.1s.

Liquid proportion versus time are shown in Fig5. The rate of liquid is in direct proportion to time. At the initial phase of melting, the speed of melting is fast, and the migration rate of phase interface is fast. At the end of melting, the melting curve become to be placid, the speed of melting is slow. The rate of liquid is 70% at 5000s, but complete fusion is at 13800s. This is because at the beginning of melting, the amount of PCM in liquid is small, the main way of heat transfer is heat conduction, the effect of natural convection can be ignored, the isothermal level is almost simultaneous to surface. With the increasing amount of liquid, the main way of heat transfer is natural convection. The temperature of PCM near capillary increase, the density decrease, moving towards surface by the effect of buoyancy lift, the melting speed of upper PCM become faster. Back flow happens because the natural convection between liquid PCM and phase interface. At the later period of melting, there are death zone which can't be melted for the reason of the decrease of temperature difference and the PCM's heat transfer coefficient is small. And the complete fusion take a long time.

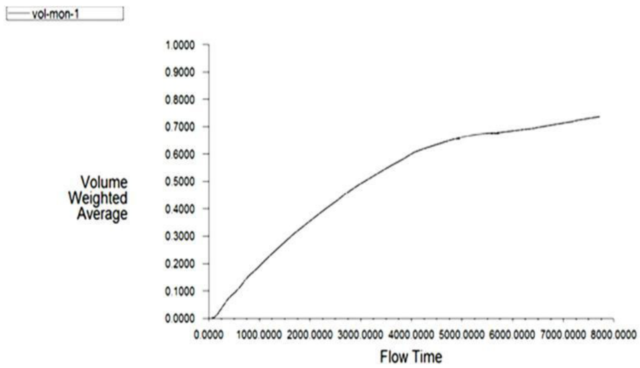

Fig. 4. liquid proportion versus time

Temperature change in phase transformation zone are shown in Fig6. Temperature increase before phase change temperature, when comes to phase change temperature, the temperature begin to wave, the extent of temperature wave increase first and the decrease. When the temperature of test point below phase change temperature, the way of heat storage is sensible heat. And when the temperature of test point comes to phase change temperature, the way of heat storage is latent heat. When comes to complete fusion, the way of heat storage is sensible heat again.

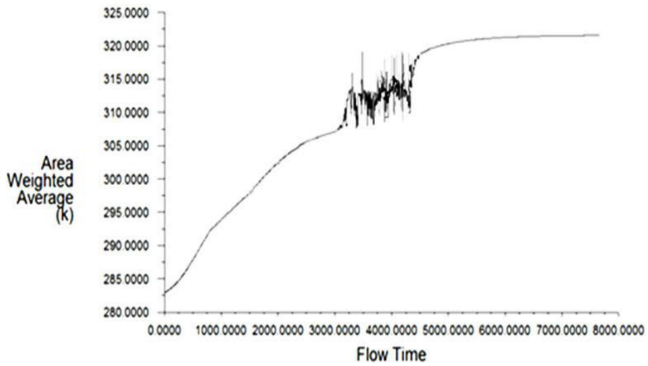

Fig. 5. temperature change curve in phase transformation zone

The temperature scattergram of x=300mm section of different time are shown in Fig6. The center of capillary is y=15mm, is the temperature of hot water and the highest temperature. The lower surface is y=0, the upper surface is y=30mm.

The temperature is decreasing from the center of capillary. And the more near to the center,the temperature gradient is bigger. The temperature increasing and speed of melting is fast because of the strong effect of heat conduction. We can concluded that the temperature is not symmetrical by y=15mm, temperature at right side is higher than left side.

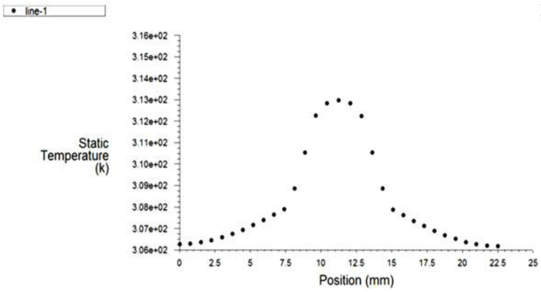

Fig. 6. (a) temperature of x=300mm t=1200s

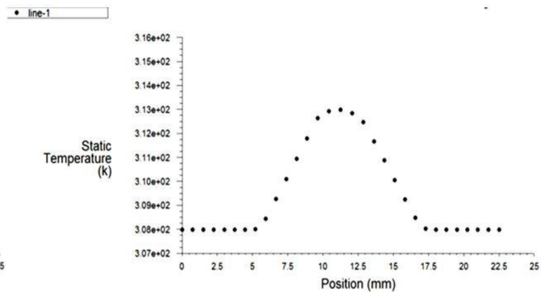

Fig. 6. (b) temperature of x=300mm t=4500s

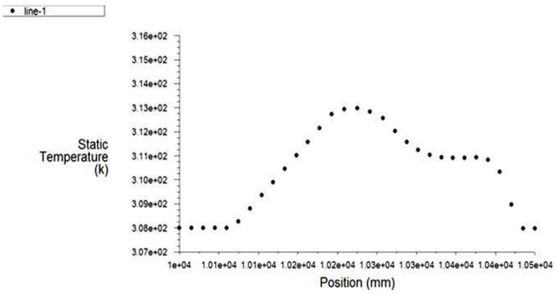

Fig. 6. (c) temperature of x=300mm t=8500s

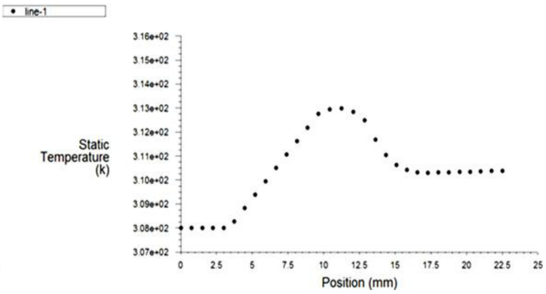

Fig. 6. (d) temperature of x=300mm t=10250s

Simulation were made to 4 working conditions, the parameters and results are shown in table2.

Table 2. The work condition of simulated results.

Parameters	Phase change temperature（K）	Temperature of heat source（K）	Thickness of panel（mm）	Inlet velocity（m/s）	Time of complete melting（s）
Condition1	283	303	25	0.125	13850
Condition2	283	313	25	0.1	10827
Condition3	283	313	30	0.1	14937
Condition4	283	313	30	0.5	14230
Condition5	283	313	35	0.1	19000

The effect of parameters on the time of complete melting can be seen form the table above: the temperature of heat source in condition1 is higher than condition2, and the inlet velocity is smaller, time of complete melting in condition1 is less than condition2; The temperature of heat source is the same in condition3 and 4, the inlet velocity is different, but time of complete melting is the same; The temperature of heat source and inlet velocity is the same in condition3 and 5, the thicker the panel is, the more time for complete melting. We can concluded that the temperature of heat source and the thickness of panel is major factor to time of complete melting, and the effect of inlet velocity can be ignored.

4. Conclusions

1. During the melting process, because of the influence of natural convection, the top of phase change regional melts faster, the temperature contour ramp to top.

2. The higher the horizon is, the temperature contour is more stable.

3. Natural convection play different role in the melting and solidification process, which accelerated melting rate in the melting process, and slowed down in solidification. The surface temperature of phase change thermal storage panel will be maintained at 26.5 ℃, within the limits of human body comfort and is able to improve the air

temperature within a certain space.

4. The temperature of heat source and the thickness of panel is major factors to time of complete melting, and the effect of inlet velocity can be ignored.

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References

[1] M. Liu, X.D. Xia, Research on heating system and energy consumption in rural residence of Liaoning province, Construction Conserves Energy. 35 (2007) 56-59.
[2] L.G. Xiao, H. Sun, The research progress of phase change energy storage material, Journal of Jilin Institute Architectural & Civil. 27 (2010) 2-5.
[3] A.L. George, Solar heat storage: latent heat material, CRC Press. 1983.
[4] S.M .HASNAIN, Review on sustainable thermal energy storage technologyies part 1: Heat storage materials and techniques, Energy Convers Mgmt. 39 (1998) 1127-1138.
[5] T.K. Stovall, J.J. Tomlinson, What are the potential benefits of including latent storage in common wallboard, Trans ASME. 117 318-325.
[6] Y.P. Zhang, H.P. Hu, X.D. Sun, Y.H. Su, Theory and application of phase change energy storage. Hefei: Press of University of Science and Technology of China, 1996.
[7] Z. Li, Y.P. Zhang, Y. Jiang, Effect of specific heat of phase change material on heat charging or discharging performance, Acta Energiae Solaris Sinica. 23 (2002) 27-31.
[8] Y.K. Guo, X.G. Liang, Y.P. Zhang, Simplified method for analyzing the transient thermal performance of composite (phase change) material. Acta Energiae Solaris Sinica. 22 (2001) 27-31.
[9] Y.P. Zhang, Y.H. Su, X.S. Ge, Prediction of the melting temperature and the fusion heat of (quasi-)eutectic PCM, Journal of china university of science and technology. 25 (1994).
[10] Zhang Yinping, Kang Yanbin, Jiang Yi, Applied research of phase change and chemical reaction in the field of energy storage in building heating and air condition, HV&AC, 1999, 29 (5) 34-37.
[11] Neeper D, Benefits of wallboard impregnated with phase change material for residential heating and cooling[R], Final Report for SERI contract DX-9-190371, Los Alamos National Laboratory, Los Alamos, NM.
[12] Feng Guohui, Yu Jin, Liang Ruobing, Feasibility study on the technology of solar energy-phase change wallboard integration[J], Construction Conserves Energy, 2007, 35 (6) 57-59.
[13] Yan Quanyin, Wang Wei, Research on PCM applied in phase change wallboard[J], Energy Conservation Technology, 2004, 22 (6) 364.
[14] Yan Quanyin, Wang Wei, Feasibility research low temperature setting PCM on applied in phase change wallboard[J], New Building Materials, 2005 (1) 13-17.
[15] Liang Chen, Preparation of phase change materials and its application in the wall[D], Beijing: Beijing Institute of Civil Engineering and Architecture: 2004.