Thermomechanical Analysis and Numerical Simulation of Storage Type Multi-Temperature Refrigerated Truck

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Abstract

There exist less-than-carload logistics in the transportation of cold chain logistics. In order to improve the economy of logistics to ensure the quality of fruit and vegetables during transportation, combined with the vacuum insulation technology, a cold storage type multi-temperature refrigerated truck was designed. The cold storage plate was filled with two prepared phase change materials and loaded on the inner wall of the car. The temperature distribution of the refrigerated compartment when it was no-load and loaded was simulated using numerical simulation. The results of this research provide support for the better future design and optimization of cold storage type multi-temperature refrigerated truck, as well as the application of cold storage technology in the fruit and vegetable cold chain logistics.

Keywords

Storage type multi-temperature refrigerated truck, Phase change cold storage, Temperature field, Heat of respiration.

1. Introduction

Refrigerated transportation is essential to reduce food waste and ensure food safety, which in turn affects the environment, water and land resources [1-3]. refrigerated trucks are the main means of transportation in cold chain logistics. With the rapid development of cold chain logistics, the annual growth rate of refrigerated truck demand is about 8% - 12% [4-6]. Compared with traditional refrigerators, Storage Type Multi-Temperature refrigerated trucks have more advantages in economy, flexibility, environmental protection, safety and controllability [7]. The cold source of storage type refrigerated truck comes from cold plate. The cooling process is completed by stably releasing the cold stored in the internal PCM after freezing, and the charging time of cold plate can be selected in the period of low electricity price and low electricity consumption [8].

The PCM has become a research hotspot in the field of energy storage due to their high energy storage density [9]. In the selection of phase change materials, good thermodynamic properties and thermal stability, as well as economy and feasibility of use should be given priority. Yang Ying et al [10] made a composite phase change material with glycol and ammonium chloride, the phase change temperature is 257.15 K, the latent heat of phase change is 206-222 J·g-1, the chemical property is stable, and no nucleating agent is needed. The experiment proves that it can be used as a phase change cold storage material. Min Li et al. [11] mixed 30wt% dodecanol and 70wt% octanoic acid, a low eutectic phase change material with a phase change temperature of 279.67 K, and measured the thermal characteristics of the eutectic mixture when it was filled and cooled. The results show that the dodecanol octanoic acid composite phase change material is a potential material for low-temperature energy storage applications. PCM has great potential in cold chain transportation. The cooling stability of PCM makes it widely used in the transportation of perishable good stuffs [12-13]. Mashup Ahmed [14] studied the thermal insulation materials of the refrigerator car body. The thermal insulation material and structure of the body directly affect the thermal insulation performance, mechanical strength, environmental protection performance and economy of the refrigerator car. The new vacuum insulation board technology can greatly reduce the thermal conductivity and improve the cold insulation time [15-16]. Liu M, et al [17] developed a new refrigeration system which can keep the refrigerator car at the ideal temperature condition by using the new cold plate phase change material. Compared with the existing phase change materials, the newly developed cold plate phase change materials have a lower cost, with a melting temperature of 246.45 K, which is suitable for refrigerated vehicles with a refrigeration temperature of 255.15 K. The analysis shows that the cost of using this system to transport refrigerated products is half of that of conventional transportation.

In order to characterize the temperature field distribution characteristics of refrigeration equipment, researchers at home and abroad have carried out a sea of researchs on refrigeration equipment. Tian Jinjin et al. [18] carried out numerical simulation on the freezing process of eutectic ice in the cold storage plate, and established the apparent heat capacity model for the freezing of eutectic ice in the cold storage plate. He Zhang [19] studied the temperature field distribution of the refrigerated box when it was empty. Each measuring point shall be arranged on the inner wall surface of the box when there is no load. The results show that the temperature field inside the refrigerated container is not uniform, and the temperature difference between the front and the back of the container is large, which is not conducive to the storage of goods. Taking tomato as an example, He Kaiqiang, et al [20] simulated the temperature and humidity distribution in refrigerated containers under different relative air humidity. In steady state, the temperature field inside the vessel is stratified. The temperature distribution of vessel section is basically the same under different relative humidity of air supply. Leave the other parameters unchanged. When the relative humidity of air supply increases, there is no significant effect on the temperature in the box, but the relative humidity in the box increases significantly. Thus, the water loss of the goods is reduced, which is conducive to the refrigerated transportation of fruits and vegetables. Phase change material is added in the refrigeration equipment to make the equipment more suitable for refrigerated food. Zhipeng Guo [21] studied the effect of vacuum insulation plate on the temperature distribution in refrigerated containers. Taking mechanical refrigerated container as the research object, the physical and mathematical models of air convection and heat transfer in the container are established, and the temperature field distribution in the vacuum insulated plate refrigerated container and polyurethane refrigerated container under steady state is simulated. The simulation results show that the distribution of temperature field in refrigerated container is better than that in polyurethane refrigerated container, and the average temperature can be reduced by 0.8k.

From the literature analysis, it can be seen that at present, the cold chain logistics box mainly uses a single temperature range of refrigerant storage and logistics containers for fresh food or drugs in the transportation process. Among them, the combination form of the storage agent and the heat preservation box is generally packaged in bags. There are many inconveniences when loading and unloading goods or stacking goods, and the bag storage agent is easy to be damaged and is not conducive to reuse. The cost of using mechanical refrigeration equipment is high, which is not suitable for the goods with high temperature control requirements in the transportation process. In view of this situation, two kinds of phase change materials were prepared in this paper. The cooling load of the multi temperature storage refrigerator car is calculated by theoretical thermodynamics, and the multi temperature distribution of the refrigerator car is designed. The transient heat transfer model of refrigerated compartment is established, and the effect of no-load and load refrigerated compartment is calculated and analyzed.

2. PCMs preparation

The lauryl alcohol, Octanoic acid and sodium formate used in the experiment were all produced by Aladdin Industrial Company in Shanghai, China, with the purity of analytical purity.

2.1 PCM1: lauryl alcohol-octanoic acid

LA and OA have good stability and no supercooling as PCM. The theoretical eutectic temperature of LA-OA can be determined by formula [22]

$$T_m = \left[1/T_i - \left(R \ln X_i\right)/H_i\right]^{-1} \quad (1)$$

where Ti and Hi are the phase change temperature and latent heat of PCM; Tm is the phase change temperature of the eutectic mixture, Xi is the content of the ith composite contained in the eutectic mixture, and R is the gas constant, 8.314 J·(mol·K)$^{-1}$.

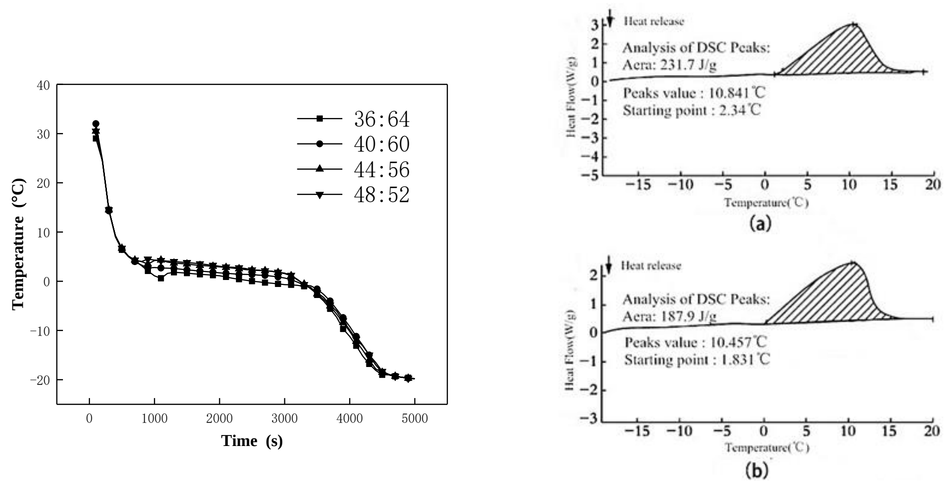

Fig. 1 Cooling and DSC curves of LA - OA

The calculated ratio is LA-OA = 44.6:55.4 by mass. According to the small concentration change, four ratios were selected, namely 36:64, 40:60, 44:56, 48:52. The step cooling curve was measured in a low temperature bath. Considering the factors of transformation temperature, transformation platform and supercooling, the LA-OA with mass ratio of 36:64 and 40:60 was selected. The latent heat of phase transformation was measured by DSC. When the mass ratio of LA-OA is 40:60 and 36:64, the starting point of phase transition temperature is 275.49 K and 274.981 K, and the latent heat of phase transition is 231.7 J·g^{-1} and 187.9 J·g^{-1}. The latent heat of LA-OA with mass ratio of 40:60 is relatively high, and its thermal conductivity is 0.324 W·(m·K)-1measured by Hot Disk. The LA-OA with this mass ratio was selected as the cool storage material in the multi temperature zone for further study.

2.2 PCM2: Sodium formate aqueous solution

According to the melting point theory of eutectic phase change materials, the theoretical low eutectic ratio is predicted. The concentration of sodium formate aqueous solution at 258.15 K is about 17%, and the four ratios are 17:83, 19:81, 21:79 and 23:77 respectively. The step cooling curve was measured, the latent heat was measured by DSC, and the thermal conductivity was measured by hot disk. Considering the factors of phase transformation temperature, phase transformation platform and supercooling degree, the sodium formate solution with 21% ratio was selected. The phase transformation temperature was -15.6 °C, and the latent heat of phase transformation was 276.1 J·g^{-1}, and its thermal conductivity is 0.914 W·(m·K)$^{-1}$. The 21% sodium formate solution was chosen as the cool storage material in the multi temperature zone.

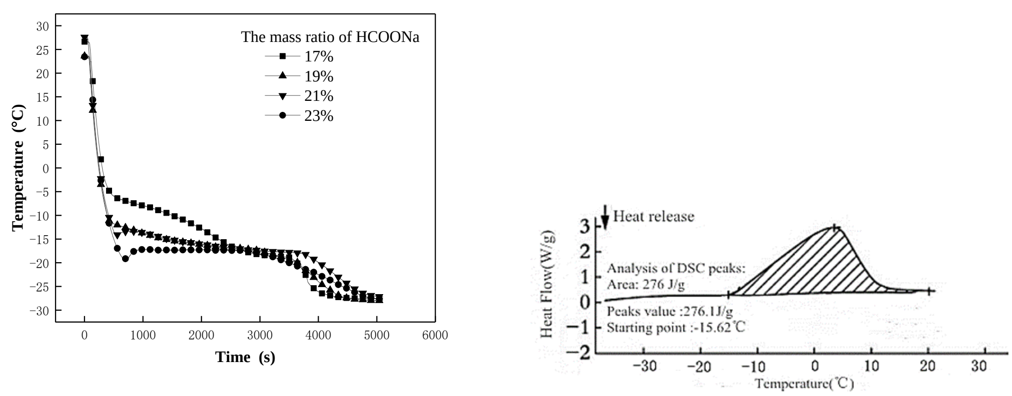

Fig. 2 Cooling and DSC curve of fractions HCOONa-H_2O

2.3 Safety aspects

Consideration needs to be given to the safety of the PCM and the heat transfer fluid when used in food transportation applications. The inorganic salt aqueous solution used as the PCM is classified as dangerous in Food Safety Law 2009/CHINA. It will cause irritation to skin and eyes and is slightly hazardous in case of ingestion. However, the PCM is sealed in cold plate and is not corrosive or reactive to plastic. The heat exchange from the PCM is via an intermediate heat transfer fluid. As long as the cold plate is tightly sealed, the whole refrigeration system will be safe for food transportation.

3. Storage system description

3.1 Refrigerated lorry design

The carriage is composed of six parts, namely, top plate, bottom plate, left and right side walls, front wall, back wall and door. Due to the requirements of the thermal insulation of the car, its skeleton should have the dual functions of bearing and heat breaking. The metal structure with high strength and rigidity is selected as the main frame for Bearing purpose. The auxiliary skeleton for the purpose of heat insulation, namely, the heat insulation bridge, is installed on the inner side of the main skeleton. The inner and outer skin of the carriage are respectively connected with the main frame and the auxiliary frame, forming a space filled with thermal insulation materials. In order to prevent the whole cargo from being damaged, the inner surface of the metal inner skin is installed with inner plywood inner skin. The skin and skeleton are connected by riveting. The frameless space between the inner and outer skin is a thermal insulation layer filled with thermal insulation materials.

The structure of refrigerated car is divided into pieces. The independent heat insulation layer of the car wall is made of the sandwich board prefabricated adhesive processing technology, and then the pieces are assembled into a complete car. The thermal insulation material of the car body is composed of 15 mm thick polyurethane board and 10 mm thick vacuum insulation board. The thermal conductivity of the selected polyurethane insulation board is 0.025 $W\cdot(m\cdot K)^{-1}$, and that of the vacuum insulation board is 0.003 $W\cdot(m\cdot K)^{-1}$.

The calculation formula of the total heat transfer coefficient K of the refrigerated chamber is as follows:

$$K=\frac{1}{\frac{1}{\alpha_1}+\frac{\delta_1}{\lambda_1}+\frac{\delta_2}{\lambda_2}+\frac{\delta_3}{\lambda_3}+\frac{\delta_4}{\lambda_4}+\frac{1}{\alpha_2}} \tag{2}$$

By substituting the data into the formula, $K = 0.243\ W\cdot(m^2\cdot K)^{-1}$.

The external dimension of the refrigerator car is designed as 2000 × 1200 × 1200 mm, and the external volume of the car is 2880 L. The car body is prefabricated and spliced with "sandwich" plate, and 15 mm thick polyurethane plate and 10 mm thick vacuum heat insulation plate are used as heat insulation materials. The thickness of FRP skin material inside and outside the car body is 2.5 mm, and the total thickness of the car body plate is 45 mm.

3.2 Multi-temperature zones design

Double temperature zone shall be designed according to the type of goods loaded. The compartment is divided into two zones separated by the intermediate insulation board. The inner box is regarded as two temperature zones, with the size of 935 × 1110 × 1110 mm. The temperature range of TI is 275.15 - 281.15 K, which is the fresh-keeping area of fruits and vegetables drinks, and also the transportation temperature range of refrigerated drugs; the temperature range of TII is 259.15 - 263.15 K, which is the light freezing area, which can keep the nutrition of food well; it is also the transportation temperature range of cold remedies.

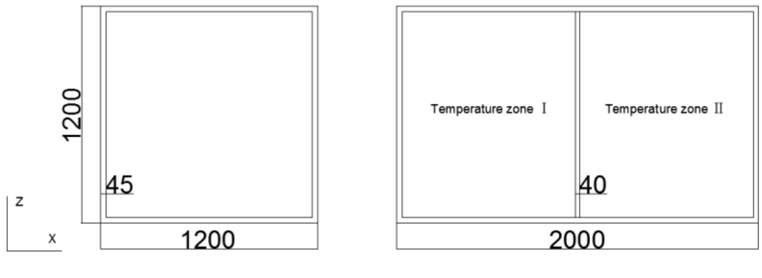

Fig. 3 Diagram of refrigerated compartment

In consideration of the discontinuity of heat transfer phenomenon of the intermediate insulating plate, it is assumed that the two temperature zones are insulated from each other, and the cargo have been precooled. The ambient temperature is set as 293.15K. empirical value. Considering the Respiration heat of cargo, the heat insulating time of the designed refrigerated compartments is 8 h. The PCMs packed in TI and TII are the prepared LA-OA with the mass of 7.42 kg and 6.7 kg, respectively.

4. Theoretical modeling

4.1 Model simplification and calculation area selection

This paper takes refrigerated department as the research object. Temperature zone is divided by theoretical calculation size. The PCM is evenly filled with the cold plate, which is attached to the front, rear, left, right and upper surfaces of the box in TI and TII.

4.2 Assumption

1) Air, PCMs, and insulating materials are isotropic;

2) The air and cold storage materials agree with the Boussinesq viscosity hypothesis;

3) Thermal resistance is not considered;

4.3 Governing equation

1) Mass conservation equation

$$\nabla(\rho_f \upsilon) = 0 \tag{3}$$

2) Momentum conservation equation

$$\frac{\partial(\rho_f \upsilon)}{\partial \tau} + \nabla(\rho_f \nu) = -\nabla p + \nabla(\mu \nu) + S \tag{4}$$

3) Energy conservation equation in phase change models

$$d_z \rho C_p \frac{\partial T}{\partial t} + d_z \rho C_p u \cdot \nabla T + \nabla \cdot q = d_z Q + q_0 + d_z Q_p + d_z Q_{vd} \tag{5}$$

Using apparent heat capacity formulation solve the heat equation after specifying the properties of PCM. Instead of adding a latent heat L in the energy balance equation exactly when thematerial reaches its phase change temperature Tpc, it is assumed that the transformation occurs in a temperature interval between Tpc − ΔT / 2 and Tpc + ΔT / 2. In this interval, the material phase is modeled by a smoothed function, θ, representing the fraction of phase before transition, which is equal to 1 before Tpc − ΔT / 2 and to 0 after Tpc + ΔT / 2.

4.4 Initial and boundary conditions

1) The ambient temperature of the refrigerated component is 293.15 K. The heat transfer coefficient between the component and the external environment is taken as the above calculated value, K=0.243 $W\cdot(m^2\cdot K)^{-1}$. When the cooling capacity released by the refrigeration system is in balance with the ambient temperature, the internal environment of the vehicle body reaches a stable state.

2) Because the heat transfer in fruits and vegetables is mainly driven by temperature gradient, the convection term is 0, and the heat generated by respiration and transpiration is defined as generalized heat source term Q_{TP} [23]

$$Q_{TP} = Qresp + Qevap \tag{6}$$

$$Q_{resp} = \rho p\, m_1(T_p + 17.8)m_2 \tag{7}$$

for the apple, $m_1 = 4.59\times10^{-5}$, $m_2 = 2.66$.

$$Q_{evap} = C_1T_p + C_2T_p + C_3 \tag{8}$$

for the apple, $C_1=9.1$, $C_2=-7.4129\times10^3$, $C_3=3.8751\times10^6$.

4.5 Numerical procedure and mesh sensitive analysis

For the present research, the governing Eqs. (4)-(13) together with Initial and boundary conditions mentioned above were solved by the Comsol Multiphysics software in the finite element method. The expansions of Taylor series is used to discretize each partial differential equation [24]. The mesh quality is especially significant for stability and accuracy of numerical computation. To obtain accurate results, the mesh needs to be refined as much as possible, however, it will lead to longer calculation times. Therefore, it is necessary to balance the efficiency of computing and the accuracy of results and it is advisable to shorten the calculation time as much as possible while ensuring accuracy. We used an unstructured gird made up of triangular elements in this work because adaptive remeshing is implemented in an automated way in Comsol Multiphysics software. For the sake of testing the effect of mesh quality, we tried to seek for the optimum cell number using three cases: normal mesh (24909 triangular elements), fine mesh (35719 triangular elements) and finer mesh (47098 triangular elements). Compared with finer mesh, the accuracy had no remarkable increase when extra fine mesh was used. Inversely, it consumed more computation time. Therefore, we employed the fine mesh finally. The schematic diagram of grid is presented in Fig.4 The time step of Δt = 10 s are chosen as to the unsteady-state numerical calculations,. In the simulations based on Comsol Multiphysics, the backward differentiation formula (BDF) method was selected for the time stepper. And the iterative method used by solver was the generalized minimal residual method (GMRES)

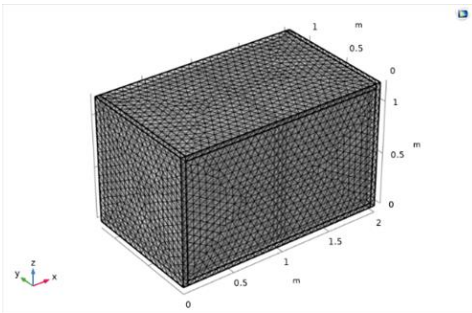

Fig. 4 Geometric model with mesh.

5. Results and discussion

Refrigerated component provides suitable storage environment for goods. This paper mainly studies the distribution of temperature field inside refrigerated component. The surface temperature distribution of goods can directly reflect the distribution of temperature field inside refrigerated component. In the post-processing, it is found that the surface temperature distribution of the left and right two trains of goods is symmetrical with respect to the longitudinal section in the middle of the compartment, and in consideration of the symmetry of the physical model geometry of the refrigerated compartment and the homogenization of the physical properties of the materials used, in order to show more clearly the distribution of the surface temperature field in the cargo area, the longitudinal section view shows the difference of the temperature field distribution in different positions in the compartment. According to the temperature requirements of the goods to be loaded, the safe temperature range of TI is set as 275.15 - 281.15 K, and that of TII is set as 259.15 - 263.15

K. In view of the three different working conditions of no-load in two temperature zones, loading fruits and vegetables in TI and quick frozen food in TII, loading refrigerated drugs in TI and loading frozen drugs in TII, the geometric center point and temperature field in temperature zone are analyzed.

5.1 Temperature profile of refrigerated compartment in empty

The temperature curve of the internal measuring point when the refrigerator is empty is shown in Figure 8. When refrigerated compartment is in empty, the initial temperature in the compartment is the same as the ambient temperature, and the cold plate is put into the corresponding temperature zone. At the beginning of the temperature drop, the cooling capacity of this part mainly comes from the sensible heat of PCM. With the release of sensible heat, the temperature of PCM decreases to the phase change temperature, and the temperature of the measurement point in the chamber tends to be stable. Through the gradual release of latent heat of PCM in the cold plate, the safe temperature range of TI and TII is maintained at 9.2 h and 6.2 h. It is different from the theoretical design time because the thermal conductivity of the intermediate insulation board is taken according to the actual value, and TI and TII are not treated according to the heat insulation zone, so the thermal conduction of the intermediate insulation board have an impact on the safe temperature time maintained in TI and TII.

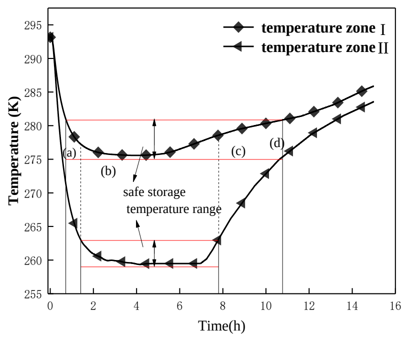

Fig. 5 Temperature curve of refrigerated compartment in empty

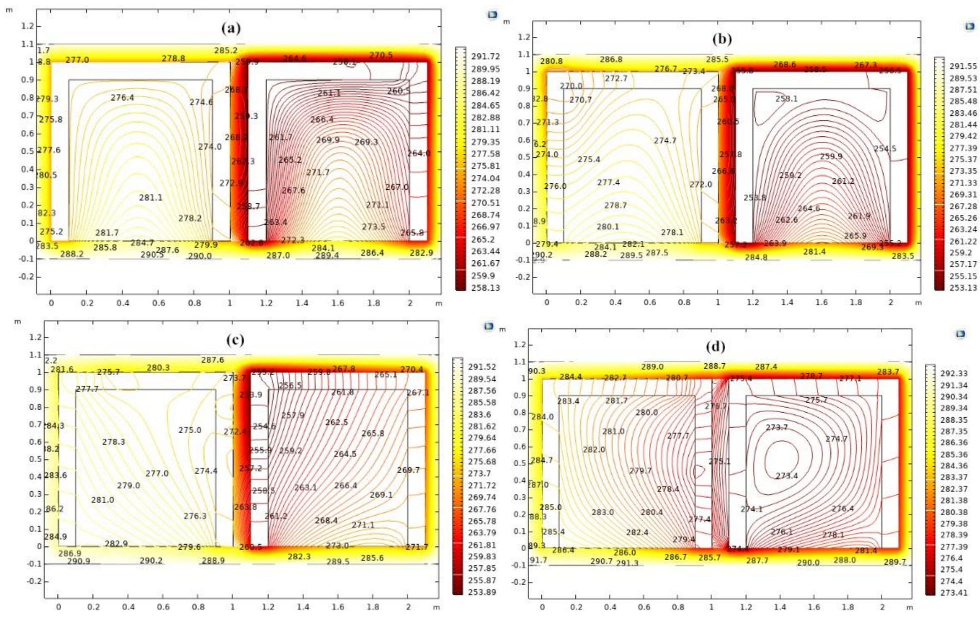

Fig. 6 Isothermal chart of refrigerated compartment in empty

The safe temperature range division of refrigerated transportation equipment is set by the temperature range demand of transportation goods. Select the start and end time of the safe temperature range to analyze the temperature distribution in the compartment. From the isotherm diagram, due to the convection heat transfer between the wall and the outside environment, the air temperature gradient near the wall becomes larger and the temperature uniformity is poor. Compared with isotherms, the temperature distribution in the compartment presents an inverted "U" shaped wave like diffusion from the bottom to the top, which also conforms to the actual situation of the arrangement of the cold storage unit above. Under the action of gravity, the cold air delivered by the cold plate diffuses and decays to the lower part of the compartment, resulting in the low intensity of convection heat transfer at the bottom of the compartment. The cooling range in this area is correspondingly small, and the uneven distribution of the temperature field intensifies, which will pose a threat to the quality and safety of the goods.

5.2 Temperature profile of refrigerated compartment with filled

When the goods are out of the cold storage, they are precooled to the corresponding safe temperature range. When the refrigerated compartment with filled, the two working conditions are simulated respectively for TI for loading fruits and vegetables and TII for loading quick frozen food, and TI for loading refrigerated drugs and TII for loading frozen drugs. The difference between the two working conditions is whether there is respiratory heat in the goods. Two physical models are built, one is to add internal heat source. Because the heat transfer in fruit is mainly driven by temperature gradient, and the convection term is zero, the respiratory heat is simplified as a linear source; Another ignored the respiratory heat as the contrast, the other conditions remained the same. Under the same time scale, the temperature distribution of the two models and the temperature change of the cargo were compared.

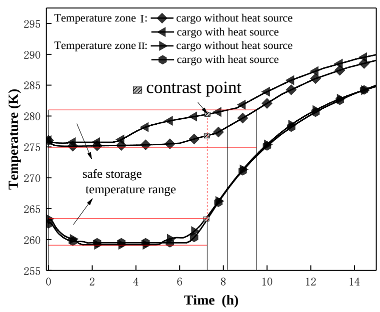

Fig. 7 Temperature curve of refrigerated compartment with filled

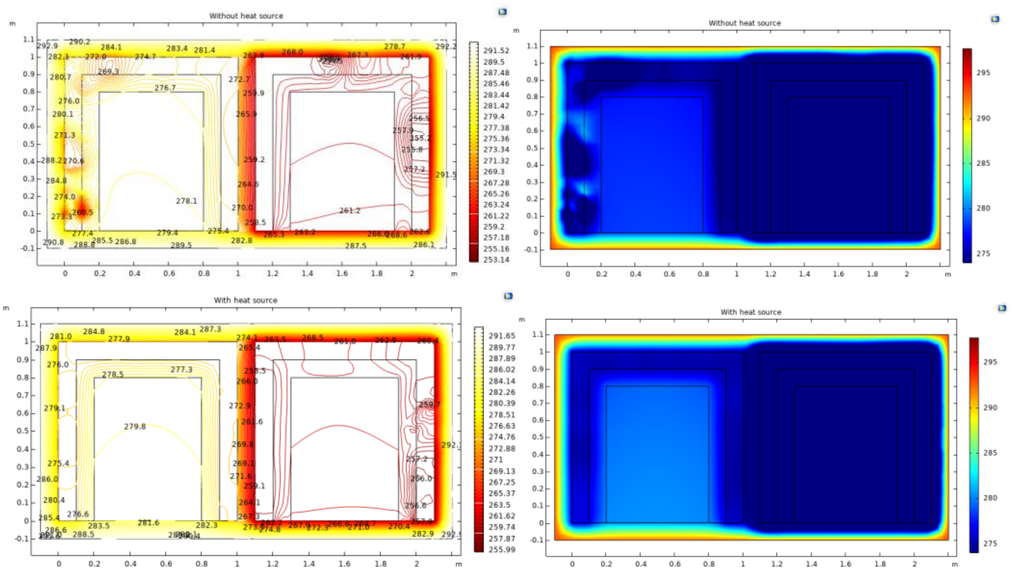

Fig. 8 Contrast diagram of temperature distribution in different working conditions of refrigerated compartment

Compared with the temperature curve of the temperature zones, the time difference of TI in the safe temperature range is 82 min. In the model, respiratory heat is modeled as a linear source, and the increment of respiratory heat is a power function with the increase of temperature. It can be seen from the temperature nephogram that their temperature distribution characteristics are roughly the same. When there is inner heat sources in the refrigerated compartment, the heat transfer resistance is high, and the gradient change is not as obvious as that without heat sources. Therefore, in order to improve the simulation accuracy of the cold storage compartment, the inner heat sources should not be ignored. Because there is a insulation board in the middle of the two temperature zones, the inner heat sources in TI has little influence on the cargo temperature in TII, and the temperature distribution of TII is relatively consistent.

6. Conclusions

(1) Two kinds of PCMs were prepared for cold chain logistics, and thermal properties and thermal stability were studied. The phase transition temperature and latent heat of LA-OA and HCOONa · $2H_2O$ were 2.34 °C and - 15.6 °C, 231.7 $J\cdot g^{-1}$and 276.1 $J\cdot g^{-1}$. The prepared PCMs featured superior phase change temperature and latent heat, thermal stability and high thermal conductivity for thermal energy storage in cold chain logistics.

(2) The storage type multi-temperature refrigerated compartment with an external dimension of 2000 × 1200 × 1200 mm was designed. A polyurethane board with a thickness of 15 mm and a vacuum insulation board with a thickness of 10 mm were used as the thermal insulation materials. The cooling load of the refrigerator compartment was calculated considering the convection heat transfer, thermal conduction and respiration heat. The usage of PCMs was 7.42 kg and 6.7 kg respectively.

(3) According to the theoretical design of refrigerated compartment, the mathematical model was simplified, and the three-dimensional unsteady model was established. The temperature field in the compartment was simulated. When the refrigerated compartment was in empty, the safe temperature range of TI and TII was maintained at 9.2 h and 6.2 h. There is a difference between the experimental value and the theoretical value because of the thermal conductivity of the intermediate insulation board. Compared with the two physical models, the effect of respiration heat on the temperature distribution was analyzed. In order to improve the simulation accuracy of the cold storage compartment, the internal heat source should not be ignored.

Acknowledgements

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References

[1] A. Rai, S.A.Tassou. Energy demand and environmental impacts of alternative food transport refrigeration systems, Energy Procedia, vol. 123 (2017), 113-120.

[2] H.X. Zhao, S Liu, C.Q. Tian, et al. An overview of current status of cold chain in China, International Journal of Refrigeration, vol. 88 (2018), 483-495.

[3] S. Mercier, S. Villeneuve, M. Mondor, et al. Time-temperature management along the food cold chain: a review of recent developments, Comprehensive Review in Food Science and Food Safety, vol. 16 (2017) No. 4, 647-667.

[4] S.J. James, C. James. The food cold-chain and climate change, Food Research International, vol. 43 (2010), 1944-1956.

[5] J.G. Liu, J. Lundqvist, J. Weinberg, et al. Food losses and waste in China and their implication for water and land, Environmental Science&Technology, vol. 47 (2013), 10137-44.

[6] G.X. Hong. Refrigerated trucks with great potential of cold chain transportation will become the pillar of the industry, Journal of Development & Reform, vol. 1 (2017), 37-41

[7] N Zhang, Y.P. Yuan, X.L. Cao, et al. Latent Heat Thermal Energy Storage Systems with Solid-Liquid Phase Change Materials: A Review. Advanced Engineer Materials, vol. 20 (2018) No. 6, 1700753.

[8] D.C. Jose Pereira, P. Eames. Thermal energy storage for low and medium temperature applications using phase change materials - A review, Applied Energy, vol. 177 (2016), 227-238.

[9] C. Veerakumar, A. Sreekumar. Phase change material based cold thermal energy storage: Materials, techniques and applications - A review, International Journal of Refrigeration, vol. 67 (2016), 271-289.

[10] Y. Yang, H.Y. Yan, H.Y. Shen. Development of a low temeperature phase transforming composed material for cool storage, Journal of Superconductivity Incorporating Novel Magnetism, vol. 23 (2010) No. 6, 1115-7.

[11] M. Li, H.T. Kao, Z.S. Wu, et al. Study on preparation and thermal property of binary fatty acid and the binary fatty acids/diatomite composite phase change materials, Applied Energy, vol. 88 (2011) No. 5, 1606-1612.

[12] J. Blackburn, G. Scudder. Supply chain strategies for perishable products:The case of fresh produce, Production and Operations Management, vol. 18 (2009) No. 2, 129-137.

[13] J.H. Johnstona, J.E. Grindroda, M. Dodds, et al. Composite nano-structured calcium silicate phase change materials for thermal buffering in food packaging, Current Applied Physics, vol. 8 (2008), 3-4.

[14] M. Ahmed, O. Meade. Reducing heat transfer across the insulated walls of refrigerated truck trailers by the application of phase change materials, Energy Conversion and Management, vol. 51 (2010), 383-392.

[15] X.F. Xu, X.L. Zhang, S. Liu. Experimental study on cold storage box with nanocomposite phase change material and vacuum insulation panel, International Journal of Energy Research, vol. 42 (2018) No. 14, 4429-4438.

[16] W.W. Xu, X.L. Zhang. Preparation and Thermophysical Properties of Nanometer Copper Oxide/Octylic-myristic Acid as PCMs for Thermal Energy Storage, Materials Review, vol. 30 (2016), 60-64.

[17] M. Liu, W. Saman, F. Bruno. Development of a novel refrigeration system for refrigerated trucks incorporating phase change material, Applied Energy, vol. 92 (2012) No. 4, 336-342.

[18] J.J. Tian, Y.G. Guo, Z. Zhang, et al. Numerical simulation and experiment research on cold plate freezing process, Cryogenics & Superconductivity, vol. 42 (2013) No. 2, 67-71.

[19] Z. Zhang, J.. Hao, M. Li, et al. Theoretical and Experimental Study on Temperature Field Inside Refrigerated Containers, Cryogenics and Superconductivity, vol. 6 (2016), 76-80.

[20] K.Q. He, C.L. Zhuang, X.F. Yang, et al. Influence of air supply relative humidity on temperature and humidity field in reefer container, Journal of Ordnance Equipment Engineering, vol. 10 (2017), 103-109.

[21] Z.P. Guo, A.K. Yan, F. Yang, et al.The Temperature Distribution in Refrigerated Containers with Vacuum Insulation Plates, Journal of Nanjing University of Aeronautics and Astronautics, vol. 49 (2017) No. 01, 29-33.

[22] Y.P. Zhang, Y.H. Su. Theoretical prediction of melting point and melting heat of eutectic phase change materials, Journal of University of Science and Technology of China, vol. 25 (1995) No. 4, 474-478

[23] X.Q. Chen, L.X. Lu, J. Wang. Numerical simulation and verification of differential pressure precooling temperature field of fruit in inner packing box, Transactions of the Chinese Society of Agricultural Engineering, vol. 30 (2014) No. 12, 249-257

[24] A. Fopah-Lele, F. Kuznik, H.U. Rammelberg. Thermal decomposition kinetic of salt hydrates for heat storage systems, Applied Energy, vol. 154 (2015), 447-458.