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Research Article

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Effect of thickness of heat insulating material in bulkhead on cabin temperature of reefer ship for agricultural products

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ABSTRACT

To select the suitable thickness of heat insulating material for the bulkhead of reefer ship for agricultural products, a steady state three-dimensional mathematical model of bulkhead is set up in this paper. The calculational conditions of the heat transfer model are defined according to the heat transfer process and reasonable simplification. Numerical simulations are performed using computational fluid dynamics (CFD) software PHOENICS as the thickness of heat insulating material, rigid polyurethane foam, is different. The obtained temperature distributions of the model in each case are analyzed. The suitable thickness is pointed out according to the effect of the thickness of heat insulating material on heat transfer property of the bulkhead.

Key words: Thickness of heat insulating material, Reefer ship, Bulkhead, Numerical simulation

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INTRODUCTION

Along with the development of economic globalization, refrigerated marine transportation has become the most important mode of transporting imports and exports of drugs and perishable agricultural products. To keep up original qualities of drugs and agricultural products, and for the the growing shortage of energy sources, the energy-saving measures of reefer ship is paid high attention to. So the requirement of thermal insulation property of bulkhead is much higher, for it can reduce energy consumption and enhance economic efficiency during the refrigerated transportation [1-2].

In recent years, experts and scholars of the world have done lots of researches on the heat transfer property of the ship cabin [3-12]. Kinds of heat insulating material for reefer ship are compared and analyzed in detail in document [3-7]. It is pointed that rigid polyurethane foam is the best heat insulating material in document [7].

The bulkhead of reefer ship is regarded as research object in this paper, and a steady state three-dimensional mathematical model of heat transfer is set up. The heat transfer model is simplified reasonably, and the calculational conditions are defined according to the heat transfer process. The temperature fields of this system are simulated and calculated using CFD software PHOENICS as the thickness of heat insulating material, rigid polyurethane foam, is different. The obtained temperature distributions of the model in each case are analyzed. The effect of the thickness of heat insulating material on heat transfer property of the bulkhead is investigated.

EXPERIMENTAL SECTION

Arithmetic element of heat-transfer model

A tiny part of the bulkhead of reefer ship is picked out and used as an arithmetic element of the heat transfer model, as shown in Fig.1. The size of the model is defined as X×Y×Z=240 (190, or 220) mm×600mm×1000mm. The structure layers of the bulkhead from external to internal are [13]: steel plate, heat insulating material, two layers of asphalt felt, and decorative veneer. In the layer of heat insulating material, there are a piece of 125mm×80mm×7mm angle steel as reinforced material and a piece of 100mm×50mm wood liner material every 600mm in Y-direction. The angle steel and wood liner material are connected together by bolts.

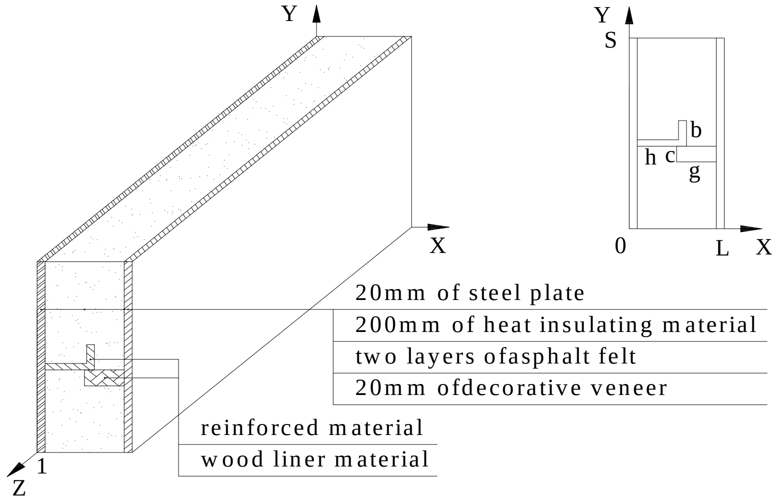

Fig.1 The arithmetic element of heat transfer model for the bulkhead of reefer ship

Model assumptions

The heat transfer process of the bulkhead is very complex in fact. But to facilitate solving and analyzing, the heat transfer model is simplified and assumed reasonably. These assumptions are as follows: Firstly, the heat transfer process of the bulkhead is assumed to be a steady state heat conduction process of three-dimensional. Secondly, the materials in the same structural layer of the bulkhead are assumed to be homogeneous, isotropic and with constant physical properties. Lastly, the thermal resistance of the asphalt felt layer, the thermal contact resistance between each layer, the heat transfer caused by bolts in the layer of heat insulating material and the moisture transfer are all assumed to be negligible.

Equation and boundary conditions

The research object is the bulkhead of reefer ship which sails on the North China Sea in summer in this paper. There is not heat source in the bulkhead of reefer ship, so the steady state three-dimensional differential equation of heat conduction of the arithmetic element of the heat-transfer model may be described as follow:

$$\frac{\partial^2 t}{\partial x^2}+\frac{\partial^2 t}{\partial y^2}+\frac{\partial^2 t}{\partial z^2}=0. \tag{1}$$

The boundary conditions of the arithmetic element are defined as follows:

The design temperature of the indoor air of the reefer ship cabin is defined as: t_n =5°C. There are fan blowers in the reefer ship, therefore the heat convective coefficient of the inner surface of the bulkhead of reefer ship is defined as: α_n =12W/m^2·°C [14]. So the boundary condition of the inner surface of the bulkhead is:

$$-\lambda\frac{\partial t}{\partial y}\Big|_{y=L_2}=\alpha_n\left(t_n-t_{nb}\right)=12\times\left(5-t_{nb}\right). \tag{2}$$

Where, λ is the heat conduction coefficient of each kind of material (W/m·°C), t_{nb} is the temperature of the inner surface of the bulkhead (°C).

In view of the increase in temperature of the outer surface of the bulkhead of reefer ship caused by solar radiation, the temperature of the outer surface of the bulkhead is defined as: t_w =40°C [2]. So the boundary condition of the outer surface of the bulkhead is:

$$t\big|_{x=0}=t_w=40\,°\text{C} \tag{3}$$

In the layer of heat insulating material, the angle steel as reinforced material and wood liner material are symmetrically placed every 600mm in Y-direction, so in the arithmetic element as shown in Fig.1, the two boundary surfaces of the model in Y-direction are approximately seemed as adiabatic surfaces and the boundaries are:

$$\frac{\partial t}{\partial y}\Big|_{y=0} = \frac{\partial t}{\partial y}\Big|_{y=S} = 0 \quad (4)$$

Similarly, the two boundary surfaces of the model in Z-direction are also approximately seemed as adiabatic surfaces and the boundaries are:

$$\frac{\partial t}{\partial z}\Big|_{z=0} = \frac{\partial t}{\partial z}\Big|_{z=1} = 0 \quad (5)$$

RESULTS AND DISCUSSION

Simulation results of heat-transfer model

When the thickness of heat insulating material is 150mm, 180mm or 200mm, and the other simulation conditions are not changed, numerical simulations of the heat transfer model of the bulkhead of reefer ship are performed using PHOENICS software. The obtained temperature distributions of the bulkhead of the model in each case are shown in Fig.2, Fig.3and Fig.4. The temperature distribution curves of points on inner surface of bulkhead and heat insulating layer in each case are shown in Fig.5, Fig.6 and Fig.7.

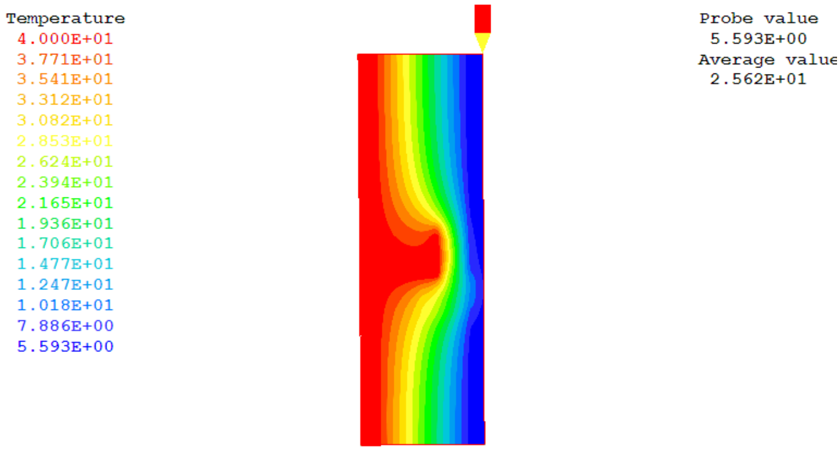

Fig.2 The temperature distribution of the model with 150mm heat insulating material

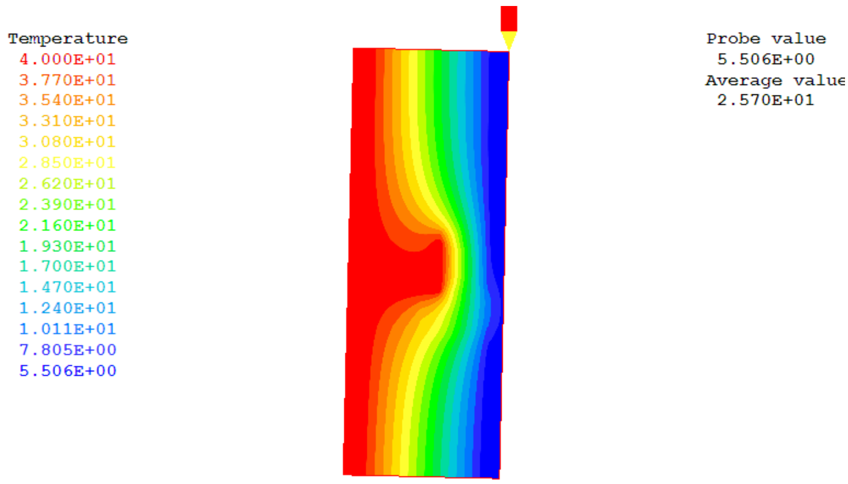

Fig.3 The temperature distribution of the model with 180mm heat insulating material

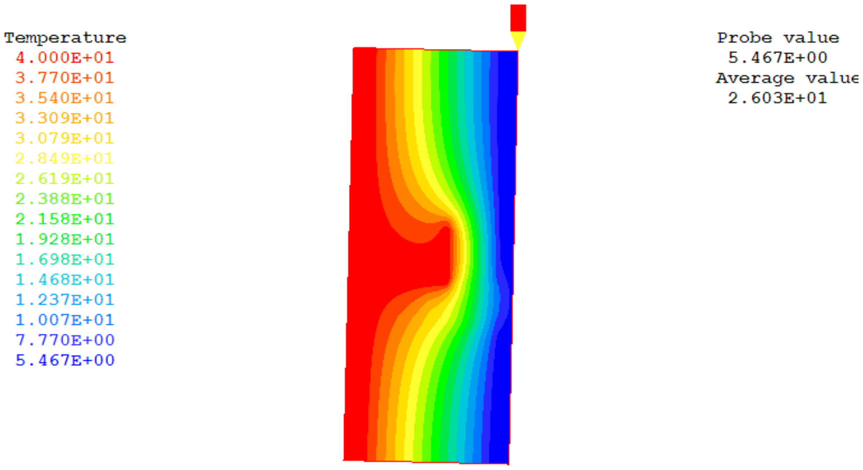

Fig.4 The temperature distribution of the model with 200mm heat insulating material

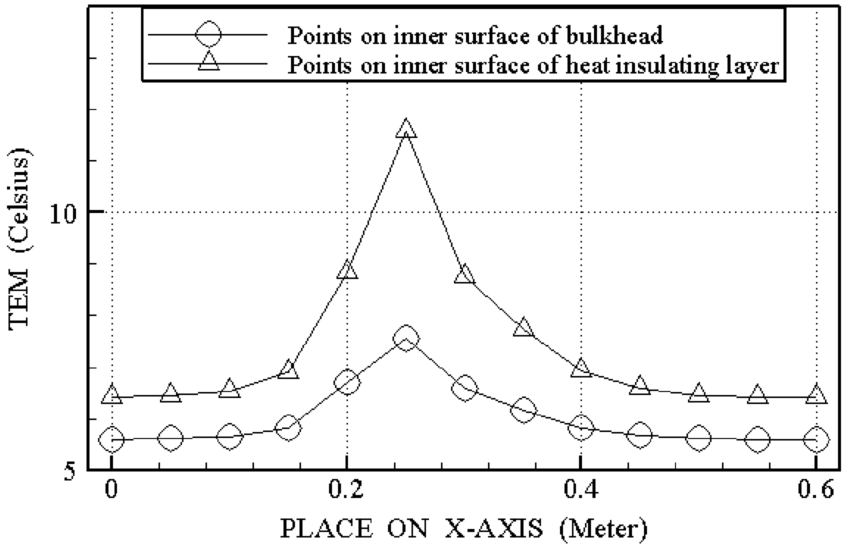

Fig.5 The point temperature distributions of inner surface of the bulkhead and 150mm heat insulating layer

The obtained numerical results are shown in Fig.2 and Fig.5 when the thickness of heat insulating material is 150mm. The average temperatures of the inner surface of bulkhead and the heat insulating layer are 6.03°C and 7.45°C. The temperature fluctuation amplitudes of each point on the inner surface of the bulkhead and the heat insulating layer are 1.98°C (from 5.59°C to 7.57°C) and 5.17°C (from 6.41°C to 11.58°C).

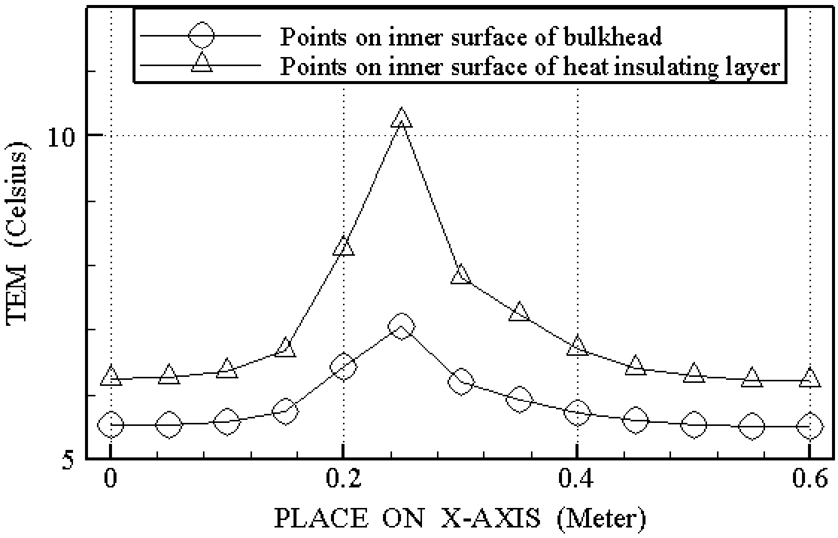

Fig.6 The point temperature distributions of inner surface of the bulkhead and 180mm heat insulating layer

The obtained numerical results are shown in Fig.3 and Fig.6 when the thickness of heat insulating material is 180mm. The average temperatures of the inner surface of bulkhead and the heat insulating layer are 5.86°C and 7.05°C. The temperature fluctuation amplitudes of each point on the inner surface of the bulkhead and the heat insulating layer are 1.53°C (from 5.51°C to 7.04°C) and 4.03°C (from 6.21°C to 10.24°C).

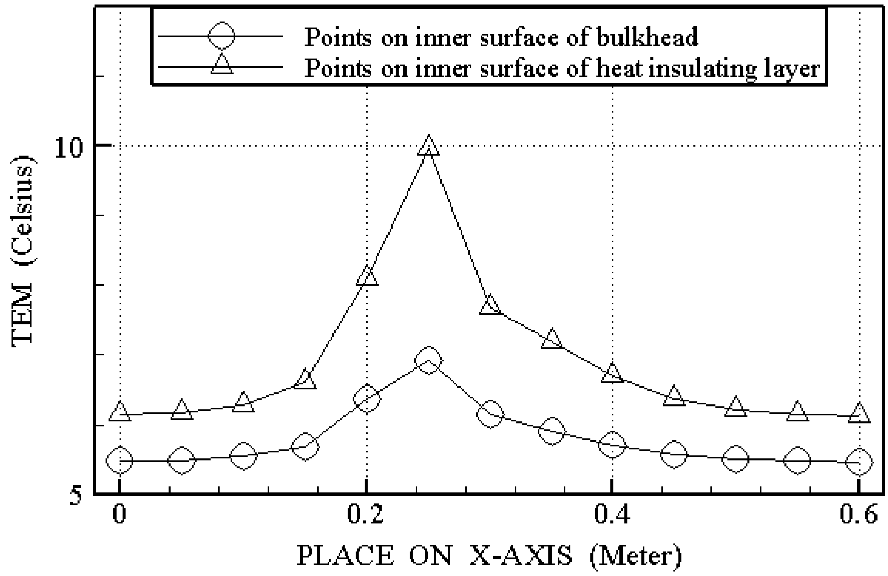

Fig.7 The point temperature distributions of inner surface of the bulkhead and 200mm heat insulating layer

The obtained numerical results are shown in Fig.4 and Fig.7 when the thickness of heat insulating material is 200mm. The average temperatures of the inner surface of bulkhead and the heat insulating layer are 5.81°C and 6.95°C. The temperature fluctuation amplitudes of each point on the inner surface of the bulkhead and the heat insulating layer are 1.46°C (from 5.47°C to 6.93°C) and 3.84°C (from 6.12°C to 9.96°C).

Numerical results analyzing

In terms of the obtained temperature distribution figures, the numerical results are analyzed. In each case, the temperature distribution of each point on the inner surface of the bulkhead is more regular than that on the inner surface of the heat insulating layer, and the temperature fluctuation amplitude is smaller, too. These indicate that the inside decorative veneer of the shipboard insulates the heat transfer further. On the inner surface of the bulkhead, the temperature is higher in the position that is close to the contact surface of wood liner material. This indicates that the heat resistance of the wood liner material is smaller comparatively, so the wood liner material plays a role of thermal bridge and intensifies the heat transfer. It is not good to insulating the heat coming from the outside of the bulkhead.

When the thickness of the heat insulating material is bigger, the average temperatures of the inner surface of the bulkhead and the heat insulating layer are both lower, and the temperature fluctuation amplitudes of each point on the two inner surfaces are both smaller. These indicate that when the heat resistance of the heat insulating material becomes bigger, the overall heat transfer coefficient of the bulkhead decreases, the heat transferred from outside to inside of the bulkhead reduces substantially. Therefore the average temperatures of the inner surface of the bulkhead and the heat insulating layer can both remain lower.

CONCLUSION

Based on the developed model of the bulkhead of reefer ship, performing numerical simulations and analyzing the obtained temperature distributions, some conclusions are summarized as follows:

The obtained average temperatures of the inner surface of the bulkhead are all near the design temperature of the indoor air of the reefer ship cabin (5°C) in every case of the model. It follows that the heat insulating materials of three different thicknesses can all insulate the heat coming from the outside of the bulkhead very well.

When the thickness of heat insulating material is 180mm or 200mm, the effectiveness is respectively better than which of 150mm, and the average temperature difference of the inner surface of the bulkhead are too tiny and can be ignored. If the thickness of heat insulating material is 180mm, the thickness of the bulkhead is thinner, too. The effective space of reefer ship can be increased, as well as the usage amount of heat insulating material is cut down. The average temperature of the inner surface of the bulkhead is very satisfying. Therefore, based on an overall consideration of various factors, the proper thickness of heat insulating material is 180mm under the simulation conditions of this paper.

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REFERENCES

[1]Yizhi Li, Guoliang Hu, Fucai Hu. Marine Auxiliary Machinery, 1st Edition, China Communications Press, Beijing, **2001**; 151-154.
[2]Chibin Yu, Anzhong Gu. Marine Refrigerating Plant, 1st Edition, National Defence Industry Press, Beijing, **1980**; 319-346.
[3]Zisen Yu. *Marine Equipment/Materials & Marketing*, **2005**, 13(5), 28-30.
[4]Mingwei Shi. *Marine Technology*, **2005**, 33(3):32-34.
[5]Shuanshi Qin. *Refractories*, **2003**, 37(5), 298-300,302.
[6] Xuemei Chen. *Fishery Machinery and Instrument*, **1994**, 21(2), 21-23.
[7] Jingfu Jia, Wei He. *Advanced Materials Research*, **2011**, 311 - 313(9), 1953-1956.
[8] Srashti Dwivedi, Priyanka Jain. *Journal of Chemical and Pharmaceutical Research*, **2013**, 5(6), 12-13.
[9] Lingfeng LI, Changhui XU, Yunxia CHEN, et al. *Journal of Chemical and Pharmaceutical Research*, **2013**, 5(9), 555-562.
[10] Boyang Li, Diyang Li. *Navigation of China*, **2008**, 31(4), 352-355,382.
[11] Liu Jie-qun, Chen Lu-wang, Liu Jin-long. *Journal of Chemical and Pharmaceutical Research*, **2013**, 5(9), 362-371.
[12] Zhao Xi, Zhang Zhimin, Zhang Baohong. *Journal of Chemical and Pharmaceutical Research*, **2013**, 5(9), 549-554.
[13] Gang Wu. Marine Refrigeration and Air-Conditioning, 1st Edition, National Defence Industry Press, Beijing, **2009**; 101-125.
[14] Jianhua Li, Chun Wang. Refrigerating House Design, 1st Edition, China Machine Press, Beijing, **2003**; 19-42.