Journal of Materials, Processing and Design (2021) 5: 12-15
Clausius Scientific Press, Canada

DOI: 10.23977/jmpd.2021.050102
ISSN 2516-0923

Modeling and Analysis of Human Heat transfer in Cryogenic Protective clothing based on the principle of Heat transfer

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Keywords: Heat transfer, cold clothing, Fourier law, the third kind of boundary condition

Abstract: In this paper, the simulation of low temperature protective clothing with phase change material is taken as the research object, and the model based on heat conduction equation is established through Fourie heat transfer law, various heat transfer modes and three kinds of boundary conditions. Based on the principle of heat transfer, two kinds of heat transfer modes, heat conduction and heat convection, are mainly considered in this paper. First of all, through the analysis of the heat transfer mechanism of low temperature protective composites in low temperature environment, the boundary conditions of thermal insulation layer and fabric layer are the third kind of boundary conditions, which can be regarded as a convective heat transfer process. Then the partial differential extraordinary model can be established according to the boundary conditions. The interior of the thermal insulation layer, the functional layer and the fabric layer are heat conduction, which can be solved by establishing a model according to Fourier law. Then this paper simulates the above two models and uses the implicit post-difference scheme (Crank method) to solve them in parts.

1. Introduction

On some specific occasions, people often need to work in extremely cold weather, such as working in high mountains, divers working underwater, cryogenic workshops in modern factories and field operations in cold climates. In order to make the work go smoothly, scientists have been studying cryogenic protective composites, trying to make protective clothing to protect workers in cryogenic environments.

The scenario studied in this paper is: suppose the experimenter is standing near the Great Wall Station in Antarctica. At that time, the environment was quiet and there was no wind on a sunny day,-40 °C. In this paper, we use the principle of heat transfer to analyze the heat transfer mechanism of cryogenic protective composites in low temperature environment, and establish a mathematical model of heat transfer.

We explain the heat transfer mechanism according to the heat transfer of the object in material science. Because the protective clothing is made of phase change material, the phase in this problem changes into solid phase and liquid phase. When the temperature is lower than a certain temperature, the interlayer will no longer release heat. Although the whole process is dynamic, in the first question, because the human body is in a static state, the existence of dynamic thermal resistance does not need to be considered for the time being. According to this, we can establish the empirical formula between the influencing factors and the protective effect index.

2. Analysis of cold protection mode of low temperature protective clothing with phase change material

The warm clothing is composed of three layers of composite structure (see figure 1). The boundary conditions of the outer and inner layers of the first and third layers are the third kind of boundary conditions. for the process of convective heat transfer, the model can be established according to the common boundary conditions of heat conduction problems. The interior of the first layer, the second layer and the third layer is heat conduction, and the model can be established according to Fourier law.

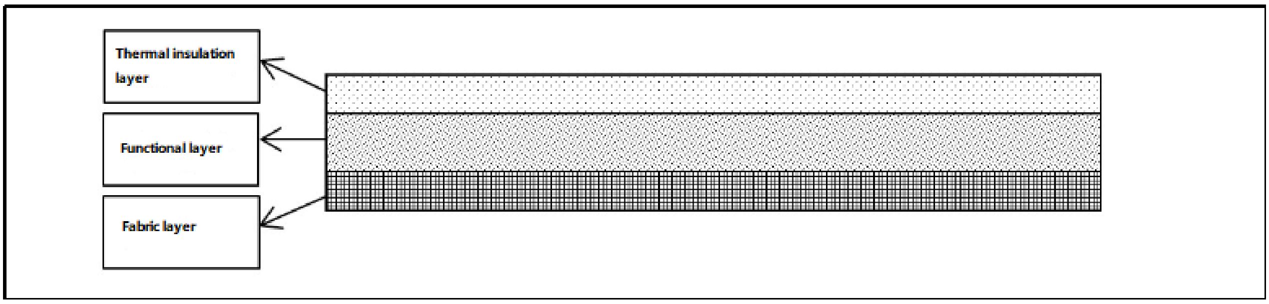

Figure 1. Structural schematic diagram of low temperature protective composites

3. Determination of heat conduction equation

The temperature change on the outside of the skin of Antarctic researchers results from the heat exchange between the layers of Antarctic environment and protective clothing and between the skin of Antarctic researchers, which can be described by unsteady heat conduction equation. Next, we establish the coordinate system, determine the heat conduction equation of each layer and the corresponding boundary conditions in turn, and finally give the model.

The heat conduction equation in a three-dimensional uniform medium satisfies the following equation:

$$\frac{\partial T}{\partial t}=\alpha(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2})+\frac{1}{c\rho}q \tag{1}$$

α、c、ρ is the thermal diffusivity, specific heat and density of the medium, respectively. T describes the change of temperature with time. $\frac{\partial^2 T}{\partial x^2}$, $\frac{\partial^2 T}{\partial y^2}$, $\frac{\partial^2 T}{\partial z^2}$ describes the variation of temperature with space. $\frac{1}{c\rho}q$ describes the effects of internal heat sources. Under the experimental condition of work suit test, there is no heat source in each layer.This formula (1) is simplified to:

$$\frac{\partial T}{\partial t}=\alpha(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}) \tag{2}$$

In order to further simplify the model, we regard each layer as a parallel infinite plate, and establish the principle analysis diagram of one-dimensional protective clothing as shown in figure 2.

Although the protection obeys the shape and geometry, it is a three-dimensional model, but for this problem, because:

1. The boundary conditions are uniformly distributed, and the heat transfer can be regarded as perpendicular to the surface of the skin.
2. The heat source of the second layer is uniform, so it is of little significance to study three-dimensional heat transfer.

So simplify the formula (3) to:

$$\frac{\partial T}{\partial t} = \alpha \frac{\partial^2 T}{\partial x^2} \tag{3}$$

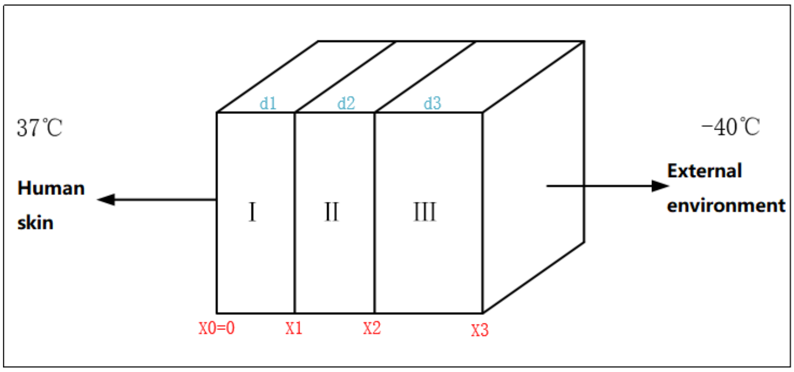

Figure 2. Principle Analysis Diagram of one-dimensional Protective clothing

And for different layers, the thermal diffusivity αi is different, and the corresponding layered heat conduction equation for i is:

$$\frac{\partial T_i}{\partial t} = \alpha_i \frac{\partial^2 T_i}{\partial x^2} \tag{4}$$

4. Dynamic Thermal Resistance of Protective clothing and its influencing factors

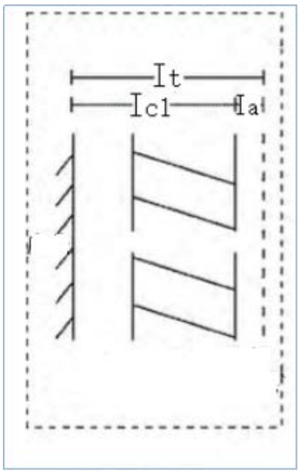

Figure 3. Principle diagram of thermal resistance change in static state

Because the dynamic change of thermal resistance caused by thermal convection needs to be considered in the analysis of protective clothing, the fundamental reason for the change of thermal resistance is that the wind and the movement of the experimenter cause forced convection between the human body and the environment, which promotes its heat transfer. As a result, the change of thermal resistance shows different rules in different clothing, because the dynamic change of thermal resistance under static condition is negligible, so the principle diagram of thermal resistance change in static state is given below, which is convenient to consider the windy environment in the second question.

5. Conclusion

In this paper, based on the principle of heat transfer, the two heat transfer modes of heat conduction and heat convection are mainly considered to model the scene of the problem solved. Firstly, we analyzed the heat transfer mechanism of the cryogenic protection composite at low temperature. The boundary conditions of the insulation layer and the fabric layer are the third type of boundary conditions, which can be regarded as a convective heat transfer process. Only we have established the partial differential nonconstant model according to the boundary conditions. For heat conduction inside the heat insulation layer, the functional layer and the fabric layer, we selected Fourier law to establish the model and solve.

Acknowledgements

Fund No.: Q20202504

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