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EFFECTS OF THE WEIGHTS OF THE EVAPORATORS ON THE CHARACTERISTICS OF A HOUSEHOLD REFRIGERATOR-FREEZER

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ABSTRACT

As a household refrigerator is on/off controlled, the heat capacities of different parts besides the heat resistances influence the characteristics of the appliance. This paper studies how to calculate the temperature changes when considering both the heat resistances and the heat capacities. How to accurately calculate the influences of the weights of evaporators on the thermal characteristics of domestic refrigerators is especially studied.

Through numerical simulation of a household refrigerator-freezer, the actions of the weights of the evaporators are analyzed. We find that the weights also influence the energy consumption.

INTRODUCTION

For a continuously running refrigerating appliance, the weights of the evaporators do not obviously influence its characteristics, only the resistances of heat transfer are important. But for a domestic refrigerator-freezer which is on/off controlled, the weights of the evaporators not only influence the temperature variation inside the rooms, but also influence the energy consumption. So we should study how to accurately calculate the action of the weights of evaporators on the appliance characteristics.

An evaporator is one part of a refrigerator and the consideration of its action effects should be combined with the whole system. Many researchers have done a lot of work on numerical simulation of refrigerators, but most of the researches are on the refrigerating system, and the calculation of dynamic heat transfer need to be developed. Through the study of the effects of the weight of the evaporator, we can improve the calculation of dynamic heat transfer and simulate the whole appliance more accurately.

We have studied the calculation of dynamic heat transfer because of the need of appliance simulation. At first we used equivalent single layer method in the solving of dynamic heat transfer equations of the thermal insulation wall. In this case, the influence of the rank order of different slabs can not be reflected, and the accuracy is limited. (See Ref.4) In Ref.3, the model and the calculation method are improved, and the effect of ranking of different thermal insulation slabs on the heat transfer is reflected. But the evaporator is treated as one part of the thermal insulation box (for freezer) or neglected because of its light weight (for refrigerator). This should be improved, and the effects of the weights of the evaporators should be correctly reflected.

MODELS AND CALCULATIONS

1. System analysis

In our country, household freezer-refrigerators are widely used. Although there are some differences between the freezer and the refrigerator, the mechanisms of heat transfer are similar, and we can simplify their heat transfer process in the same way. (see Fig.1). Q_0 is the heat transferred to the outside face, Q_i is the heat transfer from the inner face to the air inside the chamber, Q_{ei} is the heat absorbed by the surface of the evaporator, and Q_e is the heat absorbed by the refrigerant. T_i , T_0 and T_e are the temperatures of the air outside the chamber, inner air, and the refrigerant differently. We do not take account the temperature differences of inner air in the same chamber, but the temperature difference of the air outside different surface of the chamber should be considered. One of the outside temperatures is the inner temperature of freezing chamber (to refrigerating chamber) or that of the refrigerating chamber (to freezing chamber).

When we simulate the dynamic running process of an actual appliance, the determination of parameters of even one moment have to iterate many times, and dynamic simulation is more complex. In order to shorten the CPU time, we have to study how to simplify the calculation.

We have already used the response coefficient method in the calculation of temperature variation (see Ref.4.). By this way, a lot of complex calculation can be finished before the appliance simulation. When calculating the temperature changes of inner air, we only need plus a certain amount of terms, with the help of the response coefficient which is already got. If we have to solve the dynamic heat transfer equations in the iteration calculation of simulating the dynamic running process , the order of calculation time magnitude will be much larger.

2. Response coefficient of the case (without evaporator)

The case of a household refrigerator has several faces, each of them is made up of several layers of plate. First we study the calculating method of the coefficient of single face which is made up of several layers of different material.

To a wall which consists of n layers of plate, the transfer function can be set up.

$$\begin{bmatrix} T_0(s) \\ q_0(s) \end{bmatrix} = \begin{bmatrix} A(s) & B(s) \\ C(s) & D(s) \end{bmatrix} \begin{bmatrix} T_i(s) \\ q_i(s) \end{bmatrix} \qquad (1)$$

here

$$\begin{bmatrix} A(s) & B(s) \\ C(s) & D(s) \end{bmatrix} = \prod_{i=1}^{n} \begin{bmatrix} A_i(s) & B_i(s) \\ C_i(s) & D_i(s) \end{bmatrix} \qquad (2)$$

$\begin{bmatrix} A_i(s) & B_i(s) \\ C_i(s) & D_i(s) \end{bmatrix}$ is transfer function matrix of the ith layer

$$\begin{cases} A_i(s) = D_i(s) = \mathrm{ch} \sqrt{\frac{s}{a_i}}\, l_i \\ B_i(s) = - \dfrac{\mathrm{sh} \sqrt{\frac{s}{a_i}}\, l_i}{\lambda_i \sqrt{\frac{s}{a_i}}} \\ C_i(s) = - \lambda_i \sqrt{\frac{s}{a_i}}\; \mathrm{sh} \sqrt{\frac{s}{a_i}}\, l_i \end{cases} \tag{3}$$

a_i, l_i, λ_i are the temperature confusion coefficient, depth and heat conduction coefficient of the ith layer separately.

$$Q_0(s)=q_0(s)$$

$$= \sum_{i=1}^{m} \left(\frac{FB}{D}\right)_i T_0(s) - \sum_{i=1}^{m} \left(\frac{F}{B}\right)_i T_{1i}(s) \tag{4}$$

$$T_0(s) = \frac{1}{\sum_{i=1}^{m} \left(\frac{FB}{D}\right)_i} \left[Q_0(s) + \sum_{i=1}^{m} \left(\frac{F}{B}\right)_i T_{1i}(s) \right] \tag{5}$$

m is the number of the faces, F_i is the area.

The triangle wave response coefficient G_0 and G_{1i} which are corresponding to

$$\frac{1}{\sum_{i=1}^{m} \left(\frac{FB}{D}\right)_i} \quad , \quad \left(\frac{F}{B}\right)_i$$

separately, can be calculated consulting Ref.2 and Ref.4.

let

$$Q_1(s) = \sum_{i=1}^{m} \left(\frac{F}{B}\right)_i T_{1i}(s) \tag{6}$$

so

$$Q_1(n) = \sum_{i=1}^{m} \left[\sum_{j=0}^{n} G_{1i}(n-j)\, T_{1i}(j) \right] \tag{7}$$

$$T_0(n) = \sum_{k=0}^{n} \left[G_0(n-k)(Q_0(k)+Q_1(k)) \right] \tag{8}$$

$T_0(n)$ is the temperature difference from initial equivalent temperature at the moment. It should be notified that all variables about temperature refer to the differences from the initial equivalent temperature.

3. Influence of weight of evaporator on the response coefficient

A proper formula for temperature calculation in the system simulation is:

$$T_0(n) = \sum_{i=0}^{n} \left[G_e(n-i)\ Q(i) \right] \tag{9}$$

Here $$Q(i)=Q_e(i) + Q_1(i) - Q_d(i) \tag{10}$$

Q_d is the heat flowing through the door gasket.

G_e is calculated with the following formula:

$$\begin{cases} G_e(0)=t(0) \\ G_e(1)=t(1)-t(0) \\ \quad\vdots \qquad\qquad \vdots \\ G_e(j)=t(j)-t(j-1) \end{cases} \tag{11}$$

$$\begin{cases} t(0)= \dfrac{G_0(0)}{1 + a\ G_0(0)} \\ t(1)= \dfrac{[1-at(0)]G_0(1) + [1+at(0)]G_0(0)}{1 + aG_0(0)} \\ \quad\vdots \qquad\qquad\qquad \vdots \\ t(j)= \left[\sum_{i=1}^{j-1} [1-at(i)+at(i-1)]G_0(j-i) \right. \\ \qquad\qquad \left. + [1-at(0)]G_0(j) + [1+at(j-1)]G_0(0) \right] / [1+aG_0(0)] \end{cases} \tag{12}$$

$$a = \frac{c}{\Delta t}$$

c is the heat capacity of the evaporator,
Δt is the time step length for response coefficient calculation.

4. Appliance simulation

The final effects of the evaporator weight is showed when simulating the working process. To finish this work, many mathematical models and calculating method should be done. This paper can not introduce all the models and solving methods in detail, and what we have already written in our published papers will not be narrated again.

Ref.1 narrate the models and solving methods for dynamic simulation of refrigerating system we developed several years ago, not including the mathematical model of thermal insulation layer. The relationship of refrigerant thermal parameters is analyzed in this article.

The improved models of condenser and evaporator are narrated in Ref.3, Ref.5 and Ref.6. Analysis of dynamic heat transfer of the thermal insulation layer is introduced in Ref.4. Ref.2 tell the improved model and the solving method of the thermal insulation layer , and the parameter coupling among the thermal insulation layer and other parts.

Here we only narrate how to make the temperature calculating formula fit the appliance simulation.

The time step length is an important parameter which can obviously influence the simulating speed. A large step length is useful to enhance the calculating speed, but it maybe decrease the accuracy, sometimes even result in divergence. In order to enhance the calculating speed and ensure the accuracy, we use variable time step length. But the time step length uses in the calculation of response coefficient is a constant, and only the temperature of integer time of this constant can be directly calculated, using formula (8), otherwise the calculating stops, so we have to study the calculating method when time step length is variable.

Let the calculating moment is 'Time'.
'Δ t' is the time step length using in the calculation of the response coefficient.

$$Tcoe = \frac{Time}{\Delta t}$$

If Tcoe < 1, then

$$T_o(Time) = G_e(0)\ Tcoe\ Q(0) \tag{13}$$

If Tcoe > 1, then

$$T_o(Time) = \left[\ \sum_{i=0}^{I} G_{eo}(i)\ Q(I-i)\ \right] + G_e(I+1)\ Q(Tcoe)\ (Tcoe-I) \tag{14}$$

I is the integer part of Tcoe.

First we simulate the running process of a special refrigerator-freezer whose characteristics has already carefully measured, and ensure that the program can carry this job quite well. Then we change the weights of freezing evaporator and refrigerating evaporator, and simulate the process again. By this way, the influences of the weights of evaporators on the characteristics of the refrigerator-freezer can be known.

Here we only show the inner air temperature of normal evaporator weights and double weights. We can know from the figures that large evaporator result in slow temperature variation. The energy consumption also decreased from 1.01 KwH/Day to 0.99 KwH/Day. This is because the running-stopping cycle become larger, and the intermittent energy losses decreased.

CONCLUSION

1. The weights of the evaporators of a household refrigerator-freezer influence the inner air temperature variation and the energy consumption. Large weights result in slow temperature change and low energy consumption.

2. Response coefficient method is a proper method in treating the weight influence. When using this method, we should notice the difference between the time step length of response coefficient calculation and that used in system simulation.

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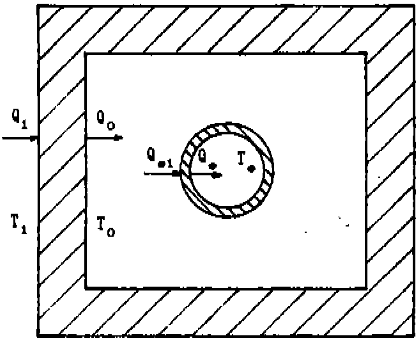

Fig.1 Heat transfer process

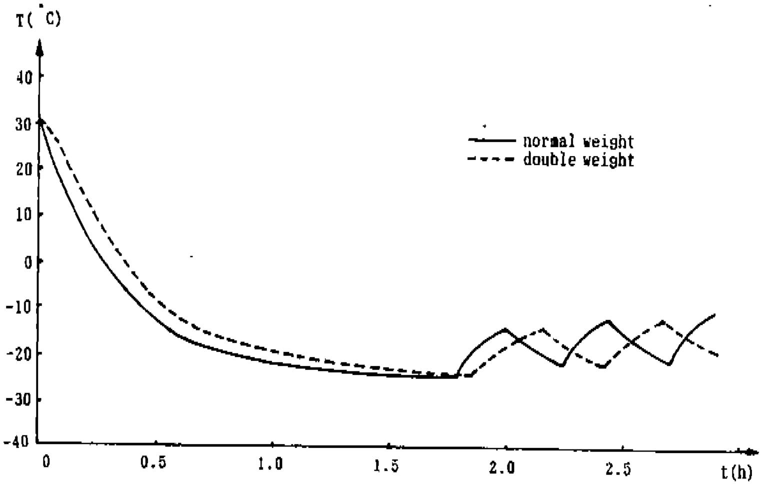

Fig.2 Air temperature on freezing chamber

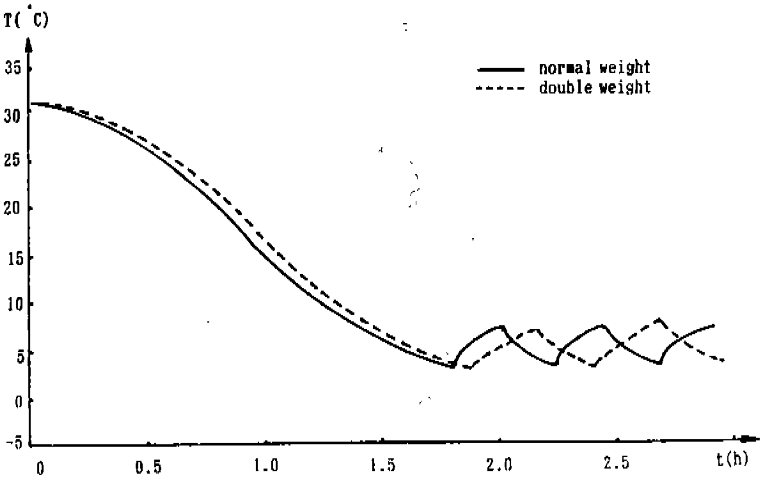

Fig.3 Air temperature on refrigerating chamber