The analysis of the factors that influence the heat transfer of water

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Abstract: A hot bath is becoming a necessary event of people's life. The temperature field of water in a bathtub is coomplex and always influenced by a series of factors, such as human body, bubble bath agent,the shape of the container.

Introduction

consider the motion of the human body, the process in water cannot considered as a normal heat conduction, the process human body absorbs part of the heat is equivalent to add a minus density of heat flow rate and build new convective heat transfer simultaneous differential equations. The bubbles' affect to a temperature field is equivalent to add an insulating layer over the surface of the water.

Analysis

The materials of common bathtub are Acrylic and glass fiber, etc. The thermal conductivity of the acrylic is 1.4 W/m*K, the thermal conductivity of glass fiber is 1.09W/m*K, the smaller thermal conductivity thermal insulation effect is better. The wall of the bathtub is simplified as an adiabatic wall. A water temperature change model of bathtub is established from the view of time and space, in order to ensure not to waste too much water, select periodic watering measures, In the case of known room temperature, the initial temperature of the bath water, the shape of the bathtub and the initial water height. Put forward the strategy of reducing excessive waste water by adjusting the hot water temperature and hot water flow also with intermittent supply of hot water. The bathtub filled with water and people in the water, when the water is stable, people on the water surface and the water reaches temperature equilibrium is zero. When people in the water and the body surface and water reach the temperature relative balance is zero moment. ①liquid stable fixed, natural convective heat transfer on the water surface temperatures decreasing three-dimensional non-steady heat conduction process;

②Process of adding hot water, the temperature gradually increased until close to the initial temperature.According to the heat conduction process of the water, a three-dimensional unsteady heat conduction model is established in process①.

According to the given boundary conditions, the temperature of any point in the water can be calculated at any moment; in process hot water through the faucet to join the water temperature in the heating bath, the ratio of the opening area of the bathtub and the outlet area of the faucet is expressed by $\frac{s}{s'} > 1000$, The volume flow of the overflow water from the opening of the bathtub is the same as that of the tap, so the ratio of the speed of the water to the faucet is less than 1000. Ignore the rate of rise, taking into account this time; add hot water and surface heating on the human body, will continue to add hot water added as a two-part process:

Ignore the rising speed of water, taking into account this time, the hot water will be added to the body surface heating, The process of adding hot water Continuously will be regarded as addition of two parts: one part is joining a continuous heat flow for a period of time, another part is adding the same amount of water as the same as the initial water temperature. Heat flux into the heat flow, including water absorption and people heat absorption. A complex dynamic process is decomposed into two single dynamic processes and a single static process, the corresponding model is established to solve the problem respectively.

The influence of factors on decision making

The shape and volume of the tub

Shape and the volume of the bathtub: water has a convection heat transfer via the top surface of water. 3D heat conduction's boundary conditions change with the change of the shape and the volume of the bathtub as well as the water temperature field of the heating and cooling process. For example, change the cuboid bathtub into a new shape. (Figure 6)The material and the volume of the new one are completely same to the former one.

$$s_1 * h_1 + s_2 * h_2 = s * H$$

Because of $s_1 < s$, so $s_2 > s$, the area of the opening of bathtub 2 is bigger than bathtub 1, the loss of the convention heat transfer increased, the time that the temperature of the water cooling down to T_l get decreased. Similarly, the time cost to heat the water gets decreased. Besides, the time can be changed by using hotter water even changing the mass flow.

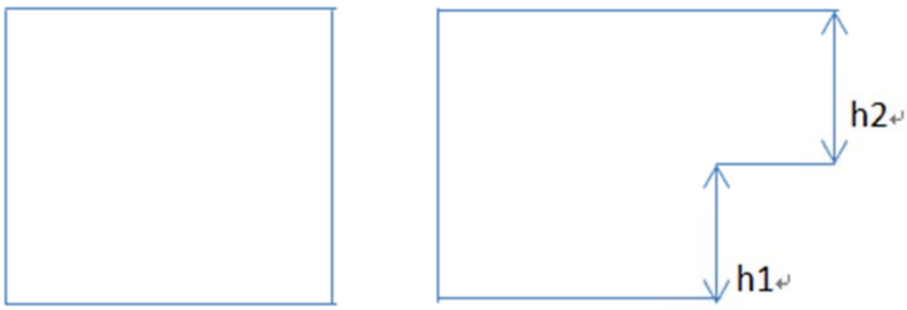


Figure 1　Bathtub section shape

The shape, volume, temperature of human body

Human bodies absorb heat from hot water cause the rise of the temperature of the surface of the body and affect the temperature field in the bathtub. According to the model 1.2.2,fomula (11) take partial derivative of Q_{body} with respect to A $\frac{\partial Q_{body}}{\partial A} > 0$,so the body superficial area and Q_{body} get increased. The variation of human body surface temperature will influence Q_{body} directly, however, the change of Q_{body} will influence the solution of adding water dynamic model which will affect the strategy.

The motion of the human body in bathtub

Considering the motion of the human body in the bathtub, the flow of the water in the bathtub is turbulent flow, the water in the bathtub cannot consider as stagnant. The water forced convective heat transfer with human body and the water in the tub forced convection with the air in the tub.The water forced convective heat transfer with human body: abstracted human's arms and legs and body to circular tube with different radius so that the motion that human do can be simplify to the model that water flow pass several pipes. Consider the practical situation; the velocity that hot water skims over the body will not be fast. Therefore, we assume that ortex will not appear and detached bow.

Characteristic number relational for fluid skim over pipe:

$$N_u = C \mathrm{Re}^n \mathrm{Pr}^{1/3}$$

When Re belong to (0.4, 4), C is equal to 0.989, n is equal to 0.330; qualitative temperature is boundary layer average temperature $t_m = \frac{t_w + t_\infty}{2}$; characteristic length is the radius d of the pipe; characteristic velocity is free stream velocity u_∞.This formula suit for the circumstance that

$Pr > 0.7$.

The calculation formula of specific surface between body and water:

$$h_{watertobody} = \frac{Nu * \lambda}{d}$$

q_1 represents unit length of body thermal convection energy , calculation formula:

$$q_1 = h * A * (T - T_{body})$$

Take any one of the representative elemental volume in three-dimensional flow direction in the bathtub, water forced convective heat transfer with body and human absorb the heat of water which is equivalent to give a VHS Q to representative elemental volume, the energy differential equation is:

$$\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} + w\frac{\partial T}{\partial z} = a\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right) - \frac{Q}{\ell c_p}$$

In this equation, c^p represent the heat capacity of representative elemental volume; ℓ represent the density of the heat capacity of representative elemental volume. Convective heat transfer differential equation for three-dimensional flow, like formula (3):

$$\begin{cases} h_{x,y} = -\dfrac{\lambda}{T_{air} - T}\dfrac{\partial T}{\partial z}\Big| z = H_{surface} \\ \vec{f} - \dfrac{1}{p}\nabla p + v\nabla^2 \vec{v} = \dfrac{d\vec{v}}{dt} \\ \dfrac{\partial u}{\partial x} + \dfrac{\partial u}{\partial y} + \dfrac{\partial u}{\partial z} = 0 \end{cases}$$

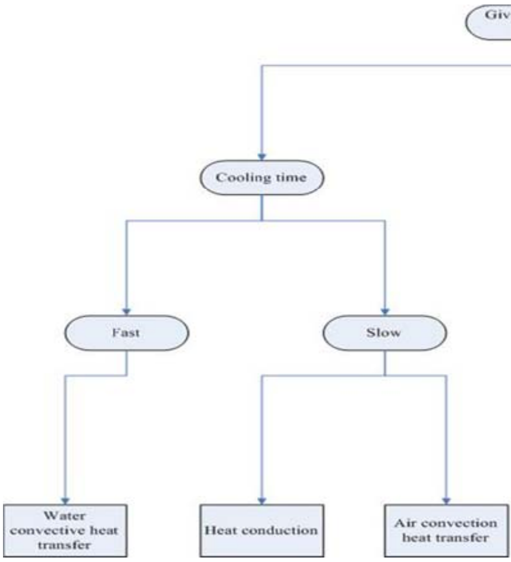
Use bubble bath agent

Using a bubble bath agent, bubble floating in the water, equivalent to a layer of insulation, the Average height of, in the bubble, the thermal conductivity of the medium for the air, so the heat Diffusion rate:

$$\frac{\partial T}{\partial t} = a_2\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2} + \frac{\partial^2 T}{\partial z^2}\right)$$

Boundary conditions:

$$\begin{cases} z = H_{surface}, T = T_f; z = H_{surface} + h_b, T = T_s \\ x = 0, \dfrac{\partial T}{\partial x} = 0; x = m, \dfrac{\partial T}{\partial x} = 0 \\ y = 0, \dfrac{\partial T}{\partial y} = 0; y = n, \dfrac{\partial T}{\partial y} = 0 \end{cases}$$



Summary

We use rationable assumptionassumptions to make models simpler and set up several models to analyse the influence of diversity factors. According to the essay, the result of the model setted up by us shows that the factors such as the moving body, the shape of the container and the using of the bubble shower agent all influence the temperature field in the water, and the analysis process can be found to be reasonable.

Reference

[1]. LewisRw.etal.Numericalheattransfer，1984

[2]. Bejan A.Entropy Generation through Heat and Fluid Flow. . 1982

[3]. Jones, D. R. (2005). IEA members urge investment in renewable energy . *Platts EU Energy*,22.