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Research on the Convective Heat Transfer Coefficient of Server Cooling

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Abstract: In this paper, the heat dissipation structure of separated heat pipe is designed and studied. Firstly, based on Newton's heat transfer law in problem 1, the calculation method of convective heat transfer coefficient is obtained by differential solution. The coefficient effectively reflects the convective heat transfer, that is, the heat dissipation intensity. The temperature gradient on the surface of solid container is calculated by assuming the flow rate of seawater and the heat dissipation temperature of server. Then, the tensile strength and foundation are compared and analyzed. The results show that when the solid container is placed on the seabed, the tensile strength will occupy a greater influence factor than the yield strength. Finally, it is concluded that AISI 1080 carbon structural steel is more suitable as container manufacturing material.

1. Introduction

"Project UDC" is to install Internet facilities such as servers in closed pressure vessels on the seabed with advanced cooling function, supply power with submarine composite cables, and return data to the Internet; Through heat exchange with seawater, the submarine data center uses a large amount of flowing seawater to dissipate heat from internet facilities, effectively saving energy. Deploying the data center in the waters near coastal cities can greatly shorten the distance between data and users. It not only does not need to occupy land resources, but also saves energy consumption. It is a completely green and sustainable big data center solution.

It is assumed that the maximum size of container shell shall not exceed 1m × 1m × 12m, combined with the analysis, how to design the structure of the container shell (such as considering the fin structure on the cylinder, cuboid, etc.) can maximize the heat dissipation effect. The result is to store more servers.

The deeper seawater has lower temperature, which can achieve better heat dissipation effect. At the same time, the increased pressure will put forward higher requirements for the pressure resistance of the container shell; It is worth noting that seawater itself is a strong corrosive medium, and all kinds of metal structures directly in contact with seawater are inevitably corroded by seawater. Further select appropriate materials and seabed depth for optimal design, further improve the heat dissipation effect, reduce the cost and improve the service life as much as possible.

2. Convective heat transfer coefficient model

Through the analysis, it can be concluded that the calculation of the number of servers is closely related to the overall structure and structure of the container. The number of servers that can be installed in the cylindrical container is not completely covered by the container, and there must be a certain free space, which leads to the waste of space resources of the overall structure. Therefore, compared with the cylindrical structure, without considering the thickness of the container wall, the cuboid structure can increase the upper limit of the number of servers to a greater extent. Taking the cuboid size and inch of 1m*1m*12m as an example, the target model is established according to the optimization equation:

$$Longitudinal\ section : Target\ \max(x \cdot y \cdot z)$$
$$\text{s.t.}\begin{cases} x \cdot 44.45 \le 12000 \\ y \cdot 525 \le 707 \\ z \cdot 482.6 \le 707 \\ xyz \cdot V_{server} \le V_{container} \end{cases} \tag{1}$$

$$Transverse\ section :\ Target\ \max(x \cdot y \cdot z)$$
$$\text{s.t.}\begin{cases} x \cdot 525 \le 12000 \\ y \cdot 482.6 \le 707 \\ z \cdot 44.45 \le 707 \\ xyz \cdot V_{server} \le V_{container} \end{cases} \tag{2}$$

After calculation, it is concluded that in the server horizontal installation mode, the maximum installation quantity of servers in X direction, Y direction and Z direction is 22, 2 and 20 respectively, while in the vertical installation mode, the maximum installation quantity of servers in X direction, Y direction and Z direction is 269, 1 and 1 respectively, Therefore, it can also be concluded that the horizontal installation mode of the server is better than the vertical installation mode of the server. To sum up, it is more beneficial to improve the storage quantity of servers by transforming cylindrical containers into rectangular containers.

By calculating the convective heat transfer coefficient caused by seawater fluid along the cuboid, this paper shows whether the cuboid structure is conducive to the heat dissipation of a large number of servers. Newton's heat transfer law is given, but in general, the factors affecting the heat transfer coefficient are very complex. In order to facilitate the calculation, the heat transfer flow between the fluid and the cuboid wall is analyzed by calculating the temperature field Ty near the cuboid container wall:

$$q_{transmit} = -\lambda \frac{\partial T}{\partial y}|_{y=0} \tag{3}$$

Into Newton's law of heat:

$$q_{transmit} = -\lambda \frac{\partial T}{\partial y}|_{y=0} = h(T_\infty - t_s) \tag{4}$$

Calculate the convective heat transfer coefficient:

$$h = -\lambda \frac{\partial T}{\partial y}|_{y=0}/(T_\infty - t_s) \tag{5}$$

Where: λ is the thermal conductivity of the fluid

In thermodynamics, there is a dimensionless number group called Prandtl coefficient, which indicates the physical parameters of the fluid, as shown in figure 1.

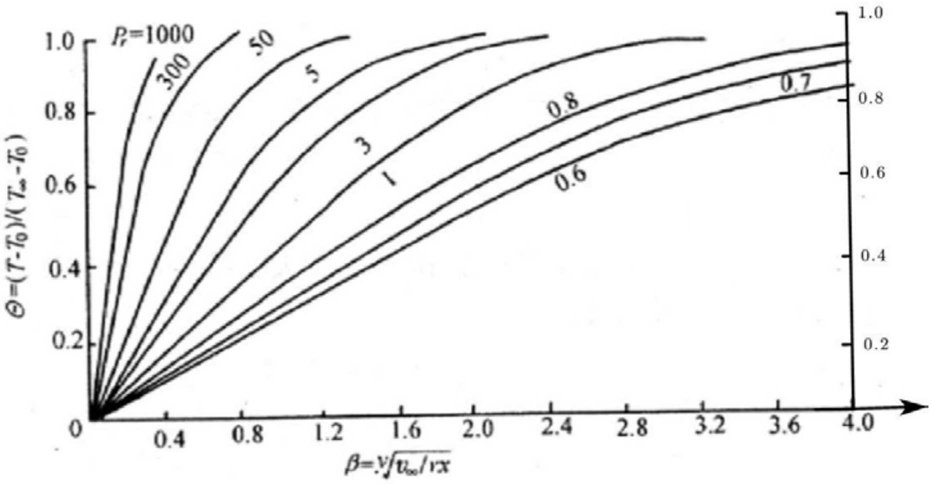

Figure 1: Dimensionless temperature distribution under different Prandtl coefficients.

The specific calculation method is:

$$P_r = \frac{\nu}{\alpha} = \frac{C_p \mu}{\lambda} \tag{6}$$

In the case of $P_r \geq 0.6$, the specific calculation method of heat transfer coefficient can be obtained:

$$h_x = 0.332\lambda P_r^{1/3}\sqrt{\frac{v_\infty}{\nu x}} \tag{7}$$

Where: $\sqrt{\frac{v_\infty}{\nu x}}$ is the value of abscissa in dimensionless temperature distribution.

According to the analysis of the data given in the question, $T_\infty = 20°C$ (normal seawater temperature). Assuming that the water flow velocity is $v_\infty = 1.2m/s$ and the heat dissipation temperature of all servers is 60℃, that is, $T_s = 60°C$, the common formula for calculating the water temperature gradient at the surface of the cuboid is:

First, the average temperature of water flow inside and outside the cuboid is obtained:

$$\mathrm{T_m} = \frac{T_\infty + T_s}{2} = 40°C \tag{8}$$

Secondly, according to the average temperature, the physical parameters of water are:

$$\lambda = 0.634\mathrm{W/mk}; \mathrm{v} = 0.659 \times 10^{-6}\mathrm{m^2/s}; P_r = 4.31 \tag{9}$$

According to the above calculation formula, the convective heat transfer coefficient at 250mm from the surface is:

$$h_x = 0.332\lambda P_r^{1/3}\sqrt{\frac{v_\infty}{\nu x}} = 0.332 \times 0.634 \times \sqrt[3]{4.31}\sqrt{\frac{1.2}{0.659 \times 10^{-6} \times 0.25}} \tag{10}$$

Get: $h_x = 924.48\mathrm{W/m^2k}$.

The calculation result of temperature gradient is:

Through the above calculation results, it can be found that near the contact surface between the cuboid and water, the temperature gradient is large, and the convective heat transfer coefficient also reaches a high value. Therefore, it can be seen that the heat dissipation of the model result is good (most of the heat can be discharged, resulting in the high temperature of the outer surface of the cuboid). For the specific result, the separated heat pipe can be used [1] For high-efficiency cooling, its structure is shown in figure 2.

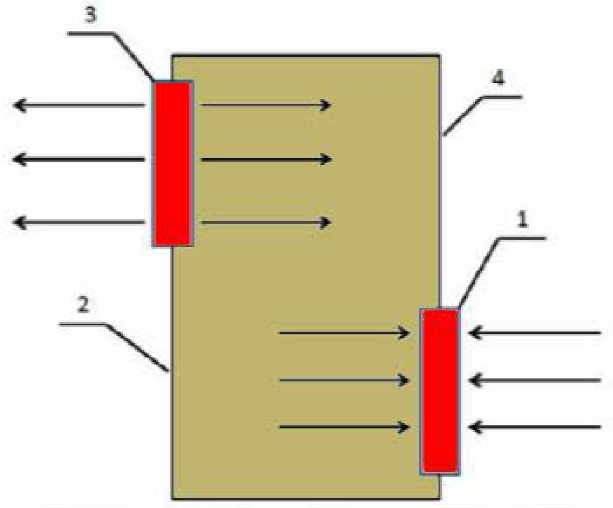

Figure 2: Structure of separated heat pipe.

In the figure, the number 1 represents the evaporation section, 2 represents the steam duct, 3 represents the condensation section, and 4 represents the liquid return pipe. The evaporation section and the condensation section are separated to realize a natural circulation circuit connecting the steam riser and the liquid downcomer. The specific working principle is as follows: during operation, the working medium absorbs heat and vaporizes in the evaporation section, the steam reaches the condensation section through the steam riser to release the latent heat and condense into liquid. Under the action of gravity, it flows to the evaporation section through the liquid downcomer, so as to realize the heat transfer.

3. Tensile strength model

Firstly, the yield strength [2] and tensile strength [3] of the material are defined:

Tensile strength: when the steel yield to a certain extent, its resistance to deformation will be improved again due to the rearrangement of internal grains. At this time, although the deformation degree will be faster, it can only be improved with the increase of stress until the stress reaches the maximum value. After that, the ability of steel to resist deformation will be obvious, and large plastic deformation will occur at the weakest part, where the section of the specimen will shrink rapidly, necking phenomenon will occur, and even fracture failure will occur.

Yield strength: when the stress exceeds the elastic limit, the deformation is obviously accelerated. At this time, in addition to elastic deformation, some plastic deformation is also produced. When the stress reaches point B, the plastic strain increases sharply and a fluctuating small platform appears in the curve. This phenomenon is called yield. The maximum and minimum stresses at this stage are called upper yield point and lower yield point respectively. Because the value of lower yield point is relatively stable, it is called yield point or yield strength as an index of material resistance.

From the above two strength definitions, it can be concluded that the importance of tensile strength in seawater is much greater than the yield strength, because the tensile strength will lead to the fracture of the container. At this time, seawater will enter the container and have an incalculable impact on the equipment, and the impact caused by yield strength is not enough plastic deformation. Theoretically, it can be avoided to reserve a certain installation space in the container.

Assuming that the depth of the container in seawater is h, the pressure calculation formula of the container in water is:

$$F = \rho \cdot g \cdot h \cdot S \tag{11}$$

Where: F represents the pressure and ρ represents the density of seawater. In this question, it is defined as $10^3 kg/m^3, g = 10N/kg$ and S is the bottom area of the container, i.e. 12m2. Therefore, it can be obtained that the pressure borne by the container in seawater is:

$$F = 1.2 \times 10^5 h/N \tag{12}$$

From the above understanding of tensile strength and yield strength, it can be seen that in this question, there must be:

$$F = \sigma_u \tag{13}$$

The units are English units, so they need to be converted. In the column of tensile strength, take the first material as the calculation case:

$$\sigma_u = 38 \times 0.45kg = 1.71 \times 10^5/N \tag{14}$$

Through the above calculation formula, the sinking depth of container container under different materials can be calculated, and the materials of the given data can be calculated one by one.

On the basis of comprehensive consideration of price and strength, AISI 1080 carbon structural steel is finally selected as the manufacturing material of storage container.

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