Analysis on heat transfer calculation of cylinder wall

Yarong Wang$^{1*}$ and Peirong Wang$^2$

$^1$Baoding Electric Power VOC.&TECH. College, Baoding, Hebei, 071051, China
$^2$Hebei Software Institute, Baoding, Hebei, 071000, China

*Corresponding author’s e-mail: bjjoycg2008@163.com

Abstract. Through long-term production practice and theoretical research, the basic law of heat transfer process is summarized. In the process of stable heat transfer, the heat transfer is directly proportional to the temperature difference between cold and hot fluids and is proportional to the heat transfer area. The heat transfer is also directly proportional to the heat transfer process’s intensity, that is, the heat transfer coefficient. According to the shape of the partition wall, the heat transfer calculation can be divided into flat wall heat transfer and cylinder wall heat transfer. The heat transfer calculation of cylinder wall is complex, and different calculation standards will get different results.

1. Introduction

1.1. Basic equation of heat transfer

There are many heat transfer problems in engineering. For example, in the heat exchange equipment of thermal power plant, the heating surfaces of the boiler are scoured by high-temperature flue gas. The water or steam that needs to be heated is inside the pipe. And the high-temperature flue gas heats water or steam through the tube wall of the heat exchange equipment.

Heat transfer process refers to the process in which hot fluid transfers heat to cold fluid through solid wall. The heat transfer in this process is usually calculated by heat transfer calculation formula [1]. Namely

$$\Phi = KA(t_{f1} - t_{f2}) = KA\Delta t \quad W$$

(1)

$$\Phi_L = K_L\pi d(t_{f1} - t_{f2}) = K_L\pi d\Delta t \quad W/m$$

(2)

Where

- $A$—heat transfer area, $m^2$
- $t_{f1}$—temperature of hot fluid, °C
- $t_{f2}$—temperature of cold fluid, °C
- $\Delta t = t_{f1} - t_{f2}$—the temperature difference between hot fluid and cold fluid, it is also called heat transfer temperature difference, °C
- $K$—heat transfer coefficient per unit area, $W/(m^2 \cdot °C)$. It represents the heat transfer capacity of the heat transfer equipment, which is numerically equal to the heat transferred by the unit heat exchange area of the cold and hot fluid in unit temperature difference and unit time [2].
- $K_L$—heat transfer coefficient per unit tube length, $W/(m \cdot °C)$

Heat transfer process is very common in engineering. If the solid wall in the middle is a pipe, such process can be called heat transfer through the cylinder wall. Due to the different surface areas of the
cylinder wall, the heat transfer equation's area values are different, the values of the diameter are different. The values of the heat transfer coefficient are also different. This paper takes a calculation as an example to compare the calculation results of different values and different calculation methods.

1.2. A calculation example

There is a steam pipe with inner and outer diameters of 60mm and 66mm, respectively. The tube wall's thermal conductivity is 50W/(m⋅℃), while the temperature of steam in the pipe is 140℃. The pipeline is wrapped with a 10 mm layer of asbestos and a 15 mm layer of fiberglass. The thermal conductivity of asbestos is 0.11W/(m⋅℃), and that of fiberglass is 0.03W/(m⋅℃). The heat release coefficient of the steam side is 8600W/(m²⋅℃). The ambient air temperature is 20℃. The heat release coefficient of the air side without insulation layer is 15W/(m²⋅℃), and 7W/(m²⋅℃) with the insulation layer. Try to find the heat loss in two cases[3]. Here, the heat loss is the heat transfer through the cylinder wall.

2. Analysis and calculation

2.1. The known basic parameters

The inner diameter of steam pipe is \( d_1 = 60 \) mm
The outer diameter of steam pipe is \( d_2 = 66 \) mm
The thickness of pipe wall is \( \delta_1 = \frac{d_2-d_1}{2} = \frac{66-60}{2} = 3 \) mm
The outer diameter of asbestos layer is \( d_3 = 66 + 2 \times 10 = 86 \) mm
The thickness of asbestos layer is \( \delta_2 = 10 \) mm
The outer diameter of fiberglass layer is \( d_4 = 86 + 2 \times 15 = 116 \) mm
The thickness of fiberglass layer is \( \delta_3 = 15 \) mm
The thermal conductivity of the tube wall is \( \lambda_1 = 50 \) W/(m⋅℃)
The thermal conductivity of asbestos is \( \lambda_2 = 0.11 \) W/(m⋅℃)
The thermal conductivity of fiberglass is \( \lambda_3 = 0.03 \) W/(m⋅℃)
The heat release coefficient of steam side is \( \alpha_1 = 8600 \) W/(m²⋅℃)
The heat release coefficient of air side without insulation layer is \( \alpha_2 = 15 \) W/(m²⋅℃)
The heat release coefficient of air side with insulation layer is \( \alpha_3 = 7 \) W/(m²⋅℃)

2.2. Actual calculation

The heat transfer through cylinder wall per unit tube length is
\[
\varphi_L = \frac{\varnothing}{L} = K_L \pi d (t_1 - t_2) = \frac{t_1 - t_2}{\frac{1}{a_1 \pi d_1} + \sum_{i=1}^{n} \frac{1}{2 \lambda_i} \ln \frac{d_i}{d_1} + \frac{1}{a_2 \pi d_{n+1}}} \quad \text{W/m}
\]

The heat transfer through cylinder wall per unit internal surface area is
\[
\varphi_1 = \frac{\varnothing}{A_1} = K_1 (t_1 - t_2) = \frac{t_1 - t_2}{a_1 \ln \frac{d_1}{d_1} + \frac{d_1}{a_2 \lambda_2}} \quad \text{W/m²}
\]

The heat transfer through cylinder wall per unit surface area outer side the pipe is
\[
\varphi_2 = \frac{\varnothing}{A_2} = K_2 (t_1 - t_2) = \frac{t_1 - t_2}{\frac{d_2}{a_1 d_1} + \sum_{i=1}^{n} \frac{d_i}{2 \lambda_i} \ln \frac{d_i}{d_1} + \frac{1}{a_2}} \quad \text{W/m²}
\]

2.3. simplified calculation

The logarithmic term is included in calculating the heat transfer coefficient of the cylinder wall, which can be simplified according to some conditions. In the actual calculation of the project, if the tube wall is thin \((d_2/d_1 \leq 2)\) or the calculation accuracy is not high, the cylinder wall can be simplified to a flat wall for calculation[3].

The heat transfer through cylinder wall per unit surface area is...
The heat transfer through cylinder wall per unit tube length is

\[
\phi_L = \frac{\phi}{L} = \frac{\phi \pi d_m}{A} = \frac{1}{\alpha_1} + \sum_{i=1}^{n} \frac{1}{\lambda_i} + \frac{1}{\alpha_2} \frac{(t_{f1} - t_{f2}) \pi d_m}{W/m}\]

Where, the thickness of the pipe wall is

\[
\delta_i = \frac{(d_{i+1} - d_i)}{2}
\]

The calculation diameter is taken as follows

If \( \alpha_1 \approx \alpha_2 \), \( d_m = \frac{d_1 + d_2}{2} \); If \( \alpha_1 \ll \alpha_2 \), \( d_m = d_1 \); If \( \alpha_1 \gg \alpha_2 \), \( d_m = d_2 \)

2.4. Solution

![Figure 1](image)

Figure 1 [4]. Heat transfer diagram of cylinder wall without insulation layer

It is shown the heat transfer diagram of a single-layer cylinder wall cut from the pipe from figure 1. Through analysis and combined with the above calculation formulas, the calculation results are shown in Table 1.

| condition                  | Without insulation layer | With insulation layer |
|----------------------------|--------------------------|-----------------------|
| Actual calculation         |                          |                       |
| \( \phi_L \) W/m           | 372.16                   | 50.77                 |
| \( \phi \) W/m²             | 1974.34                  | 269.36                |
| \( \phi_1 \)                | 1794.86                  | 167.03                |
| simplified calculation     |                          |                       |
| \( \phi_L \) W/m           | 372.24                   | 51.08                 |
| \( \phi_1 \) W/m²           | 1795.25                  | 163.50                |

It can be seen from the table:

1. Due to the different diameter and area of cylinder wall, the heat transfer per unit area is different based on different area.
2. The results of the simplified calculation are very close to the actual ones.
3. The heat transfer of the cylinder wall is greatly reduced after the insulation layer is added.

3. Conclusion

Traditionally, the engineering calculation is based on the surface area outer side the pipe [5]. Only when the ratio of an inner and outer diameter of the cylinder wall is less than or equal to 2, that is, the
cylinder wall is very thin, or the calculation accuracy is not high, the heat transfer calculation of the cylinder wall can be simplified to the calculation of the flat wall.

There are many heat transfer problems encountered in engineering. In addition to calculating heat transfer, we will also encounter many problems involving how to enhance and weaken heat transfer. Increasing the heat transfer coefficient is the most effective measure to enhance heat transfer. From the calculation of the heat transfer coefficient, it is not difficult to see the main factors affecting it. The best way to enhance heat transfer is to reduce the maximum local thermal resistance. On the contrary, to weaken the heat transfer is to reduce the heat transfer coefficient. The most widely used method in engineering is to cover pipes and equipment with thermal insulation materials. The thermal conductivity of thermal insulation material is minimal. Therefore, the heat transfer coefficient of the heat transfer process is small to weaken the heat transfer.

Students in vocational and technical colleges have little practical experience during their early learning. With the comparison of the above data, they have more perceptual knowledge of the relevant situation and conducive to the mastery of theoretical knowledge.

References
[1] Wu, T.H., Wang, X.M., Xu, G.L., Pan, Y., Chen, W.H. (2011) Engineering Heat Transfer. Huazhong University of Science and Technology Press, Wuhan.
[2] Zhang, X.Z., Huang, W., Liu, Q.G. (2011) Heat Transfer. National Defence Industry Press, Beijing.
[3] Jing, Z.H. (2009) Thermal Engineering. China Electric Power Press, Beijing.
[4] Cheng, X. H. (2013) Thermal Engineering. China Electric Power Press, Beijing.
[5] Yang, S.M., Tao, W.Q. (1998) Heat Transfer. Higher Education Press, Beijing.