Heat Transfer Characteristics of Steam Condensation Flow in Vacuum

Horizontal Tube

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Abstract

The heat transfer characteristics of steam condensation flow in a vacuum horizontal long tube were studied experimentally when the saturation temperature varies from 50 to 70°C, mass flow rate is no more than 11 kg/(m²·s) and temperature differences between steam and cooling water are 3, 5 and 7°C respectively. The results of experiments indicate that the steam temperature decreases and the condensation temperature difference decreases first and then increases along the flow direction. The effects of mass flow rate and total temperature difference on temperature distribution are also discussed in the paper. The condensation heat transfer coefficient increases first and then decreases along the flow direction. The heat transfer coefficient increases with mass flow rate in most cases, but may decrease in the first section at high mass flow rate. The heat transfer coefficient also increases with saturation temperature and decreases with condensation temperature difference. The heat transfer rate decreases along the flow direction and increases with mass flow rate.

Keywords: condensation; horizontal tube; heat transfer coefficient

1. Introduction

Many countries in the world have suffered from a shortage of natural fresh water. The seawater desalination is an effective method to solve the shortage of water resources in offshore area. In the numerous seawater desalination methods, low temperature multi-effect evaporation (LT-MEE) technique has the significant advantages on utilizing low temperature heat sources, low energy consumption, high desalinated water quality and stable operation [1, 2]. In the process of LT-MEE desalination, the steam is condensed into water in horizontal tubes, which provides heat source for seawater evaporation outside the tube. In-tube condensation is also widely used in various industrial fields, such as nuclear power, chemical engineering and refrigeration, etc.

Cavallini et al. [3] proposed a review of refrigerants condensation inside and outside smooth and enhanced tubes in 2003. A lot of experimental research were mentioned and summarized in the review. Later, Miyara [4] reviewed condensation of hydrocarbons inside and outside tube and in plate heat exchanger. An intensive review of various aspects of condensation in tube was proposed by Dalkilic and Wongwises [5], including the heat transfer, flow pattern, void fraction and pressure drop. Zhang et al. [6] reviewed 28 condensation heat transfer correlations in horizontal channels and compared them with 2563 experimental data points.

The steam and tube wall temperature distributions along flow direction in a horizontal tube with heat transfer length of 3.0 m and inner diameter of 27.5 mm when the inlet pressure is 0.2 MPa is shown in Wu and Vierow's study [7]. Both the steam and tube wall temperature decrease along the flow direction.

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Similar distributions are also measured in a tube with the length of 1.75 m at the pressure 0.1 MPa by Ren et al.[8]. But there is little research on the temperature distribution in a continuous horizontal long tube in vacuum state and the effect of mass flow rate on the temperature distribution.

During the condensation in a horizontal tube, the flow patterns are dominated by gravity and shear force. When the mass flow rate is low, the shear force between steam and condensation liquid is rather small. The steam condenses into liquid on the inner tube wall and forms the liquid film. And the condensate is collected in the bottom of the tube, presenting stratified flow pattern, which is controlled by gravity force. The dominant heat transfer mechanism in this flow pattern is conduction across the film at the top of tube[9]. This type of condensation is commonly referred to as film condensation, which can be analyzed by the classical Nusselt theory[10]. Based on the experimental data, Thome[11] proposed a new condensation model with the assumptions of two types of heat transfer mechanisms occur in the tube: film condensation at the top of tube and convective condensation at the bottom.

The main factors affecting the condensation heat transfer coefficient are mass flow rate, vapor quality, saturation temperature and temperature difference. The condensation of steam and various kinds of refrigerants have been studied extensively. A lot of experimental results[12-17] show that condensation heat transfer coefficient increases with the increase of mass flow rate and vapor quality. But there are some different conclusions in special cases. Dobson[9] and Cavallini et al.[18] considered that the heat transfer coefficient has no obvious relationship with vapor quality during low mass flow rate and it increases with vapor quality during high mass flow rate. Yan's experiment[19] shows that the mass flow rate has less effect on heat transfer coefficient when the vapor quality is low. The saturation temperature influences the physical properties, for example, the density, viscosity and thermal conductivity of vapor and liquid, then affects the heat transfer coefficient. With the change of saturation temperature, some physical properties of steam and refrigerants show a different variation tendency. For refrigerant[14, 18, 19], heat transfer coefficient decreases with saturation temperature in most cases. But there are some special cases. Hossain et al.[13] pointed out that saturation temperature has no effect on heat transfer coefficient when the mass flow rate is low, because the heat transfer mechanism is forced convection, not the free convection. For steam[20], heat transfer coefficient increases with saturation temperature. The temperature difference affects the heat transfer coefficient primarily by influencing the condensation rate and film thickness. Cavallini's experiment[18] shows that heat transfer coefficient has no relationship with temperature difference when the mass flow rate is high while it decreases with temperature difference when the mass flow rate is low and the dominant force is the gravity. Dobson and Chato[9] pointed out that large temperature difference leads to thicker condensation film and smaller heat transfer coefficient when the flow pattern is stratified while the temperature difference has less effect on heat transfer coefficient when the flow pattern is annular. The research of Yan and Lin[19] shows that the condensation rate is proportional to heat flux when the mass flow rate is constant, and the heat transfer coefficient decreases with heat flux.

In the LT-MEE desalination plant, steam condensation has the characteristics of high vacuum, low mass flow rate and small temperature difference. The density of steam is very small in vacuum state, so the mass flow rate is rather small although the steam velocity is high. The steam saturation temperature is more sensitive to the pressure in vacuum state. So the flow resistance of steam condensation can significantly affect the steam saturation temperature, and thereby affects the temperature difference and heat transfer coefficient. This paper studies the heat transfer characteristics of steam condensation in vacuum horizontal tube by experiment.

2. Experimental apparatus

Figure. 1 shows the schematic diagram of the experimental apparatus. The water is heated to saturation temperature and then evaporates to steam in an evaporator which electric power is 12kW. The steam flows through four identical test sections. All or part of steam condenses into water and releases latent heat in the test sections. There is a quartz glass tube with the same inner diameter of test tube after each test section. The flow pattern can be observed through the quartz glass tube. The steam and condensation water flow together into the steam-liquid separator which is connected to the last test section. Due to the gravity, condensation water leaves in the separator while steam enters into two double-pipe condensers, where the steam is condensed completely by cooling water. In the end, all the condensation water is collected into the water tank. A vacuum pump connected to the second condenser enables the experimental system to achieve and maintain vacuum state. A water pump and a cooling water tank provide cooling water at constant temperature for four test sections respectively.

The total length of the test tube is 8 m. For lower the increment of cooling water temperature, the main experimental apparatus is divided into four identical test sections. Each test section is a double-pipe heat exchanger. The inner tube is made of aluminum brass, which is also used in desalination plant. The inner diameter is 18mm and effective heat transfer length is 1.8m. The outer tube is made of stainless steel, with an inner diameter of 35mm. The steam flows and condenses in the inner tube while the cooling water countercurrently flows in annular area and takes away the condensation latent heat.

A cross section is selected to place the thermocouples in each heat exchanger. The position is in the middle of the test section. There are 6 tiny grooves on the outer wall of test tube at the cross section. A T-type thermocouple is welded in each groove, and then the surface is polished smoothly. The condensate is collected at the bottom of tube, so the temperature change at the bottom is bigger than at the top. In order to obtain the tube wall temperature accurately, thermocouples are distributed from the bottom up circumferentially at 0° , 20° , 40° , 60° , 90° and 180° of the tube. The cooling water temperatures at the inlet and outlet of each test section are measured by T-type thermocouples. All the thermocouples were calibrated by a thermostatic waterbath with the accuracy of 0.1°C . The liquid level meters were equipped in the separator and condensers, so the mass flow rate of steam and the condensation water can be measured. The mass flow rate of cooling water in each test section is measured by rotameter with an accuracy of 10 L/h. The absolute pressure in evaporator and the inlet and outlet of the whole test tube are measured by pressure transducers, which precision is $\pm 28\text{ Pa}$. Pressure drop of steam condensation flow in each test section is measured by differential pressure transducers which precision is 0.1% within its full span. All the experimental data were collected and recorded by a National Instruments SCXI data acquisition system.

Fig.1. Schematic diagram of experimental apparatus

The heat transfer coefficients are measured in vacuum state. The steam saturation temperature changes from 50 to 70°C, which means the absolute pressure varies from 12335 to 31160 Pa. The steam velocity at the inlet of test section can be very high, but the mass flow rate is very small, because the density of the steam is very small in vacuum state. The mass flow rate in the experiment is no more than 11 kg/(m²·s). Changing the cooling water temperature can change the heat transfer rate in the test section. Three temperature differences between steam and cooling water are selected in the experiment, which are 3, 5 and 7°C at the end of test section respectively.

3. Data processing and error analysis

3.1. Data processing

The heat transfer rate (Q) in each test section is calculated by measuring the temperature difference between inlet and outlet of cooling water, as shown in following equation:

$$Q = m_c c_p (T_{c,out} - T_{c,in}) \quad (1)$$

here, m_c is the mass flow rate of cooling water in the test section and c_p is the specific heat at constant pressure, which is assumed to be constant in each test section. $T_{c,in}$ and $T_{c,out}$ are the cooling water temperatures at the inlet and outlet of the test section.

The average absolute pressure in each test section can be calculated from the pressure at the inlet of whole test tube and pressure drop in each test section. The steam saturation temperature (T_s) in the test tube corresponding to the absolute pressure can be determined by the steam physical property. The thermocouples at different positions measure the local temperatures (T_θ) at different angles (θ) on the test tube. Each measuring point represents different tube wall area, so using the weighted average tube wall temperature (T_w) can be more accurate. It is calculated by following equation:

$$T_w = \frac{1}{180} (10T_0 + 20T_{20} + 20T_{40} + 25T_{60} + 60T_{90} + 45T_{180}) \quad (2)$$

The thermal resistance in the tube wall can be ignored, because the thickness of the test tube wall is only 0.5 mm, so the inner and outer tube wall temperatures are the same. The total temperature difference (ΔT_{sc}) is the difference between the steam temperature and the cooling water temperature. The steam condensation heat transfer temperature difference (ΔT) is the difference between the steam temperature and the weighted average tube wall temperature. These two average temperature differences are shown in equation (3) and (4).

$$\Delta T_{sc} = T_s - T_c \quad (3)$$

$$\Delta T = T_s - T_w \quad (4)$$

The heat transfer rate and temperature difference of in-tube condensation process are obtained by above calculations. So the condensation heat transfer coefficient (h) can be calculated by equation (5).

$$h = \frac{Q}{F \cdot \Delta T} \quad (5)$$

where, F is the effective heat transfer area of the test section.

3.2. Error analysis

The mass flow rate of cooling water was controlled accurately to ensure that the increment of cooling water temperature is larger than 1 °C. So the uncertainty is less than 0.14 °C. The inner diameter

of test tube is measured by a vernier caliper. The average square method[21] is used to evaluate the uncertainties of other parameters. All uncertainties are list in Table. 1.

Table.1. The uncertainties of experimental parameters

Parameters	Uncertainty
Innerdiameter of test tube D	$\pm 0.05\text{mm}$
Effective heat transfer length L	$\pm 2\text{mm}$
Steam temperature T_s	$\pm 0.05^\circ\text{C}$
Average tube wall temperature T_w	$\pm 0.05^\circ\text{C}$
Increment of cooling water temperature $T_{c,\text{out}} - T_{c,\text{in}}$	$\pm 0.14^\circ\text{C}$
Condensation temperature difference ΔT	$\pm 0.07^\circ\text{C}$
Mass flow rate of cooling water m_c	$\pm 1.3\%$
Heat transfer rate Q	$\pm 14\%$
Average condensation heat transfer coefficient h	$\pm 15.7\%$
Mass flow rate of steam m	$\pm 2.5\%$

4. Experimental data and discussions

4.1. Temperature distribution

In order to study heat transfer performance of steam condensation flow in a horizontal long tube in the experimental apparatus, the first priority is to get the temperature distributions. The distributions of steam temperature and average tube wall temperature at different mass flow rates are shown in figure 2 and 3 respectively, with which the steam temperature is 50°C and the total temperature difference is 3°C . It is important to note that the steam saturation temperature is controlled by adjusting the absolute pressure by the vacuum pump at the end of the experiment apparatus. The steam temperatures at the outlet of the whole test tube are controlled accurately at 50, 60 or 70°C at different conditions in the experiments. And the total temperature difference refers to the steam temperatures at the outlet of the whole test tube minus the cooling water temperature at the inlet of test section.

Fig.2. Steam temperature distribution

There is flow resistance when steam condensation flow in the tube, so both the steam pressure and temperature decrease along the flow direction. The steam temperature decreases gently at low mass flow rate and dramatically at high mass flow rate. For example, the temperature reduction is only 0.18 °C when $G=3.0 \text{ kg}/(\text{m}^2 \cdot \text{s})$ and soars to 2.59 °C when $G=8.9 \text{ kg}/(\text{m}^2 \cdot \text{s})$. The steam temperatures are almost the same in the last test section and increase with rising mass flow rate in the first three test sections. The largest increase of steam temperature occurs in the first test section. The flow resistance has a greater effect on the steam temperature distribution than other pressure conditions when steam condenses and flows in a vacuum horizontal long tube.

The steam temperature distribution has a profound impact on other temperature distributions, thereby affecting the heat transfer coefficient. The average tube wall temperature also shows a downward trend along the flow direction, as shown in figure 3. The slopes of tube wall temperature drops in the four test sections along the flow direction are not much different. But there is a particular case, which is the change from third section to the last section when $G=3.0 \text{ kg}/(\text{m}^2 \cdot \text{s})$. Because the steam condenses into water completely in the last section, the tube wall temperature approaches to the cooling water temperature. The tube wall temperature reduction is larger than steam temperature reduction as $G=3.0 \text{ kg}/(\text{m}^2 \cdot \text{s})$. The reductions of steam temperature and tube wall temperature are almost the same as $G=4.2 \text{ kg}/(\text{m}^2 \cdot \text{s})$ and $G=5.2 \text{ kg}/(\text{m}^2 \cdot \text{s})$. But the decreases of tube wall temperature are much smaller than the decreases of steam temperature for the three highest mass flow rates conditions. For example, the steam temperature reduction is 2.59 °C and the tube wall temperature reduction is only 1.58 °C as $G=8.9 \text{ kg}/(\text{m}^2 \cdot \text{s})$.

Fig.3. Average tube wall temperature distribution

Fig.4. Local tube wall temperature distribution

Figure 4 shows the local tube wall temperature distributions along the flow direction at different positions when the mass flow rate is $6.5 \text{ kg}/(\text{m}^2 \cdot \text{s})$. The local temperature decreases along the flow direction at all the angles and it increases with the angle at four cross sections. The tube wall can be divided into three parts in the circumferential direction. The temperatures at 0° and 20° are the lowest, because tube wall in the bottom is covered by condensate. The temperatures at 40° and 60° decrease fast, because the tube wall in this area is in direct contact with steam in the first section, and then covered by the condensate gradually. The temperatures at 90° and 180° are always the highest and the difference between two positions is very small.

Fig.5. Condensation temperature difference distribution

From the above analysis, the steam and tube wall temperatures present different decline tendencies. The decrement of steam temperature is larger than the decrement of tube wall temperature in the first half of the test tube and smaller in the second half. So the condensation temperature difference decreases first and then increases, shown in figure 5. With the increase of mass flow rate, the changes of temperature difference are different in different test sections. The temperature difference increases in the first section and decreases in other sections. In the three low mass flow rate conditions, the temperature differences bottom out at the second section and peak at the last section. However, in the three high mass flow rate conditions, the steam temperatures play a more important role, so the lowest point of temperature difference is in the third section and the highest point is in the first section. The lowest points of temperature difference are around $1.1 \text{ }^\circ\text{C}$ at different mass flow rates. The highest point can be up to $2.36 \text{ }^\circ\text{C}$ in the first section at the highest mass flow rate, or $2.94 \text{ }^\circ\text{C}$ in the last section at the lowest mass flow rate.

Changing the cooling water temperatures will change the temperature distributions. Figure 6 illustrates the steam and tube wall temperatures distribution along flow direction at three different total temperature differences when the saturation temperature is $50 \text{ }^\circ\text{C}$ and mass flow rate is $7.9 \text{ kg}/(\text{m}^2 \cdot \text{s})$. With the decrease of cooling water temperature, steam temperature declines slightly and the decrements are reduced along the flow direction. The decrements of tube wall temperature are larger than that of the steam temperature, and much the same in the first three sections. The situation in the last section when the total temperature difference is $7 \text{ }^\circ\text{C}$ is like the particular case in figure 3, that is the steam condenses into water completely and tube wall temperature approaches to the cooling water temperature. So the tube wall temperature may decrease to cooling water temperature in the last section when the total temperature difference is large.

Fig.6. Effect of total temperature difference on temperature distribution

Fig.7. Average heat transfer coefficient distribution

4.2. Average heat transfer coefficient distribution

The heat transfer coefficient distributions at different mass flow rates and different temperature differences when the saturation temperature is 50 °C are shown in figure 7. The heat transfer coefficients increase first and then decrease, reach the peak at the second section. For example, the heat transfer coefficient is 5108 W/(m²·K) in the first test section when the mass flow rate is 5.2 kg/(m²·s) and total temperature difference is 3°C. Then it increases to 6147 W/(m²·K) in the second section and finally

decreases to $3624 \text{ W/(m}^2\cdot\text{K)}$ in the last section. With the condensation process, the vapor quality decreases along the flow direction. The thickness of liquid film attached to the upper inner tube wall increases and the condensation water is collected in the bottom of the tube. So the thermal resistance in both upper and bottom of the tube significantly increases and tube wall area of filmwise condensation is reduced. On the other hand, the steam velocity decreases along the flow direction, which makes the heat transfer between steam and condensation film **weakened**, because the shear stress between steam and condensation liquid decreases.

4.3. Effect of temperature difference

Another important factor **affecting** heat transfer coefficient is the condensation temperature difference, which is discussed above and shown in figure 5. The main heat transfer mechanism of stratified flow condensation is the film condensation, which is **mainly** influenced by the film thickness. The increase of condensation temperature difference leads to the increases of heat transfer rate and condensation rate. The condensation film thickness is thicker when the condensation temperature difference is larger. So the heat transfer coefficient decreases with the rising condensation temperature difference.

Since the condensation temperature difference in the first section is significantly greater than that in the second section, so the heat transfer coefficient in the first section is smaller than that in the second section. The temperature differences are almost the same in the last three sections at low mass flow rate **nevertheless** both the vapor quality and steam velocity decrease quickly at low mass flow rate, so the heat transfer coefficient decreases significantly along the flow direction at low mass flow rate. The heat transfer coefficients remain in the same level in the second and third section at high mass flow rate. This is **because of** the combined effect of condensation temperature difference and other influence factors.

Lowering the cooling water temperature will change the temperature difference, which also affects the condensation heat transfer coefficient distribution. The steam condenses more quickly at large temperature difference, so the vapor quality is lower and the condensation film thickness is thicker in the tube. The increase of heat transfer coefficient from first section to the second section becomes slowly and the decrease in the last three sections becomes rapidly when the total temperature difference is large. The heat transfer coefficient decreases monotonically in the whole tube at some low mass flow rate conditions. Because no phase change occurs in the last half test tube, single phase heat transfer coefficient is much smaller than condensation heat transfer coefficient.

Fig.8. Effect of temperature difference on heat transfer coefficient

A more **visualized** comparison of heat transfer coefficients at different temperature differences when

the mass flow rate is $7.9 \text{ kg}/(\text{m}^2 \cdot \text{s})$ is shown in figure 8. The heat transfer coefficient exhibits higher values at smaller temperature difference. The highest value of heat transfer coefficients are 7013, 6043 and $5598 \text{ W}/(\text{m}^2 \cdot \text{K})$ for three temperature differences respectively.

4.4. Effect of mass flow rate

The increase of mass flow rate has two effects on the heat transfer coefficient. On the one hand, it leads to the increase of steam velocity, which will improve the shear stress between steam and condensate and reduce the condensate film thickness. The momentum transfer between steam and condensate film also increases. So in most experimental conditions, heat transfer coefficients increase with mass flow rate. The heat transfer coefficients increase 1155 and $1845 \text{ W}/(\text{m}^2 \cdot \text{K})$ in the first two sections when the mass flow rate increases from 3.0 to $7.9 \text{ kg}/(\text{m}^2 \cdot \text{s})$ and the total temperature difference is 3°C . On the other hand, the steam temperature increases obviously at the first two sections with mass flow rate, so the condensation temperature difference increases with mass flow rate, especially at high mass flow rate, which will weaken the heat transfer coefficient. So when the mass flow rate increases from 7.9 to $8.9 \text{ kg}/(\text{m}^2 \cdot \text{s})$, the heat transfer coefficient decreases in the first section and remains constant in the second section when the total temperature difference is 3°C and the heat transfer coefficient increases gently when the total temperature differences are 5 and 7°C .

4.5. Effect of saturation temperature

Figure 9 shows the heat transfer coefficients at three different steam temperatures when the mass flow rate is $6.6 \text{ kg}/(\text{m}^2 \cdot \text{s})$ and temperature difference is 5°C . When the saturation temperature increases, the viscosity of condensation liquid decreases, which leads to accelerate liquid film flowing from top to the bottom of tube and reduce the film thickness. Higher saturation temperature also improves conductivity of both steam and liquid. So heat conduction is enhanced in the condensation liquid film. On the other hand, the density of steam is larger when the saturation temperature is higher. So the velocity of steam is lower at the same mass flow rate. The above analysis shows that the decrease of steam velocity weakens the convection heat transfer between steam and liquid film. The major heat transfer resistance is conduction resistance in the liquid film. So heat transfer coefficient increases when the saturation temperature increases. However, there is a particular case in the last section when the saturation temperature is 70°C . At this condition the vapor quality is very low in the last section.

Fig.9. Effect of saturation temperature on heat transfer coefficient

4.6. Heat transfer rate distribution

Figure 10 shows the heat transfer rate per meter distributions along the flow direction at different mass flow rates when the steam temperature is 50°C and the total temperature difference is 3°C . Both the

steam velocity and vapor quality decrease with the condensation process, so the heat transfer weakens. Another important factor is the temperature difference, which is the heat transfer driving force. It is larger in the first section than in the second and third sections. So the heat transfer rate declines along the flow direction, slightly at low mass flow rate and dramatically at high mass flow rate. The heat transfer rate presents a sharp drop in the last section at the mass flow rate $3.0 \text{ kg}/(\text{m}^2 \cdot \text{s})$, because all the steam condenses into water, there is no phase change in this section. Both the temperature difference and steam velocity increase with the rising mass flow rate, so the heat transfer rate per meter also increases significantly with mass flow rate. The heat transfer rate per meter in the first section increases from 361 to $743 \text{ W}/\text{m}$ when the mass flow rate increases from 3.0 to $8.9 \text{ kg}/(\text{m}^2 \cdot \text{s})$.

Fig.10. Heat transfer rate distribution

The effect of temperature difference on heat transfer rate per meter when the mass flow rate is $7.9 \text{ kg}/(\text{m}^2 \cdot \text{s})$ is shown in figure 11. Increasing the temperature difference between the steam and cooling water will significantly improve the heat transfer rate in the sections. However, the heat transfer rate in the last section is very low as the temperature difference is largest, because steam condenses into water completely in the first three sections.

Fig.11. Effect of temperature difference on heat transfer rate

5. Conclusion

Heat transfer characteristics of steam condensation flow in vacuum horizontal tube were studied experimentally. The parameter distributions along the flow direction are shown, such as the saturation

temperature, tube wall temperature, heat transfer coefficient and heat transfer rate. The steam saturation temperature is more sensitive to the pressure in vacuum state. So the flow resistance of steam condensation can significantly affect the steam saturation temperature, and thereby affects the temperature difference and heat transfer coefficient. The effects of main factors are analyzed. Some conclusions are summarized as following.

1. The steam temperature decreases along the flow direction apparently. The condensation temperature difference decreases first and then increases along the flow direction.
2. Condensation heat transfer coefficient increases first and then decreases along the flow direction. The heat transfer coefficient increases with mass flow rate in most cases, but may decrease in the first section at high mass flow rate. The heat transfer coefficient also increases with saturation temperature and decreases with condensation temperature difference.
3. The heat transfer rate decreases along the flow direction and increases with mass flow rate and temperature difference.

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Nomenclature

c_p — constant pressure specific heat, $\text{kJ}/(\text{kg} \cdot ^\circ\text{C})$

D — diameter, m

F — effective heat transfer area, m^2

G — mass flow rate, $\text{kg}/(\text{m}^2 \cdot \text{s})$

h — heat transfer coefficient, $\text{W}/(\text{m}^2 \cdot \text{K})$

m — mass flow rate, kg/s

L — length, m

Q — heat transfer rate, W

q — heat transfer rate per meter, W/m

T — temperature, $^\circ\text{C}$

Greek symbols

Δ — difference

θ — angle

subscripts

c — cooling water

in — inlet

out — outlet

s — steam

w — wall

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