Experimental Study of Convective Heat Transfers

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Ⅰ.Objective and requirements

Understand the basic principle of convective heat transfer.

Measure the heat transfer coefficient h for free and forced convection.

Understand the factors that influence the heat transfer coefficient.

Ⅱ.Principles

Convective heat transfer:

Convective heat transfer is the transfer of heat between two bodies by currents of moving gas or fluid.

Natural convection: air or water moves away from the heated body as the warm air or water rises and is replaced by a cooler parcel of air or water.

Forced convection: air or water is forcibly moved across the body surface (such as in wind or wind-generated water currents) and efficiently removes heat from the body.

The equation for convection can be expressed as:

$$Q = K * A * \Delta T$$

Q is the heat transferred per unit time

A is the heat transfer area of the surface

ΔT is temperature between the body and its surroundings

K is the convective heat transfer coefficient of the process

Measuring method

The heat transferred to the air is mainly the latent heat:

$$Q = G * r$$

G is the condensation rate

r is the latent heat of vaporization, which can be obtained from a table

In this experiment, the condensed water flows into the graduated glass tube, so the amount of condensed water per unit of time can be calculated as :

$$G = \frac{h * g_S * \rho}{\tau}$$

h is the change in the height of the liquid in the graduated tube in the τ time period

g_s is the equivalent cross-sectional area of the glass tube

ρ is the density of water

In this experiment, $g_s = 3.4636 \times 10^{-6} m^3/cm$, $\rho = 1000 kg/m^3$

The convective heat transfer coefficient

$$K = \frac{Q}{A * \Delta T} = \frac{G * r}{A * \Delta T} = \frac{h * g_S * \rho}{\tau * A * \Delta T} * r$$

$$A = \pi d * L$$

The diameter of the pipe $d = 0.025m$

For glass wool insulation pipe and sawdust insulation pipe, $d = 0.076m$

For nature convection, $L = 0.616m$, while for forced convection $L = 0.5m$.

Ⅲ.Data processing and results

1.Record the experimental parameters on the datasheet, calculate the result, and write out the detailed calculation process for one pipe.

Choose the black plated pipe to calculate:

h=26.5-5.1=21.4mm=2.14cm

τ=5*60+6=306s

r=2345.5kJ/kg at 0.025MPa from the table

$$G = \frac{h * g_S * \rho}{\tau} = \frac{2.14cm * 3.4636 \times \frac{10^{-6} m^3}{cm} * 1000 kg/m^3}{306s} = 2.4223 * 10^{-5} kg/s$$

$A = \pi d * L = \pi * 0.025 * 0.616 = 0.04838\ m^2$

$\Delta T = 100.2 - 30.4 = 69.8℃$

$K = \frac{Q}{A * \Delta T} = \frac{2.4223 * \frac{10^{-5} kg}{s} * 2345.5 \text{kJ/kg}}{0.04838\ m^2 * 69.8℃}$=16.82(W/($m^2$°C))

Table 1 Natural Convection

Natural Convection	Black plated pipe	Chrome plated pipe	Bare copper pipe	Finned pipe	Glass wool insulation pipe	Sawdust insulation pipe
Initial liquid level (mm)	5.1	8.0	18.0	30.1	7.9	10.0
Final liquid level (mm)	26.5	36.7	35.9	63.0	22.9	23.0
Time duration τ (min)	5'06"	5'06"	5'06"	5'06"	5'06"	5'06"
Pipe temperature (°C)	100.2	97.0	100.7	99.6	99.3	98.5
Steam temperature (°C)	99.7	99.7	99.6	99.6	99.6	99.6
Ambient temperature (°C)	30.4	30.4	30.4	30.4	30.4	30.4
Steam pressure (Mpa)	0.025	0.025	0.026	0.027	0.026	0.026
Latent heat of vaporization r (KJ/kg)	2240.3	2240.3	2240.3	2240.3	2240.3	2240.3
gs (m^3/cm)	3.4636E-06	3.4636E-06	3.4636E-06	3.4636E-06	3.4636E-06	3.4636E-06
Condensed water G (kg/s)	2.4223E-05	3.2485E-05	2.0261E-05	3.7239E-05	1.6978E-05	1.4715E-05
Heat transferred Q (W)	54.27	72.78	45.39	83.43	38.04	32.97
heat transfer area A (㎡)	4.8381E-02	4.8381E-02	4.8381E-02	4.8381E-02	1.4708E-01	1.4708E-01
convective heat transfer coefficient K (W/(㎡*°C)	16.07	22.59	13.35	24.92	3.754	3.291

Table 2 Forced Convection

Forced Convection	Black plated pipe	Chrome plated pipe	Bare copper pipe	Finned pipe	Glass wool insulation pipe	Sawdust insulation pipe
Initial liquid level (mm)	50.0	11.2	5.0	4.0	2.1	12.0
Final liquid level (mm)	80.0	32.1	17.9	50.0	16.9	34.5
Time duration τ (min)	4'29"	3'01"	3'07"	2'00"	3'11"	4'04"
Pipe temperature (°C)	96.5	94.0	92.3	97.4	96.6	98.4
Steam temperature (°C)	97.0	99.3	99.3	99.3	99.5	96.9
Ambient temperature (°C)	35.6	28.1	28.7	29.2	29.8	36.7
Steam pressure (Mpa)	0.026	0.024	0.026	0.027	0.028	0.026
Latent heat of vaporization r (KJ/kg)	2240.3	2240.3	2240.3	2240.3	2240.3	2240.3
gs (m^3/cm)	3.4636E-06	3.4636E-06	3.4636E-06	3.4636E-06	3.4636E-06	3.4636E-06
Condensed water G (kg/s)	3.8628E-05	3.9994E-05	2.3893E-05	1.3277E-04	2.6838E-05	3.1939E-05
Heat transferred Q (W)	86.54	89.60	53.53	297.4	60.13	71.55
heat transfer area A (㎡)	3.9270E-02	3.9270E-02	3.9270E-02	3.9270E-02	1.1938E-01	1.1938E-01
convective heat transfer coefficient K (W/(㎡*°C)	36.18	34.62	21.43	111.1	7.540	9.714

2. Discuss the result and make a conclusion.

For free convection at 0.025 MPa

The heat transfer Q in descending order is:

Finned pipe > Chrome plated pipe > Black plated pipe > Bare copper pipe > Glass wool insulation pipe > Sawdust insulation pipe

The corresponding heat transfer coefficient K in descending order of magnitude is:

Finned pipe > Chrome plated pipe > Black plated pipe > Bare copper pipe > Glass wool insulation pipe > Sawdust insulation pipe

For forced convection at 0.025 MPa

All tubes' heat transfer and the heat transfer coefficient increase with forced convection.

The increase in heat transfer in descending order:

Finned pipe > Sawdust insulation pipe > Black plated pipe > Glass wool insulation pipe > Chrome plated pipe > Bare copper pipe

The increase in heat transfer coefficient in descending order:

Finned pipe > Black plated pipe > Chrome plated pipe > Bare copper pipe > Sawdust insulation pipe > Glass wool insulation pipe

The heat transfer in descending order:

Finned pipe > Chrome plated pipe > Black plated pipe > Sawdust insulation pipe > Glass wool insulation pipe > Bare copper pipe

The heat transfer coefficient in descending order:

Finned pipe > Black plated pipe > Chrome plated pipe > Bare copper pipe > Sawdust insulation pipe > Glass wool insulation pipe

In this experiment, the factors that can qualitatively determine the heat transfer and heat transfer coefficient are convection (free or forced), tube surface treatment, tube diameter, and length.

Ⅳ.Questions

1.According to the experiment results, discuss the relationship between the heat transfer coefficient of copper pipes and the external surface treatment and airflow state.

External surface treatment

In the case of free convection and forced convection:

Black plated pipe: The surface of the copper tube is blackened, and from the experimental results, the heat transfer coefficient increases compared to the bare copper tube, probably because black is more conducive to heat absorption.

Chrome plated pipe: The surface of the copper tube is chrome-plated, and from the experimental results, the heat transfer coefficient increases compared to the bare copper tube.

Bare copper pipe: The surface of the copper pipe is polished, which has no obvious effect on heat transfer.

Finned pipe: By adding fins to expand the heat transfer area, from the experimental results, compared with bare copper tubes, the heat transfer coefficient can be greatly improved.

Glass wool insulation pipe: Glass wool is filled between the inner and outer pipes to reduce air convection heat transfer, and the heat transfer coefficient is greatly reduced.

Sawdust insulation pipe: Sawdust is filled between the inner and outer pipes to reduce air convection heat transfer and greatly reduce the heat transfer coefficient.

Airflow state:

When the flow state is changed from free convection to forced convection, the heat transfer coefficient of all copper tubes increases.

2.Discuss whether testing with different vapor pressures would infect the heat transfer coefficient results

Under different vapor pressures, the latent heat of vaporization r is different, according to the equation:

$$K = \frac{Q}{A * \Delta T} = \frac{G * r}{A * \Delta T} = \frac{h * g_s * \rho}{\tau * A * \Delta T} * r$$

so testing with different vapor pressures will infect the heat transfer coefficient results.

3.Discuss the error sources and make suggestions for improvements

Error sources:

1) When data processing, the selected water density is 1000kg/m^3, but in fact, the density of water will be higher than this value, which leads to small results obtained by data processing, and meanwhile, the latent heat of vaporization r selected is the value at steam pressure (0.025MPa + 0.101MPa), but in the actual experiment, the value of steam pressure fluctuates, when it is higher than 0.025MPa, the r value will be less than 2240.3kJ/kg, which leads to large experimental results obtained by data processing.
2) During the experiment, in the process of reading the liquid level after starting and stopping the timing, due to the slow speed of the experimenter's reading, there may be a situation where the liquid level increases due to the continued condensation of water, which will lead to an increase in the liquid level recorded during the timing time period, resulting a larger calculated heat transfer, which leads to a large heat transfer coefficient.
3) The device that experimentally records the ambient temperature is located near the heating source, resulting in a higher ambient temperature recorded compared to the actual ambient temperature, which will lead to a small temperature difference between the pipe body and its surrounding ΔT, which in turn will obtain a large heat transfer coefficient.
4) During the experiment, there will be droplets attached to the tube, so the height of the liquid level read is smaller than the actual amount of condensed water, which will lead to small heat transfer, which in turn leads to a small heat

transfer coefficient.

Suggestions:

1) Consider installing an electronic reader device to record the liquid level height, which can lock the read value at the beginning and end of the timekeeping, which can reduce the error of the experimenter's reading, and also avoid the problem of large liquid level data due to slow speed during reading.
2) Install a thermometer around the tube to record ambient temperature, or install the device in the instrument to record ambient temperature a little away from the heating source to obtain a more accurate temperature difference ΔT.