Comparison between Actual and Theoretical Heat Transfer Coefficient in Constant Wall Surface Temperature

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Abstract: ***Comparing between the values of coefficient of heat transfer as actual and theoretical by using double tube heat exchanger experimentally.***

Keywords: Actual coefficient of heat transfer, Theoretical coefficient of heat transfer, heat load, LMTD, Pr-Nu-Re

1. Introduction

In this paper I would like to investigate and calculate different values of coefficient of heat transfer by using experimental internal forced convection double tube heat exchanger at constant surface wall temperature due to heating water at different mass flow rates by saturated steam at 1 bar. Constant wall temperature in one of the important systems we faced in condensation and evaporation process like water chillers and different types of heat exchangers.

1. Research Methods

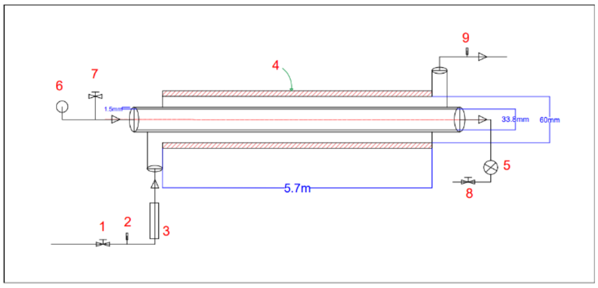
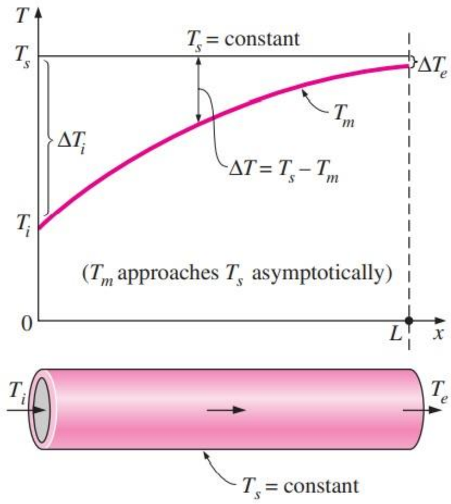


Figure 1: Double Tube Heat Exchanger

[1] Water inlet control valve.
[2] Water inlet temperature sensor, Ti, C.
[3] Water inlet flow meter, m3/hr.
[4] Shell side insulation.
[5] Steam trap set.
[6] Steam pressure gauge, bar.
[7] Safety valve.
[8] Condensate valve.
[9] Water outlet, Te, C.

The measurement of heat transfer coefficient under constant wall temperature condition is usually realized by steam condensation on the other wall surface.



The fluid is pumped through the tube by a pump equipped with a flow rate regulation. The fluid flowing inside the tube is heated by the saturated steam from a steam boiler. The saturation temperature and pressure of the steam are measured by a temperature sensor and an absolute pressure gauge, respectively. We can regulate the valve to control the flow rate of the water and keep the inlet fluid temperature Ti at the specified value. We can measure the condensate flow rate.

The heat load from the steam side is determined with the measured mass flow rate and the evaporation enthalpy Δh_{fg}

at the measured saturation temperature Ts as

$$Q^{\circ} = m_s{}^{\circ} . \Delta h_{fg} \qquad \text{Eqt 1}$$

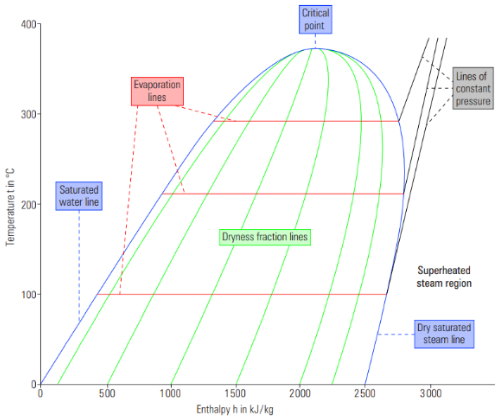


Figure 2: Steam p-h curve

The heat load from the fluid side can be obtained from the measured inlet and outlet fluid temperatures Ti and Te:

$$Q^{\circ} = m_w{}^{\circ}.cp.(Te - Ti) \qquad \text{Eqt 2}$$

$$Q^{\circ} = \rho.V^{\circ}.cp.(Te - Ti) \qquad \text{Eqt 3}$$

$$m_w{}^{\circ} = \rho.\frac{\pi}{4}.di^2.V_m \qquad \text{Eqt 4}$$

Cp, water specific heat, w/m. k.

Q°, heat load, w.

$m_s{}^{c}$, steam mass flow rate, kg/sec.

Δh_{fg}, specific enthalpy.

V_m, mean velocity, m/sec.

di, tube inside diameter, m.

$m_w{}^{\circ}$, water flow rate, m3/sec.

Where all fluid properties are evaluated at the bulk mean fluid temperature $T_b = (T_e + T_i)/2$.

The heat load from the fluid side can also be obtained from the measured calculate log mean temperature difference, LMTD, inside tube surface area and calculation of coefficient of heat transfer, h. as per this equation:

$$Q^{\circ} = h_{act}.As.LMTD \qquad \text{Eqt 5}$$

The rate of heat transfer between the two fluids at a location in a heat exchanger depends on the magnitude of the temperature difference at that location, which varies along the shell-and-tube heat exchanger. Therefore, in the heat transfer analysis of heat exchangers, it is convenient to establish an appropriate mean value of the temperature difference between the hot and cold fluids such that the total heat transfer rate Q& between the fluids, and that can be determined during the next equations.

$$LMTD = \frac{(\Delta Ti - \Delta Te)}{ln\ (\Delta Ti/\Delta Te)} \qquad \text{Eqt 6}$$

Where:

$$\Delta Ti = Ts - Ti \qquad \text{Eqt 7}$$

$$\Delta Te = Ts - Te \qquad \text{Eqt 8}$$

Heat transfer mode in a double tube heat exchanger usually involves convection in fluid at shell side and we will neglect the effect of conduction through the wall. In the analysis of double tube heat exchanger at our special case, it is convenient to work with a coefficient of heat transfer coefficient.

By using previous equations, we can calculate coefficient of heat transfer as actual values by using all data collected by the experimental heat exchanger. Now it the time to calculate values of coefficient of heat transfer as theoretical and comparing between all results.

Reynolds number is most important parameter used to indicate the value of coefficient of heat transfer as the following equation.

$$Re = \frac{\rho.v_m.d_h}{\mu} \qquad \text{Eqt 9}$$

Where:

ρ, water density, kg/m3.
d_h, hydraulic diameter, m.
μ, dynamic viscosity of water, pa. sec

$$d_h = d_o - d_i \qquad \text{Eqt 10}$$

At large Reynolds numbers, the inertia forces, which are proportional to the density and the velocity of the fluid, are large relative to the viscous forces, and thus the viscous forces cannot prevent the random and rapid fluctuations of the fluid. At small Reynolds numbers, however, the viscous forces are large enough to overcome the inertia forces and to keep the fluid "in line. " Thus, the flow is turbulent (greater than 2300) in the first case and laminar (less than 2300) in the second.

The empirical correlation used to calculate the theoretical coefficient of heat transfer by using the values of Reynolds numbers and Prandtl numbers at different exit water temperature.

$$Nu = \frac{h_{theo}.d_h}{kf} \qquad \text{Eqt 11}$$

$$Nu = 0.023\ Re^{0.8}Pr^{n} \qquad \text{Eqt 12}$$

$0.6 < pr < 100$
$2500 < Re_d < 1.25x10^5$

Where:

n = 0.4 for heating and 0.3 for cooling.

Nu, Nusselt number.

Pr, Prandtl number.

if Reynold number below these values we will use other equation for laminar developing flow at constant wall temperature.

$$Nu = 3.66 + \frac{0.0668\left(\frac{d}{L}\right)Re_d\,Pr}{1+0.04\left[\left(\frac{d}{L}\right)Re_d\,Pr\right]^{2/3}} \qquad \text{Eqt 13}$$

$$L_h = 0.05\,.Re.d \qquad \text{Eqt 14}$$

$$L_t = 0.05.Re.d.pr \qquad \text{Eqt 15}$$

But in turbulent flow

$$L_h = L_t = 10\,d \qquad \text{Eqt 16}$$

Where:

L_h, Dynamic entrance length.

L_t, thermal entrance length.

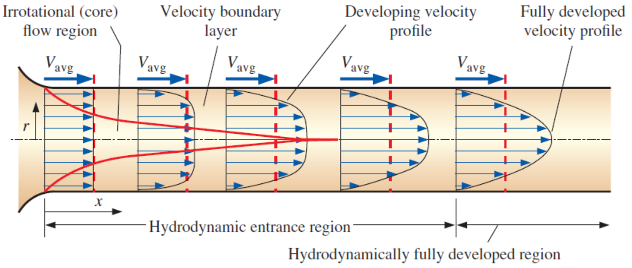


Figure 3: Entrance region Inside tube

2. Research Results

Water properties at mean temperature as per below table.

Table 1: Water Properties at mean temperature

Ti	Te (actual)	Tm	density (kg/m3)	k (w/m. k)	cp	pr	dynamic viscosity (pa. s)
38	70	54	985.7	0.636	4182	3.315	0.0005042
38	68	53	985.7	0.636	4182	3.315	0.0005042
38	66	52	988	0.6305	4181	3.628	0.0005471
38	60	49	988	0.6305	4181	3.628	0.0005471
38	58	48	988	0.6305	4181	3.628	0.0005471
38	80	59	983.2	0.641	4183	3.045	0.0004666

Table 2: deviation between actual and theoretical coefficient of heat transfer

Flow m3/hr	Ti	Te	Ts steam	Re	LMTD	h actual	h theo	correction
0.5	38	70	92	3, 687.5	35.6	**780.5**	**643.4**	17.5%
1	38	68	92	7, 375.1	36.9	**1, 409.8**	**1, 120.2**	20.54%
1.5	38	66	92	10, 219.0	38.3	**1, 910.0**	**1, 494.5**	21.75%
2	38	60	92	13, 625.3	42.04	**1, 823.1**	**1, 881.3**	-3.19%
2.5	38	58	92	17, 031.6	43.2	**2, 014.9**	**2, 249.0**	-11.61%
0.25	38	80	92	1, 987.3	27.9	**652.2**	**325.0**	50.16%

The readings were taken according to the previous table for the actual and theoretical heat transfer coefficient was calculated. To comment on the results shown in the table, we find that there is a difference between the actual and theoretical heat transfer coefficient readings, as the higher the Reynolds number (turbulent flow), the closer the results are, and vice versa, the lower the Reynolds number (laminar flow), the greater the difference between the actual and theoretical values of coefficient of heat transfer.

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Author Profile

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