King Abdulaziz University

Mechanical Engineering Department

MEP460

Heat Exchanger Design

Double pipe heat exchanger iterative design procedure

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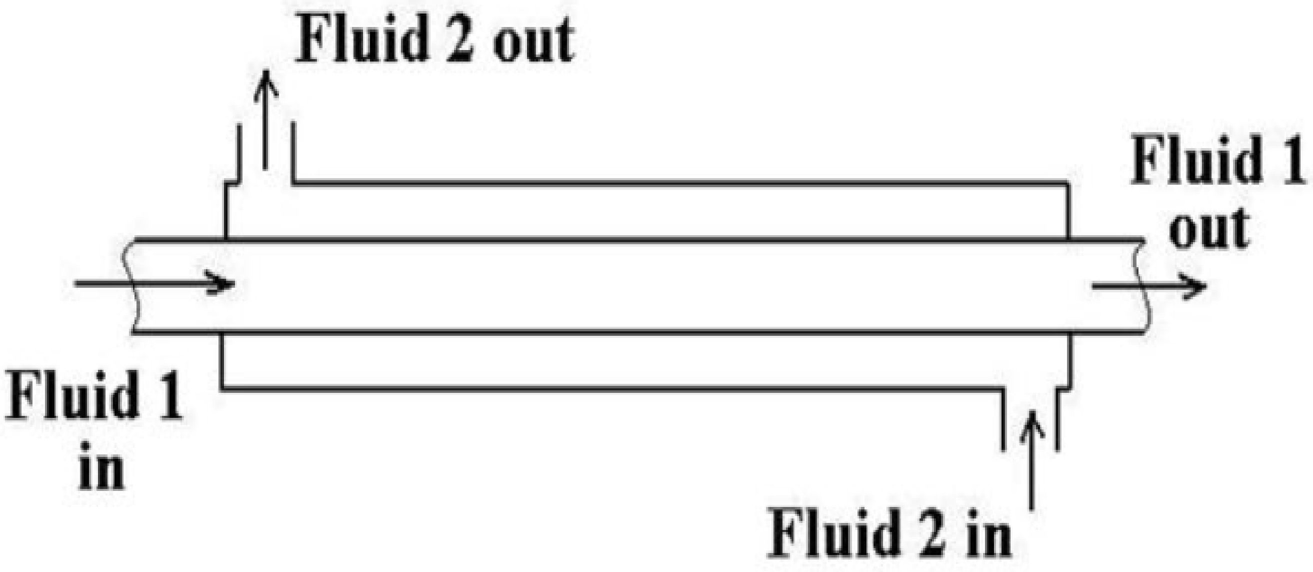
Introduction



The objective is to design a double pipe heat exchanger i.e. finding the heat exchanger heat transfer area (which include the inner tube inside diameter, the heat exchanger length which fulfils the heat load and not exceeding the maximum pressure in the tube or annulus flow

Input data

1-fluids flowing in the tube side and in the annulus.
2-mass flow rate for cold and hot streams
3-inlet and outlet temperatures or at least three temperatures and mass flow rates
4-maximum pressure drop in the tube side and in the annulus side i.e. $\Delta p_{t,max}$ and $\Delta p_{a,max}$
5-thermal conductivity of the tube material, k_t

Required

1-Area of the heat exchanger for clean and fouled heat exchanger (A_c A_f ,d_i, L, ….)

Input data

tube side mass flow rate	annulus side mass flow rate	Tube side fluid	Annulus side fluid	Inside fouling factor	Outside fouling factor	Tube thermal conductivity
$\dot{m}_t$	$\dot{m}_a$			R_{fi}	R_{fo}	k_t
[kg/s]	[kg/s]			[m^2.K/W]	[m^2.K/W]	

Inlet cold fluid temp.	Outlet cold fluid temp.	Inlet hot fluid temp.	Outlet hot fluid temp.	Tube side Max. allowable pressure drop	Annulus Max. allowable pressure drop
T_{ci}	T_{co}	T_{hi}	T_{ho}	$\Delta P_{t,max}$	$\Delta P_{a,max}$
[ºC]	[ºC]	[ºC]	[ºC]	[Pa]	[Pa]

Assumptions

1-Tube wall thickness, t [mm]
2-Fouling factors (inside and outside i.e. R_{fi}, R_{fo})
3-Initial guess for the tube and annulus velocities ($V_{t,max}$ & $V_{a,max}$)

Procedure

1-Calculate the fourth temperature if not given using the heat balance equation i.e.

$$q = C_c \Delta T_c = C_h \Delta T_h$$

Then calculate $LMTD_{CF}$

$$LMTD_{CF} = \frac{(T_{ho} - T_{ci}) - (T_{hi} - T_{co})}{ln\,(T_{ho} - T_{ci})/(T_{hi} - T_{co})}$$

2-Calculate the fluid properties at the mean temperatures

Property	Cold side	Hot side
Density	ρ_c	ρ_h
Specific heat	C_{pc}	C_{ph}
Thermal conductivity	k_c	k_h
Viscosity	μ_c	μ_h
Prandtl number	Pr_c	Pr_h

3-Based on an assumed max velocity for tube side $V_{t,max}$ for tube side, get d_i.

$$\dot{m}_t = \rho_t V_{t,max} A_{ct}$$

where A_{ct} is the cross section area of the tube. V_t is the tube velocity. The Cross section area of the tube

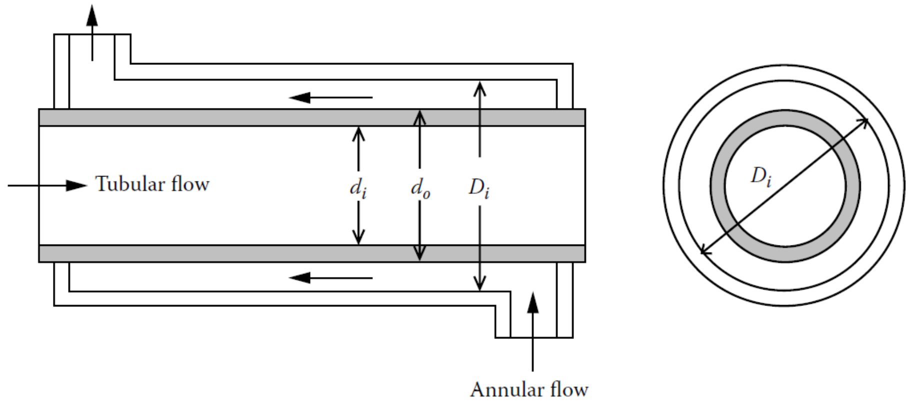
$$A_{ct} = \frac{\pi}{4} d_i^2$$

Assume typical wall thickness t and get d_o

4-Using the given mass flow rate in the annulus and the assumed annulus max velocity, calculate the inside diameter of the annulus D_i.

$$\dot{m}_a = \rho_a V_{a,max} A_{ca} \qquad A_{ca} = \frac{\pi}{4}\left(D_i^2 - d_o^2\right)$$

Also calculate the hydraulic diameter D_e



$$D_e = \frac{4(\pi D_i^2/4 - \pi d_o^2/4)}{\pi d_o} = \frac{D_i^2 - d_o^2}{d_o}$$

Also calculate the hydraulic diameter D_h as follows

$$D_h = \frac{4A_{ca}}{P} = \frac{4A_{ca}}{\pi D_i + \pi d_o} = \frac{4\left(\frac{\pi}{4}(D_i^2 - d_o^2)\right)}{\pi(D_i + d_o)} = D_i - d_o$$

5-For tube side calculate Re_t , Nu_t & h_t

6-For annulus flow Calculate Re_a ,Nu_a , & h_a

7-You may assume typical values for the fouling resistances i.e. R_{fi} , and R_{fo}

8-Based on assumed k_t , calculate U_c and U_f

$$\frac{1}{U_f} = \frac{1}{h_t(A_i/A_o)} + \frac{R_{fi}}{A_i/A_o} + \frac{A_o \ln(d_o/d_i)}{2\pi k L} + \frac{1}{h_a} + R_{fo}$$

9-Use the equation

$$q = U_o A_o LMTD_{CF}\, F \qquad A_o = \pi d_o L$$

get the heat exchanger length L

10-Calculate the pressure drop in tube side Δp_t and the annulus side Δp_a

Use very simple equations to find the friction coefficient as a function of Re number

For laminar flow

$$f = 16/Re$$

For turbulent flow inside a smooth pipe

$$f = [1.58\ln(Re) - 3.28]^{-2}$$

$$\Delta p_t = 4 f_t \frac{L}{D_t}\, \rho_t \frac{V_t^2}{2} \qquad \Delta p_a = 4 f_a \frac{L}{D_a}\, \rho_a \frac{V_a^2}{2}$$

11-Calculate the difference between the allowable pressure and the pressure calculated from the previous step. It is called Residual Sum of Squares RSS

$$R_{ss} = \sqrt{\left(\Delta P_t - \Delta P_{t,max}\right)^2 + \left(\Delta P_a - \Delta P_{a,max}\right)^2}$$

When R_{ss} is higher than a prescribed value, one can restart the iteration process by computing the tube and annulus velocities from the allowable pressure drop for each side

$$\Delta p_{t,max} = 4 f_t \frac{L}{D_t} \rho_t \frac{V_t^2}{2} \qquad \Delta P_{a,max} = 4 f_a \frac{L}{D_h} \rho_a \frac{V_a^2}{2}$$

$$V_t = \left[\left(\Delta P_{t,max}/4 f_t\right)(d_i/L)(2/\rho_t\right]^{0.5} \qquad V_a = \left[\left(\Delta P_{a,max}/4 f_a\right)(D_h/L)(2/\rho_a\right]^{0.5}$$

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