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MEP460
Heat Exchanger design
Fall 2021

Simple iterative procedure to design un-finned double pipe heat exchanger

1. Problem statement:

A double pipe heat exchanger is to be sized (i.e. to find the area A_o, heat exchanger length L, and the inner pipe diameter d_i) to meet a given heat load and not to exceed certain pressure drops in the tube and annulus sides. The mass flow rates and the temperatures for the two streams are given.

2. Given data

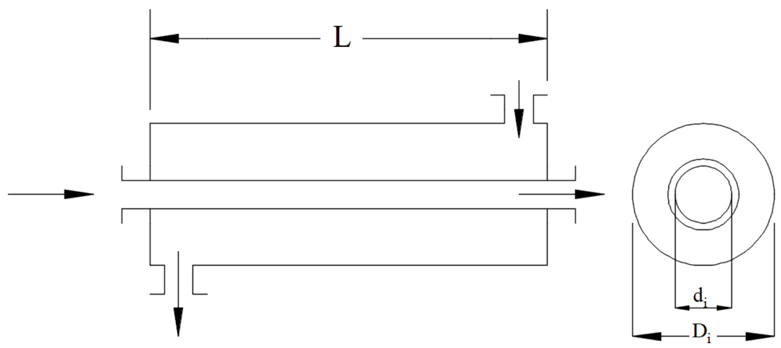
Tube side mass flow rate	Annulus side mass flow rate	Tube side fluid	Annulus side fluid	Inside fouling factor	Outside fouling factor	Tube wall thickness
$\dot{m}_t$	$\dot{m}_a$	√	√	R_{fi}	R_{fo}	t
[kg/s]	[kg/s]			[m^2.K/W]	[m^2.K/W]	[mm]

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]

Tube side operating pressure	Annulus side operating pressure	Which fluid in the tube side	Tube thermal conductivity	
P_t	P_a	√	k_t	
[Pa]	[Pa]		W/m.K	

3. Assumptions

Tube wall thickness	Max. tube velocity	Max. annulus velocity
t	$V_{t,max}$	$V_{a,max}$
[mm]	[m/s]	[m/s]



Double pipe heat exchanger

4. Procedure

1-Calculate the fourth temperature if not given using heat load to be the same for the cold and hot side.

$$q = C_c \Delta T_c = C_h \Delta T_h \tag{1}$$

Then calculate the $LMTD_{CF}$

$$LMTD_{CF} = \frac{(T_{ho} - T_{ci}) - (T_{hi} - T_{co})}{ln(T_{ho} - T_{ci})/(T_{hi} - T_{co})} \tag{2}$$

Also calculate the LMTD correction factor F if required.

2-Calculate the fluid properties at the mean temperatures

Property	Cold side	Hot side
Average Temp.	T_{ca}	T_{ah}
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 $V_{t,max}$ for tube side, get d_i.

$$\dot{m}_t = \rho_t V_{t,max} A_{ct} \tag{3}$$

where A_{ct} is the cross-section area of the tube.

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

$V_{t,max}$ is the tube assumed maximum velocity. Assume typical wall thickness t 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.

$$\dot{m}_a = \rho_a V_{a,max} A_{ca} \tag{5}$$

where the cross-section flow area of the annulus flow side is

$$A_{ca} = \frac{\pi}{4}(D_i^2 - d_o^2) \tag{6}$$

Calculate the equivalent diameter D_e for heat transfer calculations

$$D_e = \frac{4(\pi D_i^2/4 - \pi d_o^2/4)}{\pi d_o} = \frac{D_i^2 - d_o^2}{d_o} \tag{7}$$

Also calculate the hydraulic diameter D_h as follows

$$D_h = \frac{4A_{ca}}{P} = \frac{4A_{ca}}{\pi D_i + \pi d_o} = \frac{4\left(\frac{\pi}{4}(D_i^2 - d_o^2)\right)}{\pi(D_i + d_o)} = D_i - d_o \tag{8}$$

5-For tube side calculate Re_t, Nu_t and h_t

6-For annulus flow calculate Re_a ,Nu_a, and h_a

7-You may assume typical value for the fouling resistances R_{fi} , and R_{fo}

8-Calculate U_c and U_f

$$\frac{1}{U_f} = \frac{1}{h_t(A_i/A_o)} + \frac{R_{fi}}{A_i/A_o} + \frac{A_o \ln{(d_o/d_i)}}{2\pi kL} + \frac{1}{h_a} + R_{fo} \tag{9}$$

9-Use the heat rate equation

$$q = U_f A_o LMTD.F \tag{10}$$

to get the heat exchanger length L, where A_o is given by

$$A_o = \pi d_o L \tag{11}$$

10-Calclate the pressure drops in tube size and the annulus flow

i.e. Δp_t and Δp_a using

$$\Delta P_t = 4 f_t \frac{L}{d_i} \rho_t \frac{V_t^2}{2} \tag{12}$$

$$\Delta P_a = 4 f_a \frac{L}{D_h} \rho_a \frac{V_a^2}{2} \tag{13}$$

where f_t and f_a are the friction coefficient (Kakac symbol for friction coefficient) for tube and annulus side respectively. For turbulent flow inside smooth pipes, it can be found using

$$f = [1.58 \ln(Re) - 3.28]^{-2} \tag{14}$$

For laminar flow

$$f = \frac{16}{Re} \tag{15}$$

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

$$R_{ss} = \sqrt{\left(\Delta P_t - \Delta P_{t,max}\right)^2 + \left(\Delta P_a - \Delta P_{a,max}\right)^2} \tag{16}$$

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

11- Based on the required maximum allowable pressure drop for both the tube and annulus sides, calculate new values for the velocity in tube and in annulus as follows

$$\Delta P_{t,max} = 4 f_t \frac{L}{d_i} \rho_t \frac{V_t^2}{2} \tag{15}$$

$$\Delta P_{a,max} = 4 f_a \frac{L}{D_h} \rho_a \frac{V_a^2}{2} \tag{16}$$

use old values of d_i, D_h, f_t and f_a.

12- Continue the iterations until the convergence criterion for R_{ss} is met

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

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

4. List of symbols

Symbols	meaning	
A_{ca}	Annulus cross section flow area	
A_{ct}	Tube cross section flow area	
A_o	Outside heat transfer area	
d_i	Outer pipe inside diameter	
D_h	Hydraulic diameter for Re and pressure drop calculations	
D_e	Equivalent annulus diameter for heat transfer calculations	
d_i	Inner pipe inside diameter	
f_a	Annulus side friction coefficient (Kakac symbol)	
f_t	Tube side friction coefficient (Kakac symbol)	
h_a	Annulus side heat transfer coefficient	
h_t	Tube side heat transfer coefficient	
k_t	Tube thermal conductivity	
L	Heat exchanger length	
$\dot{m}_a$	Annulus side flow rate	
$\dot{m}_t$	Tube side flow rate	
R_{fi}	Internal flow fouling resistance	
R_{fo}	External flow fouling resistance	
t	Inner pipe wall thickness	
V_t	Tube side flow velocity	
V_a	Annulus side flow velocity	
$V_{t,max}$	Max. Tube side flow velocity	
$V_{a,max}$	Max. Annulus side flow velocity	
Δp_t	Tube side pressure drop	
Δp_a	Annulus side pressure drop	
$\Delta p_{t,max}$	Max. Tube side pressure drop	
$\Delta p_{a,max}$	Max. Annulus side pressure drop	

Example

2. Given data

Tube side mass flow rate	Annulus side mass flow rate	Tube side fluid	Annulus side fluid	Inside fouling factor	Outside fouling factor	Tube wall thickness
$\dot{m}_t$=1.36	$\dot{m}_a$=1.39	water	water	R_{fi}=0.00176	R_{fo}=0.00176	k_t=2 mm
[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}=20	T_{co}=35	T_{hi}=140	T_{ho}=125	$\Delta P_{t,max}$=850	$\Delta P_{a,max}$=4825
[ºC]	[ºC]	[ºC]	[ºC]	[Pa]	[Pa]

Tube side operating pressure	Annulus side operating pressure	Which fluid in the tube side	Tube wall thermal conductivity	
P_t=15	P_a=150	hot fluid	k_t=20	
[MPa]	[kPa]		W/(m.K)	

Property	Cold side	Hot side
Average temperature	T_{ca}=27.5 ºC	T_{ha}=132.5 ºC
Density	ρ_c=996.3 kg/m^3	ρ_h=932.8 kg/m^3
Specific heat	C_{pc}=4.183 kJ/kg. K	C_{ph}=4.272 kJ/kg.K
Thermal conductivity	k_c=0.5989 W/m.K	k_h=0.6697 W/m.K
Viscosity	μ_c=8.42E-4 Pa.s	μ_h=2.087E-4 Pa.s
Prandtl number	Pr_c=5.882	Pr_h=1.331

Start the integrations by assuming maximum velocity in the tube and annulus side as 2.5 m/s. i.e.

$V_{t,}$max=2.5 m/s

$V_{a,max}$=2.5 m/s

	V_t	V_a	d_i	Re_{di}	Re_{Dh}	h_t	h_a	U_f	A_o	L	ΔP_t	ΔP_a	Rss
	[m/s]	[m/s]	[m]	[-]	[-]	W/m^2.K	W/m^2.K	W/m^2.K	[m^2]	[m]	[Pa]	[Pa]	
1	2.5	2.5	0.02725	304524	29060	15011	4579	1283	0.6477	6.6	10158	49813	45941
2	0.7232	0.7781	0.0507	163788	16514	4916	1586	758	1.096	6.4	499.4	2950	1908
3	0.9435	0.9952	0.04436	187078	18670	6245	1980	868	0.957	6.3	932.8	5218	401
4	0.9006	0.957	0.0454	182775	18284	5989	1913	850	0.977	6.3	833.4	4761	66
5	0.909	0.963											