LMECA2854 - Heat & Mass Transfert II

Heat Exchanger Laboratory (Part 2)

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1 Introduction

After the laboratory carried out in S8 on a heat exchanger and the variation of the water temperature at different points of the circuits in this exchanger, we collected different data. Mainly on the correlation between the temperature at different locations in the circuit and the mass flow at the inlet of the exchanger for different configurations. Thus, we now have a large quantity information that will allow us to compare our theoretical results to reality.

2 Comparison of theory and practice

2.1 Recalculation of $R_{conv,c}$

After the lab and a discussion with the assistant, the computation of $R_{conv,c}$ can be improved. Indeed, it has been recommended to look at one of the reference books of the course, *Fundamentals of Heat and Mass Transfer by T. Bergman, A. Lavine, F. Incropera and D. Dewitt.* First, as recommended in the book on page 520, the hydraulic diameter used should be $D_o - D_i = 0,0076m$. We used previously the distance between the radii (0,0038 m), so the Reynolds number for each mass flow rate at the cold side will also be recalculated. Second, the equation (29) in the formula sheets can still be used for this case, but taking into account that we have a coaxial assembly. This leads to replacing the value of 3.66 with one found in a tabular the book also on page 520, which is displayed on figure (1). Knowing that for this case $\frac{D_i}{D_o} = 0,5$, the value used will be $Nu = 4,43$.

	Temperature $[K]$	Dynamic viscosity μ [Pa.s]	Re
Cold fluid	290	0,001080	414,54
	300	0,000855	523,62
	310	0,000695	644,16
	320	0,000577	775,9

Table 1: Recalculation of the Reynolds number at the cold side for $\dot{m}_c = 40kg/h$ and $\dot{m}_h = 15kg/h$ (lower limit of mass flow rate)

	Temperature $[K]$	Dynamic viscosity μ [Pa.s]	Re
Cold fluid	290	0,001080	414,54
	295	0,000959	466,84
	300	0,000855	523,62

Table 2: Recalculation of the Reynolds number at the cold side for $\dot{m}_c = 40kg/h$ and $\dot{m}_h = 40kg/h$ (upper limit of mass flow rate)

TABLE 8.2 Nusselt number for fully developed laminar flow in a circular tube annulus with one surface insulated and the other at constant temperature

D_i/D_o	Nu_i	Nu_o	*Comments*
0	—	3.66	See Equation 8.55
0.05	17.46	4.06	
0.10	11.56	4.11	
0.25	7.37	4.23	
0.50	5.74	4.43	
≈1.00	4.86	4.86	See Table 8.1, $b/a \rightarrow \infty$

Figure 1: Tabular from *Fundamentals of Heat and Mass Transfer*

$$\overline{Nu(L)} = 4,43 + \frac{0,0668 G_z(L)}{1 + 0,04 G_z(L)^{\frac{2}{3}}} \quad With \quad G_z(L) = \frac{RePr}{\frac{L}{D}} \tag{1}$$

$\dot{m}_h[kg/h]$	$\dot{m}_c[kg/h]$	Highest Re	Pr	G$_z(L)$	Nu(L)	h_c $[W/m^2K]$	$R_{conv,c}[K/W]$
15	40	775,9	3,89	10,9232	5,0396	411,1253	0,0307
40	40	523,62	5,76	10,9152	5,0392	411,0926	0,0307

Table 3: Values of Nu for the recalculation of $R_{conv,c}$

U can then be recomputated using :

$$U = \frac{1}{(R_{conv,h} + R_{cond} + R_{conv,c})A} \tag{2}$$

$\dot{m}_h[kg/h]$	$\dot{m}_c[kg/h]$	$R_{conv,h}$ [K/W]	R_{cond} [K/W]	$R_{conv,c}$ [K/W]	U [W/Km^2]
15	40	0,0504	0,00107	0,0307	153,7221 or 177,3717
40	40	0,0394	0,00107	0,0307	177,4813 ou 204,7861

Table 4: Theoretical values of the global heat transfer coefficient for one coaxial tube

2.2 comparison with data obtained in the laboratory

We calculated the value of the global heat transfer coefficent with the data obtained in the Laboratory via the LMTD method with the formula:

$$Q = UA\frac{(\Delta T_2 - \Delta T_1)}{\ln(\frac{\Delta T_2}{\Delta T_1})} = UA\Delta T_m$$

$$Q_h = \dot{m}_h * c_p * (T_{h,i} - T_{h,o})$$

$$Q_c = -\dot{m}_c * c_p * (T_{c,i} - T_{c,o})$$

	Co-Flow			Counter Flow			
Mass flow [kg/s]	30	35	40	20	25	30	40
U$_h[W/(m^2K)]$	296.66	304	338.25	469.86	452.34	486.63	411.67
U$_c[W/(m^2K)]$	436.37	468.32	505.22	300.46	299.75	260.63	289.9

Table 5: Values of the global heat transfer coefficient for two coaxial tubes

	Co-Flow			Counter Flow			
Mass flow [kg/s]	30	35	40	20	25	30	40
U$_h[W/(m^2K)]$	335.42	327.71	366.13	334.29	361.92	316.46	433.86
U$_c[W/(m^2K)]$	447.09	451.77	490.38	108.41	139.47	127.28	186.64

Table 6: Values of the global heat transfer coefficient for one coaxial tube

We calculated the global heat transfer coefficient for the co-flow and counter flow configuration. However, we obtained different heat fluxes for hot and cold, we assume that this difference is due to losses in the wall and therefore U is different for hot and cold as well.

From these results, we notice several things. First, the global heat transfer coefficient U_h is always greater in counter flow than in co flow, conversely the U_c is always greater in Co flow than in counter flow. This can be explained by the fact that in a counterflow configuration, the temperature difference between the fluids remains high throughout the tube, thus promoting efficient heat transfer. At the beginning of the tube, this difference is maximum and so we have a rapid heat transfer. Although the difference gradually decreases, it is generally still higher than co-flow. By co-flow, the temperature difference decreases rapidly along the exchanger, reducing heat transfer efficiency. So, in co-current, the coefficient U is generally higher on the cold fluid side.

Secondly, we also notice that U generally increases with mass flow in all configurations. This is logical since a greater mass flow rate increases the turbulence which allows better heat diffusion because it reduce the thermal resistance and therefore we obtain a higher overall heat transfer coefficient.

Finally, we observed that the theoritical global heat transfert coefficient is much larger in reality than that calculated before, if we want that the results correspond with what we calculated it would be necessary to add a factor 2. Honestly we have no hypotheses other than an error when taking measurements or high roughness of the pipes to explain this difference.

3 Result and analysis

Column1	Column2	Column3	Column4	Column5
mass flow [kg/s]	20	25	30	40
One coaxial tube counter flow				
Th_init [K]	335,17	331,47	321,89	312,18
Th_final [K]	308,98	309,7	308,25	302,55
Delta_Th [K]	26,19	21,77	13,64	9,63
Tc_init [K]	289,82	289,82	289,82	289,82
Tc_final [K]	299,62	299,5	296,15	294,6
Delta_Tc [K]	9,8	9,68	6,33	4,78
Two coaxial tube in series counter flow				
Th_init [K]	335,17	331,47	321,89	312,18
Th_final [K]	298,74	300,84	298,2	299,27
Delta_Th [K]	36,43	30,63	23,69	12,91
Tc_init [K]	289,82	289,82	289,82	289,82
Tc_final [K]	316,7	313,24	304,46	300,31
Delta_Tc [K]	26,88	23,42	14,64	10,49
One coaxial tube co-flow				
mass flow [kg/s]	30	35	40	
Th_init [K]	324,07	321,58	320,27	
Th_final [K]	310,97	310,17	309,73	
Delta_Th [K]	13,1	11,41	10,54	
Tc_init [K]	289,82	289,82	289,82	
Tc_final [K]	305,11	303,32	302,85	
Delta_Tc [K]	15,29	13,5	13,03	
Two coaxial tube in series co-flow				
Th_init [K]	324,07	321,58	320,27	
Th_final [K]	307,88	306,68	306,38	
Delta_Th [K]	16,19	14,9	13,89	
Tc_init [K]	289,82	289,82	289,82	
Tc_final [K]	306,47	304,93	304,5	
Delta_Tc [K]	16,65	15,11	14,68	

Figure 2: Data for different circuit configuration

Our lab being at the end of the day we had less time to experiment with various configurations. We therefore asked one of the previous groups to provide us the data for the Co-flow. Thanks to the data collected, we can now create graphs that allow us to compare the temperature difference between the different configurations.

As explained in the first part of the report, the temperature of hot water at the inlet depends only on its mass flow, while cold water is constant at the inlet. We can therefore see, and it is rather logical, that the temperature difference between the hot water and cold water circuit tends to decrease with a higher mass flow.

3.1 Impact of the Mass flow on the Temperature

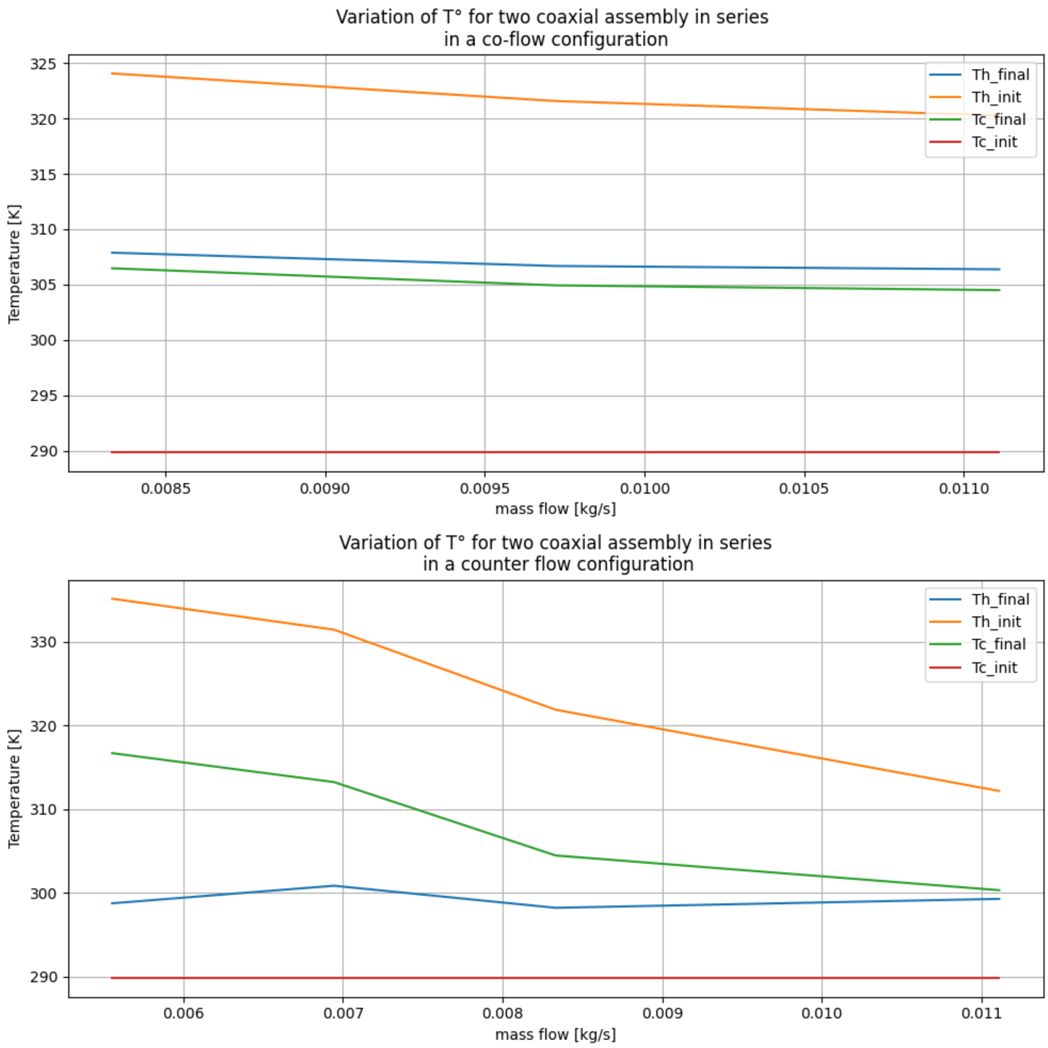

Figure 3: Variation of T° for different configuration

These graphs highlight the fact that for the co-flow configuration, the temperature difference ΔT between the hot at the inlet and at the outlet tends to remain constant despite the temperature variation at the inlet, the same for the cold circuit.

For the counter-flow circuit it is different, in fact the delta T tends to decrease. Moreover, for low mass flow rates the final temperature of the cold circuit is **higher** than that of the hot circuit. The more we increase the flow rate, the more the final temperature of the hot and cold tends to stabilize at 300°c.

3.2 Variation of Temperature along the tube

In our case we have always taken for convenience a mass flow rate for the hot circuit equal to the mass flow rate of the cold. Under the hypothesis that the heat capacity of water varies only very slightly between 15°c and 50°c which are our two temperature extremes, we are in the case $C_c = C_h$. "

$$C_c = |C_h|$$
$$C_c dT_c = dQ$$
$$-|C_h| dT_h = -dQ$$
$$=> dTh - dTc = 0$$
$$=> d(\delta T) = 0$$
$$=> dQ = cst$$

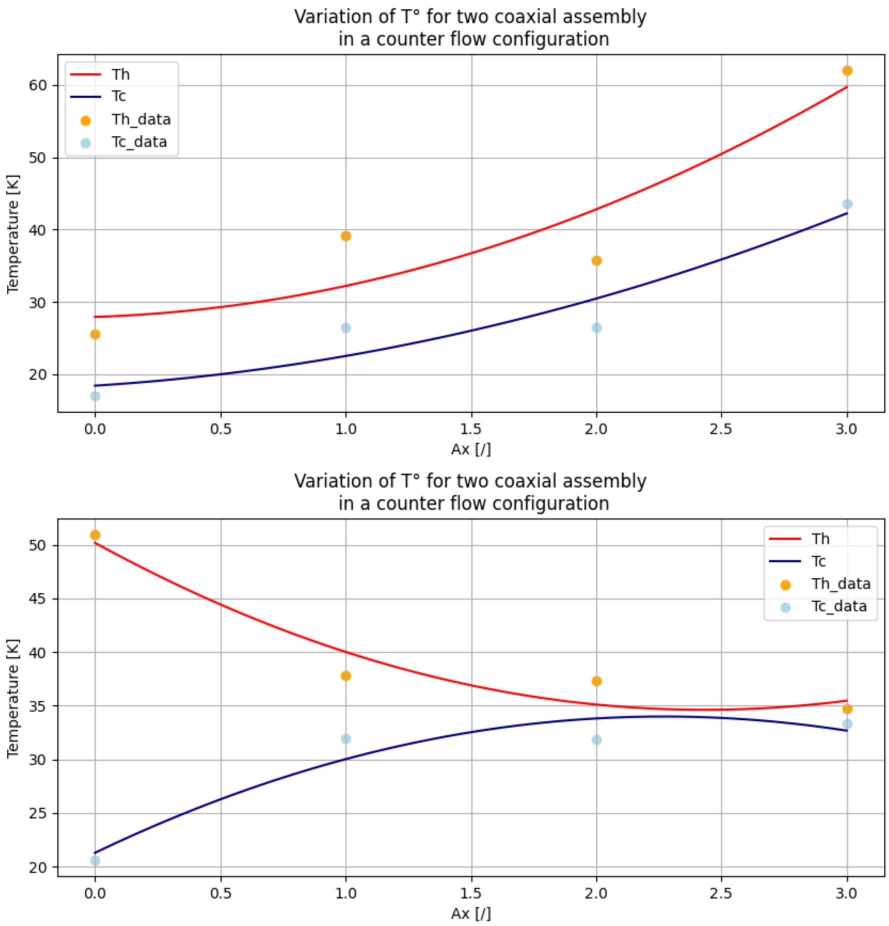

Figure 4: Variation of the T° along the tube for different configurations

The graph above shows the evolution of the temperature along the tube, after interpolating our points to obtain a better result, we notice that the curves correspond to the expected result, i.e. a constant temperature difference between hot and cold for the counter flow and a temperature difference between Th,i and Th,o equal to Tc,i and Tc,o for co flow. Some variations may appear due to losses, moreover it was difficult to precisely adjust the mass flow of each circuit.

3.3 Heat exchanger efficiency

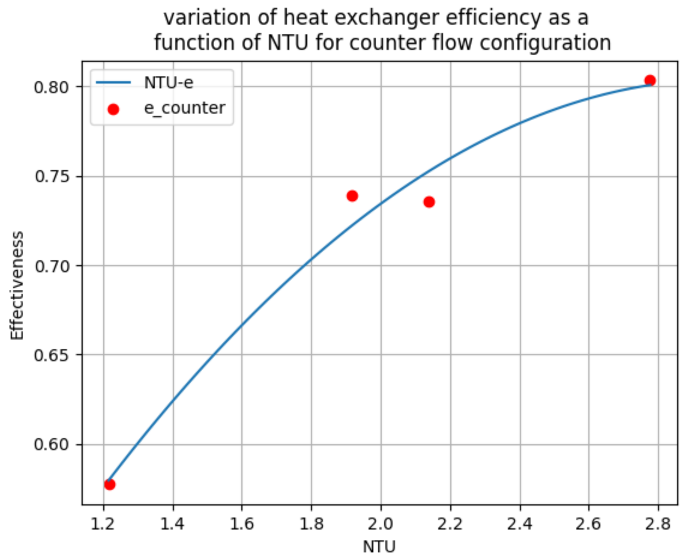

Figure 5: NTU-e for Counter flow

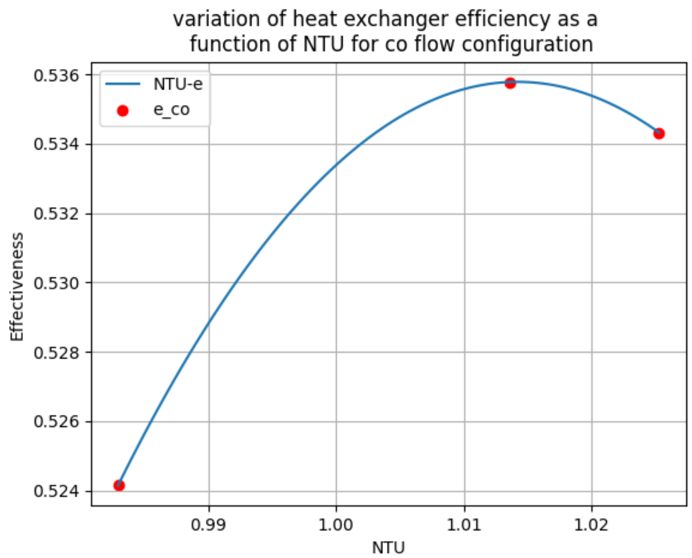

Figure 6: NTU-e for Co-Flow

With our data collected during the laboratory we can also create the NTU-e graph for the co-flow and counter flow configuration. The result for the counter flow seems correct with the interpolation, however for the co-flow, the curved shape is not the expected one. Normally the effectiveness should tend towards a constant as NTU increases. This may be due to a measurement error but also due to lack of data. Finally, the efficiency will normally always be greater with a higher initial T_h and therefore a lower mass flow.

4 Conclusion

In conclusion, thanks to this laboratory and following the analysis of the data we are able to deduce several results and affirm our theoretical estimates. Indeed, the curve profiles are mostly consistent with the estimates but the value of U was not as expected. Finally, we can also say that the efficiency of counter flow at low mass flow rate is in cases significantly higher than that of co-flow.