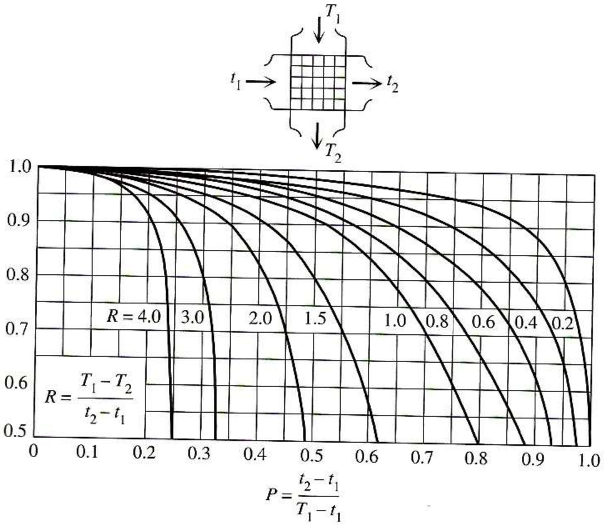
Heat exchanger examples:

1. A heat exchanger operates with an oil with c_p of 1.67 kJ/kgK and density 910 kg/m^3 and water with c_p of 4.2 kJ/kgK and density 1,000 kg/m^3. The oil volume flow rate is 3,158 l/h and the water flow rate is 2,000 l/h. What is the capacity rate of the oil and of the water?
2. In the example of qu 3, the water enters at 50°C and leaves at 70°C and the oil enters at 120°C and leaves at 85°C. The heat exchanger is of the shell and tube type with counter-current flow. What is the logarithmic mean temperature difference?
3. What is the surface area of the heat transfer surface within the heat exchanger of qu 3 if it has an overall heat transfer coefficient of 1,100 W/m^2K? If this is done with a tube having diameter 12mm, what is the length of tube in the exchanger?
4. A compact heat exchanger is constructed with a cross-flow matrix arrangement with unmixed streams for cooling oil in an air stream.



The oil enters at 70°C and is required to leave at 30°C. The oil density is 700kg/m^3. The flow rate of oil is 5 litres per minute and it has a specific heat capacity c=1.7 kJ/kgK at 10°C and 2.5 kJ/kgK at 100°C.

(a) What is a suitable average specific heat capacity of the oil over the working range?

(b) What is the rate of heat transfer?

5. The air stream in question 4 enters at 20°C and the mass flow rate of the air is 0.5 kg/s.
   (a) What is the exit temperature of the air?
   (b) What is the correction factor?
   (c) What is the LMTD for this situation?

6. The overall heat transfer coefficient of the exchanger is 200W/m²K. What is the required volume of the heat exchanger in order for it to be classified as a compact heat exchanger?

7. A lung moves a volume of 3 litres every 5 seconds in air at a temperature of 2°C. The blood flow rate is 50 cc per second. Calculate the capacity rate of the air and the blood. Will the blood be significantly cooled by breathing?

8. Given that the area density of lung tissue is 30,000 m^2 per m^3, what is the effective surface area exchanging heat in the lungs? If the air leaves the lung at 30°C, what is the LMTD of the situation? What is the rate of heat transfer to the air? What is the overall heat transfer coefficient of the lung? Is the lung a good heat exchanger?

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9. Steam in a power station superheat generator heat exchanger flows at 100kg/s with a starting temperature of 250°C. The heat exchanger can be modelled as a counter-current single tube and shell with a mean tube diameter of 32 mm. The hot gases flow at the rate of 250 kg/s, enter at 900°C. Given that the heat transfer coefficient between the steam and the inner tube wall is 300 W/m²K and that between the hot gases and the out tube wall is 200 W/m²K, what is the overall heat transfer coefficient, assuming the pipe wall resistance is negligible?

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1. Capacity rate is m.c$_p$. For the oil 3,158 l/h × 0.91 kg/l × 1.67 kJ/kgK = 4,799 kJ/Kh or 1.333 kW/K. For the water 2,000 l/h × 1 kg/l × 4.2 kJ/kgK = 8,400 kJ/Kh or 2.333 kW/K.

2. The log mean temp diff is $LMTD = \Delta T_m = \dfrac{\Delta T_a - \Delta T_b}{\ln(\Delta T_a / \Delta T_b)}$. At the oil hot end, the water is hottest, so ΔT_a = 120-70 = 50°C. At the oil cool end, the water is coolest, so ΔT_b = 85-50 = 35°C. The ΔT_m is (50-35)/ln(50/35) = 42°C.

3. Using the form of Newton's Law with overall heat transfer coefficient, q=UAΔT, with ΔT_m = 42°C and U = 1,100 W/m^{2}K. The heat transfer rate is, from either fluid 46.66 kW. The surface area required to do this is 46.66 kW / 1.1 kW/m^{2}K × 42 K = 1 m^2. The length of tube is from πdL = 1. 3.14×0.012×L = 1 and L = 26m.

4. a) suitable average c$_p$ of the oil might be one based on the average temperature over the range, in this case between 70°C and 30°C. Average is 50°C. Use interpolation as follows:

$$\frac{c_p - 1.7}{2.5 - 1.7} = \frac{50 - 10}{100 - 10} \rightarrow c_{p,65C} = \frac{40}{90} \times 0.8 + 1.7 = 2.06 \text{ kJ/kgK.}$$

   b)rate of heat transfer is indicated by the amount of heat absorbed by the oil. Mass flow rate is vol-flow rate × density = 0.005/60 (m^3/s) × 700 (kg/m^3) = 0.058 kg/s. Now the heat transfer is:

$$\dot{q} = \dot{m} c_p \Delta T = 0.058 \times 2060 \times (70 - 30) = 4{,}779 \text{ W.}$$

5. a) given the mass flow rate and the heat transfer (from question 4), the temperature of the air at the exit is from a heat balance by energy conservation, heat transferred = energy gained by the fluid. The specific heat capacity of air is from the tables 1.005 kJ/kgK. $\dot{q} = \dot{m} c_p \Delta T = 0.5 \times 1005 \times (T_2 - 20) = 4{,}779$. Therefore T_2 = 29.5°C.

   b) The correction factor is from the chart in the question. Work out the factors P and R. Take the air as the stream with T_1 entering (20°C) and T_2 exiting (29.5°C) and take the oil as the stream with t_1 entering (70°C) and t_2 exiting (30°C). Therefore P = (30-70)/(20-70) = 0.8, and R = (20-29.5)/(30-70) = 0.24. The correction factor from the chart is about 0.92.

   (c) the LMTD is calculated assuming a counter-flow tube and shell heat exchanger with the position A at the hot oil end, and B at the cold oil end. $\Delta T_m = \dfrac{\Delta T_A - \Delta T_B}{\ln\left(\Delta T_A / \Delta T_B\right)} = \dfrac{(70 - 29.5) - (30 - 20)}{\ln \dfrac{70 - 29.5}{30 - 20}} = 21.8^\circ$ C

6. The heat exchanged by this heat exchanger is $\dot{q} = UAF\,\Delta T_m$ = 200×A×0.92×21.8 = 4,779 and hence A = 1.19 m^2. A compact heat exchanger is one which has a surface density of at least 700 m^2/m^3. The required volume is therefore 1.19/700 = 0.0017 m^3 or 1.7 litres.

7. C_{air} = (0.003 [m^3] × 1.2 [kg/m^3] / 5 [s])×1005 [J/kgK] = 0.724 W/K. Assuming blood has the same thermodynamic properties as water, C_{blood} = 50×10^{-6} [m^3/s] × 1,000 [kg/m^3] × 4,200 [J/kgK] = 210 W/K. Therefore the blood has a far higher thermal capacity rate than the air, and the blood will not change temperature significantly compared with change in the air temperature.

8. Surface area in 3 litres of lung is 0.003 × 30,000 = 90 m^2. Given that the air enters at 2°c and leaves at 30°C, and assuming the blood does not change temperature, the LMTD is

$$\Delta T_m = \frac{\Delta T_A - \Delta T_B}{\ln\left(\Delta T_A / \Delta T_B\right)} = \frac{(2 - 37) - (30 - 37)}{\ln \dfrac{2 - 37}{30 - 37}} = \frac{-28}{\ln \dfrac{-35}{-7}}$$

=-17.4°C; the minus sign is not of concern – it is just the magnitude that is important not the direction. The overall heat transfer coefficient for q=UAΔT_m requires the heat transferred to the air, which is 0.724×28 = 20 W. U is therefore 20/(90×17.4) = 0.013 W/m^{2}K. The heat exchanger is not good at exchanging heat; this is because of the low thermal capacity rate of the air.

9. This is a tube with convective heat transfer on the outside and inside, and the heat transfer coefficients are stated. Simple heat transfer question. On the outer surface, the thermal resistance is 1/(200×π×0.032×1) = 0.050 W/K per m length of tube. On the inner surface, the thermal resistance is 1/(300×π×0.032×1) = 0.033 W/K per m length of tube. Note in this case, we assume that there is negligible thermal resistance due to the pipe wall – it is a very good conductor and is relatively thin. Therefore, total thermal resistance is 0.05 + 0.033 = 0.083 W/K per m of tube. This very simplified and assumes no temperature effects due to the changing temperatures of the two fluids. The overall heat transfer coefficient is $1/AR_{th}$. Therefore the overall heat transfer coefficient is 1/(π×0.032×1)×0.083 = 120 W/m^2K.