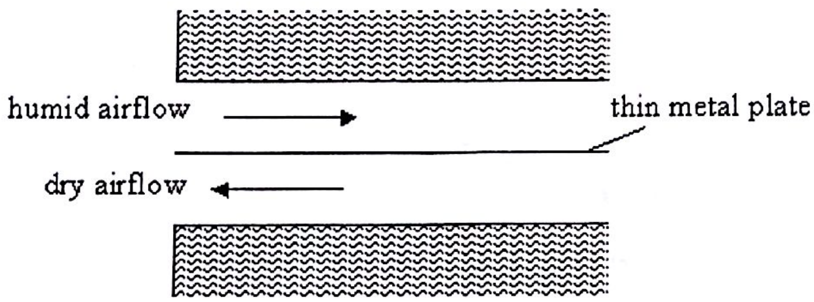
Ene-39.4024 Design of Heat Exchangers **Exam 26.5.2016 at 16-20**

Answer all the four questions.

1. *8 points*

The condensation of a humid airflow is observed by using an arrangement where a thin metal plate separates two airflows, moving to opposite directions (picture below). The walls of both of the channels are insulated (except the metal plate). The width of the metal plate is 0,19 m and both channels are of the same height, 0,01 m (hence, the cross-section of a channel is 0,19 m × 0,01 m). A humid airflow enters into the upper channel at 25°C and with relative vapor pressure $\varphi = 45$ %. The mass flow rate of dry airflow in the humid airflow is $\dot{m}_i = 0{,}01$ kg/s. The dry airflow, $\dot{m} = 0{,}01$ kg/s, departs from the lower channel at 15°C.



Convective heat transfer coefficient α can be assumed to be approximately equal on both surfaces of the plate and it can be calculated from the Hausen correlation $Nu = 0{,}037\,(Re^{0,75} - 180)\,Pr^{0,42}$, which holds approximately for tubeflow when Re > 4000.

a) Calculate the temperature of the humid airflow at the point where water begins to condensate on the plate surface.

b) Calculate the length of the dry part of the metal plate, in flow direction.

2. *8 points*

An evaporator is made of 20 horizontal copper tubes, inner diameter 13 mm and outer diameter 15 mm. The refrigerant is R134a, and it flows into the tubes at 0°C and with vapor content $x_0 = 0{,}2$. The total mass flow rate of the refrigerant is $\dot{m} = 0{,}2$ kg/s and vapor content of the liquid-vapor mixture departing from the evaporator is $x_l = 0{,}8$. The heat source in the shell-side (outside of the tubes) is water, which is flowing at the volume flow rate of 0,0015 m³/s. The cross-sectional area of the waterflow used for calculations is $\sqrt{A_q A_l} = 0{,}004\,\text{m}^2$ (geometric mean of transverse and longitudinal flow cross-section areas). The water enters at 10°C and the thermal resistance of the foul layer in the water side is $1 \cdot 10^{-4}$ m²K/W.

Calculate the heat transfer rate of the evaporator and the length of one tube.

Instruction: You can calculate the heat transfer coefficient in the refrigerant side according to Gungor & Winterton with the following assumptions:

- average constant value for the steam content can be used $\bar{x} = \dfrac{x_0 + x_l}{2}$
- value for the heat flux through tube inner surface is $q = 5000$ W/m²

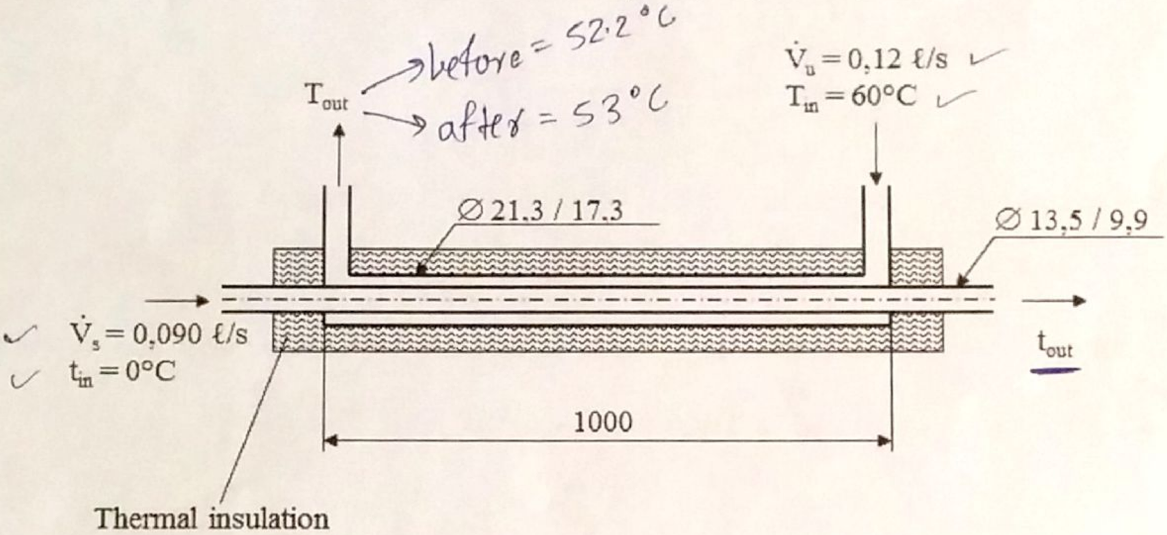
3. *6 points*

The thermal resistance of a foul layer caused by dirty water is usually expressed as a value of the expression δ_k/λ_k (m^2K/W), where δ_k = foul layer thickness and λ_k = foul layer conductivity. Hence, the foul layer has been assumed to be so thin that it can be considered approximately as planar even if the layer was on tube surface.

The thermal resistance of a foul layer could be measured for example by a double-pipe heat exchanger (a heat exchanger made of two co-axial tubes, picture below), where the dirty water is delivered into the inner tube so that the foul layer is formed on the inner surface of the inner tube. The outlet temperature of the outer tube is measured first without the foul layer and then again after the formation of the foul layer. Clean water is delivered into the outer tube. In the picture, the dimensions (mm) of the heat exchanger, volume flows (litres/s) and the intake temperatures have been given. Volume flows and intake temperatures are kept constant. The outlet temperature T_{out} of the outer tube is 52,2°C before the formation of the foul layer and after the formation it is 53,0°C. Both of the flows are at 1 bar.

a) Calculate the conductance of the foul layer (W/K).

b) Calculate the thermal resistance of the foul layer δ_k/λ_k (m^2K/W).



4. *8 points*

The cooling element below is used for cooling of an electronic component. Estimate the cooling power achieved (W/m^2) in the interface of the component and the element as the velocity of the air in the gap is 3 m/s, the average temperature of the air is 35°C and the maximum temperature in the interface is 95°C.