OPEN POND PRODUCTION OF *ARTHROSPIRA PLATENSIS*
Correction

Part 1: Managing evaporation

Question 1

There are two characteristic lengths, hence two Reynolds numbers:

$$Re_L = \frac{v_{wind} L}{\nu_{air}} = 16.9 \times 10^6$$
$$Re_l = \frac{v_{wind} l}{\nu_{air}} = 3.39 \times 10^6$$

Question 2

A correlation has to be chosen. The criteria for choosing one are:
- configuration: flat plate / tube ? => flat plate
- the flow regime: laminar / turbulent / both (one then the other) => both

Thus we would use $Sh_L = (0.037\, Re_L^{4/5} - 871) Sc^{1/3}$ after verifying the validity range.
Reynolds numbers are obviously fine. Schmidt number of water in air has to be computed:

$$Sc_{water/air} = \frac{\nu_{air}}{D_{water/air}} = 0.651$$

The second criterion is valid (0.6 < Sc < 60), thus we can use the correlation and obtain:

$$Sh_L = \frac{k_L L}{D_{water/air}} = 18.7 \times 10^3$$
$$Sh_l = \frac{k_l l}{D_{water/air}} = 4.61 \times 10^3$$

Question 3

To compute the rates of evaporation (Ψ) we need the mass transfer coefficients, which we have (Question 2), the surface area of the pond (A_{pond} = lxL = 500 m²) and the transfer potential, *i.e.*, the concentration difference.

At the surface of the pond, the partial pressure of water is the vapour pressure of water at 35 °C: P^{sat}(35 °C) = 5626.7 Pa. Using ideal gas law, it is possible to obtain the density of water at this point:

$$C_{sat} = \frac{P^{sat} M_{Water}}{RT} = 0.0395\, kg/m^3$$

Far away from the pond, the relative humidity is Y_∞ = 20 %, meaning that the concentration is:

$C_\infty = Y_\infty C_{sat} = 7.91\, 10^{-3}\, kg/m^3$ (assuming air is also at 35 °C)

Then, we can compute the evaporation rates:

$$\Psi_L = A_{pond} k_L (C_{sat} - C_\infty) = 0.149\, kg/s$$
$$\Psi_l = A_{pond} k_l (C_{sat} - C_\infty) = 0.184\, kg/s$$

<u>Question 4</u>

Using an averaged evaporation rate, the quantity of water that is lost over the 10 days of culture is:

$$V_{evap} = \frac{\Psi_L + \Psi_l}{2} \times 8 \times 3600 \times 10 \frac{1}{\rho_{water}} = 47.9\, m^3$$

which corresponds to an height of $\frac{V_{evap}}{A_{pond}} = 9.59\, cm$ to be compared to the 30 cm initially present in the pond.

<u>Question 5</u>

The diffusion time of water through e_{sheet} = 200 µm polypropylene sheet can be estimated using:

$$t_{diff} = \frac{e_{sheet}^2}{D_{water/PP}} = 55.6\, h$$

This value is larger than the day/night cycle, hence, we can be sure that water vapour will condense at night and stay in the pool.

Part 2: Thermal management

<u>Question 1</u>

First we have to compute the additional power absorbed by the pond P_{rad}:

$$P_{rad} = A_{pond} Q_{rad} = 50\, kW$$

Then, drawing a transient heat balance over the pond over the time required to increase the pond temperature by 5 °C (ΔT). We get:

$$\rho_{water} C_{pwater} V_{pond} \frac{\Delta T}{\Delta t_{+5°C}} = P_{rad} \text{ so } \Delta t_{+5°C} = \frac{\rho_{water} C_{pwater} V_{pond} \Delta T}{P_{rad}} = 17.4\, h$$

This time is much higher than the duration we can expect for the thermal forcing. Hence, we can neglect it.

<u>Question 2</u>

The heat loss is calculated by direct application of the formula:

$$P_{loss} = A_{pond} Q_{loss} = A_{pond} 0.90 \times 5.67.10^{-8} \left((273.15 + 35)^4 - 3^4 \right) = 230\, kW$$

Note: T_{pond} variation are negleted in this calculation as we assume $\Delta T_{8h} \ll T_{pond}$ (in K) which will have to be verified.

Over 8 hours, this would induce a temperature decrease of:

$$\Delta T_{8h} = \frac{P_{loss} \times 8 \times 3600}{\rho_{water} C_{pwater} V_{pond}} = 10.6°C$$

Our former assumption stands as 10.6 << 308.15.

Question 3

The heat balance is drawn over a small length distance dz, as illustrated on Figure 1, assuming steady state operation.

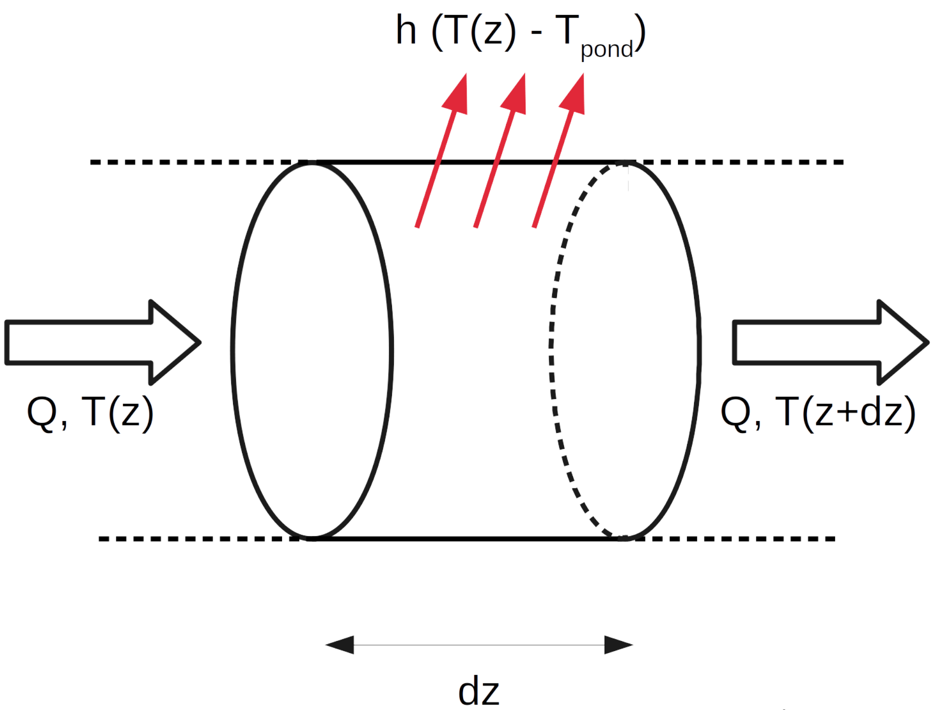

Fig. 1: schematic view of the tube, where Q is in m^3/s

First we write a classical balance over fluid enthaly:

Accumulation = Inlet + Production – Outlet – Sink + Transfer

Here, Accumulation is null because the operation mode is steady state. The Production and Sink terms are null because there is no chemical reaction. Only enthalpy input, output and transfer remain. Hence, we get

$$0 = Q\rho_{water} C_{pwater} T(z) - Q\rho_{water} C_{pwater} T(z+dz) - h(T(z) - T_{pond}) \pi d_t dz$$

Or the differential form:

$$Q\rho_{water} C_{pwater} \frac{dT}{dz} = -h(T - T_{pond}) \pi d_t$$

Question 4

First, we have to obtain the temperature profile in order to evaluate the transfer term ($h(T(z)-T_{pond})$) over the tube length. We can integrate the former equation with T(z=0) = T_{ech} = 50 °C and get:

$$\frac{T(z)-T_{pond}}{T_{ech}-T_{pond}}=\exp\left(\frac{-h\pi d_t}{Q\rho_{water}C_{pwater}}z\right)$$

Then, the transfer term is integrated over the tube wall and yields:

$$P_{ech}=\int_0^{l_t} h(T(z)-T_{pond})\pi d_t dz=Q\rho_{water}C_{pwater}(T_{ech}-T_{pond})\left[1-\exp\left(\frac{-h\pi d_t}{Q\rho_{water}C_{pwater}}l_t\right)\right]$$

Question 5

Assuming turbulent flow in a pipe, we can use $Nu_D=\frac{h d_t}{\lambda_{water}}=0.023\,Re_D^{4/5}Pr^{0.3}$. Still, validity has to be checked. Water Prandtl number ($Pr=\frac{\nu_{water}}{\alpha_{water}}$) is 6.85 and l_t/d_t = 591, so these parameters are fine. Reynolds number is unknown and will have to be checked afterwards.

Heat transfer coefficient can be expressed as:

$$h=\frac{\lambda_{water}}{d_t}0.023\,Re_D^{4/5}Pr^{0.3} \text{ and } Re_D=\frac{\frac{Q}{\pi d_t^2/4}d_t}{\nu_{water}}$$

Then, by substituting in the former equation (Question 4) we obtain:

$$P_{ech}=Q\rho_{water}C_{pwater}(T_{ech}-T_{pond})\left[1-\exp\left(\frac{-\lambda_{water}0.023\,Re_D^{4/5}Pr^{0.3}\pi}{Q\rho_{water}C_{pwater}}l_t\right)\right]$$

With 2 coil exchangers a power equal to P_{loss} has to be supplied, hence we have to find which value of Q satisfies $P_{ech}(Q)$ = P_{loss} / 2. This is done graphically in our case (Fig. 3).

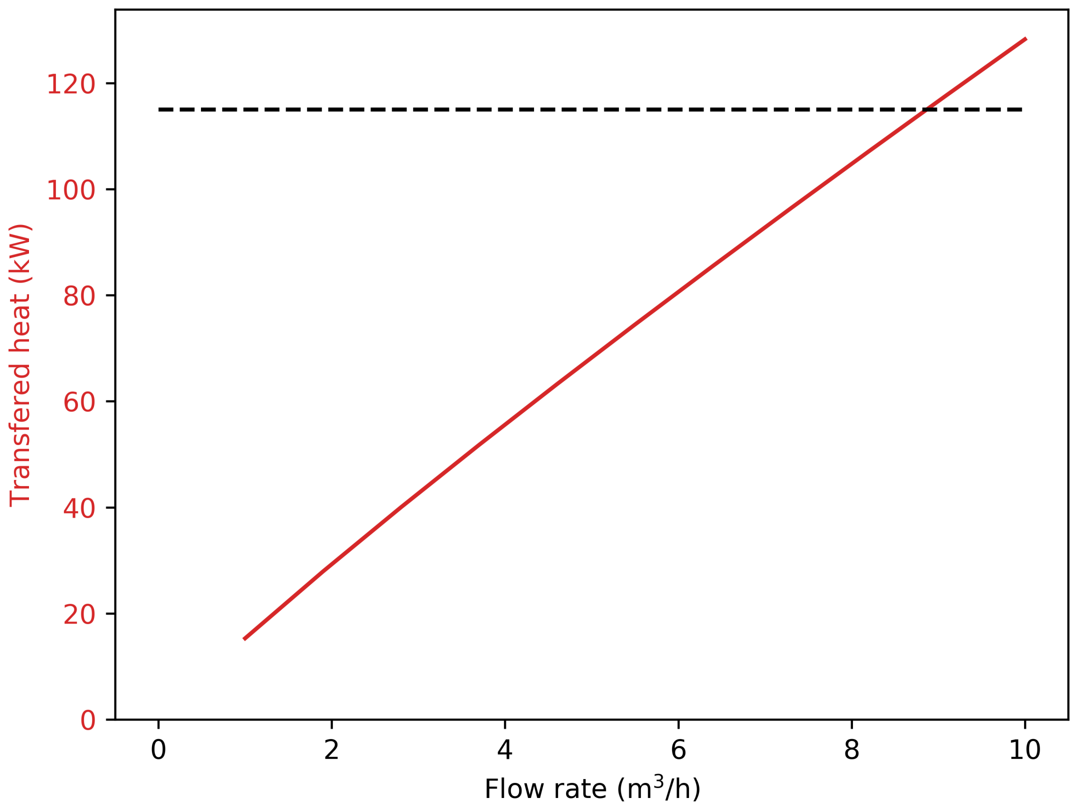

Fig. 2: exchanger power versus flow rate. Dashed line: P_{loss} / 2

The obtained flow rate is Q = 8.90 m^3/h.

Finally the associated Reynolds number has to be checked. With this flow rate $Re_D = 1.24\ 10^5$, which lies within the correlation validity range.