OPEN POND PRODUCTION OF *ARTHROSPIRA PLATENSIS*

Microalgae (including cyanobacteria) are nowadays seen as a way to produce quality food and feed as well as high added value molecules. Among them, *Arthrospira platensis* has now reached commercial deployment (under the commercial name *Spirulina*). Several bioreatcors can be used to grow this cyanobaterium, among them, open raceway ponds offer a cheap large scale solution (Fig. 1). Still, those bioreactors have two drawbacks. First water tend to evaporates, increasing the salinity of the growth medium which may be a source of stress for the cells. Second, they have to be operated at constant temperature, around the optimum for the microorganism (here, 35 °C). These two problems will be addressed hereinafter.

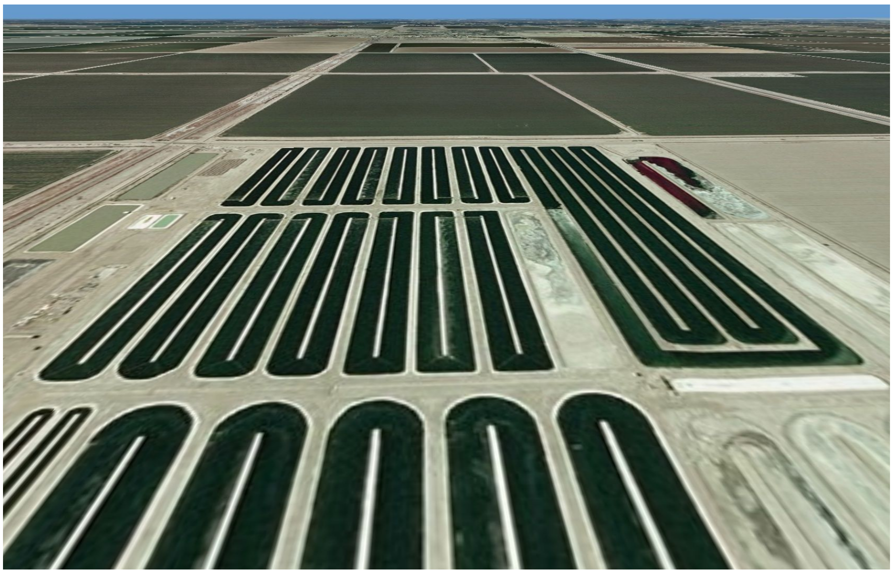

Fig. 1: picture of raceway open ponds (credit: Duke University, Nicholas School blogs)

Assumptions

Medium is assumed to be water

Medium is assumed to be at a constant temperature of 35 °C (T_{pond})

v_{wind} = 20 km/h, wind velocity

Thermodynamic data

T_{air} = 35 °C, average air temperature above the pond

P^{sat}(35 °C) = 5626.7 Pa, vapour pressure of water at 35 °C

$\nu_{air} = 1.64\ 10^{-5}$ m²/s, air viscosity at 35 °C

$D_{water/air} = 2.52\ 10^{-5}$ m²/s, water mass diffusivity in air

$D_{water/PP} = 2.00\ 10^{-13}$ m²/s, water mass diffusivity in polypropylene

Y_∞ = 20 %, relative humidity far away from the pond ($Y_\infty=C_\infty/C^{sat}$)

$\alpha_{water} = 1.46\ 10^{-7}$ m²/s, water heat diffusivity

Cp_{water} = 4183 J/kg/K, specific heat of water

Pond design and operation data
L = 50 m, length
l = 10 m, width
e = 0.30 m, depth
T = 35 °C, culture medium temperature

Coil heat exchanger data
T_{ech} = 50 °C, heating water inlet temperature
d_t = 2.54 cm, tube diameter
l_t = 10 m, tube length

Correlation list
Flat plate, forced convection:
Laminar flow -averaged
$Sh_L = 0.664\, Re_L^{1/2}\, Sc^{1/3}$ for 0.6 < Sc < 60 and Re < 5 10^5

Combined laminar and turbulent flow -averaged
$Sh_L = (0.037\, Re_L^{4/5} - 871)\, Sc^{1/3}$ for 0.6 < Sc < 60 and 5 10^5 < Re < 10^7

Tube, forced convection:
Turbulent flow
$Nu_D = 0.023\, Re_D^{4/5}\, Pr^{0.3}$, for L/D > 10, 0.6 < Pr < 160 and 10^4 < Re_D
Laminar flow
Nu_D = 3.66

With dimensionless number being expressed as
$Re_L = \frac{v\, L}{\nu}$, $Sc_{water/air} = \frac{\nu_{air}}{D_{water/air}}$, $Sh_L = \frac{k_L\, L}{D_{water/air}}$, $Pr = \frac{\nu_{water}}{\alpha_{water}}$, $Nu_L = \frac{h\, L}{\lambda_{water}}$

where L is the characteristic length (width, length, diameter depending on the case).

Objectives of the TD
- Assess evaporation
- Size overnight heating system

Part 1: Managing evaporation
1. Calculate the Reynolds number for both axial and transverse wind configurations.

2. Calculate the Sherwood numbers for both axial and transverse wind configurations.

3. Calculate the rates of evaporation for both axial and transverse wind configurations.
For that we have to combine the equations of slides 6.6 and 6.7 :
$J_s = \frac{-D_s}{\eta}(C_i - C_\infty)$ and $k = \frac{-D_s}{\eta}$ thus $J_s = -k(C_i - C_\infty)$ in kg/m²/s (that should then be multiplied by par A_{pond})

4. Compute the evaporated fraction pond content over 8 hours per day during the 10 days that lasts a culture. From now on, we will consider an averaged evaporation flow rate

In order to avoid excessive evaporation, a polypropylene sheet (200 µm thickness) has been placed on top of the pond.

5. Estimate water diffusion time through the polypropylene sheet. Conclude on the efficiency of this material as a barrier.

Part 2: Thermal management

The sheet induces a thermal forcing of Q_{rad} = 100 W/m² at midday in the summer while there is no wind (worst case scenario).

1. How long would it take for the pond temperature to increase of 5 °C. Conclude on the need to manage this additional heat.

While daytime additional heat does not seem to be a problem, night heat loss may have to be considered. Assuming purely radiative loss with a clear sky night, the thermal loss can be expressed $Q_{loss}=0.90\times5.67.10^{-8}(T_{pond}^4-T_{space}^4)$, in W/m², where T_{space} = 3 K.

2. Compute the value of this lost power and the temperature decrease of the pond over 8 hours.

In order to counter this temperature, some fatal heat coming from a nearby boiler can be used. To transfer this heat to the pond, two coil heat exchangers are installed in the pond (Fig. 2).

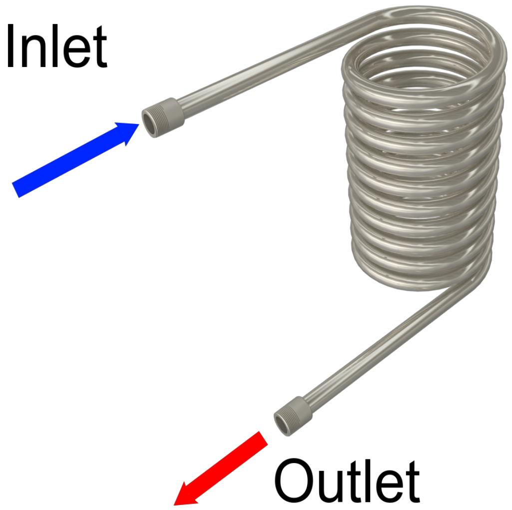

Fig. 2: Coil heat exchanger (credit deltahydro.com)

3. Draw a heat balance over the temperature water circulating <u>inside</u> of the heat exchanger assuming the pond temperature is constant over the coil.
Hints: considered a small size element of fluid, dz. Describe heat transfer with $h(T(z)-T_{pond})$ formulation.

4. Integrate the former expression to obtain the heat flux exchange over the coil as a function of the flow rate and the heat exchange coefficient.

5. Bearing in mind that turbulent flow are much more efficient at transferring heat, compute the flow rate that should be pumped through the coil.
Hint: You may start by substituting the heat transfer coefficient by its dependency over the flow rate in the former expression.
Then, use a plot of the transferred heat versus flow rate to obtain the desired operating condition.