Heat transport

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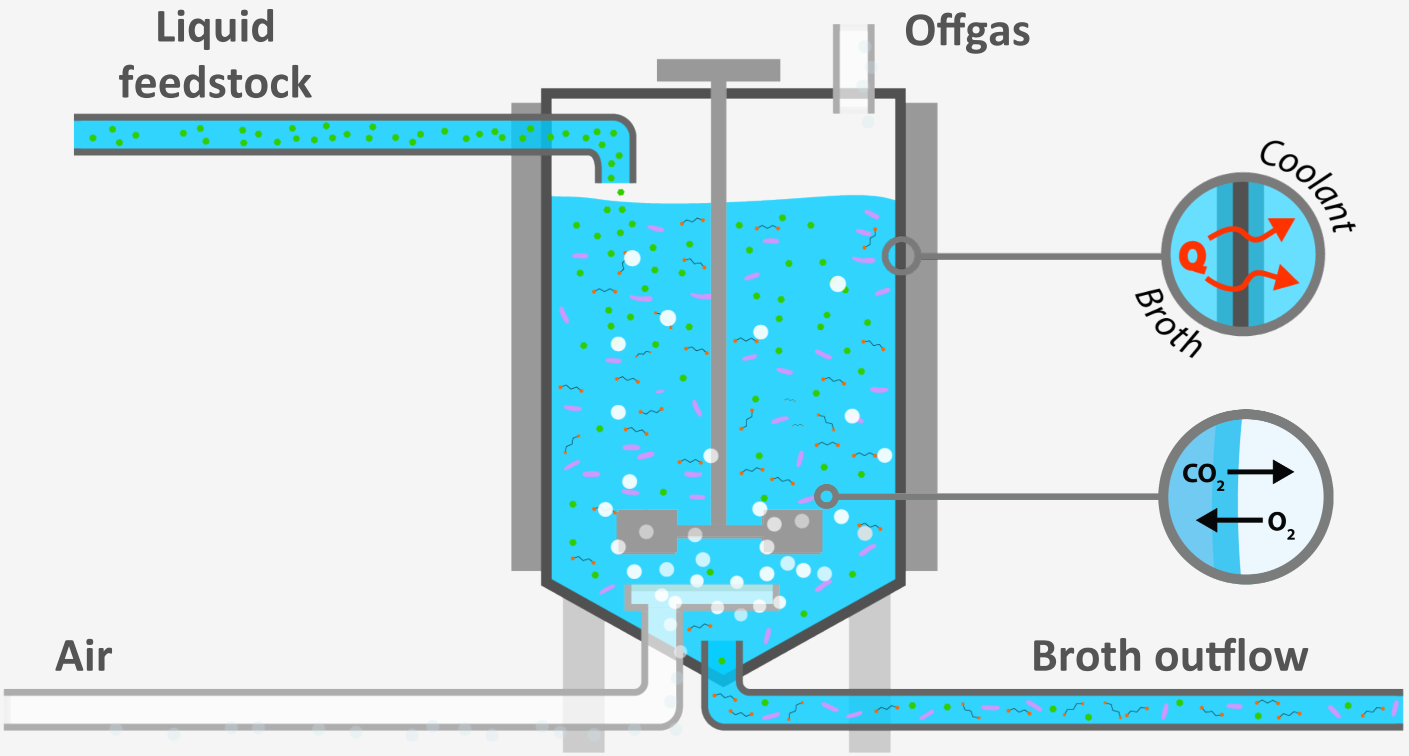
One of four limiting transport steps: Heat removal

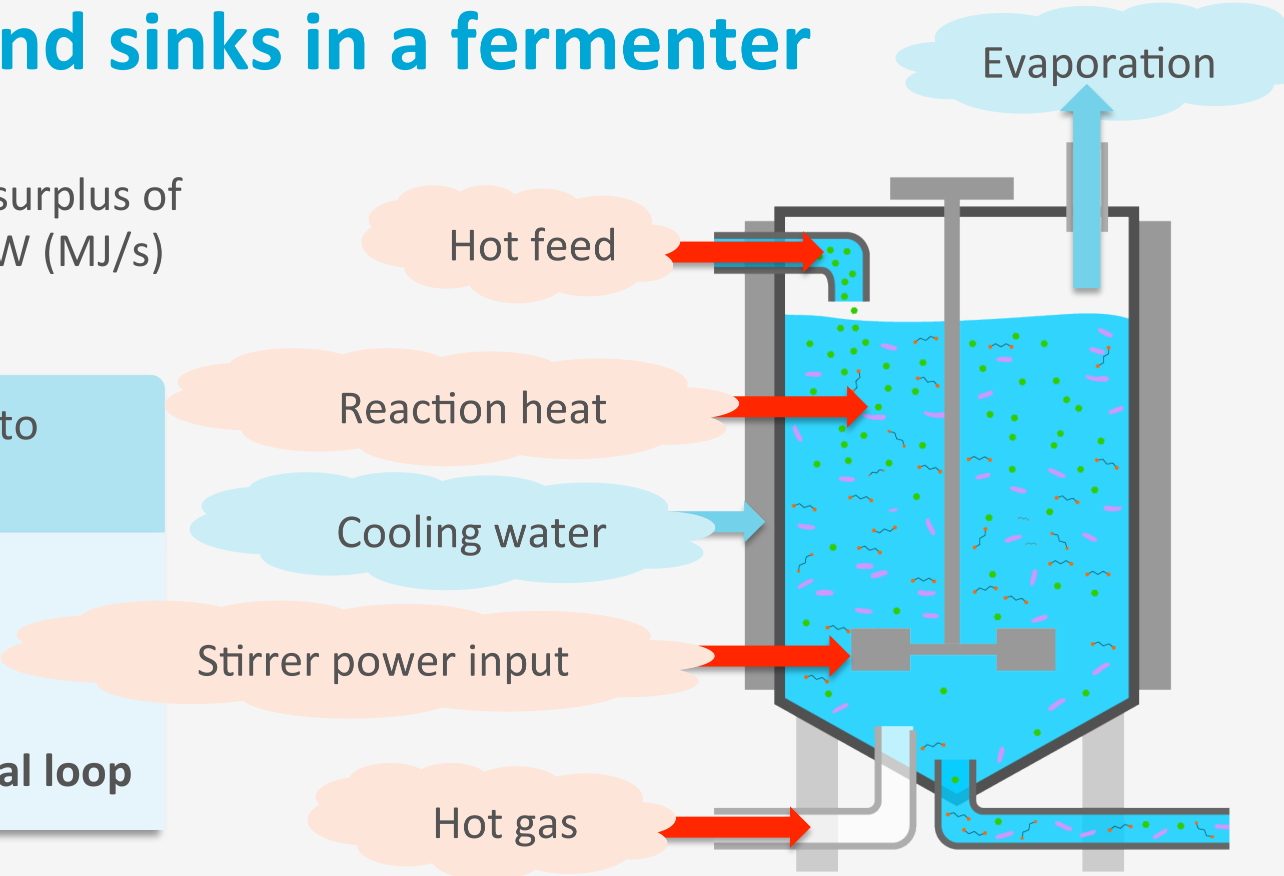


Heat sources and sinks in a fermenter

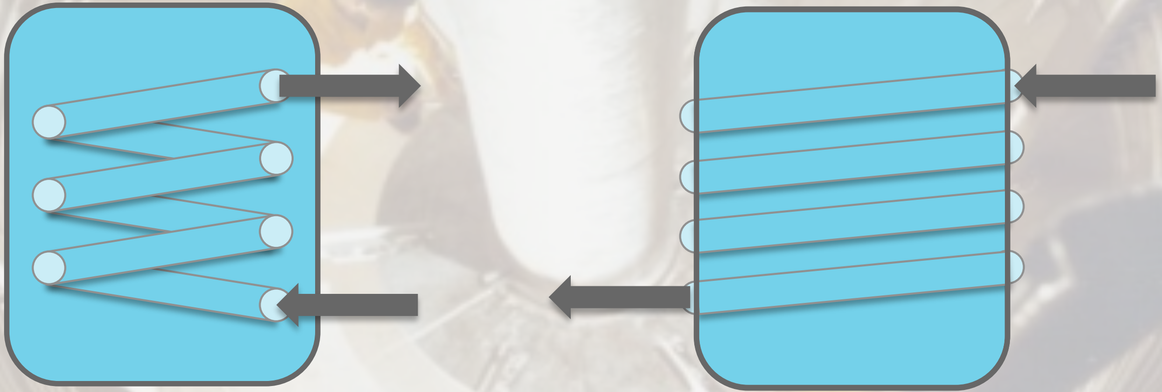
In aerobic processes usually surplus of heat generated of several MW (MJ/s)

This needs to be transferred to cooling water via:

- **Cooling coil**
- **Vessel wall**
- **Cooling baffles**
- **Heat exchanger in external loop**



Transport path of heat removal using coils (1)



Internal coil

External coil

Transport path of heat removal using coils (2)

3 steps in the removal heat path

Step 1. Convection

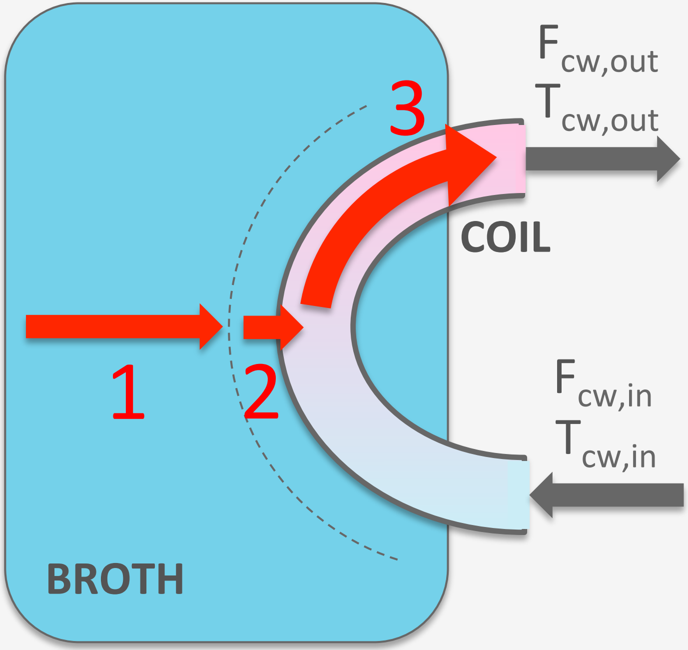
Convection in broth

Step 2. Transfer

Heat transfer through coil:
Coil outside boundary layer → Coil → Coil inside boundary layer

Step 3. Convection

Convection in cooling water



Transport path of heat removal using coils (2)

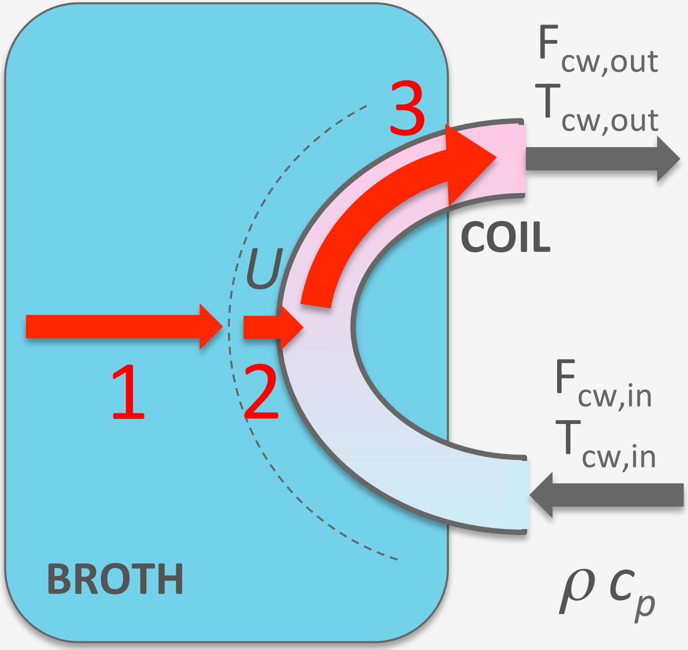
Two important terms:

Heat transfer coefficient: $U \frac{kJ/h}{m^2K}$

m^2 cooling area

Heat capacity of cooling fluid: $\rho c_p \frac{kJ/K}{m^3}$

m^3 cooling fluid



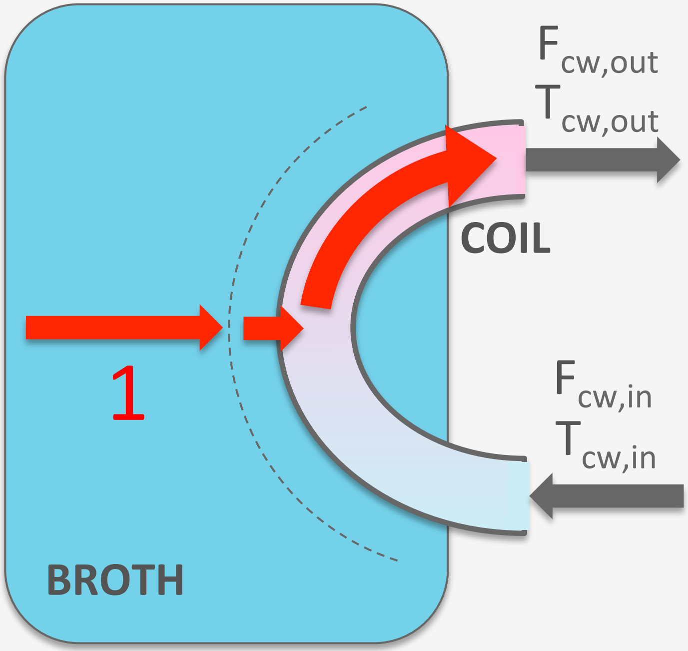
Transport path of heat removal using coils (3)

Step 1 Convective heat transport in broth

Are there temperature gradients?

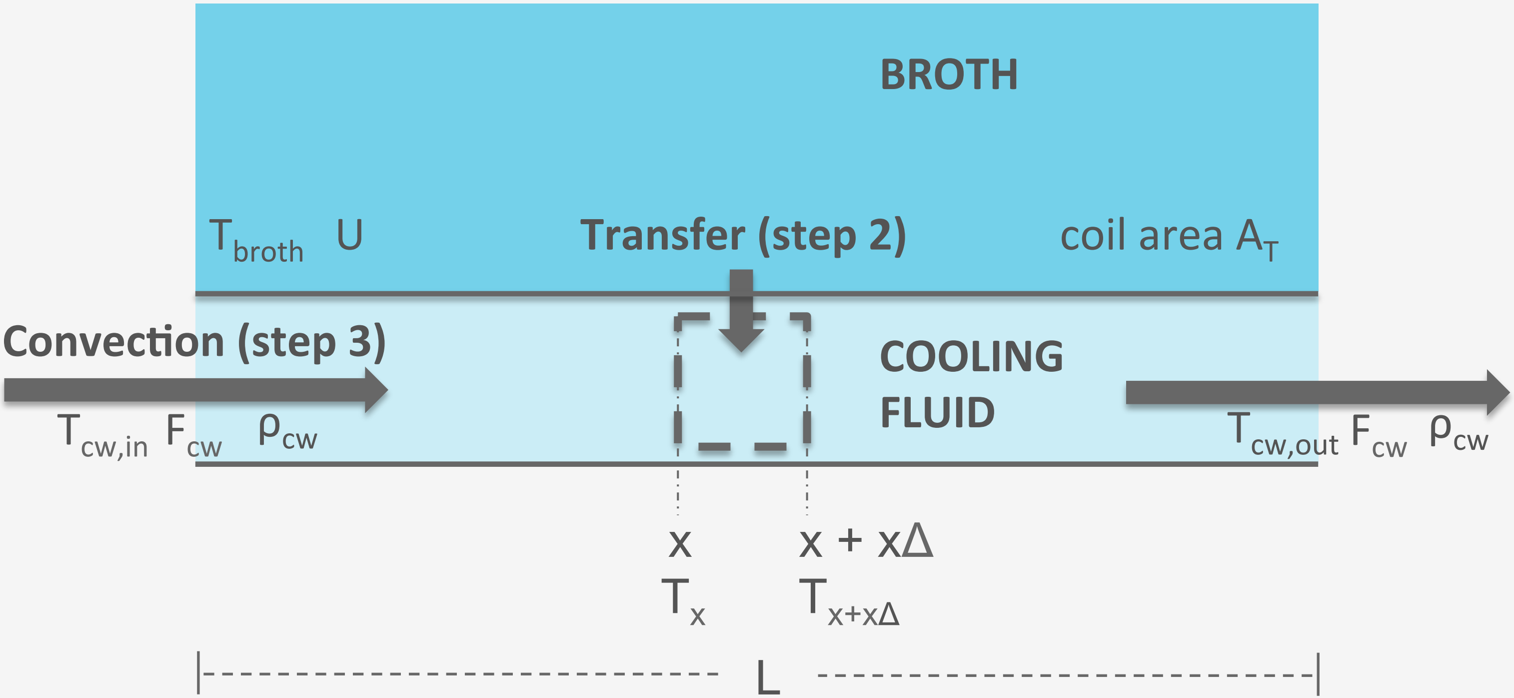
No!

Temperature T_{broth} only varies by ± 0.2°C



Transport path of heat removal using coils (4)

Step 2 and 3 How do they relate?



Transport path of heat removal using coils (5)

$$St_{heat} = \frac{UA_T}{\rho_{cw} c_p F_{cw}} \left(= \frac{(capacityStep2)}{(capacityStep3)}\right) = \frac{\text{Heat transfer capacity through coil}}{\text{Convection capacity in cooling water}}$$

St_{heat} →

0.1 | 1 | 10

Transfer is bottleneck

$T_{cw,out} = T_{cw,in}$

Convection capacity >> Transfer capacity

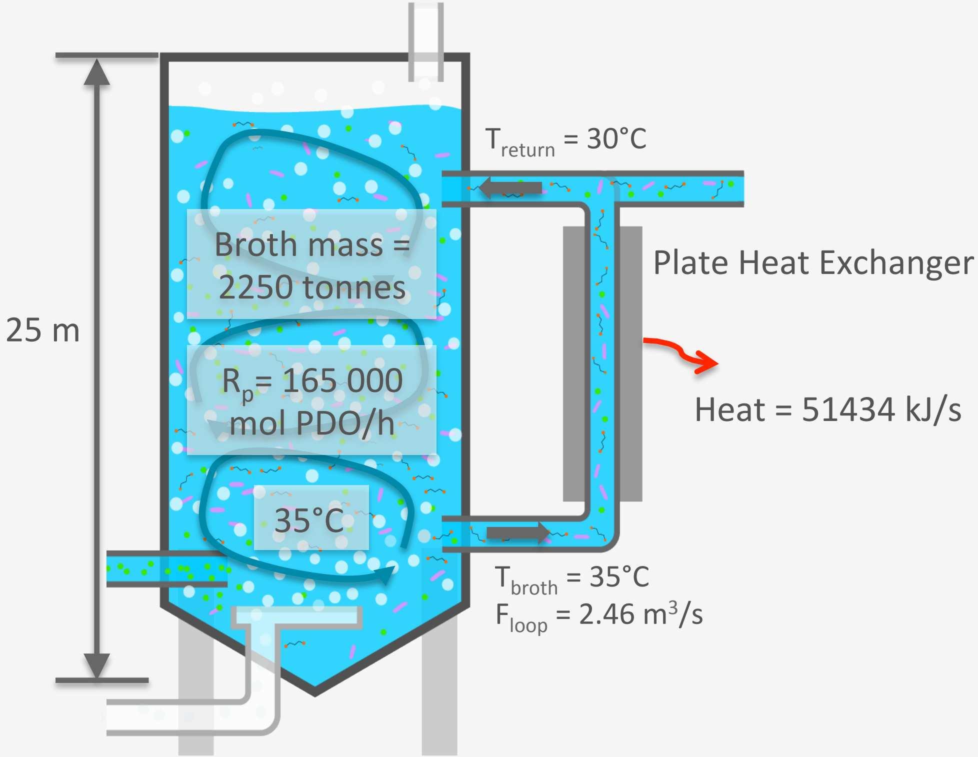
Cooling water flow is bottleneck

$T_{cw,out} = T_{Broth}$

Convection capacity << Transfer capacity

Scale-up: $A_T / V_L = 4 / T$ will get too small → external cooling is needed

Transport path of heat removal using external cooling loop in the PDO process



Advantages

- Greater design freedom
- Faster heat transfer

Challenges

- Cold shocks
- Shear stress in the pump
- Oxygen and substrate depletion in the loop

Heat removal capacity [kJ/s] = $F_{loop}\,\rho C_p\,(T_{broth} - T_{return})$

$$F_{loop} = \frac{51434\ \frac{kJ}{s}}{1000\ \frac{kg}{m3} \cdot 4.18\ \frac{kJ}{kg \cdot °C} \cdot (35\ °C - 30\ °C)} = 2.46\ \frac{m^3}{s}$$

$$\text{Cold shock every } \frac{2250\ m^3}{2.46\ \frac{m^3}{s}} = 915\ s\ (\sim 15min)$$

Heat transfer design

- T control requires good heat transfer design
- Process reaction: 450 kJ heat produced/mol O_2 consumed
- Evaporation: some cooling
- Impeller energy dissipation: 10-30% more heat
- Be aware of hot and cold spots at large scale!
- Sterilized feeds/compressed gas: hot!
- At megascale (>1000 m^3) need for external loop cooling

- Cold shock: microbes may change metabolic network fluxes (e.g. through temperature-induced genetic switch for product formation)
- Oxygen or substrate depletion in the external loop

See you in the next unit!