Problem 6.1

A 150 m^3 reactor is operated at 35 ºC to produce biomass from glucose. The O_2 consumption rate is 1.5 Kg m^{-3} h^{-1}. The stirrer dissipates heat at the speed of 1 kW m^{-3}. The cooling water flows at a temperature of 10 °C and at a flow rate of 60 m^3/h, it passes inside a coil placed inside the reactor. If the system operates in steady state, determine the temperature of the cooling water leaving the reactor.

Data: Q generated by mo= 460 kJ molO_2^{-1}

Cp H_2O= 75.4 J mol^{-1} ºC^{-1}

$$T_{out} = ?$$

$$\Delta H = M\ Cp\ \Delta T$$

ΔH – entalpia da reação

M – caudal de água (mássico)

Cp – capacidade calorífica

ΔT – variação da temperatura

$$\Delta T = T_{out} - \underbrace{T_{in}}_{10\ ºC}$$

Calcular: M

Cp

Calcular: M

Flow: 60 m^3/h

Volumetric flow → *Mass flow*

$$M = 60\ m^3\ h^{-1} \times \underbrace{1000\ kg\ m^{-3}}_{\text{Density of water}} = 60000\ kg\ h^{-1} = 16{,}7\ kg\ s^{-1}$$

Calcular: Cp

$$Cp = 75{,}4\ J\ mol^{-1}\ ºC^{-1} = 4{,}19\ kJ\ kg^{-1}\ ºC^{-1}$$

Calcular: ΔH

$$\Delta H_{rxn} = -460\ kJ\ mol^{-1} \times 1{,}5\ kg\ m^{-3}\ h^{-1} \times 150\ m^3$$

$$= -898\ kJ\ s^{-1} = -898\ kW$$

$$W_s = 1\ kW\ m^{-3} \times 150\ m^3 = 150\ kW$$

$$Q = 898 + 150 = 1048\ kW$$

Calcular: T_{out}

$$1048 = 16{,}7\ kg\ s^{-1} \times 4{,}19\ kJ\ kg^{-1}\ ºC^{-1} \times \Delta T$$

$$\Delta T = 15\ ºC$$

$$\Delta T = T_{out} - T_{in}$$

$$15 = T_{out} - 10$$

$$T_{out} = 25\ ºC$$

Problem 6.2

A fermenter used to produce an antibiotic should have a temperature of 27°C. After considering the oxygen requirements of the microorganisms and the heat dissipated by the stirrer, the maximum amount of heat to be transferred was estimated at 550 kW. The cooling water enters at a temperature of 10°C and leaves at 25°C. The heat transfer coefficient in the fermentation fluid was estimated at 2150 W m^{-2} $^{o}C^{-1}$ and the heat transfer coefficient of the cooling water has the value of 14000 W m^{-2} $^{o}C^{-1}$. The steel cooling coil has an outer diameter of 8 cm and a thickness of 5 mm, the thermal conductivity of steel is 60 W m^{-1} $^{o}C^{-1}$. Calculate the length of coil needed under these conditions.

$$Q = h\ A\ \Delta T$$

Q – velocidade de transferência de calor = 550 kW

h – coeficiente global de transferência de calor

A – área de transferência de calor

ΔT – diferença de temperatura entre os fluidos/média logarítmica

Calcular ΔT

O fluido do sistema é mantido constante: 27 ºC

$$\Delta T = \frac{2\ T_{fluido} - (T_1 + T_2)}{2} = 9{,}5\ ºC$$

Calcular h

$$\frac{1}{h} = \frac{1}{hi} + \frac{1}{he} + \frac{B}{k_w}$$

hi – coeficiente de transferência de calor do fluido = 2150 W m^{-2} $ºC^{-1}$

he – coeficiente de transferência de calor da água = 14000 W m^{-2} $ºC^{-1}$

B – espessura da parede = 5×10^{-3} m

k_w– condutividade térmica da parede = 60 W m^{-1} $ºC^{-1}$

$$h = 1614\, m^{-2}\, ºC^{-1}\, W$$

$Q = h\ A\ \Delta T$

Calcular A

$Q = 550\ kW$

$\Delta T = 9{,}5\ ºC$

$h = 1614\ m^{-2}\ ºC^{-1}\ W$

$A = 35{,}87\ m^2$

$A = 2\ \pi\ r\ l$

Diâmetro = 8 cm

$l = 142{,}8\ m$

Problema 6.3

Saccharomyces cerevisae grows anaerobically in a continuous reactor at 30 °C. Glucose is used as a carbon source at a mass flow rate of 36 kg/h and ammonia is used as a nitrogen source at a mass flow rate of 0.40 kg/h. As fermentation products, 2.81 kg/h of cells are obtained, 7.94 kg/h of glycerol, 11.9 kg/h of ethanol, 13.6 kg/h of CO_2 and 0.15 kg/h of water. Determine the system's cooling needs.

$$\text{Glucose} + NH_3 \longrightarrow \text{Biomassa} + \text{glicerol} + \text{etanol} + CO_2 + H_2O$$

$P_M$glucose=180
$P_M NH_3$=17
P_M glicerol=92
$P_M$etanol=46

Balanço

$$-\Delta H_{rxn} - Q = 0 \;\Leftrightarrow Q = -\Delta H_{rxn}$$

$$-\Delta H_{rxn} = \sum M\,\Delta h_c(reagentes) - \sum M\,\Delta h_c(produtos)$$

$$= M_{gluc}\,\Delta h_{gluc} + M_{NH3}\,\Delta h_{NH3} - M_{cel}\,\Delta h_{cel} - M_{glic}\,\Delta h_{glic} - M_{et}\,\Delta h_{et} - M_{CO2}\,\Delta h_{CO2} - M_{H2O}\,\Delta h_{H2O}$$

$$M_{gluc} = 36 \text{ kg } h^{-1}$$

$$M_{NH3} = 0{,}4 \text{ kg } h^{-1}$$

$$M_{glic} = 7{,}94 \text{ kg } h^{-1}$$

$$M_{et} = 11{,}9 \text{ kg } h^{-1}$$

$$M_{CO2} = 13{,}6 \text{ kg } h^{-1}$$

$$M_{H2O} = 0{,}15 \text{ kg } h^{-1}$$

$$M_{cel} = 2{,}81 \text{ kg } h^{-1}$$

$$\Delta h_{gluc} = -2805 \text{ kJ } mol^{-1} = -1{,}558 \times 10^4 \ kJ \ kg^{-1}$$

$$\Delta h_{NH3} = -382{,}6 \text{ kJ } mol^{-1} = -2{,}251 \times 10^4 \ kJ \ kg^{-1}$$

$$\Delta h_{glic} = -1655{,}4 \text{ kJ } mol^{-1} = -1{,}799 \times 10^4 \ kJ \ kg^{-1}$$

$$\Delta h_{et} = -1366{,}8 \text{ kJ } mol^{-1} = -2{,}971 \times 10^4 \ kJ \ kg^{-1}$$

$$\Delta h_{CO2} = 0$$

$$\Delta h_{H2O} = 0$$

$$\Delta h_{cel} = -21{,}2 \text{ kJ } g^{-1} = -2{,}12 \times 10^4 \ kJ \ kg^{-1}$$

$$\Delta H_{rxn} = -3{,}6\ W$$

$$Q = 3{,}6\ W$$

Problema 6.4 (Esterilização)

The operation of a continuous bioreactor requires sterilization of the culture medium in a continuous sterilizer. The medium inlet flow to the sterilizer is 2 m^3/h. The culture medium contains bacterial spores at a concentration of $5x10^{12}/m^3$. The values for the activation energy and the Arrhenius constant for the destruction of these spores are: 283 Kj/mol e $5.7x10^{39}$ h^{-1}, respectively. An acceptable criterion is the risk of contamination of a surviving microorganism in every 60 days of operation. The sterilizer has an internal diameter of 0.1 m and a length (holding section) of 24 m. The density of the medium is 1000 Kg/m^3 and the viscosity is 3.6 Kg/m.h. Determine what sterilization temperature is necessary to meet the established criteria.

perfect gas constant R = 8.3144J/K.mol

$$T = ?$$

$$k = A\, e^{-E/_{R\,T}}$$

Calcular k

A – Constante de Arrhenius = $5{,}7\times10^{39}$ h^{-1}
E – energia de ativação = 283 kJ/mol
R – constante dos gases perfeitos = 8,3144 J/K mol

Pelo gráfico: N/N_0 vs Da vs Pe

$$Da = k\,\frac{L}{v}$$

Da – número de Damkohler
L – comprimento do esterilizador = 24 m
v – velocidade linear do fluido no esterilizador

Calcular pelo caudal

N – nº de microrganismos ativos
N_0 – nº de microrganismos ativos iniciais

Calcular

$$Pe = \frac{v\,L}{D_z}$$

Pe – número de Peclet
Dz – coeficiente de dispersão

Pelo gráfico Dz/uD vs Re

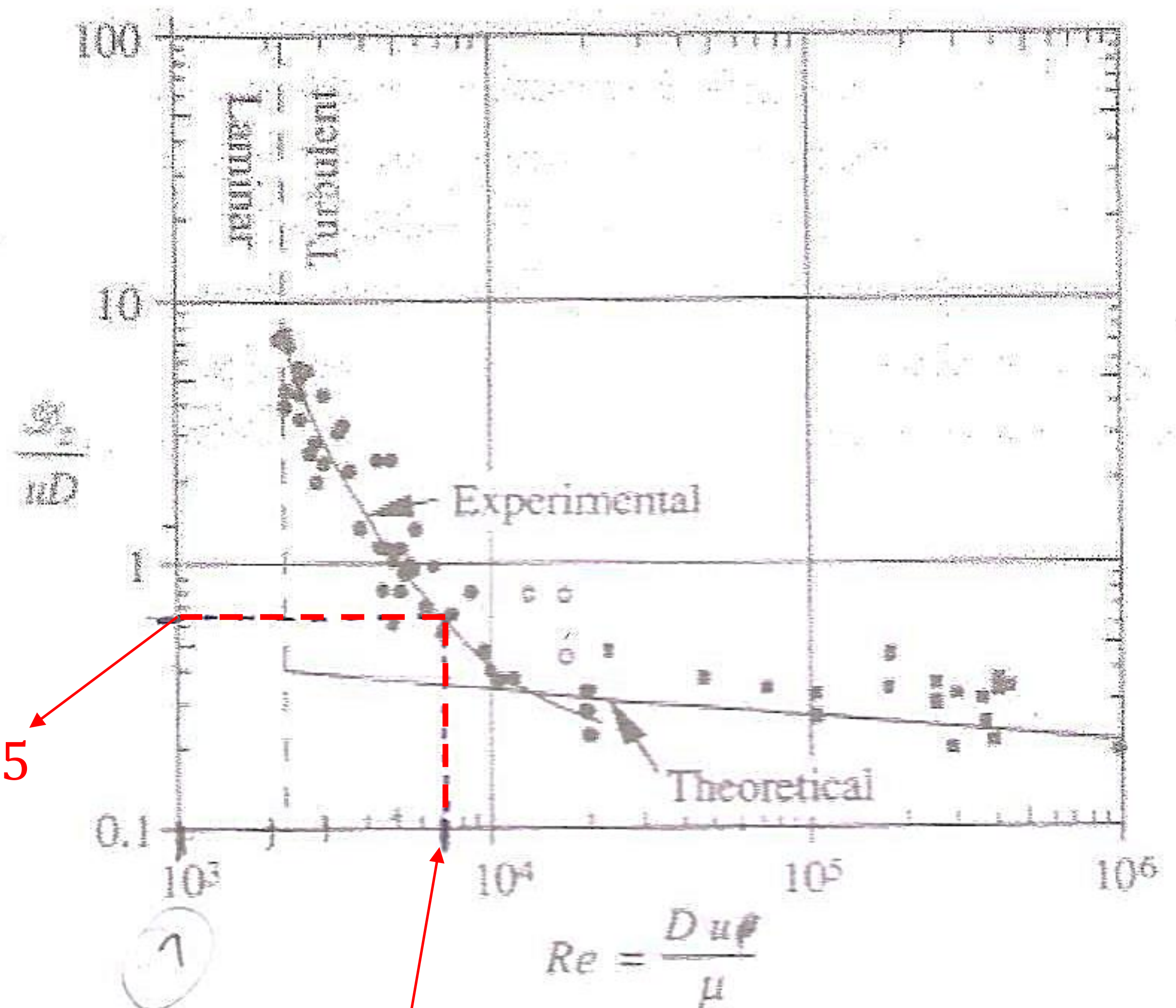
Calcular Re

$$Re = \frac{D\ v\ \rho}{\mu}$$

D – diâmetro do esterilizador = 0,1 m
v – velocidade linear do fluido no esterilizador

$$v = \frac{caudal}{área} = \frac{2\ m^3\ h^{-1}}{\pi\ (\frac{0,1}{2})^2\ m^2} = 254,6\ m\ h^{-1}$$

$$Re = 7,07 \times 10^3$$



$$\frac{D_z}{v\,D} = 0{,}65$$

$$Re = 7{,}07 \times 10^3$$

Calcular Re

$$Re = \frac{D\ v\ \rho}{\mu}$$

D – diâmetro do esterilizador = 0,1 m
v – velocidade linear do fluido no esterilizador

$$v = \frac{caudal}{área} = \frac{2\ m^3\ h^{-1}}{\pi\ (\frac{0,1}{2})^2\ m^2} = 254,6\ m\ h^{-1}$$

$$Re = 7,07 \times 10^3$$

$$\frac{D_z}{v\ D} = 0,65 \Leftrightarrow D_z = 16,6\ m^2\ h^{-1}$$

$$Pe = \frac{v\ L}{D_z} = 368$$

Calcular N/N_0

Critério aceitável: risco de contaminação de 1 mo em 60 dias

Calcular nº de células que entram no esterilizador em 60 dias

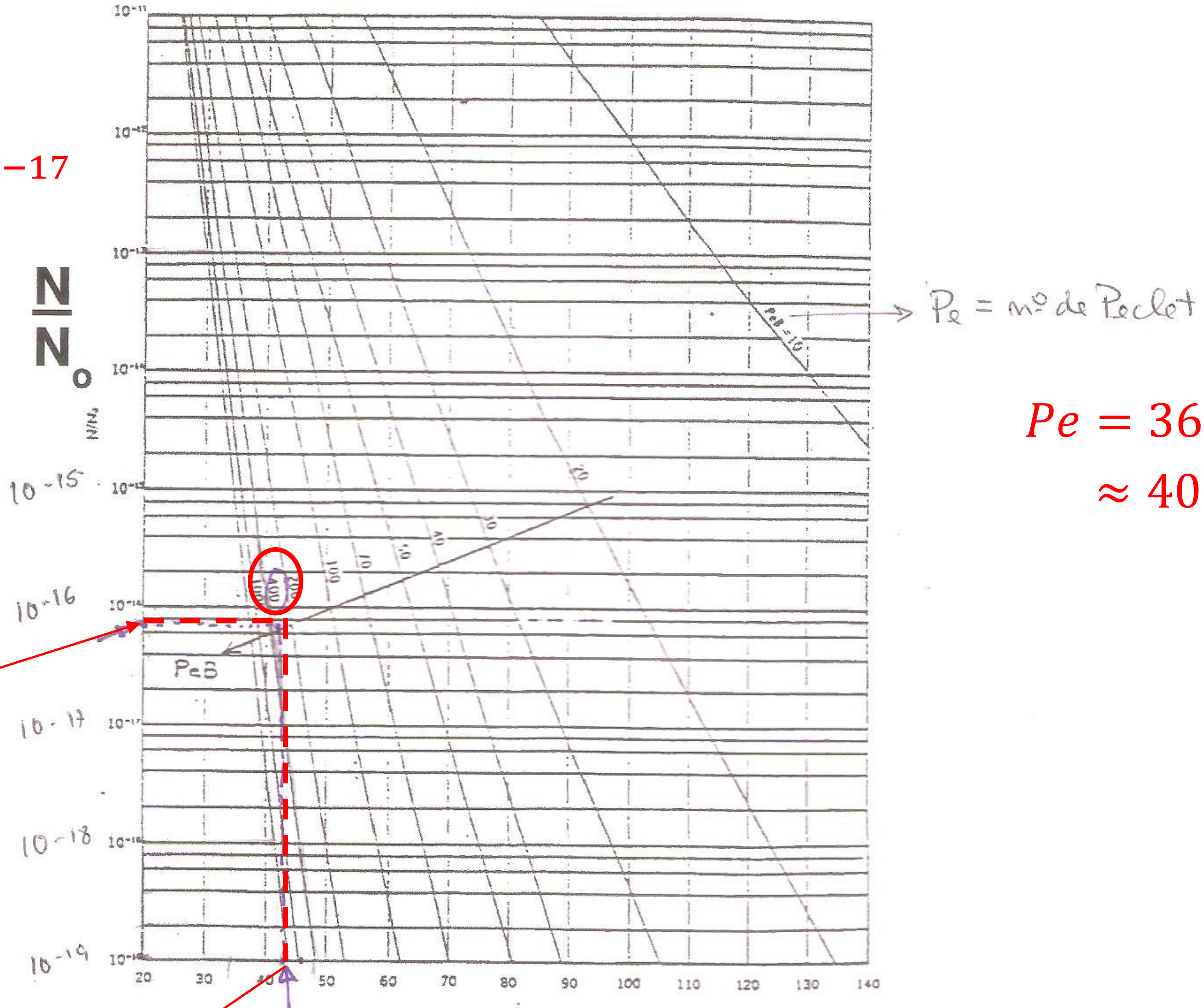
$$N_{entrada(60\ dias)} = 5 \times 10^{12} m^{-3} \times 2\ m^3\ h^{-1} \times 24 \times 60\ h$$

$$= 1{,}44 \times 10^{16}$$

$$N_{saída(60\ dias)} = 1$$

$$\frac{N}{N_0} = \frac{N_{saída}}{N_{entrada}} = 6{,}9 \times 10^{-17}$$

$$\frac{N}{N_0} = 6{,}9 \times 10^{-17}$$



$Pe = 368$

≈ 400

$Da = 42$

$$Da = k\frac{L}{V}$$

Calcular k

$$Da = k\frac{L}{v} \Leftrightarrow k = 445{,}6\ h^{-1}$$

Calcular T

$$k = A\ e^{-E/_{R\ T}} \Leftrightarrow \ln k = \ln A\ \frac{-E}{R\ T}$$

$$\Leftrightarrow \ln\frac{k}{A} = \frac{-E}{R\ T}$$

$$\Leftrightarrow T = 398{,}4\ K = 125\ ºC$$