Practice Problems

1.

Use the laboratory pilot-study data provided to design a reactor with a 35 000 L capacity. The fluid has a viscosity of 0.01 kg/m · s and specific gravity of 1.1.

laboratory data	
vessel diameter	25 cm
impeller diameter	7.5 cm
impeller type	4-bladed, 45° pitched-blade turbine
liquid level	25 cm
baffle width	2 cm
number of baffles	4
impeller speed	690 rpm
vessel volume	13.5 L
power	7.0 W

What is the power requirement of the new impeller?

(A)

96 W

(B)

1314 W

(C)

18 150 W

(D)

3.38×10^6 W

2.

Heat transfer in clean, round pipes follows the empirical correlation,

$$\mathrm{Nu} = 0.0225\mathrm{Re}^{0.8}\mathrm{Pr}^{0.4}$$

In a pilot-scale unit, a heat-transfer coefficient of 300 $W/m^2{\cdot}K$ is measured for fluid flowing at 5 m/s through a 3 cm diameter pipe. Calculate the heat-transfer coefficient when the process is scaled up to a geometrically similar 15 cm diameter pipe, using the same fluid.

(A)

22 $W/m^2{\cdot}K$

(B)

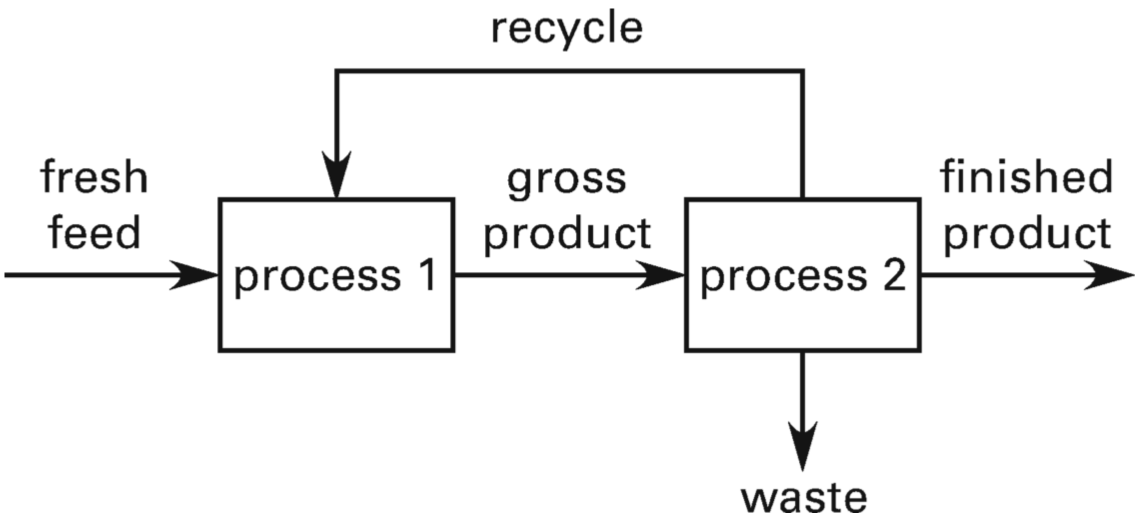
60 W/m^2 ·K
(C)

83 W/m^2 ·K

(D)

300 W/m^2 ·K
3.

10 000 kg/h of fresh feed is provided to process 1. As the gross product exits process 1, x is the fraction of the gross product that is recycled product. The gross product then enters process 2. y is the fraction of the gross product that exits process 2 as waste, and z is the fraction of the gross product that exits process 2 as finished product. The remainder of the gross product is recycled product that exits process 2 and is transferred to process 1.



The ratio of recycled to finished product is

(A)

1/2

(B)

(gross product/x)/(1 – x – y)

(C)

x/(1 – x)

(D)

x/(1 – x – y)

Solutions

1.

For geometric similarity, the number of baffles must be the same as the laboratory unit (4) and the impeller type must be the same (4-bladed, 45° pitched-blade turbine). The other geometric quantities are calculated with a scale factor, R, that is estimated from the reactor volumes.

$$R = \frac{D_f}{D_p} \approx \left(\frac{V_f}{V_p}\right)^{1/3} = \left(\frac{35\,000 \text{ L}}{13.5 \text{ L}}\right)^{1/3} = 13.7$$

The required impeller speed for the full-scale reactor is calculated by maintaining kinematic similarity.

$$n_f = n_p \left(\frac{D_p}{D_f}\right) = \frac{n_p}{R} = \frac{690\ \frac{\text{rev}}{\text{min}}}{13.7} = 50.4\ \text{rpm}$$

As in *NCEES Handbook:* Tank Mixing, the power number is held constant for dynamic similarity.

$$\begin{aligned} N_{p,f} &= N_{p,p} \\ \frac{P_f}{\rho n_f^3 D_f^5} &= \frac{P_p}{\rho n_p^3 D_p^5} \\ P_f &= P_p \left(\frac{n_f}{n_p}\right)^3 \left(\frac{D_f}{D_p}\right)^5 = P_p \left(\frac{1}{R}\right)^3 R^5 \\ &= P_p R^2 \\ &= (7.0\ \text{W})\,(13.7)^2 \\ &= 1314\ \text{W} \end{aligned}$$

The answer is (B).

2.

Maintaining a constant Reynolds number, as shown in *NCEES Handbook* table "Various Forms of Reynolds Numbers and Their Units in Circular Conduits (Pipes)," provides kinematic similarity.

$$\begin{aligned} \text{Re}_p &= \text{Re}_f \\ \left(\frac{D\text{v}\rho}{\mu}\right)_p &= \left(\frac{D\text{v}\rho}{\mu}\right)_f \\ \text{v}_f &= \text{v}_p \left(\frac{D_p}{D_f}\right) = \left(5\ \frac{\text{m}}{\text{s}}\right)\left(\frac{3\ \text{cm}}{15\ \text{cm}}\right) = 1\ \text{m/s} \end{aligned}$$

The heat-transfer coefficient in the full-scale unit can be obtained by scaling the given design equation. The Nusselt equation is in *NCEES Handbook:* Convective Mass Transfer. The Prandtl equation is in *NCEES Handbook* table "Dimensionless Numbers." The constant terms and fluid properties will cancel.

$$\begin{aligned} \frac{\text{Nu}_p}{\text{Nu}_f} &= \frac{0.0225\text{Re}_p^{0.8}\text{Pr}_p^{0.4}}{0.0225\text{Re}_f^{0.8}\text{Pr}_f^{0.4}} = \left(\frac{\text{Re}_p}{\text{Re}_f}\right)^{0.8} \left(\frac{\text{Pr}_p}{\text{Pr}_f}\right)^{0.4} \\ \frac{h_p D_p}{h_f D_f} &= \left(\frac{\text{v}_p D_p}{\text{v}_f D_f}\right)^{0.8} \\ h_f &= h_p \left(\frac{D_p}{D_f}\right)^{0.2} \left(\frac{\text{v}_f}{\text{v}_p}\right)^{0.8} \\ &= \left(300\ \frac{\text{W}}{\text{m}^2\text{·K}}\right)\left(\frac{3\ \text{cm}}{15\ \text{cm}}\right)^{0.2} \left(\frac{1\ \frac{\text{m}}{\text{s}}}{5\ \frac{\text{m}}{\text{s}}}\right)^{0.8} \\ &= 60\ \text{W/m}^2\text{·K} \end{aligned}$$

The answer is (B).

3.

The flow of gross product is

$$\begin{aligned} \text{gross product} &= \text{fresh feed} + \text{recycle} \\ &= 10\,000\ \tfrac{\text{kg}}{\text{h}} + \text{recycle} \end{aligned}$$

The flow of the recycle is

$$\text{recycle} = x\,(\text{gross product})$$

The flow of the finished product is

$$\begin{aligned}\text{finished product} &= \text{gross product} - \text{recycle} - \text{waste} \\ &= \text{gross product} - x\,(\text{gross product}) \\ &\quad - y\,(\text{gross product})\end{aligned}$$

The ratio of recycle to finished product is

$$\begin{aligned}\frac{\text{recycle}}{\text{finished product}} &= \frac{x(\text{gross product})}{\text{gross product} - x(\text{gross product}) - y(\text{gross product})} \\ &= \frac{x}{1-x-y}\end{aligned}$$

The answer is (D).