An-Najah National University
Faculty of Engineering and IT

جامعة النجاح الوطنية
كلية الهندسة وتكنولوجيا المعلومات

Chemical Engineering Department
Wastewater Effluent Treatment Processes (10626584)
Midterm Exam

Instructor Name: Amjad El-Qanni
Academic Year: 2021/2022
Semester: Fall
Credit Hours: 3
Date: November 18th, 2021
Exam Duration: 80 minutes

Student Name: ………………………
Registration Number: ……………....
Serial Number: ..…………………….
Section: ………………………………
Total Exam Mark: 25
Exam Weight: 25

Question	Marks	Question Grade
Q1	5	
Q2	4	
Q3	6	
Q4	4	
Q5	6	
Total Grade		

Notes: ***Exam***

1- Closed Books & Notes.
2- Read each problem carefully before attempting to solve it.
3- Write all work on this exam paper.
4- Show **complete solutions** to get full marks.

Good Luck

Q1 (10 Marks):

Below you have 10 short questions. For each question indicate if it is True or False. Fill out your answers in the Table.

1. Settling tanks are also called as sedimentation tanks.
2. Rapid sand filters require large area compared to slow sand filters.
3. The direction of water in filter beds is reversed for backwashing or cleaning.
4. Flocculent settling is the step involved in the settling process in solid thickening facilities.
5. Sieves and screens are examples of depth filters.
6. Baffle walls provided in sedimentation tanks to prevent short circuit.
7. Sedimentation is a process using gravity to remove suspended solids from water.
8. The accumulated layer at the bottom of the sedimentation tank is called sludge.
9. Turbidity is the main factor usually used for the selection of the filtration method.
10. According to the gravity separation theory, non-spherical particles settle slower than spherical particles.

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
T	F	T	F	F	T	T	T	T	T

Q2 (4 Marks): What power input in (kW) is required to achieve a mixing intensity (G) of 950 s^{-1} in a mechanical rapid mixing tank with a mean hydraulic detention time of 50 s at a water flow of 6000 m^3/day? Assume a water viscosity of 1.3×10^{-3} Pa.s.

Q3 (6 Marks): The rate of reaction for an enzyme-catalyzed substrate in a batch reactor can be described by the following relationship:

$$r_c = \frac{kC}{K + C}$$

where k = maximum reaction rate (mg/L)

C = substrate concentration (mg/L)

K = constant (mg/L)

Using this rate expression, derive an equation that can be used to predict the reduction of substrate concentration with time in a batch reactor. If $k = 40$ mg/L.min and $K = 100$ mg/L, determine the time required to decrease the substrate concentration from 1000 to 100 mg/L.

Accumulation = inflow – outflow + generation

$$\frac{dC}{dt}V = 0 - 0 + \left(-\frac{kC}{K + C}\right)V$$

2. Solve the mass balance for t

$$\left(\frac{K + C}{C}\right) dC = -k\, dt$$

$$\int_{C_o}^{C} \left[\left(\frac{K}{C}\right) + 1\right] dC = -k \int_0^t dt$$

$$K \ln(C_o/C) + (C_o - C) = kt$$

$$t = \frac{K \ln(C_o/C) + C_o - C}{k}$$

3. Compute t for the given data:

$C_o = 1000$ mg/m^3

$C = 100$ mg/m^3

$k = 40$ mg/m^3•min

$K = 100$ mg/m^3

$$t = \frac{100 \ln(1000/100) + (1000 - 100)}{40} = 28.3 \text{ min}$$

Q4 (4 Marks): The contents of a tank are to be mixed with a turbine impeller that has six flat blades ($N_P = 3.5$). The diameter of the impeller is 3 m, and the impeller is installed 1.25 m above the bottom of 6 m deep tank. If the temperature is 30 °C ($\rho = 995.7 \frac{kg}{m^3}$ and $\mu = 0.798 \times 10^{-3} Pa.s$) and the impeller is rotated at 30 rev/min, calculate Reynolds number and the power consumption in (kW)?

1. Compute the Reynolds number (N_R) using Eq. (5-11) in p337.

$$N_R = \frac{D^2 n \rho}{\mu}$$

Required data:

D = 3 m

n = 30 r/min = 0.5 r/s

ρ= 995.7 kg/m^3 (Table C-1)

μ = 0.798 x 10^{-3} N•s/m^2 (Table C-1)

$$N_R = \frac{(3\,\text{m})^2(0.5\ \text{r/s})(995.7\ \text{kg/m}^3)}{(0.798 \times 10^{-3}\,\text{N}\cdot\text{s/m}^2)} = 5.6 \times 10^6 \quad \text{(turbulent mixing)}$$

2. Compute the power consumption using Eq. (5-9) in p336.

$P = N_P \rho n^3 D^5$

Required data: N_P = 3.5 (see Table 5-11 in p338).

P = (3.5)(995.7 kg/m^3)(0.5 r/s)^3 (3 m)^5 = 105,855 kg•m^2/s^3 (W)

Q5 (6 Marks): Giving your background industrial wastewater treatment, you have been asked to design a single rectangular sedimentation tank to treat an effluent wastewater flow of 70 L/s at a design overflow rate of 40 $m^3/m^2.d$ and a temperature of 10 ^oC. Determine:

1) The tank dimensions (width, length, and depth) for a detention time of 3 h and a length to width ratio of 4 to 1.

2) The sedimentation tank behaves like an ideal plug flow reactor, will all particles with a diameter $\geq$ 50 µm and a density of 1250 kg/m^3 be completely removed by the ideal sedimentation tank? (Assume Stock's law applies, and for water at 10 ^oC, $\mu = 1.306 \times 10^{-3}$ $N.s/m^2$ and density = 1000 kg/m^3).

3) If the flow rate to the sedimentation tank is doubled, resulting in a higher overflow rate, would the particle removal efficiency decrease, increase, or stay the same? Explain briefly and qualitatively.

Formula Sheet

Constants / Conversions		
$R = 8.314 \frac{kPa.m^3}{kmol.K} = 8.314 \frac{J}{mol.K}$	$N_A = 6.023x10^{26} \frac{molecules}{kmol}$	$g = 9.81 m/s^2$
$R = 0.08205 \frac{atm.m^3}{kmol.K}$	$k = \frac{R}{N_A} = 1.3805x10^{-23} J/K$	$1\ cP = 10^{-3}\ Pa.s$
101.325 kPa =1 atm	1 bar = 100 kPa	1 L = 1000 cm^3= 1000 mL = 0.001 m^3
	760 mmHg = 1 atm	

Reactor Design		
Batch	CSTR	PFR
$\frac{dC}{dt}V = rV$	$\frac{dC}{dt}V = QC_o - QC_e + rV$	$-\boldsymbol{Q}\frac{\partial \boldsymbol{C}}{\partial \boldsymbol{V}} + \boldsymbol{r} = \frac{\partial \boldsymbol{C}}{\partial \boldsymbol{t}}$
CSTR in series $C_i = \frac{C_o}{(i-1)!}\left(\frac{t}{\tau_i}\right)^{i-1} e^{-t/\tau_i}$		General PFR (n≥0, n≠1): $\tau = \frac{V}{Q} = \frac{1}{k}\left(\frac{C_o^{-n+1}}{-n+1} - \frac{C^{-n+1}}{-n+1}\right)$

Geometric Shapes		
$V_{sphere} = \frac{4}{3}\pi r^3$	$SA_{sphere} = 4\pi r^2$	$V_{cylinder} = \pi r^2 h$

Mixing and Power		
Power: $\boldsymbol{P = \gamma Q h}$		
$G = \sqrt{\frac{P}{\mu V}}$	$G\tau = \frac{V}{Q}\sqrt{\frac{P}{\mu V}} = \frac{1}{Q}\sqrt{\frac{PV}{\mu}}$	
Static Mixer	Turbine Mixer:	
$h \approx k\left(\frac{v^2}{2g}\right) \approx K_{SM}v^2$	$P = N_P \rho n^3 D^5$ $Q = N_Q n D^3$	$N_R = \frac{D^2 n \rho}{\mu}$ $Turbulent\ range, N_R \geq 10{,}000$
Paddle mixer:		
$F_D = \frac{C_D A \rho v_p^2}{2}$ $P = F_D v_p = \frac{C_D A \rho v_p^3}{2}$		

Gravity Separation Theory		
Newton's Law: $v_{p(t)} = \sqrt{\frac{4g}{3C_d\phi}\left(\frac{\rho_p-\rho_w}{\rho_w}\right)d_p} \approx \sqrt{\frac{4g}{3C_d\phi}(S_{gp}-1)d_p}$	$C_d = \frac{24}{N_R} + \frac{3}{\sqrt{N_R}} + 0.34$	$N_R = \frac{v_p d_p \phi \rho_w}{\mu} = \frac{v_p d_p \phi}{\nu}$
Stokes Law for spherical particles: $v_p = \frac{g(\rho_p-\rho_w)d_p^2}{18\mu} \approx \frac{g(sg_p-1)d_p^2}{18\nu}$	$v_c = \frac{h_o}{\tau} = \frac{h_o Q}{V} = \frac{Q}{LW} = \frac{Q}{A_s} = OR$	
Discrete Particle Settling: $X_r = \frac{v_P}{v_c}$	$Fraction\ removed = (1-X_c) + \int_0^{x_c}\frac{v_P}{v_c}dx$	$Total\ fraction\ removed = \frac{\sum_{i=1}^{n}\frac{v_{n_i}}{v_c}(n_i)}{\sum_{i=1}^{n} n_i}$
Flocculent settling (column test): $v_c = \frac{H}{t_c}$	$\boldsymbol{R}, \% = \sum_{h=1}^{n}\left(\frac{\Delta h_n}{H}\right)\left(\frac{R_n + R_{n+1}}{2}\right)$	

Depth Filtration		
ES = d_{10}	UC= d_{60}/d_{10}	Darcy-Weisbach equation: $\Delta P = \lambda \frac{L}{D}\frac{\rho v^2}{2}$
Backwash Hydraulic:		
$F_G = mg = (\rho_P - \rho_W)\left(\frac{\pi}{6}d^3\right)$	$F_D = \begin{cases} 3\pi\mu v d, R_e < 2.0 \\ \frac{2.31}{R_e^{0.6}}\pi\rho_w v^2 d^2, 2 \le R_e \le 500 \end{cases}$	$v = \left[\frac{g(\rho_P-\rho_W)d^{1.6}}{13.9\rho_W^{0.4}\mu^{0.6}}\right]^{0.714}$
$h = L_e(1-\varepsilon_e)\left(\frac{\rho_s-\rho_w}{\rho_w}\right)$	$\frac{L_e}{L} = \frac{1-\varepsilon}{1-\varepsilon_e} = \frac{1-\varepsilon}{1-(v/v_s)^{0.22}}$	$\frac{L_e}{L} = (1-\varepsilon)\sum\frac{p}{(1-\alpha_e)}$
$\frac{d_1}{d_2} = \left(\frac{\rho_2-\rho_w}{\rho_1-\rho_w}\right)^{0.625}$	$H_t = H_o + \sum_{i=1}^{n}(h_i)_t$	$(h_i)_t = a(q_i)_t^b$