AY20/21 paper

Class	EN2003
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Materials	
Reviewed	☐
Type	

1.

a.

(i)

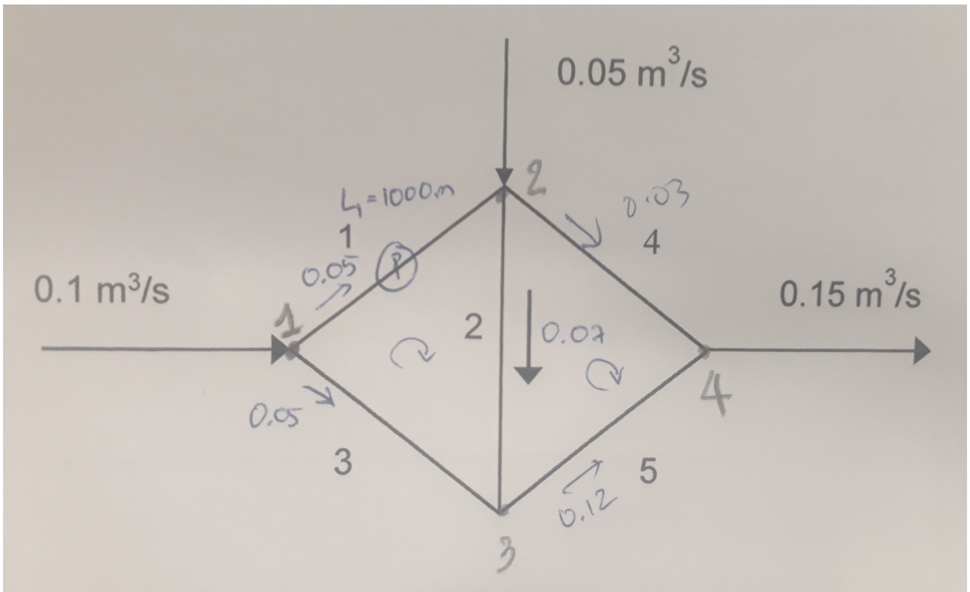


Figure Q1

Initial flow rates: (clockwise as positive)

$$0.05 + Q1 = Q2 + Q4 \Rightarrow 0.05 + 0.05 = 0.07 + 0.03 \Rightarrow valid$$

$Q1 = 0.05m^3/s, Q2 = 0.07m^3/s, Q3 = -0.05m^3/s, Q4 = 0.03m^3/s, Q5 = -0.12m^3/s$

Node 1:

$$0.1 = Q1 + Q3 \Rightarrow 0.1 = 0.05 + 0.05 \Rightarrow valid$$

Node 3: $$Q3 + Q2 = Q5 \Rightarrow 0.05 + 0.07 = 0.12 \Rightarrow valid$$

Node 2:

Node 4: $$Q4 + Q5 = 0.15 \Rightarrow 0.03 + 0.12 = 0.15 \Rightarrow valid$$

(ii) (iii)

Table Q1

Pipe	L (m)	D (m)	K	Q	H_L	|H_L/Q|	Delta Q (m3/s)
1	1000	0.25	1299.3	0.05	5.091	101.82	
2	700	0.25	909.51	0.07	6.641	94.87	-0.012
3	1000	0.25	1299.3	-0.05	-5.091	101.82	
Untitled							
4	2500	0.25	3248.3	0.03	4.947	164.90	
5	1500	0.25	1949.0	-0.12	-38.574	321.45	0.037
2	700	0.25	909.51	-0.07	-6.641	94.87	
Untitled							

$$Q2_{new} = 0.07 + (-0.012) - 0.037 = 0.021 m^3/s$$

(iv)

Energy conservation for loop: $\Delta E = \sum h_L - \sum E_p = 0$

Hence: $\sum h_L = \sum E_p = 3m$

b.

$$Q = VA = V \times \frac{\pi}{4} D^2 \Rightarrow V = \frac{4Q}{\pi D^2}$$

$$H_L = f\frac{L}{D}\frac{(4Q/\pi D^2)^2}{2g} = (\frac{4}{\pi})^2 f\frac{L}{D^5} \times Q^2 = 0.083 f\frac{L}{D^5} \times Q^2$$

Hence:

$$\alpha = 2$$
$$K = 0.083 f\frac{L}{D^5}$$

2.

a.

(i) Since there is no settling of particles during flocculation, /omega is constant

$$\Omega = \frac{\pi}{6} N_I d_I^3 = \frac{\pi}{6} \times (10^7/L) \times (2 \times 10^{-6} m)^3 = 4.19 \times 10^{-8}$$

$$\frac{dN}{dt} = -\frac{4}{\pi} G \alpha \Omega N \Rightarrow \frac{N_E - N_I}{t} = -\frac{4}{\pi} G \alpha \Omega N_E$$

$$\Rightarrow \frac{N_E}{N_I} = \frac{1}{1 + \frac{4}{\pi} \alpha G \Omega t}$$

The number of particles reduced by 50%

$$\Rightarrow \frac{N_E}{N_I} = 50\%$$

$$\Rightarrow \frac{1}{1 + \frac{4}{\pi} \alpha G \Omega t} = 0.50 \quad (*)$$

$$\Rightarrow \frac{1}{1 + \frac{4}{\pi} \times 0.9 \times 50 \times 4.19 \times 10^{-8} \times t} = 0.50$$

$$\Rightarrow t = 416546 s = 115.7 h$$

(ii) $$\Omega = \frac{\text{floc concentration}}{\text{solid content of floc}} = \frac{10.5 \; mg/L}{0.035 \; g/cm^3} = 3 \times 10^{-4}$$

Subst into $(*)$:

$$\frac{1}{1 + \frac{4}{\pi} \times 0.9 \times 50 \times 3 \times 10^{-4} \times t} = 0.50$$

$$\Rightarrow t = 58.2 s$$

(iii) The amount of time required in part (ii) is much smaller than in part (i). The difference is due to the addition of coagulant. The coagulation process destabilizes colloidal particles, which makes them more unstable in water. Consequently, the flocculation process will group destabilized particles into larger flocs more easily.

b.

(i)

Water alkalinity

$$OH^- + H^+ \rightarrow H_2O$$

$$HCO_3^- + H^+ \rightarrow H_2O + CO_2$$

$$CO_3^{2-} + 2H^+ \rightarrow H_2O + CO_2$$

(ii) Aluminium sulphate can react with water alkalinity. Hence, if adequate alkalinity is not present in water, the coagulant will react with all of the alkalinity, causing the lowering of pH.

(iii)

$$Al_2(SO_4)_3 + 6HCO_3^- \rightarrow 2Al(OH)_3\downarrow + 6CO_2 + 3SO_4^{2-}$$

$342\,g$ $\quad$ $366\,g$

$$50\,mg/L \rightarrow \frac{366}{342} \times 50 = 53.5\,mg/L$$

$$EW \text{ of } HCO_3^- = \frac{61}{1} = 61$$

$$EW \text{ of } CaO = \frac{56}{2} = 28$$

$$EW \text{ of } Na_2CO_3 = \frac{106}{2} = 53$$

Water alkalinity consumed

$$= \frac{53.5}{61} \times 28 = 24.6\,mg/L \text{ as } CaO$$

$$= \frac{53.5}{61} \times 53 = 46.4\,mg/L \text{ as } Na_2CO_3$$

C.

Advantages of a compartmentalized flocculation basin:

- High efficiency
- Less detention time
- Smaller tank volume

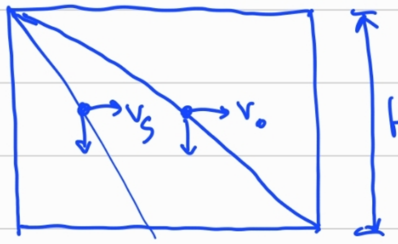
3.

a.

(i)

1. size of particles is not constant for flocculent settling. Size increases over settling time. For discrete, size is constant
2. velocity for flocculent is not constant
3. trajectory: curve for flocculent, linear for discrete
4. design: for discrete, only depends on SOR. For flocculent, depends on SOR and time

(ii)



For a particle to be 100% removed, it must reach the bed of the tank during detention time t

$$\Rightarrow \frac{H}{v_s} \leq t \Rightarrow v_s \geq \frac{H}{t} = \frac{V}{W \times L \times t} = \frac{Q}{W \times L} = v_o = SOR$$

∴ The settling efficiency only depends on surface overflow rate, not on the depth of the tank

(iii) If the depth of the tank is too shallow, particles can be resuspended due to high horizontal velocity

b.

(i)

Smallest settling velocity for 100% removal

$$= v_o = \frac{Q}{W \times L}$$

$$\Rightarrow (v_s)_{min} = \frac{g(\rho_s - \rho) d_{min}^2}{18\mu} = \frac{Q}{W \times L}$$

$$\therefore d_{min} = \sqrt{\frac{18\mu Q}{g(\rho_s - \rho) W L}}$$

(ii) Removal efficiency can be calculated as

$$X_r = \frac{v_s}{v_o}$$

when water flow rate is increased to 1.5Q, SOR would also increase by 1.5 times. Hence, the removal efficiency is

$$X_{r,new} = \frac{v_s}{1.5 v_o} = 0.67 X_r$$

The efficiency drops by 33%

(iii) Higher temperature in the summer induces smaller water viscosity. Since the settling velocity is inversely proportional with viscosity, the settling velocity will be larger. Consequently, removal efficiency is higher

c.

In the $MgCl_2$ solution:

$[Mg^{2+}] = \frac{95 g/L}{95 g/mol} = 1 M$

$[Cl^-] = 2 \times \frac{95 g/L}{95 g/mol} = 2 M$

Total molecular concentration = 1 + 2 = 3 M

Osmotic pressure $\pi_1 = CRT$

$= 3 \times 0.082 \times (27 + 273)$

$= 73.8$ atm

In the phenol solution:

$[C_6H_5OH] = \frac{95 g/L}{94 g/mol} = 1.01 M$

Osmotic pressure $\pi_2 = CRT$

$= 1.01 \times 0.082 \times (27 + 273)$

$= 24.8$ atm

Since phenol does not disassociate in water like magnesium chloride, the total molecular concentration in the phenol solution is smaller although both solutions have the same concentration in mg/L. Hence the respective osmotic pressure in the phenol solution is smaller

4.

a.

(i)

$$Re = \frac{\phi V_s d_p}{v} = \frac{0.8 \times \frac{240}{1000 \times 60} \times 0.5/1000}{1.003 \times 10^{-6}} = 1.60$$

$$C_d = \frac{24}{Re} + \frac{3}{\sqrt{Re}} + 0.34 = \frac{24}{1.60} + \frac{3}{\sqrt{1.60}} + 0.34 = 17.7$$

$$h_f = \frac{1.067}{\phi} C_d \frac{1}{e^4} \frac{L}{d_p} \frac{V_s^2}{g} = \frac{1.067}{0.8} \times 17.7 \times \frac{1}{0.45^4} \times \frac{0.50}{0.5/1000} \times \frac{0.004^2}{9.81} = 0.94m$$

The initial clean water head loss exceeds the design guideline

(ii) When the temperature increases, water viscosity decreases. Since Reynolds number is inversely proportional with water viscosity, Re will subsequently increase. Thus, drag coefficient reduces, which results in lower clean water head loss

b.

(i)

- Replace conventional filtration unit
- Used as pretreatment of RO and NF

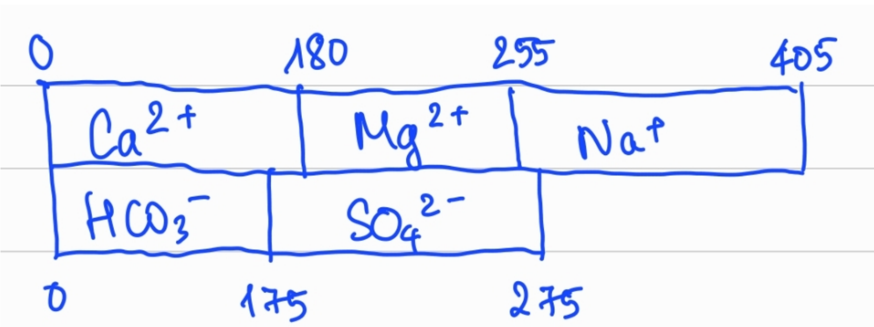
(ii) for inorganic fouling, we can use citric acid to dissolve precipitation of less soluble inorganic species. For organic fouling, base can be used to reduce the adsorption of organic molecules on surface

C.

Free chlorine is a more powerful disinfectant because for the same disinfection efficiency of 99%, the C×t value of free chlorine is much lower than that of chloramine. This means for the same concentration, free chlorine will need less time to reach the required efficiency.

d.

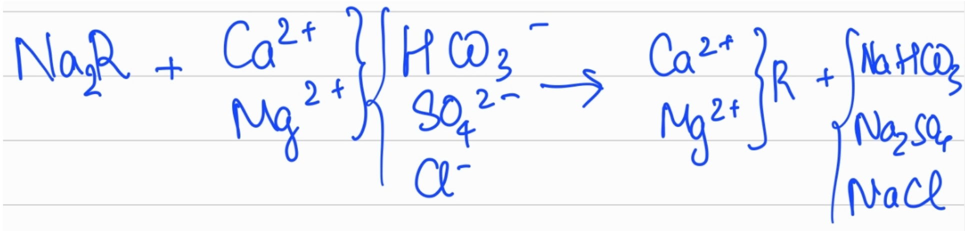
(i)



(ii) CH=175 mg/L as $CaCO_3$; NCH = 255 - 175 = 80 mg/L as $CaCO_3$

(iii)

- Ion exchange: Ca^{2+} and Mg^{2+} are removed and replaced with sodium by a cation resin (solid beds)



- Nanofiltration: the membrane rejects multivalent ions from passing through.