## Subjects : Environmental Engineering

## DETAILED EXPLANATIONS

**1. Solution:**

For extinguishing one fire, we use 3 jets with each having discharge of 1100 litres/minute.

$$\text{Per capita fire demand} = \frac{3 \times 1100 \times 4 \times 2 \times 60}{4000000}$$

$$= 0.396 \ lpcd$$

**2. Solution:**

Storativity or the storage coefficient is the volume of water released from storage per unit decline in hydraulic head in the aquifer per unit area of the aquifer.

**3. Solution:**

| Parameter | Acceptable limit (mg/*l*) | Cause for rejection limit (mg/*l*) |
|---|---|---|
| Chlorides | 250 | 1000 |
| Alkalinity | 200 | 600 |
| Ammonia | 0.5 | 0.5 |
| Nitrates | 45 | 45 |

**4. Solution:**

$$\text{DO of sample} = \frac{(15\times0.8)+(285\times8.8)}{(15+285)}$$

$$= 8.4 \text{ mg}/l = DO_i$$

$$DO_f = 3.8 \text{ mg}/l$$

$$\text{Dilution factor} = \frac{300}{15} = 20$$

$$\therefore \quad BOD_5 = (8.4 - 3.8) \times 20 = 92 \text{ mg}/l$$

**5. Solution:**

Tapered aeration is an aeration method in which air supply is gradually decreased along the length of the aeration tank.

**6. Solution:**

Kjeldahl nitrogen is the sum of ammonia nitrogen and organic nitrogen present in sewage.

**7. Solution:**

Transmissivity is the rate of flow of water under a unit hydraulic gradient through a unit width of aquifer of given saturated thickness.

**8. Solution:**

Self-cleansing velocity is the minimum flow velocity that prevents deposition of solids and scours deposited particles in sewers.

**9. Solution:**

$$Q = 0.8 \text{ m}^3/\text{d}$$

Detention time,

$$D_t = \frac{V}{Q} = \frac{4\times2\times2 \text{ m}^3}{0.8 \text{ m}^3/\text{day}} = 20 \text{ days}$$

$$\therefore \quad L_t = \frac{L_0}{1+k_e t} = \frac{54}{1+0.1\times20} = 18 \text{ mg}/l$$

**10. Solution:**

Short-circuiting is the direct passage of water from inlet to outlet without settlement of particles thereby reducing effective detention time and treatment efficiency.

**11. Solution:**

Flow through velocity, $V = \frac{Q}{BH}$

$\Rightarrow$ $\frac{Q}{B} = V \times H = 0.3 \times 0.9 = 0.27 \text{ m}^2/\text{s}$

For 100% efficiency, settling velocity ($V_s$) = SOR

$$V = \frac{Q}{BL} = \frac{0.27}{7.5} = 0.036 \text{ m/s}$$

Now, $V_s = \frac{\rho_w g}{18}\left(\frac{S_s - 1}{\mu}\right) d^2 = 0.036$

$$\Rightarrow \quad d^2 = \frac{0.036 \times \mu \times 18}{\rho_w \times g \times (S_s - 1)}$$

$$\Rightarrow \quad d^2 = \frac{0.036 \times 1.002 \times 10^{-3} \times 18}{1000 \times 9.81 \times (2.5 - 1)}$$

$$\Rightarrow \quad d^2 = 4.41 \times 10^{-8}$$

$$\therefore \quad d = 2.10 \times 10^{-4} \text{ m} = 0.21 \text{ mm}$$

**12. Solution:**

Biochemical Oxygen Demand (BOD) is the amount of dissolved oxygen required by aerobic bacteria to biologically decompose organic matter in wastewater. Only biologically active organic matter contributes to BOD. The standard $BOD_5$ test measures oxygen consumed over 5 days at 20 °C, which represents about 68% of total BOD and is used as a standard index of organic pollution.

**13. Solution:**

Head loss of expanded bed = Head loss of unexpanded bed

$$\Rightarrow \quad D'(1 - \eta')(G - 1) = D(1 - \eta)(G - 1)$$

$$\Rightarrow \quad D'(1 - \eta') = D(1 - \eta)$$

$$\Rightarrow \quad D' = \frac{D(1-\eta)}{(1-\eta')}$$

Now, $\eta' = \left(\frac{v_B}{v_s}\right)^{0.22}$

Backwash velocity, $v_B = \frac{Q_B}{A} = \frac{Q_B}{LB} = \frac{3.6}{4 \times 3 \times 60} \text{ m/s}$

$$\eta' = \left(\frac{3.6}{4 \times 3 \times 60 \times 0.05}\right)^{0.22} = 0.603$$

$$\therefore \quad D' = 0.8\frac{(1-0.4)}{(1-0.603)} = 1.21 \text{ m}$$

**14. Solution:**

Time, $t = \dfrac{\text{Distance } (d)}{\text{Velocity } (v)}$

where, $v = \dfrac{Q_S + Q_R}{A} = \dfrac{0.2+5}{40} = 0.13 \text{ m/sec}$

$\therefore$ $t = \dfrac{3 \times 10^3}{0.13 \times 86400} = 0.267 \text{ days}$

$$\text{BOD}_5 = \text{BOD}_u(1 - e^{-k \times 5})$$

$\Rightarrow$ $\text{BOD}_u = \dfrac{500}{(1-e^{-0.3\times5})} = 643.61 \text{ mg}/l$

$$\text{DO}_{\text{mix}} = \frac{Q_R \text{BOD}_u + Q_S \cdot \text{BOD}_u}{Q_S + Q_R}$$

$$= \frac{5 \times 30 + 0.2 \times 643.61}{5+0.2} = 53.6 \text{ mg}/l$$

$\therefore$ BOD remaining at 3 km downstream from the mixing location is,

$$L_t = L_0 e^{-k \times t}$$
$$= 53.6 e^{-0.3 \times 0.267}$$
$$= 49.47 \text{ mg}/l$$

**15. Solution:**

Self-purification is the natural process by which a polluted river restores its original quality after sewage discharge. This occurs due to the action of natural physical, chemical and biological forces. The main forces responsible are:

(i) Dilution and dispersion

(ii) Sedimentation

(iii) Sunlight action

(iv) Biological oxidation

(v) Reduction

**16. Solution:**

Thickness of aquifer, $H = 20$ m

$r_1 = 10$ m

$r_2 = 100$ m

$h_2 = H - S_{w1} = 20 - 5 = 15$ m

$h_1 = H - S_{w2} = 20 - 1 = 19$ m

Now discharge from an unconfined aquifer is given as

$$Q = \frac{\pi \cdot K\left[h_1^2 - h_2^2\right]}{\ln\left[\frac{r_2}{r_1}\right]} = \frac{\pi \times 10 \times \left[19^2 - 15^2\right]}{\ln\left[\frac{100}{10}\right]}$$

$\Rightarrow$ $Q = 1855.55 \text{ m}^3/\text{day}$

**17. Solution:**

Advantages of using free molecular chlorine as a disinfectant:

1. Free chlorine can be stored safely for long durations without any significant loss in strength.
2. It is an economical disinfectant and is readily available.
3. It occupies less space for storage.
4. Transportation of chlorine is simple and inexpensive.
5. The quantity of chlorine to be applied can be accurately controlled, thereby reducing chances of under-dosing or over-dosing.
6. The capital cost of installing a chlorination plant is comparatively low.
7. Chlorine is a strong disinfectant and remains in water for a sufficient period as residual, particularly in the presence of ammonia.
8. It allows uniform distribution throughout the entire volume of water being treated.
9. Plant operation is simple and does not demand highly skilled supervision, though careful handling during storage and use is necessary.
10. No sludge is produced during chlorination, unlike treatments using hypochlorites or chloramines.

 

**18. Solution:**

Given data:

$$k_1 = 0.18\ \text{day}^{-1},\ T_1 = 20°\text{C}$$
$$t_1 = 5\ \text{days},\ y_1 = 180\ \text{mg/l}$$
$$k_2 = ?,\ T_2 = ?$$
$$t_2 = 2.5\ \text{days},\ y_2 = 180\ \text{mg/l}$$
$$L_{01} = \text{Ultimate BOD} = L_{02}$$

$$\therefore \quad \frac{y_1}{y_2} = \frac{1-e^{-k_1t_1}}{1-e^{-k_2t_2}}$$

$$\Rightarrow \quad \frac{180}{180} = \frac{1-e^{-0.18\times5}}{1-e^{-2.5k_2}}$$

$$\Rightarrow \quad e^{2.5k_2} = e^{0.9}$$

$$\Rightarrow \quad k_2 = 0.36\ \text{day}^{-1}$$

Now, $$k_T = k_{20°C}(1.047)^{T-20}$$

$$\Rightarrow \quad 0.36 = 0.18\ (1.047)^{T-20}$$

$$\Rightarrow \quad T = 35.09°\text{C}$$

**19. Solution:**

Wastewater flow = 5 MLD

BOD of wastewater = 300 mg/*l*

$$y_0 = 300 \times 10^{-6} \times 5 \times 10^6\ \text{kg/day} = 1500\ \text{kg/day}$$

BOD removal in PST = 25%

$\therefore$ BOD applied on filter, $y = 1500 \times (1 - 0.25) = 1125$ kg/day

Desired BOD of treated wastewater,

$$y_e = 50\ \text{mg/}l$$
$$= 50 \times 10^{-6} \times 5 \times 10^6\ \text{kg/day} = 250\ \text{kg/day}$$

$\therefore$ Efficiency of filter required, $\eta = \left(\frac{y-y_e}{y}\right)\times100 = \left(\frac{1125-250}{1125}\right)\times1000 = 77.78\%$

**(i) Design of high rate trickling filter**

Recirculation ratio, $\frac{R}{I} = 1.4$

$\therefore$ Recirculation factor, $$F = \frac{\left(1+\frac{R}{I}\right)}{\left(1+0.1\frac{R}{I}\right)^2}$$

$$\Rightarrow \quad F = \frac{(1+1.4)}{(1+0.1\times1.4)^2} = 1.847$$

$\because$ Efficiency,
$$\eta = \frac{100}{\left(1+0.0044\sqrt{\frac{y}{V.F.}}\right)}$$

$$\Rightarrow \quad 77.78 = \frac{100}{1+0.0044\sqrt{\frac{1125}{V\times1.847}}}$$

$$\Rightarrow \quad V = 0.1445\ ha\text{-m} = 1445\ \text{m}^3$$

Assume depth of filter medium,

$$H = 1.5\ \text{m} \qquad (1.2\ \text{m} < H < 1.8\ \text{m})$$

$\therefore$ Area of circular filter,
$$A = \frac{V}{H}$$

$$\Rightarrow \quad \frac{\pi}{4}D^2 = \frac{1445}{1.5}$$

$$\Rightarrow \quad D = 35.02\ \text{m} ; 35\ \text{m (say)}$$

$\therefore$ Diameter of high rate trickling filter should be 35 m and depth of filter 1.5 m

**(ii) Design of low rate trickling filter**

$$\frac{R}{I} = 0$$

$$\therefore \quad F = 1$$

$$\therefore \quad \eta = \frac{100}{\left(1+0.0044\sqrt{\frac{y}{V.F}}\right)}$$

$$\Rightarrow \quad 77.78 = \frac{100}{1+0.0044\sqrt{\frac{1125}{V\times1}}}$$

$$\Rightarrow \quad V = 0.2669\ ha\text{-m} = 2669\ \text{m}^3$$

Assume depth of low rate trickling filter

$$H = 2.0\ \text{m} \qquad (1.6\ \text{m} < H < 2.4\ \text{m})$$

$\therefore$ Area of the filter,
$$A = \frac{V}{H}$$

$$\Rightarrow \quad \frac{\pi}{4}D^2 = \frac{2669}{2}$$

$$\Rightarrow \quad D = 41.22\ \text{m} \simeq 42.0\ \text{m}$$

$\therefore$ Diameter of slow rate trickling filter should be 42 m and depth of filter 2.0 m.

 

**20. Solution:**

**Coagulation** is a chemical technique which is directed towards the destabilization of the charged colloidal particles. Flocculation on the other hand, is the slow mixing technique which promotes the agglomeration of the stabilized particles. For all practical purposes, however, the entire process of addition of chemicals (coagulants) and mixing (flocculation) is usually referred to as coagulation. In water treatment plants chemical coagulation is usually accomplished by the addition of trivalent metallic salts such $Al_2(SO_4)_3$ or $FeCl_3$. The mechanisms of coagulation which are thought to occur are ionic layer compression, adsorption and charge neutralization, sweep coagulation and interparticle bridging.

**(i) Ionic layer compression:**

- The quantity of ions in the water surrounding a colloid has an effect on the decay function of the electrostatic potential.
- A high ionic concentration compresses the layers composed predominantly of counter ions towards the surface of colloid.
- If this layer is sufficiently compressed, then the Van-der Waals force will be predominant across the entire area of influence, so that the net force will be attractive and no energy barriers will exist.
- Although coagulants such as aluminium and ferric salts used in water treatment ionise, at the concentration commonly used they would not increase the ionic concentration sufficiently to affect ionic layer compression.

**(ii) Adsorption and charge neutralization:**

- The nature rather than quantity of the ions is of prime importance in the theory of adsorption and charge neutralization.
- The ionisation of $Al_2(SO_4)_3$ and $FeCl_3$ in water produces $SO_4^{2-}$ and $Cl^-$ along with $Al^{3+}$ and $Fe^{3+}$. The $Al^{3+}$ and $Fe^{3+}$ cations react immediately with water to form a variety of aquometallic ions and hydrogen.
  $Al^{3+} + 3H_2O \longrightarrow Al(OH)_3 + 3H^+$
  $Fe^{3+} + 3H_2O \longrightarrow Fe(OH)_3 + 3H^+$
- The aquometallic ions thus formed become part of the ionic cloud surrounding colloid and because they have a great affinity for surfaces are adsorbed onto the surface of the colloid where they neutralize the surface charge.
- Once the surface charge has been neutralized, the ionic cloud dissipates and the electrostatic potential disappears so that contact occurs freely.

**(iii) Sweep coagulation**

- The last product formed in the hydrolysis of alum is $Al(OH)_3$.

- The $Al(OH)_3$ forms amorphous, gelatinous flocs that are heavier than water and settle by gravity.
- Colloids may become entrapped in a floc as it is formed, or they may become enmeshed by its sticky surface as the flocs settle.
- The process by which colloids are swept from suspension in this manner is known as sweep coagulation.

**(iv) Interparticle bridging:**

- Large molecules may be formed when aluminium or ferric salts dissociate in water.
- Synthetic polymers may also be used instead of, or in addition to, metallic salts which may be linear or branched and are highly surface reactive.
- Several colloids may become attached to one polymer and several of the polymer-colloid groups may become enmeshed resulting in a settleable mass.
- In addition to the adsorption forces, charges on the polymer may assist in the coagulation process.
- Metallic polymers formed by addition of aluminium or ferric salts are positively charged while synthetic polymers may carry positive or negative charges or may be neutral.
- Judicious choice of appropriate charges may do much to enhance the effectiveness of coagulation.

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