Assuming the depth of the filter as 1.5 m, we have

Surface area required = $\frac{2000}{1.5}\text{m}^2 = 1333.3\ \text{m}^2$

$\therefore$ Diameter of the circular filter required

$$= \sqrt{1333.3 \times \frac{4}{\pi}} = \mathbf{41.2m}.$$

Hence, use a high rate trickling filter with 41.2 m diameter, 1.5 m deep filter media, and with recirculation (single stage) ratio is 1.5.

25. The sewage is flowing @ 4.5 Million litres per day from a primary clarifier to a standard rate trickling filter. The 5-day BOD of the influent is 160 mg/l. The value of the adopted organic loading is to be 160 gm/m³/day, and surface loading 2000 l/m²/day. Determine the volume of the filter and its depth.

Solution.

Total 5-day B.O.D. present in sewage

$$= \frac{160 \times 4.5 \times 10^6}{10^3} = 7,20,000\ \text{gm/day}$$

Volume of the filter media required

$$= \frac{\text{Total B.O.D.}}{\text{Organic loading}}$$

$$= \frac{7,20,000\ \text{gm/day}}{160\ \text{gm/m}^3\text{.day}} = \mathbf{4,500\ m^3}$$

Surface area required for the filter

$$= \frac{\text{Total flow}}{\text{Hydraulic loading}}$$

$$= \frac{4.5 \times 10^6\ \text{l/d}}{2000\ \text{l/m}^2\text{.d}} = \frac{4.5 \times 10^6}{2000}\text{m}^2$$

$$= 2250\ \text{m}^2$$

$$\therefore \text{Depth of the bed required} = \frac{4500}{2250}\ \text{m} = \mathbf{2m}.$$

26. A rectangular sedimentation basin is to handle 10 million litres/day of raw water. A detention basin of width to length ratio of 1/3 is proposed to trap all particles larger than 0.04 mm in size. Assuming a Relative density of 2.65 for the particles & 20°C as the average temperature, Compute the basin dimensions? If the depth of tank is 3.5 m. Calculate the Detention time?

Solution.

Settling velocity of particles,

$$V_s = 418d^2(G_s - 1)\left(\frac{3T + 70}{100}\right)$$

$$= 418 \times 0.04^2 \times 1.65\left(\frac{3 \times 20 + 70}{100}\right)$$

$$= 1.435\ \text{mm/sec.}$$

Now, $\frac{V}{V_s} = \frac{L}{H}$,

$\Rightarrow$ $V = V_s \cdot \frac{L}{H} = 1.435\frac{L}{H}$

Given, $L = 3B$

Let detention period = T hours.

$$\text{Capacity of tank} = \frac{10 \times 10^6 \times T}{10^3 \times 24} = 416.67\ \text{m}^3$$

Now $L \times B \times H = 416.67\ T$

or $\frac{60 \times 60 \times 1.435}{1000}\frac{L}{H} \times T \times B \times H = 416.67T$

or $3B^2 = 80.66$

or $B = 5.20$ m

$\therefore$ $L = 3B = 15.60$ m

$$\text{Detention period, } T = \frac{15.60 \times 5.20 \times 3.5}{416.67} \times 60$$

$$= \mathbf{41\ minutes}$$

27. Calculate the diameter required for a single-stage trickling filter which is to yield an effluent BOD_5 of 20 mg/l. When treating settled domestic sewage with a BOD_5 of 120 mg/l. The waste water flow is 2200 m³/day and the recirculation is constant at 4000 m³/day. The filter depth is 1.5m.

Solution.

$$\text{Efficiency of filter} = \frac{100}{120} \times 100 = 83.33\%$$

Now $$\eta\% = \frac{100}{1 + .0044\sqrt{Y/V.F.}}$$

where $$\frac{R}{I} = \text{Recirculation Ratio}$$

$$= \frac{4000}{2200} = 1.818$$

$\therefore$ Recirculation Factor,

$$F = \frac{1 + R/I}{(1 + .1R/I)^2}$$

$$= \frac{1 + 1.818}{(1 + .1 \times 1.818)^2} = 2.02$$

Total BOD applied to Filter,

$$Y = \frac{120 \times 1000 \times 2200}{10^6}$$

$$= 264\ \text{kg/day}$$

$$\therefore \quad 83.33 = \frac{100}{1 + .0044\sqrt{264 / V \times 2.02}}$$

Volume of filter, V = .0632 ha-m = 632.30 m³

Assuming depth of filter as 1.5 m, we have

$$\frac{\pi}{4}d^2 \times 1.5 = 632.30$$

$\therefore$ Diameter of filter, $d = \mathbf{23.20\ m}$

28. Design a circular settling tank unit for a primary treatment of sewage at 12 million litres per day. Assume suitable values of detention period (presuming that trickling filters are to follow the sedimentation tank), and surface loading.

Solution. Assuming the normal detention period for such cases as 2 hr, and surface loading as 40,000 litres/sq. m/day; we have

Quantity of sewage to be treated per 2 hours

$$= 12 \text{ M. litres} \times \frac{2}{24}$$

$$= 1 \text{ M. litres} = 1000 \text{ m}^3$$

$\therefore$ Capacity of tank = 1000 m^3

$$\text{Now, Surface loading} = \frac{Q}{\text{surface area of tank}}$$

$$= \frac{Q}{\pi / \pi.d^2}$$

or $$40{,}000 = \frac{12 \times 10^6}{\pi / 4.d^2}$$

where d = diameter of the tank

or $$\frac{\pi}{4} d^2 = \frac{12 \times 10^6}{40{,}000}$$

or $$d = \sqrt{\frac{300 \times 4}{\pi}} = 19.55 \text{ m}$$

$$\approx \mathbf{19.6\ m}$$

Now, effective depth of tank

$$= \frac{\text{Capacity}}{\text{Area of X-section}}$$

$$= \frac{1000}{\frac{\pi}{4} \times (19.6)^2} = 3.2 \text{ m.}$$

Hence, use a settling tank with 19.6 m dia and 3.2 m water depth. (with free board of 0.3 m extra depth).

29. The colony of an Industrial Estate has population of 2600 persons. The sewage flow is 125 l/c/day. The 5 day BOD of the sewage is 350 ppm. Design the oxidation pond for the treatment of sewage.

Solution. Total flow of sewage/day

$$= 2600 \times 125 = 325000 \text{ litres}$$

$$= 325 \text{ m}^3$$

$$\text{BOD per day} = \frac{350 \times 325}{1000} = 113.75 \text{ kg}$$

Assuming Rate of loading

$$= 300 \text{ kg/hectare/day}$$

Area (surface) of oxidation pond

$$= \frac{113.75}{300} = 0.38 \text{ hectares}$$

$$= 3800 \text{ m}^2$$

Assuming L = 2B

$\therefore$ $2B^2 = 3800$

or B = 43.60 m

$\therefore$ L = 87.20 m

Using pond with effective depth = 1.20 m

Capacity of pond = $87.20 \times 43.60 \times 1.20$

= 4562.3 m^3

Now Detention time = Capacity/sewage flow per day

$$= \frac{4562.3}{324} = 14 \text{ days}$$

Hence Provide an oxidation pond with

L = 87.20 m,

and B = 43.60 m

Detention time = 14 days

depth = 1.2 + 1 = 2.2 m

30. Calculate the dimensions of an oxidation pond and determine the detention time for treating sewage from residential colony in the Southern State with a population of 8000 persons. Assume the sewage to be treated is at the rate of 125 lpcd, the 5 day B.O.D. of sewage is 325 ppm and specific gravity of organic load is one.

Solution.

Population = 8000

Daily flow of sewage 125 l/c/day

$$= \frac{8000 \times 125}{1000} = 1000 \text{ m}^3\text{/day}$$

Total B.O.D. load per day

$$= \frac{325 \times 1000 \times 1000}{10^6}$$

$$= 325 \text{ kg/day}$$

Assuming organic loading

$$= 300 \text{ kg/hectare/day}$$

$$\text{Surface area of pond} = \frac{325}{300} = 1.083 \text{ hact.}$$

$$= 10830 \text{ m}^2$$

Taking L = 2B, we have $2B^2 = 10830$

or B = **73.60 m**

$\therefore$ L = **147.20 m**

Take effective depth = 1.20 m

i.e., Total depth, H = 1.20 + 1

= **2.2 m**

Capacity = daily flow × Detention period

or $147.20 \times 73.60 \times 1.20 = 1000 \times T$

$\therefore$ Detention time, T = **13 days**

31. Estimate the size of a septic tank (length to width ratio 2.25, liquid depth 2 m with 300 mm freeboard), desludging intervals in years, and the total trench area (m^2) of the percolation field, for a small colony of 300 people. Assume water supply of 100 litres per capita per day, waste water flow at 80% of water consumption, sludge production of 0.04 cubic metre per capita per year, and the retention time of 3 days at start up. Desludging is done when the tank is one-third full of sludge. A percolation test indicated an allowable hydraulic loading of 100 L per square metre per day.

Solution.

Given, $\frac{L}{B} = 2.25$, $D_w = 2\text{m}$

Free-board = 0.3 m;

Population = 300;

Water supply = 100 l/c/day;

Waste flow = 80% of water supplied

Sludge production = 0.04 m^3/c/year;

Retention time = 3 days

Using the above data, we have

Water supply to the colony

= 100 l/c/d × 300 persons

= 30,000 L/d

Sewage produced per day

= 80% × 30,000 l/d

= **24,000 l/d**

Sewage produced in 3 days (*i.e.*, during retention period) = 3 × 24,000 l/d = 72,000 L = **72 m^3**

Desludging is done when the tank is filled up to 1/3rd of its capacity (C). Hence, sludge volume collected is C/3.

∴ Capacity, C = Maximum sewage volume retained + sludge volume retained

$$= 72 \text{ m}^3 + \frac{C}{3}$$

or $\frac{2}{3}C = 72 \text{ m}^3$

∴ $C = 72 \times \frac{3}{2} = \mathbf{108 \text{ m}^3}$

Hence, the capacity of the tank = **108m^3**

But $C = L \times B \times D_w$

$= (2.25 \text{ B})(\text{B})(2 \text{ m})$

$= 108 \text{ m}^3$

∴ $B^2 = \frac{108}{4.5} = 24$

or $B = \mathbf{4.9 \text{ m}}$

$L = 2.25 \times 4.9 = \mathbf{11.1 \text{ m}}$ (say)

∴ **Tank size = 11.1 m × 4.9 m × (2 + 0.3 m) depth.**

Sludge volume removed in desludging = $\frac{C}{3} = 36 \text{ m}^3$.

Sludge produced per year

$$= 0.04 \frac{\text{m}^3}{\text{capita year}} \times 300 \text{ persons}$$

= 12 m^3/year capita year

∴ 36 m^3 of sludge will produce in = $\frac{1}{12} \times 36$ years

= 3 years.

∴ **Desludging interval = 3 years.**

Hydraulic loading of percolation trench

= 100 L/m^2/day.

Out flowing sewage per 3 days = 72 m^3.

Out flowing sewage per 1 day

= 24 m^3 = 24,000 L/d.

∴ *Trench area required* = $\frac{24{,}000 \text{ L/d}}{100 \text{ L/m}^2/\text{d}} = \mathbf{240 \text{ m}^2}$

32. Calculate the area of bed required for drying the sludge from the digestion tank for 40,000 population, Assume volume of wet sludge as 44.4 m^3/day. Also design the dimensions of beds.

Solution. The volume of wet sludge from the sewage of 40,000 population was worked out as 44.4 m^3/day. Let it be spread in 22.5 cm thick layer (*i.e.,* between 20 to 30 cm thick layer) on under-drained sand beds, then

Area of beds required = $\frac{44.4}{0.225} \text{ m}^2 = 197.3 \text{ m}^2\text{/day}$

Under tropical Indian conditions, the beds get dried out in about 10 days, and hence taking 2 weeks as average drying time including wet days of rainy season, we can use the same bed = $\frac{52}{2} = 26$ times in an year.

∴ Area of bed required per year

$$= \frac{197.3 \times 365}{26} = 2770 \text{ m}^2$$

Making 100 per cent allowance for space for storage, repairs, and resting of beds, etc., we have

Total area of beds required = 2 × 2770 m^2 = 5540 m^2 = **0.554 hectares.**

Using 15 × 30 m sized beds, we have

Number of beds required = $\frac{5540}{15 \times 30} = 12.3$

Use 14 beds, with size as; Area = $\frac{5540}{14} = 395.7 \text{ m}^2$

Using 15 m width, length = $\frac{395.7}{15} = 26.4$ m.

Hence, use 14 beds, of size 15 m × 26.4 m in plan.

33. Design a septic tank for a hostel having 50 students with probable peak discharge of 63 litres/minute. Assume suitable data.

Solution. Assume, detention period = 24 hours

Quantity of sewage to be handled

$= 63 \times 60 \times 24 = 90720$ l/day

$\therefore$ Capacity of tank = 90720 litres

Now assuming the rate of sludge deposition as 30 litres/capita/year and the cleaning period equal to one year.

Volume of sludge deposited

$= 50 \times 30 = 1500$ litres

Total capacity of tank required

$= 90720 + 1500$

$= 92220$ litres $= 92.22$ m^3

Assuming depth of tank = 2 m

Surface area of tank $= \dfrac{92.22}{2} = 46.11$ m^2

Let $\quad L = 3B$ therefore $3B^2 = 46.11$

or $\quad B = 3.92$ m

$\therefore \quad L = 11.76$ m

Thus size of tank = **11.75 × 3.94 × (2 + 0.3) m**

34. Design a septic tank for a hostel of 250 inmates. Assume average daily sewage flow as 120 litres/capita/day and other data suitably.

Solution. Daily sewage flow = 250 × 120 = 30,000 litres

Assuming rate of accumulation of sludge = 30 litres/capita/year and cleaning interval of one year.

Volume of accumulated sludge

$= 250 \times 30$

$= 7500$ litres

Required capacity of septic tank

$= 30{,}000 + 7500$

$= 37500$ litres $= 37.5$ cum.

Assuming effective depth of tank = 1.2 m

Surface area of tank $= \dfrac{37.5}{1.2} = 31.25$ m^2

Let $\quad L = 3B$.

Thus $\quad 3B^2 = 31.25$

or $\quad B = 3.25$ m

$\therefore \quad L = 9.75$ m

Overall depth of tank = **1.2 + 1.0 = 2.2 m**

35. Design the dimensions of a septic tank for a small colony of 150 persons provided with an assured water supply from the municipal head-works at a rate of 120 litres per person per day. Assume any data, you may need.

Solution.

Quantity of water supplied

= Per capita rate × Population

$= 120 \times 150$ litres/day $= 18{,}000$ *l*/day.

Assuming that 80% of water supplied becomes sewage, we have

Quantity of sewage produced $= 18{,}000 \times 0.8$

$= 14{,}000$ *l*/day.

Assuming the detention time to be 24 hours, we have

Quantity of sewage produced during the detention period (i.e., the capacity of the tank)

$= 14{,}400 \times \dfrac{24}{24} = 14{,}400$ litres.

Now assuming the rate of deposited sludge as 30 litres/capita/year; and also assuming the period of cleaning as 1 year, we have

Volume of sludge deposited

$= 30 \times 150 \times 1 = 4{,}500$ litres.

$\therefore$ Total required capacity of the tank

= Capacity for sewage

+ Capacity for sludge

$= 14{,}400 + 4{,}500$

$= 18{,}900$ litres = **18.9 cu-m.**

Assuming 1.5 m as the depth of the tank, we have

Surface area of the tank $= \dfrac{18.9}{1.5}$ m$^2 = 12.6$ m^2

If the ratio of the length to width is kept as 3 : 1, we have

$3.\ B^2 = 12.6$

or $\quad B = \sqrt{\dfrac{12.6}{3}} = 2.05$ m; **say 2.1 m.**

$\therefore$ Provide width = 2.1m; and

Provide length of the tank = 6 m.

$\therefore$ Area of cross-section provided = 6 × 2.1

= **12.6 m²** (same as required)

Thus, dimensions of the septic tank will be 6 m × 2.1 m × (1.5 + 0.3) m overall depth

Here 0.3 m used as free-board.

Hence, use a tank of size 6 m × 2.1 m × 1.8 m.

36. Design the dimensions of a suitable sedimentation tank for raw supplies from a town of population 100,000 with a daily per capita availability of water of 120 litres. Assume detention period of 6 hours and velocity of flow as 20 cms/minute.

Solution.

Daily water to be treated $= 100{,}000 \times 120$

$= 12 \times 10^6$ litres

Detention period = 6 hours

Volume of water to be treated during detention period of 6-hours

$$= \frac{12 \times 10^6}{24} \times 6 = 3 \times 10^6 \text{ litres}$$

$$= 3000 \text{ m}^3$$

$\therefore$ Capacity of sedimentation tank = 3000 m^3

Length of tank = Velocity of flow × Detention period

$$= 0.20 \times 60 \times 6 = 72 \text{ m}$$

Gross-section area of tank required

$$= \frac{3000}{72} = 41.70 \text{ m}^2$$

Assuming water-depth in the tank = 4.0 m

Width of tank required

$$= \frac{41.70}{4} = 10.42 \text{ say } 10.5 \text{ m}$$

Use a free board of 0.5 m

Overall depth of tank = 4.0 + 0.5 = 4.50 m

Overall size of Rectangular sedimentation tank

$$= \mathbf{72 \times 10.5 \times 4.5 \text{ m}}$$

37. An average operating data for conventional activated sludge treatment plant is as follows:

Waste water flow = 35,000 m^3/day

Volume of aeration tank = 10,900 m^3

Influent BOD = 250 mg/lit

Effluent BOD = 20 mg/lit.

MLSS = 2500 mg/lit

Effluent suspended solids = 30 mg/lit

Waste sewage suspend solids = 9700 mg/lit.

Quantity of waste sludge = 220 m^3/day

Determine

(*i*) Aeration period in hrs.

(*ii*) F/M ratio (a 3 kg BOD per day/kg MLSS)

(*iii*) efficiency of BOD removal

(*iv*) Sludge age in days.

Solution.

Given, $Q = 35000 \text{ m}^3/\text{day}$, $Y_0 = 250$ mg/lit

$V = 10{,}900 \text{ m}^3$, $Y_E = 20$ mg/lit

$X_t = 2500$ mg/lit, $Q_R = 9700$ mg/lit

$X_E = 30$ mg/lit, $Q_w = 220 \text{ m}^3/\text{day}$

(*i*) Aeration Period,

$$t = \frac{V}{Q} \times 24 = \frac{10{,}900}{35{,}000} \times 24$$

$$= 7.47 \text{ Say } 7.5 \text{ hrs.}$$

(*ii*)

$$F = Q.Y_0 = \frac{35{,}000 \times 250}{1000}$$

$$= 8750 \text{ kg/day}$$

$$M = V.X_t = \frac{10{,}900 \times 2500}{1000}$$

$$= 27{,}250 \text{ kg}$$

$$\therefore \quad \text{F/M ratio} = \frac{8750}{27{,}250} = \mathbf{0.32}$$

(*iii*) Efficiency of BOD removal

$$= \frac{\text{Incoming BOD} - \text{Outgoing BOD}}{\text{Incoming BOD}}$$

$$= \frac{250 - 20}{250} \times 100 = \mathbf{92\%}$$

(*iv*) Sludge age,

$$\theta_c = \frac{X_t.V}{Q_w X_R + (Q - Q_w) X_E}$$

$$= \frac{27{,}250}{\frac{(220 \times 9700)}{100} + \frac{(35000 - 220)}{100} \times 30}$$

$$= \frac{27{,}250}{2134 + 1043.4} = \mathbf{8.58 \text{ days.}}$$

DISPOSING OF SEWAGE

38. A city discharges 100 cumecs of sewage into a river, which is fully saturated with oxygen and flowing at the rate of 1500 cumecs during its lean days with a velocity of 0.1 m/sec. The 5 days BOD of sewage at the given temperature is 280 mg/l. Find when and where the critical D.O. deficit will occur in the downstream portion of the river, and what is its amount. Assume coefficient of purification of the stream (f) as 4.0, and coefficient of deoxygenation (k_D) as 0.1.

Solution. Initial D.O. of river = Saturation D.O. at the given temperature = 9.2 mg/l (say)

D.O. of mix at $t = 0$ *i.e.*, at start

$$= \frac{9.2 \times 1500 + 0 \times 100}{1500 + 100}$$

(*assuming that D.O. of sewage is nil*)

$$= 8.62 \text{ mg/l}$$

Initial D.O. deficit of the stream

$$= D_0 = 9.2 - 8.62 = \mathbf{0.58 \text{ mg/l}}$$

Also, 5-day BOD of the mixture of sewage and stream is given by

$$C = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$$

$$= \frac{280 \times 100 + 0 \times 1500}{100 + 1500}$$

$$= \mathbf{17.5 \text{ mg/l}}.$$

$\therefore$ 5 day BOD of mix at the given temperature,

$$Y_5 = 17.5 \text{ mg/l}$$

$$Y_5 = L\left[1-(10)^{-k_D \times 5}\right]$$

and $k_D = 0.1$ (at 20°C)

$\therefore$ Ultimate BOD of the mix (*i.e.*, L)

$$= \frac{17.5}{0.684} = 25.58 \text{ mg/l.}$$

Now, we have

$$\left[\frac{L}{D_c \cdot f}\right]^{f-1} = f\left[1-(f-1)\frac{D_0}{L}\right]$$

or

$$\left[\frac{25.58}{D_c \times 4}\right]^3 = 4\left[1-\frac{3\times 0.58}{25.58}\right]$$

or

$$D_c = \mathbf{4.12 \text{ mg/l.}}$$

Now, we have

$$t_c = \frac{1}{k_D(f-1)}\log_{10}\left[f\left\{1-(f-1)\frac{D_0}{L}\right\}\right]$$

$$= \frac{1}{0.1(4-1)}\log_{10}\left[4\times\left(1-\frac{3\times 0.58}{25.58}\right)\right]$$

$$= \frac{1}{0.3}\times 0.571 = \mathbf{1.905 \text{ days.}}$$

Now,

Distance = Velocity of river × Travel time

= 0.1 m/sec × (1.905 × 24 × 60 × 60 sec)

= 16,460 m = **16.46 m**

Hence, the most critical deficit will occur after 1.905 days and at point 16.46 km downstream of the point of sewage disposal.

39. The treated domestic sewage of a town is to be discharged in a natural stream. Calculate the percentage purification required in the treatment plant with the following data:

Population = 50,000

BOD contribution per capita = 0.07 kg/day

BOD of stream on u/s side = 3 mg/litre

Permissible max. BOD of stream on D/S side = 5 mg/litre

DWF of sewage = 140 litres/capita/day

Minimum flow of stream = 0.13 m^3/sec

Solution.

Total BOD/day = 0.07 × 50,000

= 3500 kg/day

Total flow of sewage/day

= 140 × 50,000

= 7 × 10^6 litres

$$\text{BOD of sewage} = \frac{3500\times 1000\times 1000}{7\times 10^6}$$

$$= 500 \text{ mg/l}$$

$$\text{Flow of sewage} = \frac{7\times 10^6}{10^3\times 24\times 60\times 60}$$

$$= 0.081 \text{ cumec}$$

Now Resultant B.O.D. of mix. required = 5 mg/l

Let B.O.D. of treated sewage = C_s mg/l

$$\therefore \quad 5 = \frac{Q_S C_S + Q_R C_R}{Q_S + Q_R}$$

$$= \frac{0.081\times C_s + .13\times 3}{.081+.13}$$

or $C_s = 8.21$ mg/l

Percentage treatment required

$$= \frac{500-8.21}{500}\times 100$$

$$= \mathbf{98.36\%}$$

40. The following observations were made on a 4 % dilution of waste water

Dissolved oxygen (D.O) of the aerated water used for dilution = 3 mg/l

Dissolved oxygen (D.O) of diluted sample after 5 days incubation = 0.8 mg/l

Dissolved oxygen (D.O) of original sample = 0.6 mg/l

Calculate the BOD of 5 days and ultimate BOD of the sample assuming that the deoxygenation coefficient at test temperature is 0%.

Solution. The 100% content of sample consists of 4% of waste water and 96% of the aerated water used for dilution

D.O. = 0.6 × 0.04 + 3 × 0.96

= 2.904 mg/l

D.O. of diluted sample after 5 days of incubation = 0.8 mg/l

D.O. consumed = 2.904 – 0.8

= 2.104 mg/l

B.O.D. of 5 days = D.O. consumed × Dilution factors

$$= 2.104\times\frac{100}{4} = 52.6 \text{ mg/l}$$

Let ultimate B.O.D., is denoted by L. Therefore

$$Y_5 = L[1-10^{-k_D 5}]$$

or

$$52.6 = L[1-10^{-0.1\times 5}]$$

$$= 0.684 \text{ L}$$

$$\therefore \quad L = 76.9 \text{ mg/l}$$

41. 125 cumecs of sewage of a city is discharged in a perennial river which is fully saturated with oxygen and flows at a minimum rate of 1600 cumecs with a minimum velocity of 0.12 m/sec. If the 5 day BOD of the sewage is 300 mg/l, find out where the critical DO will occur in the river. Assume

(*i*) the coefficient of purification of the river as 4.0,

(*ii*) the coefficient of DO as 0.11; and

(*iii*) the ultimate BOD as 125% of the 5 day BOD of the mixture of sewage and river water.

Solution.

Assume *Saturation D.O. concentration of the given river* D_s = **9.2**.

D.O. of the river at the mixing point after disposal of sewage

$$D = \frac{125 \times 0 + 1600 \times 9.2}{125 + 1600}$$

$= 8.53$ mg/l

Initial D.O. deficit, $D_0 = D_s - D = 9.2 - 8.53$

$= \mathbf{0.67}$ **mg/l.**

BOD_5 of the river at the mixing point after disposal of sewage

$$Y_5 = \frac{125 \times 300 + 1600 \times 0}{125 + 1600}$$

$= \mathbf{21.74}$ **mg/l.**

Ultimate BOD of river (mix) at mixing point

$(L) = 125\%\ BOD_5$

$= 1.25 \times 21.74 = \mathbf{27.17}$ **mg/l.**

Now, we have $BOD_5 = L\,[1 - (10)^{-K_D \times 5}]$

or $21.74 = 27.17\left[1 - (10)^{-K_D \times 5}\right]$

or $0.8 = \left[1 - (10)^{-5K_D}\right]$

or $(10)^{-5k_D} = 0.20$

or $-5k_D \log 10 = \log 0.20$

or $k_D = \mathbf{0.14}$.

Coefficient of DO or BOD (k_D) assumed to be 0.11, as against its value of 0.14 computed above. Under such a difficult situation, we may solve the question by using both the values of k_D *i.e.*, 0.11 as well as 0.14. *The k_D value of 0.14 will, however, give more D.O. deficit and will displace the critical point upstream; and will thus provide more conservative design values*:

Case (1): When k_D = 0.11.

$$t_c = \frac{1}{k_D(f-1)} \log\left[\left\{1 - (f-1)\frac{D_0}{L}\right\} f\right]$$

$$= \frac{1}{0.11(4-1)} \log\left[\left\{1 - (4-1)\frac{0.67}{27.17}\right\} 4\right]$$

$= \mathbf{1.723}$ **days**.

Distance along the river, where the critical D.O. deficit will occur

S = Velocity × Time

$= 0.12$ m/sec × (1.723 × 24 × 3600 sec)

= **17.86 km; say 18 km**

Hence, critical D.O. deficit will occur at 18 km downstream of the sewage disposal point.

Case (2) : When k_D = 0.14

$$t_c = \frac{0.11}{0.14} \times 1.723 = 1.354 \text{ days}$$

$$S = 17.86 \times \frac{1.354}{1.723} = 14.04 \text{ km}$$

Hence, critical D.O. deficit will occur at 14 km downstream of sewage disposal point.

42. 125 cumecs of sewage of a city is discharged in a perennial river which is fully saturated with oxygen and flows at a minimum rate of 1600 cumecs with a minimum velocity of 0.12 m/sec. If the 5-day BOD of sewage is 300 mg/l. Find out where the critical D.O. deficit will occur.

Assume: Co-efficient of purification of river as 4.0, co-efficient of DO is 0.11. Ultimate BOD of the mixture of sewage and river water.

Solution.

Initial D.O. of the river = 9.2 mg/l (at 20°C)

At $t = 0$,

$$\text{D.O. of mixture} = \frac{1600 \times 9.2 + 125 \times 0}{1600 + 125} = 8.53 \text{ mg/l}$$

Initial D.O. deficit,

$$D_0 = 9.2 - 8.53 = 0.67 \text{ mg/l}$$

5-day ROD of mixture of sewage and river water

$$C = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R} = \frac{125 \times 300 + 0 \times 1600}{1725} = 21.74 \text{ mg/L}$$

Ultimate BOD of mixture,

$$L = 21.74 \times 1.25 = 27.17 \text{ mg/L}$$

Now, we have

$$\left(\frac{L}{f D_c}\right)^{f-1} = f\left[1 - \frac{D_0}{L}(f-1)\right]$$

or $$\left(\frac{27.17}{4 \times D_c}\right)^3 = 4\left[1 - \frac{0.67}{27.17}(3)\right]$$

or $D_c = 4.39$ mg/L

Now $$t_c = \frac{1}{k_D(f-1)} \log_{10}\left[f\left\{1 - (f-1)\frac{D_0}{L}\right\}\right]$$

$$= \frac{1}{0.11 \times 3} \log_{10}\left[4\left\{1 - 3 \times \frac{0.67}{27.17}\right\}\right]$$

$= 3.96$ days

$$\text{Distance} = \frac{0.12 \times 60 \times 60 \times 24 \times 3.96}{1000} = \mathbf{41.06 \text{ kms}}$$

43. A city discharges 1500 litres per second of sewage into a stream whose minimum rate of flow is 6000 litres per second. The temperature of sewage as well as water is 20°C. The 5 day B.O.D. at 20°C for sewage is 200 mg/l and that of river water is 1 mg/l. The D.O. content of sewage is zero, and that of the stream is 90% of the saturation D.O. If the minimum D.O. to be maintained in the stream is 4.5 mg/l, find out the degree of sewage treatment, required. Assume the de-oxygenation coefficient as 0.1, and re-oxygenation coefficient as 0.3.

Solution. Value of saturation D.O. at 20.C is 9.17 mg/l.

D.O. content of the stream

$$= 90\% \text{ of the saturation D.O.}$$

$$= \frac{90}{100} \times 9.17 = 8.25 \text{ mg/l}$$

D.O. of mix at the start point (*i.e.*, at $t = 0$)

$$= \frac{8.25 \times 6000 + 0 \times 1500}{6000 + 1500}$$

[*Assuming D.O. of sewage as zero*]

$$= 6.6 \text{ mg/l}$$

$\therefore$ D_0 = initial D.O. deficit

= [Saturation D.O. at mix. temperature – D.O. of mix.]

= 9.17 – 6.6 [*Assume instantaneous mixing*]

= **2.57mg/l**

Minimum D.O. to be maintained in the stream = 4.5 mg/l.

$\therefore$ Maximum permissible saturation deficit (*i.e.*, critical D.O. deficit)

$$D_c = 9.17 - 4.5 = 4.67 \text{ mg/l.}$$

Now, the first stage B.O.D. of mixture of sewage and stream (L) is given by

$$\left[\frac{L}{D_c f}\right]^{f-1} = f\left[1-(f-1)\frac{D_0}{L}\right]$$

where, D_0 = 2.57 mg/l, D_c = 4.67 mg/l

$$f = \frac{k_R}{k_D} = \frac{0.3}{0.1} = 3$$

$$\therefore \quad \left[\frac{L}{4.67 \times 3}\right]^{3-1} = 3\left[1-(3-1)\frac{2.57}{L}\right]$$

$$\text{or} \quad \left[\frac{L}{14.01}\right]^{2} = 3\left[\frac{1-5.14}{L}\right]$$

Solving by hit and trial,

we get $\quad L = 21.1$ mg/l

Now, using the relation,

$$Y_t = L\left[1-10^{-k_D \cdot t}\right]$$

Maximum permissible 5 day B.O.D. of the mix (at 20°C)

$$Y_5 = 21.1\,[1 - 10^{-0.1 \times 5}]$$

(where k_D at 20°C = 0.1)

$$= 14.43 \text{ mg/l.}$$

Now, $\quad C = \dfrac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$

where C stands for concentrations of B.O.D.

$$\therefore \quad 14.43 = \frac{C_S \times 1500 + 1 \times 6000}{1500 + 6000}$$

where C_s = permissible B.O.D.$_5$ (at 20°C of course) of the discharge waste water.

Solving, we get C_s = 68.16 mg/l.

$\therefore$ Degrees of treatment required (per cent)

$$= \frac{\text{Original B.O.D. of sewage} - \text{Permissible B.O.D}}{\text{Original B.O.D}} \times 100$$

$$= \frac{200 - 68.16}{200} \times 100 = \mathbf{65.9\%}.$$

44. A waste water effluent of 560 l/s with a BOD = 50 mg/l, DO = 3.0 mg/l and temperature of 23°C enters a river where the flow is 28 m³/sec, and BOD = 4.0 mg/l, DO = 8.2 mg/l, and temperature of 17°C, k_1 of the waste is 0.10 per day at 20°C. The velocity of water in the river downstream is 0.18 m/s and depth of 1.2 m. After mixing of waste water with the river water, determine, Combined discharge, BOD, DO; and temperature.

Solution.

Particulars of Sewage thrown	Particulars of River
Q_s = 560 l/s = 0.56 m³/sec	Q_R = 28 m³/sec
Concentrations (C_s)	**Concentration (C_R)**
BOD = 50 mg/l	BOD = 4.0 mg/l
DO = 3.0 mg/l	DO= 8.2 mg/l
Temperature = 23°C	Temperature= 17°C

k_1 at 20. = 0.1 per day

Combined discharge

$$= Q_s + Q_R$$

$$= 0.56 + 28 = \mathbf{28.56\ m^3/sec.}$$

Now, for concentration of mix,

$$C = \frac{C_S \cdot Q_S + C_R \cdot Q_R}{Q_S + Q_R}$$

$$\text{BOD of mix} = \frac{50 \times 0.56 + 4.0 \times 28}{0.56 + 28}$$

$$= \frac{140}{28.56} = \mathbf{4.9\ mg/l}$$

$$\text{DO of mix} = \frac{3.0 \times 0.56 + 8.2 \times 28}{0.56 + 28}$$

$$= \mathbf{8.098\ mg/l.}$$

$$\text{Temperature of mix} = \frac{23 \times 0.56 + 17 \times 28}{0.56 + 28}$$

$$= \mathbf{17.12°C}$$

45. An environmental survey for a town with population of 30,000 revealed the following:

Domestic sewage produced at the rate of 240 litres per capita per day.

The per capita BOD of the domestic sewage being 72 g/day.

Industrial wastes produced were estimated as 4 million lit per day with BOD of 1500 mg/l.

The sewage effluents can be discharged into a river with a minimum dry weather flow of 4500 litres/s and a saturation dissolved oxygen content of 7 mg/l. It is necessary to maintain a dissolved oxygen content of 4 mg/l in the stream. For designing a sewage treatment plant, determine the degree of treatment required to be given to the sewage.

Assume:

k_D = Deoxygenation coefficient = 0.1, and

k_R = Reoxygenation coefficient = 0.3

An overall expansion factor of 10% be provided.

Solution. Per capita sewage produced = 240 litres per day

Per capita B.O.D. of domestic sewage = 72 gm/day

BOD per litre of domestic sewage

$$= \frac{72 \times 1000}{240} = 300 \text{ mg/litres}$$

Amount of domestic waste produced per day

= population × 240

= 30,000 × 240

= 7.2×10^6 litres per day

Amount of Industrial waste produced

= 4×10^6 litres/day

B.O.D. of industrial waste = 1500 mg/l

Net B.O.D. of domestic + industrial waste

$$= \frac{[7.2 \times 300 + 4 \times 1500] \times 10^6}{(7.2 + 4) \times 10^6}$$

$$= 728.6 \text{ mg/l}$$

Initial D.O. deficit,

$$D_0 = 0$$

Allowable D.O. deficit,

$$D_c = 7 - 4 = 3 \text{ mg/l}$$

$$\frac{L}{D_c} = (f)^{f/f-1}$$

where, $f = \dfrac{K_R}{K_D} = \dfrac{0.3}{0.1} = 3$

or $\dfrac{L}{3} = (3)^{3/2}$

or $L = 15.6$ mg/l

Q_R = discharge of river

= 4500 litres/s

Discharge of sewage (domestic + industrial) including 10% of expansion

$$Q_s = (7.2 + 4) \times 1.1 \times 10^6 \text{ litres/day}$$

$$= \frac{12.32 \times 10^6}{24 \times 3600} \text{ litres/s}$$

$$= 142.60 \text{ litres/sec.}$$

Permissible concentration. (*i.e.*, B.O.D.) of mixture,

$$C = \frac{C_S Q_S + C_R Q_R}{Q_S + Q_R}$$

or $15.6 = \dfrac{C_S \times 142.6 + 0 \times 4500}{142.6 + 4500}$

or $C_s = 507.9$ mg/l

Which implies that permissible B.O.D. of combined wastes (Domestic + industrial)

= 507.9 mg/l

Actual B.O.D of waste = 728.6 mg/l

Degree of treatment required

$$= \frac{728.6 - 507.9}{728.6} \times 100 = \mathbf{30.3\%}$$

EXERCISE - I

1. The averaging is done for per capita water demand is over a period of time

(*a*) 24 hours (*b*) one year

(*c*) 10 years (*d*) 35 years

2. The multiplying factor, as applied to obtain the peak hourly demand, in relation to the maximum daily demand (per hour) is

(*a*) 1.5 (*b*) 1.8

(*c*) 2.0 (*d*) 2.7

3. If the average daily water consumption of a city is 24000 cum, the peak hourly demand (or the maximum day) will be

(*a*) 1000 cu m/hr (*b*) 1500 cu m/hr

(*c*) 1800 cu m/hr (*d*) 2700 cu m/hr

4. Total water requirement of a city is generally assessed on the basis of

(*a*) maximum hourly demand

(*b*) maximum daily demand + fire demand

(*c*) average daily demand + fire demand

(*d*) greater of (*a*) and (*b*) above

5. Water treatment units may be designed, including 100% reserves, for water demand equal to

(*a*) average daily (*b*) twice of average daily

(*c*) maximum daily (*d*) none of the above

6. Coincident draft in relation to water demand, is based on

(*a*) peak hourly demand

(*b*) maximum daily demand

(*c*) maximum daily + fire demand

(*d*) greater of (*a*) and (*c*) above

7. Distribution system in water supplies, is designed on the basis of

(*a*) average daily demand

(*b*) peak hourly demand

(*c*) coincident draft

(*d*) greater of (*b*) and (*c*) above

8. Suitable method for forecasting population for a young and a rapidly developing city is

(*a*) arithmetic mean method

(*b*) geometric mean method

(*c*) comparative graphical method

(*d*) none of the above

9. The average per capita consumption of water per day in an Indian city is about

(*a*) 135 l (*b*) 300 l

(*c*) 450 l (*d*) 600 l

10. Demand for public use is about .... of the total demand

(*a*) 5% (*b*) 10%

(*c*) 15% (*d*) 20%

11. Industrial and commercial demand accounts for..........of the total demand

(*a*) 40% (*b*) 30%

(*c*) 20% (*d*) 10%

12. $Q = 3.182\sqrt{P}$ is the formula for fire demand furnished by

(*a*) Kuichling

(*b*) Freeman

(*c*) National Board of Fire Protection

13. Water is said to be contaminated, if it contain

(*a*) pathogens

(*b*) undesirable suspended matter, making it unfit for drinking and domestic use

(*c*) dissolved salts

(*d*) none of the above

14. 'Safe water' does not contain

(*a*) pathogenic bacteria

(*b*) turbidit

(*c*) any taste

(*d*) any colour

15. 'Wholesome water' does not contain

(*a*) pathogenic bacteria

(*b*) suspended matter in quantities harmful to man

(*c*) fire and public-use demand

(*d*) all of the above

16. Water demand of a city includes

(*a*) domestic water demand

(*b*) commercial and industrial demand

(*c*) dissolved matter in quantities harmful to man

(*d*) all of the above

17. Industrial and commercial water demand in a city as compared to total demand of city, is

(*a*) 10 to 15% (*b*) 15 to 20%

(*c*) 20 to 25% (*d*) 30 to 40%

18. The fire demand of a city is generally calculated by

(*a*) Under writers formula

(*b*) Freeman formula

(*c*) Kuichling's formula

(*d*) All of the above

19. The per capita consumption of a locality is affected by
(*a*) climatic condition
(*b*) quality of water
(*c*) distribution pressure
(*d*) all of the above

20. Decrease in per capita consumption occurs by
(*a*) use of metering system
(*b*) hot climate
(*c*) good quality water in supplied
(*d*) all of the above

21. Ratio of maximum hourly consumption and average hourly consumption of the maximum day, is
(*a*) 1.2 (*b*) 1.5
(*c*) 1.8 (*d*) 2.7

22. Goodrich's formula, used for determining the ratio of peak demand rates to their corresponding average value, is
(*a*) $P = 120\, t^{-0.10}$ (*b*) $P = 150\, t^{-0.10}$
(*c*) $P = 180\, t^{-0.10}$ (*d*) $P = 270\, t^{-0.10}$
where, P = percent of the annual average draft for the time t in days t =time in days from $\frac{2}{24}$ to 365 days

23. Factor affecting, prediction of future population of a city is
(*a*) Births (*b*) Deaths
(*c*) Migrations (*d*) all of the above

24. If P_n is population estimated after N years, P is present population and I is the average percentage growth, then

$$P_n = P\left(1 + \frac{I}{100}\right) \text{ represents}$$

(*a*) arithmetic increase
(*b*) geometric increase
(*c*) exponential increase
(*d*) none of the above

25. The population growth curve, is
(*a*) straight line curve
(*b*) circular shaped curve
(*c*) S-shaped curve
(*d*) none of the above

26. An ideal population growth curve is called
(*a*) S-shaped curve (*b*) logistic curve
(*c*) geometric curve (*d*) none of the above

27. If the population of a city is 2 lakh, and average water consumption is 200 lpcd, then the capacity of the pipe mains, should be
(*a*) 108 Mld (*b*) 72 Mld
(*c*) 60 Mld (*d*) 40 Mld

28. Based on the cobalt scale, the maximum permissible colour for domestic supplies is
(*a*) 100 (*b*) 50
(*c*) 25 (*d*) 20

29. Permissible hardness of water as per I.S. is
(*a*) 100 ppm (*b*) 150 ppm
(*c*) 250 ppm (*d*) 350 ppm

30. The B-Coli tests is conducted to serve as a
(*a*) very good indicator of pathogenic bacteria
(*b*) very good indicator of acidity
(*c*) very good indicator of alkalinity
(*d*) means of detect turbidity

31. Drinking water will be safe if its biochemical oxygen demand (B.O.D.) is
(*a*) 25 (*b*) 15
(*c*) 10 (*d*) Nil

32. For controlling algae, the chemical usually used is
(*a*) Alum
(*b*) Lime
(*c*) Bleaching powder
(*d*) Copper sulphate

33. The main disadvantage of hard water is
(*a*) Unpleasant colour
(*b*) Unpleasant odour
(*c*) More turbidity
(*d*) Increased soap consumption

34. For Maximum acidity, the pH-value of water should be
(*a*) zero (*b*) 0.1
(*c*) 1.0 (*d*) 1.4

35. Presence of algae in water indicates that the water is
(*a*) hard (*b*) soft
(*c*) acidic (*d*) pure

36. Maximum permissible turbidity for drinking water is
(*a*) 1 to 4 ppm (*b*) 5 to 10 ppm
(*c*) 15 to 20 ppm (*d*) 25 to 30 ppm

37. For public water supply, the maximum permissible limit of nitrates is
(*a*) 250 ppm (*b*) 200 ppm
(*c*) 100 ppm (*d*) zero