ENGI 9601, ENVS 6004

Water Problems – 2

7 – 38)

7 – 39)

7-38) $BOD_5 = 30$ mg/L after wastewater undergoes secondary treatment.

BOD_5 usually refers to results of lab tests conducted at 20°C which is the standard procedure.

$$UBOD = \frac{BOD_t}{(1-e^{-Kt})} = \frac{30 \text{ mg/L}}{(1-e^{-0.4375 \times 5})} = 33.79 \text{ mg/L}.$$

There are two options here. One can assume that at 16°C the UBOD will have the same value. Alternatively, and slightly more accurately, one can use the empirical formula for calculating the UBOD at 16°C. The second option will be used.

$$UBOD_T = UBOD_{20}\left[1 + 0.02(T-20)\right]$$

$$= 33.79\left[1 + (-0.08)\right] = 31.09 \text{ mg/L} = UBOD_{W,16}$$

$$UBOD_m = \frac{UBOD_W Q_W + UBOD_R Q_R}{Q_W + Q_R}$$

$$= \frac{(31.09)(0.1507) + (11.40)(1.08)}{1.2307}$$

$$= \frac{4.685 + 12.312}{1.2307} = 13.81 \text{ mg/L}$$

To travel 15.55 km downstream requires travel time of:

$$\frac{15.55 \text{ km}}{} \; \frac{s}{0.390 \text{ m}} \; \frac{1000 \text{ m}}{\text{km}} \; \frac{\text{day}}{86{,}400 \text{ s}} = 0.4615 \text{ days}.$$

Also needed is D_{MO} calculated previously as 2.85 mg/L

7-38) continued. Find D_m at 2nd town and then DO at 2nd town.

$$D_m = \frac{k_d\ UBOD}{k_r - k_d}\left(e^{-k_d t} - e^{-k_r t}\right) + D_{mo}\, e^{-k_r t}$$

$$= \frac{0.2804\,(13.81)}{0.1924}\left(e^{-0.2804 \times 0.4615} - e^{-0.4728 \times 0.4615}\right) + 2.85\, e^{-0.2182}$$

$$= 20.126\,(0.8786 - 0.8040) + 2.2913 = 3.793 \text{ mg/L.}$$

$$DO = DO_{sat} - D_m = 9.95 - 3.793 = \underline{\underline{6.16 \text{ mg/L}}}$$

> 5.00 mg/L O.K.

Find $DO_{critical}$ from $D_{critical}$ and after t_c.

$$t_c = \frac{1}{k_r - k_d} \ln\left\{\frac{k_r}{k_d}\left[1 - \frac{D_{mo}(k_r - k_d)}{k_d\ UBOD_m}\right]\right\}$$

$$= \frac{1}{0.1924} \ln\left\{\frac{0.4728}{0.2804}\left[1 - \frac{2.85\,(0.1924)}{0.2804\,(13.81)}\right]\right\} = 1.922 \text{ days.}$$

$$D_c = 20.126\left(e^{-0.2804(1.922)} - e^{-0.4728(1.922)}\right) + 2.85\, e^{-0.9087}$$

$$= 20.126\,(0.5834 - 0.4030) + 1.149 = 4.78 \text{ mg/L.}$$

$$DO_c = DO_{sat} - D_c = 9.95 - 4.78 = \underline{\underline{5.17 \text{ mg/L.}}}$$

> 5.00 mg/L O.K.

$$\frac{1.922\ d \times 0.390\ \frac{m}{s} \times 86{,}400\ \frac{s}{d} \times \frac{km}{1000\ m}}{} = \underline{\underline{64.76\ km}}$$

downstream.

7-39)

Wastewater

$Q_w = 1.148\ m^3/s$.
$BOD_{5,15} = 90.0\ mg/L$
$BOD_{u,15}$
$DO = 1.0\ mg/L$
Temp. = $15°C$
k at $20°C, d^{-1} = 0.3685$
s

River

$Q_r = 7.222\ m^3/s$
$BOD_{5,15}$
$BOD_{u,15} = 7.66\ mg/L$
$DO = 6.0\ mg/L$
Temp. = $15°C$

Speed, = 0.3 m/s
Depth, = 2.92 m.
Bed activity, $\eta = 0.100$.
Allowable DO = 5.00 mg/L

What is critical DO of river and how far downstream from discharge of wastewater does it occur?

Since river and wastewater are at 15°C, this will be the temperature of their mixture and all rate constants must be considered at 15°C.

Find UBOD of wastewater: with k at 15°C.

$$UBOD_W = \frac{BOD_t}{(1-e^{-kt})} = \frac{90.0}{(1-e^{-0.1956 \times 5})} = 144.2\ mg/L.$$

$$k_T = k_{20} \times \theta^{T-20} = 0.3685 \times 1.135^{15-20} = 0.1956$$

Find UBOD of mixture.

$$UBOD = \frac{UBOD_W\, Q_W + UBOD_r\, Q_R}{Q_W + Q_R}$$

$$= \frac{144.2\,(1.148) + 7.66\,(7.222)}{1.148 + 7.222}$$

$$= \frac{165.54 + 55.32}{8.368} = 26.39\ mg/L.$$

7-39) continued. Find DO of mixture at time zero

$$DO = \frac{DO_w Q_w + DO_r Q_r}{Q_w + Q_R} = \frac{1.0(1.148) + 6.0(7.222)}{8.368}$$

$$= \frac{1.148 + 43.332}{8.368} = 5.315 \text{ mg/L}.$$

Find initial oxygen deficit of mixture at time zero.

At 15°C, DO_{sat} = 10.15 mg/L.

$$D_{mo} = DO_{sat} - DO_{mo} = 10.15 - 5.315 = 4.835 \text{ mg/L}.$$

Find K_r and k_d at 15°C.

$$K_{d,20} = k + \frac{u}{H}\eta = 0.3685 + \frac{0.3 \text{ m/s}}{2.92}(0.100) = \frac{0.3788}{d}$$

$$K_{r,20} = \frac{3.9\,u^{1/2}}{H^{3/2}} = \frac{3.9(0.3^{1/2})}{2.92^{3/2}} = \frac{2.136}{4.990} = 0.4281\ d^{-1}$$

$$K_{d,15} = K_T = K_{20} \times \theta^{T-20} = 0.3788 \times 1.135^{15-20} = 0.2011\ d^{-1}$$

$$K_{r,15} = K_{20} \times \theta^{T-20} = 0.4281 \times 1.024^{15-20} = 0.3802\ d^{-1}$$

Find critical time in order to find critical oxygen deficit and thus critical oxygen concentration.

$$t_c = \frac{1}{k_r - k_d} \ln\left\{\frac{k_r}{k_d}\left[1 - \frac{D_{mo}(k_r - k_d)}{k_d\ UBOD_m}\right]\right\}$$

$$= \frac{1}{0.3802 - 0.2011} \ln\left\{\frac{0.3802}{0.2011}\left[1 - \frac{4.835(0.3802 - 0.2011)}{0.2011\ (26.39)}\right]\right\}$$

$$= \frac{1}{0.1791} \ln\left\{\frac{0.3802}{0.2011}\left[1 - 0.1631\right]\right\} = 2.56 \text{ days}.$$

7-39) continued

$$D_c = \frac{k_d\, UBOD_m}{k_r - k_d}\left(e^{-k_d t} - e^{-k_r t}\right) + D_{mo}\, e^{-k_r t}$$

$$= \frac{0.2011\,(26.39)}{0.1791}\left(e^{\overset{-0.5148}{-0.2011 \times 2.56}} - e^{\overset{-0.9733}{-0.3802 \times 2.56}}\right) + 4.835^{-0.3778}$$

$$= 29.632\left(0.5976 - 0.3778\right) + 0.5514 = 7.065 \text{ mg/L.}$$

$$DO_c = DO_{sat} - D_c = 10.15 - 7.065 = \underline{\underline{3.085 \text{ mg/L}}}$$

This is $\not>$ 5.00 mg/L and is not acceptable.

River speed is 0.3 m/s and travel distance in 2.56 days is:

$$0.3\ \frac{m}{s} \times 86{,}400\ \frac{s}{d} \times 2.56 \text{ days} = 66{,}355 \text{ m or } \underline{66.36 \text{ km}}$$

downstream discharge