Sample Questions Agricultural and Biological Engineering Examination

III. Process Engineering

III.A. Biological and chemical kinetics (e.g., rates, yields)

Water-soluble vitamins begin to leach from fish food pellets upon contact with pond water. The level of pantothenic acid (vitamin B_5) in pellets is estimated to be reduced at a rate of 40% for every 30 seconds in pond water. Assuming initial pantothenic acid level is 80 mg/kg dry food, the maximum time allowable (seconds) between spreading pellets upon the pond surface and consumption by fish before pantothenic acid level drops below 18 mg/kg dry food is most nearly:

(A) 2.9
(B) 49
(C) 88
(D) 130

Correct answer (C)

Reference: *Transport Processes and Separation Process Principles* by Geankoplis

Leaching of water-soluble vitamins into water as presented is recognized as a first-order decay/destruction/loss reaction and that each unit time period is 30 s in length. Therefore, *k* and allowable time can be determined using:

$$\ln\frac{C_0}{C} = kt$$

where C_0 is initial concentration, C is concentration at t, t is time period and k is reaction velocity constant.

Calculating k at t = 1 30-s period with C_0 = 80 mg/kg dry food and C = 48 mg/kg dry food (i.e., 100% - 40% or 60% of 80 mg/kg dry food after one time period).

$$k = \frac{\ln\frac{80}{48}}{1} = 0.511\ time\ period^{-1}$$

$$t = \frac{\ln\frac{80}{18}}{0.511} = 2.92\ time\ periods$$

allowable time = 2.92 time periods × (30 s/time period) = 88 s

III. B. Biological transformation (e.g., fermentation, biofiltration, nitrification, denitrification)

Locally-produced ethanol is being considered as a carbon-source replacement for currently-used methanol in a biological nitrogen removal (denitrification) system that processes 5,000 gal/day (18,950 L/day) of water containing a maximum nitrate (NO_3-N) level of 25 mg/L.

The respective specific denitrification rate (SDNR in *mg* NO_3*-N/mg VSS·day*) relationships, shown below, for use of methanol and ethanol in the system are assumed applicable:

$$SDNR_T = 0.0738(1.11)^{(T-20)} \qquad \text{methanol}$$

$$SDNR_T = 0.161(1.13)^{(T-20)} \qquad \text{ethanol}$$

where T is temperature (°*C*) and VSS is volatile suspended solids.

When operation of the system occurs at 12°C using 150 mg VSS/L for denitrification, the difference in time (*days*) to reach an effluent NO_3-N level of 10 mg/L when using ethanol versus when using methanol is most nearly:

A) 3.1
B) 2.5
C) 1.5
D) 0.3

Solution

Correct answer (C)

Reference: *Wastewater Engineering: Treatment and Reuse*, 5th ed. Tchobanoglous et al. McGraw-Hill 2013

Denitrification with either carbon source will remove 15 (25-10) mg NO_3-N/L. Given that VSS level is targeted at 150 mg/L, then denitrification removes 0.1 (15/150) mg NO_3-N/mg VSS.

Operating at 12°C, then denitrification rates are found as:

$$\text{MeOH } SDNR_T = 0.0738(1.11)^{(12-20)} = 0.0738 \times 0.434 = 0.032\ mgNO_3 - N/mgVSS \cdot day$$

$$\text{EtOH } SDNR_T = 0.161(1.13)^{(12-20)} = 0.161 \times 0.376 = 0.061\ mgNO_3 - N/mgVSS \cdot day$$

Time needed for system to denitrify using either carbon source can be found by dividing nitrate/VSS value by respective SDNR value. Doing such finds times of:

$$\text{MeOH } Time = \frac{0.1\dfrac{mgNO_3 - N}{mgVSS}}{0.032\dfrac{mgNO_3 - N}{mgVSS \cdot day}} = 3.1\ days$$

$$\text{EtOH } Time = \frac{0.1\dfrac{mgNO_3 - N}{mgVSS}}{0.061\dfrac{mgNO_3 - N}{mgVSS \cdot day}} = 1.6\ days$$

Difference in time between when system is using ethanol versus when system is using methanol is 1.5 (3.1-1.6) days.

III.C. Bulk solids characterization (e.g., angle of repose, constitutive relationships, coefficient of friction, density)

A building with an 8-foot high wall is storing grain. Grain was placed into the storage building and leveled until it was within 6 inches of the top of the wall. Assuming lateral-to-pressure ratio (*k*) = 0.5, grain bulk density is 56 lb_m/bu, the lateral force per unit length (lb_f/ft) at the base of the wall is most nearly:

(A) 1,270
(B) 790

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(C) 720
(D) 630

Correct answer (D)

Reference: *ASABE Standards* EP545 Loads exerted by free-flowing grain on shallow storage structures

Using Eq. 6 from Section 5.9.1 and recognizing β = 0 since grain has been leveled,

$$P_H = L(H)\left(\frac{H}{2}\right) = L(z)\left(\frac{H}{2}\right) = kV(z)\left(\frac{H}{2}\right) = kWG(z)\left(\frac{H}{2}\right)$$

where *k* = 0.5 = lateral-to-pressure ratio, *W* = 56 lb_m/bu, *H* = 8 ft – 0.5 ft = 7.5 ft, and *z* = 7.5 ft down from top of grain to base of wall, so:

$$P_H = (0.5)\left(\frac{56\ lb_m}{bu}\right)\left(\frac{1\ bu}{1.244\ ft^3}\right)\left(\frac{1\ lb_f}{1\ lb_m}\right)(7.5\ ft)\left(\frac{7.5\ ft}{2}\right) = 633\ {}^{lb_f}\!/_{ft}$$

III.E. Physical and chemical properties of biological materials (e.g., rheology, thermal properties, electrical properties, optical properties, corrosion, mixability, contamination,compatibility, water activity, D-value)

Aeration of stored soybeans at 9% moisture (wet basis) begins and uses air at 10°C (dry bulb) and 80% relative humidity. If aeration is continued until equilibrium moisture content is reached, the moisture content (% wet basis) of the soybeans will:

(A) remain the same
(B) decrease
(C) vary depending on air velocity
(D) increase

Correct answer (D)

Reference: *ASABE Standards* ASAE Standard D245.5

Solution:

Soybeans as a biological material will reach an equilibrium state between relative humidity of storage air and bean moisture content. The equilibrium relationship has been empirically described visually using a graphical isotherm such as seen in Figure 8 from ASAE Standard D245.5 and mathematically described using an expression such as the Modified Halsey equation, Modified Chung-Pfost equation, Modified Henderson equation, or GAB equation. Reading off moisture content (% wet basis) on Figure 8 at 10°C (dry bulb) and 80% relative humidity finds a value of ≈16%. Using a rewritten expression such as the Modified Halsey equation for USA soybeans using A, B, and C values of 2.87, -0.0054, and 1.38, respectively, as given in Table 2 of ASAE Standard D245.5, finds:

$$\%MC_D = \left[\frac{-e^{(A+[B\times T])}}{\ln RH}\right]^{\frac{1}{C}} = \left[\frac{-e^{(2.87+[-0.0054\times 10])}}{\ln 0.8}\right]^{\frac{1}{1.38}} = 22.8\%$$

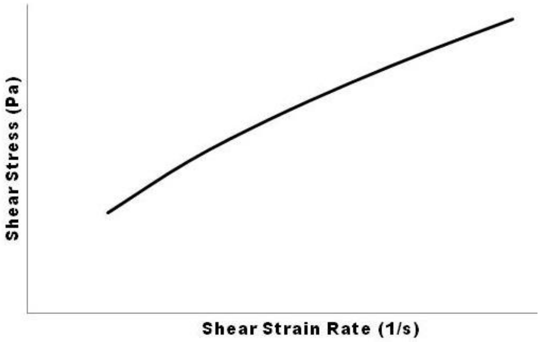
$$\%MC_W = \frac{\%MC_D}{100\% + \%MC_D} = 18.6\%$$

Additionally, by referencing Table 1c, under Soybeans in the D245.5 standard and noting that at 80%RH of 10 °C air results in an EMC above the initial moisture content of the soybeans indicating the beans gain moisture. Therefore, moisture content of soybeans will increase over time as aeration continues and equilibrium is reached regardless of air velocity.

III.E. Physical and chemical properties of biological materials (e.g., rheology, thermal properties, electrical properties, optical properties, corrosion, mixability, contamination,compatibility, water activity, D-value)

Swine manure with 13% total solids at 25°C has a density of 1,045 kg/m^3, a consistency coefficient of 3.9 Pa·s^n, a flow behavior index of 0.6, and no yield stress. Assuming the properties described above and shear stresses observed over the range of shear strain rates depicted in the figure, which term below best describes the rheological behavior of the manure?

(A) Newtonian
(B) Bingham
(C) Pseudoplastic
(D) Dilatant



Correct answer (C)

Reference: *Principles of Process Engineering* by Henderson, Perry, and Young or *Transport Processes and Separation Process Principles* by Geankoplis

Recognize flow behavior index (i.e., *b* value as denoted by Henderson, Perry, and Young) is less than 1, which describes a pseudoplastic fluid, or comparing given curve to curve in Figure 2.5 of Henderson, Perry, and Young 1997 (note Figure 2.5 axes are switched from convention used in many other references) or Figure 3.5.1 of Geankoplis 2003, which is denoted for pseudoplastic fluids.

III.H. Fuel characteristics (e.g., energy values, products of combustion, emissions, storage, efficiency)

A 3,500 lb vehicle is annually driven 10,000 miles and averages 15 mpg. Assume a gasoline density of 5.8 lb/gal and that gasoline is 85% carbon by weight. An estimate of the annual carbon dioxide emissions (lb CO_2/yr) is most nearly:

(A) 3,300

(B) 7,700
(C) 8,800
(D) 12,100

Solution
Correct answer (D)
References: *Engine and Tractor Power,* 4th ed., by Goering and Hansen, p.115, table 6.1
Periodic Table

Carbon (C) atomic mass units – 12 g/g-mole or 12 lb/lb-mole
Oxygen (O) atomic mass units – 16 g/g-mole or 16 lb/lb-mole
Carbon dioxide (CO_2) atomic mass units – 44 g/g-mole or 44 lb/lb-mole

$$\frac{10{,}000\ \frac{mi}{yr}}{15\ \frac{mi}{gal\ gas}} \times \frac{5.8\ lb\ gas}{gal\ gas} \times \frac{0.85\ lb\ carbon}{lb\ gas} \times \frac{44\ \frac{lb\ carbon\ dixoide}{lb - mole}}{12\ \frac{lb\ carbon}{lb - mole}} = 12{,}051\ \frac{lb\ carbon\ dioxide}{yr}$$

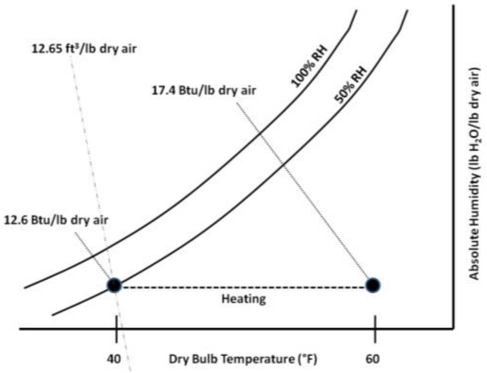
III.I. Applied psychrometric processes (e.g., grain drying, livestock environments, dehydration, crop water use, evaporation)

A gas-fired batch dryer is to be used for drying barley. Drying air is blown directly into a cavity below a perforated floor in the dryer and then forced upward through the barley kernels as they rest on the perforated floor. Assuming outside air conditions during the drying period are 40°F (dry bulb) and 50% relative humidity, and outdoor air is blown in at a rate of 1,000 ft^3/min, an estimate of the sensible heat (Btu/min) that must be added to the outside air to raise the temperature of the drying air to 60°F (dry bulb) is most nearly:

(A) 380
(B) 1,000
(C) 1,375
(D) 4,800

Correct answer (A)
Reference: *Principles of Process Engineering* by Henderson, Perry, and Young.

Solved with the aid of a psychrometric chart by recognizing energy per time (P) needed is found by multiplying change in enthalpy (Δh) of air-water mixture by air flowrate (m_{dot}). Relevant state points are shown in chart below.



$V_{\text{air in}}$ = 12.65 $\text{ft}^3/\text{lb}_{\text{da}}$

m_{dot} = mass flow air = $Q/V_{\text{air in}}$ = (1,000 ft^3/min)/(12.65 $\text{ft}^3/\text{lb}_{\text{da}}$) = 79 lb_{da}/min

h_1 = 12.6 $\text{BTU}/\text{lb}_{\text{da}}$

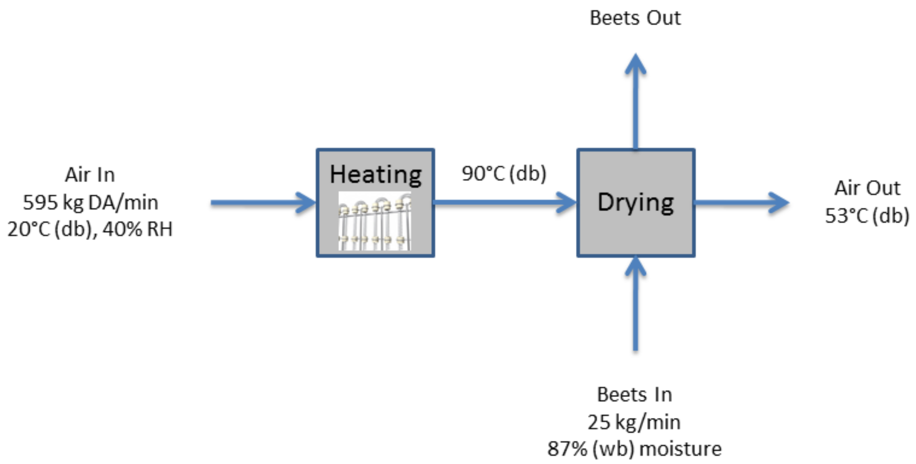
h_2 = 17.4 $\text{BTU}/\text{lb}_{\text{da}}$

Δh = 4.8 $\text{BTU}/\text{lb}_{\text{da}}$

P = $m_{\text{dot}} \times \Delta h$ = 79 lb_{da}/min × 4.8 $\text{BTU}/\text{lb}_{\text{da}}$ = 379 BTU/min

III.I. Applied Psychrometric Processes (e.g., grain drying, livestock environments, dehydration, crop water use, evaporation)

Twenty-five kilograms per minute of 87% moisture content (wet basis) diced beets are dried in a concurrent flow, single-pass tunnel dryer on a conveyor belt. Outside air at 20°C (dry bulb) and 40% relative humidity is heated to 90°C in a preheater using a resistance element before being passed over the beets. An intake fan delivers 500 m^3/min (595 kg/min) of outside air to the preheater while exhaust air exits the dryer at 53°C (dry bulb). Assuming steady-state conditions at any point within the dryer and no heat losses from the dryer to the environment except for the exiting beets and air stream, the moisture content (% wet basis) of the exiting beets is most nearly:

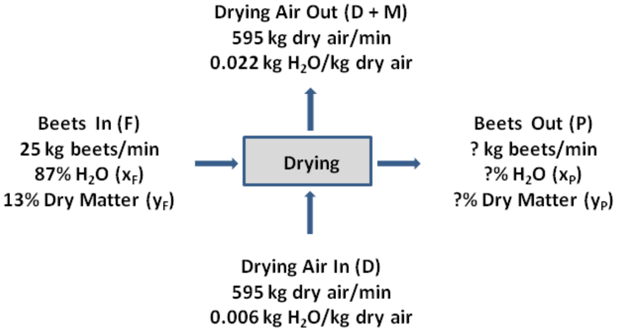


(A) 49
(B) 55
(C) 73
(D) 79

Correct answer (D)

Reference: *Transport Processes and Separation Process Principles* by Geankoplis

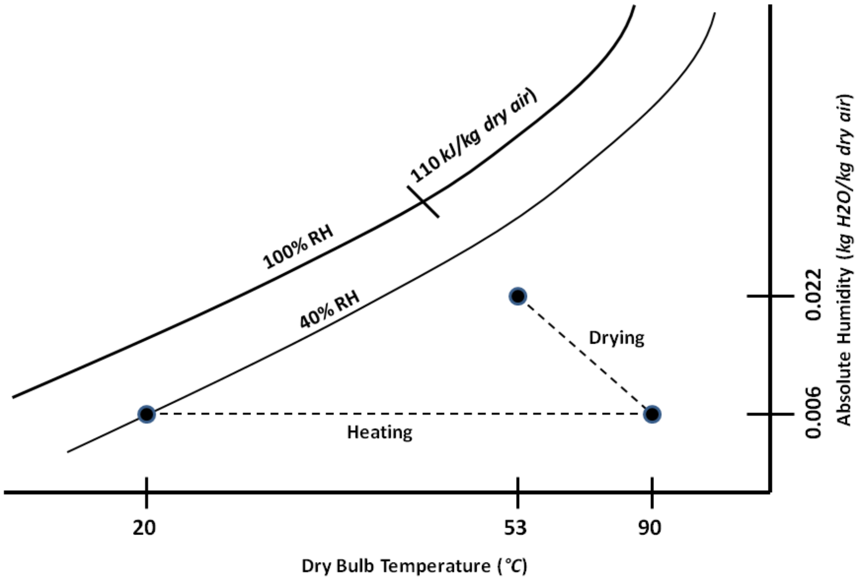
Using a high-temperature, SI-unit psychrometric chart, the air heating (enthalpy increase with no moisture change) and subsequent drying (adiabatic humidification and cooling) processes are sketched on the chart as depicted below to find relevant state conditions. Additionally, a mass balance around the drying process indicates moisture gain/min (M) by the drying air has to equal moisture loss/min from the beets (F – P). Dry matter (non-water) mass in the beets will remain constant ($Fy_F = Py_P$).



Moisture gain (kg H_2O/kg dry air) by drying air = 0.022 – 0.006 = 0.016 kg H_2O/kg dry air

Moisture gain (kg H_2O/min) by drying air = M = 0.016 kg H_2O/kg dry air × 595 kg dry air/min = 9.52 kg H_2O/min

Dry matter flow rate (kg dry matter/min) in beets entering/exiting dryer = $Fy_F = Py_P = 25$ kg beets/min × 0.13 kg dry matter/kg beets = 3.25 kg dry matter/min
Moisture loss rate (kg H_2O/min) from beets = F – P = M = 9.52 kg H_2O/min



Initial moisture mass flow rate (kg H_2O/min) in beets entering dryer = Fx_F = 25 kg beets/min × 0.87 kg H_2O/kg beets = 21.75 kg H_2O/min
Final moisture mass flow rate (kg H_2O/min) in beets exiting dryer= Px_P = 21.75 kg H_2O/min – 9.52 kg H_2O/min = 12.23 kg H_2O/min

$$\%MC_W = \frac{Px_P}{Px_P + Py_P} \times 100\% = \frac{12.23}{12.23 + 3.25} \times 100\% = 79\%$$

III.I. Applied Psychrometric Processes (e.g., grain drying, livestock environments, dehydration, crop water use, evaporation)

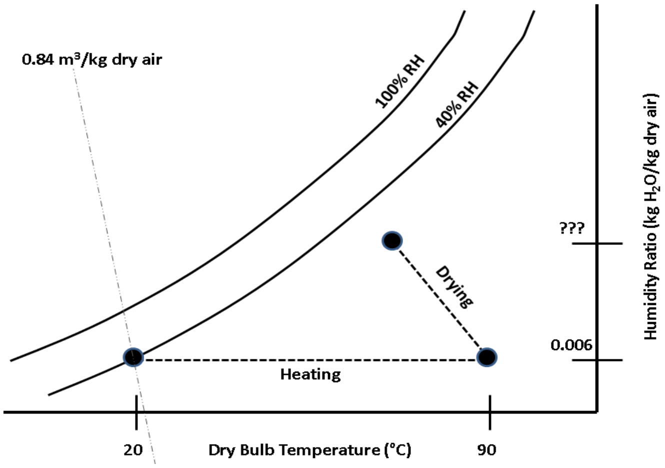
Water, at a rate of 86.2 kg/min, is being removed from shiitake mushrooms as they dry in a tunnel dryer. An intake fan brings in 50 m^3/sec of outside air at 20°C (dry bulb) and 40% relative humidity for heating to 90°C (dry bulb) in a pre-heater, and then passing over the mushrooms. Assuming steady-state conditions at any point within the dryer and no heat losses from the dryer to the environment except through the exiting mushrooms and air stream, the humidity ratio of the air (kg water/kg dry air) exiting the dryer is most nearly:

(A) 0.006
(B) 0.024
(C) 0.030
(D) 0.040

Correct answer (C)

Reference: *Principles of Process Engineering* by Henderson, Perry, and Young or *Transport Processes and Separation Process Principles* by Geankoplis

Recognize that entering air has an initial humidity ratio (i.e., dry basis moisture content) which will increase as water is added from the drying mushrooms as the air passes through the dryer. The initial humidity ratio (0.006 kg water/kg dry air) and specific volume (0.84 m^3/kg dry air) of the air can be found using a psychrometric chart as depicted below.



Moisture is coming off the mushrooms at a rate of 86.2 kg water/min and mixing with air moving at a rate of

[(50 m^3/sec × 60 sec/min) ÷ 0.84 m^3/kg dry air] = 3571 kg dry air/min.

$$0.006\frac{\text{kg water}}{\text{kg dry air}}+\frac{86.2\frac{\text{kg water}}{\text{min}}}{3571\frac{\text{kg dry air}}{\text{min}}}=0.030\frac{\text{kg water}}{\text{kg dry air}}$$

III.J. Mass Balances

A biomass gasification facility is taking in 2 ton/hr of 42% moisture content (wet basis) switchgrass to gasify. Removal rate (lb/hr) of residual ash from the gasifier to balance with incoming ash in the biomass is most nearly:

Elemental Analysis (% wt, dry basis) of Different Biomass Fuel Sources

Biomass	C	H	O	N	S	Ash
Bagasse (sugarcane)	44.8	5.3	39.6	0.38	0.01	9.8
Barley straw	45.7	6.1	38.3	0.4	0.1	6
Cotton stalk	43.6	5.8	43.9	-	-	6.7

Corn grain	44.0	6.1	47.2	1.2	0.14	1.3
Corn stover	43.7	5.6	43.3	0.61	0.01	6.3
Rice straw	41.8	4.6	36.6	0.7	0.08	15.9
Switchgrass	47.5	5.8	42.4	0.74	0.08	3.5
Wheat straw	43.2	5.0	39.4	0.61	0.11	11.4

(A) 810
(B) 140
(C) 80
(D) 40

Correct answer (C)
References: *Introduction to Environmental Engineering* by Davis and Cornwell, and *Transport Processes and Separation Process Principles* by Geankoplis

Ash removal rate has to equal ash input rate. Ash input rate can be found by multiplying ash content of dry biomass by dry biomass input rate.

2 tons per hour of wet switchgrass × 2,000 lb/ton = 4,000 lb/h of wet switchgrass

4,000 lb wet switchgrass/h × (1 – 0.42) lb dry switchgrass/lb wet switchgrass =
2,320 lb dry switchgrass/h

2,320 lb dry switchgrass/h × 0.035 lb ash/lb dry switchgrass = 81 lb ash/h

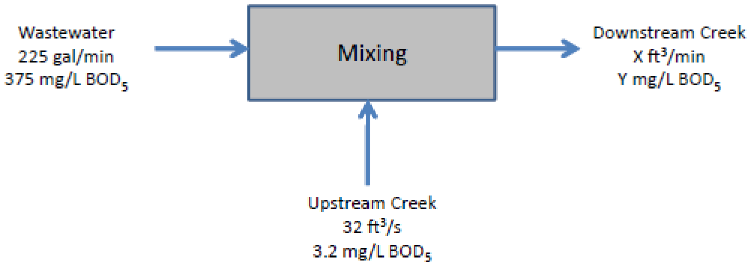
III.J. Mass Balances

A break in a retaining wall has occurred and allows wastewater to enter a nearby creek at the rate of 225 gpm. The BOD_5 concentration of the wastewater is 375 mg/L. The upstream creek flow is at 32 cfs with a BOD_5 concentration of 3.2 mg/L. The BOD_5 (mg/L) in the downstream creek after the wastewater enters the upstream flow and thoroughly mixes is most nearly:

(A) 9
(B) 42
(C) 183
(D) 378

Correct answer (A)
Reference: “Principles of Process Engineering” 4th edition, S.M.Henderson, R.L.Perry, and J.H.Young. 1997 ASAE. Ch.2 “Fluid Mechanics: Basic Considerations” p.11-15 – has good coverage of “**conservation of mass**” and “**conservation of energy**.”

Recognize *mass in = mass out* but no need to convert volume to mass since density of all flows is essentially the same (i.e., all are dilute water where $\rho \approx 62.4\ lb_m/ft^3$).



Total mass (volume) balance

$$(225 \text{ gal/min} \div 7.481 \text{ gal/ft}^3) + (32 \text{ ft}^3\text{/s} \times 60 \text{ s/min}) = X$$

$$X = 30 + 1{,}920 = 1{,}950 \text{ ft}^3\text{/min}$$

BOD_5 mass balance

$$[(375 \text{ mg/L} \times 30 \text{ ft}^3\text{/min}) + (3.2 \text{ mg/L} \times 1{,}920 \text{ ft}^3\text{/min}) = (X \times Y)] \times 28.316 \text{ L/ft}^3$$

$$Y = (11{,}280 + 6{,}144) \div 1{,}950 = 8.9 \text{ mg/L}$$