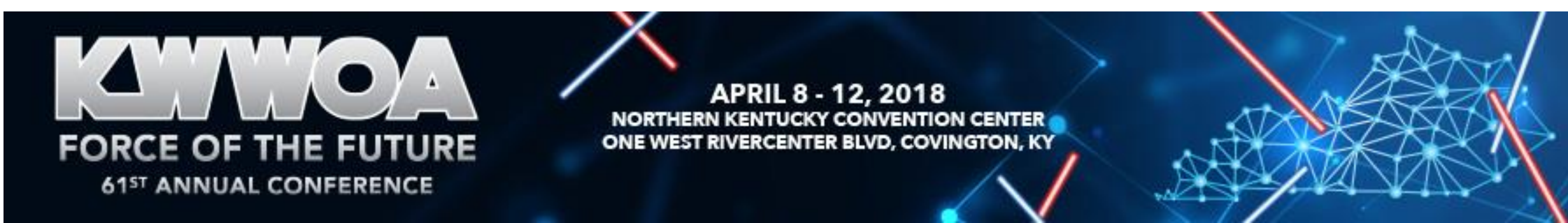
Hazen

KWWOA
Kentucky Water & Wastewater Operators Association

Math is Your Friend: Math Basics

April 11, 2018



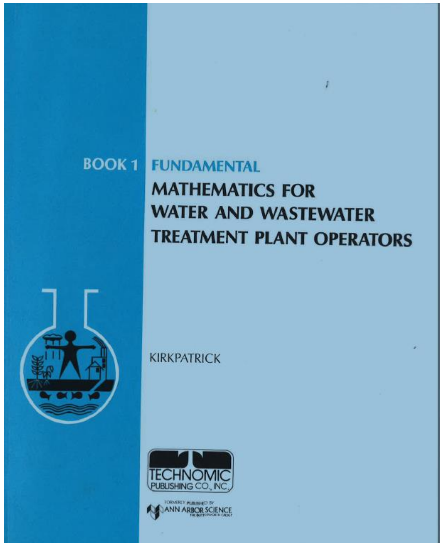
Agenda

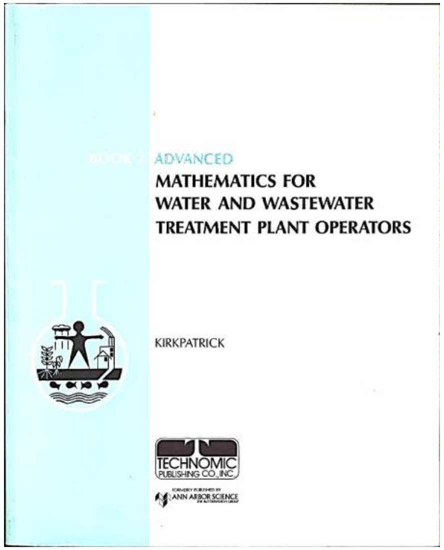
- Math Basics
  - pH as a function of decimal logarithm
  - Gallons to Pounds
  - Cubic Feet to Gallons
  - Average and Weighted Average
  - Cubic Feet to Pounds
  - Area of Square
  - Area to Volume to Weight
  - Flow Conversions
  - Area of Triangle and Circle
  - Volume of Basic Shapes

Expected Learning Outcomes

- Attendees will be given fundamental math skills for water and wastewater operators.
- Attendees will be provided basic skills for applying arithmetic functions.
- Attendees will be provided basic skills as a foundation to more advanced process control concepts and calculations.

Introduction





- Basic math skill training is using Joanne Kirkpatrick's training manuals.
- Joanne was a "training officer" with the State Water Resources Board – Sacramento, California.
- Now she is Joanne Kirkpatrick Price and her current publications are available from Amazon.

https://www.amazon.com/Joanne-Kirkpatrick-Price/e/B001KIRFJA

pH and the pH scale (from YSI Website)

- The term "pH" originates from Latin and is an acronym for "potentia hydrogenii" - the power of hydrogen. The pH scale is commonly used to represent hydrogen ion activity.
- On the pH scale, pH values below 7 represent acidic solutions (hydrogen ion activity greater than hydroxide ion activity) while values above 7 represent basic solutions. At pH = 7, hydrogen ion and hydroxide ion activity are equal (Table 1).

pH using the decimal point (from YSI website)

Table 1: Hydrogen ion and hydroxide ion activities on the pH scale

	pH	H+ Activity		OH- activity
	0	1.E+00	1	0.00000000000001
	1	1.E-01	0.1	0.0000000000001
	2	1.E-02	0.01	0.000000000001
acid	**3**	1.E-03	0.001	0.00000000001
	4	1.E-04	0.0001	0.0000000001
	5	1.E-05	0.00001	0.000000001
	6	1.E-06	0.000001	0.00000001
neutral	**7**	**1.E-07**	**0.0000001**	**0.0000001**
	8	1.E-08	0.00000001	0.000001
	9	1.E-09	0.000000001	0.00001
	10	1.E-10	0.0000000001	0.0001
base	**11**	1.E-11	0.00000000001	0.001
	12	1.E-12	0.000000000001	0.01
	13	1.E-13	0.0000000000001	0.1
	14	1.E-14	0.00000000000001	1

Gallons to Pounds

Applying decimals

Example 2: (Multiplication of Decimal Numbers)

200.9 gallons of wastewater enter a tank in 1 minute. How many lbs of wastewater enter the tank in 1 minute?*

When we are converting gallons of wastewater to lbs of wastewater, we are moving from a smaller number (gal) to a larger number (lbs). Therefore multiplication by 8.34 is indicated:

(200.9 gal) (8.34) = 1675.506 lbs

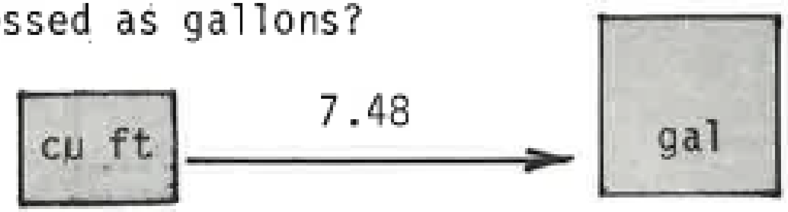
- 200.9: 1 Decimal Place Represented
- 8.34: 2 Decimal Places Represented
- 1675.506: TOTAL of 3 Decimal Places Represented

Cubic Feet to Gallons

Applying decimals

Example 3: (Multiplication of Decimal Numbers)

A particular tank has a capacity of 80,000 cubic feet. What is this volume expressed as gallons?



When we are converting cubic feet of volume to gallon volume, we are moving from a smaller number (cu ft) to a larger number (gal). Therefore multiplication by 7.48 is indicated:

(80,000. cu ft) (7.48) = 598,400.00

0 Decimal Places Represented

2 Decimal Places Represented

TOTAL of 2 Decimal Places Represented

Average

Arithmetic Mean

A. Arithmetic Mean

The arithmetic mean is the most commonly used measurement of average value, and most mathematical calculations of average are associated with the arithmetic mean rather than the median or mode average.

When evaluating information based on averages, we must keep in mind that the "average" reflects the general nature of the group and does not necessarily reflect any one element of that group.

The arithmetic mean is calculated as follows:

$$\frac{\text{Total of All Samples}}{\text{Number of Samples}}$$

Example 1: (Arithmetic Mean)

For the primary influent flow, the following composite-sampled suspended solids concentrations were recorded for the week: Monday-320 mg/l; Tuesday-317 mg/l; Wednesday-308 mg/l; Thursday-313 mg/l; Friday-325 mg/l; Saturday-316 mg/l; and Sunday-310 mg/l. What was the average daily suspended solids concentration?

1. Monday----------	320 mg/l SS
2. Tuesday----------	317 mg/l SS
3. Wednesday--------	308 mg/l SS
4. Thursday---------	313 mg/l SS
5. Friday-----------	325 mg/l SS
6. Saturday---------	316 mg/l SS
7. Sunday-----------	310 mg/l SS
TOTAL	2209 mg/l SS

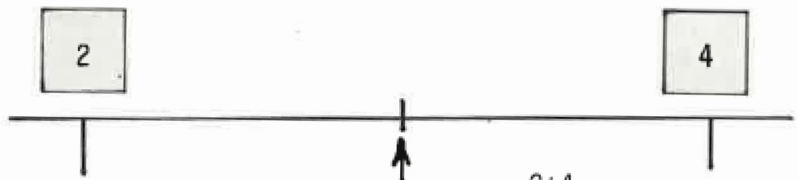
$$\text{Arithmetic Mean} = \frac{\text{Total of All Samples}}{\text{Number of Samples}}$$

Weighted Average

Weighting the average greatest frequency of numbers

SAMPLE: 2,4

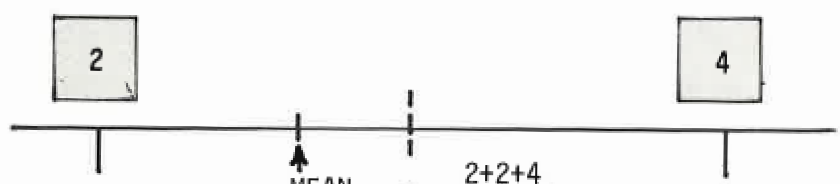
As long as each number occurs only once, they are considered to be weighted equally (1:1 ratio of frequency).



$$\text{MEAN} = \frac{2+4}{2} = \frac{6}{2} = 3$$

SAMPLE: 2,2,4

Now the number 2 is represented twice. This should have the effect of weighting the average toward the "2 end" of the spectrum. 2 is now twice as "heavy" in terms of the number of times it occurs (2:1 ratio of frequency).



$$\text{MEAN} = \frac{2+2+4}{3} = \frac{8}{3} = 2\frac{2}{3}$$

Weighted Average

Combining flow streams

Weighted average by flow & concentration:

40 MGD Effluent @ 10 mg/L BOD_5

80 MGD Stream Flow @ 3 mg/L BOD_5

40 MGD * 10 mg/L = 400 mg/L MGD

80 MGD * 3 mg/L = 240 mg/L MGD

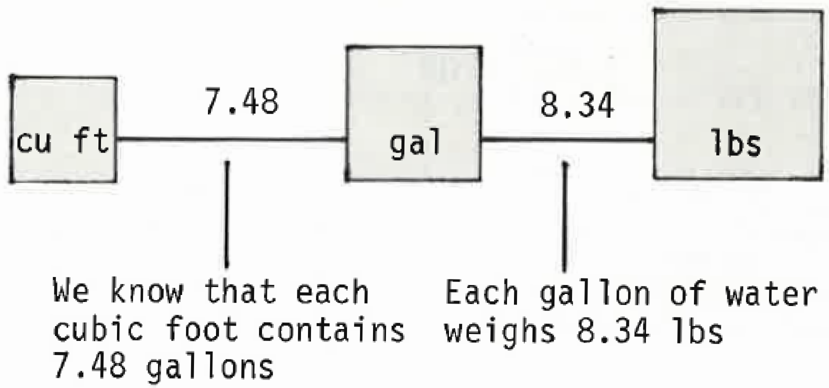
$$\frac{400 \text{ mg/L MGD} + 240 \text{ mg/L MGD}}{40 \text{ MGD} + 80 \text{ MGD}} = \frac{640 \text{ mg/L MGD}}{120 \text{ MGD}}$$

= 5.3 mg/L

Conversions: Cubic Feet to Pounds

A. Cubic Feet to Pounds Conversions*

The relationship among cu ft, gal and lbs may be expressed by diagram:**



Assuming water temperature at 20 degrees C

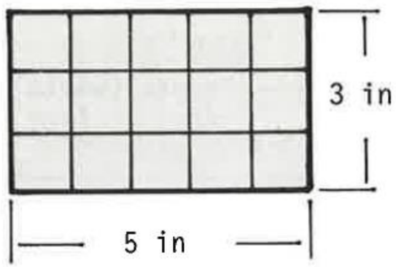
Specific Gravity is 1. The density of a substance compared to a liquid (water). Less than 1, floats, more than 1 sinks.

1 cf of water weighs 62.38 lbs (7.48 * 8.34)

Area of Square/Rectangle

Length x Width

Example 1: (Area of a Rectangle)

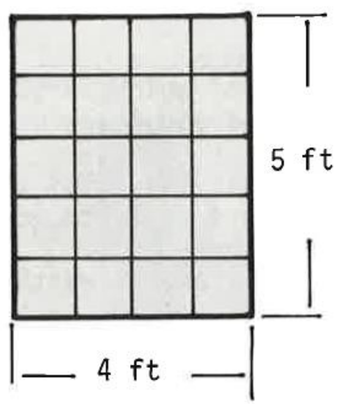


Area Rectangle = (length)(width) inches inches

= (5") (3")

= **15 sq in Surface Area**

Example 2: (Area of a Rectangle)



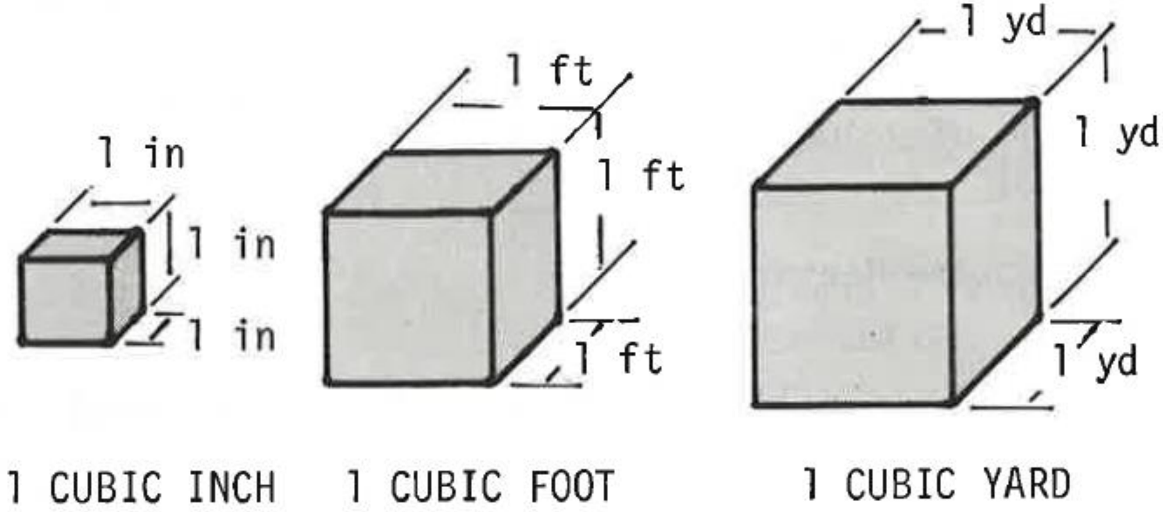
Area Rectangle = (length)(width) feet feet

= (4') (5')

= **20 sq ft Surface Area**

Area to Volume to Weight

Weight of 1 cf of water



Volume adds a third dimension to area (height)

1 cubic ft of water weighs 62.38 pounds

Area of cubic foot is 12 inches x 12 inches = 144 square inches.

Each square inch has 0.433 pounds of pressure.

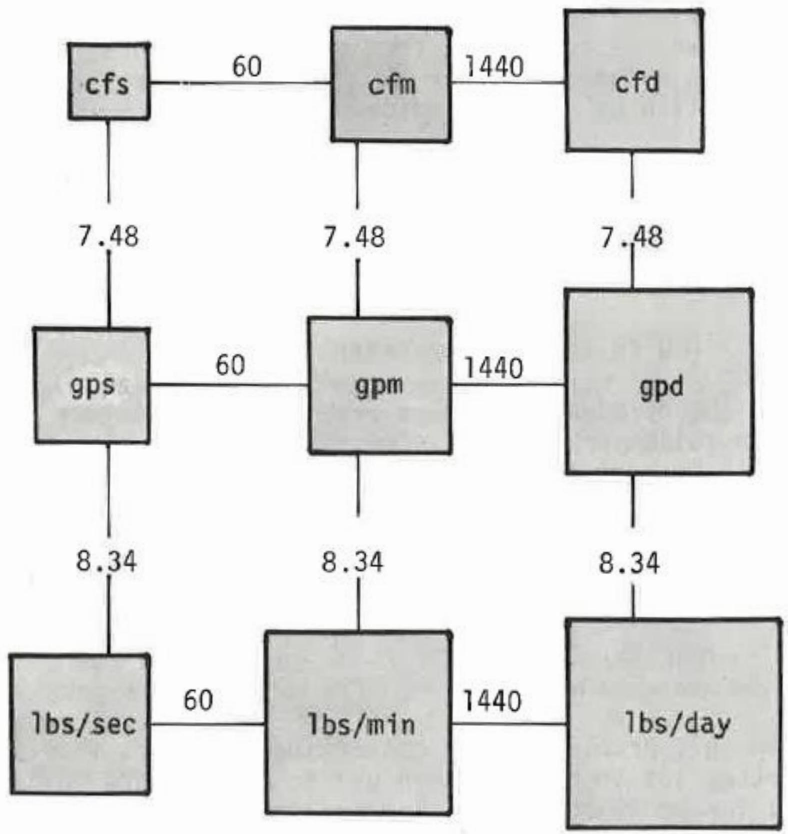
62.38 lbs / 144 square inches = 0.433 psi

Flow Conversions

Units of Flow by Diagram

B. Flow Conversions*

The relationship among the various wastewater flow units may be shown by diagram:



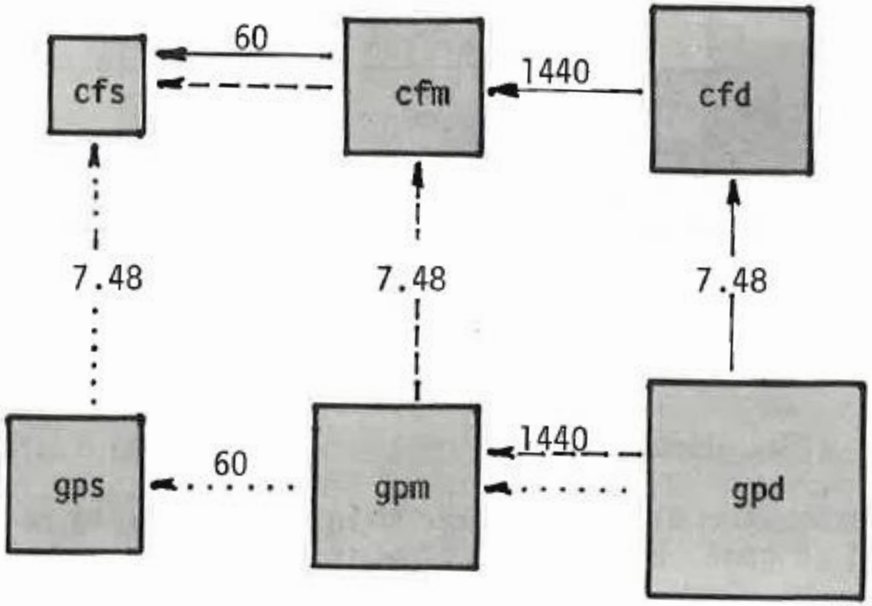
cfs	=	cubic feet per second	gps	=	gallons per second
cfm	=	cubic feet per minute	gpm	=	gallons per minute
cfd	=	cubic feet per day	gpd	=	gallons per day

Flow Conversions

GPD to CFS

Example 2: (Flow Conversions)

The flow to a grit chamber is 2,450,000 gpd. At this rate, what is the average cfs flow?



There are three possible paths from gpd to cfs. In each case we are moving from a larger box to a smaller box, thus indicating division by 7.48, 1440 and 60 (in any order):

Area of a Triangle

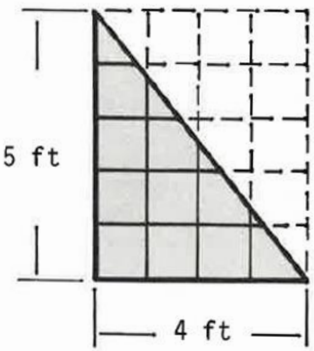
B. Area of a Triangle*

$$\boxed{\text{Area of Triangle}} = \boxed{\frac{(\text{length})(\text{width})}{2}} \quad \boxed{\frac{(\text{base})(\text{height})}{2}}$$

Often the equation using base and height is given rather than the (length)(width) equation because the height of the triangle MUST BE MEASURED VERTICALLY FROM THE HORIZONTAL BASE.

Only the actual length of ONE SIDE of a triangle is of importance. It is chosen as the base, it is rotated to the horizontal position and the height of the triangle is then measured vertically from that base.

Example 1: (Area of a Triangle)

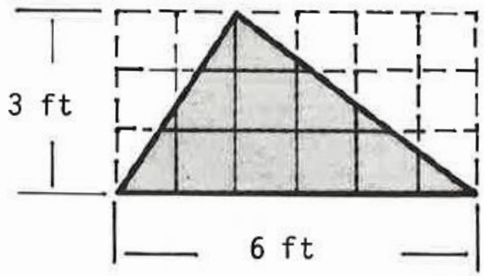


$$\text{Area of Triangle} = \frac{(\text{base})(\text{height})}{2}$$

$$= \frac{(4')(5')}{2}$$

$$= \boxed{\text{10 sq ft Surface Area}}$$

Example 2: (Area of a Triangle)



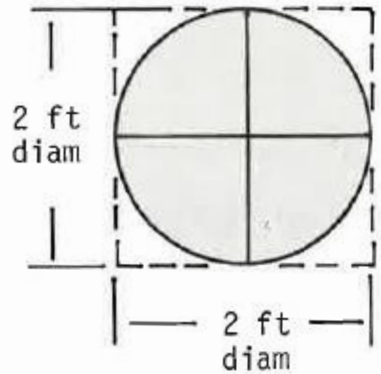
$$\text{Area of Triangle} = \frac{(\text{base})(\text{height})}{2}$$

$$= \frac{(6')(3')}{2}$$

$$= \boxed{\text{9 sq ft Surface Area}}$$

Area of Circle

Using Diameter

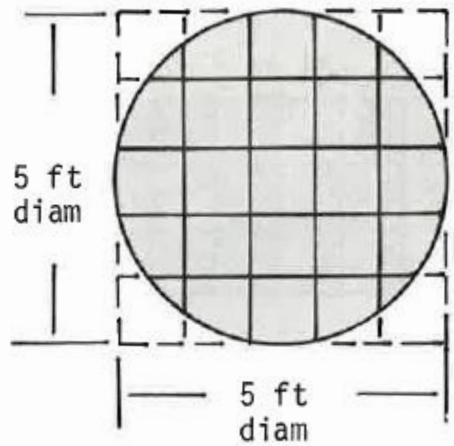


When a circle with a 2 ft diameter is inscribed in the 2 ft square, it is clear that the surface area of the circle is less than that of the square (4 sq ft surface area.)

Area of Circle = (.785)(Area of the Square)

It is not necessary to construct a square around each circle to be calculated. Mathematically the $(\text{diameter})^2$ of the equation represents that square. Thus, in finding the area of the circle, .785 is essential to the equation, as it is only this factor which differentiates the circle from a square.

Example 1: (Area of a Circle)



Area of Circle $= .785\ D^2$

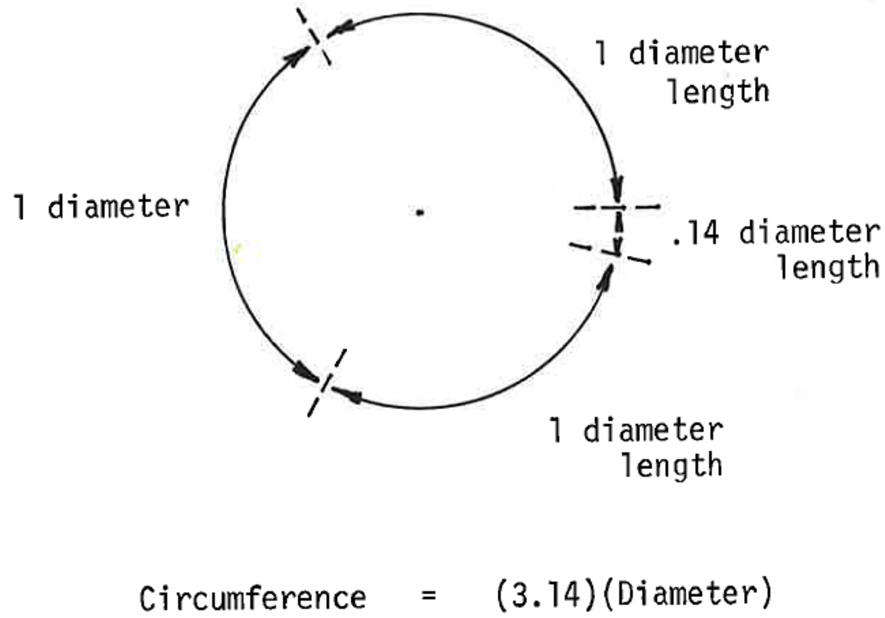
$= (.785)(5')(5')$

$= (.785)(25\text{ sq ft})$

$= 19.6$ sq ft Surface Area

Area of Circle

Using Radius



$$A = \pi r^2$$

Pi is rounded to 3.14 for our session

Radius is ½ of the diameter

Area of 7 ft diameter circle is:

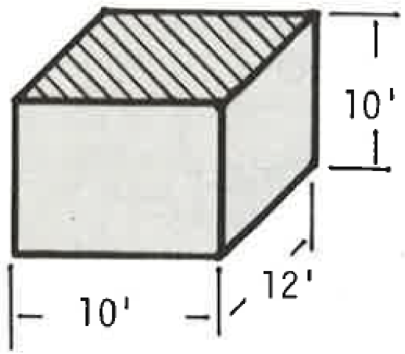
(3.14) * (3.5 ft) * (3.5 ft) = 38.5 sf

(0.785) * (7 ft) * (7 ft) = 38.5 sf

Rectangle Representative Surface

Volume of Tank

Example 1: (Volume Measurement)



Volume = Area of Surface x third dimension

The rectangle is the representative surface.

In this case the dimension not used in the area calculation is the depth.

Volume = (12')(10')(10')

= (120 sq ft) x (10')

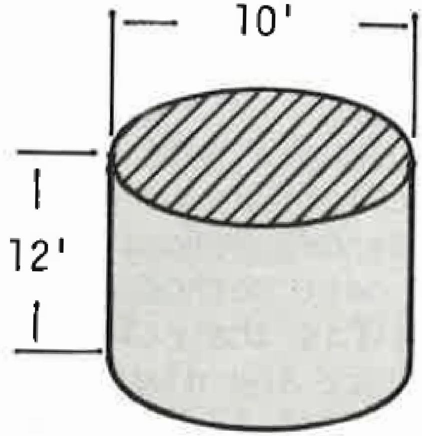
= 1200 cu ft VOLUME

Circle Representative Surface

Volume of Cylinder

Example 3: (Volume Measurement)

Volume = Area of Surface x third dimension



The circle is the representative surface. — depth

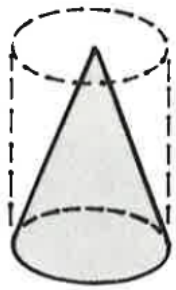
= (.785 D^2) x 12'

= (.785) (10') (10') (12')

= 942 cu ft VOLUME

Circle Representative Surface

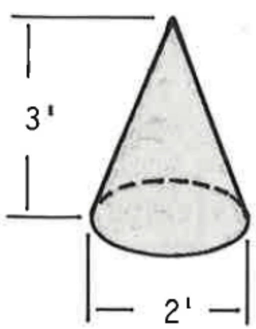
Volume of a Cone



We already know how to calculate the volume of a cylinder. The volume of a cone represents 1/3 of that volume. This concept will be easier to remember if we associate some diagram with that concept such as shown to the left.

<u>Example 4:</u> (Volume Measurement)

Calculate the volume of the cone whose dimensions are shown on the diagram.



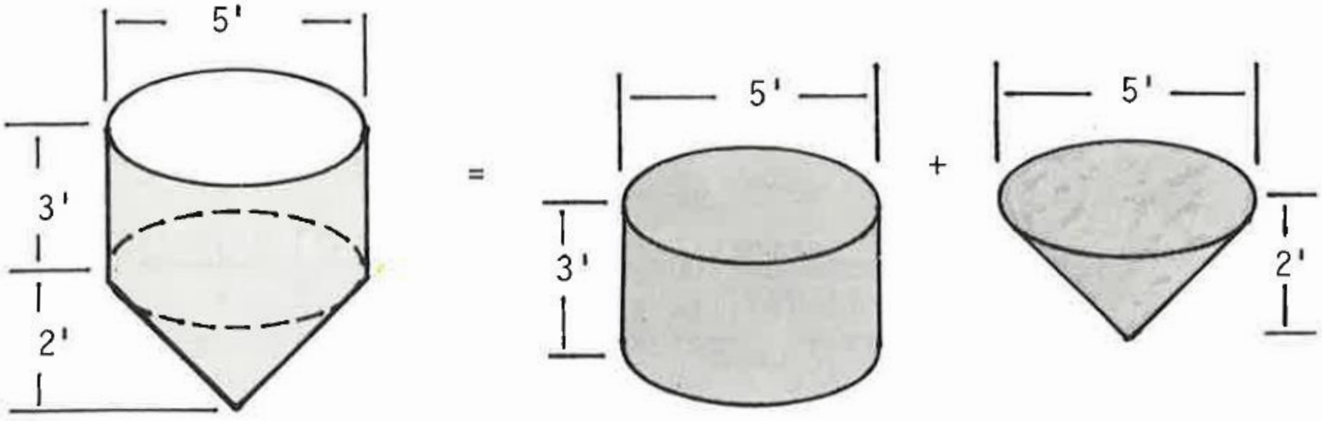
Volume of a Cone = (.33)(Volume of the Cylinder)

= (.33)(.785)(2')(2')(3')

= **3.1 cu ft VOLUME**

Circle Representative Surface

Combine Cylinder and Cone for Tank Volume



TOTAL VOLUME OF THE TANK = Volume of the Cylinder + Volume of the Cone

$$= (.785)(D^2)(\text{depth}) + \frac{(.785)(D^2)(\text{height})}{3}$$

$$= (.785)(5')(5')(3') + \frac{(.785)(5')(5')(2')}{3}$$

$$= 58.9 \text{ cu ft} + 13.1 \text{ cu ft}$$

= **72 cu ft TOTAL VOLUME**

Hazen

KWWOA
KENTUCKY WATER & WASTEWATER OPERATORS ASSOCIATION

Math is Your Friend: Aeration Process Concepts and Math Calculations

April 11, 2018

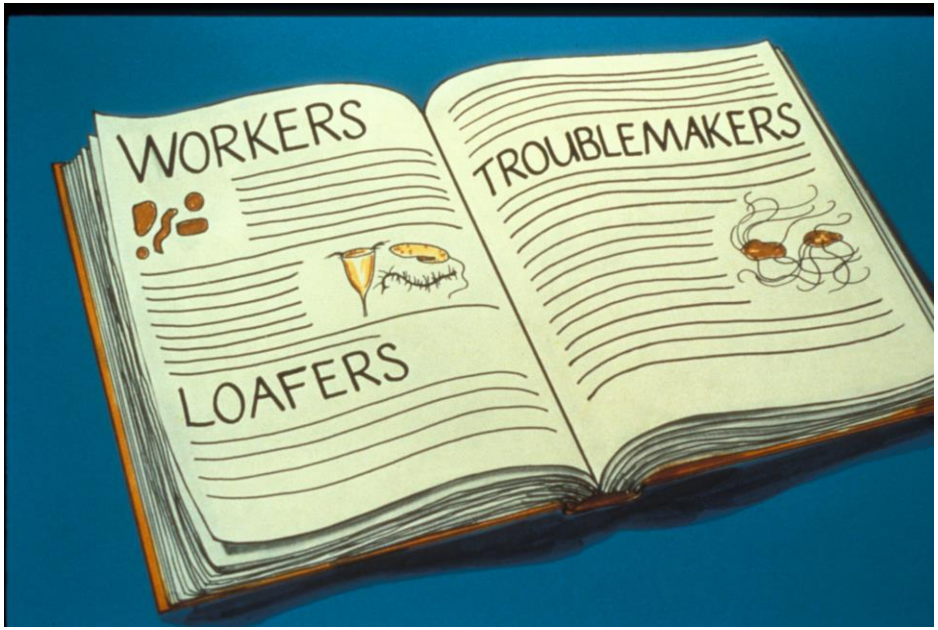
Expected Learning Outcomes

- Attendees will be review math skills for wastewater operators to control a secondary treatment aeration process.
- Attendees will review applying arithmetic functions for process control performance insight.
- Attendees will be provided more advanced process control concepts and calculations.

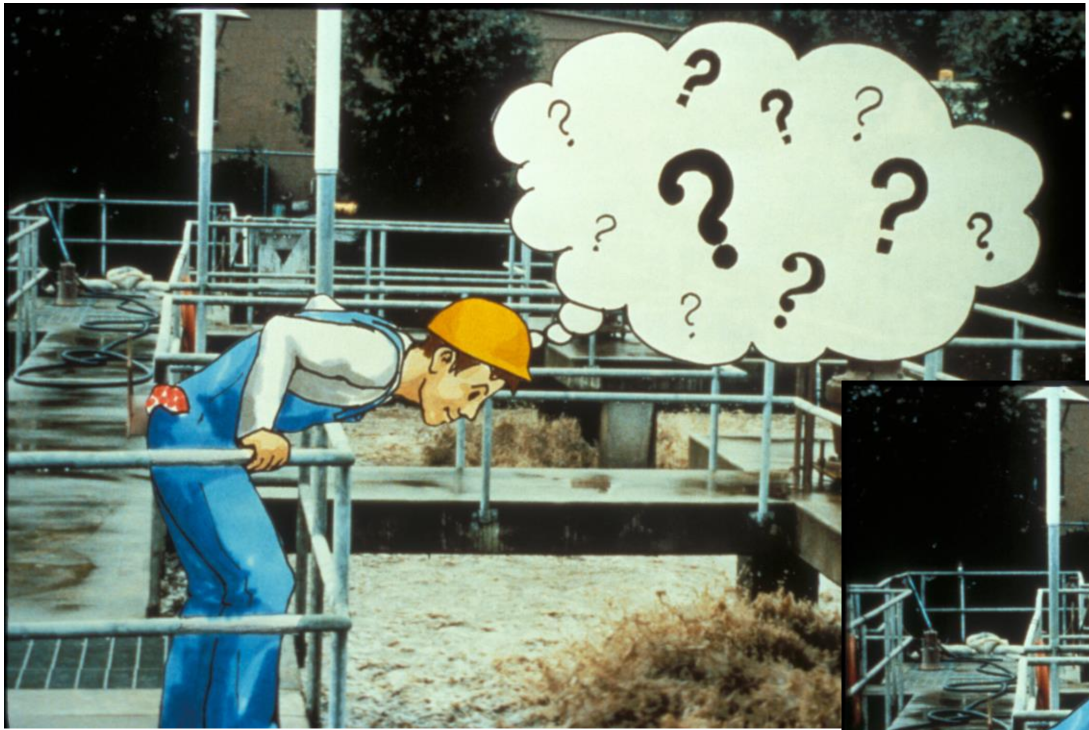
Agenda

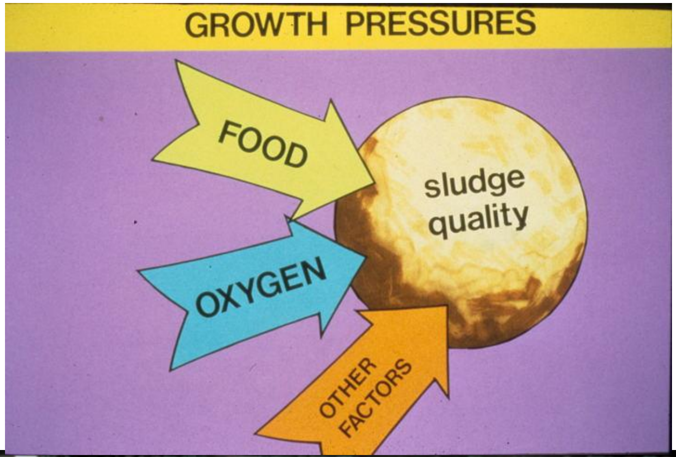
Aeration Process Calculations:

- SVI
- Solids Inventory
- Mean Cell Residence Time
- Aerobic SRT
- Gallons to WAS using MCRT
- Organic Loading Rate
- F/M Ratio
- Detention Time
- Treatment Time



Aeration Process Calculations





Sludge Quality

Sludge Volume Index

An example of a SVI calculation. Assume a MLSS concentration of 2,600 mg/L and, during a settleometer test, the sludge settled to 230 ml/L after 30 minutes. SVI determined in aeration.

SVI CALCULATION

Data required:

a. 30-min settleable solids, 230 ml/L
b. MLSS concentration, 2,600 mg/L

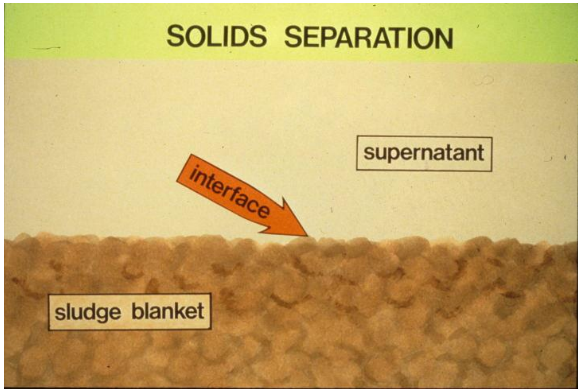
Formula:

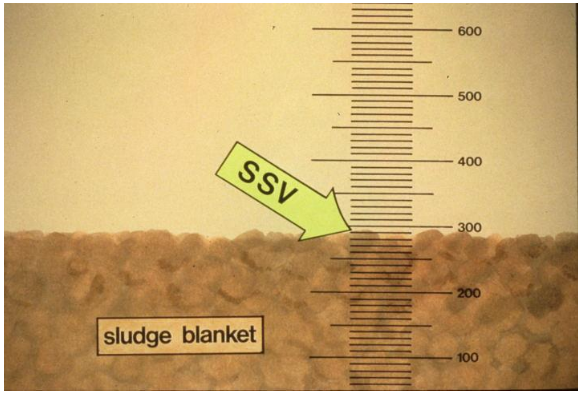
$$SVI = \frac{\text{30-min settleable solids, mL/L x 1000 mg/g}}{\text{MLSS, mg/L}}$$

Solution:

$$SVI = \frac{\text{230 mL/L x 1000 mg/g}}{\text{2,600 mg/L}}$$

$$= \textbf{88} \text{ mls/gm}$$





Solids Inventory

Biological Solids in Aeration and Clarification

SOLIDS INVENTORY CALCULATION, POUNDS

Data required:

a. Volume of the Aeration, V_{aer} = 8.915188 MG
b. MLSS, 2,600 mg/L
c. RAS_{ss}, 5,500 mg/L
d. Total blanket depth, Clarifiers 1-6; $DOB_{1\text{-}6}$ = 9 feet
e. Clarifier volume per foot, V_{clr} = 0.0992 MG

Formula:

S.I. = (V_{aer}, MG x MLVSS, mg/L x 8.34 lbs/gal) +
[$DOB_{1\text{-}6}$ x $V_{1\text{-}6}$ x (MLSS + RAS_{ss})/2 x 8.34 lbs/gal]

Solution:

S.I. = (8.915188 x 2,600 x 8.34) + [9 x .0992 x ((2,600 + 5,500)/2) x 8.34]

S.I. = 223,473 lbs MLSS

Mean Cell Residence Time

Solids in Secondary Treatment divided by wasted and effluent (if significant)

MEAN CELL RESIDENCE TIME (MCRT) CALCULATION

Data required:

a. Volume of the Aeration, V_{aer} = 8.915188 MG
b. MLSS, 2,600 mg/L
c. RAS_{ss}/WAS_{ss}, 5,500 mg/L
d. Total blanket depth, Clarifiers; DOB = 9 feet
e. Clarifier volume per foot, V = 0.0992 MG
h. Effluent TSS concentration, 10 mg/L
i. WAS flow, Q_{WAS}, 0.304 MGD
j. Plant flow, Q_{INF}, 33 MGD

Formula:

$$MCRT = \frac{\text{lbs of solids in secondary treatment}}{\text{lbs/day of solids wasted and lost in the effluent}}$$

Mean Cell Residence Time

Solids in Secondary Treatment divided by wasted and effluent (if significant)

Formula:

$$\text{MCRT} = \frac{\text{lbs of solids in secondary treatment}}{\text{lbs/day of solids wasted and lost in the effluent}}$$

$$\text{MCRT} = \frac{\text{Solids Inventory, Total Solids Pounds (calculated previously)}}{(Q_{WAS},\ \text{MGD x WAS, mg/L x 8.34 lbs/gal}) + (Q_{INF},\ \text{MGD x Eff TSS, mg/L x 8.34 lbs/gal})}$$

Solution:

$$\text{MCRT} = \frac{\text{223,473 lbs Total Solids}\ldots\ldots\ldots}{(\text{0.304 MGD x 5,500 mg/L x 8.34 lbs/gal}) + (\text{33 MGD x 10 mg/L x 8.34 lbs/gal})}$$

$$= \frac{\text{223,473 lbs/day}}{\text{13,944 lbs/day + 2,752 lbs/day}}$$

$$= \textbf{13.4 days}$$

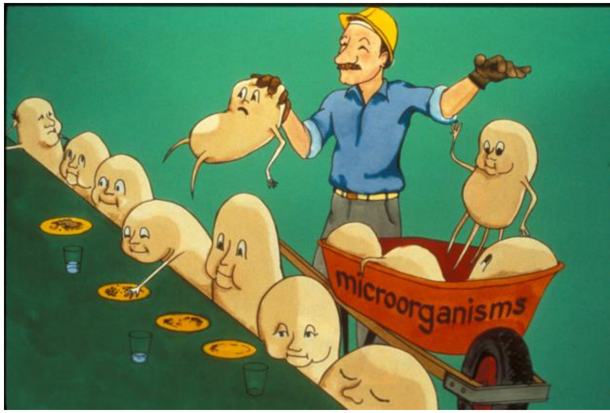
Aerobic SRT

Aerobic portion (aeration) of Secondary Treatment divided by Solids Lost/Wasted

AEROBIC SRT

Data required:

a. Volume of the Aeration, V_{aer} = 8.915188 MG
b. MLSS, 2,600 mg/L
c. RAS_{ss}/WAS_{ss}, 5,500 mg/L
h. Effluent TSS concentration, 10 mg/L
i. WAS flow, Q_{WAS}, 0.304 MGD
j. Plant flow, Q_{INF}, 33 MGD



Formula:

$$SRT = \frac{\text{lbs of solids in aeration}}{\text{lbs/day of solids wasted and lost in the effluent}}$$

$$SRT = \frac{V_{aer} \text{ x MLSS, mg/L x 8.34 lbs/gal}}{(Q_{WAS}\text{, MGD x WAS, mg/L x 8.34 lbs/gal}) + (Q_{INF}\text{, MGD x Eff TSS, mg/L x 8.34 lbs/gal})}$$

Solution:

$$MCRT = \frac{(8.915188 \text{ MG x 2,600 mg/L x 8.34 lbs/gal})}{(0.304 \text{ MGD x 5,500 mg/L x 8.34 lbs/gal}) + (33 \text{ MGD x 10 mg/L x 8.34 lbs/gal})}$$

$$= \frac{193{,}316 \text{ lbs}}{13{,}944 \text{ lbs/day} + 2{,}752 \text{ lbs/day}}$$

= **11.58 days**

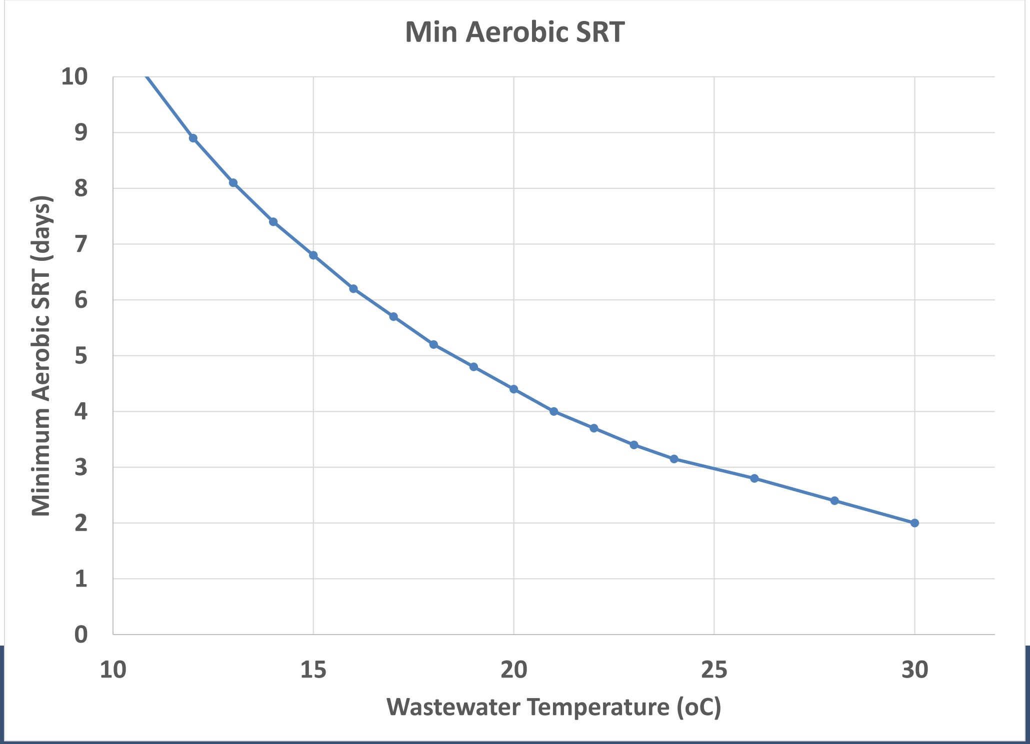
How much do I waste?

Control by…….

1. Aerobic SRT – assuming nitrification is a compliance objective, using the aerobic volume of the biomass will provide the critical biomass concentration based on tank volume, temperature and biomass concentration. Those three (3) conditions must be taken into consideration when adjusting for treatment.
2. Nitrification is the controlling the MLSS concentration if biological phosphorus removal and total nitrogen control are necessary.
3. Nitrifiers are temperature sensitive, slow growing and dictate MLSS and number of basins online
4. Dictates the Aerobic SRT required

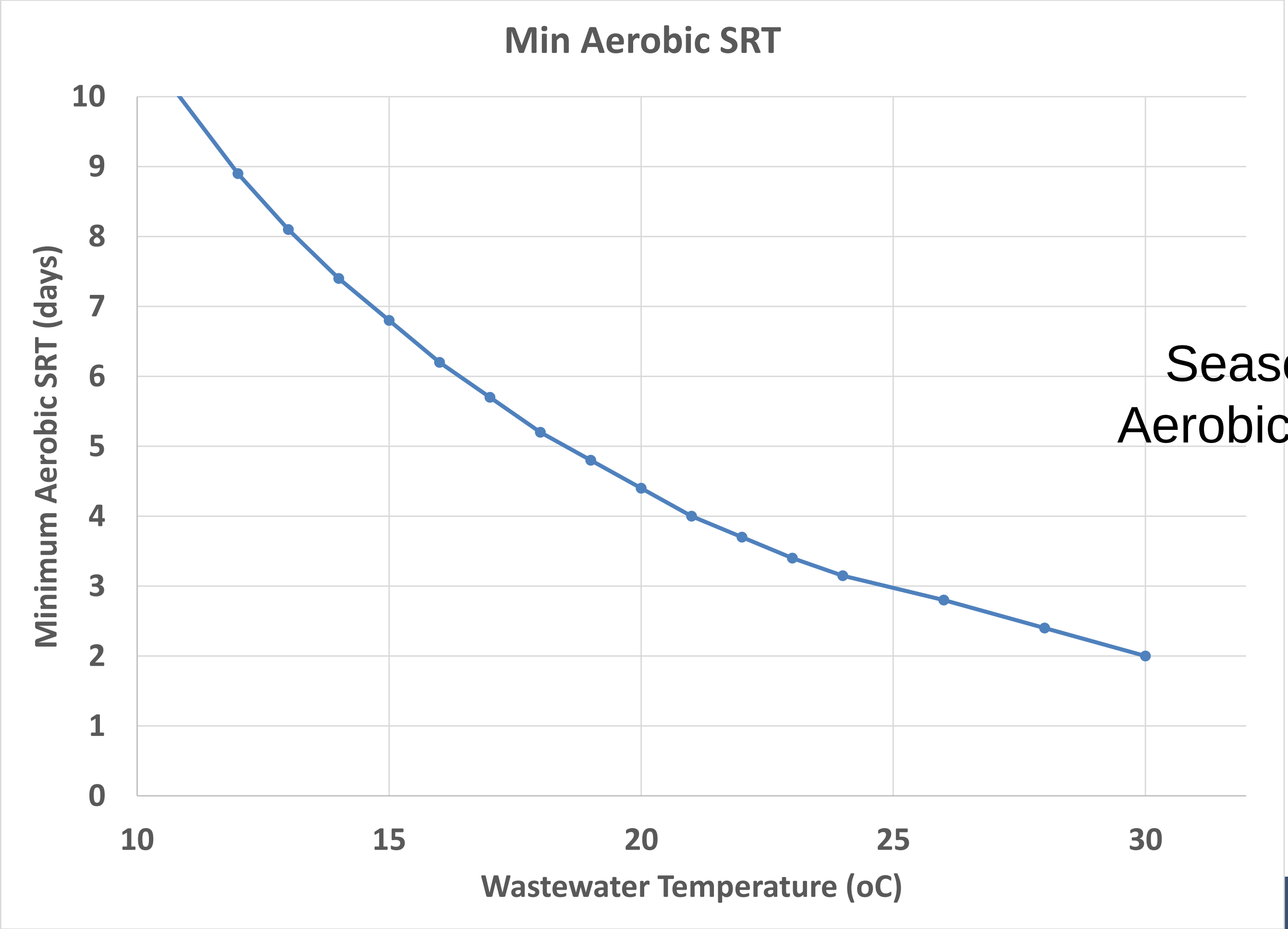
Nitrification Requirements

- Key Factors:
  1. Slow growth requires adequate **aerobic SRT**
  2. **DO** typically ≥ 2 mg/L
  3. **pH** 6.8 - 7.5 S.U.
  4. Target effluent alkalinity of 75 mg/L as $CaCO_3$

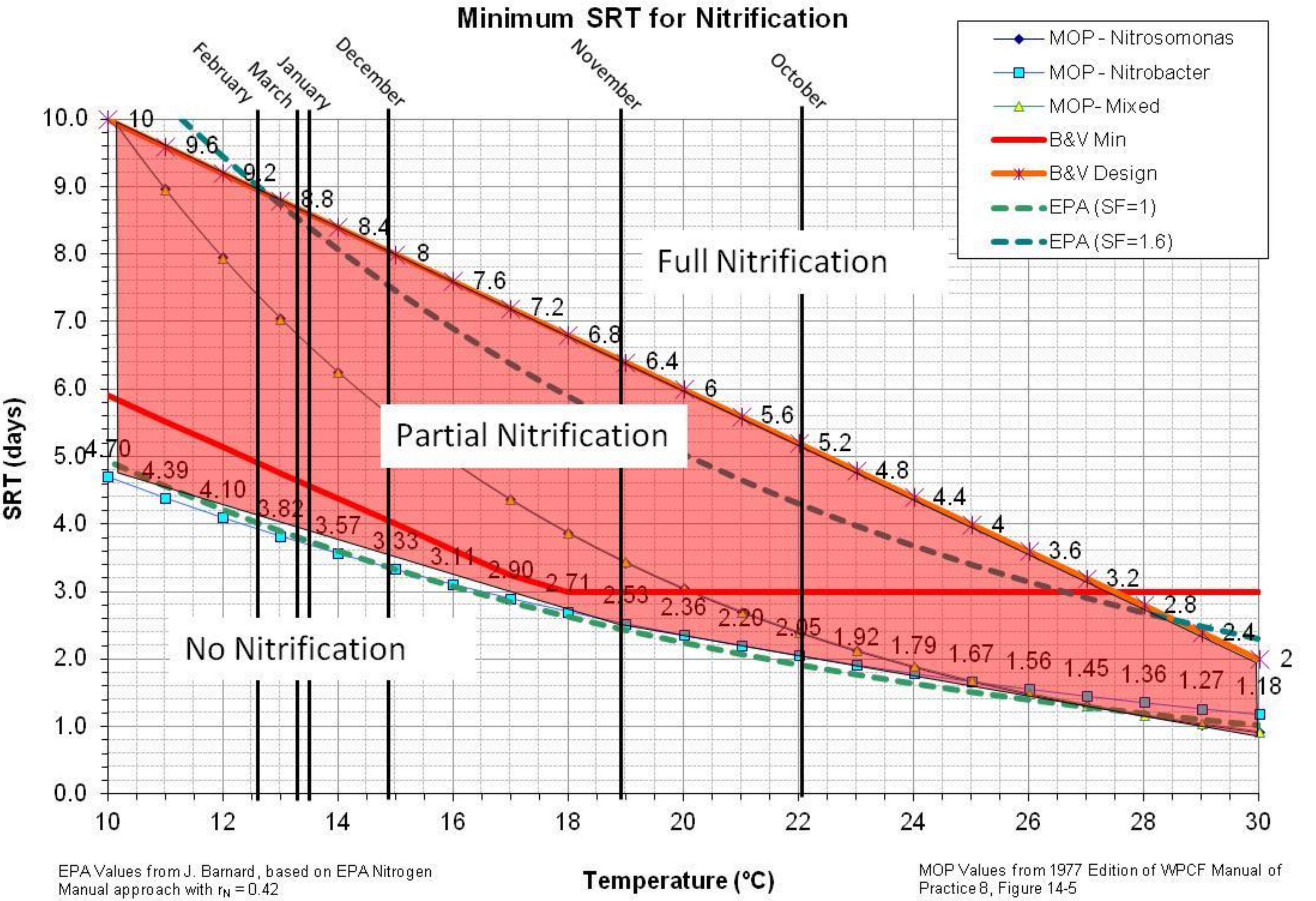


Nitrification Requirements, Solids Retention Time (SRT)

- **Key Performance Indicator for Nitrification**
  - Aerobic SRT maintains adequate Solids Inventory



Seasonal Aerobic SRTs



Minimum SRT for Nitrification
MOP - Nitrosomonas
MOP - Nitrobacter
MOP- Mixed
B&V Min
B&V Design
EPA (SF=1)
EPA (SF=1.6)
February
March
January
December
November
October
Full Nitrification
Partial Nitrification
No Nitrification
SRT (days)
Temperature (°C)
10 9.6 9.2 8.8 8.4 8 7.6 7.2 6.8 6.4 6 5.6 5.2 4.8 4.4 4 3.6 3.2 2.8 2.4 2
4.70 4.39 4.10 3.82 3.57 3.33 3.11 2.90 2.71 2.53 2.36 2.20 2.05 1.92 1.79 1.67 1.56 1.45 1.36 1.27 1.18
EPA Values from J. Barnard, based on EPA Nitrogen Manual approach with r_N = 0.42
MOP Values from 1977 Edition of WPCF Manual of Practice 8, Figure 14-5

Gallons to Waste using MCRT

Select the MCRT (Sludge Age)

GALLONS TO WASTE AS DETERMINED BY MCRT USING POUNDS

Data Required:

a. Desired Sludge Age, 16 days
b. Solids Inventory, 223,473 lbs
c. RAS_{ss}/WAS_{ss} Concentration, 5,500 mg/L

Formula:

$$\text{MG to Waste} = \frac{\text{Solids Inventory, Total Pounds}}{\text{Desired MCRT, days x WAS, mg/L x 8.34lbs/gal}}$$

Solution:

$$\text{MG to Waste} = \frac{223{,}473 \text{ lbs}}{16 \text{ days} * 5{,}500 \text{ mg/L} * 8.34 \text{ lbs/gal}}$$

$$= 0.304492 \text{ MG or } 304{,}492 \text{ gallons}$$

Organic Loading

Expressed as Pounds of BOD_5 per 1,000 cf of aeration

ORGANIC LOADING CALCULATION

Data Required:

a. Plant flow, Q, = 33 MGD
b. Primary Effluent $cBOD_5$ concentration, 91 mg/L
c. Volume of Aeration System, 1,191,870 cf

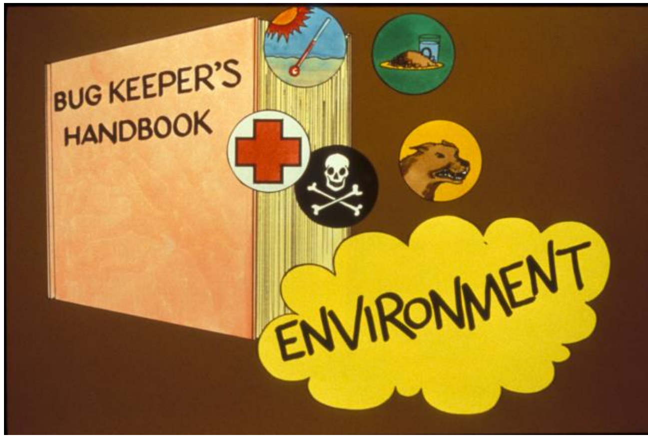
Formula:

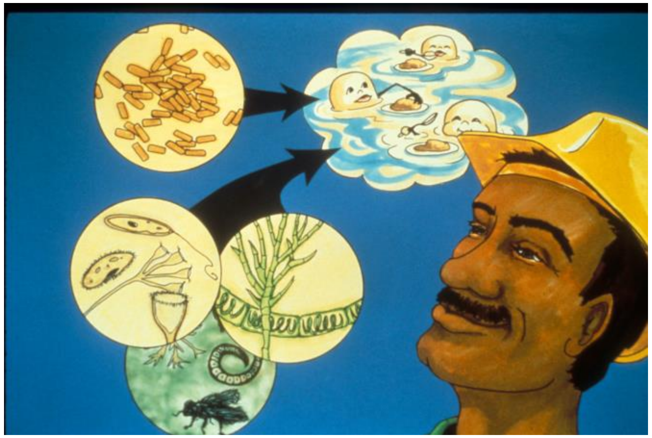
$$\text{lbs cBOD/1,000 cf} = \frac{\text{Q, MGD x BOD, mg/L x 8.34 lbs/gal}}{\text{Basin volume, cf/1,000}}$$

Solution:

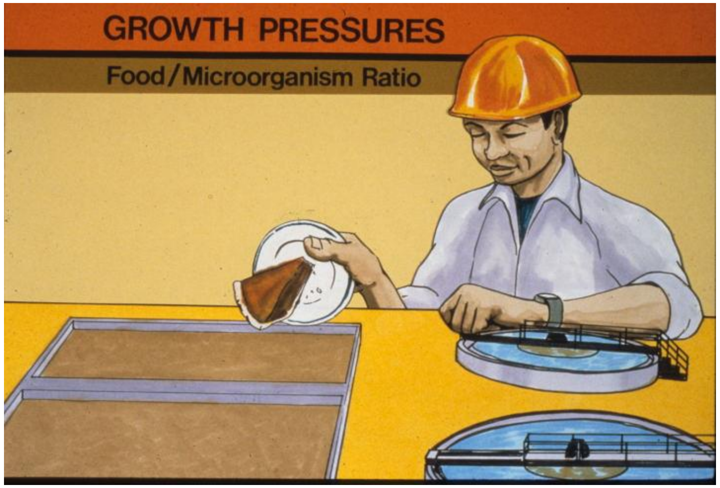
$$\text{lbs cBOD/1,000 cf} = \frac{\text{33 MGD x 91 mg/L cBOD x 8.34 lbs/gal}}{\text{1,191,870 cf/1,000}}$$

$$= \textbf{21 lbs } \mathbf{BOD_5}\textbf{/1000 cf}$$





F/M Ratio



A concept more than a control method

- The use of the F/M Ratio is based on the concept that the amount of organic matter (food) entering the process directly affects the growth rate of the microorganisms.
- It is desirable to keep a definite ratio between the incoming food (F) and the microorganisms (M). If too many or too few microorganisms are present for the amount of food entering the plant, operating problems may occur affecting effluent quality, sludge quality and settling.
- The term "ratio" is a key concept. If a person who weighed 200 pounds ate 10 pounds of food today. The ratio of food to weight would be 10 pounds to 200 pounds or 10/200 which equals 0.05.

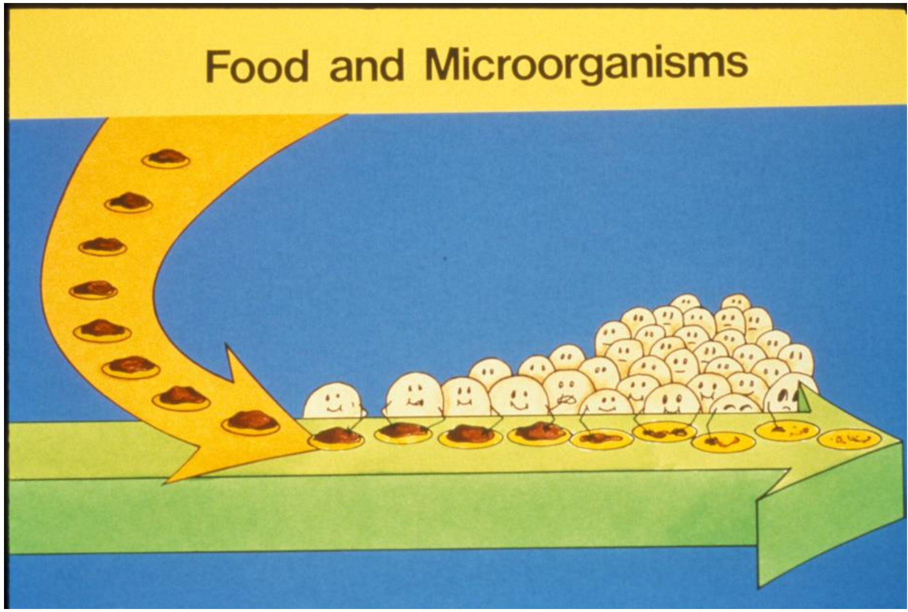
F/M

BOD$_5$ Load (lbs) compared to microorganism mass (lbs)

FOOD TO MICROORGANISM RATIO (F/M) CALCULATION

Data Required:

a. Influent flow, Q, 33 MGD
b. Primary Effluent cBOD$_5$, 82 mg/L
c. Volume of aeration basin, V_{aer}, 8.915188 MG
d. MLSS, 2,600 mg/L (optional to using MLVSS)



Formula:

$$F/M = \frac{Q, MGD \times BOD, mg/L \times 8.34\ lbs/gal}{V_{aer}, MG \times MLSS, mg/L \times 8.34\ lbs/gal}$$

Solution:

$$F/M = \frac{33\ MGD \times 82\ mg/L \times 8.34\ lbs/gal}{8.915188\ MG \times 2{,}600\ mg/L\ MLSS \times 8.34}$$

$$= \mathbf{0.1167}$$

Detention Time

Aeration holding time for influent flow rate

The amount of time that the wastewater is in the aeration basin is calculated by dividing the volume of the aeration basin by the influent flow rate.

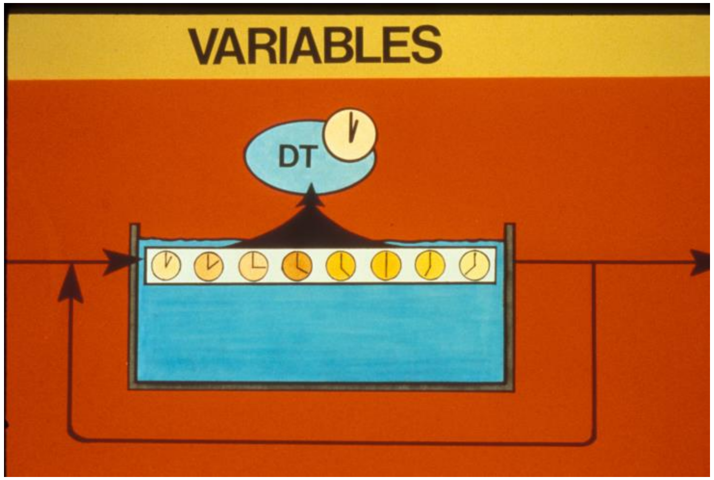
DETENTION TIME CALCULATION

Data required:

a. Volume of the aeration system, V_{aer}, 8.915188 MG
b. Influent flow, Q, 33 MGD

Formula:

$$\text{Detention time } (D_t) = \frac{V_{aer}\text{, MG x 24 hrs/day}}{\text{Q, MGD}}$$



Solution:

$$D_t\text{, hours} = \frac{\text{8.915188 MG x 24 hrs/day}}{\text{33 MGD}}$$

$$= \textbf{6.48 hours}$$

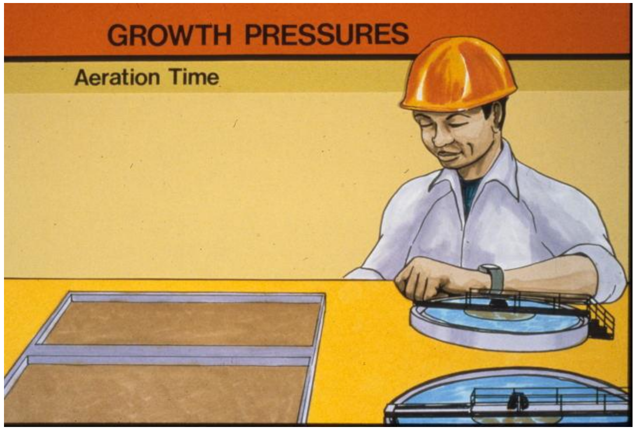
Treatment Time

Actual time return sludge and influent flows are in aeration basin

TREATMENT TIME CALCULATION

Data required:

a. Volume of the aeration system, V_{aer}, 8.915188 MG
b. Influent flow, Q_{INF}, 33 MGD
c. Return sludge flow, Q_{RAS}, 29.6 MGD



Formula:

$$\text{Treatment Time, } (T_t) \text{ hrs.} = \frac{V_{aer}, \text{ MG x 24 hrs/day}}{Q_{INF} + Q_{RAS}, \text{ MGD}}$$

Solution:

$$\text{Treatment Time, } (T_t) \text{ hrs.} = \frac{8.915188 \text{ MG x 24 hrs/day}}{(33 + 29.6) \text{ MGD}}$$

$$= \textbf{3.42 hours}$$

Questions

Dan Miklos
dmiklos@hazenandsawyer.com