Energy & Nutrient Optimization for Municipal WWTPs

Enhancing Activated Sludge Performance & Saving Energy with the Bio-Tiger Model

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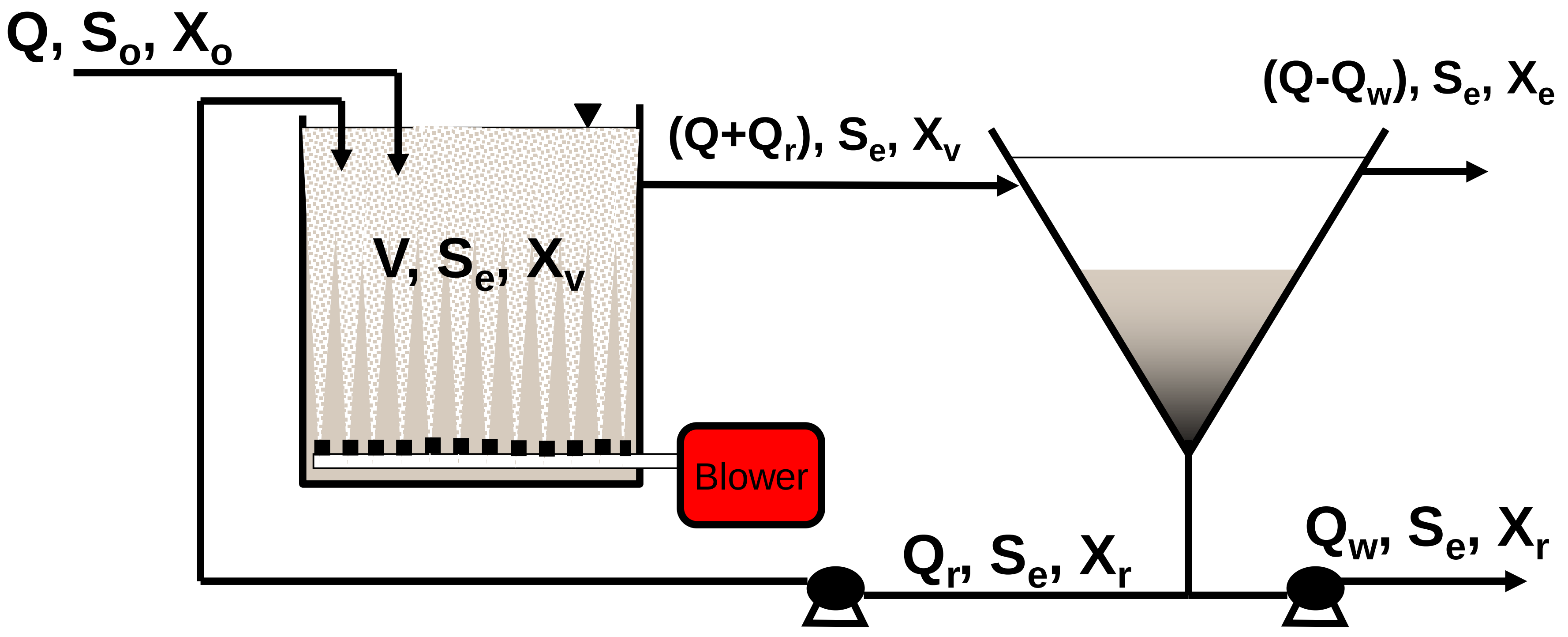
Predicting Performance of the Activated Sludge Process Using Biokinetic Relationships

***Note to participants: I will show some equations very briefly, but don’t worry about the equations … listen to Larry’s explanations of activated sludge concepts!!!**

Activated Sludge Process Schematic



Biological Reactor with Aerated Mixed Liquor
(diffused aeration)

Biomass Settling

- Settleometer
  - Use settleometer not graduated cylinder
  - Indicator of clarifier performance
  - How well the biomass-settles, compacts, clears
  - May give mixed signals
  - Part of the SVI test

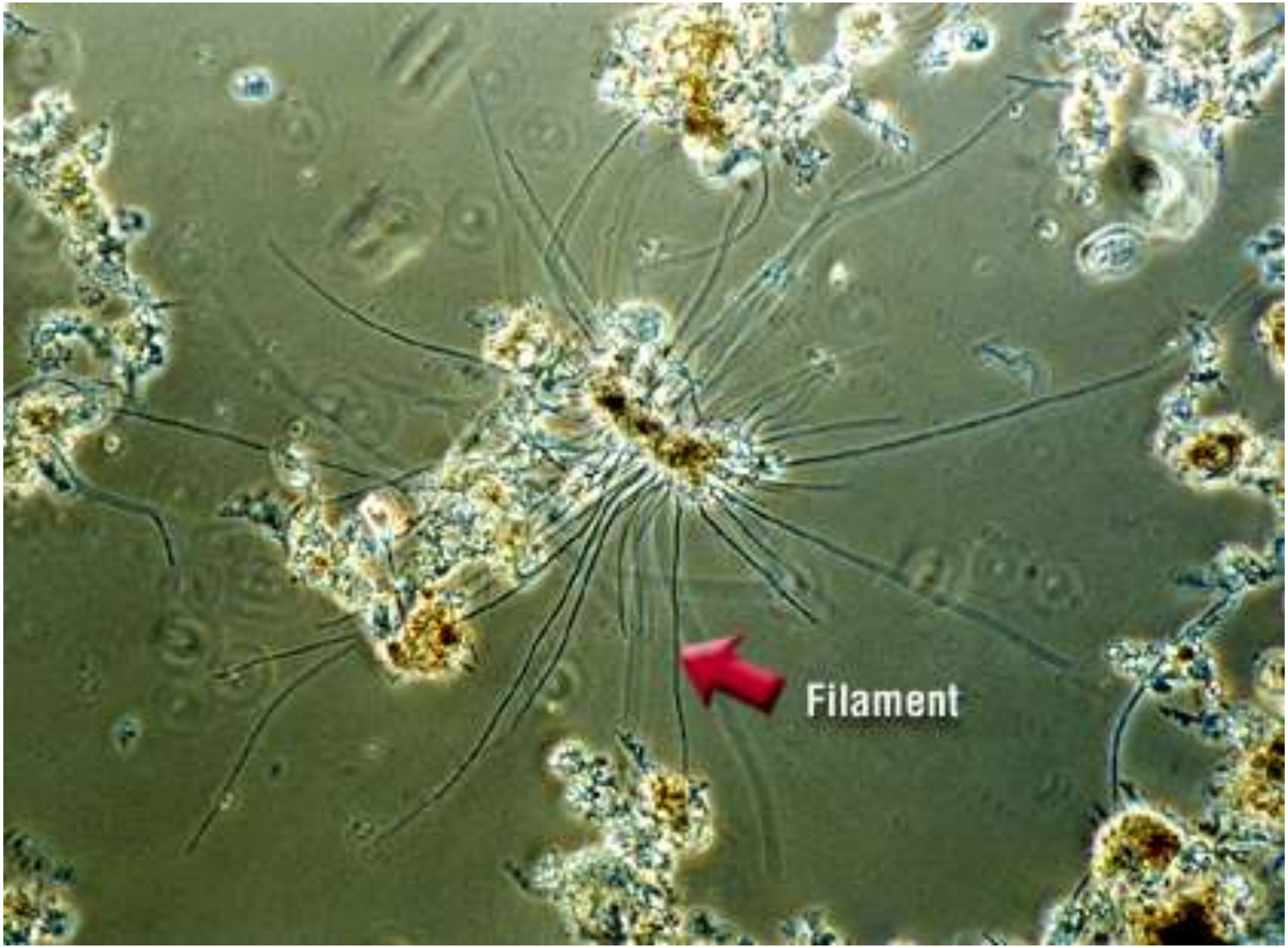
Activated Sludge Process Goals

- CBOD removal
- Nitrification (where required)
- TSS removal
- Maintaining neutral pH

Additional Process Goals

- Minimizing the mass of solids produced
- Optimizing the energy used
- Denitrification
- Phosphorus removal

Activated Sludge Microbiology



Roles of Microbes in Wastewater Treatment

- **Oxidation of organic matter** in wastewater is accomplished biologically using a variety of microorganisms, primarily bacteria:

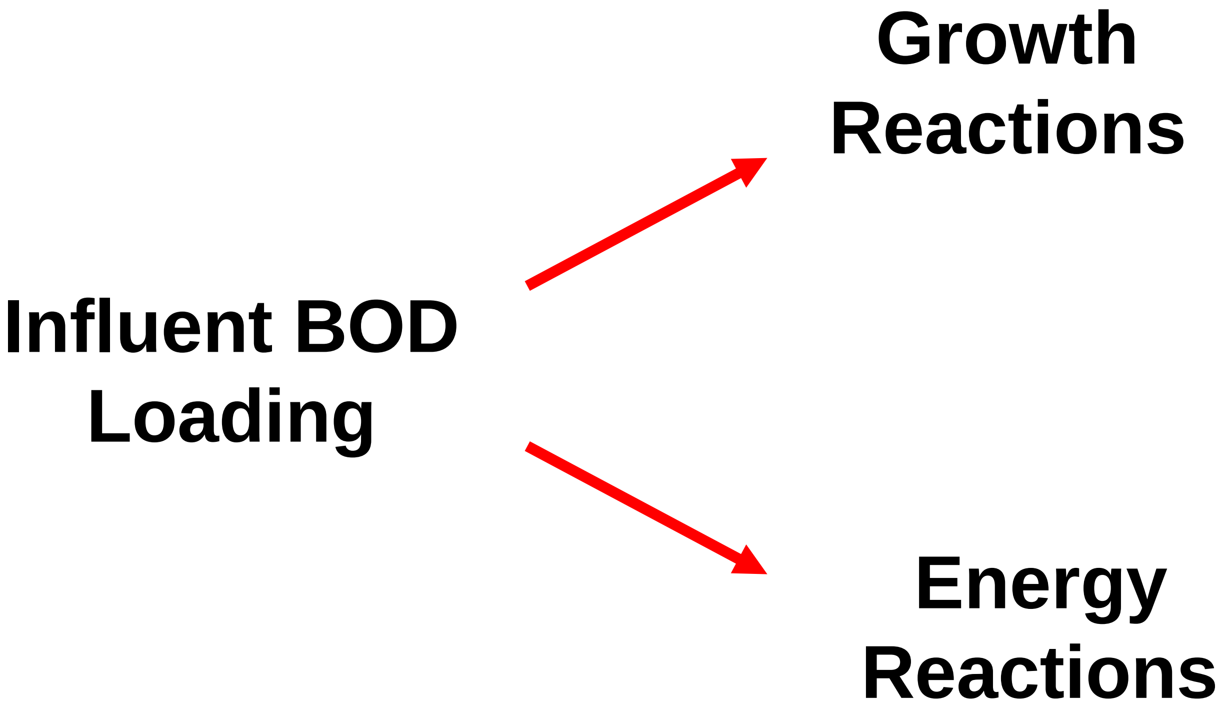
$$\text{Organics} + O_2 + NH_3 + PO_4 \xrightarrow{\text{microbes}} \text{New cells} + CO_2 + H_2O + \text{energy}$$

- **New cells** represent the biomass produced as a result of consumption of organic matter and nutrients
- **Energy** is produced by the oxidation of organic matter to CO_2 and water

Bacterial "Eating" Process

Adsorption
Exocellular Digestion } Chunky BOD

Absorption → Dissolved BOD


Influent BOD Loading
Growth Reactions
Energy Reactions

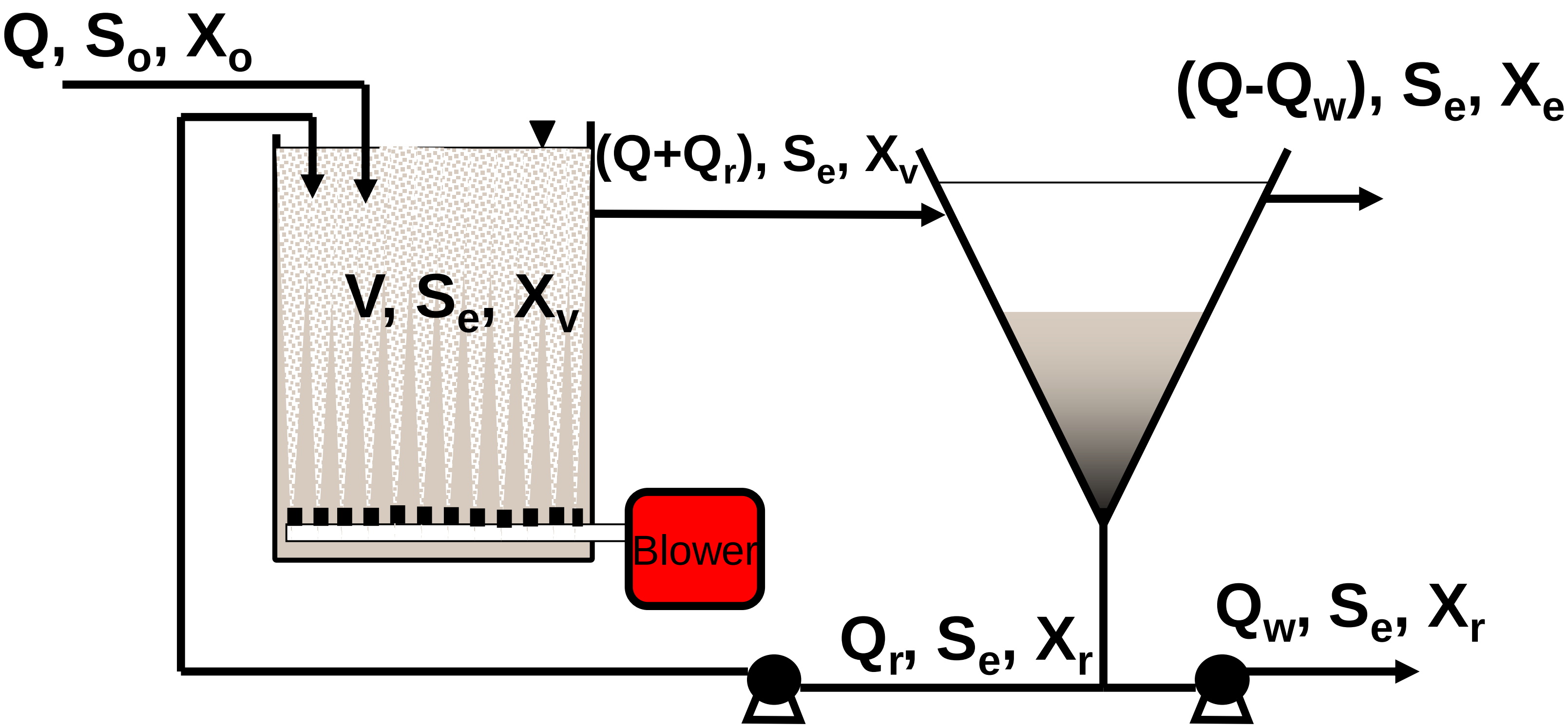
Questions?

Remember:

θ_c = MCRT = SRT = sludge age

It is how long in days (on average) the biomass stays in the activated sludge system until the biomass exits the system as waste activated sludge solids or as TSS in the effluent.

Determining θ_c Using Plant Data



$$\theta_c = \frac{XV}{Q_w X_r + (Q - Q_w) X_e} \approx \frac{XV}{Q_w X_r}$$

Relation of Biomass Growth and θ_c

$$\mu = \frac{1}{\theta_c} + k_e$$

θ_c = mean cell residence time or sludge age

μ = specific growth rate of biomass

Activated Sludge Biokinetic Constants

μ_{max} = maximum specific growth rate

K_s = saturation constant

k_e = microbial decay coefficient ($k_e = k_d$)

Y = biomass yield constant

k = maximum specific substrate utilization rate

$\mu_{max} = Yk$

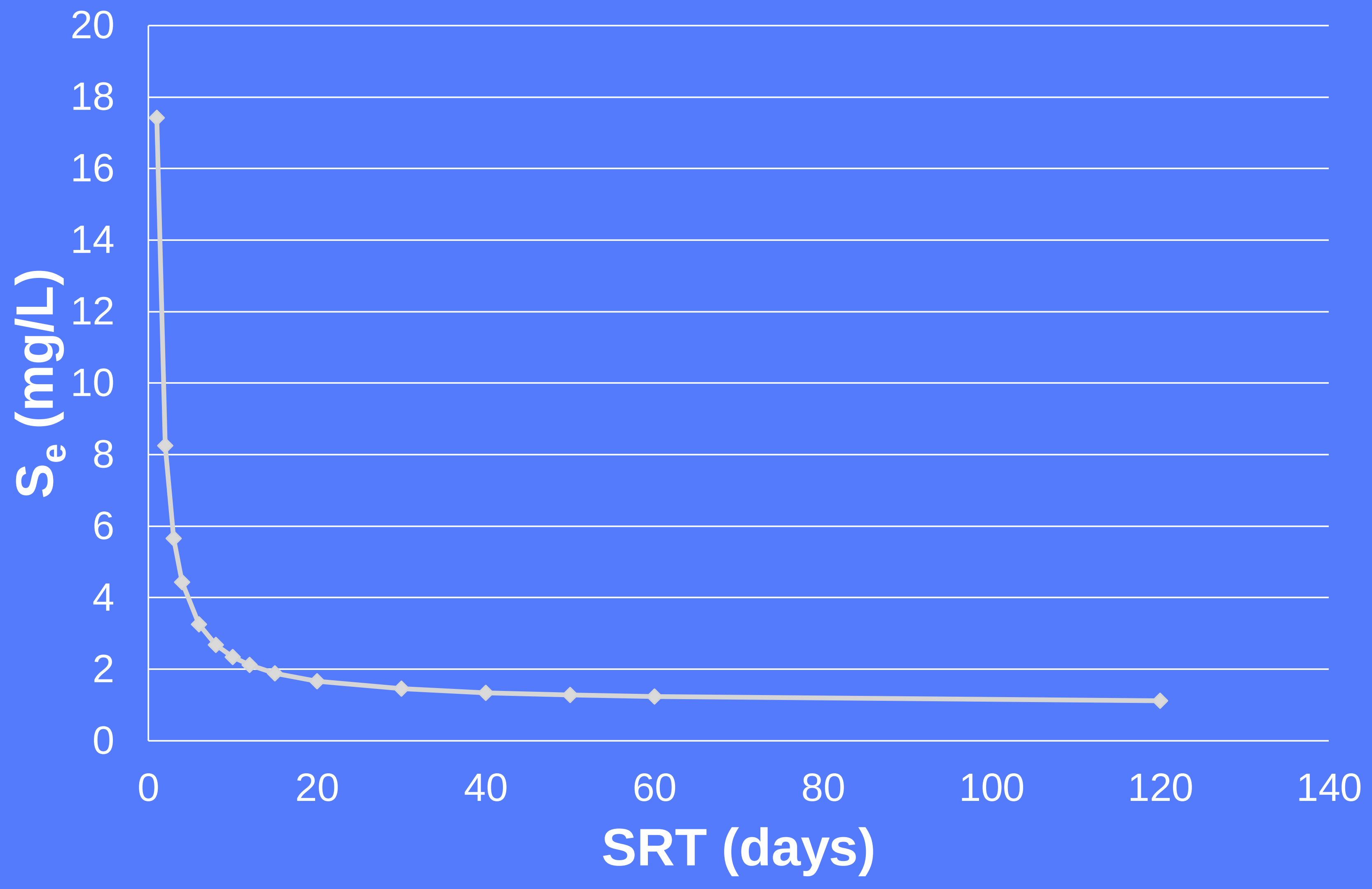
Determining S_e Using Biokinetic Approach

$$S_e = \frac{K_s(1 + k_e \theta_c)}{\theta_c(\mu_{max} - k_e) - 1}$$

S_e is the soluble $CBOD_5$ concentration in the effluent; it does not include $CBOD_5$ contributed by solids.

This equation is only valid for *Monod kinetics.*

S_e versus SRT



Activated Sludge Evaluation

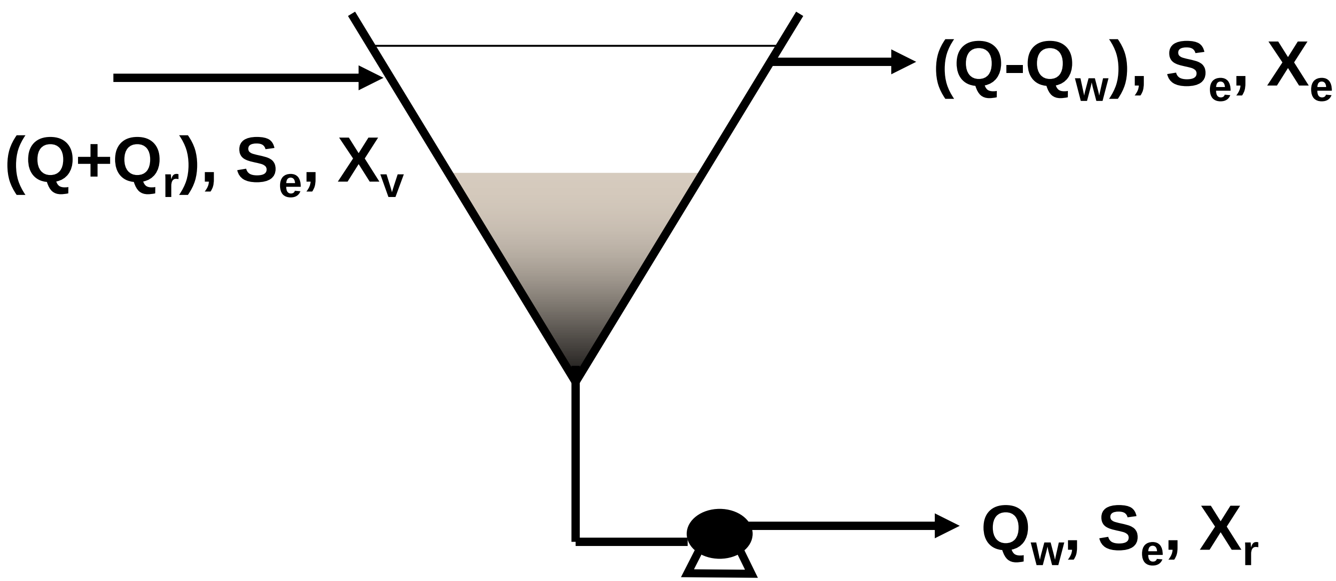
Step 1: Determine effluent Total $CBOD_5$ concentration

$$CBOD_{5eff} = S_e + f\,X_e$$

where X_e = TSS in final effluent

S_e = soluble $CBOD_5$

f = g $CBOD_5$/g TSS = 0.3 to 0.6



Activated Sludge Evaluation

Step 2: Determine kinetic coefficients

Coef.	Range and units	Typical Value
$\mu_{m/20}$	2 to 10 day^{-1}	5.0 day^{-1}
K_s	25 to 100 mg/l BOD_5	60 mg/L
k_e	0.05 to 0.15 day^{-1}	0.08 day^{-1}
$Y_{x/s}$	0.4 to 0.8 VSS/BOD_5	0.6 VSS/BOD_5

Activated Sludge Evaluation

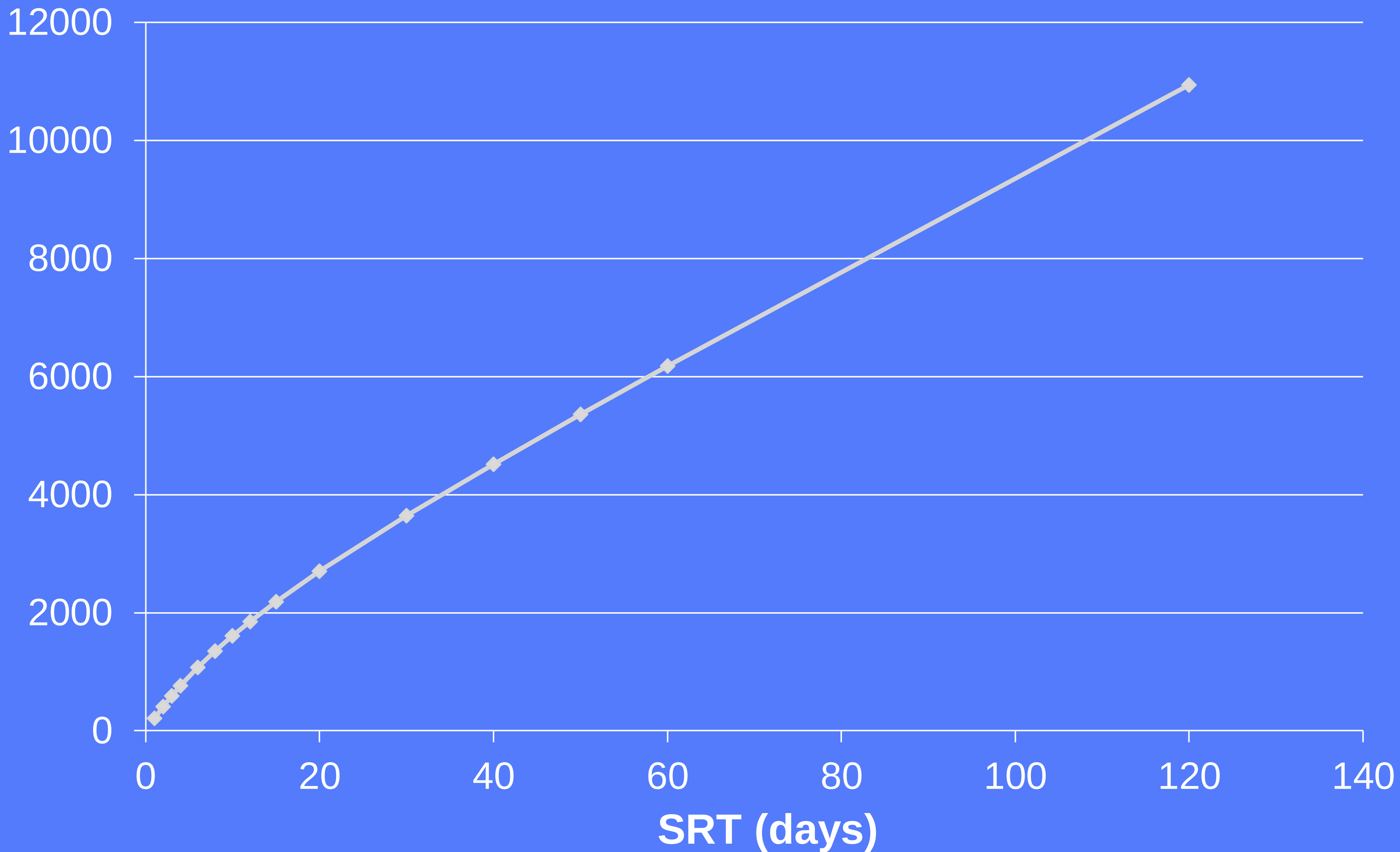
Step 3: Typical MLVSS concentration in aeration basin.

X_v = 1,000 to 2,500 mg/L for conventional act. sldg
1,000 to 3,000 mg/L for extended air

Step 4: Relationship between SRT (Θ_c) and biomass (X_v) concentration

$$V = \frac{Q Y_{x/s} \theta_c (S_o - S_e)}{X_v (1 + k_e \theta_c)}$$

MLSS versus SRT –
1.0 mgd Extended Aeration Act. Sludge



Questions?

Activated Sludge Evaluation

Step 5: Determine the mass of volatile solids to be wasted (Pxvss)

$$P_{XVSS} = A + B + C$$

$$A + B = \text{biomass production} = VSW$$

A = heterotrophic biomass
B = cell debris
C = nonbiodegradable VSS in influent

$$P_{XVSS} = \frac{QY(S_o - S_e)}{1 + k_d\theta_c} + \frac{f_d(k_d)YQ\,(S_o - S_e)\,\theta_c}{1 + k_d\theta_c}$$

$$+ \; QX_{oi}$$

Activated Sludge Evaluation

Step 6: Determine the mass of **total** solids to be wasted (Px)

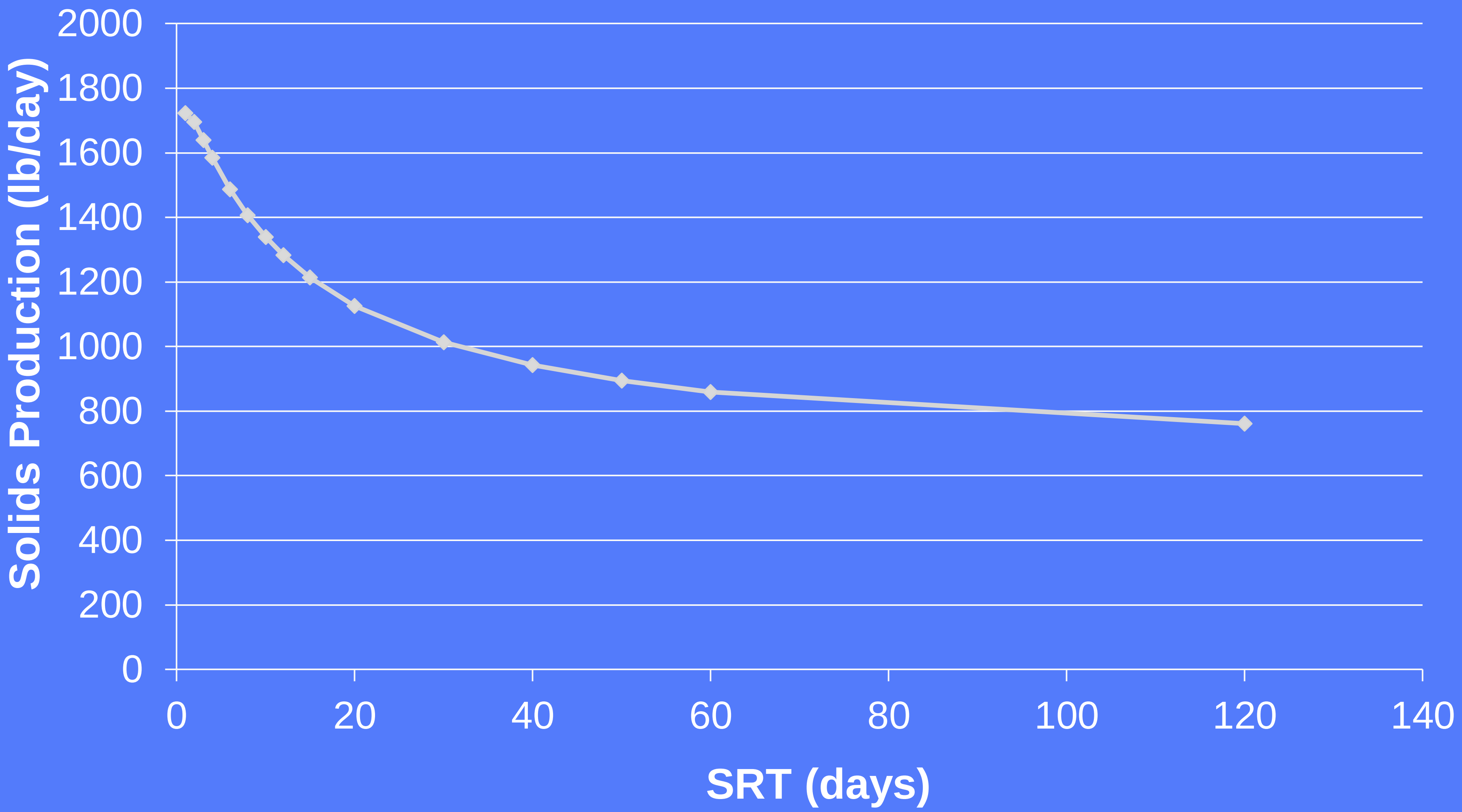
$$P_{XTSS} = A/0.85 + B/0.85 + C + Q(TSS_o - VSS_o)$$

where P_{XTSS} = net waste activated sludge produced each day, mass/day

TSS_o = influent TSS concentration

VSS_o = influent VSS concentration

Sludge Production (TSS, lb/d) vs SRT - 1.0 mgd Extended Aeration Act. Sludge



Activated Sludge Evaluation

Step 7: Determine the oxygen requirements (CBOD and NBOD)

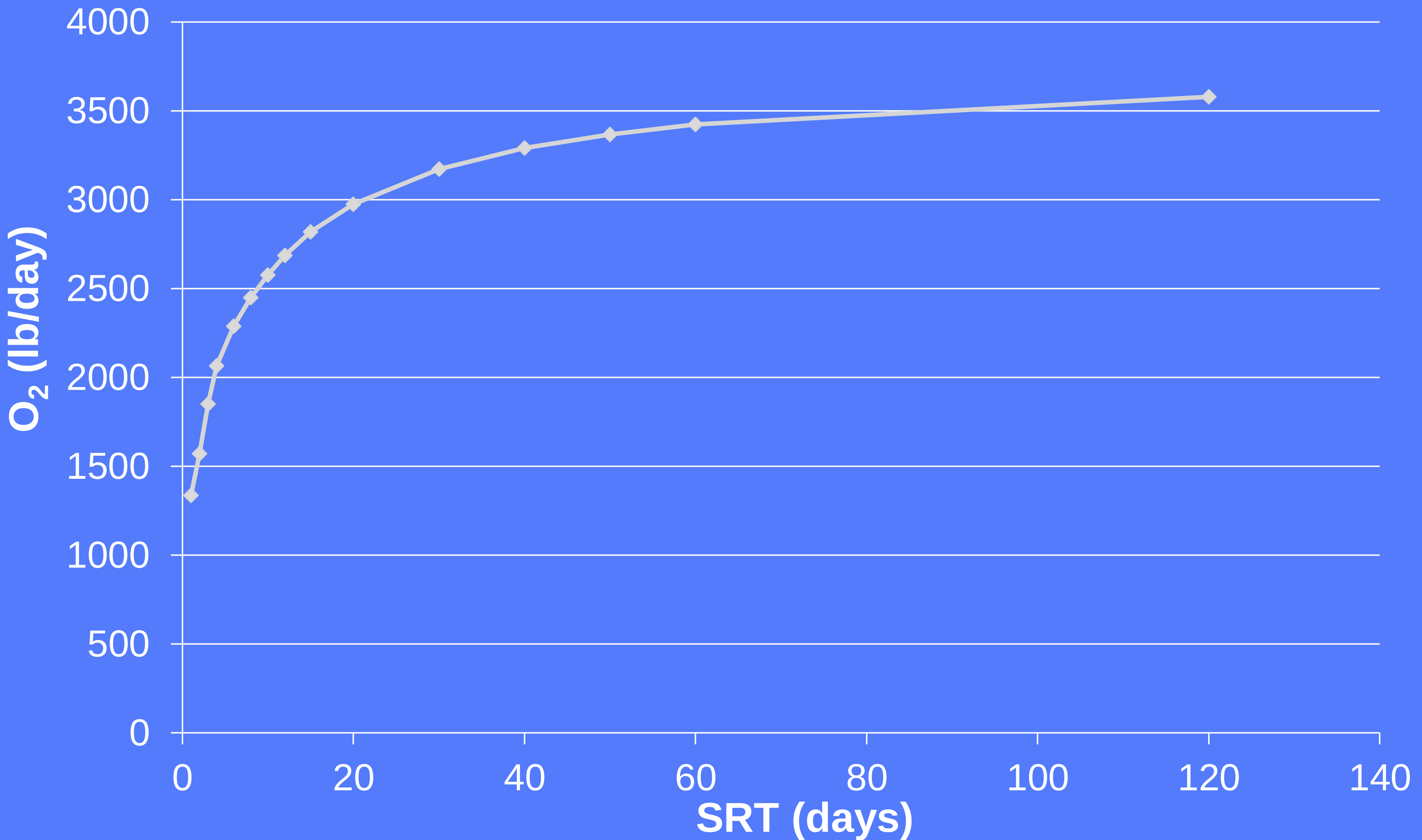
$$O_2(\text{lb/day}) = 8.34Q\left[\frac{S_o - S_e}{0.67}\right] - 1.42(\text{VSW})$$

$$+ 4.33(N_{ox})(Q)(8.34)$$

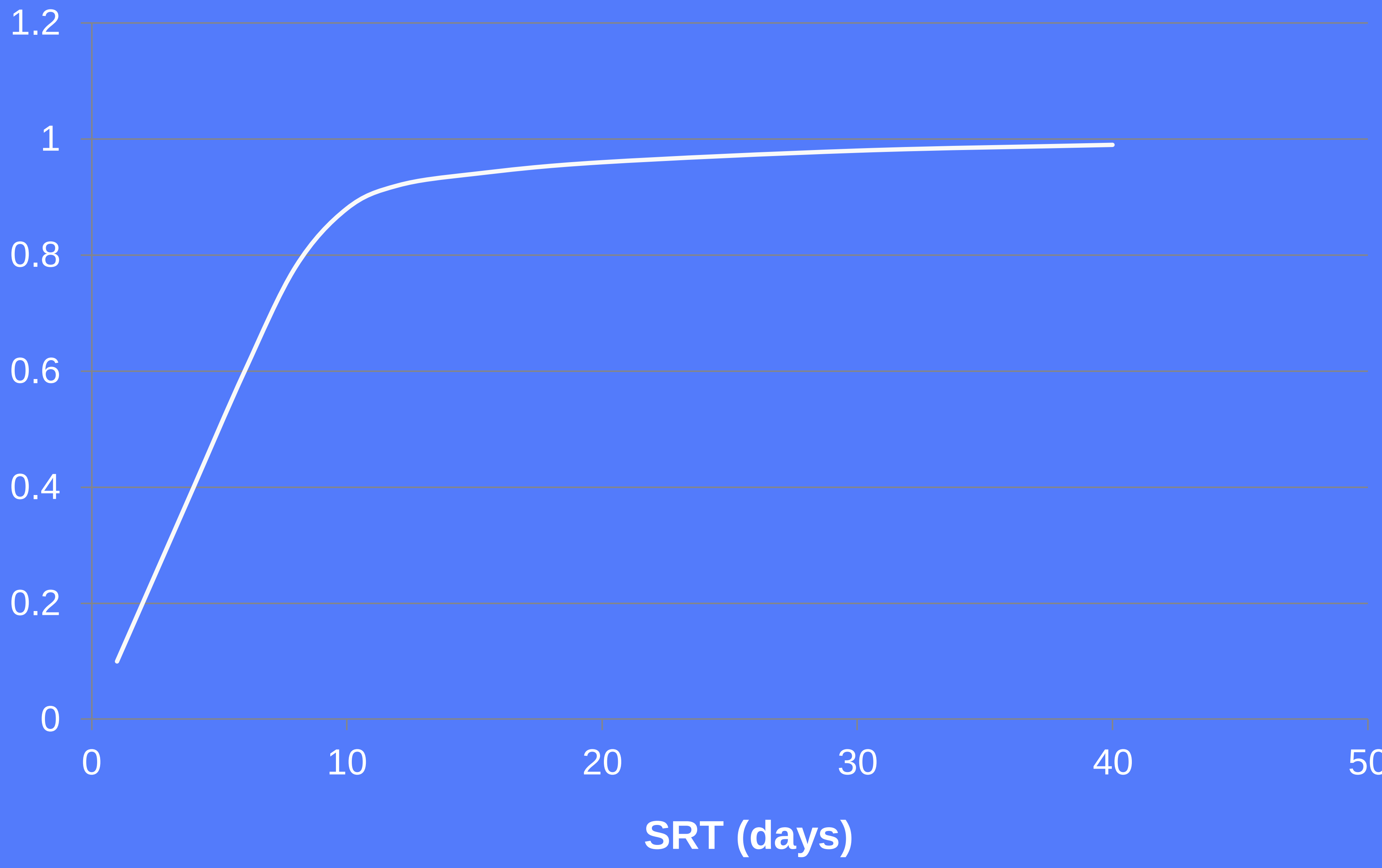
*Note: VSW = biomass production = A + B in previous equations

1.42(VSW) = ultimate CBOD that goes to cell growth

Oxygen Required (Carb+Nit) vs SRT – 1.0 mgd Extended Aeration Act. Sludge



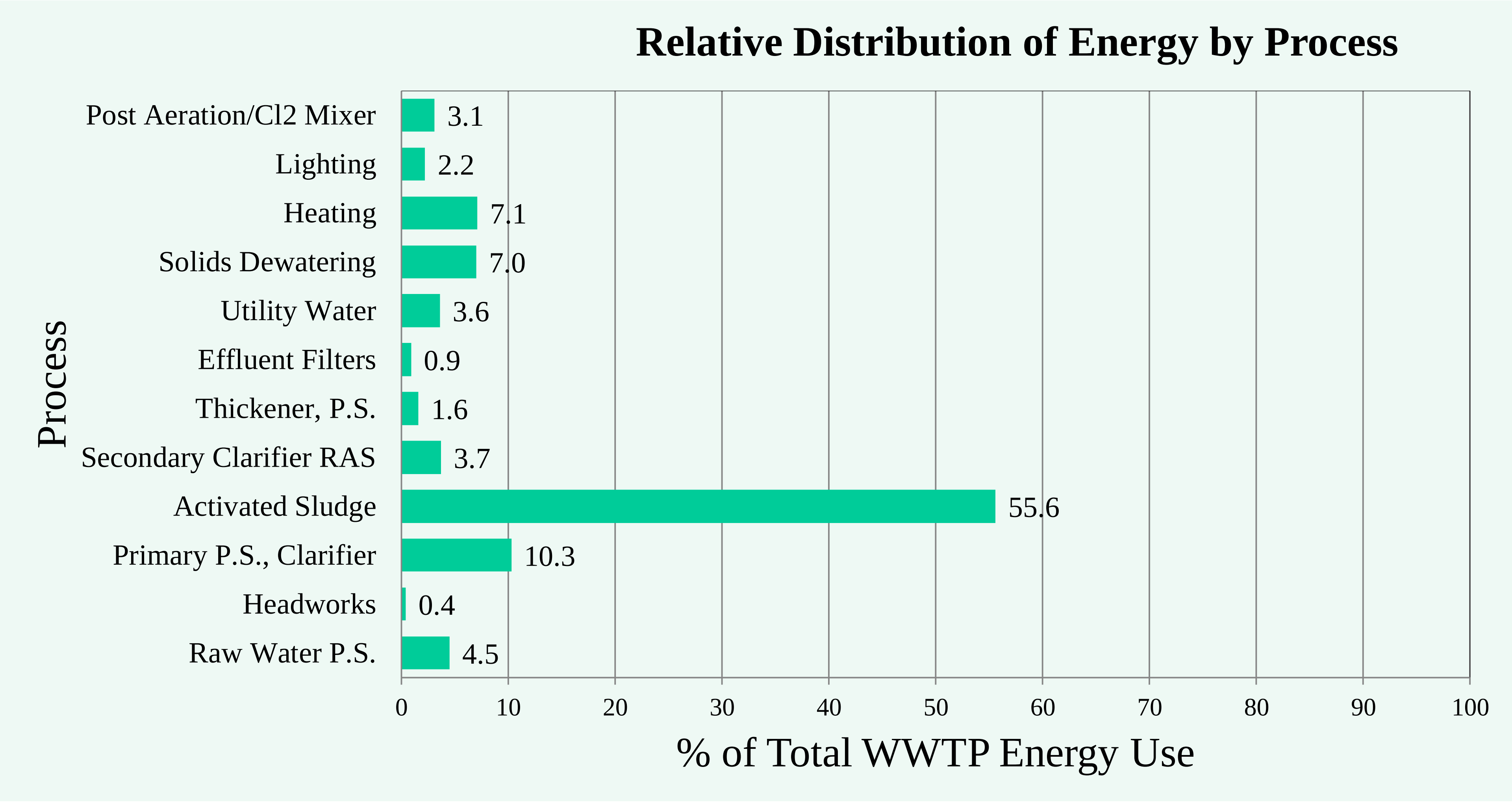
Fraction N_{ox} Oxidized at 20˚C



Understanding the Oxygen Transfer Capability of Various Types of Aeration Equipment

The best way to reduce energy use at your plant is to use your aeration equipment efficiently!!!

Relative distribution of energy use at a secondary wastewater treatment plant*:



* Sample 7.5 MGD WWTP

Types of Aeration Equipment

- Activated sludge aeration equipment uses large horsepower motors and multiple units such as:
  - Centrifugal-type blowers
  - Positive-displacement blowers
  - High-speed turbine (HST) blowers
  - Surface aerators

- Adding excessive air into the aeration tanks will only result in a waste of energy!!!

Effect of DO on Aeration Efficiency

DO Conc, mg/L	Aeration Efficiency (approx.)
1.0	115%
2.0	100%
3.0	84%
4.0	69%
5.0	53%

Typical Standard O_2 Transfer Rates

- Pump type aerators (high speed)
  – 2.0 to 3.3 lb O_2/(HP-hr)
- Aspirating aerators
  – 1.6 to 2.6 lb O_2/(HP-hr)
- Horizontal rotor aerators
  – 2.0 to 3.3 lb O_2/(HP-hr)
- Nonporous diffusers
  – 1.0 to 2.4 lb O_2/(HP-hr)
- Porous diffusers
  – 2.0 to 3.8 lb O_2/(HP-hr)

Standard Conditions for Mechanical Aerators

Elevation = sea level

Temperature = 20˚C

Initial DO concentration = zero mg/L

Tap water

Determine Field O_2 Transfer Rate for Mechanical Aerators

$$OTR = OTR_{standard}\,\alpha\,\frac{(\beta\rho C_s - C)}{9.2}\,1.024^{(T-20)}$$

$OTR_{\mathbf{standard}}$ = oxygen transfer rate at 20°C (lb O_2 hp^{-1} $hour^{-1}$), 1 atm, tap water, and initial DO = zero mg/L

C = dissolved oxygen level in basin (typically 1.5 to 2 mg/L)

C_s = saturated dissolved oxygen level in mg/L

α = (K_La of wastewater)/(K_La of tap water); use α = 0.80 to 0.90 unless specified otherwise.

β = C_s wastewater/C_s tap water = 0.92 for municipal wastewater

ρ = factor that corrects for elevation differences

Approximate Field O_2 Transfer Rates

- Pump type aerators (high speed)
  - 1.2 to 2.0 lb O_2/(HP-hr)
- Aspirating aerators
  - 1.0 to 1.6 lb O_2/(HP-hr)
- Horizontal rotor aerators
  - 1.2 to 2.0 lb O_2/(HP-hr)

α = 0.84, β = 0.92, ρ = 1, DO = 2 mg/L, Elevation < 500 ft

Additional Assumptions for Diffused Aeration

Compressor efficiency = 75%

Tank depth = 15 ft

Diffusers located 1.5 ft above tank bottom

Approximate Field O_2 Transfer Rates

- Nonporous diffusers
  - 0.6 to 1.5 lb O_2/(HP-hr)
- Porous diffusers
  - 1.2 to 2.3 lb O_2/(HP-hr)

α = 0.84, β = 0.92, ρ = 1, DO = 2 mg/L

Elevation < 500 ft, Compressor efficiency = 75%

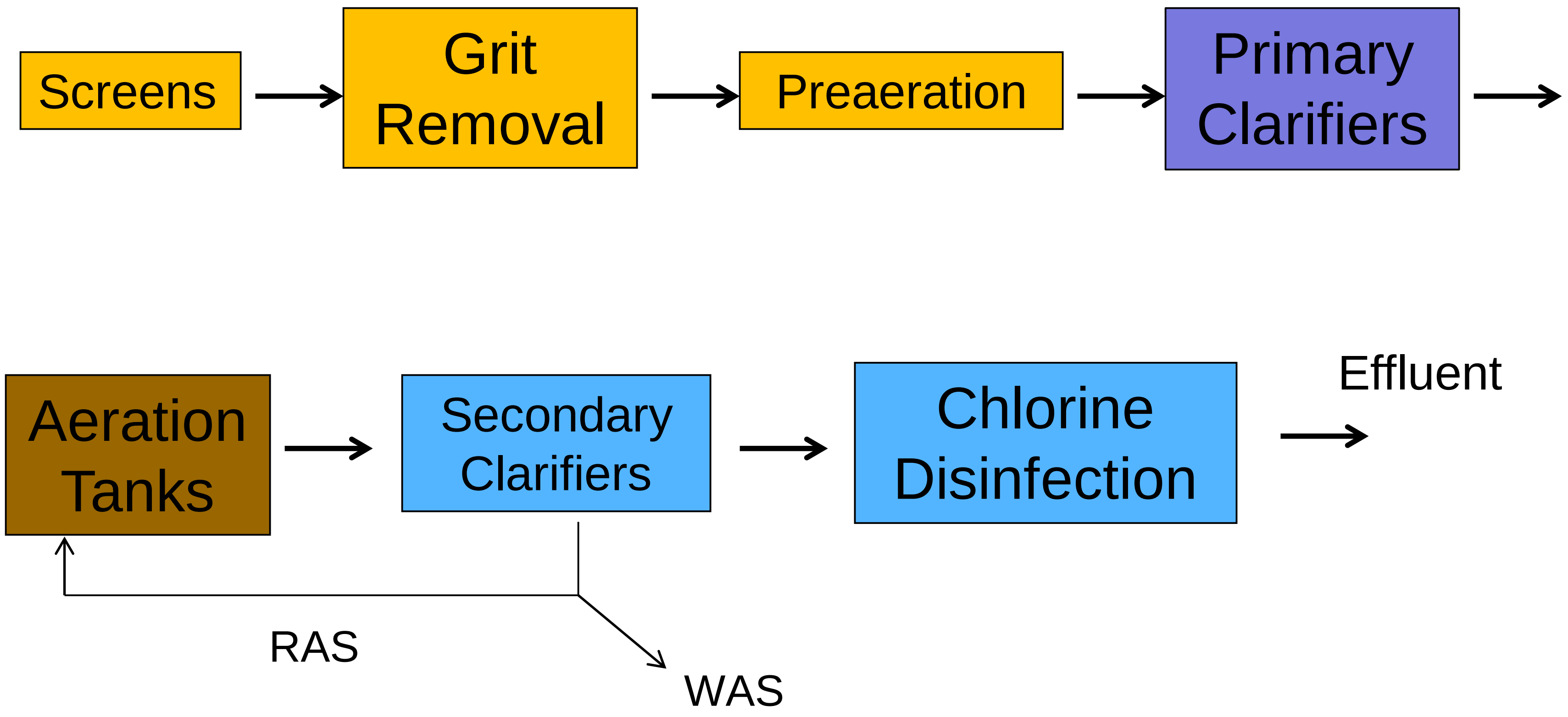
Tank depth = 15 ft, Diffusers located 1.5 ft above tank bottom

Energy Conservation in Aeration

- Determine actual oxygen requirements
  - Dr. Moore’s model
- Determine field transfer rate of aerators
  - Use previous data
- Optimize aeration use to satisfy oxygen needs efficiently
- Consider on-off operation of aerators to achieve nitrification-denitrification and save energy

Questions?

Case Study: Fort Rucker WWTP



*Aeration basin diffusers are flexible-membrane, fine-bubble diffusers.

Design Parameters for Fort Rucker WWTP

Flow rate	=	2.5 mgd (ave. daily)
$CBOD_5$	=	250 mg/L (ave)
TSS	=	350 mg/L (ave)
TKN	=	45 mg/L (ave)
Ammonia-N	=	25 mg/L (ave)

Summer NPDES Limits for Fort Rucker WWTP

$CBOD_5$	=	12 mg/L (mo. ave)
TSS	=	30 mg/L (mo. ave)
Ammonia-N	=	3 mg/L (mo. ave)

Existing Conditions: Fort Rucker WWTP

Total average daily flow rate	0.58 mgd (half to each aer tank)
Aeration volume in service	0.66 mil gal (0.33 mil gal each)
Sec. influent BOD_5 concentration	90 mg/L
Sec. influent BOD_5 mass loading	435 lb/day (total)
Biomass inventory (MLVSS)	14,300 lb (in aeration tanks)

Existing Conditions: Fort Rucker WWTP

Biomass inventory (MLSS)	19,300 lb (in aeration tanks)
F/M ratio	0.031 lb BOD_5/(lb MLVSS-day)
Solids Retention Time	160 days
MLSS	3500 mg/L
MLVSS	2600 mg/L

Existing Conditions: Fort Rucker WWTP

TSS Sludge Production	99 lb/day (intentional wastage) 1050 lb/day (primary solids)
TSS in activated sludge effluent	19 lb/day (unintentional wastage)
Oxygen Requirements for Act Sldg (actual)	1300 lb/day
Oxygen required for aerobic digestion = 2.3 x VSS destroyed	900 lb/day

One 60-hp PD blower runs 22 hrs/day for aeration basin
One 75-hp PD blower runs 24 hrs/day for aerobic digesters

Existing Conditions: Fort Rucker WWTP

Total Oxygen Supplied by aer. basin blower	**1,400 lb/day**
Mixing intensity in aeration tanks with 60 hp	91 hp/mil gal
DO in aeration basins	4.5 mg/L
RAS flow rate	0.66 mgd (total)
WAS flow rate	0.0018 mgd
RAS TSS concentration	6500 mg/L

Questions?

New Conditions: Use Only One Aer. Basin and Run the Blower Only 16 Hours/Day

Total average daily flow rate	0.58 mgd (all to one aer tank)
Aeration volume in service	0.33 mil gal (one basin)
Sec. influent BOD_5 concentration	90 mg/L
Sec. influent BOD_5 mass loading	435 lb/day (total)
Biomass inventory (MLVSS)	7,200 lb (in aeration tank)

New Conditions: Use Only One Aer. Basin and Run the Blower Only 16 Hours/Day

Biomass inventory (MLSS)	9,600 lb (in aeration tanks)
F/M ratio	0.060 lb BOD_5/(lb MLVSS-day)
Solids Retention Time	70 days
MLSS	3500 mg/L
MLVSS	2600 mg/L

New Conditions: Use Only One Aer. Basin and Run the Blower Only 16 Hours/Day

TSS Sludge Production	117 lb/day (intentional wastage)
TSS in activated sludge effluent	19 lb/day (unintentional wastage)
Oxygen Requirements for Act Sldg (actual)	1270 lb/day
Oxygen required for aerobic digestion = 2.3 x VSS destroyed	900 lb/day

One 60-hp PD blower runs 16 hrs/day for aeration basin
One 75-hp PD blower runs 12 hrs/day for aerobic digesters

New Conditions: Use Only One Aer. Basin and Run the Blower Only 16 Hours/Day

Total Oxygen Supplied by aer. basin blower	**1,200 lb/day**
Mixing intensity in aeration tanks with 60 hp	182 hp/mil gal
DO in aeration basins	4 mg/L
RAS flow rate	0.67 mgd (total)
WAS flow rate	0.0022 mgd
RAS TSS concentration	6500 mg/L

Fort Rucker WWTP Estimated Energy Savings

Energy savings for aeration basin blower:

= 60 hp x 6 hr/day x 30 day/mo x 0.75 kWh/hp-hr x 0.85
≈ 6,900 kWh per month

Energy savings for aerobic digester blower:

= 75 hp x 12 hr/day x 30 day/mo x 0.75 kWh/hp-hr x 0.85
≈ 17,200 kWh per month

Energy cost savings = 24,000 kWh per month x $0.053/kWh
= $1,270 per month (20% savings)

Questions?