Operating efficiently—energy conservation for small to medium wastewater treatment facilities

Minnesota Pollution Control Agency
79th Annual Wastewater Operations Conference

March 24th, 2016
Marriott Northwest, Brooklyn Park, Minnesota
7025 Northland Drive N, MN 55428

8:00 AM to 11:30 AM

Minnesota Pollution Control Agency

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Speaker

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2

Please:

- Ask Questions!
  - At Any Time
  - About Anything
- Share Your Experiences
- Cell Phones Off
  - Voice
  - Text

3

Agenda

- 8:00 to 8:30 Electric Costs, Baselines, and Benchmarks
- 8:30 to 9:00 Energy Conservation Opportunities
- 9:00 to 9:30 Aeration Systems
- 9:30 to 9:40 Break
- 9:40 to 10:00 Pumping Systems
- 10:00 to 10:30 VFDs and Controls
- 10:30 to 11:00 Payback, Financing Options
- 11:00 to 11:15 Measurement and Verification
- 11:15 to 11:30 Q and A
- 11:30 Adjourn

4

Is Electric Power Cost Significant for wastewater treatment?

- Energy for WWTP (WRRF) represents 30% to 60% of the typical municipality's energy use
- Electric power accounts for 15% to 40% of the operating budget for the typical WRRF
  - Second only to staffing
  - The smaller the plant the greater the impact of energy: 35% is typical for small plants
- Electricity for water and wastewater treatment represent about 4% of the total US electric power use

YES

5

Electric Power Cost and Benchmarks

- Electric energy costs are complex
- They reflect utility costs for generation and distribution
- Very few operators or managers actually see electric bills
  - Even fewer understand them
- Work with your utility's engineers!
  - They want to help you save energy
  - Conservation measures may be mandated by law or driven by need to avoid building new generators
  - They can provide usage history, demand charts, rate details, etc.
- The objective is to reduce COST, not just consumption

6

Electric Power Cost and Benchmarks

- Energy ≠ Power ≠ Electric cost
- Energy = Capacity to do work (kWh, ft-lb)
- Power = Work done per unit time (kW, hp)
- Cost = Expenditure required to obtain electricity
  - Cost = Money and other outlays (time, CO_2, labor, water …..)

7

Electric Power Cost and Benchmarks

- ***Energy*** cost usually consists of several components:
  - Time of Day Energy Consumption
  - On-Peak 9:00 AM to 9:00 PM weekdays for typical customer
    - 60 hours per week
  - Off-Peak Weekends and Nighttime
    - 108 hours per week
- Peak Demand ***Power*** = Average Power Consumption Over 15 Minutes During On-Peak
- Power Factor – may be assessed against peak demand
  - if PF < 85%

8

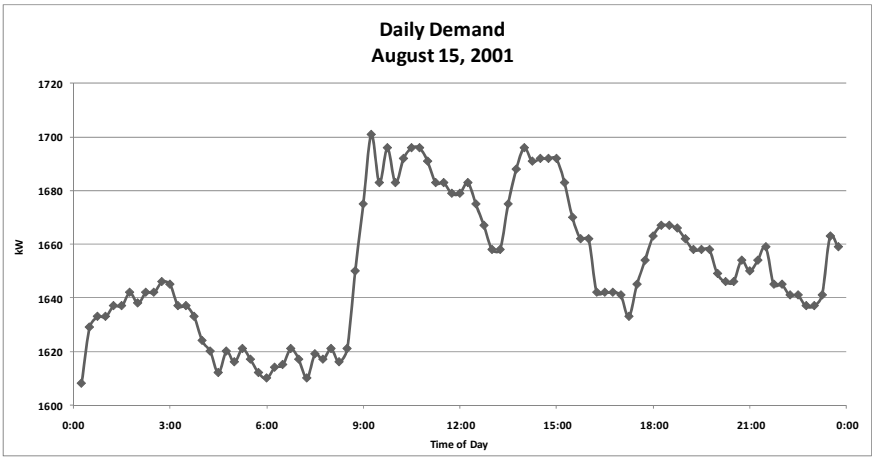
Electric Power Cost and Benchmarks

- Typical WWTP 1/3 On-Peak $, 1/3 Off-Peak $, 1/3 Demand $
- Billing structures usually vary with the amount of power used
  - Small users like a pump station may have only fixed rate energy charges
    - $0.08 per kWh typical
  - Slightly larger requirements may justify time of day billing
  - Large users like a mid-size treatment plant will probably have demand charges in the billing structure
- The additional revenue must offset the cost of more expensive metering

9

Electric Power Cost and Benchmarks

- Sample wastewater treatment plant demand profile:



Courtesy Wisconsin Focus on Energy

10

Electric Power Cost and Benchmarks

- Determining Composite ("average") power cost

Fictional Sample Electric Bill

Charge	Usage		Rate	Cost of	Total
Service and Meter				$500	5%
On-Peak Energy	41,000	kWh	$0.08	$3,280	30%
Off-Peak Energy	65,000	kWh	$0.07	$4,550	41%
Demand	280	kW	$8	$2,240	20%
Taxes			5%	$528.50	5%
Total	106,000			$11,099	
Composite Rate				0.1047 $/kWh	

11

Electric Power Cost and Benchmarks

A statistician is a man who drowns in a river with an average depth of 3 feet.

Anonymous

12

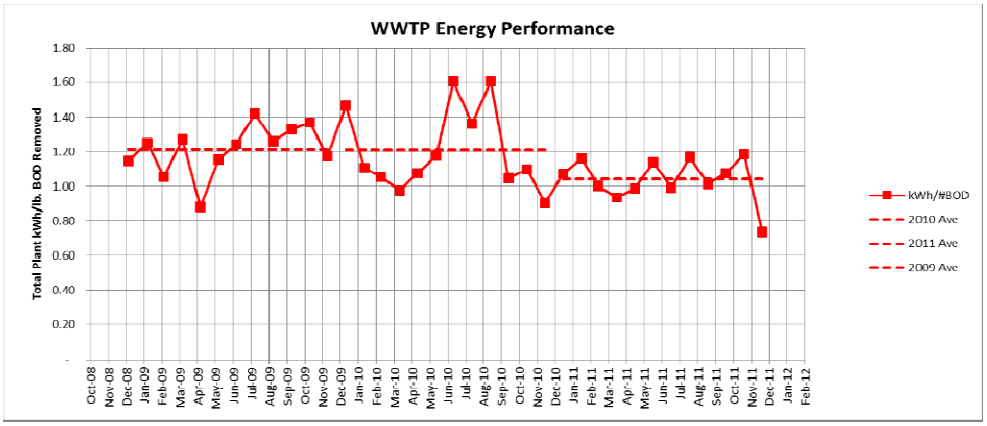
Electric Power Cost and Benchmarks

- "Metrics" are parameters or combinations of parameters that allow comparison between measurements from different times and places
  - kWh per degree day
  - Cost per year for electricity
  - kWh per MG (kilowatt hours per million gallons) treated
  - kWh per lb. BOD removed
- A "baseline" is performance developed from operating data and energy cost to establish existing energy consumption
- A "benchmark" is the expected performance for a similar facility employing "best practices"

13

Electric Power Cost and Benchmarks

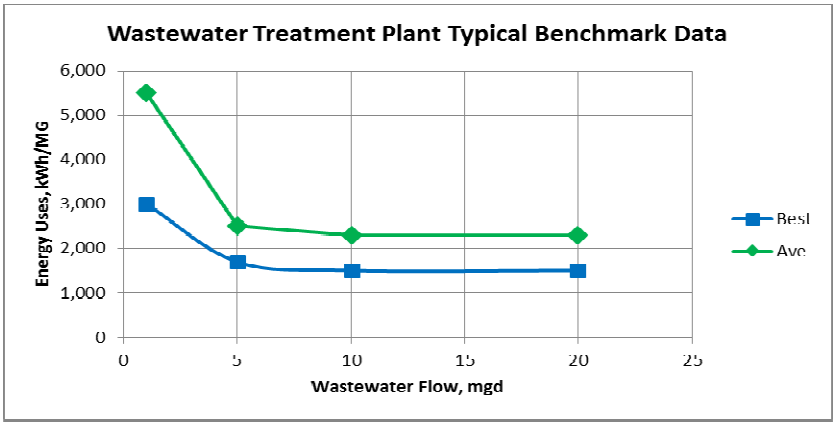
- Example Baseline:



14

Electric Power Cost and Benchmarks

- Typical Benchmark:



15

Energy Conservation Opportunities

- Collect Baseline Energy Cost
- Collect Baseline Process Data
- Record Process Equipment Data
- Benchmark Energy Consumption
- Identify, Prioritize, and Recommend ECMs (Energy Conservation Measures)

16

Energy Conservation Opportunities

- ECMs are usually implemented based on financial justification alone
- Process benefits are a bonus
- Better Efficiency ≠ Lower Energy
- The Most Efficient System May Not Have Lowest Power Requirement
  - Efficiency Is Often Misinterpreted
  - Gozoutas Divided By Gozintas
- Operation at design point or at steady state is almost non-existent in WWTPs
- You don't pay for efficiency, you pay for energy and power!

17

Energy Conservation Opportunities

- Process considerations ***always*** take precedence over energy or cost
  - They don't build plants to save energy!
- Energy improvements usually mean process improvements as well
- Limits on process equipment may limit energy savings
  - Blower and pump turndown
  - Aeration basin mixing

18

Energy Conservation Opportunities

- Look for continuously running loads
  - 1 year = 8760 hours continuous running
  - 1 year of 40 hours/week = 2080 hours
    - Some utility rebate programs require a minimum of 2080 hours/year to qualify
  - Examples:
    - Influent pumps, RAS pumps
- Seasonal or intermittent loads OK if they create demand charges
- Look for loads that start and stop frequently
  - Demand charges can be significant compared to continuous running
  - May indicate over-sized equipment
  - Examples: Float switch controlled pumps, Belt presses and centrifuges

19

Energy Conservation Opportunities

- Look for high horsepower loads
  - For a given % savings cost reduction will be higher
    - Cost of ECM may also be higher
  - Examples: Influent pumps, Aeration blowers
- Look for loads where equipment capacity exceeds process current process demand
  - Equipment is often designed for 20 plant year life and worst case operating conditions
    - Sometimes designers specify two units @ 100% worst case design capacity units
    - Might be better to have 4 units @ 33% capacity or 2 @ 50% + 2 @ 25%
    - Turndown capability may be ignored
  - Examples: Lift station pumps, Blowers and mechanical aerators, Booster pumps

20

Energy Conservation Opportunities

- Integrated Approach Is Essential
- Process impacts must be discussed in ECM justification
- Instrumentation may require upgrading
- Include SCADA and PLC requirements in cost estimates
- Accommodate current and near term loads (hydraulic and organic)
- Adjustability and flexibility are important (turndown)
- Many opportunities require no capital investment
  - Taking aeration tanks out of service, perform operations off-peak

21

Energy Conservation Opportunities

- Must include time of day and demand in calculations
  - Average wastewater flow During On-Peak Time = 115% of ADF (Average Daily Flow)
  - Average wastewater flow During Off-Peak Time = 85% of ADF
  - Peak wastewater flow (basis of Demand Charge) = 120% of ADF
- Impact on demand charges of starting equipment is exaggerated
  - Demand charge is averaged over 15 minutes
  - Inrush at starting is only seconds (or less)
  - Operation of two loads during “warm up” creates high demand

22

Energy Conservation Opportunities

- You can reduce cost without reducing energy
  - Take advantage of time of day rates
    - Operate, start and alternate equipment at off-peak times
      - Alternating blowers and pumps
      - Running sludge storage and digestion mixing
      - Testing equipment
        - Notify electric utility **BEFORE** testing
      - Bumping diffusers
      - Treating hauled in wastes
      - Side streams like decanting digesters
        - Equalization can save energy and demand charges
      - Backwashing filters

23

Energy Conservation Opportunities

- Don't wait for the next upgrade or permit change to implement ECMs
- Don't just go by the savings in deciding to implement ECM
  - Payback is important
  - Low capital investment matters
  - Available utility incentives are important
  - Time needed to implement should be considered
- Don't just use design values for evaluation
- Don't just use average power cost for evaluation
- Don't just use nameplate motor horsepower for evaluation

24

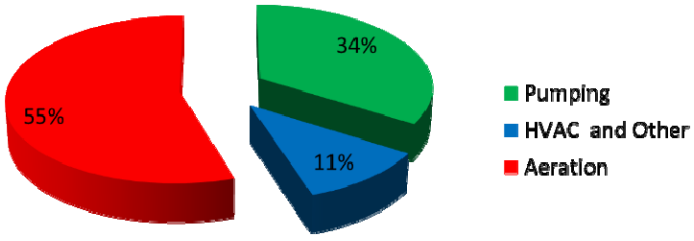
Energy Conservation Opportunities

- Examples:
- Reduce MLSS
- Match number of tanks in service to process needs
- Use equalization basins to limit loading variations to process
  - Influent and sidestream loads
- Flow pace RAS pumping
- Reduce WAS pumping rate and waste on off-peak times
- Thicken WAS before digestion
- Decant digesters on off-peak times

25

Aeration Systems

- Aeration is the most energy intensive operation in most WWTPs
- Activated sludge is the most common treatment process
  - Hundreds of variations are in operation



26

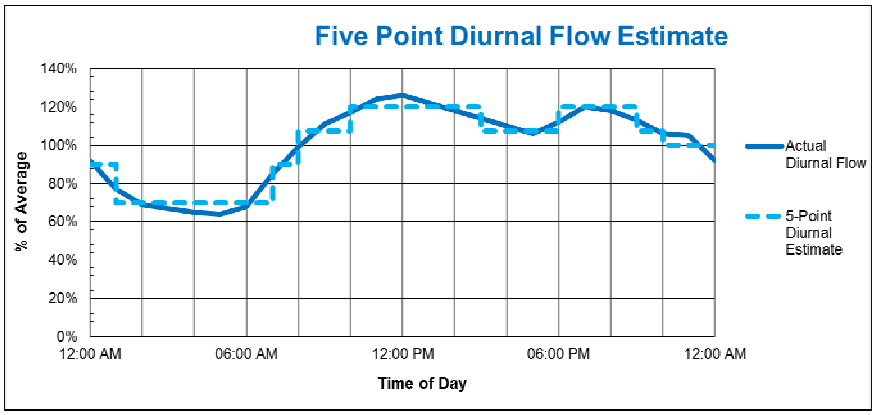
Aeration Systems

- Aeration ECMs must consider BOTH ends of the air system
  - Aeration basins and process demand
  - Blower/aerator efficiency
- Must consider type of aeration
  - Diffused
  - Mechanical
- Must consider limitations of equipment and process
  - Blower/Aerator Turndown
  - Diffuser min/max flow
  - Mixing Limits

27

Aeration Systems

- Efficiently matching O_2 supply to variable loads is the source of many aeration system savings



28

Aeration Systems

- Process and aeration system limitations are often neglected in energy evaluations
  - Mixing limits in aeration basins
    - Can accomplish with intermittent aeration
  - Max flow for diffusers
  - Min flow for diffusers
  - Tanks must be protected from floating and freezing
  - O_2 demand and OTE constantly vary
- Primary objective: supply O_2 needed to metabolize waste
- Secondary objective: Do it at the lowest possible energy cost

29

Aeration Systems

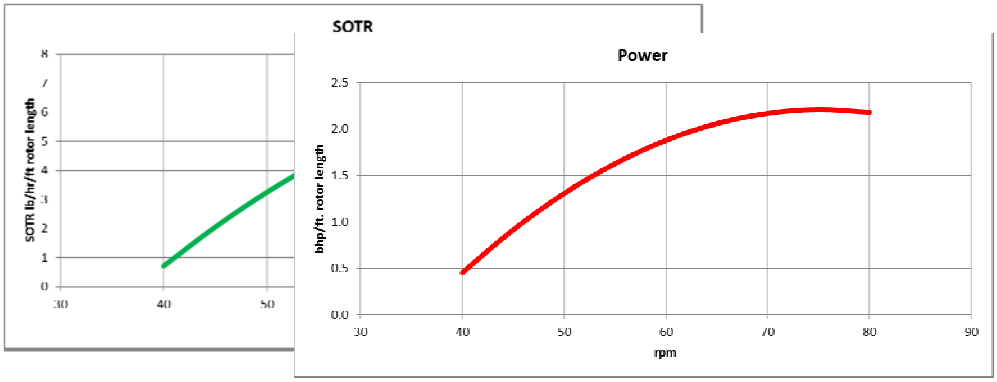
- ECMs include variable speed or On/Off control for mechanical aerators
  - Timer based or DO based
  - Most DO probes have Hi/Lo "alarm" contacts that can control aerators
  - Timers are usually added to limit off time
- Mixing is maintained after aerators turn off
  - Solids re-suspend quickly



30

Aeration Systems

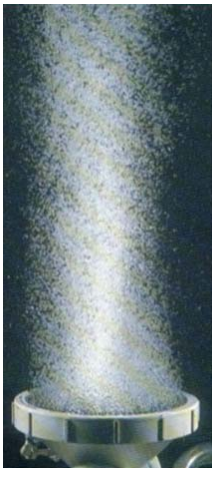
- With variable speed OTR drops with speed, but power consumption drops off faster



31

Aeration Systems

- Generally more energy efficient than mechanical aeration
- Fine pore diffusers more efficient than coarse bubble
- Many variations are available
- Most common in new installations is EPDM membrane



32

Aeration Systems

- More efficient diffusers can save as much as 50% on air demand
- Diffuser performance is usually given as "Standard Oxygen Transfer Efficiency" (SOTE)
  - Standard Conditions:
    - 20˚C (68˚F) wastewater temperature
    - 0.0 ppm initial DO concentration
    - 14.7 psia barometric pressure
- Performance must be corrected to field conditions for accurate comparison
  - Varies with air flow per diffuser

33

Aeration Systems

- Blowers typically receive the most attention in aeration ECMs
- Modulating blower air flow to match process demand is the best way to achieve savings
- Blower power consumption is more complex than pumps
  - Type and size of blower influences efficiency
  - Power consumption varies with flow and pressure
  - Power consumption varies with air density for given flow and pressure
  - Flow may be expressed as ICFM or SCFM – makes comparisons difficult
- Energy savings varies greatly with type of control
  - Each type of blower has different requirements for control method

34

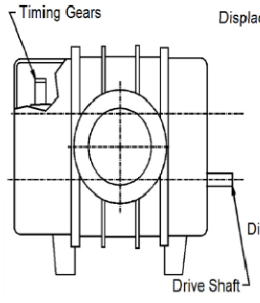
Aeration Systems

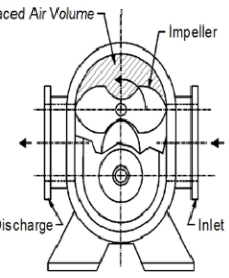
- Blowers produce flow, not pressure
- Blower control method is a function of the type of blower
- All types of blowers have limits on safe operation
  - Max pressure – limited by physical damage (both PD and centrifugal) or capability (centrifugal only)
  - Min flow – limited by heat (both PD and centrifugal) or surge (centrifugal)
  - Max flow – limited by motor power or physical limits of bearings and rotors
- Turndown is usually more important than efficiency
  - Most blowers can provide turndown of ≈ 50%
  - **Too much air at high efficiency is still wasted energy!**

35

Aeration Systems

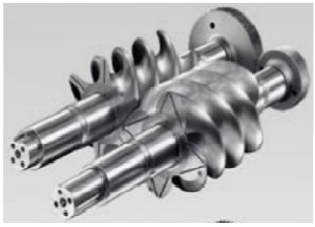
- Lobe type positive displacement (PD) blowers are "established" technology (1855)
- Every revolution moves a fixed volume of air
- VFD control is only practical method

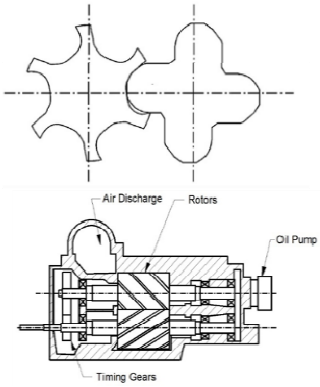




Aeration Systems

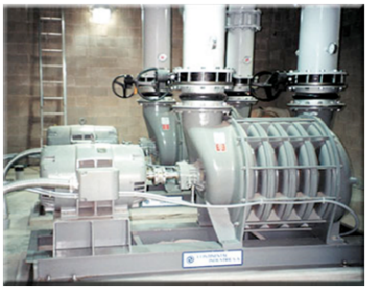
- Screw type positive displacement (PD) blowers are newer technology, only recently being applied to water/wastewater
- More efficient in many cases than lobe type
- VFD control is most practical method

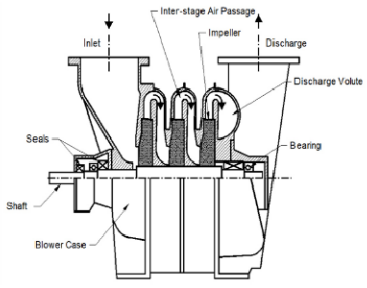




Aeration Systems

- Three types of centrifugal (dynamic) blowers are in common use
- Multistage is the most common in mid size plants
- Obtain required pressure by series compression

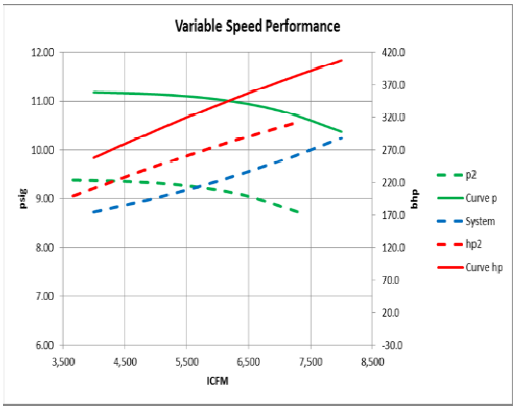




38

Bowers and Blower Control

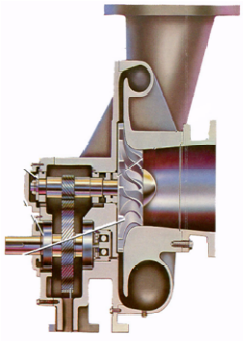
- Multistage blowers can be controlled by throttling or VFD
- VFD is much more efficient
  - With VFD power consumption can be close to single stage or turbo blower power

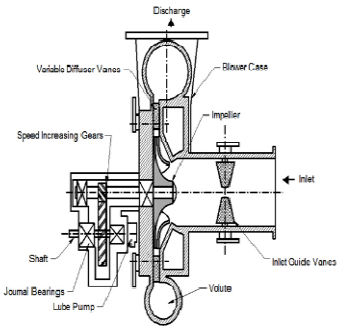


39

Aeration Systems

- Single stage (geared) centrifugal blowers are generally used in large plants
- Can be controlled by throttling, guide vanes, or VFD
  - VFD most efficient, medium voltage VFDs now cost effective
  - Obtain required pressure with high speed impeller





40

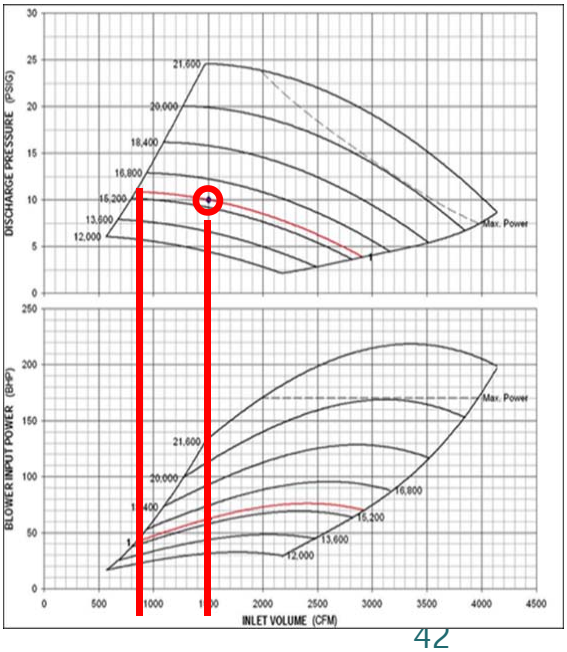
Aeration Systems

- Turbo blowers are newest technology
- Always have integral controls and VFDs – this is main source of high efficiency
- Technically single stage, they also obtain pressure with high speed impeller
- Direct coupled motors operate at > 60 Hz and high rpm

41

Aeration Systems

- Turbo blower turndown may be limited
- For any blower specify more than one performance point!



42

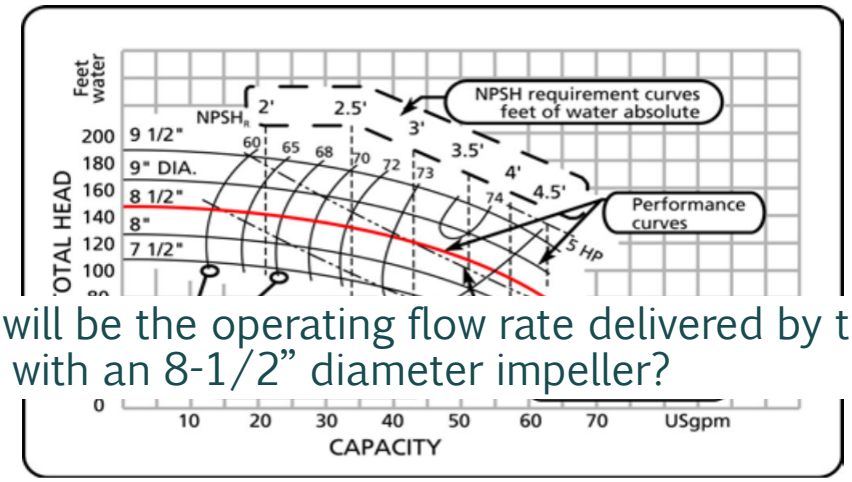
Break Time! Please be back in 10 minutes.

Pumping Systems

- Pumps are the most common equipment in most WWTPs
- Most are centrifugal pumps of one type or another
- Three variables control pump energy
  - Flow rate
  - Pressure
  - Efficiency
- There isn't much you can do about efficiency in existing pumps
- Flow should be matched to process demands
- Reducing flow may also reduce head

44

Pumping Systems

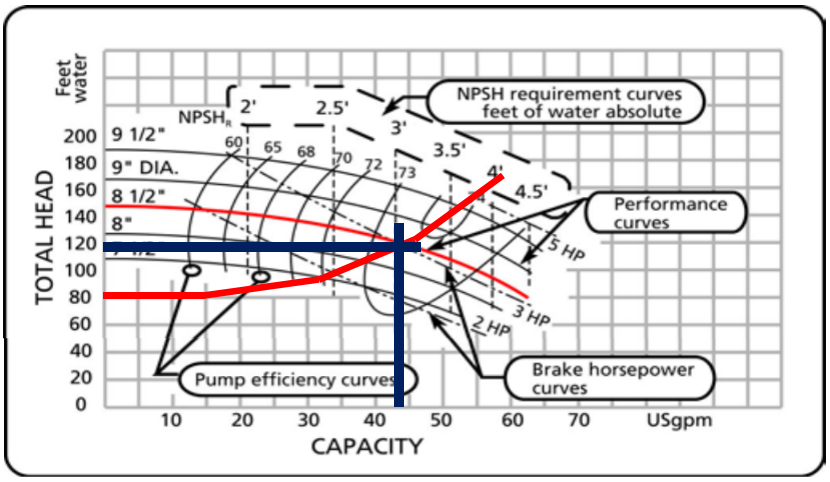


What will be the operating flow rate delivered by this pump with an 8-1/2" diameter impeller?

- Pump curves have a lot of info and should be consulted before implementing ECMs

45

Pumping Systems



- You can't tell performance without adding the system curve

46

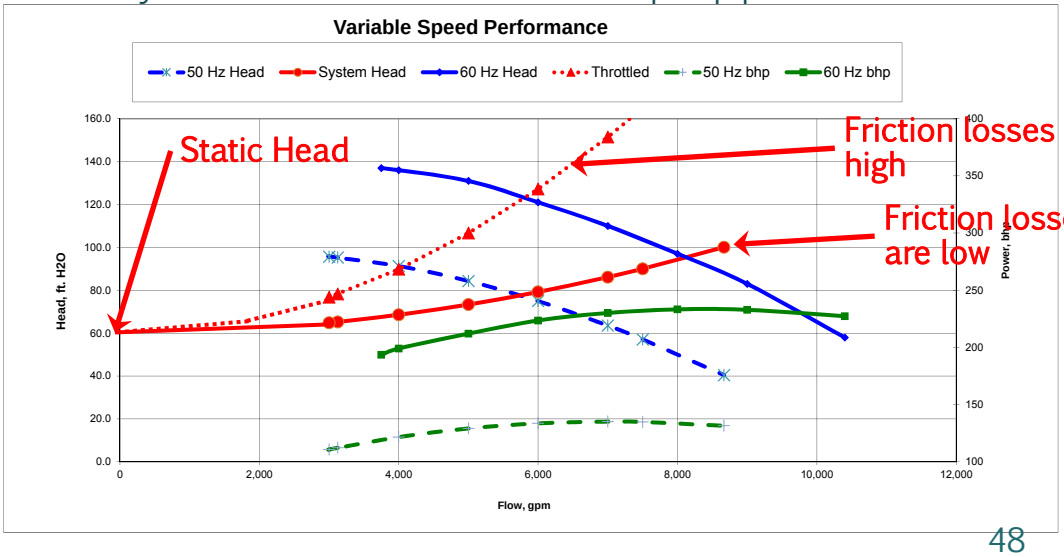
Pumping Systems

- Variable speed pumping is commonly used to reduce pump power
- Affinity laws:
  - Flow is reduced by ratio of speeds
  - Head is reduced by square of ratio of speeds
  - Power is reduced by cube or ratio of speeds
- Affinity laws must be applied to points on pump curve, not the current operating point!
- System curve affects new operating point

47

Pumping Systems

- The system curve is needed to evaluate pump performance:



48

Pumping Systems

- Pumping continuously at lower flow rate may or may not save cost compared to on/off control at higher flow rate
  - If head is mostly friction: pumping continuously at a lower flow rate will cut energy and power, reducing energy charges and demand charges
  - If head is mostly static lift: power will be reduced but total energy won't change much
    - If there are demand charges cost will be reduced
    - If there are NOT demand charges cost will be unchanged
- Some considerations for variable speed pump control
  - Periodic high flow operation to flush wet wells and pipes
  - Ramp speed to eliminate water hammer
  - Select pumps with BEP to the right of typical operating speed

49

Pumping Systems

- If design flows greatly exceed operating flows, sizes should be examined for pumps AND motors
- Replacing or adding smaller pumps may be cost effective
- Changing only some pumps may be feasible
  - Can accommodate seasonal variations
- If actual heads are much lower than design head the pump may operate too far to the right of the curve
  - This isn't near the BEP (Best Efficiency Point)
  - May also result in overheating, vibration and mechanical damage
- If excess throttling is employed operation too far to the left can have similar issues

50

Pumping Systems

- Trimming or replacing impellers can be very cost effective
  - Reducing impeller diameter has the same impact as reducing speed
  - Save the old impellers for future flow increases
  - Usually limited to 75% of max diameter
  - Must watch NPSHR (Net Positive Suction Head Required)
- The affinity laws for diameter change are similar to those for speed change
- Trimming only some pumps may be feasible
- The system curve is needed to verify performance
- Always coordinate with pump manufacturer

51

Pumping Systems

- Many pumps have more capacity than specified design point
- Energy may be saved by installing a larger motor
  - One pump running continuously may be less power than two running intermittently
  - Continuous running may reduce demand charges

52

Pumping Systems

- It is the differential head across the pump that dictates power draw
- Power can be saved by raising wet well levels
- Example: for a typical 700 gpm pump (1 mgd) with power at $0.11 per raising wet well level 1 foot will save almost $200 per year
- Zero cost to implement

53

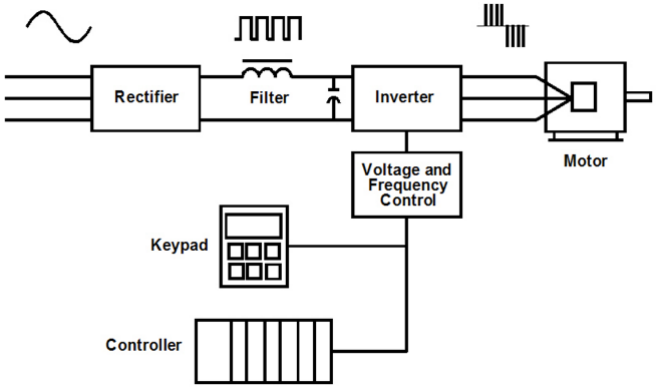
VFDs and Controls

- The Variable Frequency Drive (VFD) is the technology of choice for most applications
- Typically 3-Phase Input
  - 4160 VAC
  - 480 VAC
  - Output Voltage Cannot Exceed Input Voltage
- Available with a wide variety of packaging, enclosures, features, communications options
- Can be liquid cooled in higher power ratings

54

VFDs and Controls

- Converts 60 Hz AC Input to output at required frequency (Hz)
  - Converts AC input to DC
  - Converts DC back to AC



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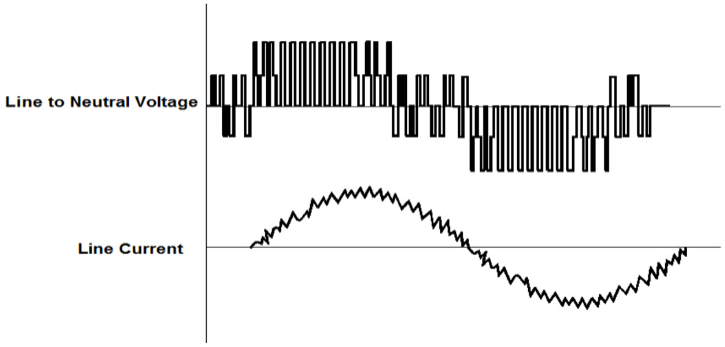
VFDs and Controls

- Most modern VFDs are Pulse Width Modulated (PWM)
- The inductance of the motor attenuates the current waveform to approximate a sine wave.



56

VFDs and Controls

- Some application considerations for VFDs
  - Most utilities offer incentives for installation
  - Harmonics may be an issue – work with your suppliers
  - Bearing fluting is a rare but severe problem
  - Good grounding and keeping power wiring short minimize problems
  - For positive displacement pumps and blowers constant torque rated VFDs are required
  - VFDs will affect standby generator sizing

57

VFDs and Controls

- Avoid over-specifying
  - NEMA 1 Enclosures usually adequate
  - Sensorless vector and other advanced controls usually not needed
  - Bypass contactors not usually required on current designs
- Can apply to existing motors if:
  - Motor has Class F insulation or better, has service factor of 1.15, is running at or below rated output
- VFDs limit starting current, provide motor overload protection

58

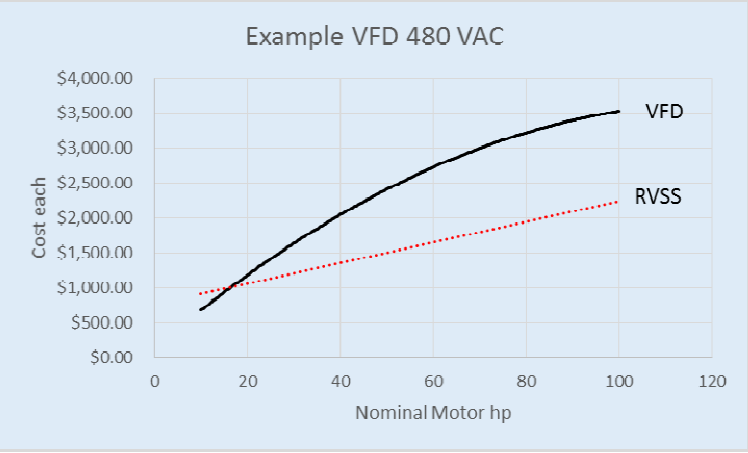
VFDs and Controls

- RVSS (Reduced Voltage Solid state Starters) or "soft starts" are not energy savings devices
- Reduce the inrush current and resulting heat induced damage for motors
- Demand savings claims for soft starts are often overstated
  - Inrush is only a few seconds
  - Demand charges are averaged over fifteen minutes

59

VFDs and Controls

- In smaller sizes VFDs may cost less than soft starts



60

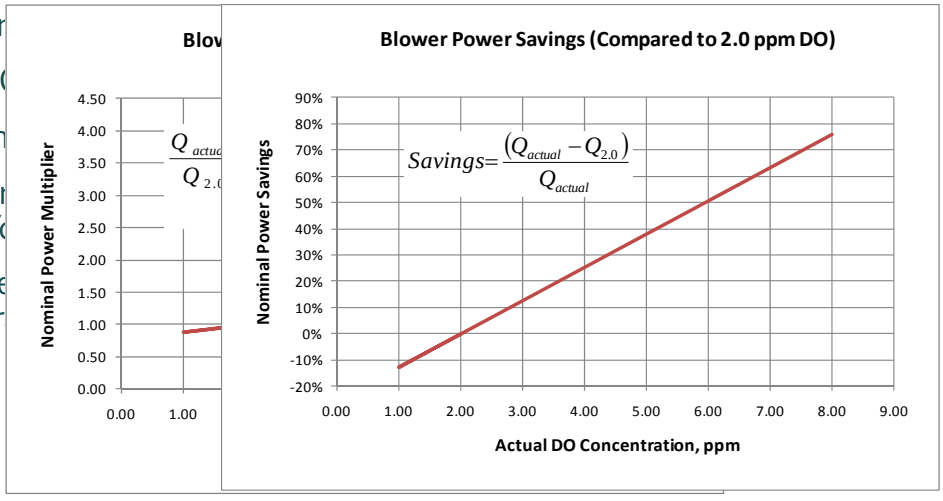
VFDs and Controls

- Controls are often the most cost effective ECMs available
- Capital cost is often low
  - Existing equipment may be used
- Examples:
  - Variable speed control of pumps and blowers
  - Wet well level control for pumps
    - Eliminates on/of cycling at constant speed
  - DO control for aeration
  - Automatic alternation of pumps and blowers during off peak hours

61

VFDs and Controls

- DO Contr
- Excess D
- Optimizin
- The differ "driving f
- The highe transfer r



62

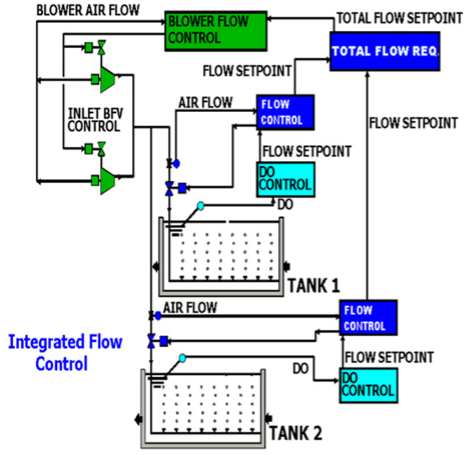
VFDs and Controls

- The function of DO control is to match air flow rate supplied by the blowers to the air flow rate demanded by the process
- Typically 25% to 50% savings compared to manual control
- Many variations and refinements are available
  - Most-Open-Valve (MOV) logic
  - Constant pressure or direct flow control based logic
  - Proportional-Integral-Derivative (PID) or proprietary control logic
  - Individual basin and individual zone control
- Savings come from eliminating excess aeration during low flow periods

63

VFDs and Controls

- Typical DO Control System for diffused aeration:



64

VFDs and Controls

- Blower and aeration control logic must be integrated
- For any automated WWTP control use suppliers that understand the process and the equipment
- Include manual overrides for all equipment
- Include connection of new equipment into SCADA

65

Payback, Financing Options

- An ECM should pay for itself with energy cost savings
- The time allowed for payback varies
- Municipal systems generally allow five years or more
- Industrial systems generally allow two years or less
- Determine the acceptable payback period before beginning energy audit

66

Payback, Financing Options

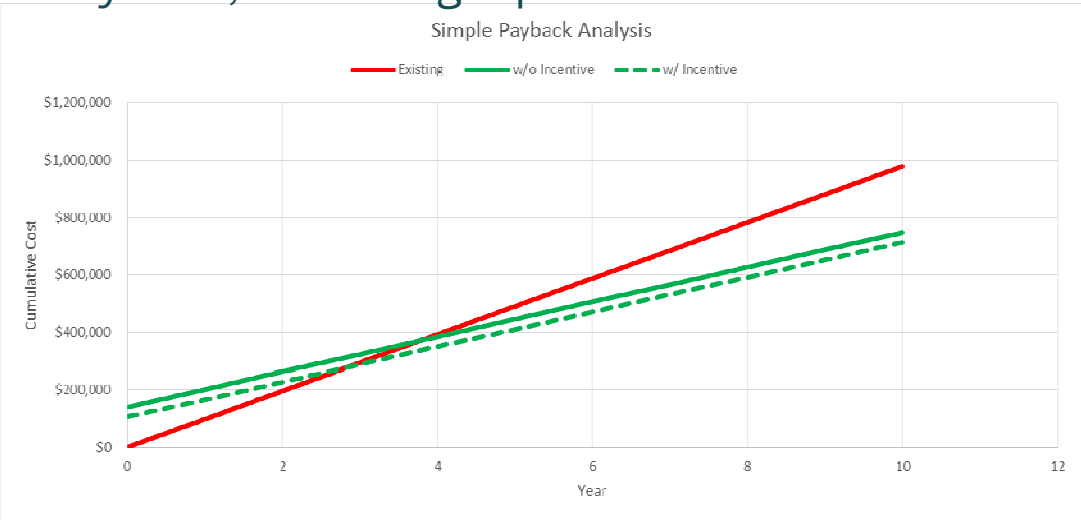
- Present worth
  - Can be more accurate for long evaluation periods
  - Requires more assumptions
    - Cost of money
    - Inflation rate
  - More difficult to calculate
- For most ECMs simple payback is preferred:

$$\text{Payback Period, Years} = \frac{\text{Installed Cost}}{\text{Savings per Year}}$$

- Graphing calculation results can add clarity

67

Payback, Financing Options



68

Payback, Financing Options

There are three kinds of falsehoods: lies, damned lies, and statistics.

Mark Twain

- Savings for multiple ECMs must be evaluated correctly

69

Payback, Financing Options

- You can't just add:

ECM		Savings
Better Diffusers	+	50%
DO and Blower Controls	+	25%
VFDs for Blowers	+	18%
High Efficiency Motors	+	12%
		105%

70

Payback, Financing Options

- You can't just add:

ECM	Savings
Better D[illegible]users	50%
DO an[illegible]Blower Con[illegible]ls +	25%
VFDs [illegible]r Blowers +	18%
High E[illegible]icienc[illegible]Motors +	12%
	105%

Will the Electric Company Owe You Money?

71

Payback, Financing Options

- You can't just multiply percentages:

ECM	Savings
Better D[illegible]users	50%
DO an[illegible]Blower Con[illegible]ls x	25%
VFDs f[illegible]Blower x	18%
High Ef[illegible]ienc[illegible]Motors x	12%
	27%

Are the savings only 27% of the original energy?

72

Payback, Financing Options

- Proper technique:

ECM	Savings		1-Savings
Better Diffusers	50%	x	50%
DO and Blower Controls	25%	x	75%
VFDs for Blowers	18%	x	82%
High Efficiency Motors	12%	x	88%
Multiply the last column: Result=New Power as Percentage of Original			27%
Savings = 1-Result:			73%

73

Payback, Financing Options

- Most utilities have some incentive programs
  - Sometimes referred to as "rebates"
- May be mandated by legislation
- Usually paid for from utility bills "conservation fund"
- Incentives may be prescriptive or custom

74

Payback, Financing Options

- Energy audits may be partially paid for as incentives
- Engineering design fees may be partially paid for as incentives
- Contact your local utility representative for info on programs
  - Pre-approval may be required

75

Payback, Financing Options

- Prescriptive Incentives have a “prescribed” value based on specific criteria
- Example: the utility may pay $35 for each light fixture upgraded from metal halide to high efficiency LED fixture
  - Must be at least 250 Watts
  - Must be in a continuously occupied area
  - New fixture must be less than 155 Watts
- Example: the utility may pay set dollar amount for replacing standard motors with premium efficiency motors
  - Incentive based on nameplate hp
  - Equipment must be used at least 2,000 hours per year

76

Payback, Financing Options

- Example: the utility may pay $40/hp for putting a VFD on a load that is currently constant speed
  - Equipment must be used at least 2,000 hours per year
  - Load must provide savings at reduced speed – for example, a centrifugal pump, and may require automated process control (not manual control)
  - Incentive may be capped at a percentage of total project cost (30% max for example)
  - Program may be capped at total motor hp (less than 500 hp for example)

77

Payback, Financing Options

- Custom Incentives provide an incentive as a percentage of project cost provided certain criteria are met
- Example: the utility may pay up to 50% of the project cost for a process based load, such as replacing old aeration blowers with high efficiency units
  - Usually requires an up front engineering evaluation – which may be partially paid for as part of the incentive
  - Usually requires a payback of more than 1 year
    - If less than 1 year you should do it anyway!
  - Usually requires measurement and verification of saving after project installation

78

Payback, Financing Options

- Custom Incentives are usually structured to meet utility priorities
- May be based on different criteria
  - Reduction in total energy use
  - Reduction in peak demand
  - Reduction in on-peak energy use
- Incentives usually change on an annual basis
  - It is important to include time limitations in ECM selection

79

Payback, Financing Options

- Incentive cost justification should be calculated without including incentives
- The utility has ultimate authority on whether or not a project will qualify
- The utility must review the project for incentive qualification **BEFORE** it is started
- The incentive is often critical to getting approval for a project
  - An incentive can move a project from marginal cost effectiveness to "no-brainer" status
  - Improves payback
  - The allure of "free money"

80

Measurement and Verification

- Investigate Utility Incentives
- Obtain Pricing, Including Installation
- Implement ECM(s)
- Measure and Verify Savings

81

A Note About Safety:

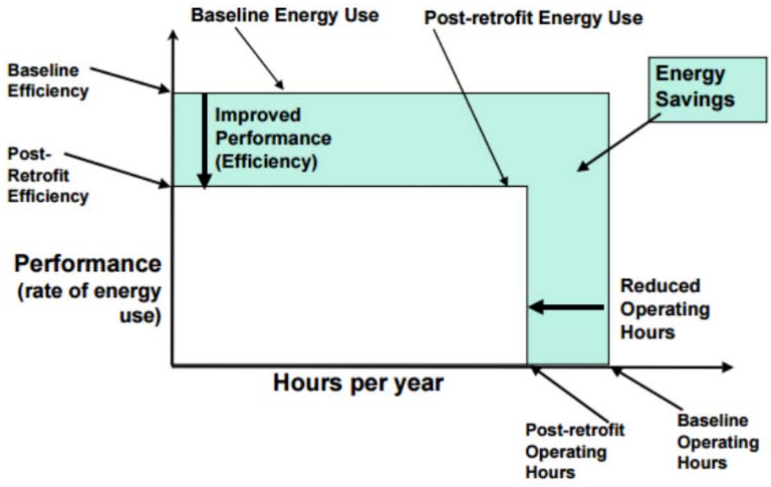
82

Measurement and Verification

- Measurement and verification may be simultaneous with testing and tuning
- Serves several purposes
  - Establish a record of the system's performance for future reference in tuning and problem diagnostics
  - Obtain acceptance by the utility and release of incentive payments
  - Provide verification of contract requirements
  - Provide the data required for a design review for use in refining future estimates and designs

83

Measurement and Verification



84

Measurement and Verification

- Must begin planning for verification during project design stages
- Need to take measurements of existing performance to establish baseline
- Determine utility requirements up front
  - May need actual power monitoring
  - Amp readings alone may be adequate, but not as accurate
  - May want measurements over a time period
  - "Snapshot" data may be sufficient
- Measurements may use permanent metering equipment or handheld / temporary test equipment
- Measurement of total plant power probably not good enough

85

Measurement and Verification

- Sub-metering is the best method - using power monitoring
- With portable instruments either verify accuracy or use the same instrumentation for before and after testing

- Don't use clamp on ammeter for VFD output!

86

Measurement and Verification

- Incentives may be based on demand reduction or energy reduction
- Notify utility before testing to eliminate demand charges
- Compare before and after data using the same metric:
  - kWh per MG treated
  - kWh per pound of BOD removed
  - Wire to air efficiency of pumps and blowers
  - kWh per gallon pumped
- Use data and experience for ongoing energy conservation efforts!

87

Q & A

88

Thank you for your attention and attendance!

Feel free to contact me for additional information or a copy of this presentation.

Tom Jenkins
414-352-5713
info@jentechinc.com

Some Basic Formulas

- Power calculations:

If voltage and current are known:

$$kW = \frac{Volts \cdot Amps \cdot \sqrt{No.\ Phases} \cdot Power\ Factor}{1000}$$

Can get Power Factor from motor data sheets. For estimating Power Factor use 0.90 at 100% load, 0.80 at 50% load

If actual load power draw is known:

$$kW = \frac{hp \cdot 0.746}{efficiency_{motor} \cdot efficiency_{VFD}}$$

90

Some Basic Formulas

- Calculating Savings
  - With Composite Rates

$$\text{Annual Savings} = \text{kW} \cdot \frac{\$}{\text{kWh}} \cdot 8760 \frac{\text{hours}}{\text{year}}$$

  - With actual rates (Ignores Power Factor Charges)

$$\text{Annual Savings} = \sum \text{On Peak\$} + \text{Off Peak\$} + \text{Demand\$}$$

$$\text{On Peak\$} = \text{kW} \cdot \frac{\text{On Peak \$}}{\text{kWh}} \cdot \frac{60 \text{ hours}}{\text{week}} \cdot \frac{52 \text{ weeks}}{\text{year}}$$

$$\text{Off Peak\$} = \text{kW} \cdot \frac{\text{Off Peak \$}}{\text{kWh}} \cdot \frac{108 \text{ hours}}{\text{week}} \cdot \frac{52 \text{ weeks}}{\text{year}}$$

$$\text{Demand\$} = \text{kW}_{\text{peak}} \cdot \frac{\text{Demand \$}}{\text{kW}} \cdot \frac{12 \text{ months}}{\text{year}}$$

91

Some Basic Formulas

- Pump Affinity Law Calculations

$$\frac{Q_2}{Q_1} = \frac{\text{rpm}_2}{\text{rpm}_1}$$

$$\frac{H_2}{H_1} = \left(\frac{\text{rpm}_2}{\text{rpm}_1}\right)^2$$

$$\frac{P_2}{P_1} = \left(\frac{\text{rpm}_2}{\text{rpm}_1}\right)^3$$

Q = flow rate
H = head
P = power

92

Some Basic Formulas

- Pump Power Calculations

$$kW = \frac{Q \cdot h}{5300 \cdot \eta_p \cdot \eta_m \cdot \eta_{VFD}}$$

kW = electric power for pump **system**
Q = flow, gpm
h = differential head, ft.
η_p = pump efficiency, decimal
η_m = motor efficiency, decimal
η_{VFD} = drive efficiency, decimal

93

Some Basic Formulas

- Converting Volume Flow Rate to SCFM (Mass Flow Rate)

$$Q_s = Q_i \cdot \frac{p_i \cdot 35.92}{T_i}$$

Q_s = mass flow rate, standard cubic feet per minute (68 °F, 14.7 psia, 36%RH)
Q_i = inlet volumetric flow rate, cubic feet per minute
p_i = actual pressure, psia
T_i = actual temperature, °R

94

Some Basic Formulas

- Calculating Turndown

$$\text{Turndown\%} = \frac{Q_{max} - Q_{min}}{Q_{max}} \cdot 100$$

$Q_{max,\ min}$ = maximum and minimum safe flow rates, ICFM or SCFM

95

Some Basic Formulas

- Aeration Calculations

$$HRT = \frac{1.795 \cdot 10^{-4} \cdot V_t}{Q_{ww}}$$

HRT = Hydraulic Retention Time, hours
V_t = Volume of tank, cu ft
Q_{ww} = wastewater flow, mgd

96

Some Basic Formulas

- Aeration Calculations

$$\text{Required}O_{2\ BOD} = 1.1\frac{lb_{O2}}{lb_{BOD}}$$

$$\text{Required}O_{2\ NH3} = 4.6\frac{lb_{O2}}{lb_{NH3}}$$

$$SCFM = \frac{0.335 \cdot mgd}{OTE} \cdot (1.1 \cdot ppmBOD_{removed} + 4.6 \cdot ppmNH3_{removed})$$

97

Some Basic Formulas

- Blower Power

$$kW = \frac{Q \cdot p_i \cdot \left[\left(\frac{p_d}{p_i}\right)^{0.283} - 1\right]}{86.88 \cdot \eta_b \cdot \eta_m \cdot \eta_{VFD}}$$

kW	= electric power for blower system
Q	= volumetric flow, ICFM
p_i, p_d	= inlet and discharge pressure, psia
η_p	= blower efficiency, decimal
η_m	= motor efficiency, decimal
η_{VFD}	= drive efficiency, decimal

98