Documenting and Improving Energy Use in Water Quality Systems

Premium Efficiency

Demand

ON-PEAK

kWh/MG

off-peak

Simple Payback

thermography

TDH

kVAR

kWh

Restructuring

Horsepower

gpm

Predictive Maintenance

Table of Contents

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Introduction

Documenting and Improving Energy Use in Water Quality Systems was written to provide energy conservation guidance and information to water quality personnel. While reading through *Documenting and Improving Energy Use* a number of the energy conservation measures (ECMs) will be familiar to individuals working at well-managed utilities. This is because good operations naturally result in energy conservation.

Documenting and Improving Energy Use provides an easy to follow format for identifying areas where ECMs may be available. For any program to be successful, management level personnel need to be involved and supportive. Management must:

1. Demonstrate a real commitment to energy conservation, which demonstrates a commitment to good operation and maintenance.
2. Provide responsibility and authority to individuals to investigate potential ECMs. A mechanism for identifying, monitoring and reporting the benefit of ECMs must be established.
3. Provide proper recognition of the people involved in making the whole process work. The potential for reducing the energy budget is very real. However, the commitment of every employee is required.

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UNIT I: SYSTEM EVALUATION CHECKLISTS

Several major systems in the water quality area with the greatest potential for ECM identification and implementation are evaluated in a checklist format.

1. Measurement/Observation - This part of the evaluation identifies information to be gathered or observed. This information may not directly relate to energy use. However, it is background information required to evaluate the overall energy efficiency of the plant.

2. Check - This part of the evaluation explains to the evaluator what needs to be done with the Measurement/Observation data. Various standard procedures are referred to in this part. The standard procedures provide the detailed information required to perform the "Check."

3. Conclusion/Corrective Action - This part of the evaluation explains the possible directions that can be taken based upon the results of the "Check." Again standard procedures are referenced to provide the details required to fully evaluate each possible action.

The System Evaluations are not intended to cover all possible ECMs or all the areas of water quality operations. They are intended to start the process of ECM identification. The conclusions and actions will need to be modified to work within the limitations of design, management, budget, personnel, etc. of the individual system.

UNIT II: STANDARD OPERATING PROCEDURES

The water quality field is becoming very technical. These standard procedures provide a common approach to the identification, evaluation and quantification of the energy management area of operations. They are intended to be a starting point to be used by water quality professionals toward the optimization of energy use.

UNIT III: STANDARD MAINTENANCE PROCEDURES

These procedures were developed to provide standard procedures for making electrical measurements and recommend specific energy related maintenance practices.

UNIT IV: FINANCIAL ANALYSIS

Justifying the additional capital or implementation costs often associated with energy conservative technologies is necessary. Unit IV describes methods that are used to calculate simple payback periods and annual worth. If the simple payback period is very short, the lost interest probably is not a consideration. However, annual worth allows the comparison of several alternative technologies and accounts for interest and salvage value at the end of the system's design life.

At the back of *Documenting and Improving Energy Use* a glossary and references are provided.

UNIT I: SYSTEM EVALUATION CHECKLISTS

LOAD MANAGEMENT EVALUATION

ELECTRICAL LOAD MANAGEMENT

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
Monthly electricity bill SOP 1-1	Time of Day and Demand charges billed.	Determine when peak electrical demands and/or flows occur, SOP 1-3. a. Perform a Energy assessment Survey, SOP 1-2. b. Evaluate load management strategies, SOPs 1-5 and 1-3.

FLOW MANAGEMENT

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
Large variations in flows.	Determine the flow/energy variations, SOP 1-3.	Reduce distribution flow peaks, SOP 1-3. Calculate pumping costs, SOP 1-4.
Large volumes of unaccounted for water	Perform an Unaccounted for Water Survey, SOP 3-1.	If unaccounted for water is excessive, SOP 3-2.

ELECTRIC MOTOR EVALUATION

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
Electrical evaluation	Voltage balance, SMP 1	Voltage unbalance <1%, system operating properly. Voltage unbalance >1%, unacceptable. a. Single phasing – check fuses, contact points, breaks in wiring or terminals, tighten screws. b. Determine if problem is in the supply or load. SMP 4.
	Voltage range, SMP 1.	Check SMP 1, Table 1 for acceptable operating ranges. Work with the power company for correction or replace motor.
	Amperage balance, SMP 2.	Amperage unbalance <5% at full load is acceptable operation. Amperage unbalance >5% at full load should be corrected.

ELECTRIC MOTOR EVALUATION

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
		a. Check voltage balance. b. Check for load changes. c. Check mechanical condition (bearing sounds, megger windings, exposure to sun, vibration, maintenance history, etc.). d. Check wiring for tightness and condition of insulation. e. Check contact points for arcing or dirt. f. Check for dirt accumulations and free circulation of airflow over the motor casing.
	Megger check, SMP 3	Monitor change over time when the resistance drops off rapidly the coils should be redipped or replacement planned. Insulation quality of any wires can be checked. This is useful for submersible pump power cables, SMP 3.
Match motor to load.	Percent full amperage being used, SMP 2 and SOP 2-2.	If operating in a poor efficiency range, resize motor. If over full load amperage: a. Reduce load. b. Check voltage and amperage balance. c. Provide shade or additional cooling. d. Check bearings, couplings, drives, etc.
	Electrical power being used by motor, SOP 2-1.	This calculation is useful to determine the amount of energy being used to drive a piece of equipment at a particular loading.
Standard efficiency motors being used.	Annual operating costs, SOP 2-2.	Compare operating costs for the installed motor and a premium efficiency model. Determine the financial benefits of installing an energy efficient motor (Unit IV).
Power factor is included in the electric bill, SOP 1-1.	Plant has a low power factor.	Correct by installing capacitors on the total plant or individual motors.

PUMP SYSTEM EVALUATION

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
System design and operating data.	Calculate suction head, SOP 2-4.	Reduce suction head to decrease power consumption, SOP 2-5. Check pump maintenance, SMP 5.
	Calculate the discharge head, SOP 2-4.	Reduce discharge head to decrease power consumption, SOPs 2-5 and 2-7. Check pump maintenance, SMP 5.
	Calculate the energy and cost of pumping, SOP #1-4.	Use the most efficient pump as lead. Check pump maintenance, SMP #5.
Pump discharge excessive.	Determine pump operating position on its pump curve, SOP 2-6.	Modify pump output. a. Lower pump rpm. 1. Variable speed drives. The actual O&M cost savings of different types of drives, mechanical and electrical, should be compared. 2. Sheaves and belts. b. Install smaller impeller.
	Pump discharge throttled.	Determine the additional cost of operating the pump in a throttled condition, SOP 2-8.

WATER DISTRIBUTION SYSTEM EVALUATION

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
Unaccounted for water.	Determine the amount of water that cannot be accounted for, SOP 3-1.	Unaccounted waster losses can result from: a. Unreported legitimate uses. b. Illegal connections. c. Leaks. d. Inaccurate metering.
	Perform a leak/illegal connection evaluation, SOP 3-2.	Repair leaks and install meters on illegal connections.
	Water meter accuracy SOP 3-1.	Develop a routine meter calibration/change-out program.
Pumping costs.	Calculate pumping costs, SOP 1-4.	Monitor, at least monthly, to note changes. Identify reasons for change.
Increased discharge head.	Calculate the discharge head, SOP 2-4.	Clean the distribution system, SOP 2-7.
Poor water quality at customer tap.	System design.	Complete loops to eliminate dead end services.
	Deposits in the pipes, indirectly indicated by flushing hydrants in the complaint area.	Temporary solution is to flush the hydrants, SOP 3-3. Permanent solution is to develop line cleaning program, SOP 3-5. Depending on age and deterioration, lines may warrant replacement.
High electrical demand during short periods of time.	Hourly water demand, SOP 1-3.	Implement storage/release strategies. Backwash filters during low electrical demand periods.

AERATION SYSTEM EVALUATION

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
	ACTIVATED SLUDGE	
Mixed liquor DO level inadequate. The plant O&M manual should be consulted for specific recommendations.	BOD loading, SOP 4-4.	Increase available oxygen.
	Amount of nitrification taking place.	If nitrification is required, increase available oxygen. If nitrification is not required, adjust control parameters to reduce nitrification.
	Amount of DO available, SOP 4-6.	Useful to compare the existing aeration equipment with alternative forms of aeration.
	Uniform mixing in aeration tank, SOP 4-7.	Unmixed areas reduce system efficiency.
	Dirty blower filters, SOP 4-8.	Change filters.
Mixed liquor DO level excessive, typically a DO >3 mg/L is not required by the process.	BOD loading, SOP 4-4. Reduce output of aeration equipment, SOP 4-8.	Decrease aeration Throttle centrifugal blowers, slow down positive displacement blowers, adjust submergence or speed of surface aerators.
Large variations in hourly BOD loadings.	Diurnal variations in mixed liquor DO, SOP 4-2 and 4-8.	Provide automatic blower control to regulate DO. Equalize influent flows.

SOLIDS HANDLING EVALUATION

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
	SLUDGE WASTING	
Waste sludge pump discharge is throttled to reduce volume.	Cost of throttling, SOP 2-8.	Change pumping system to make throttling unnecessary.
Thin sludge being wasted and returned.	Return activated sludge rate.	Determine the RAS rate, SOP 2-3 and adjust to desired rate.
	AEROBIC DIGESTION	
DO level inadequate, below 1 mg/l or problem odors.	VSS loading, SOP 4-9.	Adjust VSS loading to design conditions.
	Amount of DO available, SOP 4-6.	Increase DO or reduce VSS loading to meet design conditions.
	Frequency and volume of feeding.	Feed sludge as continuously possible.
DO level greater than 2 mg/l.	VSS loading, SOP 4-9.	Increase the VSS loading by reducing the tank volume or increasing sludge concentration. Reduce aeration, SOP 4-8 and/or mixing, SOP 4-7.
Excessive foaming	VSS loading, SOP 4-9.	See Excessive DO, above.
	ANAEROBIC SLUDGE DIGESTION	
Low solids content in feed sludge.	Compare to typical values, SOP.	Increase solids concentration by: a. Decreasing the pumping rate. b. Increasing the number of pumping cycles and decreasing the length of each cycle. c. Using chemical flocculants.
Higher sludge temperature than necessary.	Check sludge residence time required at the current operating temperature, SOP 4-9.	Reduce the temperature to provide adequate digestion at the current solids retention time. Gas production may decrease.

SOLIDS HANDLING EVALUATION

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
	Check the Volatile Solids Reduction achieved, SOP 4-9.	Check the digested sludge volatile solids content to determine adequate stabilization.
Highly variable digester temperatures.	Sludge temperature changes by more than 2°C per day.	Check heat exchanger and its controls. Pump thicker sludge. Gradually lower digester temperature until stable conditions are achieved. Check volatile solids to ensure proper stabilization is obtained.
Flaring or not recovering digester gas.	Evaluate the gas volume and quality (See: *Anaerobic Sludge Digestion: Operations Manual*, EPA 430/9-76-0011976.	Recover digester gas and use for: a. digester heating. b. building heating and cooling. c. sale to gas utility. e. cogeneration and heat recovery.
Waste gas burner pilot operates continuously.	The amount of purchased fuel used by the pilot.	Change the pilot to an electronic ignition type.

INCINERATION

Excessive pilot fuel.	Pilot fuel greater than 20% of total Btu.	Reduce the fuel used for flame stabilization. This may create temperatures too low to destroy odors, or an unstable flame. Install economizer to predry sludge. Go to semi-continuous operation. Extinguish pilot flame during extended shutdown. Use alternative methods of sludge disposal.

SOLIDS HANDLING EVALUATION

MEASUREMENT/OBSERVATION	CHECK	CONCLUSION/CORRECTIVE ACTION
Excess oxygen concentration in stack gases.	Oxygen concentration in stack gases.	Reduce fan output.
Heat losses up the stack or into cooling water.	Temperature of stack gases and cooling water.	Consider heat recovery for: a. process or building heating. b. lime recalcining, activated carbon regeneration, or ammonia stripping with steam. c. heating anaerobic digesters or heat treatment processes.

SLUDGE HAULING

Hauling thin sludge.	Total solids of sludge.	Thicken sludge as much as possible to reduce the number of trips. Hauling 10% solids sludge requires 1/2 the trips or tank truck capacity that would be required to haul 5% solids sludge. Evaluate the payback for mechanical sludge thickening equipment.
Hauling long distances.	Locate local disposal sites, if possible.	If local disposal sites cannot be secured alternative disposal methods should be evaluated.
	Total operating costs for hauling operation.	Compare operating costs with alternative sludge disposal methods. Selected method(s) for sludge disposal should be flexible and practicable at all times.

UNIT II: STANDARD OPERATING PROCEDURES

SECTION 1:KNOW YOUR SYSTEM

SOP 1-1: Power Bill Charges

PURPOSE: To justify expenditures and document energy savings the utility billing procedure and charges must be understood. The charges will vary between utilities, by the amount of power used, and how the power is used. There is no uniform summary of information provided on the power bill.

DISCUSSION: Restructuring of the electric utility industry, often called deregulation, is the separation or unbundling of charges for energy generation and transmission/distribution. Restructuring also transfers the control of energy generation from the government regulators to the free market. Simply put, under restructuring, the customer can choose which company will produce their electricity. The delivery of electricity will continue to be provided by the distribution company, formerly the companies that provided all the electric service.

You can now choose a supplier or do nothing. Doing nothing means receiving the Standard Offer and being able to select a new supplier when you are ready. The choices include:

- Choose an electricity supplier
- Join a buying group
- Receive standard offer service

Customers may shop around for electricity supply based on:

- Price
- Terms of contract
- Customer service options
- Mix of renewable and non-renewable energy sources

With restructuring, consumers can have a direct positive effect on the environment. That's because consumers have the option to choose suppliers with power plans that include more renewable energy in their power mix. Renewable energy typically costs more to produce, but with more consumer support, the costs of renewable power should go down. You can affect the availability and affordability of renewable energy by choosing an energy supplier who is more environmentally responsible.

Group Buying. Buying groups, sometimes known as aggregates, enter purchasing agreements with electricity suppliers at favorable rates or terms for their members. Group buying can give a facility the buying clout of a larger consumer and may receive such advantages as discounted prices, special billing services, or power from preferred sources, such as, renewable power. The supplier benefits by having a ready-made group of consumers, this reduces marketing costs, and provides a predicable customer load that reduces their risk.

Joining a buying group means entering into a business relationship with the rest of the group. As with any business arrangement, a facility must look carefully at the group's make-up, financial viability and goals. For further information on utility restructuring or group buying contact your state Public Utilities Commission.

Evaluate Your Costs. Understanding your utility bills, present and future, and how charges are assessed is also essential to develop a strategy to reduce energy costs. In fact, most bills include a number of separate charges. While the utility bill indicates how much energy and power was used, the rate structure is the guide for determining how costs are allocated. Ask your electric utility and energy suppliers for a printed rate schedule that describes the various rates available and illustrates how charges are calculated. Most utilities are willing to change a customer's rate schedule free of charge, providing you qualify for the new rate.

Conduct an Energy Assessment: To better understand where your energy is being used and what improvements can be made, conduct an energy assessment of your facility. An energy assessment can: identify where energy is wasted; help develop an energy purchasing strategy; provide a baseline for tracking energy use; and provide a basis for an action plan. This process is described in SOP 1-2, page 16.

Determining your current electricity costs in a meaningful measure, such as dollars per million gallons treated, can be useful. This allows you to establish a baseline operating cost against which to measure improvements as well as compare to other facility operating costs. It is also a useful tool when explaining energy or cost issues.

In general, restructuring should result in lower rates for consumers. Like all consumers, municipal facilities will be in a much better position if they understand how they use energy and are informed about the changes occurring in their state. Your current utility and state utilities commission are able to advise you on how restructuring may affect you. If you choose to do nothing, your utility, or a utility appointed by the utilities commission, will continue to provide you with reliable power. However, you are encouraged to take the time to investigate the options available to you through restructuring.

Utility Assistance Programs. Electric utility Demand Side Management (DSM) refers to programs implemented by utilities to help customers focus on energy conservation and energy management techniques. The customer benefits by managing their energy needs better and lowering their costs. The utility benefits because it helps defer the need for new sources of power and the environment benefits by reduced air emissions. These benefits are accomplished primarily through efficiency programs that reduce overall energy use, and peak load (energy use) reduction programs that focus on reducing energy use during periods of high consumption. If you have not already done so, assess the benefits of boosting efficiency and adjusting energy use to off-peak hours to take advantage of lower utility rates. A number of the following SOPs provide strategies for documenting energy demand use and how to lower it.

Many utilities offer a free assessment of your facility's energy practices. Where equipment replacement is recommended, rebates or discounts may be available. Contact your utility account representative for more information on product and services. However, assessments performed by the utilities are usually confined to evaluating the use of energy over an operating day and the efficiency of energy consuming equipment, such as motors. The power utility does not commonly have the expertise to evaluate a facility's treatment options or pumping systems. Before making improvements to electrical or mechanical equipment, it would be prudent to perform a pumping and aeration system assessment. There are engineering firms and energy service companies that can assess treatment systems as well as energy use and efficiency. Most energy efficiency improvements have a fast payback time, and any delay in implementing them only causes your facility to continue to spend more than it needs to for energy.

PROCESS:

Below are the types of charges that are fairly typical in an electric bill. Get a copy of your facility's electric rate schedule and/or contract to learn the specifics of each charge.

1. Rate Schedule – identifies the rate schedule being applied.

2. Energy used - charge per kilowatt-hour (kWh), varies with the amount of work accomplished during the specified billing period. There may be a billing constant and/or meter multipliers. The product of the current and potential transformer ratios installed on the service determines the multipliers.

3. Demand Charge - peak kiloWatts used in a 15, 30, or 60 minute period called the demand "window." Demand is charged because the power utility is responsible for providing enough generating capacity to meet the entire system's demand, whether used or not. Brownouts and blackouts occur when the system demand cannot be met.

   In some cases, demand can account for as much as 50% of the monthly bill. It is also, in most cases, relatively easy to reduce the demand by careful management practices without additional equipment purchases. See SOP 1-6 for demand reducing strategies.

   A high monthly peak demand can affect the demand charge for the following 11 months, unless an even higher demand is produced. Some utilities charge demand based on a demand ratchet. The minimum amount that will be billed depends upon the ratchet, which is a percentage value. The ratchet is the percentage of the previous peak demand that will be used for billing purposes if the present actual demand is lower. This charge is used to compensate for the additional generating capacity available to provide the peak demand should it be required.

3. Reactive Power Charge – recovers the cost of providing the "Wattless power" consumed by inductive loads (as in an electric motor coil). Even though this energy is not recorded on the wattmeter the increased electrical energy must be transmitted through the power lines and transformers. The reactive power is measured in kVAR hours (kVARh).

4. Power factor (PF) is another measurement used to recover reactive power. PF is normally expressed as a decimal and is always less than or equal to 1.00. The lower the power factor, the larger the power lines and transformers that are required to carry the same kilowatts.

Many electric utilities include a penalty charge if a customer's power factor is below a stated minimum value, such as 0.90. Some utilities provide a credit if the power factor is higher than a stated minimum value. Check your utility's rate schedule.

Demand Penalty Example:

Table 1 lists the demand use information for a treatment facility that is billed on a 70% ratchet. During January (last year) a new peak demand of 523 kW was established. For the following eleven (11) months the minimum demand bill will be366 kW unless a higher peak is established. During the months of August and October (last year) and April (this year) the actual demand was below the 70% ratchet. However, the ratchet value was used for billing. The demand penalty is the amount of demand that is paid for, but not used.

A new 70% ratchet value was established in January (this year) at 342 kW. This value was based on the maximum peak (November (last year), 489 kW) that occurred since the previous peak during January (last year).

TABLE 1:ANALYSIS OF MONTHLY DEMAND USAGE

MONTH	DEMAND METER READING, kW	70% RATCHET VALUE, kW	DEMAND BILLED, kW	DEMAND PENALTY, kW
JAN last year	523	366	523	0
FEB	456	366	456	0
MAR	412	366	412	0
APR	463	366	463	0
MAY	418	366	418	0
JUN	428	366	428	0
JUL	472	366	472	0
AUG	325	366	366	41
SEP	391	366	391	0
OCT	291	366	366	71
NOV	489	366	489	0
DEC	465	366	465	0
JAN this year	477	342	477	0
FEB	403	342	403	0
MAR	376	342	376	0
APR	319	342	342	23

For small water/wastewater utilities there may be no power factor penalty or credit. However, the power factor can still have an impact on performance of the electrical system. As an example, if two customers have identical kilowatts of peak demand, and they have power factors of 0.6 and 0.8, the transformers and cables serving the customer with a 0.6 power factor would have to be sized to carry 33% more current.

5. Fuel Adjustment - billed for fluctuations in the cost of fuel.

6. Time of Day Rates – differential charges that provide a very real incentive to spread the use of electricity away from peak hours. The cost for off-peak electrical usage is typically significantly lower. Typically, on-peak hours occur during the daytime. Check with your power supplier as peak hours can change with time of year and other factors.

Portions of this SOP were adapted from *Modern Industrial Assessments, A Training Manual, Version 2.0*, Rutgers University, Office of Industrial Productivity and Energy Assessment, September 2001. The manual is available at http://oipea-www.rutgers.edu/documents/IndAssess.html

SOP 1-2: Energy Assessment

PURPOSE: The energy assessment is used to calculate the amount of energy a treatment or pumping process uses. Once this is known, a plan can be developed (in conjunction with controlling in-plant flows, SOP 1-5) to balance the peaks and valleys of electrical consumption. The survey is used to identify processes that can be shifted to off-peak hours and balance loads to reduce the peak demand.

PROCESS: The energy assessment should be used to calculate energy use of the controllable plant processes. Activities that are scheduled at regular or irregular intervals during the day, such as, filter backwashing, sludge dewatering, aerobic digester blower operation, line charging or flushing in the distribution system, etc., are prime candidates for rescheduling during off-peak periods. Even water production processes may be examined, as it is entirely possible in some systems with large storage capacities to produce and distribute at different times. Note unit processes that must operate together. The next step in analyzing the electrical demand of the system is to determine:

1. When and how frequently peak electrical demands occur?
2. How much the peak demands exceed the lowest possible operating demand values?
3. Which processes can be scheduled at other times to reduce the peak electrical demand?

Discussion of the Energy Assessment Survey form.

1. Process Name: Analyze each unit process for energy use.

   For example, sludge digestion may have raw sludge pumping, aeration or mixing, and digested sludge pumping. Enter the specific process name in the column.

2. kW: For each energy using operation that contributes to a process, determine the kW consumed (SOP 2-1) and enter in the kW column. This is the contribution of a process to the electrical demand.

3. Run Time: Determine, in hours, how long the process functions during each cycle for intermittently operated equipment and enter in the Run Time column.

4. Frequency: Determine how many operating cycles there are for the process daily and enter in the Frequency column.

5. Total kWh: Multiply the kW times the run time times the frequency to determine the total amount of energy consumed by the operation each day and enter the value in the Total kWh column.

Energy Assessment Survey

Process Name	kW	Run Time	Frequency	Total kWh

Create the Energy Assessment Survey as a computer spreadsheet and the calculations are simplified.

SOP 1-3: Survey of Flow and Energy Demand Peaks

PURPOSE: To manage peak electrical loads, when and why they occur must be known. Typically, peak electrical loads occur at peak flows. Changes in the active treatment processes can cause high energy consumption at low flows (as when backwashing filters) or high flows at low energy consumption levels. A "Process Activity Survey" helps verify what these high flows and loads are and when they are occurring,. This survey divides the day into parts and tracks how much water is being processed at any one time, then compares it to the electricity being used at the facility. The survey establishes a base line electrical load and identifies the most energy intensive processes.

PROCESS: The energy use patterns are especially easy to see when put in graph form. By adjusting the scales both the flow and kWh can be plotted together on the Y-axis with time in hours on the X-axis. The flow peaks should remain relatively constant with some modifications, such as a delay on weekends, wet/dry conditions and seasonal changes.

Facilities with SCADA can collect the data from the database. Otherwise, getting the most complete data requires monitoring over a 24-hour period. If this is not possible, collect data during staffed periods and use the average for the time that is unstaffed. Generally, the highest energy consumption will be when the facility is staffed.

Once this information is available, the next step is to examine the various treatment processes for energy consumption (SOP 1-2). The processes are then operated on a schedule that will tend to level out the daily demand variations or shift use to off-peak hours.

Discussion of the Peak Survey form.

1. Flow Totalizer: The reading from the flow totalizer should be entered on the hour. The initial reading should be taken at the beginning of the 24-hour period. This reading is placed in the first box at the top of the form. Each hour the totalizer reading for the previous hour is subtracted from the new reading to get the gallons of flow during the past 60 minutes. The difference is placed in the Flow/Hour cell.

2. kWh Totalizer: The reading from the facility’s electric meter should be entered on the hour. The initial reading should be taken at the beginning of the 24-hour period and placed in the first cell on the form. Each hour the totalizer reading for the previous hour is subtracted from the new reading to get the kWh of electricity used during the past 60 minutes. The difference is placed in the kWh/Hour cell.

Create the Process Activity Survey as a computer spreadsheet and the calculations are simplified.

Process Activity Survey				
TIME	Flow Totalizer Reading	Hourly Flow gallons/liters	kWh Meter Reading	kWh/Hour

SOP 1-4: Electricity Costs for Treatment and Pumping

PURPOSE: Calculation of the cost of treating a gallon of product water provides a benchmark to compare treatment efficiencies from month to month. It also allows the comparison of unit energy consumption between treatment plants of similar and dissimilar types.

PROCESS: To document the electrical energy costs associated with the total operation, the following form can serve as a point to start. It is important to remember that the treatment month and electric readings will probably not be the same. The flows must be for the same days used for the electric billing period.

When a SCADA is available this calculation can be automated.

Discussion of the Electricity Costs For Treatment And/Or Pumping form.

1. Electric Meter Reading Dates: Enter the dates on which the electric meter was read. A daily meter reading by plant staff provides a more detailed analysis. Read the electric meter at approximately the same time as the daily flow total.

2. MG Produced or Pumped: Enter the number of million gallons (MG) processed during the period covered by the electric meter reading dates.

3. kWh Used: Enter the kWh used during the period covered by the meter reading dates.

4. kWh/MG: Divide the kWh Used by the MG Produced or Pumped. The result of this calculation must be compared against the total operation to obtain any meaning.

   In general, the lower the number the more efficient the operation is. However, there are circumstances where this is not true. A clear example is for collection systems and wastewater treatment facilities that are subject to high infiltration/inflow (I/I). In this situation the kWh/MG will be lowest when the I/I flows are highest. This is because some energy use, for example aeration, is relatively independent of flow.

5. Demand kW: Enter the metered demand during the meter reading period. Caution must be taken to ensure that the value on the electric bill is the value metered. Some electric utilities indicate the value of the demand ratchet if the actual demand was below the ratchet value (SOP 1-1).

6. Total Bill, $: Enter the amount charged for the electricity used during the meter reading period.

7. $/MG: Divide the MG Produced or Pumped by the Total Bill.

ELECTRICITY COSTS FOR TREATMENT AND/OR PUMPING

Elect. Meter Reading Dates		MG Produced or Pumped	kWh Used	kWh/MG	Demand kW	Total Bill, $	MG/$
From	To						

This example is for flow. Other parameters could be Pounds of BOD removed, Pounds of TSS removed, etc. The idea is to use benchmarks that allow comparison over time and/or after implementing changes.

Creating the form as a computer spreadsheet will simplify the calculations.

SOP 1-5: Controlling In-Plant Flows

PURPOSE: Flows required for in-plant operations often contribute significantly to the peak demand. These flows need to be monitored and controlled to minimize their volume and, if possible, timed during off-peak periods. Although the following discussion mainly concerns water treatment, similar awareness will be of value in wastewater treatment.

PROCESS:

1. The major water consuming treatment process in a water plant is filter backwashing. Facilities can use as much as 15% of the total production to clean filters. This significant amount of water is controllable in three respects.

    a. The amount of water can be minimized. Developments in turbidity and particle counting techniques have produced instrumentation that can give a much better indication of when a filter needs to be cleaned. During backwashing, the meter will indicate when the filter has been cleaned. Many treatment facilities have changed to this method rather than Loss-of-Head or a set number of gallons and have shown significant reductions in the gallons of water (and energy) used. The initial cost of instrumentation can be significant, and professional consultation may be needed for selection and installation.

    b. Filter backwashing can be scheduled. The optimum time for backwashing can be planned by using the information developed from SOPs 1-2, 1-3 and 1-7. Scheduling should also take into account the available energy discounts (see SOP 1-1).

    c. Many facilities have the choice of backwashing by either using water pumped from the clearwell or released from overhead storage. The most energy efficient method should be used. This can be calculated by using SOP 1-2 and SOP 1-4. What must be compared is the efficiency of the backwash pump vs. the availability of water in elevated storage. There must be enough time to recharge storage before it is required to offset pumping demands.

2. Backwash water reprocessing or disposal affects energy use. Treatment systems that can reprocess the backwash water should do so at the most economical time. It is not unusual to find backwash water being reprocessed at peak flow times. This adds to the system's energy demands, when the operation could, with no additional cost, be done at low flows.

SOP 1-6: Electrical Load Shedding Strategies

PURPOSE: To reduce electrical demand (see SOPs 1-1, 1-2, 1-3) a facility load management plan to reduce worse case peaks and high demand situations is essential. To be most effective, an automatic load shedding system could be installed. But, since they are expensive a manual load-shedding strategy can be used as a no cost alternative for smaller treatment facilities.

Treatment facilities with Supervisory Control and Data Acquisition (SCADA) systems can, with minimal investment, integrate load shedding into the control scheme. The same logic process will be involved to determine the combinations of equipment that can work together to maintain a lower demand.

PROCESS:

1. Treatment systems can plan a manually controlled load shedding scheme using the data from the Energy assessment Survey (SOP 1-2) and establishing priorities.

   The essentials of a load-shed plan include:

   a. Prioritizing all system processes based on their relationship to meeting treatment objectives. How processes interact will, to some degree, depend on the configuration of a treatment plant. Some examples that are typically encountered follow.

      i. Filter backwash operations.
      ii. Sludge handling operations.
      iii. Heating and cooling in buildings. This can be handled with programmable thermostats. However, there are often not enough zones set to obtain uniform heating and cooling.

   b. Planning which systems are both demand compatible (their energy demands do not exceed a given kilowatt goal) and process compatible (processes working in a logical sequence of treatment).

   c. Scheduling electrical loads throughout the treatment day in accordance with the above plans and adhering to the schedule. Most important is informing all personnel involved of the plan, the reasons for it and getting them involved.

2. A remote kilowatt meter (demand meter) display should be located where the operators can observe it frequently or integrated into the SCADA. It is best if an audible and visual alarm is provided to trip at a point slightly under the desired demand peak. This allows time for the operators to begin dropping out the loads that have been prioritized in Step 1. If a SCADA is being used, it can drop loads in a programmed sequence.

SOP 1-7: Calculating Chemical Dosages

PURPOSE: It is imperative that chemicals added to a treatment process accomplish the intended goal and are added in the appropriate amounts. This saves both direct and indirect energy costs, as well as maximizing process efficiency,

There are two ways to calculate proper dosages. One is to add the chemicals to the process, wait and see what happens. The other is to model what should happen when the chemical is added by performing jar tests. Jar testing does not totally eliminate the "art" involved in chemical dosing, but it does provide a degree of predictability.

The jar test also provides a way to eliminate chemicals that would be unsuitable for the job. It also estimates the range of dosages that should be tested at full scale. Because source waters or wastewaters tend to change with time, jar tests should be repeated at regular intervals.

PROCEDURE: The following procedure describes using jar testing in a water treatment application. The basic procedure is the same for wastewater clarification or sludge dewatering applications.

1. Making Stock Solution: Dissolve 1.00-g of dry chemical or 1.00-ml of liquid chemical in 100-ml of water. Use either distilled water or preferably the water you will be using to makeup the working solution.

   This stock solution will contain 1-mg of chemical for each 0.1-ml of solution added.

2. For best results, a gang stirrer with 6 stirring paddles should be used. Beakers (1000-ml) or rectangular jars should be used to hold the sample. The rectangular jars are used to reduce vortexing that occurs with round beakers. Using 1000-ml of raw water, start the mixers at the same rpm as the chemical flash mixers (40-50 rpm, if unknown or if flash mixers are not present).

3. Add stock solution in different volumes to each 1000-ml sample and mix for the same length of time as the flash mixers (30-60 sec., if unknown).

4. Reduce mixers to same speed as flocculators (10-20 rpm, if unknown) and mix for the same length of time as the detention time of the flocculators (4-30 minutes, if unknown).

5. Remove paddles and watch the floc settle. For each sample record the time required for the floc to settle, the characteristics of the floc, the settled volume, and the product water turbidity. This process will be repeated several times to identify the optimum dosage.

6. Apply the dosage that produced the best results with minimum chemical in the jar test. Monitor the full-scale application by collecting samples and observing settling. Adjust the dosage to optimize flocculation.

   Occasionally there are interfering factors that will give different results in the plant than in the jar tests even after all major influences have been accounted for. This is sometimes due to hydraulic factors, such as, large or sudden change in flow that interferes with basin performance. These situations require correction on a mechanical level for any attempt at control to be effective.

SOP 1-8: Lighting

PURPOSE: Lighting is often overlooked for energy saving opportunities at treatment facilities because it is overshadowed by the energy use of motor and pumps. At other types of facilities (schools, police stations, office building) lighting is a major energy consumer and is one of the first areas evaluated to improve efficiency and reduce costs. For example, the increased cooling demand generated by inefficient lighting systems can add 10% to cooling energy costs. Many businesses are lowering their lighting and cooling bills by installing energy-efficient equipment. Likewise, municipal treatment facilities should also take full advantage of advances in lighting technology to reduce both the energy costs and the higher maintenance of older lighting systems.

DISCUSSION: Lighting technology and design have had many new developments in recent years. Many of these developments have been electronic controls for lighting, either daylight-linked or occupancy-linked. Motion sensors provide a passive way to turn off lights in areas that have intermittent activity. Photocells and timers are often be used to control outside parking and walk lighting. Because exterior lighting is usually a metal halide bulb, startups take a few seconds and should be minimized.

Technology improvements have increased lamp efficiency, improved color rendering and extended lamp life. New electronic ballasts enable fluorescent lamps to operate flicker-free, last longer, start faster and operate cooler. In addition, some ballasts provide smooth and silent dimming. Improvements in lighting fixtures offer better reflection of light and can reduce the number of bulbs needed. The payback for the costs of a lighting upgrade is typically between 1 and 3 years. Here is a simple example.

Existing Lighting system:

- 4 - 40-watt T 12 fluorescent lamps (1.5 inch diameter by 4 feet)
- 2 - 16-watt magnetic ballasts
- Time used: 3000 hours per year
- Annual Cost: (192 watts x 3000 hrs) x 1 kW/1000watts x 0.10 $/kW
- Annual Cost = $ 57.60

Replacement Lighting system:

- 2 - 32-watt T 8 fluorescent lamps (1 inch diameter by 4 feet)
- 1 - 2-watt electronic ballast
- 1 - new Reflector Fixture that provides more lumens to the work surface
- Annual Electric Cost = $ 19.80
- Capital Cost for New Equipment = $65.00

$$Simple\ Payback = \frac{Capital\ Cost}{Annual\ Savings}$$

$$= \frac{\$65.00}{\$57.60 - \$19.80}$$

$$= 1.7\,years$$

This example shows the benefits of changing a lighting fixture that is working. For fixtures that are in disrepair (blown, darkened, or discolored bulbs, or defective ballasts), replacing them with an energy efficient system is the only practical way to go. This example is for one lighting fixture. Even small facilities will have many of these fixtures throughout a building. In this example, after 1.7 years the savings are $37 per fixture per year.

Exit lights can also waste energy. Typical older exit lights have two 15 or 20 watt incandescent lamps. The new exit lights have either one 7 watt fluorescent lamp or two 1/2 watt Light Emitting Diodes (LED). Exit lights are on all the time (8760 hours per year). Two 15 watt lamps at 0.10 $/kWh will use more than $25 per year in power. An LED retrofit kit only costs about $25. Converting older style exit lights to LEDs will pay for themselves in about a year, and thereafter cost almost nothing to operate. Also, LEDs can last up to twenty-five years. Becoming aware of today's efficient lamps, ballasts, reflective fixtures, and control options available is the first step toward reducing your lighting costs.

LIGHTING STANDARDS:
How much light is enough? Adopt an illumination standard. Table 1 provides a summary of DuPont’s recommended levels of illumination for various working environments. These are single values that are applied depending upon the task being performed. The Illuminating Engineering Society of North America (www.iesna.org) has recommendations that provide a range of illuminance for various room designs and tasks.

Table 1: Recommended Lighting Levels

Area	Foot-candles	Area	Foot-candles
Office		Shops	
General	70	Rough bench and machine work	50
Stenographic	100	Medium bench and machine work	100
Drafting room	125	Fine bench and machine work	200*
Conference Room	70	Instrument Shop	
Corridors and Stairs	20	General	70
Electrical – Bench work	70	Bench work	100
Janitor’s Closets	10	Pump Houses	20
Laboratories-General	50	Toilets and Washrooms	20
Lunch Areas	30	Welding Shop	50
Lobbies	30	Parking lot, general parking	0.3

*Combination of general and specialized supplementary lighting.

There are a number of computer models available to establish appropriate illumination. Many of them incorporate the IESNA model. Two models that are available free are:

GE Lightbeams – *http://www.gelighting.com/na/specoem/lightbeams.html*
Lithonia Lightware – *http://www.lithonia.com/software/Lightware6/default.asp*

LIGHT METER AUDIT:
After the standards have been adopted, a light mete audit to determine existing lighting levels and duration should be conducted. The condition of lamps and fixtures should be taken into account. Their cleanliness can greatly affect light output. Light loss from standard 40-Watt fluorescent lamps can be 10-15% as they approach the end of their life. Also the room size, wall and floor color will affect the results. It is possible that a lighter paint color will be more economical than changing the lights.

ACTION PLAN:
Once the amount of light needed and available in various areas of the facility it is time to reconcile the two conditions. This can be accomplished in a variety of ways.

- Turn lights off when leaving an area. Incandescent bulbs should be turned off every time they are not needed. Fluorescent tubes should be turned off when they will not be needed for 15 minutes or more. High-intensity discharge (HID) lamps should not be turned off for periods of less than 30 minutes because of their long warm up time.

- Use automatic controllers. There are infrared, capacitance, or ultrasonic detectors that can be installed in a room and turn lights off when it is unoccupied for a prescribed period of time. These devices remove the need for people to remember to turn off the lights.

- Remove lamps from fluorescent fixtures if illumination level is higher than needed for the tasks being performed. Keep in mind that the ballast still draws current (approximately 10% of the total load) even though no lamps are in the fixture. The best alternative would be to evaluate replacing the fixtures to provide the correct illumination as described in the example at the beginning of this SOP.

- Maintain lamps and fixtures. At a minimum dust and dirt accumulations should be removed from fixtures each time lamps are replaced. Dusty and dirty luminaire diffusers should be cleaned as needed to maintain correct illumination levels. When diffusers get discolored their replacement or removal should be considered.

- Lower Wattage fluorescent lamps and ballasts. Rather than removing lamps and disconnecting electromagnetic ballasts it is more energy conservative to replace the old fixtures with performance matched electronic ballasted fixtures. This was the point of the example at the beginning of this SOP.

- Task lighting. Provide lighting in specific areas that matches the task being performed. This eliminates the need to illuminate a larger area to meet the higher candlepower required for a task. Electronic ballasts can operate with a dimmer that allows adjustment of the candlepower being projected.

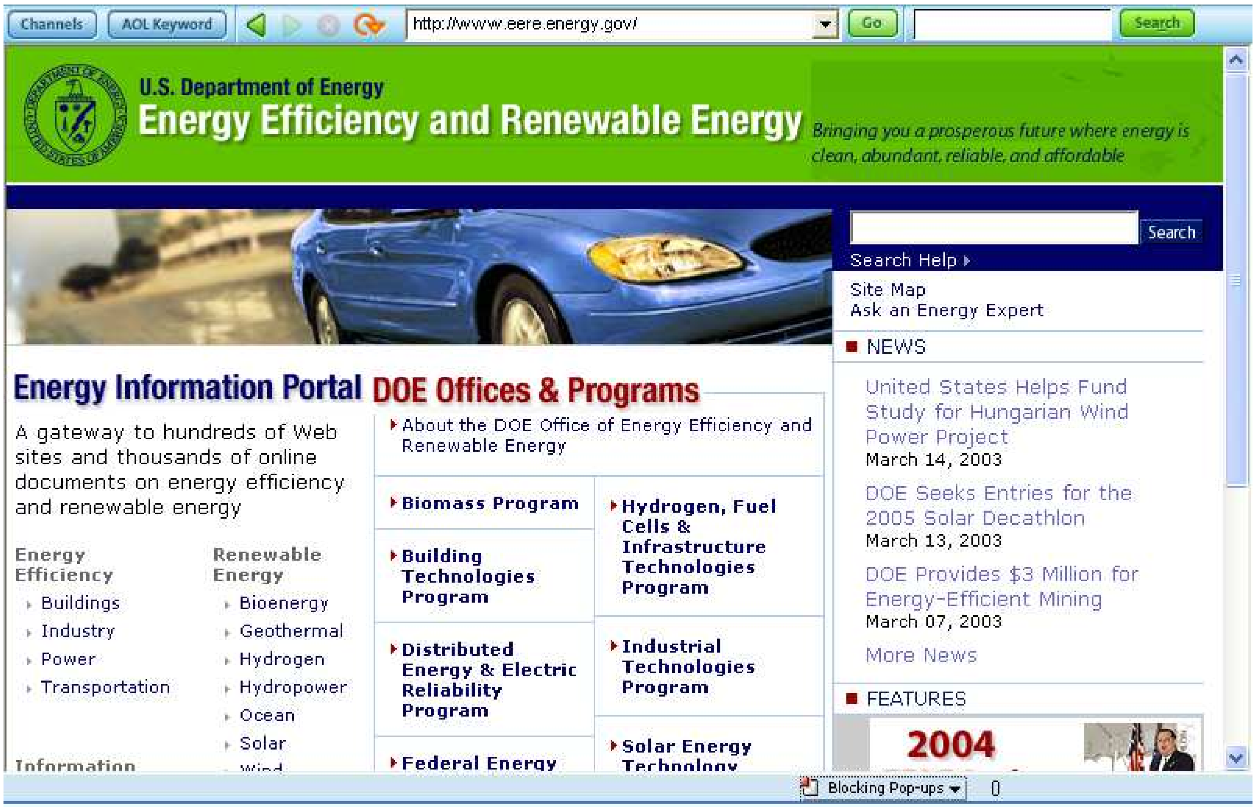
- Lighting system replacement. Existing incandescent and mercury vapor lighting systems are often good candidates for replacement. The lighting models can be used to advantage to evaluate alternative lighting systems and estimate savings.

This SOP was adapted from *Modern Industrial Assessments, A Training Manual, Version 2.0*, Rutgers University, Office of Industrial Productivity and Energy Assessment, September 2001. The manual is available at *http://oipea-www.rutgers.edu/documents/IndAssess.html*

SOP 1-9: Internet and Energy Conservation

Purpose. The Internet is a wealth of information that should be investigated when evaluating how to conserve energy. Since the Internet is a changing media a search should be conducted on topics of interest. The U.S. Department of Energy websites are a good place to start. Following are screen captures of several DOE websites that have a wealth of information and resources.

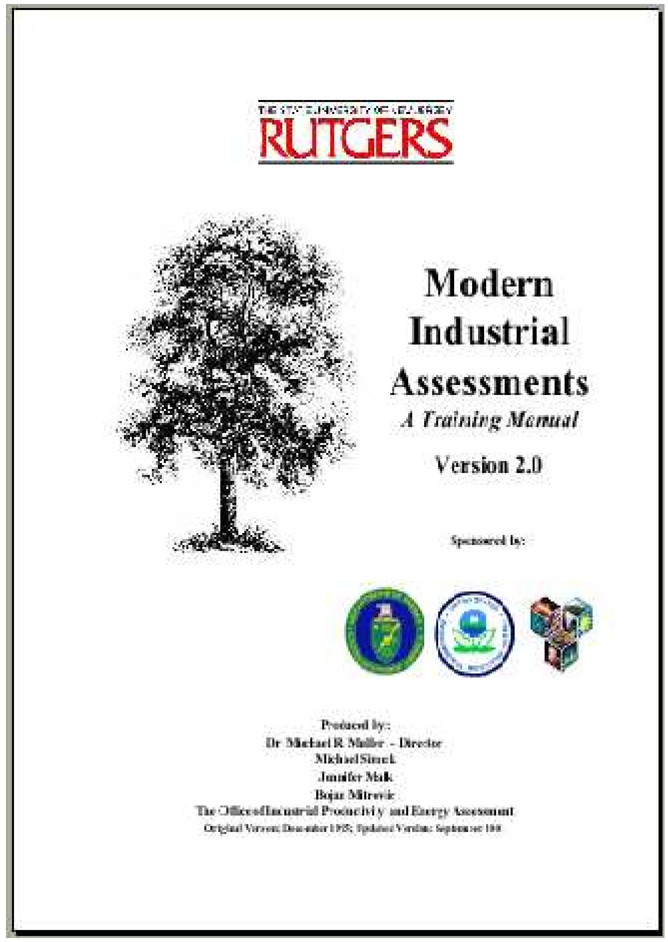
U.S. Department of Energy - *www.eere.energy.gov*



The Office of Industrial Technologies has a program called Motor Challenge, *www.oit.doe.gov/bestpractices/motors*, that has many excellent case studies and evaluation tools. Anyone evaluating pumps and/or motors should visit this site.

Another site with useful information is the National Renewable Energy Laboratory, *www.nrel.gov*.

The training manual *Modern Industrial Assessments* contains a wealth of energy conservation information and is available on-line at *http://oipea-www.rutgers.edu/documents/IndAssess.html.* It can be downloaded in pdf format. Using Acrobat Reader is convenient for doing searches for topics of interest.



SECTION 2: MOTORS AND PUMPING

SOP 2-1: Calculating Power and Horsepower

PURPOSE: Wire power is the actual electrical energy used by an electrical device to do work. It can be measured directly or estimated from shaft power. Determining wire power using direct electrical measurements is the most accurate method. Shaft horsepower can be calculated using the same data and estimated efficiencies.

Shaft horsepower is the nameplate horsepower. It is the amount of power the motor will deliver to move the load. It will always be less than the motor horsepower, because of inefficiencies within the motor.

The Watt is the basic unit used to measure electrical power and is usually expressed in units of kiloWatts (1000 Watts). Horsepower is a common unit used to measure mechanical power. One horsepower = 746 Watts or 0.746 kW. To calculate the operating costs of the motor, the wire power is calculated.

PROCESS 1: WIRE POWER BY DIRECT MEASUREMENT

Wire power is calculated using electrical data from the operating motor. This method is useful to document the benefits of system modifications that are intended to change the motor load.

1. Calculate the power (kW) being used by the motor or use a kiloWatt meter to measure the power directly.

$$P = \frac{V \; x \; A \; x \; PF \; x \sqrt{3}}{1000}$$

Where: P = power (demand) consumption in kW.
V = volts, measured with voltmeter.
A = amps, measured with ammeter.
PF = power factor[1]
$\sqrt{3}$ = 1.732

[1]Measurement with a power factor meter is required for meaningful calculations.

2. If desired, the wire horsepower (demand) being used by the motor can be calculated.

$$whp = \frac{P}{0.746 \, kW / hp}$$

Where: 0.746 kW/hp, converts electrical power to horsepower

3. When comparing costs of premium efficiency motors it is often necessary to calculate the demand based on calculated shaft horsepower and published efficiency ratings.

$$Demand\,(kW) = \frac{Shaft\ Horsepower\ x\ 0.746\,kW/hp}{Efficiency\,(decimal\ percent)}$$

Where:	Demand	= estimated kW used by the replacement motor
	Shaft Horsepower	= Actual horsepower applied to the load
	0.746 kW/hp	= conversion factor from horsepower to kW
	Efficiency	= published efficiency for replacement motor

PROCESS 2: BRAKE HORSEPOWER

To compare the operating costs of different motors one must start with the brake horsepower that is required by the load. A motor only consumes as much power as the load requires. Often motors are oversized and thus running under loaded. This condition lowers the efficiency of the motor and, more important, lowers the power factor. When this situation is identified, changing the motor to a lower horsepower should be evaluated. There are other formulas that can be used to estimate the brake horsepower a motor is supplying. However, the following formula is the most practical to apply.

Calculate the brake horsepower being used by a motor using the following formula. It is usually safe to ignore the efficiency part of the formula because a motor's efficiency is relatively constant until it is very under loaded.

$$BHP = \frac{A\ x\ PF\ x\ Eff\,@\,Load}{FL\ A\ x\ FL\ PF\ x\ Eff\,@\,FL}\ x\ FL\ HP$$

Where:	FL A	= Nameplate amperage
	FL PF	= Nameplate power factor (or manufacturer's literature)
	Eff @Load	= Efficiency at current load (motor curve from manufacturer)
	Eff @FL	= Efficiency at full load (manufacturer's literature)

SOP 2-2: Calculating Electric Motor Operating Costs

PURPOSE: It is often necessary to determine the actual cost of operating an electric motor when evaluating a piece of motor driven equipment.

PROCESS:
1. Calculate the power the motor is using (SOP 2-1).

2. Calculate the kilowatt-hours used annually.

   kWh, annual = kW x annual hours of operation

3. Calculate the annual energy cost.

   Annual operating cost = kWh x $/kWh

4. If the motor operates 24 hours per day or during peak demand periods calculate the demand charge.

   Cost for demand, $ = kW x $/kW x 12 months

SOP 2-3: Estimating Liquid Flow Rates

PURPOSE: Many of the activities required to evaluate ECMs need flow information. However, most facilities do not have, or necessarily need, electronic or mechanical meters on all the flows of interest. In many cases weirs are not available. Therefore, other methods for estimating flow are required.

The methods described in this SOP are:
1. Measuring the level change in a tank.
2. California Pipe Method.
3. Using pump curves (SOPs 2-4 and 2-6).

PROCESS: MEASURING THE LEVEL CHANGE IN A TANK
1. The tank must not have any other sources of flow into or out of it other than the one being evaluated. All other sources of flow must be stopped.

2. Determine the tank volume per inch of depth.

   a. Calculate the surface area in ft^2.

   b. Calculate the volume, in ft^3, of 1 inch of depth by multiplying the area by 0.083 in/ft. (One inch is equal to 0.083 ft)

   c. Convert the volume in ft^3 to gallons. The conversion is 7.48 gallons/ft^3.

3. Determine the pumping rate, filling rate, etc.

   a. Measure the tank depth, in inches.

   b. Operate the pump for a measured amount of time. The longer the operating period the more accurate the final calculation.

   c. After the pump has been stopped, measure the tank depth.

   d. Determine the volume pumped. Multiply the number of inches pumped by the gallons/inch (Step 2c).

   e. Determine the pumping rate in gallons per minute. Divide the volume pumped by the number of minutes the pump operated.

CALIFORNIA PIPE METHOD

1. The California Pipe Method can be used to calculate the flow in a partially filled horizontal pipe with a free discharge. The horizontal portion of the pipe should be at least 6 times the diameter. This method is described in *Handbook for Monitoring Industrial Wastewater*, USEPA, August 1973. Figure 1 illustrates the data requirements for using the method.

2. The equation used is:

$$Q = T \times W$$

Where: Q = flow in gpm
d = diameter of pipe, in feet
a = d minus water depth, in feet

$$T = 3900\left(1 - \frac{a}{d}\right)^{1.88}$$

$$W = d^{2.48}$$

The values for T and W are obtained from Tables 2 and 3.

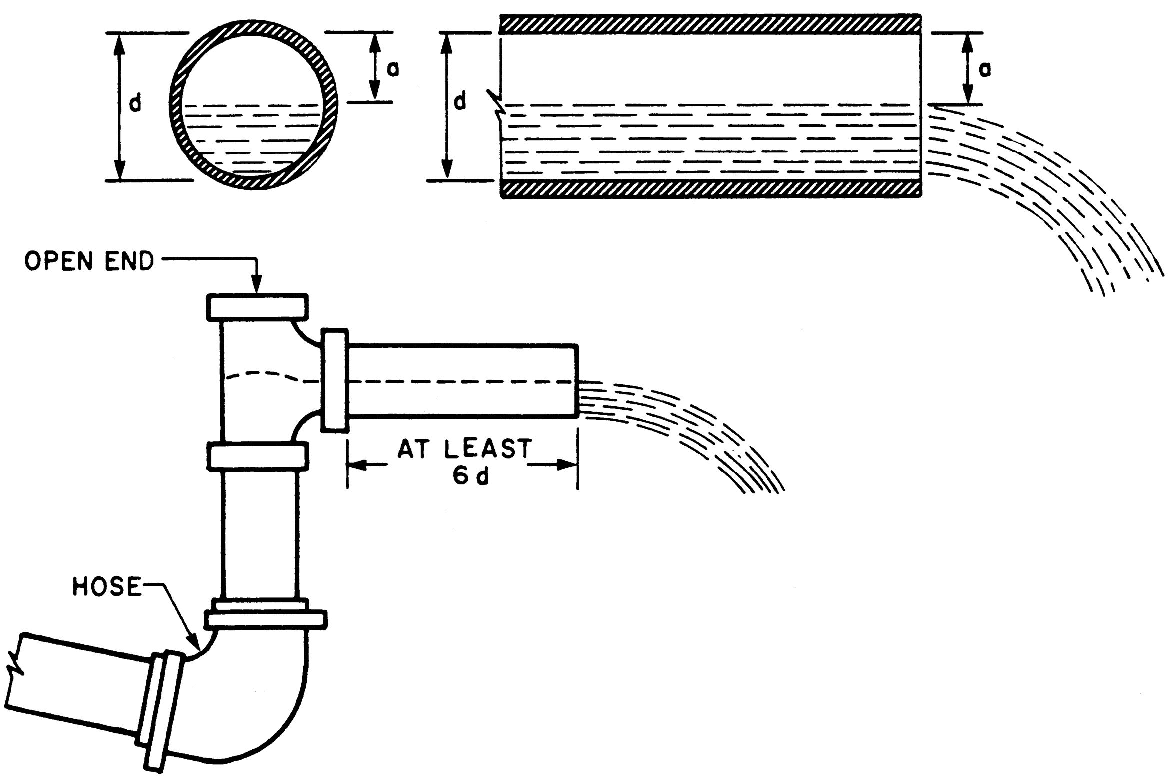


Figure 1: California Pipe Flow Method (USEPA, August 1973)

TABLE 2: Values of T for California Pipe Flow Formula

$\frac{a}{d}$	T	$\frac{a}{d}$	T	$\frac{a}{d}$	T
0.00	3900	0.35	1740	0.70	410
0.01	3830	0.36	1690	0.71	380
0.02	3760	0.37	1640	0.72	360
0.03	3690	0.38	1590	0.73	330
0.04	3610	0.39	1540	0.74	310
0.05	3540	0.40	1490	0.75	290
0.06	3470	0.41	1450	0.76	270
0.07	3400	0.42	1400	0.77	250
0.08	3330	0.43	1350	0.78	230
0.09	3260	0.44	1310	0.79	210
0.10	3200	0.45	1270	0.80	100
0.11	3130	0.46	1230	0.81	170
0.12	3070	0.47	1180	0.82	160
0.13	3000	0.48	1140	0.83	140
0.14	2930	0.49	1100	0.84	125
0.15	2870	0.50	1060	0.85	110
0.16	2810	0.51	1020	0.86	97
0.17	2750	0.52	930	0.87	85
0.18	2690	0.53	915	0.88	73
0.19	2630	0.54	905	0.89	61
0.20	2570	0.55	870	0.90	51
0.21	2510	0.56	830	0.91	42
0.22	2450	0.57	800	0.92	34
0.23	2390	0.58	760	0.93	26
0.24	2330	0.59	730	0.94	20
0.25	2270	0.60	700	0.95	14
0.26	2210	0.61	660	0.96	9
0.27	2160	0.62	630	0.97	5
0.28	2100	0.63	600	0.98	3
0.29	2050	0.64	570	0.99	1
0.30	1990	0.65	540		
0.31	1940	0.66	510		
0.32	1890	0.67	480		
0.33	1840	0.68	460		
0.34	1790	0.69	430		

TABLE 3: Values of W for California Pipe Flow Formula

Pipe Diameter inches	d feet	W
3	0.25	0.032
4	0.33	0.064
6	0.50	0.179
8	0.67	0.370.
10	0.83	0.630
12	1.00	1.00
14	1.17	1.48
15	1.25	1.74
16	1.33	2.03
18	1.50	2.73
20	1.67	3.57
21	1.75	4.01
22	1.83	4.48
24	2.00	5.58
27	2.25	7.47
30	2.50	9.70
33	2.75	12.29
36	3.00	15.25

EXAMPLE: At an activated sludge plant a 6-inch pipe is used to move the return activated sludge (RAS). The air from the air lift pump is released and the pipe is gravity flow for over 3 feet. The operator needs to know the RAS flow for process control.

1. From Table 3 the value of ***d*** (0.5 ft) and ***W*** (0.179) for a 6-inch diameter pipe is determined.
2. For a 1-inch depth of flow the value of ***a*** would be 0.417 feet (5-inches/12-inches per foot).
3. From Table 2 the value of ***T*** for ***a/d*** (0.417/0.5 = 0.83) is 140.
4. Calculate the flow (Q) in gallons per minute (gpm) when 1-inch of water is flowing by gravity from a 6-inch diameter pipe.

   Q = T x W = 140 x 0.179 = 25 gpm

Calculations for depths of 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0-inches can be performed by determining the value of T at each depth. The calculated flows at the various depths can then be applied for daily process control.

SOP 2-4: Calculating Pump Head

PURPOSE: When evaluating existing pumping systems it is necessary to determine the pump head. This information is of value to determine when pump and/or system maintenance is required. A pump system design is based on a number of assumptions. Even if all of the assumptions turn out to be accurate, over time the pump wears and piping characteristics change.

PROCESS: Gauges are used to collect the measurements needed to calculate the total dynamic head (TDH) for a pump. The gauges display the pressures on both the suction and discharge sides of the pump. Submersible pumps take a little more effort to get the suction pressure, Figure 3.

It is important to note that gauges should be calibrated in order to insure accurate measurements. The most reliable calibration method uses a dead weight tester. Less reliable, but typically acceptable, is checking the gauge against a reference gauge. Gauges that connect to water systems should be checked frequently to make sure the lines connecting the gauge to the system are free of air bubbles that can introduce significant inaccuracy.

To maximize the benefit of data collection other information should also be collected. The Pump Evaluation Data Sheet provides a starting point. As the wet well elevation decreases the positive suction head decreases. Thus the table requires documentation of the wet well level so future evaluations can be comparative.

1. Measure and record suction pressure. Convert to feet of water by multiplying by the following constants:

   Gauge Pressure (psi) x 2.31 = Pressure (ft. of water)
   Gauge Pressure (in.Hg) x 1.13 = Pressure (ft. of water)

2. Measure and record discharge pressure. Convert to feet of water.

3. Determine the vertical distance, in feet, between the suction and discharge gauges. See Figures 2 and 3.

4. To calculate pump head apply the following equation with all values in feet:

$$\textit{Head}\,(\textit{ft}) = \textit{Discharge Pressure} - \textit{Suction Pressure} + \textit{Vertical Distance Between Gauges}$$

Note: This equation does not include velocity head (i.e., the head required to change the velocity of the fluid from inlet to exit). This value is generally small (<1 foot) and can usually be neglected.

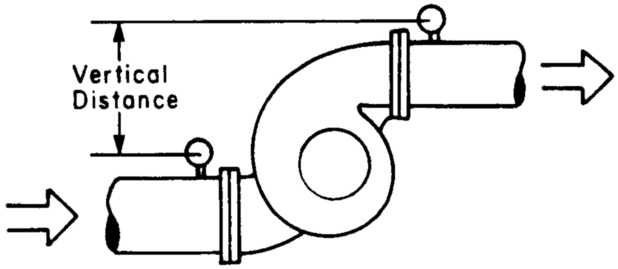


Figure 2: Head Correction for Pressure Gauge Location

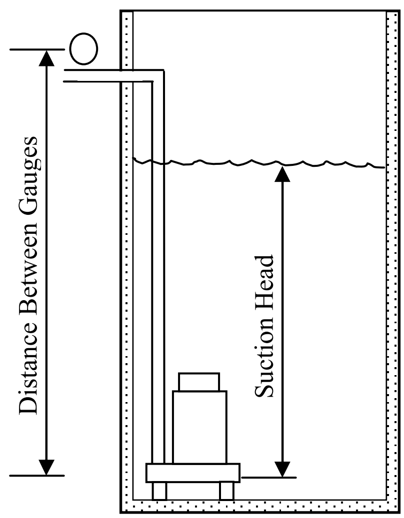


Figure 3: Submersible Pump Performance

EXAMPLE 1: Suction Gauge Reads a Vacuum

Suction Pressure	7 inches Hg vacuum
Discharge Pressure	35 psi
Vertical distance between gauges	3 feet

Suction Head = -7 in Hg x 1.13 ft/in Hg = -7.9 ft

Discharge Head = 35 psi x 2.31 ft/psi = 80.9 ft

Total Head = 80.9 ft - (-7.9 ft) + 3 ft = 92 ft

EXAMPLE 2: Suction Gauge Reads a Positive Pressure

Suction Pressure	5 psi
Discharge Pressure	35 psi
Vertical distance between gauges	3 ft

Suction Head = 5 psi x 2.31 ft/psi = 11.6 ft

Discharge Head = 35 psi x 2.31 ft/psi = 80.9 ft

Total Head = 80.9 ft - 11.6 ft + 3 ft = 72 ft

Pump Evaluation – Data Sheet

Date ____________

Pump Location ______________________________

Vertical Distance between gauges, inches ____________

Pump Number ______________________________

Static Pressure psi		Operating Pressure psi		Wet well depth, ft	Power Factor	Amperage	kW	Flowrate gpm
Suction	Discharge	Suction	Discharge					

Evaluated by: ______________________________

SOP 2-5: Adjusting Pumping Heads

PURPOSE: There are several methods available to modify pumping heads. The pumping head should be used that provides optimum operation and economy.

PROCESS:

1. The present pumping head can be determined and compared to the design pump head. If the head has increased since the pump was installed, the maintenance of the pump, suction piping, and discharge piping should be evaluated. The objective is to move the largest amount of liquid with the minimum energy input.

2. Methods used to modify the pump head are:

    a. Change Pump Impeller Size - Changing the diameter of the pump impeller will change the pump head. Changing to a smaller impeller will reduce the pump head. Refer to the manufacturer's data on the pump to evaluate other impeller sizes. Also see SOP 2-6.

    b. Change Pump Operating Speed - changing to a motor that operates at a different speed or by changing the drive mechanism between the pump and motor can change pump operating speeds. Reducing the pump operating speed will reduce the pump head.

       For direct drive pumps the most frequent method used to change pump speed is the variable frequency drive (VFD). Another benefit of using a VFD is that the pump is accelerated slowly (soft start) and thus saved from the wear and tear of instantly accelerating to the full motor rpm.

    c. Throttle Pump Output - The pump head can be adjusted by throttling although this approach is not recommended since it results in an increase in operating costs. Throttling is frequently used due to its ease of control, but the higher operating costs make it a poor choice. Also see SOP 2-8. Throttling should only be used as a very temporary practice.

    d. Reduce system head - This can be accomplished by:

       i. Reducing system pressure under normal operating conditions.

       ii. Raise the average level of wet wells, storage ponds, etc. This increases the suction head and decreases the total dynamic head on the system.

       iii. Maintain the full pipe diameter and smoothness by cleaning (SOP 2-7).

SOP 2-6: Reading a Pump Curve

PURPOSE: Pump curves are used to determine optimal performance of an existing pump. In the design of new pumping facilities, they are used to select the appropriate pump for installation.

PROCESS:

1. Determine the pump operating speed and the pump impeller diameter. For any combination of impeller diameter and speed, there is only one pump curve. Keep in mind that the curve will change as the pump impeller and volute wear.

   Figure 4 shows a pump curve for a pump operating at a specific speed and impeller diameter. Notice that as head increases, the flow rate decreases. This is the principle behind throttling; as a throttling valve is closed, head is increased, which decreases the flow rate.

   Figure 5 shows a graph that is more likely to be encountered. It shows a series of pump curves with 11, 11 ¼, 11½-inch impellers, all operating at 1750 rpm. The pumps operating characteristics can be estimated if impeller size, rpm, and either flow rate or head are known.

   For example, determine the head on a pump with an 11½-inch impeller operating at 1750 rpm and delivering 800 gpm. Figure 5 represents the pump curve.

   a. Draw a vertical line from 800 gpm until it intersects with the 11½-inch impeller curve. This intersection is called the operating point.

   b. Draw a horizontal line from the operating point to the Y-axis. The head, read off the vertical scale, is 94 ft. Compare this to the actual TDH calculated in SOP 2-4.

   c. The brake horsepower (shaft power) is approximately 34 horsepower (interpolated between the 30 and 40-horsepower lines).

2. The operating point can also be determined if head (instead of flow) is known. For example, determine the design operating point of a pump with an 11-inch impeller operating at 1750 rpm at a head of 70 ft (see SOP 2-4) using Figure 5.

   a. Draw a horizontal line from 70 ft.

   b. The operating point is the intersection of this line and the 11-inch impeller curve. In this case, flow rate is 1170 gpm, and brake horsepower is 33 horsepower.

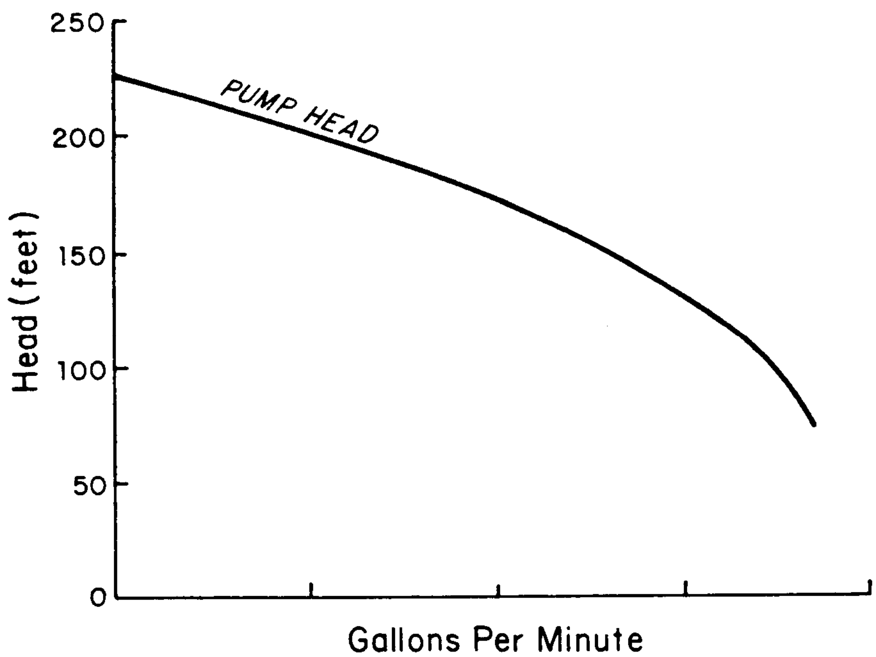


Figure 4: Basic Pump Curve (TREEO, 1986)

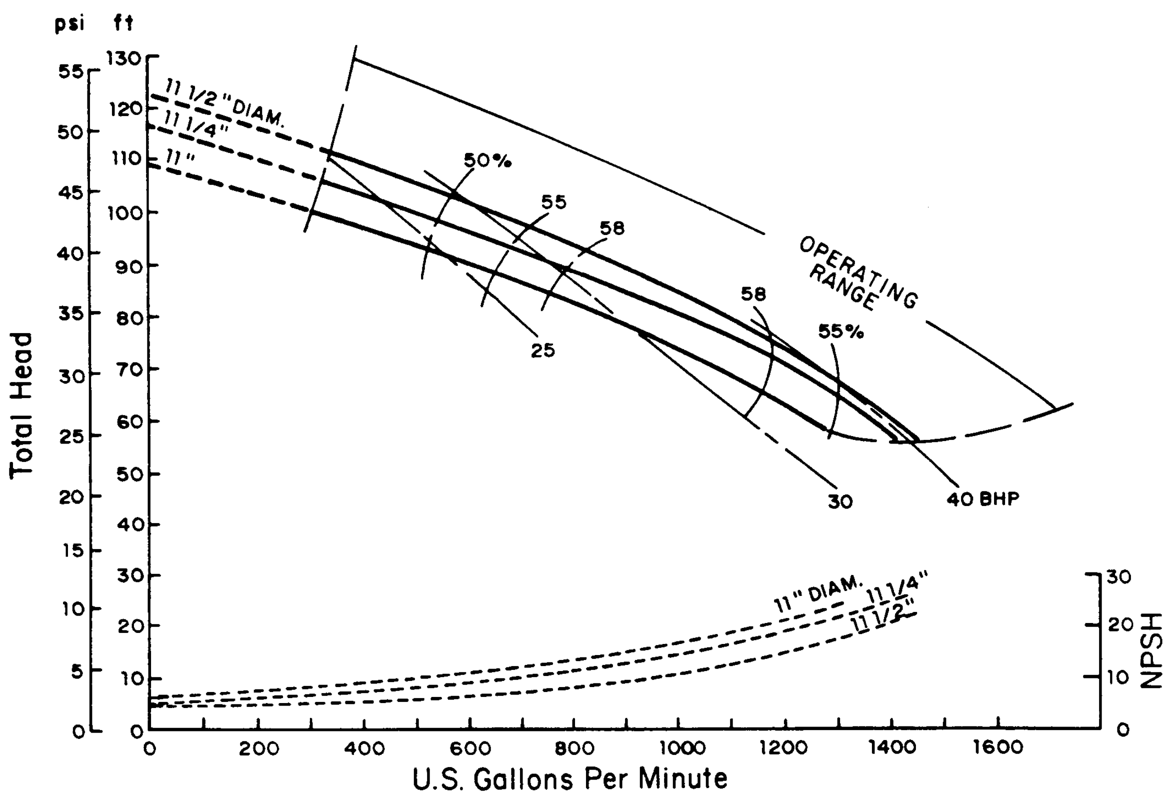


Figure 5: Typical Manufacturer's Pump Curve (Adapted from G-R Pump Curve)

SOP 2-7: Pipe Cleaning Methods and Benefits

PURPOSE: All system piping should be clean and intact for optimum economy of operation (SOP 1-4). This is true whether the system is pressure or gravity. In gravity collection systems the benefits are a better quality influent, fewer emergency calls to clear sewer backups, and improved maintenance. In pressure systems the benefit is directly observable in lower operating pressures (head) and lower electric bills for pumping the same liquid volume.

PROCESS:
PRESSURE SYSTEMS - Both water distribution and wastewater collection systems have portions that are pressurized. Over time deposits accumulate on the sides and bottoms of the piping. These deposits increase the friction of the pipe and reduce the pipe diameter. The effect of the deposits is to increase the total head the pump must overcome to move the liquid. The higher the head the higher the wire horsepower required (SOP 2-1). It is recommended that pressurized piping systems be designed to allow periodic cleaning.

The easiest and most frequently used method of cleaning pressurized piping systems is the plastic pig, which looks like a large plastic bullet. Pigs come in various sizes and types depending upon the amount and type of deposits to be removed from the pipe. The plastic pigs are moved through the system using normal system operating pressures. The major expense involved is the installation of pig launching and retrieval equipment.

The required system cleaning frequency can be determined by monitoring the pressure changes at the pump discharge. This obviously means that accurate, calibrated pressure gauges are available. An example of an installation that would require frequent cleaning would be a lift station that receives large amounts of fats. Some pipe cleaning is required because of poor potable water treatment plant operation, e.g. excessive lime or insufficient recarbonation.

Line cleaning can be performed by contractors or experienced utility personnel. A thorough knowledge of the line being cleaned is imperative.

GRAVITY SYSTEMS - There are two common methods used to clean gravity collection systems. They are a flusher truck, and sewer rodder. Typically, the flusher truck is the method employed for preventive maintenance cleaning. The sewer rodder is typically used to remove blockages.

SOP 2-8: Pump Throttling

PURPOSE: Pump throttling is a means of reducing the flow rate and the motor load. Pumps are usually throttled during startup to reduce motor overloads or when the system is over designed. Throttling as a means of flow control should be avoided since it results in an increase in operating costs. Variable frequency drives (VFDs) are reliable and inexpensive ways to deal with the need to adjust pumping rates. Of course, the application should also be evaluated. It may be that the incorrect type of or size of pump was installed.

SOP 2-5 discusses acceptable methods of adjusting pump output. This SOP provides a strategy to document the cost of pump throttling.

PROCESS: To demonstrate the additional costs per unit of flow pumped perform the following calculations:

1. Determine electric power required for an unthrottled flow rate (SOP 2-1).

2. Divide electric power for an unthrottled flow by the flow rate to find the energy consumption per unit flow.

   Flow (gpm) x 60 (min/hr) = Flow (gph)

   $$Energy\ /\ Unit\ Pumped = \frac{Electric\ Power}{Flow}$$

   Where: Energy/Unit Pumped = kWh/gal
   Electric Power = kW
   Flow = gal/hour

3. Repeat steps 1 and 2 for throttled flow rate. Note that shaft power may be lower for the throttled condition, but energy consumption per unit flow will be higher.

4. Subtract the result obtained in step 2 from the result obtained in step 3.

   Increase in Consumption = Throttled Consumption – Unthrottled Consumption

5. Calculate the increased costs per hour from throttling by multiplying the results of step 4 by the local electric rate in cents per kiloWatt-hour.

   Increased cost = Increase in Consumption x Electrical Unit Cost

EXAMPLE: Using the pump curve represented by Figure 6, the additional cost of pumping under throttled conditions can be calculated.

1. Data:

	THROTTLED	UNTHROTTLED
Electric Power, kW	53.4	62.2
Flow, gpm	2100	3090

2. Throttled unit energy consumption calculation:

$$Throttled = \frac{53.4\,kW}{2100\,gpm\,x\,60\,\min/\,hour}\,x\,1000$$

$$= 0.42\ kWh/1000\,gal$$

3. Unthrottled unit energy consumption calculation:

$$Unthrottled = \frac{62.2\,kW}{3090\,gpm\,x\,60\,\min/\,hour}\,x\,1000$$

$$= 0.33\ kWh/1000\,gal$$

4. Calculate the increase in consumption:

$$Consumption\ Increase = Throttled\ Consumption - Unthrottled\ Consumption$$

$$= 0.42\,k\ Wh/1000\,gal - 0.33\ kWh/1000\,gal$$

$$= 0.09\ kWh/1000\,gal$$

5. Calculate the increase in electricity consumption. The cost of electricity is assumed to be \$0.07/kWh.

$$Increased\ Cost = Electrical\ Increase\ x\ Electrical\ Unit\ Cost$$

$$= 0.09\ kWh/1000\,gal\ x\ 0.07\ \$/kWh$$

$$= 0.0063\ \$/1000\,gal\ or\ \$6.30\ per\ MG$$

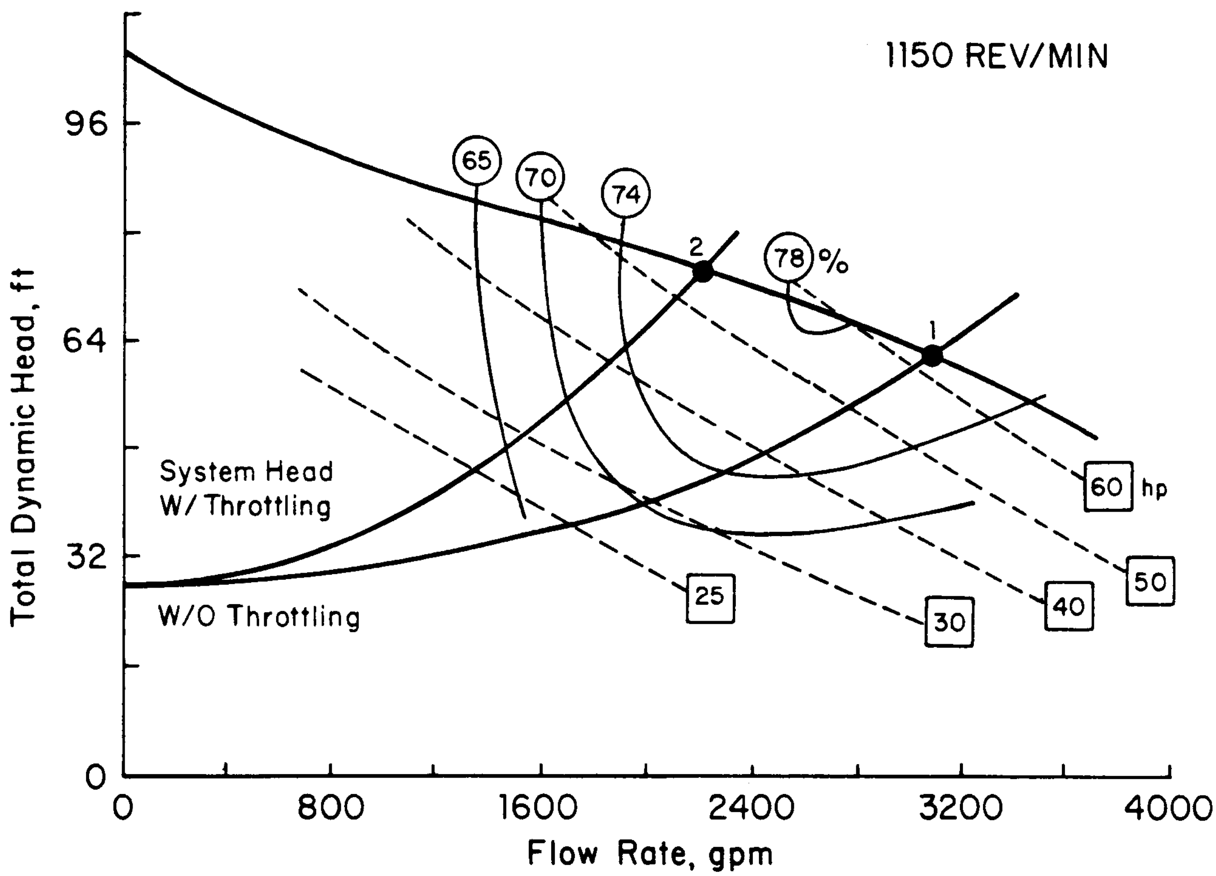


Figure 6: Pump Throttling (Adapted from GIT, 1981)

SECTION 3: WATER SYSTEMS

SOP 3-1: Determining Unaccounted For Finished Water

PURPOSE: Accounting for the amount of water produced and water paid for is an important tool for water utilities. Most potable water treatment systems' budgets are based on the revenues they produce, not the amount of water they produce. It is not uncommon for as much as 20% of water that has cost the utility energy, chemicals, maintenance and personnel to be unaccounted for in revenues. Tracking and controlling this water has many benefits, including increased budget and increased overall treatment and distribution efficiency.

PROCESS: Using the Unaccounted For Finished Water form, or one more specific to your utility, determine the amount of water that is unaccounted for.

The lower the percentage of total production unaccounted for the better. Percentages in the range of 10-15% are generally considered acceptable; however, in some cases these levels of unaccountability may be unacceptable, for instance when expensive treatment processes (e.g. reverse osmosis, carbon adsorption, electrodialysis, etc.) are necessary.

Once this unaccounted for water has been calculated and an acceptable level has been determined, professional help in developing a correction program is often recommended.

REMEMBER: Many times the utility or municipality is responsible for much of the unaccounted for water. All users should be metered, including parks, water treatment plants, fire hydrants used for testing and flushing, etc.

Discussion of the Unaccounted For Finished Water Form.

1. Meter Error Correction: As they age water meters usually under record the water passing through them. Municipalities should have a meter calibration or change-out program to minimize the volume of unbilled water going to the customer. An average meter error can be determined from the data gathered by the calibration program. The meter error correction factor will be a number greater than 1. It would be 1.00 for a meter that is 100% accurate.

2. MG Produced: Enter the amount of water, in MG, produced during the period between the water meter reading dates.

3. MG Purchased: Enter the amount of water that is accounted for through billing procedures.

4. Adjusted Purchased Water: Multiply the MG Purchased by the Meter Error Correction to get a more accurate volume of water that was delivered to the customers.

5. Flushing, Fire, and Municipal Uses: These categories are to keep track of unmetered water uses. Those individuals responsible for authorized unmetered water use should be required to maintain a log estimating their water use.

6. Total Accounted: Enter the sum of the Adjusted Purchased Water and Flushing, Fire, Municipal Uses.

7. Total A: Add up the MG Produced for the year.

8. Total B: Add up Total Accounted water for the year.

9. Percentage Of Unaccounted For Water: Subtract B from A and divide by A. Multiply the result by 100. This calculation should be made on a monthly basis. Each utility should decide what level of unaccounted for water is acceptable. In large systems, leak detection and water meter calibration programs should be established as preventive maintenance operations.

Unaccounted For Finished Water

Utility Name ______________________________

Population Served ______________________________

Number of Meters ______________ Meter Error Correction ______________

Enter all flow values in million (MG) units.

MO/ YR	MG Produced	MG Purchased	Adjusted Purchased	Flushing, Fire, Municipal, Other	Total Accounted
		Add rows as needed			
Total	(A)				(B)

$$Percent\ Unaccounted\ For\ Water = \frac{A - B}{A}\ x\ 100$$

SOP 3-2: Leak Detection

PURPOSE: A leak detection program should be instituted as a preventive maintenance operation. Depending upon the soil type, very large leaks can go undetected for a long time. Major benefits are to reduce the amount of unaccounted for finished water (see SOP 3-1) and to increase consumer safety. Keep in mind that a leak that lets water out of the system can become a cross connection if there is a loss of system pressure.

Advantages:
1. Helps account for unaccounted for water.
2. Provides documentation necessary to set rates.
3. Provides part of the work required for a valve and hydrant maintenance program.
4. The distribution maps are updated and corrected.
5. Provides an indication of total system metering inaccuracies.

PROCESS: A leak detection program consists of two major steps. First, a water audit (SOP 3-1) is performed, comparing field recorded flows in the distribution system to the amount metered and paid for. This process will note the amount of water loss caused by leaks, inaccurate meters, and/or unauthorized taps. Second, a planned repair program is carried out to eliminate the major leaks. This may require help from a consultant and/or contractor.

EQUIPMENT NEEDS:
1. A portable flow meter (accurate to ±2%) that can record continuous flows for up to 24 hours. A pitot tube flow meter can be installed temporarily at various points throughout the distribution system through a 1-inch corporation stop.

2. A listening device to locate leaks. Listening devices range in complexity from simple earphones to computerized ultrasonic equipment. Check with your equipment suppliers and/or do an internet search to identify the latest equipment options. In many states the Rural Water Association has listening devices that can be borrowed.

SOP 3-3: Hydrant Flushing

PURPOSE: Hydrant flushing is frequently viewed as a method used to clean the distribution system. Hydrant flushing may be acceptable as a temporary means to reduce customer complaints while more adequate cleaning methods are being implemented (SOP 2-7). The benefits of such an operation do not generally justify the costs. Large volumes of product water are used and only very light loose materials are cleaned from the distribution system.

PROCESS:

1. Preliminary Considerations:

    a. Notify customers before the flushing activity. Use the notification as a public relations opportunity. Some turbidity can be expected, so timing the flushing during low use periods will minimize phone calls.

    b. Work in teams and work from the pressure source toward the outlying runs of the distribution system.

2. Flushing Procedure:

    a. Monitor and record the amount of water used for the hydrant flushing operation. This volume can be obtained most accurately using a meter or fire flow test procedures that follow

    b. Locate the hydrant shutoff valve, in case the hydrant cannot be closed at the conclusion of the flushing operation. Mark any defective hydrant and notify the fire department.

    c. Remove the steamer cap and hose caps as needed to reach flushing velocity.

    d. Position the Flushing Board so that the hydrant discharge will not cause damage to private property or the street.

    e. The hydrant should be fully open for at least 2 minutes per 1000 foot of main being flushed or until clear water is flowing. The AWWA Standard C651 requires a flushing velocity of 2.5 fps (0.76 m/sec) or greater to be achieved for effective cleaning. See the box below for an example calculation.

    f. Do not reduce the residual pressure at a fire hydrant to zero when there are isolated mains downstream. States usually have a minimum pressure that must be maintained, often 20 psi. Check with your state regulatory agency.

    g. Upon conclusion of the hydrant flushing the hydrant should be closed slowly to prevent water hammer. Once the valve is closed, back it off 1/4 turn and listen at the nut to make sure there are no leaks. If the valve is leaking, open fully and repeat.

h. Careful closing prevents damage to the hydrant stem or valve seat. Once the sudden resistance to turning is noted, do not continue tightening. Applying additional pressure to the hydrant may cause the stem to snap, making the hydrant unavailable for use. Leaking seats are frequently undetected because the flow drains into the bedding material through the weep hole.

Firemen, should be trained, by the water utility, to correctly open and close hydrants. They also should be involved in maintaining water use records for the unaccounted water evaluation (SOP #16).

Calculating the flowrate needed to achieve flushing velocity (*Opflow*, 1996)

Given: 12-inch (305-mm) diameter main
2.5 fps (0.76 m/s) desired velocity

$$Q_{ft^3/s} = A \ x \ V$$
$$= (3.14 \ x \ 0.5 \, ft \ x \ 0.5 \, ft) \ 2.5 \, fps$$
$$= 1.96 \, ft^3 / s$$

$$Q_{m3/s} = A \ x \ V$$
$$= 3.14 \ x \ (0.1525 m)^2 \ x \ 0.76 \, m/s$$
$$= 0.055 m^3 / s$$

$$Q_{gpm} = 1.96 \, ft^3 / s \ x \ 7.48 \, gal / ft \ x \ 60 \, s / \min$$
$$= 880 \, gpm$$

$$Q_{L/s} = 0.055 m^3 / s \ x \ 1000 \, L / m^3$$
$$= 55 \, L / s$$

i. Clean and lubricate the hydrant nozzle threads before replacing the caps. Tighten the caps securely.

j. Collect the equipment used and repair any damage caused by the discharged water.

k. Fill out the field data sheets.

RECORDS:

Field data sheets similar to those used for fire flows (SOP 3-4) should be used to record all pertinent data. The information can then be transferred to the permanent record. Maps showing the locations of hydrants, valves, lines, etc. should be available to the team. Notes about any variations should be made so the drawings can be corrected to reflect the actual system design.

SOP 3-4: Fire Hydrant Flow Tests

PURPOSE: Fire hydrant flow testing is a means to check on the condition of the water mains. Over time it is not unusual for deposits to reduce the carrying capacity of the main. This will result in higher pumping heads and increased energy use. The National Fire Protection Association has developed *NFPA 291: Recommended Practice for Fire Flow Testing and Marking of Hydrants*. A copy of *NFPA 291* should be obtained for reference and a full set of the tables. The following procedure outlines the process and provides an example calculation.

EQUIPMENT AND SUPPLIES: List specific equipment and supplies that are typically used.

PROCEDURE:

1. Locate map of water system.

2. Select fire hydrants for testing. Critical fire hydrants are found at the points where the water mains leaving the plant reduce in size.

   a. Two fire hydrants should be selected at each location. The fire hydrant closest to the source will be the one that is flowed (fire hydrant 1). The next fire hydrant downstream should be fitted with a cap gauge, Figure 7, to read residual line pressure (fire hydrant 2). If there is no fire hydrant on the same water main to serve as fire hydrant two then a hose bib gauge can be installed on the next customer downstream of fire hydrant one.

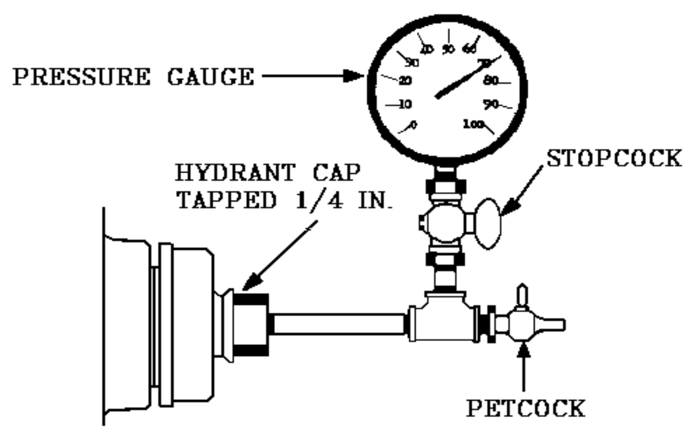


Figure 7: Hydrant cap gauge (After AWWA 1986(1))

   b. The number of major water mains serving the system will determine the number of test sites.

3. Time of Test. If possible, flow test should be done late in the evening or at night. Flushing the fire hydrants will stir up sediment in the water mains.

4. Test Procedure (requires two persons)

   a. Second person will flush fire hydrant two and close it. NOTE: Fire hydrants must always be closed very slowly to prevent water hammer. The usual procedure is to turn wrench 1/4 turn and then pause. Repeat this procedure until the fire hydrant is completely closed.

b. Install a cap gauge on fire hydrant two or install a hose bib gauge on the next customer downstream from fire hydrant one.

c. Second person will open fire hydrant two fully.

d. Second person will record Static Pressure at fire hydrant two.

e. First person will remove one nozzle cap (either 2-1/2" or 1-1/2") from fire hydrant one. The shape of the corner leading from the hydrant barrel to the nozzle must be noted. Correction factors are used, Figure 8, in the calculation or selection of appropriate tables.

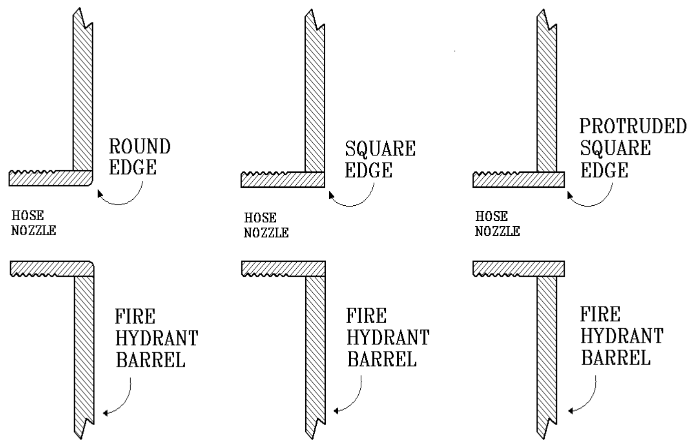


Figure 8: Value for nozzle coefficient

f. First person will open fire hydrant one fully. If erosion may be a problem then a diffuser should be installed.

g. First person will wait until fire hydrant one has reached full flow and then signal second person.

h. First person will use a pitot gauge to measure flow from fire hydrant one. The pitot blade should be held so that opening is in center of water stream and blade is held at right angles to end of fire hydrant nozzle.

i. Second person will record residual pressure on fire hydrant two at same time pitot gauge reading is recorded.

NOTE: If the residual pressure at fire hydrant two drops less than 5 psi, then the second hose nozzle on fire hydrant one, or additional hydrants, must also be flowed and pitot readings taken on both nozzles. If more than one flowing hydrant is used, locate the residual pressure gauge between them.

j. First person will signal that test is complete and will begin to close fire hydrant one. Record the time, in minutes, that water was flowed so the volume can be estimated.

k. When fire hydrant one is fully closed, second person observes the static pressure again to compare reading in step c. The static pressures should always be exactly the same before and after the flow test. Second person then closes fire hydrant two, removes cap gauge and replaces nozzle cap.

NOTE: Some fire hydrants are fitted with weep holes. These holes are designed to empty the fire hydrant after use. If the fire hydrant is left partially open then water running continuously from the weep holes will erode the area around the fire hydrant and the hydrant will separate from the water main.

5. Calculations: The calculations are described on the following pages. Actual data are best manaed with a computer spreadsheet for calculation.

   a. Flow produced at hydrant one. This value can be obtained from Table C-1 or by using the following formula.

$$Q_1 = 29.83\ C\ d^2\ \sqrt{R_1}$$

Where: Q_1 = flow at P, gpm
29.83 = formula constant
C = nozzle coefficient
d = nozzle diameter
R_1 = flowing pressure in psi

   b. Flow available in the water main at 20 psi.

$$Q_{20} = Q_1 \left(\frac{S - R_2}{S - R_1} \right)^{0.54}$$

Where: Q_{20} = flow rate at 20 psi
Q_1 = flow at P, gpm
S=static pressure, psi
R_1 = flowing pressure in psi
R_2 = 20 psi
$x^{0.54}$ can be obtained by calculation or Table C-3

Sample Calculation

The discharge rate according to Table C-1 for hydrant one, pitot pressure of 25 psi from a 2 2-inch outlet, is 840 gpm.

This can also be determined by calculation. A computer spreadsheet simplifies use of the formula.
Static Pressure (S) - 60 psi
Residual Pressure (R_1) - 44 psi at fire hydrant two
Pitot Pressure (P) at fire hydrant one - 25 psi
Nozzle Coefficient C - 0.9 (rounded end of 2-1/2-inch diameter (d) nozzle in hydrant barrel)

$$
\begin{aligned}
Q_1 &= 29.83\ C\ d^2\ \sqrt{R_1} \\
&= 29.83 \times 0.9 \times (2.5\ \text{inches})^2 \times \sqrt{25\ \text{psi}} \\
&= 839\ \text{gpm}
\end{aligned}
$$

There is good agreement between Table C-1 and the calculated discharge rate for the operating conditions described. Next the flow rate must be adjusted to conditions at the minimum pressure of 20 psi (R_2).

$$
\begin{aligned}
Q_{20} &= Q_1 \left(\frac{S - R_2}{S - R_1} \right)^{0.54} \\
&= 839\ \text{gpm} \left(\frac{60\ \text{psi} - 20\ \text{psi}}{60\ \text{psi} - 44\ \text{psi}} \right)^{0.54} \\
&= 839\ \text{gpm} \left(\frac{7.33\ \text{psi}}{4.47\ \text{psi}} \right) \\
&= 1376\ \text{gpm} @ 20\ \text{psi}
\end{aligned}
$$

Obtain the required numbers to the 0.54 power from Table C-3, y^x button on a calculator or computer spreadsheet. The values for the example are:

$(40)^{0.54}$ = **7.33**
$(16)^{0.54}$ = **4.47**

TABLE C-1: Discharge Table for Circular Outlets, 2 1/4 - 2 11/16 inch.
(Outlet pressure measured by pitot gauge)

Outlet Pressure psi	Outlet Diameter, inches							
	2 1/4	2 3/16	2 3/8	2 7/16	2 ½	2 9/16	2 5/8	2 11/16
	gallons per minute							
11	450	480	500	530	560	590	610	640
¼	460	480	510	530	560	590	620	650
½	460	490	510	540	570	600	630	660
¾	470	490	520	550	580	600	630	660
12	470	500	520	550	580	610	640	670
½	480	510	540	560	590	620	650	690
13	490	520	550	570	610	640	670	700
½	500	530	560	590	620	650	680	710
14	510	540	570	600	630	660	690	730
½	520	550	580	610	640	670	700	740
15	530	560	590	620	650	680	720	750
½	540	570	600	630	660	700	730	760
16	540	570	610	640	670	710	740	780
½	550	580	620	650	680	720	750	790
17	560	590	620	660	690	730	760	800
½	570	600	630	670	700	740	770	810
18	580	610	640	680	710	750	780	820
½	590	620	650	690	720	760	800	830
19	590	630	660	700	730	770	810	840
½	600	640	670	700	740	780	820	860
20	610	640	680	710	750	790	830	870
21	620	660	690	730	770	810	850	890
22	640	670	710	750	790	830	870	910
23	650	690	730	770	810	850	890	930
24	670	700	740	780	820	860	910	950
25	680	720	760	800	840	880	920	970
26	690	730	770	810	860	900	940	990
27	710	750	790	830	870	920	960	1010
28	720	760	800	840	890	930	980	1020
29	730	770	820	860	910	950	1000	1040
30	750	790	830	870	920	970	1010	1060
31	760	800	840	890	940	980	1030	1080
32	770	810	860	900	950	1000	1050	1100
33	780	830	870	920	970	1010	1060	1110
34	790	840	880	930	980	1030	1080	1130
35	810	850	900	940	990	1040	1090	1140
36	820	860	910	960	1010	1060	1110	1160

Table C-3: Values of *h* to the 0.54 power

h	$h^{0.54}$	h	$h^{0.54}$	h	$h^{0.54}$	h	$h^{0.54}$	h	$h^{0.54}$	h	$h^{0.54}$	h	$h^{0.54}$
1	1.00	26	5.81	51	8.38	76	10.37	101	12.09	126	13.62	151	15.02
2	1.45	27	5.93	52	8.44	77	10.44	102	12.15	127	13.68	152	15.07
3	1.81	28	6.05	53	8.53	78	10.51	103	12.22	128	13.74	153	15.13
4	2.11	29	6.16	54	8.62	79	10.59	104	12.28	129	13.80	154	15.18
5	2.39	30	6.28	55	8.71	80	10.66	105	12.34	130	13.85	155	15.23
6	2.63	31	6.39	56	8.79	81	10.73	106	12.41	131	13.91	156	15.29
7	2.86	32	6.50	57	8.88	82	10.80	107	12.47	132	13.97	157	15.34
8	3.07	33	6.61	58	8.96	83	10.87	108	12.53	133	14.02	158	15.39
9	3.28	34	6.71	59	9.04	84	10.94	109	12.60	134	14.08	159	15.44
10	3.47	35	6.82	60	9.12	85	11.01	110	12.66	135	14.14	160	15.50
11	3.65	36	6.93	61	9.21	86	11.08	111	12.72	136	14.19	161	15.55
12	3.83	37	7.03	62	9.29	87	11.15	112	12.78	137	14.25	162	15.60
13	4.00	38	7.13	63	9.37	88	11.22	113	12.84	138	14.31	163	15.65
14	4.16	39	7.23	64	9.45	89	11.29	114	12.90	139	14.36	164	15.70
15	4.32	40	7.33	65	9.53	90	11.36	115	12.96	140	14.42	165	15.78
16	4.47	41	7.43	66	9.61	91	11.43	116	13.03	141	14.47	166	15.81
17	4.62	42	7.53	67	9.69	92	11.49	117	13.09	142	14.53	167	15.86
18	4.78	43	7.62	68	9.76	93	11.56	118	13.15	143	14.58	168	15.91
19	4.90	44	7.72	69	9.84	94	11.63	119	13.21	144	14.64	169	15.96
20	5.04	45	7.81	70	9.92	95	11.69	120	13.27	145	14.69	170	16.01
21	5.18	46	7.91	71	9.99	96	11.76	121	13.33	146	14.75	171	16.06
22	5.31	47	8.00	72	10.07	97	11.83	122	13.39	147	14.80	172	16.11
23	5.44	48	8.09	73	10.14	98	11.89	123	13.44	148	14.86	173	16.16
24	5.56	49	8.18	74	10.22	99	11.96	124	13.50	149	14.91	174	16.21
25	5.69	50	8.27	75	10.29	100	12.02	125	13.56	150	14.97	175	16.25

FIRE HYDRANT FLOW TESTING

Date__________________________________Time___________________ (a.m./p.m.)

Location______________________________ City_________________________________

Hydrant 1 location _____________________________ at ___________________________

Hydrant 2 location _____________________________ at ___________________________

Hydrant 3 (if needed)____________________________ at ___________________________

Discharge diameter of hydrant 1 ________inches Hydrant 1 nozzle coefficient ______

Pressure Data.

Hydrant Number	Static Pressure (psi)	Residual Pressure (psi)	Pitot Pressure (psi)	Time Flowed minutes
1				Testing
2				Flush
3				Gallons

Flow at residual pressure of _____psi is ________gpm Flow at 20 psi is ________gpm

Diagram of Hydrant Positions and Valve Settings.

SOP 3-5: Water Main Cleaning

PURPOSE: All system piping should be clean and intact for optimum economy of operation. As time goes by many systems develop turbuncles, encrustation, etc. that severely increase friction losses. There are several methods available to remove these deposits (AWWA 1991).

EQUIPMENT AND SUPPLIES: List specific equipment and supplies that are typically used.

DISCUSSION: There are several ways to clean a water main. A specific process will not be presented in detail. The following discussion is provided to explore the process and its benefits.

The effect of the deposits in a pipe is to increase the total head the pump must overcome to move the water. The higher the head, the higher the wire horsepower required. It is recommended that distribution systems be designed to allow periodic cleaning. If a distribution system is cleaned periodically, the severe encrustation will not develop.

The easiest and most frequently used method of cleaning pressurized piping systems is the plastic pig, which looks like a large plastic bullet. Pigs come in various sizes and types depending upon the amount and type of deposits to be removed from the pipe. The plastic pigs are moved through the system using normal system operating pressures. The major expense involved is the installation of pig launchers and pig retrieval.

Lining the cleaned pipe requires downtime. However, studies have shown that unlined metal pipe quickly loses the Hazen & Williams C-value improvements obtained from a cleaning. Lining is beneficial because capacity is restored approximately to that of new pipe. Lining protects the pipe from internal corrosion and stops leaks.

The required system cleaning frequency can be determined by monitoring the pressure and flow changes at the pump discharge. This means that accurate, calibrated pressure gauges and flow meters are used. Some pipe cleaning is required only because of poor treatment plant operation, e.g., excessive lime or insufficient recarbonation. Obviously, after cleaning operations are done, the water quality should be adjusted to provide effective corrosion control.

SOP 3-6: Elevated Storage Tank Management

PURPOSE: The entire contents of an elevated storage tank should be turned over every 24 hours. When the tank contents are not turned over frequently, the water quality can deteriorate. If the chlorine residual is lost, the potential for taste, odor, and bacteriological problems increases. The ideal time to release the stored water is during the peak flow period of each day. This will reduce the amount of high service pumping that will be required during this period.

DISCUSSION: The distribution system design must be evaluated. The altitude valve adjustments, necessary system pressures, etc. must be known. Then a strategy to ensure that the elevated storage is turned over each day can be developed.

Manage the elevated storage so it is released during peak use. This strategy will lower high service pumping during this period, which typically coincides with peak electrical demand. Then refill the elevated storage during the off-peak period.

This operating strategy will ensure that the elevated storage content is turned over daily and also, lower the kilowatt-hours and demand during the on-peak electrical period.

SECTION 4: WASTEWATER SYSTEMS

SOP 4-1: Infiltration/Inflow

PURPOSE: The cost of treating infiltration/inflow (I/I) is a significant portion of many wastewater collection and treatment budgets. The additional costs are mainly due to the increased pumping and capacity required for the additional flow. Another concern is sanitary sewer overflows (SSOs). Excessive I/I, poor collection system maintenance, or marginal dry weather capacity generally result in SSOs.

Determining the amount of flow contributed by I/I is an important monitoring activity. The periods with high I/I can be compared with the data generated from SOPs 1-2 and 1-3.

As a general rule municipal flows greater than 120 gpd/capita are considered to have excessive I/I. If I/I is excessive, a more detailed study is needed to identify the problem areas so cost effective remediation can be planned. All that is needed to begin the process is a portable open channel flow meter.

PROCESS:

1. In-Plant Analysis: Careful data collection is the basis of producing useful results. This analysis will provide a basis for further investigations to determine if the I/I being received can be economically reduced.

   a. Data and information that are required:
      i. Flow charts, calibrated accurately
      ii. Total daily flows, calibrated accurately
      iii. Accurate rainfall and/or groundwater depth data

   b. Figures 9 and 10 illustrate how the flow and rainfall/groundwater depth data can be graphed for the entire collection system or an individual sewershed. Graphing the data makes the relationship between rainfall/groundwater and I/I clearer.

      Both graphs were generated using real data from a municipal collection system. Figure 9 reflects data obtained during a dry period when the groundwater level and rainfall were low. The daily flow variations due to community activity provide more fluctuation in flow than the small rain events. The average daily flow during this period was 0.43 MGD.

      When evaluating flows, the effects of tourism, industry, commercial operations, etc. must be considered.

      Figure 10 shows data from the wettest part of the year. On day 1 the flow is about 1.8 MGD or more than 4 times the average dry weather flow. In the period between days 1 and 16, the flow only decreases to about 0.8 MGD, even though no significant rainfall occurs. This elevated flow is due to infiltration of the high groundwater into the collection system. The sharp spikes in the flow that occurred on days 17 and 18 can be attributed to inflow that enters the collection system rapidly from the surface.

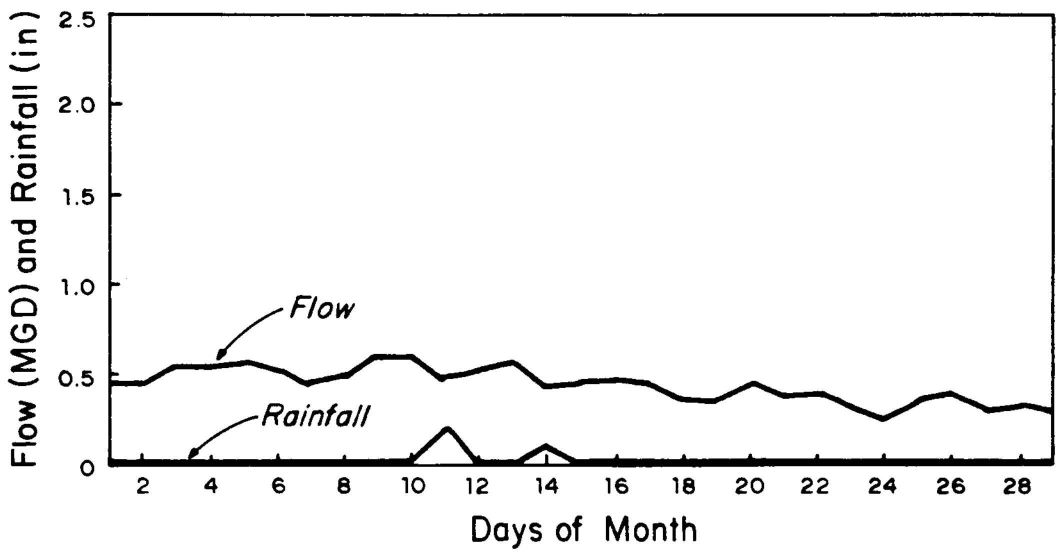


Figure 9: Dry Weather Flow and Rainfall

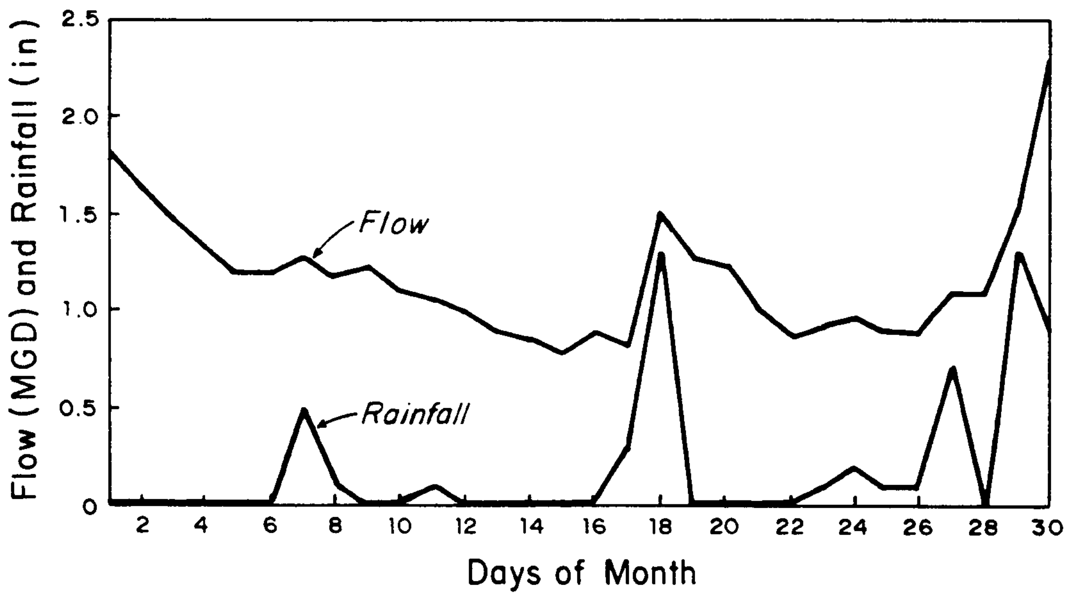


Figure 10: Wet Weather Flow and Rainfall

c. Examination of the daily flowcharts can provide a good indication of the amount of inflow being received by the treatment facility. Observing the time it takes for a severe rain event to increase the influent flow and the amount of the increased flow indicates how open the collection system is to the ground surface. Inflow is relatively inexpensive to detect and correct. Smoke testing (SMP #7) is an inexpensive and low technology method of locating inflow and some infiltration.

Engineering consultants typically perform a thorough Collection System Survey. However, simply lifting manholes and measuring the flows in various parts of the collection system can determine major problem areas. This analysis is best when performed during the night to reduce the impact of flows from human activities. In a municipal system, high flows during early morning hours when groundwater levels are high indicate significant infiltration.

To provide more complete documentation portable open-channel flow meters can be placed in interceptor sewers for periods of time. Often very significant sources of inflow can be traced to easily remedied situations. Some common examples are roof leaders, basement sump pumps, and poorly located or designed manholes. Identifying sources of infiltration is more difficult. However, TV equipment is becoming more affordable and within the reach of many communities. An alternative is for two or three communities to purchase this equipment and share.

SOP 4-2: Flow Equalization

PURPOSE: Flow equalization is a process designed to "smooth" out the peaks and valleys of flow in a wastewater treatment plant. By reducing the peak loading on the system, cost and energy savings can be achieved since equipment can be sized to accommodate the average loads on the plant. If flow equalization is not used, equipment must be sized to meet diurnal peaks that may occur for only short periods of time. Larger equipment is more expensive to purchase and usually operates inefficiently (and more costly) when under loaded. For additional information on flow equalization a good introduction is *Evaluation of Flow Equalization in Municipal Wastewater Treatment*, EPA-600/2-79-096, May 1979.

It should be understood that flow equalization can be used to economize the operation of a facility that does not have a significant I/I contribution. It is false economy to provide flow equalization and not correct excessive I/I. Although the plant will be easier to operate, but the operating costs will still be higher than necessary.

The evaluation and design of flow equalization facilities is complex and beyond the scope of this publication. The following material provides an introduction to the subject and a simple method of estimating the tank size that would be required to equalize a particular diurnal flow.

PROCESS:

1. First determine the I/I contribution. A detailed study is preferable; however, average flows in excess of 120 gpd/capita are a good indication that a problem exists. Industrial uses that may inflate the flows need to be taken into account.

2. Figure 11 indicates the diurnal wastewater flow from a hypothetical wastewater treatment plant. Most flow meters provide data to generate this graph via a SCADA system or download to a PC.

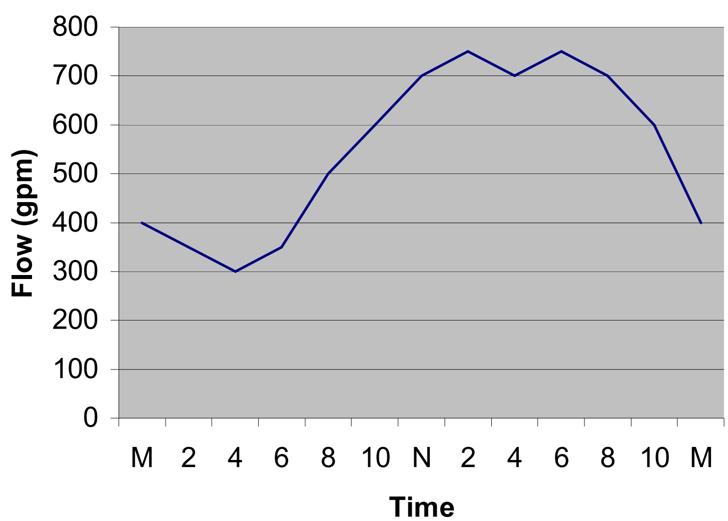


Figure 11: Typical Diurnal Flow Variations

3. There are two basic methods of equalizing flows, in-line tankage placement or side-line tankage placement (Figure 12). There are advantages and disadvantages to each method. Therefore, depending upon the specific installation one will generally operate with greater efficiency and economy.

4. A hydrograph of the data, Figure 13, indicates that a tank volume of at least 130,000 gallons would be required to equalize the flow received.

The graph is created by graphing the cumulative flow received over a 24-hour period. The dashed line represents the average flow received during the period. Lines A and B are drawn tangent to the flow extremes and parallel to the average flow. The volume represented by the vertical distance between lines A and B is the tank volume required to equalize that particular diurnal flow.

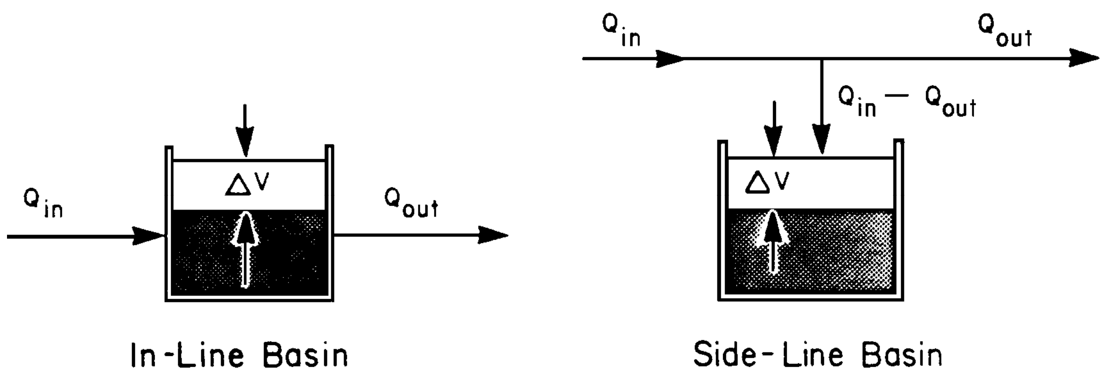


Figure 12: Simple Flow Balance Schematics (EPA 1979)

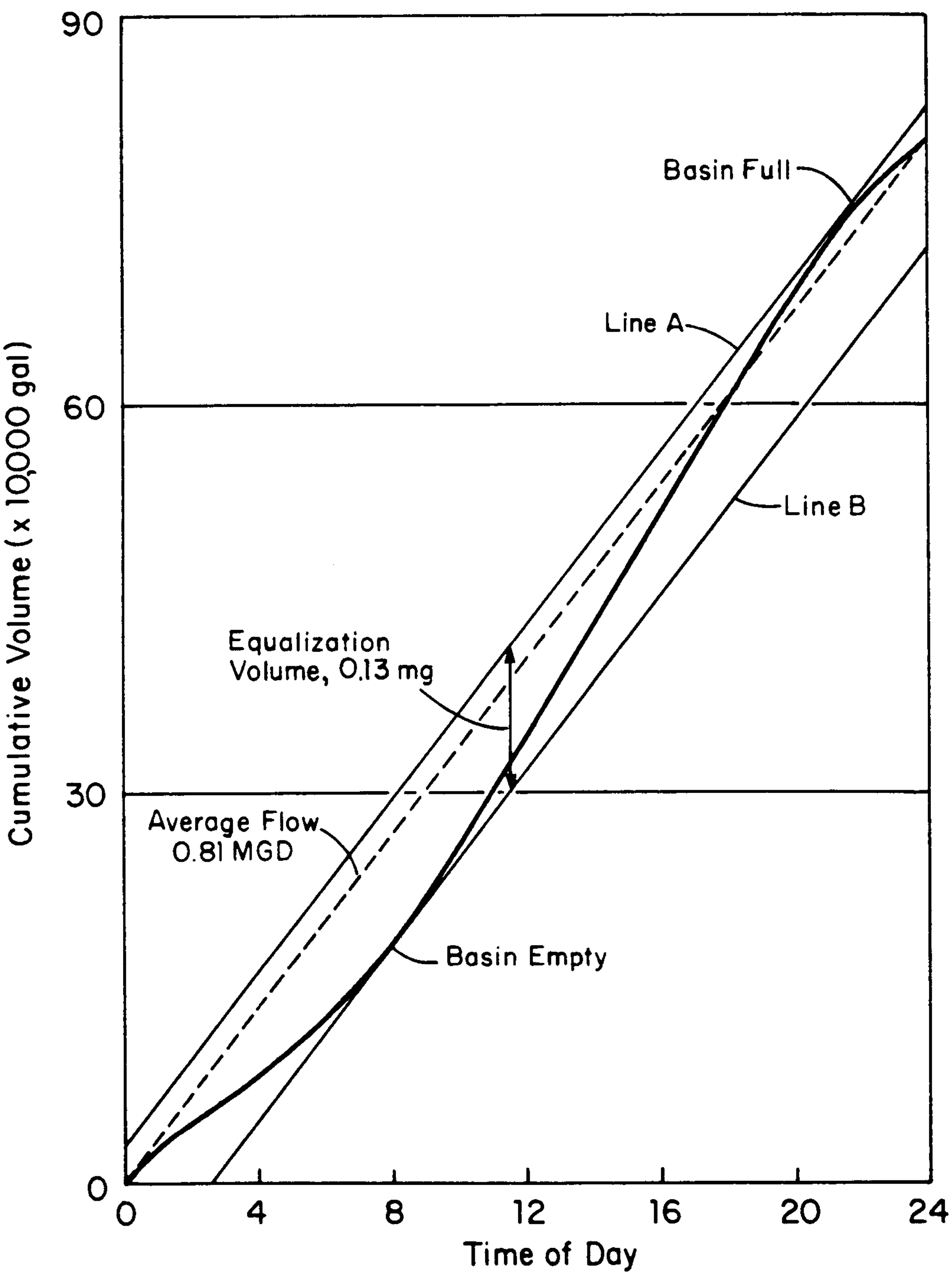


Figure 13: Hydrograph of Figure 7 Diurnal Flow Data

SOP 4-3: Smoke Testing Collection Systems

PURPOSE: During rainy, wet periods many wastewater collection systems experience large increases in flow. These flows are called infiltration/inflow (I/I) and are described in detail in SOP 4-1. Smoke testing is a low technology means of locating inflow and some types of infiltration. Smoke testing is a helpful diagnostic tool to help figure out the sewer arrangement in old systems with poor mapping.

PROCESS:

1. Since smoke testing requires that staff closely investigate around foundations, yards, streets, etc. it is important that residents, police, and fire departments are notified before testing begins.

    a. All homes that are connected to the collection system should show smoke at the vent stack. Seeing smoke coming from the roof of homes can cause some panic if residents are not aware of the testing program. A more serious situation is when floor drains do not have water in the trap and smoke enters the building.
    b. Following are examples of a letter to be sent to individual residents and a public notice for the local newspaper.

> Smoke Testing & Sewer Survey
> Sanitary Sewer System
>
> An Anywhere Water Pollution Control Facility inspection crew will be conducting a survey of [street names]. The survey will involve opening manholes in streets and easements. A non-toxic smoke will be blown into the sewer mains to locate breaks and defects in the sewer system. The smoke that may be seen coming from vent stacks on buildings or holes in the ground is **NON-TOXIC, HARMLESS, AND CREATES NO FIRE HAZARD**. The smoke should NOT enter your home, unless the plumbing is defective or drain traps are dry. If you have any seldom used drains, pour water into the drain to fill the trap.
>
> If smoke should enter your home or building, correction of defects on private property are the responsibility of the owner. A licensed plumber should be consulted to ensure the corrections are properly made. If smoke is observed you may contact a member of the survey crew working in your area. They will be pleased to assist you in identifying the source of the smoke.
>
> Some sewer mains and manholes may cross property line easements or other rights of way. Whenever these lines require investigation, the crew will need access to the sewer mains and manholes. Clearing of some easements to facilitate access may be performed prior to the survey.
>
> Video records or photographs are to be made of leaks that are found. The survey should begin on [date] and require up to [number]-days for the fieldwork. If you have questions or observe smoke in your home please call [phone number that will be manned during testing].

Dear Resident: Date

The ANYWHERE Water Pollution Control Facility (WPCF) will be conducting smoke tests [date]. The areas of the sanitary sewer system to be studied this year are; [street names]. A non-toxic smoke will be blown into the sewer system to reveal leaks that allow stormwater and other surface waters to enter. Removing these leaks will conserve valuable capacity at the treatment facility.

The smoke is manufactured specifically for this purpose, leaves no residuals or stains, and has no effects on plants or animals. It has a distinctive, but not unpleasant, odor. The visible smoke and odor last only a few minutes, where there is adequate ventilation.

The smoke should not enter your building. However, if smoke does enter your building any of the following items are the probable cause.

- The vents connected to your building's sewer lateral are inadequate, defective, or improperly installed.
- The traps under sinks, tubs, basins, showers, floor drains, etc. are dry, defective, improperly installed, or missing.
- The pipes, connections, and seals of the building's sewer system are damaged, defective, have plugs missing, or are improperly installed.

During the week prior to [projected test date] pour water down ALL drains in your home or building to ensure that traps are full.

If traces of the smoke or its odor do enter your building, it is an indication that odor from the sewer system may also be entering. This can be unpleasant, dangerous, and a potential health hazard. Locating and eliminating the source of any smoke entering your building is urgently advised.

The ANYWHERE WPCF can provide assistance in locating the source of smoke entering your building. However, correction of any defects in the pipes and sewer on private property is the responsibility of the owner. If smoke is observed in your building and the source is not readily identified or you have any questions, please call [phone number that will be manned during testing].

Sincerely,

2. The equipment and materials required to conduct a collection system smoke test are:

   a. Smoke candles or liquid smoke, depending upon blower design.
   b. A blower, with a minimum capacity of 1,500 cfm, that can be tightly fitted to the top of a manhole.
   c. Sewer plugs or sandbags with attached lines, to aid positioning, are required to isolate areas of the collection system.

3. Information required to obtain the maximum benefit from a collection system smoke test:

   a. Drawings of the collection system being tested.
   b. Measuring, locating devices to position smoke plumes on the drawing.
   c. A log book to record observations.

d. A camera, still or video, to record observations.

4. Public Notification. Fire and police personnel should also be advised daily of areas that will be smoke tested.

5. If building traps are dry or are not present, the smoke will be forced into the building. This may require the evacuation and ventilation of the building. If smoke does enter a building, the owner should be required to correct the situation. This is a public health and safety concern because sewer gases could also enter the building.

6. A smoke testing crew is frequently made up of 3 persons, more eyes are better. Typically, a section of the collection system with three (3) manholes is smoked. Plugs are installed first on the upstream side of the upstream manhole and then on the downstream side of the downstream manhole. Smoking produces the best results during the driest part of the year. This is because the soil is dry and any cracks will be larger. Also the flow of I/I into the sewer will be minimal.

   Position the blower over the manhole. CAUTION: If a gasoline engine operates the blower, it should not be started over the manhole. Explosive gases may be present in the manhole and could be ignited by the engine spark.

   Either smoke candles or liquid smoke can be used, depending upon the design of the blower. If smoke candles are used a bucket is suspended in the manhole. After the smoke candle is lit and dropped into the bucket, the blower is positioned over the manhole. At the same time other personnel located at the other two manholes should block the flow with the plugs or sandbags and close the manhole cover when smoke is visible in the manhole. One crewmember is required to tend the blower.

7. The other crew members carefully walk through the area served by the section of sewer being tested. Smoke appearing at the surface should be located, recorded and photographed. Each building vent should be checked to ensure that it is working properly. Typical locations to observe smoke are, lots that formerly had buildings, roof leaders, around foundations, and storm drainage basins.

8. After all sources of smoke reaching the surface have been identified, the sandbags/plugs should be removed. The blower is then turned off and removed from the manhole. Before moving to the next location make sure the manhole covers are secure.

SOP 4-4: Cleaning Forced Sewer Mains

Purpose: Long forced mains typically do not reach flushing velocity because the pumping cycles are too short. To increase the length of the pumping cycles would require much larger wet wells adding significantly to the cost of the pumping station. What this means is that solids settle out during the off cycle and are incompletely resuspended during the pumping cycle. As the pipe accumulates solids the pump head increases, flowrate decreases, and pump run-times increase. Cleaning the lines periodically will reduce the pump run-time, saving power and pump maintenance costs.

Preliminary Information: As with many of the energy conservation measures described in this manual, it is important to collect before and after data. These data are necessary to support and defend the energy conservation efforts. For this exercise it would be useful to know:
1. Pump runtimes. Should be available from pump station monitoring logs.
2. Pump kW. Need a powerfactor or kiloWatt meter.
3. Pump total dynamic head. See SOP 2-4.

DISCUSSION: Pigging
1. Using poly pigs is a good way to clean very long forced mains. The process should be approached cautiously and probably is best accomplished, at least the first time, by a professional line cleaner.

2. Pigs are launched downstream of the pump and any check valves. Specially designed pig launchers can be installed, either temporarily or permanently. A wye with a blind flange, or better a companion flange with a quick connect for the flusher truck, will also serve as a relatively convenient way to get the pig into the pipe.

3. Depending upon the system's design and amount of obstruction, the pumps may be adequate to drive the pig the full length of the line. Having another source of pressurized water available facilitates the flushing activity. A flusher truck is a safe and very effective source for this water. The pressure available minimizes any chance that the pig could become stuck.

4. Because of the amount of solids that will be removed it is advisable to have a vacuum truck positioned at the downstream manhole. Allowing these solids to enter the gravity portion of the collection system may result in blockages.

DISCUSSION: Flushing
1. Short forced mains can be cleaned using a flusher truck. The length of the hose carried on the flusher determines the length of main that can be flushed.

2. Exercise caution as the check valve is approached to prevent damaging it. Design of the forced main can limit the ability to flush effectively.

3. The solids removed should be collected with a vacuum truck.

SOP 4-5: Calculating BOD Load on Aeration Tanks

PURPOSE:
To enable the operator to determine whether or not the loading applied to the aeration basin(s) of an activated sludge plant is within practical guidelines. If a facility has multiple process trains it is possible, especially in the years immediately after an upgrade, to take some tankage off-line and still meet all permit requirements. In some cases process performance may even be improved.

PROCESS:

1. The term "BOD" refers to biochemical oxygen demand. In the standard test, BOD is measured after 5 days at a temperature of 20ºC.

2. The BOD loading may be expressed in terms of volumetric loading or food-to-mass ratio (F/M).

3. Volumetric BOD loading in units of lb BOD/(1000 ft^3) is calculated as follows:

$$Volumetric\ BOD\ Load = \frac{BOD_{IN}\ x\ Q\ x\ 8.34}{Tank\ vol.in\ MG\ x\ 134}$$

   Where: BOD_{IN}, influent BOD in mg/l
   Q, influent flow in MGD
   8.34 lb/gal converts mg/l x MGD to lb/day
   134 converts MG to 1000 ft^3

4. F/M in units of lb BOD/(lb MLVSS·d) is calculated as follows:

$$F/M = \frac{BOD_{IN}\ x\ Q}{Tank\ vol.in\ MG\ x\ MLVSS\ in\ mg/l}$$

   In the contact stabilization process, the MLVSS in both the contact and reaeration tanks should be included in the calculation.

5. The guidelines for volumetric BOD loading and F/M are given in Table 8.

Example: Calculate the volumetric BOD loading and F/M at a conventional activated sludge system having the following parameters. Determine if the plant is overloaded or underloaded.

Influent flow = 5.0 MGD
Influent BOD = 180 mg/l
Aeration tank volume = 1.5 MG
MLVSS = 2200 mg/l

$$Volumetric\ BOD\ Loading = \frac{5.0\ MGD\ x\ 180\, mg/l\ x\ 8.34}{1.5\ MG\ x\ 134}$$

$$= 38\, lb\ BOD / 1000\ ft^3 \cdot d$$

Conclusion: The plant is operating within the guideline for volumetric BOD loading in the conventional activated sludge process [20-40 lb BOD/(1000 ft^3)] and also within the guideline for F/M in the conventional activated sludge process [0.2-0.4 lb BOD/(lb MLVSS)].

TABLE 8: Guidelines for Volumetric BOD Loading and F/M in Activated Sludge Processes (Metcalf & Eddy 1972)

Process modification	Parameter	
	Volumetric loading lb BOD/(1000 $ft^3 \cdot d$)	F/M lb BOD/(lb MLVSS·d)
Conventional	20-40	0.2-0.4
Complete mix	50-120	0.2-0.6
Step aeration	40-60	0.2-0.4
Contact stabilization	60-75	0.2-0.6
Extended aeration	10-25	0.05-0.15
Pure oxygen	100-250	0.25-1.0

SOP 4-6: Impact of Nitrification on Aeration Requirements

PURPOSE:
To enable the operator to determine whether nitrification will occur in the activated sludge process and, if it does occur, how much additional aeration is required.

PROCESS:
1. Bacteria that oxidize ammonia to nitrate (nitrifiers) are relatively slow growers and therefore establish significant populations only at relatively long sludge ages. Temperature, dissolved oxygen and pH also impact nitrification rates

2. About 4.6 pounds of oxygen are required to oxidize 1.0 pound of ammonia nitrogen. Facilities that nitrify thus have much greater aeration requirements than those that do not.

3. In systems that utilize anoxic and/or anaerobic zones for nutrient removal the sludge age of the tank volume that is aerobic is called the aerobic sludge age. The aerobic sludge age may be used to evaluate the nitrification potential of an activated sludge system.

$$Aerobic\ Sludge\ Age, days = \frac{MLSS\ x\ Tank\ Volume}{(Q_{WAS}\ x\ WAS_{TSS}) + (Q_{EFF}\ x\ EFF_{TSS})}$$

Where:
- MLSS, mixed liquor suspended solids in mg/l
- Tank Volume, aerobic tank volume in MG
- Q_{WAS}, WAS flow in MGD
- WAS_{TSS}, WAS total suspended solids in mg/l
- Q_{EFF}, effluent flow in MGD
- EFF_{TSS}, effluent total suspended solids in mg/l

4. Figure 14 indicates the probability of nitrification in an activated sludge process at various temperatures and values of aerobic sludge age. This figure was developed assuming that the average dissolved oxygen is at least 2.0 mg/l and in no case is allowed to fall below 1.0 mg/l. The potential for nitrification is decreased at lower dissolved oxygen concentrations.

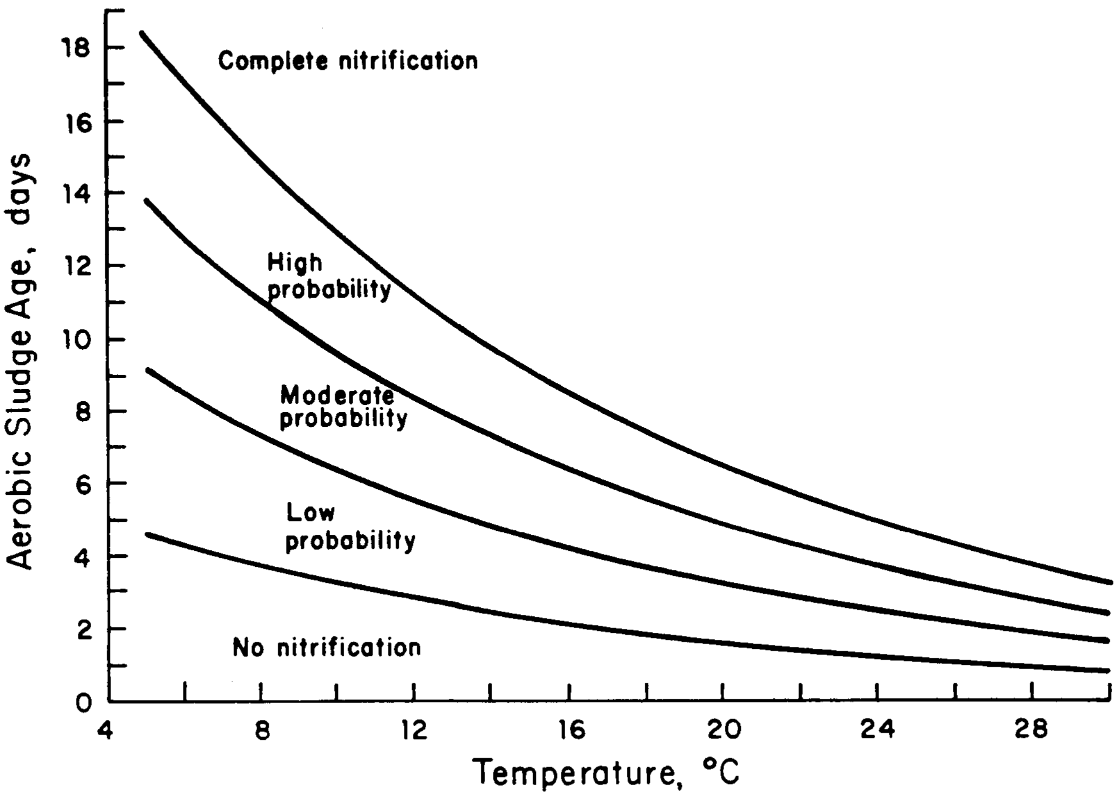


Figure 14: Nitrification Potential in Activated Sludge

5. Oxygen requirements in units of lb/day for single stage, nitrifying activated sludge are calculated as follows:

$$OD = Q\,[(F\ x\ \Delta BOD) + (4.6\ x\ \Delta TKN_{OX})]\ 8.34$$

Where: OD, oxygen demand in lb O½2/dayÞFÞ
Q, influent flow in MGD
8.34, converts mg/l x MGD to lb/day
F, unit oxygen demand for BOD removal in lb O_2/lb BOD
)BOD, total influent BOD minus the soluble effluent BOD in mg/l
4.6, oxygen requirement for TKN removal in lb O_2/lb TKN_{OX}
)TKN_{OX}, TKN oxidized, influent TKN minus the sum of the TKN assimilated into biological mass and the effluent TKN in mg/l

6. The oxygen requirement calculated above is for average flow. The aeration system must be capable of meeting simultaneous peaks in BOD and TKN loading.

Example: Given the following activated sludge system parameters:

Influent flow = 5.0 MGD
Influent BOD = 180 mg/l(no primary clarification)
Influent TKN = 25 mg/l
Aeration tank volume = 1.5 MG
MLSS = 2930 mg/L
Effluent TSS = 15 mg/l
WAS TSS = 30,500 mg/l (3.05% solids)
WAS flow = 0.023 MGD

Determine:

1. The mixed liquor temperature where the probability of nitrification become moderate or higher?

$$AerobicSludgeAge = \frac{1.5\,MG\ x\ 2930\,mg/l}{(0.023\,MGD\ x\ 30500\,mg/l) + (5.0\,MGD\ x\ 15mg/l)}$$

$$= 5.7\,days$$

From Figure 12, there is a moderate probability of nitrification over the temperature range of 12ºC to 18ºC.At mixed liquor temperatures exceeding 18ºC, the probability of nitrification at a sludge age of 5.7 days is high.

2. Determine the percent increase in average oxygen requirements if nitrification takes place.

The oxygen requirement without nitrification is: (Assume F = 1.0 lb O_2/lb BOD and the effluent soluble BOD is negligible.)

$$OD\,w/o\,nit = 5.0\,MGD\ [(1.0\,lbO_2 / lbBOD\ x\ 180\,mg/l) + (4.6\,lbO_2 / lbTKN\ x\ 0\,mg/l)]\,8.34$$

$$= 7510\,lbO_2 / d$$

The oxygen requirement with nitrification is: (Assume that the TKN oxidized is equal to 80% of the influent TKN)

$$TKN_{OX} = 0.80\ x\ 25\,mg/l$$

$$= 20\,mg/l$$

$$OD\,with\,nit = 5.0\,MGD\ [(1.0\,lbO_2 / lbBOD\ x\ 180\,mg/l) + (4.6\,lbO_2 / lbTKN\ x\ 20\,mg/l)]\,8.34$$

$$= 11{,}346\,lbO_2 / d$$

Percentage increase in O½2 requirement = 100 x (11,346 - 7510)/7510=51%

SOP 4-7: Comparing Aeration Methods and Oxygen Availability

PURPOSE: The ability to provide adequate dissolved oxygen is a frequent problem for wastewater treatment operations personnel. The ability to calculate the approximate amount of oxygen available can be a useful troubleshooting tool. During plant upgrades the choice of aeration equipment can use the same process. The selection should be based on which equipment will provide the most process flexibility at the lowest life-cycle cost. Frequently designs are selected because the capital investment is low. However, high operating costs can frequently offset the low installation costs in short time.

The following material is based on a procedure outlined in *Handbook: Improving POTW Performance Using the Composite Correction Program Approach*, USEPA, October 1984.

PROCESS:

1. The BOD loading on the aeration tank must be calculated in pounds per day. This is equivalent to the Food calculation in the F/M ratio.

   If nitrification is necessary to achieve effluent standards, then the ammonia loading on the aeration tank must be calculated in pounds per day.

2. Calculate the amount of oxygen required to achieve treatment (SOP 4-5).

3. Calculate the wire horsepower (SOP 2-1) being used to provide the present level of aeration. The volt and amp readings are obtained from the motor of the blower or surface aerator.

4. Convert Standard Oxygenation Rates (SOR) to Actual Oxygenation Rates (AOR).

$$AOR = SOR(\alpha)\left(\frac{\beta C_{SW} - C_L}{C_S}\right)\theta^{(T-20)}$$

Where: AOR, actual oxygen transfer rate, lb OI2/hp-hr

SOR, -standard oxygen transfer rate, lb O_2/hp·hr, in clean water. Use equipment manufacturer test data or estimate from Table 11.

∀, relative rate of oxygen transfer in wastewater compared to clean water. Estimate from Table 12.

∃, relative to oxygen saturation value in wastewater compared to clean water. Estimate ∃ = 0.95 for mixed liquor.

2, temperature correction constant, 2 = 1.024.

C_s, oxygen saturation value of clean water at standard conditions, 9.17 mg/l.

C_{SW}, oxygen saturation value of clean water at site conditions of temperature and pressure, mg/l

$$C_{SW} = C_{14.7}\left(\frac{P}{14.7\ psia}\right)$$

C_L, mixed liquor DO concentrations, mg/l (1.5mg/l)

T, temperature of the liquid, ºC

$C_{14.7}$, oxygen saturation value of clean water at standard pressure of 14.7 psi and actual water temperature. See Table 13.

P, -actual pressure at oxygen transfer point.

(i) For surface aerators, use atmospheric pressure at the plant elevation above sea level. Use Figure 13.

(ii) For others, use atmospheric pressure (Figure 13) plus the pressure at 0.5 times the submergence of the diffusers (i.e., diffuser depth in feet x 0.5 x 0.434 psi/ft).

5. Calculate the oxygen transfer capacity for the aeration equipment.

$$Oxygen\ Transfer\ Capacity\ (lb\ O_2\ /\ d) = Wire\ HP\ x\ \ Actual\ Oxygen\ Transfer\ Rate\ x\ 24hr\ /\ d$$

6. Calculate the oxygen availability.

$$Oxygen\ Availability\ (lbO2\ /\ lb\ BOD, NH_3) = \frac{Oxygen\ Transfer\ Capacity\ (lb\ O_2\ /\ d)}{BOD, NH_3\ loading\ (lb\ /\ d)\ from\ Step\ 2}$$

The oxygen availability should equal and preferably exceed the oxygen required as calculated in Step 2.

Table 11: Typical Standard Oxygen Transfer Rates (EPA 1984)

AERATION SYSTEM	STANDARD OXYGEN TRANSFER RATE, lb OI2/hp-hr
Coarse Bubble Diffusers[1]	2.0
Fine Bubble Diffusers[2]	6.5
Surface Mechanical Aerators	3.0
Submerged Turbine Aerators[3]	2.0
Jet Aerators[4]	2.8

[1]For 2.7-3.6 m (9-12 ft) submergence
[2]For 18-26 w/m3 (0.7-1.0 hp-hr/100 ft3)
[3]Includes both blower and mixer horsepower
[4]Includes both blower and pump horsepower

Table 12: Typical Values of Alpha (∀) Used for Estimating AOR/SOR

AERATION SYSTEM	TYPICAL ALPHA
Coarse Bubble Diffusers	0.85
Fine Bubble Diffusers	0.50
Jet Aeration	0.75
Surface Mechanical Aerators	0.90
Submerged Turbines	0.85

Table 13: Oxygen Saturation at Standard Pressure and Actual Water Temperature

TEMPERATURE, ºC	DISSOLVED OXYGEN AT SATURATION, mg/l
0	14.62
1	14.23
2	13.84
3	13.48
4	13.13
5	12.80
6	12.48
7	12.17
8	11.17
9	11.59
10	11.33
11	11.09
12	10.83
13	10.60
14	10.37
15	10.15
16	9.95
17	9.74
18	9.54
19	9.35
20	9.17
21	8.99
22	8.83
23	8.68
24	8.53
25	8.38
26	8.22
27	8.07
28	7.92
29	7.77
30	7.63

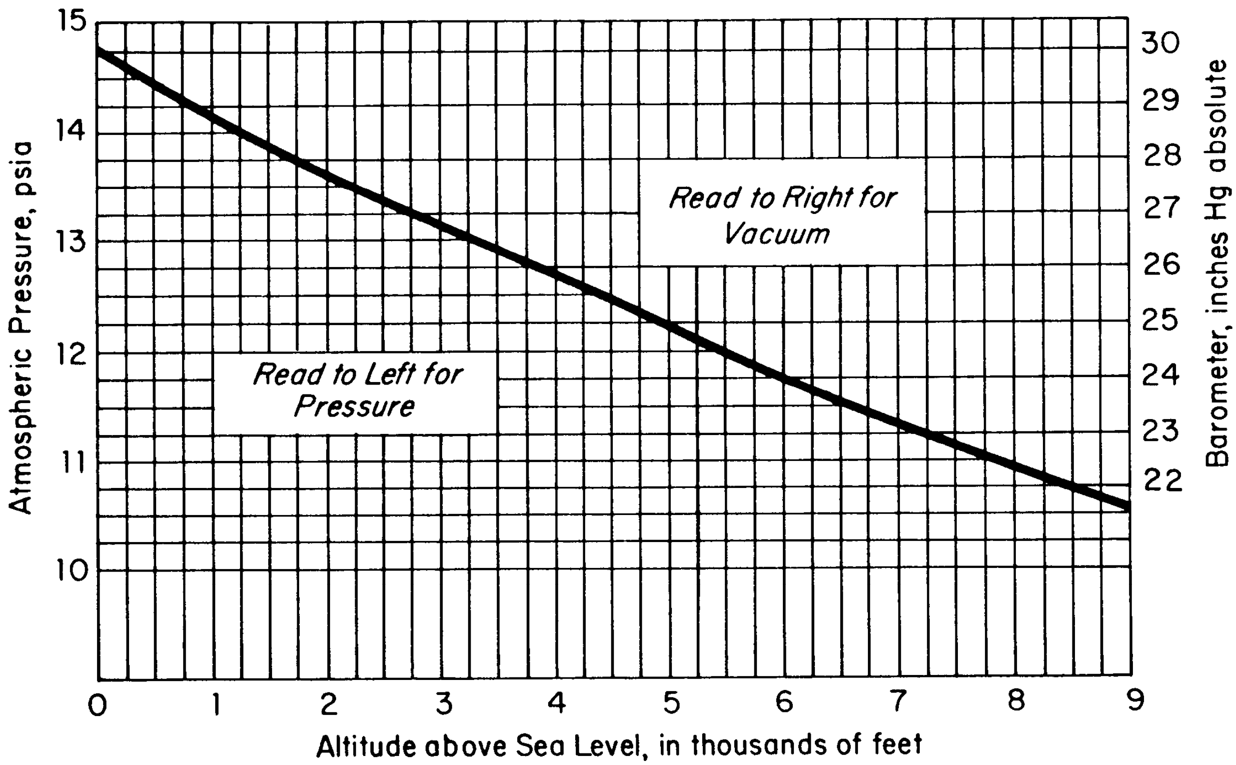


Figure 15: Atmospheric Pressure at Various Altitudes (EPA 1984)

SOP 4-8: Aeration Tank Mixing

PURPOSE: To enable the operator to determine if the air or energy input to the aeration tank is adequate for mixing.

PROCESS:

1. The aerator selected for an activated sludge aeration tank must not only transfer the needed amount of oxygen into the wastewater, but also provide the degree of mixing which prevents separation of activated sludge solids from the bulk liquid. Excessive mixing is undesirable, however, because it tends to shear (break up via turbulence) biological flocs. If shear is excessive in the aeration basin, poor settling may result in the secondary clarifier.

2. Experience has shown that the average velocity throughout the aeration tank should be maintained at approximately 1 ft/sec. Average velocities as low as 0.4 ft/sec may prevent deposition if turbulent currents create random, high velocities. Mixing requirements in terms of air or energy input are summarized in Table 14.

Table 14: Aerator Mixing Requirements (WPCF 1977)

Type of aeration	Aerator	Pattern	Minimum mixing requirements
Diffused	Fine bubble domes	Multi-line, full-floor cover	0.12 scfm/ft^2
Diffused	Coarse bubble	Spiral roll	20 scfm/1000 ft^3
Mechanical	Slow speed, fixed	Full tank	0.5 hp/1000 ft^3

SOP 4-9: Controlling Aeration Blowers

PURPOSE: In activated sludge plants, aeration is the single greatest consumer of energy; hence, a large potential for energy conservation lies in this area. Conservation is possible by adjusting blower output to meet dissolved oxygen (DO) demand. The output can be adjusted on a one-time basis, or it can be adjusted continuously.

For centrifugal blowers, the most energy efficient means of output control is by throttling the inlet or controlling the speed. For positive displacement blowers, speed control is the only practical means of controlling the output since this type of blower should not be throttled.

In-tank DO probes can be used with a SCADA computer to automate blower speed or control butterfly valves on centrifugal blower inlets. Over the years the electrical savings available from this practice will help off-set the cost of the SCADA.

PROCESS:

1. Centrifugal Blowers

    a. Inlet Throttling—Output is controlled by throttling the inlet valve.

        i. Check DO-It is typically maintained between 1 and 2 ppm.
        ii. If DO is high, close the inlet valve slightly.
        iii. Allow sufficient time for aeration basin to reach equilibrium; then recheck DO.
        iv. Repeat as needed to maintain the desired dissolved oxygen concentration.

        Note: Centrifugal blowers have distinct maximum and minimum limits for the throttling valve. The throttling valve should not be open to the point that the motor current draw exceeds the nameplate value. Nor should the throttling valve be closed to the point where surge (pulsing noise and low frequency vibration) occurs.

    b. Speed Control--Speed control is accomplished in the same way as it is for pumps (i.e. changing pulley diameters or installing a variable speed control device). Different variable speed drives should be evaluated. Some types have flat power curves and do not provide significant energy savings.

2. Positive Displacement Blowers

    a. Speed Control--Speed control is the only method of output reduction for positive displacement blowers.

DO CONTROL

For all the above methods, the objective is to maintain the DO at the minimum acceptable level that will achieve treatment objectives. This is typically stated as 1-2 mg/l for BOD removal and nitrification. However, to be more accurate the minimum DO is dependent upon the BOD loading to the aeration zone. Thus, if blower output is to be maintained at a constant level (i.e. no automatic adjustment), be sure that the output can produce sufficient DO during peak organic loadings. Automatic controllers take care of this by continually adjusting the output to meet the minimum DO requirement.

SOP 4-10: Sludge Digester Process Control

PURPOSE: The optimum use of sludge digestion facilities is to provide only sufficient energy to accomplish the stabilization process. The volatile solids (VS) loadings, sludge detention times, volatile solids reduction, and operating temperature provide the operator with indications of how the system is operating.

PROCESS:

1. Volatile solids reduction is the purpose of sludge stabilization processes. Therefore, the endpoint of digestion can be assumed to be attainment of a specific volatile solids content. 40 CFR Part 503 allows a VS reduction of 38% for digestion processes to meet vector attraction reduction requirements. Other parameters are available to verify vector attraction reduction, however for digester operators VS reduction is one of the key process control variables. VS reduction is calculated using the formula:

$$VS\,\mathrm{Re}duction\,(\%) = \frac{VSin(\%) - VSout(\%)}{VSin(\%) - [VSin(\%)\ x\ VSout(\%)]}$$

   Where: VSin(%) = VSin / TSin

   VSout(%) = VSout / TSout

   VSin, Volatile solids of sludge pumped into the digester in mg/l.

   VSout, Volatile solids of digested sludge removed from the digester in mg/l.

   TSin, Total solids of sludge pumped into the digester in mg/l.

   TSout, Total solids of sludge removed from the digester in mg/l.

2. The VS loading rate is a value typically used for digester design and forgotten. For conventional, single stage digesters the design value for a standard rate VS loading rate ranges from 0.03 to 0.10 lb VS/ft^3 (hydraulic detention time ranges from 30 to 90 days). In high rate digesters with well-mixed primary digesters the design value for the VS loading rate ranges from 0.10 to 0.40 lb VS/ft^3 (hydraulic detention time ranges from 10 to 20 days).

   Knowing the actual loading rate is valuable for process control and troubleshooting. The design VS loading should be obtained from the plant O&M manual.

   The operating loading rate must account for actual temperature, type of sludge, detention time, etc. Table 16 illustrates the relationship between several factors for an anaerobic digester that operates at a constant temperature. The operation of an aerobic digester is more technical because of the temperature variations that occur. The VS loading is calculated using the formula:

$$VS\ Loading\,(lb\,/\,ft^3 \cdot d) = \frac{VSin\ x\ SludgeAdded\ x\ 8.34}{Digester\ Capacity}$$

WHERE: VSin, VS concentration of the sludge pumped into the digester in mg/l.
Sludge Added, the sludge pumped into the digester in MGD
8.34, converts mg/l x MGD to lb/d
Digester Capacity, tank volume in ft^3

3. A study of Table 16 indicates that as one factor affecting VS reduction is changed, the other factors also are changed. For example, for a hypothetical high rate digester, if the sludge can be thickened to 10% (100,000 mg/l) total solids (TS) then a 0.239 VS loading will have a hydraulic detention time of 20 days. For the same digester, 5% TS sludge at a 0.239 VS loading will have a hydraulic detention time of 10 days.

   These interrelationships are why it is necessary to monitor and trend chart all operating factors for optimum performance to be obtained. Then if operational problems do develop there will be sufficient information available for effective troubleshooting.

4. Hydraulic detention time is a typical value used to determine solids stabilization. Obviously, given a tank of specific volume, the thicker the sludge pumped, the longer the hydraulic detention time. Hydraulic detention time for digesters is determined with the formula:

$$Hydraulic\ Detention\ Time, days = \frac{Digester\ Capacity}{Sludge\ Added}$$

WHERE: Digester Capacity, tank volume in gallons
Sludge Added, daily sludge volume added in gal

TABLE 16: Anaerobic Digestion, Several Factors Affecting Volatile Solids Loading (Metcalf & Eddy 1979)

Sludge Concentration, %	Volatile Solids Loading Factor, $lb/ft^3 \cdot d$			
	10 day[1]	12 day[1]	15 day[1]	20 day[1]
4	0.191	0.159	0.127	0.095
5	0.239	0.199	0.159.	0.119
6	0.286	0.239	0.191	0.144
7	0.334	0.278	0.223	0.167
8	0.382	0.318	0.255	0.191
9	0.430	0.358	0.286	0.215
10	0.477	0.398	0.318	0.239

[1]Hydraulic detention time available.

5. In anaerobic digestion, with normal loadings, the temperature is a major variable that can be manipulated to conserve the energy required for digester heating. The digester should be operated at the lowest temperature that will produce a good sludge. In mesophilic digesters, temperatures above 95ºF typically do not increase the rate of digester gas production or VS reduction.

   Pumping the thickest sludge possible will also reduce the heating requirement because the volume of sludge pumped will be less.

SOP 4-11: Using Digester Gas for Cogeneration

Purpose: Anaerobic digestion is an attractive sludge stabilization process for numerous reasons. One that is often not exploited is the fuel value of the digester gas. By using the digester gas as fuel for a generator one gets electrical energy and waste heat. The electricity can be used to offset in plant energy demands and the waste heat is available for digester heating.

DISCUSSION:
1. Cogeneration is the recovery and use of waste heat resulting from the generation of electricity. Thus much more of the energy released by fuel combustion is converted to useful forms.
2. Internal combustion engines, microturbines and, some day soon, fuel cells can be used for cogeneration. Microturbine technology has matured to the point where it is often the driver of choice when designing cogeneration processes. Microturbines are designed for continuous operation and produce very low Nox emissions.
3. Electric generation can operate in grid-parallel mode or isolated from the grid.
   a. Grid parallel mode synchronizes to the voltage and frequency of the power grid. The electricity produced by the generator reduces the amount used from the grid. Some microturbine controls will keep designated equipment operating without significant interruption if a grid outage occurs.
   b. Continually operating a treatment facility or process that is isolated from the grid is rare. Generally, the only time it occurs is when the grid is out. Emergency generation is often accomplished using internal combustion engines that are not designed for continuous operation.

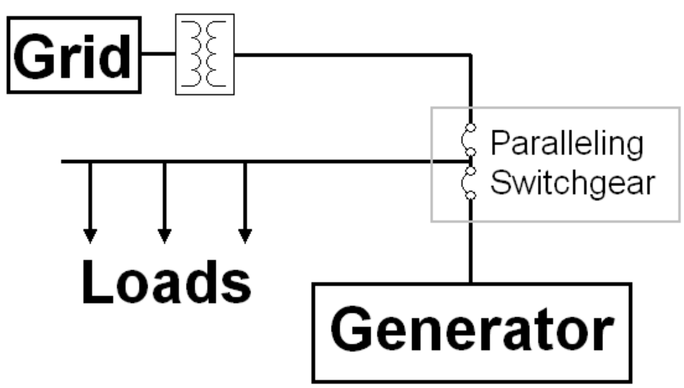


Figure 16: Grid Parallel Control Scheme

Following is some feasibility data to consider the viability of a microturbine. Consult the U.S. Department of Energy website (SOP 1-9) for up-to-date information and a listing of microturbine manufacturers.

Typical digester gas	700 BTU/ft^3
70 kW microturbine	requires 30,000 ft^3/day

70kW – equipment cost $100,000, plus installation cost
250 kW – equipment cost $260,000, plus installation cost
Depending upon local cost of power – 3-4 year payback

Depending on the quality of the digester gas additional conditioning equipment may be required.

That costs will decrease with advances in the technology and increased use. For facilities with anaerobic digesters or landfills with gas recovery systems the microturbine option should be investigated. Contact the local power distributor and determine if any incentives or design assistance are available.

UNIT III: STANDARD MAINTENANCE PROCEDURES

SMP 1: Voltage Measurements: 3-Phase Equipment

PURPOSE: Voltage measurements between phases of 3-phase equipment (mainly motors) are required to ensure that the phases are balanced and within the proper operating range for the equipment. When the voltage between the phases is unbalanced, the motor generates excessive heat and operates less efficiently.

For proper operation the average voltage must be within specific tolerances relative to the nameplate voltage for a particular motor.

CAUTION: This procedure is performed with the equipment operating. **ALWAYS** wear properly tested high voltage rubber insulating gloves with leather outer gloves, in addition to other appropriate PPE. For more information check OSHA standard 29 CFR 1910.137 Electrical Protective Devices.

PROCESS:

1. Using an accurate voltmeter measure the voltage between the phases, Figure 17, at the motor's starter. Long cable runs or undersized wiring can cause excessive voltage drops and may need to be taken into consideration.

   The motor should be at normal operating temperature.

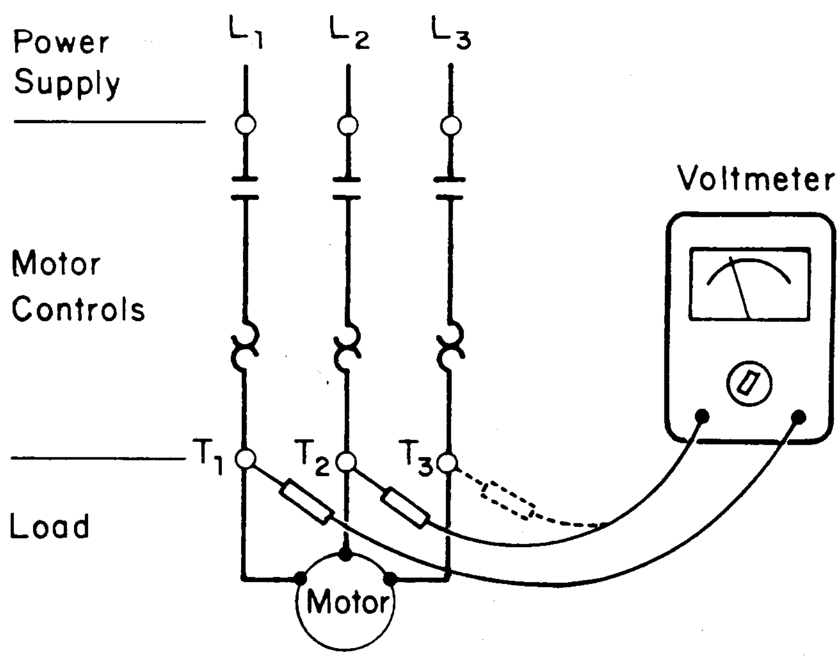


Figure 17: Checking 3-Phase Motor Voltage (Adapted from FLYGT)

2. To calculate the PERCENT VOLTAGE UNBALANCE.

$$Percent\ Unbalance = \frac{Maximum\ Deviation\ from\ Average}{Average\ of\ 3\ \mathrm{Re}adings}\ x\ 100$$

Example:

L1-L2 = 472 Volts
L1-L3 = 477 Volts
L2-L3 = 474 Volts

Average of the 3 readings = 474 V

Note: Also, use this average value for Step 3, below.

Max. Deviation from the Average: 477 V - 474 V = 3 V

$$Percent\ Unbalance = \frac{Maximum\ Deviation\ from\ Average}{Average\ of\ 3\ \mathrm{Re}adings}\ x\ 100$$

$$= \frac{3\,V}{474\,V}\ x\ 100 = 0.6\%$$

The percent voltage unbalance should be less than 1%. If it is greater than 1%, consult SMP 4 for possible causes and correction alternatives.

3. Note the nameplate voltage specified for the motor. The acceptable range for the average supply voltage is listed in Table 17. If the average supply voltage is above or below these ranges it must be determined whether:
   a. The problem could be the power company, on-site transformers, or poor system maintenance.
   b. The motor installed was improperly specified.

Table 17: Acceptable Motor Supply Voltages

200V motor – (±10%)	180V - 220V
220V motor – (±10%)	198V - 242V
230V motor – (-14 +10%)	198V - 253V
440V motor – (±10%)	396V - 484V
260V motor – (-14 +10%)	396V - 506V
550V motor – (±10%)	495V - 605V
575V motor – (-14 +10%)	495V - 632V

SMP 2: Amperage Measurements: 3-Phase Equipment

PURPOSE: The balance of the current (amperage) being used by the 3 phases of a motor is necessary to reduce heat and obtain maximum efficiency. At full load the maximum allowable unbalance is 5%. However, slightly higher amperage unbalances are acceptable for motors operating at less than full load. For maximum efficiency a motor should be operated near full load.

The amount of voltage unbalance must be determined (SMP 1) since it can produce an amperage unbalance that is several times greater. That is, a 0.5% voltage unbalance could produce a current unbalance of up to 5%.

CAUTION: This procedure is performed with the equipment operating. **ALWAYS** wear properly tested high voltage rubber insulating gloves with leather outer gloves, in addition to other appropriate PPE. For more information check OSHA standard 29 CFR 1910.137 Electrical Protective Devices.

PROCESS:

1. Using an ammeter measure the amperage on each leg of the motor electrical supply as illustrated in Figure 18. The system should be at operating temperature and under normal load. To obtain repeatable results the same ammeter should be used and periodically calibrated.

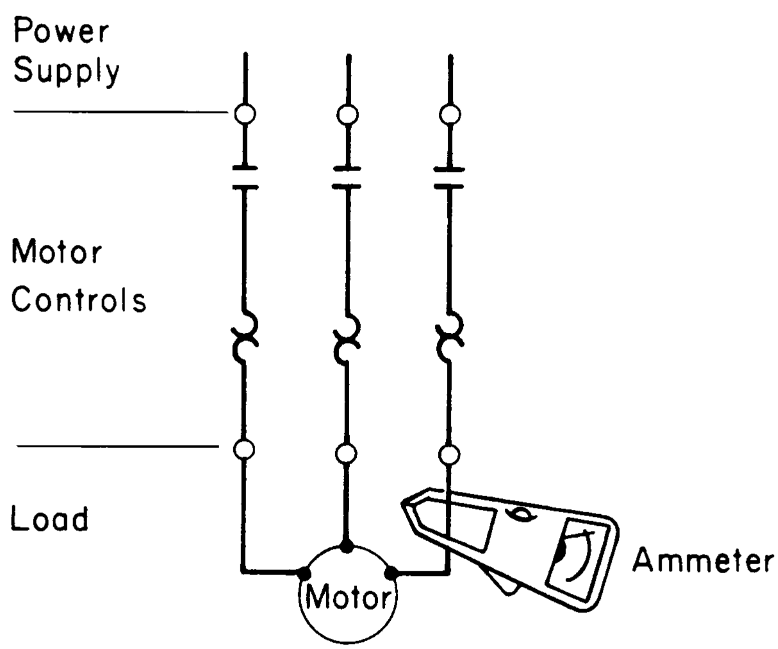


Figure 18: Checking 3-Phase Motor Amperage (Adapted from Flygt)

To calculate the PERCENT AMPERAGE UNBALANCE.

$$\textit{Percent Unbalance} = \frac{\textit{Maximum Deviation from Average}}{\textit{Average of } 3\ \textit{Readings}}\ x\ 100$$

Example:

L1 = 98 amps
L2 = 98 amps
L3 = 108 amps

Nameplate Full Load Amp. = 161

Operating at 63% of Full Load

Average of 3 Readings = 101 amps

Max. Deviation from Average: 108 amps - 101 amps = 7 amps

$$\textit{Percent Unbalance} = \frac{\textit{Maximum Deviation from Average}}{\textit{Average of } 3\ \textit{Readings}}\ x\ 100$$

$$= \frac{7\ A}{101\ A}\ x\ 100 = 6.9\%$$

The unbalance calculated is greater than 5%. The troubleshooting procedure should be followed to see if there are ways to reduce the amount of unbalance. However, a 6.9% current unbalance may be the best operating condition possible since the motor is loaded at 63%.

SMP 3: Sources of Voltage and Amperage Unbalance

PURPOSE: If voltage (SMP 1) or amperage (SMP 2) unbalances are identified, they must be eliminated or justified. Voltage unbalances usually result from the power supply or defects in the load (motor). Amperage unbalances can be produced by voltage unbalances, defects in the load, and motors operating at less than full load. Another common problem is loose terminals. Periodically the terminals in a MCC panel should be checked for tightness.

PROCESS:

1. Determine if the source of the unbalance is the power supply or the load.

    a. Changing all three motor leads and checking the voltage and amperage for each combination accomplish this. CAUTION: If only two leads are changed the motor rotation will be reversed.

    Example:

    The system is normally operated with the leads connected in the lead combination described as #1 in Table 18. The other combinations that will result in the same motor rotation are combinations #2 and #3.

TABLE 18: POSSIBLE LEAD COMBINATIONS

LEAD COMBINATION	Motor Lead		
	T_1	T_2	T_3
1	Red	Black	White
2	Black	White	Red
3	White	Red	Black

    b. When the unbalance follows the same motor lead, the problem is usually associated with the wiring to the motor or the stator windings. Figure 19 illustrates a condition where the black motor lead is the one that is drawing the excessive amount of amperage.

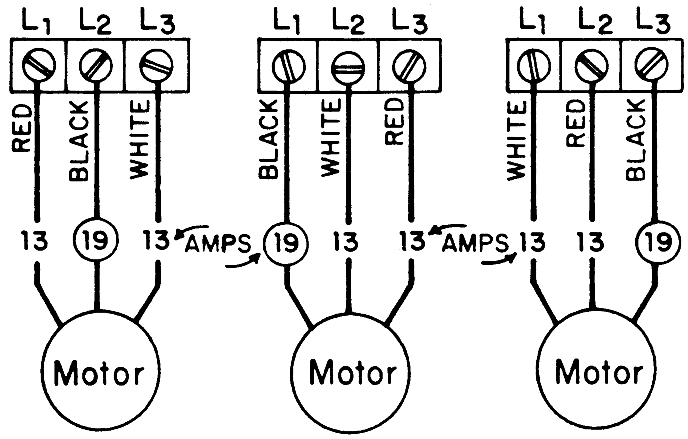


Figure 19: Unbalance Caused by Load (Adapted from FLYGT)

c. When the unbalance does not change from a specific terminal, the problem is usually associated with the power supply. Before calling the power company, check to make sure all connections have good contact and are tight. Figure 20 illustrates a condition where the T_2 terminal is the one with the high amp draw regardless of which lead is connected.

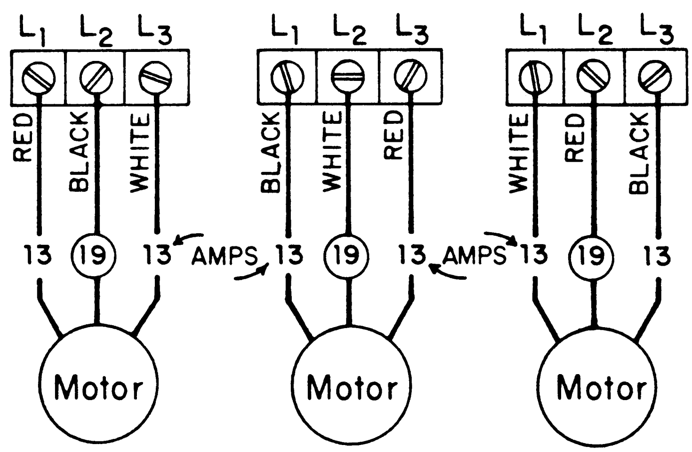


Figure 20: Unbalance Caused on Supply Side of Controls (Adapted from FLYGT)

SMP 4: Using a Megohmmeter

PURPOSE: A megger or megohmmeter can be used for preventive maintenance as well as corrective maintenance. It is used to determine the integrity of wiring insulation and continuity. Frequently, detecting the potential problem before it becomes critical can eliminate unscheduled, emergency repairs. The instrument provides resistance readings in the megohm (MΩ) range. Meg being the System International prefix for million.

PROCESS:

1. **Using the megohmmeter.** A megger applies voltage to a conductor and measures how much of it gets through the insulation. The voltage can vary with 500 or 1000 volts being typical for the less expensive megohmmeters.

   a. When a megger is being used the power must always be **OFF**. The wire being tested should be checked with a voltmeter to make certain there is no voltage present. Capacitors are often a source of voltage long after the breaker has been opened. Use a resistor to discharge any capacitors that have retained voltage.

   b. For routine testing the test period is 1.0 minutes. The longer voltage is applied, typically the better the reading gets. One minute is a standard to provide repeatable results.

   c. Insulation resistance (IR) varies inversely with temperature. Rule of thumb is that the IR changes by a factor of two for each 10ºC change. For example, a reading of 100 MΩ at an insulation temperature of 30ºC would be 200 MΩ at 20ºC. The easiest means of obtaining the motor temperature is with a handheld infrared thermometer.

2. **Check Motor Coil to Casing (ground).** This test checks the primary insulation of the motor. It can be performed at the motor starter or at the motor. If performed at the motor starter, the insulation of the conductors to the motor is also being inspected.

   Some motor manufacturers suggest 2MΩ/hp as minimum insulation resistance value before the motor coils are dipped and rebaked to restore the primary insulation. The insulation resistance value for new motors should be infinite (∞), i.e., perfect. It is safer to have the coils dipped and rebaked when the resistance reaches no less than 50 MΩ for any motor. The cost of this process, which should include new bearings, needs to be compared to replacement with a new motor.

   If the resistance is graphed there will often be a point where the resistance begins to decrease rapidly. When this trend is noted, the maintenance personnel are aware that the insulation is deteriorating at an accelerated rate.

   a. Testing at the Motor Starter - It is preferable to disconnect the motor leads from the contactor. However, if the motor starter is in good condition, the same results will result without the effort of removing the motor leads. As a preventive maintenance procedure this operation should be performed semi-annually. The procedure begins at **c** below.

For submersible pumps and motors with long wire runs the possible deterioration of the cable insulation must be eliminated if low resistance readings are obtained. Removing the conductors from the motor and checking coil to ground at the motor eliminates the effects of deteriorated conductor insulation.

b. Testing at the Motor – Remove the cover on the side of the motor and remove the electrical tape covering the wire nuts or split bolt connectors. Perform the test as follows.

c. Attach one megger lead to the motor casing or MCC panel ground and the other, one at a time, on each motor lead, Figure 21. Apply the test voltage from the megger for 1.0 minute. Record the resistance readings and motor temperature. If needed the readings can be corrected to a standard temperature.

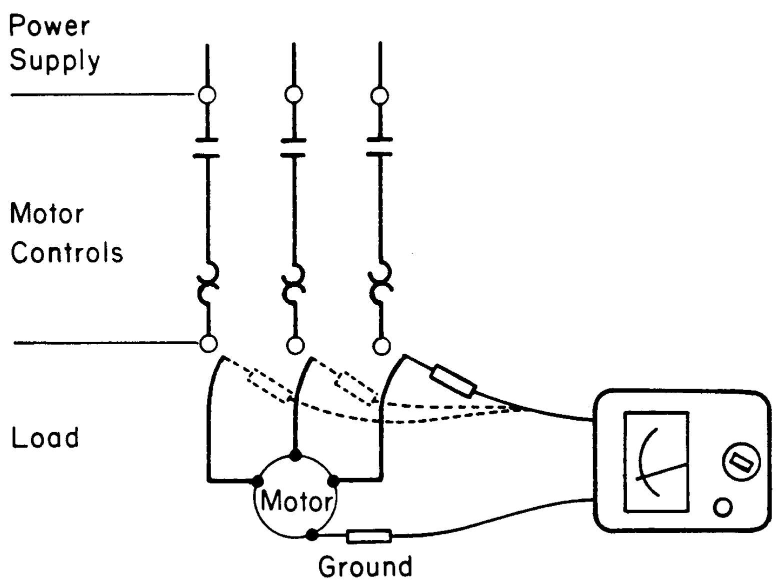


Figure 21: Checking Primary Insulation (Adapted from FLYGT)

3. **Check Motor Coil to Motor Coil.** The secondary insulation barrier prevents current from short-circuiting between the separate coils that make up the motor windings. The value of this test is primarily for troubleshooting and determining the cause of a motor failure.

    a. The coil leads are separated at the motor. One test lead of the megger is then attached to one coil and the other lead is attached to another coil. The resistance between all possible coil combinations is then evaluated.

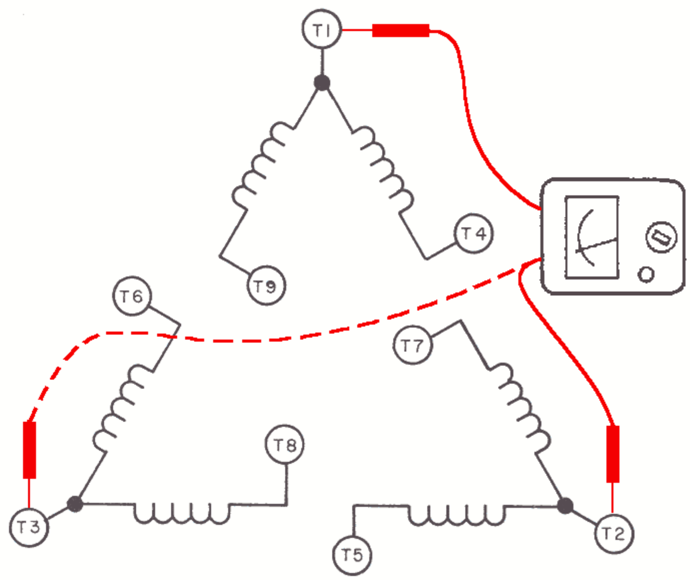


Figure 22: Motor Coil to Coil Insulation Check

4. **Checking Cable Insulation.** It might be necessary to check the integrity of submersible pump power cables when troubleshooting a problem.

    a. To check the resistance between the cable leads and ground, coil up the cable and place it in a bucket of water, with the ends out of the water. If the bucket is plastic a metal rod must be placed in the water. One megger lead is attached to the rod while the other lead is attached to the cable leads that are twisted together. The resistance between the cable leads and ground should be infinity (∞).

    b. To check the resistance between each of the cable leads separate the leads at each end of the cable so that none are touching. Then check the resistance with the megger between all combinations of leads.

5. **Coil Open Circuit or Self-Shorting Failure.** Another useful troubleshooting test is to check for coil open circuits or coils that have shorted but welded back together. This test uses an ohmmeter because the resistance of the wire is being checked.

   a. The motor coils need to be separated. Make certain each lead is labeled so the motor can be rewired if everything checks out and the fault is not the motor. Wiring schematics are located on the motor nameplate.

   b. Carefully zero the ohmmeter on the lowest setting, typically 1X, before use. Place the ohmmeter test leads on each end of the motor coil being tested and read the resistance as accurately as possible. Similar sets of coils should have exactly the same resistance. For instance, coils T1–T4, T2–T5, and T3–T6 in a wye wound motor should have the same resistance. If the readings are not exactly the same or there is no resistance, the motor will not operate properly.

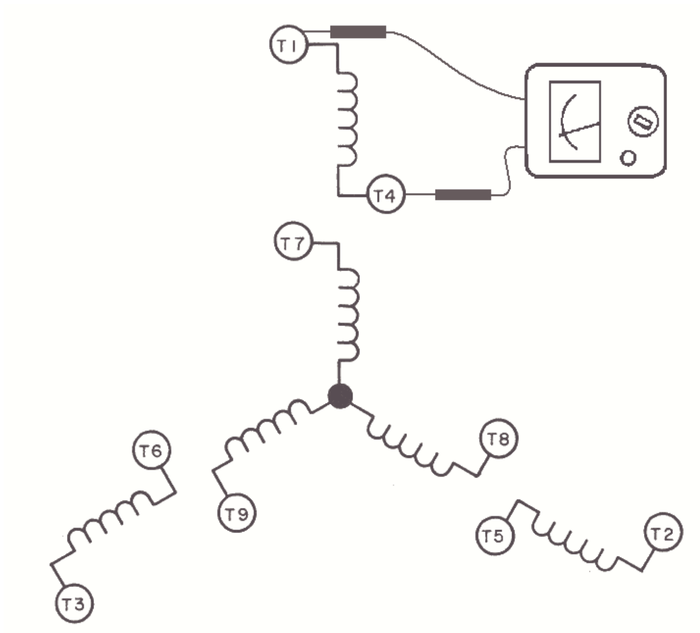


Figure 23: Testing for coil open circuits

   c. The open circuit and self-shorting tests can be performed at the MCC panel as a troubleshooting activity. Of course keeping in mind that the conductors providing power to the motor are also being tested.

   If the test at the MCC panel indicates a problem, then the test should be repeated at the motor to eliminate the power supply conductors.

SMP 5: Recommended Pump Maintenance

PURPOSE: Pump maintenance is frequently limited to greasing and checking the packing or mechanical seals. However, this level of maintenance can allow an inefficient pump to operate for years.

PROCESS:

1. Daily inspection of the motor/pump should include:

   b. Visual inspection for:

      (1) Any unusual conditions.
      (2) Dirt and/or grease accumulations.

   b. Auditory inspection for unusual sounds or vibrations.

   c. Tactile inspection for:

      (1) Excessive heat.
      (2) Unusual vibrations.

2. Wear surface clearances of centrifugal pumps should be inspected periodically. Ideally, replaceable wear rings should be fitted to all centrifugal pumps. This feature makes restoring original tolerances very easy.

   a. Every 6-months: Check wear surface clearances of pumps that pump raw sewage or other abrasive liquids.

   b. Every 12-months: Check the wear surface clearances of all pumps. Check the total dynamic head (SOP 2-4) and flowrate.

3. Improperly adjusted packing can significantly increase the amount of energy used by a pump. Packing that is too tight acts like a brake on the pump shaft. These situations are indicated by inadequate leakage and wear on the shaft sleeve.

   Mechanical seals operate without the friction on the shaft sleeve. Frequently, the cost of a mechanical seal is offset by the manpower and materials required for packing maintenance added to the energy savings.

4. When a pump is removed from service for maintenance or any other reason, the impeller, volute, and casing should be inspected for wear or damage.

SMP 6: Recommended Motor Maintenance

PURPOSE: To operate at an optimum level of performance all mechanical equipment must be well maintained. The frequencies for the various observations and tests are a suggested starting point. Experience will indicate whether a more or less frequent schedule is required.

PROCESS:

1. Daily inspection of the motor/pump should include:

   a. Visual inspection for:

      i. Any unusual conditions.
      ii. Dirt and/or grease accumulations.

   b. Auditory inspection for unusual sounds or vibrations.

   c. Tactile inspection for:

      i. Excessive heat.
      ii. Unusual vibrations.

2. Megger the motor. Additional discussion is found in SMP 3.

   a. Every 6-months: Check coil-to-ground.
   b. Every 12-months: Check coil-to-coil.

3. Voltage and Amperage Characteristics. Additional discussion is found in SMPs 1 and 2. Every 6-months:

   a. Check voltage range and balance.
   b. Amperage balance and % full load.

   When checking the voltage and amperage a SMP should be developed that describes the load, speed, etc. to be used during the electrical evaluation of a specific motor. Variable frequency drives often must be turned off and the evaluation performed at full speed.

4. Check the tightness of all control panel electrical connections once each year. These screws can work loose over a period of time. A loose connection can produce various problems such as voltage and amperage unbalances, single phasing, and shorting. These situations have a tendency of becoming critical at about 2 a.m. during a rainstorm.

5. Lubrication. Follow the manufacturer's O&M instructions for proper lubrication frequency and lubricant type. If a grease relief fitting is provided, make sure it is removed prior to lubrication. If the relief fitting is not removed, the inner seal may be broken and allow grease to be pumped into the motor windings.

Over greasing does not allow the heat to dissipate from the bearing. The buildup of heat can cause the bearing to fail prematurely.

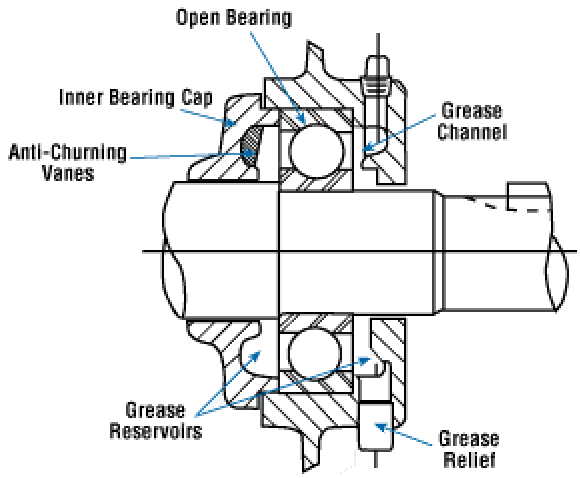


Figure 24: Bearing

6. Belt-driven installations require checks of the sheave alignment, belt tension, and belt condition. Follow the manufacturer's O&M information in setting the proper belt tension. When the belts show signs of cracking or fraying the complete set should be replaced. Never replace just one belt of a set.

   a. Every month: Evaluate the belt tension and condition.
   b. Every 12-months: Check the sheave alignment and anchor bolt tightness.

7. Coupling driven equipment requires checks of the shaft alignment and condition of coupling parts. Some types of couplings require lubrication of metal parts, while others require periodic replacement of rubber parts. The manufacturer's O&M literature should be consulted for specific alignment tolerances and technique.

   a. Per Manufacturer's recommendations: inspection and greasing.
   b. Daily: Listen for unusual sounds or vibrations.
   c. Every 12-months: Check shaft alignment and anchor bolt tightness.

SMP 7: Infrared Temperature Measurement

PURPOSE: The temperature of equipment can be measured using handheld infrared (IR) thermometers or IR photometry. The main purpose of any maintenance program should be to keep equipment operating at peak efficiency. If equipment is producing excess heat it is not efficiently converting the electrical energy to mechanical energy. Thus by periodically monitoring the heat produced by equipment it is possible to make corrections before failures occur. IR thermometry and thermography are a major component of any predictive maintenance program.

EQUIPMENT:

Pistol type IR thermometer
IR thermography

DISCUSSION: The least expensive way to get started in IR thermometry is the handheld pistol type thermometer. They are inexpensive and used carefully produce acceptable results.

The best way to evaluate the heat being produced by equipment is IR thermography. This is certainly a case of "a picture being worth a thousand words." IR thermography equipment is expensive and interpretation is enhanced with experience. Because of this the typical approach is to use a testing contractor that performs the service and provides a report.

The following figures are two examples where IR thermography clearly illustrates future problems. Although these electrical devices are currently working, without attention they will eventually be down for emergency maintenance.

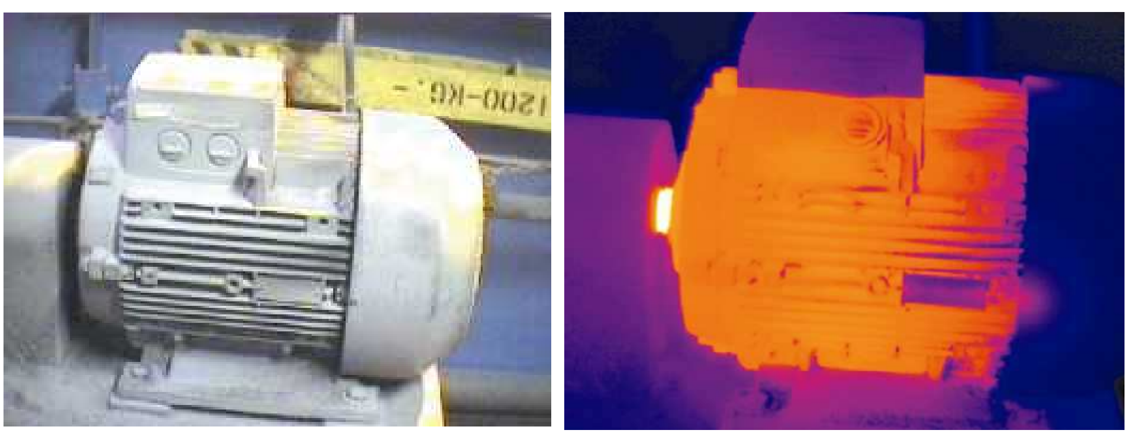


Figure 25: Bad windings (Courtesy of FLIR Systems, Inc., N. Billerica, MA)

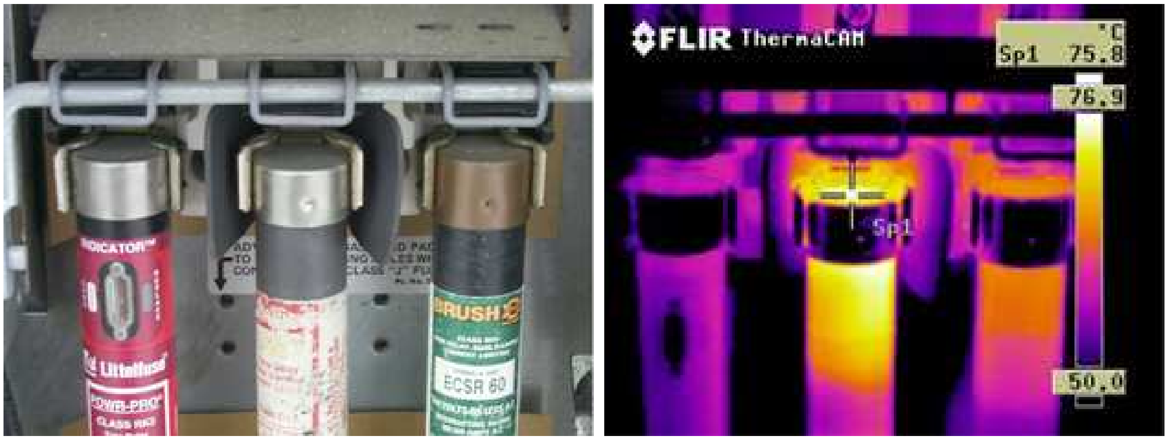


Figure 26: Overheating fuse (Courtesy of FLIR Systems, Inc., N. Billerica, MA

SMP 8: Vibration Analysis

PURPOSE: Another predictive maintenance procedure that is becoming affordable to most utilities is vibration analysis. "Vibration analysis can be used to determine the cause of vibration, including such factors as unbalance, misalignment, or bearing defects." (Linda K. Fischer, 2002)

DISCUSSION: Vibration analysis has been primarily in the realm for contracted services. Two factors drove this situation. One was the expense of the equipment and the second was that interpretation of results required a considerable amount of experience. The second factor is still valid, however with the use of the computer logging software available from equipment vendors some of the art has been eliminated. When selecting vibration monitoring equipment the value of the software should be a major selection variable. Some software will integrate with computerized maintenance management systems to simplify the ability to predict equipment condition.

As with any predictive maintenance establishing appropriate monitoring points and obtaining good baseline data is critical to success. Staff that will be collecting, downloading, and interpreting data must be trained to provide consistent results. Data can be collected continuously from highly critical equipment or periodically.

Purchasing complex test equipment, that may be responsible for investing significant sums of money to maintain process equipment, should be done carefully. Investigate the cost of the equipment, training, software support after purchase, calibration requirements, etc.

Justifying the expense of vibration monitoring becomes somewhat problematic for public utilities. They are not profit oriented organizations. However, we do have a product. Documenting equipment reliability and various benchmarks (kWh/MG, $/MG, number and cost of emergency repairs, etc.) will help to illustrate the value of improved maintenance to budget managers.

SMP 9: Oil Analysis

PURPOSE: Often the oil change frequencies specified by manufacturers are very conservative. A carefully thought out oil analysis program can extend the periods between oil changes while maintaining the lubrication required for normal wear.

PROCESS:

1. Identify an oil analysis lab. There are many to choose from. Some are affiliated with oil suppliers and some are independent. Look at their credentials, the services provided, and cost.
2. Identify equipment with oil reservoirs that are large enough to justify the cost of analyzing the oil.
   a. Typically operating time is the main factor used to determine when oil should be changed. However, for equipment that operates infrequently the accumulation of water may be an issue. Damaging amounts of water can be in oil without observing the creamy look of very water contaminated oil.
   b. Large splash-lubricated gear drives are excellent candidates.
   c. Emergency gen-sets usually have few operating hours in a year's time. But get their oil changed anyway.
3. Test labs provide plastic containers and labels to make submitting samples easy.
4. Always perform an analysis of new oil of the type being used to serve as the benchmark. Then one can monitor how additives decrease, wear metals accumulate, viscosity changes, etc. Most labs will make it very clear in their report when the oil should be changed. They will often note when it is getting close to that time.
5. If equipment is under warranty, always change oil at the frequency specified by the manufacturer.

Unit IV: Financial Analysis

PURPOSE: For an Energy Conservation Measure (ECM) to be implemented it is often necessary to demonstrate that one method is more economical than another. The following discussion of simple payback and annual worth serves as an introduction to engineering economy methods.

PROCESS:

1. Simple payback is typically used to compare a more efficient alternative to an existing system. The cost of implementing the alternative system is divided by the annual energy savings. The result is the number of years required to recover the cost of the alternative system. Simple payback does not account for interest rates, salvage value, service period, etc.

   EXAMPLE
   An aeration blower installation uses 30-hp standard efficiency motors. Aeration requirements call for two blowers to be operated continuously. Table 1 describes the measured electrical operating data and operating costs (SOP 2-2) for each of the blowers. The operators wish to determine the simple payback period for replacing the motors with premium efficiency models. The electricity used costs \$0.074/kWh.

   TABLE 1: Comparison of Standard and Premium Efficiency Blower Motors

	BLOWER #1	BLOWER #2	BLOWER #3	AVERAGE
Present (91% efficiency) kW	20.2	23.3	17.9	20.5
Premium Efficiency (93.6% efficiency) kW	19.6	22.6	17.4	19.9
Differenc in kW usage	0.6	0.7	0.5	0.6
Annual Savings				
kW	5256	6132	4380	5256
Dollars	\$389	\$454	\$324	\$389

   Cost for premium efficiency motors @\$700 each = \$2100

   Annual savings from replacing all three blower motors = \$778

$$Simple\ Payback = \frac{Implementation\ Cost}{Annual\ Savings} = \frac{2100\,\$}{778\,\$\,/\,year} = 2.7\ years$$

2. Annual worth takes all the capital, operating, maintenance, etc. costs of a system and converts them into uniform annual amounts. The annual worth of a project is determined by

calculating the capital recovery costs. The system with the lowest annual worth is then selected for implementation. When determining the total cost, any salvage value of the system is subtracted from the total. It accounts for the loss of interest income on the money invested. The interest value used in the calculation is called the minimum attractive rate of return and is established by the utility.

To calculate capital recovery cost use the formula:

$$CR = P(A/P, i\%, n) - S(A/F, i\%, n)$$

Where: CR = capital recovery
P = first cost
A/P = capital recovery factor[1]
A/F = sinking fund factor[1]
i% = minimum attractive rate of return
n = expected service life in years
S = estimated salvage value at the end of expected service life

[1]Available from compound interest tables. A source of these tables and further discussion is Grant, Eugene L., Ireson, W.Grant, Leavenworth, Richard S., *Principles of Engineering Economy*, John Wiley & Sons, New York, 1982.

EXAMPLE:
The same motors described in the simple payback example will be used. It is assumed that maintenance costs will be equal and that service life will be 10 years. In fact the maintenance requirement for the premium efficiency motor should be lower and service life should be longer. The minimum attractive rate of return has been set at 6%. Check with the utility's financial officer to get the current return percentage that can be expected.

Using the Annual Cost Method the annual savings using premium efficiency motors would be $493. The old standard efficiency motors may have some salvage value, however no salvage value has been assessed. Operating time is a very important factor when considering changing from standard to high efficiency motors. Typically, if the operating time is less than 25%, the energy saving will not justify the higher cost of the premium efficiency motor. Each situation should be evaluated carefully.

The calculation of the capital recovery cost and a portion of the compound interest table follows:

a. Determine the capital recovery factor, A/P, to be used for minimum attractive rate of return of 6% and a service life of 10 years.

TABLE 21: 6% Compound Interest Factors (Grant 1982)

n	Capital Recovery Factor, A/P
1	1.060 00
2	0.545 44
3	0.374 11
4	0.288 59
5	0.237 40
6	0.203 36
7	0.179 14
8	0.161 04
9	0.147 02
10	**0.135 87**

b. Calculate the capital recovery cost.

$$CR = P(A/P, i\%, n) - S(A/F, i\%, n)$$

$$= \$2100 * 0.13587 \quad \textit{No salvage value}$$

$$= \$285$$

c. Calculate the annual savings. Repeat the following calculation for the premium efficiency motor.

$$\textit{Annual Operating Cost} = \textit{Average kW x } \$ / kWh \textit{ x } 8760 hr / year$$

$$= 2 \textit{ blowers } (20.5 kW \textit{ x } 0.074 \$ / kWh \textit{ x } 8760 hr / year)$$

$$= \$26578$$

TABLE 22: Comparison of Annual Worth – Standard vs. Premium Efficiency Motor

	Standard Efficiency Motor	Premium Efficiency Motor
Capital Recovery Cost	$ 0	$ 285
Annual Operating Cost	$ 26578	$ 25800
Total Annual Cost	$ 26578	$ 26085

GLOSSARY

Activated Sludge (AS) - Sludge floc produced in raw or settled wastewater by the growth of organisms in the presence of dissolved oxygen. It is called "activated" because the sludge is teeming with active, or living microorganisms.

Actual Power - The power carried in a circuit that is used by the load to accomplish work. Also called real power. Measured in kilowatts, (kW).

Aerobic Digestion - Sludge stabilization using aerobic microorganisms; free oxygen must be available.

Aerobic – The condition when "free" or dissolved oxygen is present in the water.

Anaerobic - The condition when "free" or dissolved oxygen is not present in the water.

Anaerobic Digestion - Sludge stabilization accomplished by anaerobic microorganisms that grow in environments that lack free oxygen.

Anoxic - The condition when free oxygen is not present, but nitrate (NO_3) is present.

Apparent power - The vector sum of actual power (real power) and the reactive power. Measured in kilovolt-amperes (kVA).

Applied Solids Flux - The weight or mass of solids applied to a treatment process per unit time. Also referred to as the solids loading rate.

Atmospheric Pressure - The pressure resulting from the weight of the atmosphere. The atmosphere pressure decreases, at higher altitudes. At sea level the atmospheric pressure is 14.7 psi.

Back Pressure - A condition when the pressure in a potable system is less than the pressure in a nonpotable system, allowing the nonpotable system or contaminants to flow into the potable system.

Backflow - A reversal in the normal direction of water flow, due to back pressure or backsiphonage.

Backsiphonage - A condition in a potable system in which the pressure has dropped below atmospheric pressure resulting in a partial vacuum. This condition allows contaminates to enter the potable system.

Basic Electricity Charge - The cost of electricity per kilowatt hour, the basic charge found on household bills.

Bioassay - Estimating the toxicity of an effluent by testing its affects on living organisms.

Biochemical Oxygen Demand (BOD) - A measure of the amount of oxygen required by the microorganisms to metabolize or digest the biodegradable organic material in wastewater.

Blower - A mechanical device used to produce relatively large volumes of air or gas at low pressures.

Brake Horsepower - The power applied to a pump by a motor. It is equivalent to shaft horsepower.

California Pipe Method - An equation used to calculate the flow in a partially filled horizontal pipe with a free discharge.

Coagulant - A chemical(s) added to destabilize, aggregate, and bind together colloids and emulsions to improve settleability, filterability, or drainability.

Complete Mix - Idealized continuous flow reaction in which fluid articles are immediately dispersed throughout the reactor.

Contact Stabilization Process - A modification of the activated sludge process in which wastewater is aerated with a high concentration of activated sludge for a short period, usually less than 60 minutes, to obtain BOD removal. The solids are subsequently separated by sedimentation and transferred to a stabilization tank where aeration is continued, starving the activated sludge before returning it to the aeration basin.

Continuity - A condition which indicates a short, or low resistance (less than 2M /Hp) when measurements are made "coil to coil" or "coil to ground" in a motor. Also a condition that indicates a complete circuit represented by a low resistance when measuring a conductor, such as, a coil.

Conventional Activated Sludge Process - An activated sludge process utilizing plug-flow through the aeration basin with primary effluent and activated sludge fed at the head end and uniform aeration throughout.

Corporation Stop - Usually a plug valve used for tapping water mains.

Cross Connection - A physical link between a potable and non-potable water system or other hazardous materials, which could allow the backflow of the non-potable system into the potable system.

Current - The flow rate of electrons in a conductor. It is measured in amperes or amps (A).

Demand Charge - A charge assessed because of peaks in the power usage. In order for the power utility to avoid brownouts they must be able to meet these peak demands whenever they occur. This charge is based on a 15, 30, or 60 minute period called a demand "window".

Deviation - How much one thing varies from another, for example the deviation between the numbers seven (7) and ten (10) is three (3).

Diffusers - Devices that are used to introduce the air discharged by centrifugal or positive displacement blowers into water or wastewater process streams.

Digester - The tank in which sludge stabilization occurs.

Digestion - The process of sludge stabilization that reduces the sludge volatile content and destroys most pathogenic microorganisms. See also aerobic digestion and anaerobic digestion.

Dissolved Oxygen (DO) - Molecular or "free" oxygen (O_2) dissolved in water or wastewater.

Diurnal Flow - The flow over a 24-hour period; it usually shows marked and regular variations through the course of a day.

Dynamic Head losses - Are the losses of energy by the liquid due to the resistance of the pipe and pipefittings to flow. It includes friction losses and form losses.

Efficiency - An effective operation as measured by a comparison of production with cost (e.g., energy costs).

Effluent - Wastewater or other liquid flowing from a basin, treatment process, or treatment plant.

Electrical Power - The rate at which the electricity in a circuit does work and is expressed in units of watts (W).

Energy Conservation Measures (ECM's) - A modification to plant operational procedures or equipment that either reduces the amount of energy consumed or reduces the price paid for the energy.

Energy - The capacity to do work.

Extended Aeration (EA) - The activated sludge modification that operates in the endogenous respiration zone. The aeration detention time is usually about 24 hours.

Filamentous Bacteria - Bacteria with a thread-like or filament like form.

Flow (Q) - A measurement of the movement of water or other liquids usually expressed in units of gallons per minute (gpm) or feet per second (ft/s).

Food to Microorganisms Ratio (F/M) - The amount of food (organic matter as BOD or COD available per unit mass of microorganisms.

Form Losses - The energy losses due to the turbulence generated in pipe fittings (valves, turns, expansions, contractions, etc.) as liquid moves through them. Also called minor losses.

Friction Losses - The energy losses due to the friction of liquid moving through the conduit.

Fuel Adjustment - Billing for increases or decreases in the cost of fuel prices.

Gator Jar - See Jar tests.

Head - An expression of the pressure or energy of fluids in terms of the height of a vertical column of water.

Horsepower - A common unit for measuring power. It is equivalent to 0.746 kW.

Impeller - The rotating element of a centrifugal pump. It accelerates the flow of the liquid being pumped and thus raises its kinetic energy.

Induction - The generation of a magnetic field due to the flow of electrons in a conductor.

Infiltration - Flow entering the collection system from surface run off during rain events.

Inflow - Flow entering the collection system from surface runoff during rain events.

Jar Tests - Laboratory test used to determine dosage rates for chemicals to produce particular results; for example, flocculants.

Kilowatt, (kW) - Equivalent to 1000 watts.

Kinetic Energy - Energy created by the motion of material bodies e.g., water.

Mass Balance - A calculation of the solids entering and leaving the treatment process.

Mechanical Aeration - The mechanical agitation of liquid and subsequent transfer of oxygen from the surrounding gas phase into the liquid. Typical oxygen transfer efficiencies are between 1.7 and 3.0 lb 0_2/hp h.

Minor Losses - See form losses.

Mixed Liquor (ML) - The mixture of wastewater and return activated sludge in the aeration tank of an activated sludge system.

Mixed Liquor Suspended Solids (MLSS) - Defined by testing method (see Standard Methods). May be roughly defined as nonfilterable solid particles in mixed liquor.

Motor Efficiency - The amount of energy use by the motor to accomplish a certain amount of work.

Nitrification - The biochemical conversion of unoxidized nitrogen (ammonia and organic nitrogen) to oxidized nitrogen (usually nitrate).

Operating Point - The pump head and flow rate developed by a pump operating in a specific piping system. It is where the pump head equals the system head.

Overflow rate - The ratio of flow rate to surface area of a clarifier.

Percentage rated load - The ratio of actual working load to the rated load or the maximum working load.

pH - A term used to express the intensity of the acid or alkaline sources. A pH of 7 is considered neutral, with acidity increasing as the pH decreases. Normal pH for wastewater treatment is 6.5 to 7.5.

Pigs - Are plastic bullet shaped devices that are used to clean water distribution lines. They come in a variety of shapes and sizes.

Potable - Water free from impurities present in amounts sufficient to cause disease or harmful physiological effects. Its bacteriological and chemical quality shall conform to the requirements of the Public Health Service Drinking Water Standards or the regulation of the public health authority having jurisdiction including secondary standards related to aesthetics.

Power - The rate at which work is done. Common units for measuring power include kilowatts (kW), Btu/h, and horsepower.

Power Factor - The ratio of the actual power (real power) to apparent power. It is normally expressed as a percentage or decimal. It is the cosine of the phase angle. (The angle by which current lags voltage in a partially inductive circuit.)

Pump datum - The centerline of the pump for horizontal and double suction vertical pumps, or the entrance of the first stage impeller for single suction vertical pumps.

Pump efficiency - Equal to the water power divided by the shaft power.

Pump Head Curve - The curve which is generated for a particular pump (for a specific impeller diameter working at a constant speed) based on it's ability to pump water at different heads (pressures) and different flows (capacities). See also Total dynamic head.

Ratchet - The percentage of the previous peak demand that will be used for billing purposes if the present actual demand is lower.

Rated Capacity - The flow rate at one unique operating point which will give the maximum pump efficiency at a given impeller diameter and speed.

Reactive Power - The power used by inductive devices such as electrical motors to create magnetic fields. It is measured in Kilovolt-amperes (kVAR).

Resistance - Reduces the flow of electrons in the circuit. It is measured in ohms (R).

Settleability - A measure of the tendency of mixed liquor suspended solids to settle.

Settleometer - Laboratory glassware used in settleable solids testing of activated sludge mixed liquor.

Shaft Power - The actual power the motor supplies to the pump. It is a percentage of the rated horsepower.

Shear - To break up due to turbulence.

Simple Payback - The amount of time (in months or years) it takes to recover the cost of an initial investment with no consideration to interest.

Sludge - The settleable solids separated form the liquid during clarification.

Sludge Age - In the activated sludge process, a measure of the length of time a particle of suspended solids has been undergoing aeration; expressed in days.

Sludge Blanket - The layer of sludge that forms at the bottom of clarifiers. If the process is operation well, there is a distinct interface between the top of the blanket and the clear water above it.

Sludge Bulking - Poor settling due to low density floc in the activated sludge process.

Sludge Volume Index (SVI) - A ratio of the mixed liquor settleability to the MLSS concentration. Indicates the ability of a particular sludge to settle.

Solids Washout - The removal of sludge solids in the effluent from the secondary clarifier of an activated sludge plant because of excessive turbulence and/or a sludge buildup.

Static Suction Head - The vertical distance form the surface of the water in the suction well to pump datum. This value is positive when the liquid is above the pump datum and negative when the liquid is below the pump datum.

Static Discharge Head - The vertical distance in feet between the pump datum and the water level in the basin into which the pump is discharging. It is positive when the liquid must be lifted.

Static Energy - Pressure or potential energy.

Synchronous Speed - The rate of rotation of the magnetic field developed in the windings (stator), as established by the design of the motor and the AC frequency. Typical synchronous speeds of commercial motors with 60 Hz current are 1200, 1800, and 3600 rev/min.

System Head Curve - The curve generated for a piping system dependant on varying the flow rate and the head of that piping system which is the sum of the total static head, dynamic head losses, and discharge velocity head.

Tactile - Perceptible through the sense of touch.

Throttling - A means of flow control, it reduces the flow rate and the motor's load. It also increases the head or pressure to the motor when liquids are being moved.

Torque - The resistance (load) placed on a motor or pump.

Total Kjeldahl Nitrogen (TKN) - The total organic and ammonia nitrogen present.

Total Static Head - The difference between the Static discharge head and the static suction head.

Total Dynamic Head - The sum of all energy required to move liquid from one elevation to another. It is equal to the sum of the total static head, the dynamic head losses, and the velocity head at the discharge point. Also called the Pump Head.

Transfer Efficiency - The amount of oxygen transferred relative to the quantity of energy consumed by the blowers (and mixers, if any), it is normally expressed in pounds of oxygen transferred per horsepower-hour (lb O_2/hp·h).

Turbidity - A measure of water clarity, or a measure of the cloudiness of wastewater due to suspended solids.

Unit Energy Consumption (E_S) - The amount of energy consumed per volume of liquid pumped. Typical units for E_S are hp·h/1000 gal.

Velocity Head - The kinetic energy of the liquid moving through the pipe. It is the ratio of the square of the velocity of liquid in the pipe (ft/s) and 64.32 ft/s^2 (for water).

Volatile Solids - That portion of the total solids and its fractions that is determined by the loss of weight after combustion at 500º - 600ºC.

Voltage - The driving force or pressure behind electrons. It is measured in volts (V).

Volute - A term applied to a pump casing having a spiral or scroll shape.

Vortexing - The action of a liquid when in a whirling motion which tends to form a cavity in the center and also draws things toward this cavity.

Water Hammer - A hydraulic condition that produces a loud "hammering" sound in a pipe when a valve is closed too rapidly. Caused by pressure changes resulting from the sudden cessation of the water flow.

Water Power - The rate at which the pump does useful work.

Watt - A unit of electrical power. It is the power available when one ampere of electricity passes through a pressure of one volt.

Weep Hole - A drain hole at the bottom of a freeze proof hydrant that allows the water to drain out of the hydrant when the valve is closed.

Wire Power - The actual electrical energy used by an electrical device to do work. It is measured in kW.

Wire-horsepower - It is equivalent to wire power except the units are in horsepower.

Wire-to-water Efficiency - The overall efficiency of converting electrical energy to fluid energy. It is equal to the waterpower divided by the electrical power demand. It is also equal to the product of the motor, drive and pump efficiencies.

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