

Section 6 – Instrumentation and Controls

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6. Instrumentation and Controls

6.1. Water Works

Controls and instrumentation should be appropriate for the plant size, complexity and number of staff and their skills for each plant. To achieve this, the designer should develop a control philosophy that will enable the plant staff to effectively monitor and control the plant and major equipment, the treatment process, water production and; plant wastes.

6.1.1. Measurement List

For plants of 1 ML/d capacity and greater, the following instruments should be provided as a minimum for the relevant processes listed. For smaller plants, pH measurement and fluoride residual may be made by bench testing but all other instruments are appropriate for the relevant processes listed.

1. Raw Water Instrumentation:

- a) Low-level switches to shut down the raw water pumps. These should be hard-wired to the starters;
- b) Running and trip indication for raw water pumps; and
- c) Raw water turbidity, pH, pressure, flowrate, and flow volume.

2. Rapid Mixer:

- a) Running and trip indication.

3. Flocculators

- a) Running and trip indication; and
- b) Speed if variable speed type.

4. Solids Contact Clarifiers

- a) Recirculator speed indication;
- b) Running and trip indication;
- c) Level indication;
- d) Blow down valve status; and
- e) Turbidity and pH following clarification.

5. Softening

- a) If lime softening is used, pH following recarbonation; and
- b) Recarbonation CO₂ feed status.

6. Filter Instrumentation

- a) Turbidity on each individual filter effluent and filter to waste. This can be a single instrument for each filter if piping arrangement permits;
- b) For constant rate filters: differential head loss across the filter media;
- c) Filter flowrate;

- d) Where the backwash sequence is automated, provide open and close limit switches or position on all filter valves and status on backwash equipment; and
- e) Filter run-time.

7. Backwash Instrumentation

- a) Running and tri p indication for backwash pump(s);
- b) Running and tri p indication for air blowers (if air scour is used); and
- c) Backwash flowrate and flow total.

8. Clearwell and Distribution Pump Instrumentation

- a) Level indication for clearwell and other tanks;
- b) Low-level switches to shut down the distribution pumps. These should be hard wired to the motor starters;
- c) Turbidity, chlorine residual, fluoride residual (if fluoridation is practiced), pH, pressure, flowrate, and flow total on plant discharge; and
- d) For variable speed pumps, indicate the pump speed.

9. Chemical Systems

- a) Running and tri p indication for chemical loading, batching and pumping equipment;
- b) Low and high level indication in storage bins, silos or tanks;
- c) Level indication for tanks;
- d) Weigh scales for hydrofluosilicic acid day tanks or storage if no day tank is used;
- e) Weigh scales for gaseous feed chemicals such as chlorine or sulphur dioxide;
- f) Speed indication on variable speed pumps;
- g) Rotameters for carrier water feed systems; and
- h) Chemical feed flowrate is desirable but not mandatory.

10. Miscellaneous Instrumentation

- a) Run time meters on all pumps and major electrically driven equipment;
- b) Speed, run time, oil pressure and temperature gauges, fault signal switches and manual start and shut down on engines;
- c) Where the plant is automated or operated remotely from either within the plant or outside, provide open and close limit switches or position on all major valves, status on all major equipment and security instruments including door switches, building temperature switches and smoke alarms; and
- d) Any additional instrumentation recommended by equipment manufacturers.

6.1.2. Degree of Automation in Plant Control

The control system may be manual or automatic or a combination thereof. Regardless, the system should be designed to promote energy efficiency, conserve water, and reduce waste while meeting the treated water quality standards and demands under all anticipated conditions. Discuss the operating philosophy with plant staff and owners to determine the appropriate degree of automation.

In the case of a manual system, all equipment is started and stopped by the operator, all backwash sequences and other process operations are controlled by the operator, and chemical and pump rates are manually adjusted. This requires that the plant be manned continuously while in operation, perhaps with more than one operator.

In the case of an automatic system, all equipment is started and stopped by the control system, with chemical feed rates and pump rates adjusted automatically to maintain the system levels, discharge pressures, etc. This may allow unattended plant operation or operation with a single operator, but requires a more complex and expensive control system, with associated maintenance. Provide the ability to manually operate all equipment.

For systems with rapidly varying raw water conditions, fully automated plants should not normally be considered.

6.1.3. Alarms and Status Indication

All alarms must be latched until the Operator has acknowledged them. If the alarm is indicated by a lamp, it must flash until acknowledged then remain steady until the alarm clears. If it is indicated on a computer screen, an appropriate colour code or symbol must be used to indicate for each alarm whether it has been acknowledged. Automated systems should log the time at which the alarm occurred, the time it was acknowledged and the time it cleared. Logs may be printed on paper or recorded electronically.

Valve and equipment status should use a consistent method of symbols and colours, whether the status is indicated through lamps or on a colour computer screen. The colour-coding scheme should be consistent with any existing equipment displays elsewhere in the plant.

As a minimum, the following alarms should be provided:

1. High turbidity on the raw water, clarifier effluent (if applicable), filter effluent, and plant discharge;
2. High and low pressure on the raw water line;
3. High flowrate on the raw water line;
4. High and low level in clarifiers or flocculators;
5. High torque on solids contact clarifier recirculator and rake;
6. High torque on flocculators;
7. High level in filters;
8. High and low level in chemical storage tanks;
9. High and low chemical feed rates;
10. High flowrate on each filter individually (also low flowrate on declining rate filters);
11. High and low levels in each clearwell, pumpwell, and reservoir;
12. High and low pH on the raw and treated water (if on-line measurements are provided);
13. High and low chlorine residual on the plant discharge (where on-line measurements are provided);
14. High head loss on the filters (if constant rate type);
15. Trip or failure to run on each pump;
16. High and low pressure on the plant discharge line;

17. High flowrate on the plant discharge line;
18. Chlorine gas detection in the chlorine storage, metering and injector rooms;
19. Chlorine scale low weight (where scales are equipped with transmitters); and
20. Valve operation failure (where valves are provided with limit switches).

More alarms may be required where additional treatment processes are provided. Alarms should be provided for all control system interlocks that can shut down equipment or systems. In plants that are left unattended for periods of time, an automatic alarm dialler should be provided.

6.1.4. Control Equipment (Automatic Systems)

Automatic systems should use either Programmable Logic Controllers (PLC's) or a Distributed Control System (DCS). The operator interface may be in the form of traditional control panels (ie: lights, gauges and switches), electronic control panels (with text and/or graphics) and computers.

Digital communication between components of the control system must be reliable and self-monitoring. The communication protocol must meet the following requirements:

1. It must include error checking and reporting, to ensure that data is correctly transferred from one component to another;
2. The components of the system must detect the failure of the communication system (either between individual components of the system or between the system and the operator); and
3. It must be compatible with a variety of manufacturer's instruments and equipment, in order to allow for expansion of the system.

If a DCS is provided, the communication protocol will be proprietary and the manufacturer should be consulted regarding reliability, error checking, and the possibility of connecting other manufacturer's equipment to the network.

If PLC's are used, the communications protocol should use one of the widely accepted industry protocols such as, but not limited to: Modicon MODBUS, Allen-Bradley DATA HIGHWAY and TCP/IP Ethernet.

The operator interface may consist of a local hard wired control panel or mimic, character based input/output panel, personal computer or workstation depending on system size, process complexity, control system functions and operator interface manufacturer. Where personal computers or workstations are used, select the hardware based on reliability, software compatibility, vendor support and suitability for continuous operation in the plant environment. The operator interface software may provide the operator with interactive control and monitoring of the plant, handle and annunciate alarms, log and trend events and process variables and generate the required reports. Process control and logic should be performed by the PLC or DCS and not the operator interface computer or workstation.

6.1.5. Field Instruments

6.1.5.1. Level Instruments

Where access to the top of the reservoir is convenient (such as in a clearwell), ultrasonic level transmitter should be used. Where access to the bottom of the reservoir is convenient (such as at a tower or above-ground reservoir), a pressure transmitter should be used as a level-sensing device.

6.1.5.1.1. Ultrasonic Level Measurement

The ultrasonic level transmitter fires a “sonar” signal toward a surface, such as the surface of the water in a well, and measures the time required to receive an “echo” in order to determine the level of the liquid.

The ultrasonic transducer should be installed so that it is protected from damage, there are no obstructions between the transducer and the water surface, and it is accessible for calibration and maintenance.

1. The transducer should be installed in the top of a stilling well to prevent turbulence from producing errors in the reading. The stilling well should be a continuous length of pipe, either PVC or steel of sufficient diameter and without couplings or fittings that could reflect a sonic echo back to the transducer thus giving a false reading.
2. The well must extend from a convenient height above the high-water line, at which level the transducer will be installed, to the low-water line.
3. Consider the transducer’s “blanking distance”, inherent its design, and ensure that the transducer is mounted high enough above the high-water line so that it will properly read the highest water level anticipated.
4. Several holes should be provided in the side of the stilling well near the bottom for water to enter the well. The holes must be large enough to prevent clogging if silt is present.
5. The controller and display should be located where it can be conveniently read by the operator.
6. Where the air temperature between the transducer and the liquid surface is not constant (this is usually the case), provide a temperature measurement for the controller in order that it can compensate for the speed of sound travel through the air, and correct for temperature variations. Note that some manufacturers include the temperature sensor in the transducer itself, while some provide a separate temperature probe.

6.1.5.1.2. Pressure-Sensing Level Transmitter

The pressure-sensing level transmitter reads the head of a column of liquid and transmits a signal proportional to the level of liquid.

1. The level transmitter should be installed as near as practical to the bottom of the tank being measured, so as not to introduce a zero offset in the reading.
2. A block and bleed valve should be provided on the pressure line so that the transmitter can be calibrated for zero level, and can be removed from service.
3. If the pressure-sensing line is small in diameter (12 mm or less), clamp it to supports or walls to provide adequate support.

4. If the transmitter is equipped with an integral display, the transmitter should be located so the display is clearly visible. If no display is provided, and the head being measured is high enough (100 kPa or higher), consider installing a pressure gauge in addition to the transmitter as a backup and calibration aid.

6.1.5.2. Flow Instruments

On line, flow meters should generally be one of the following types:

1. Turbine (or nutating disk);
2. Magnetic; and
3. Ultrasonic (either transit-time or Doppler).

All of these types of instruments can be equipped to provide both flow rate and flow total measurements.

Price, line size, flowrate, flow range, required accuracy and water quality will dictate the election of the type of instrument. The following are some general guidelines:

1. Where considerable silt is present (as in many raw waters), either a magnetic or a Doppler-type ultrasonic meter should be used. Turbine meters will wear rapidly and are not practical. Transit-time meters may not operate properly if there is considerable silt (consult the manufacturer).
2. An ultrasonic meter is generally more economical than a magnetic type on lines of 300 mm diameter and larger.
3. For, on lines of very low flowrate (less than 0.3 m/sec), turbine or magnetic flow meter is recommended. Where chemicals are present in the water, check with the manufacturer to ensure that the meter will not suffer damage.
4. Corrosion and abrasion resistant linings should be considered for these applications. Regardless of the meter type, the minimum flow velocity should be within the specified range of the meter.
5. For, on lines of high flow velocity (higher than 5 m/sec), magnetic or ultrasonic flow meter is recommended. Regardless of the meter type, the maximum flow velocity should be within the specified range of the meter.
6. Where the water is free of solids and bubbles (as is the case on a potable distribution line), Doppler-type ultrasonics will not operate; a transit-time type should be used.

6.1.5.2.1. Turbine Flow Meters

Turbine flow meters determine the flowrate by reading the rotating speed of the turbine, which is immersed in the fluid. A flow totalizer is almost always included, and a flow transmitter is usually available. Because they totalize volume without power, they will continue to operate during power failures and because they will operate without any configuration on the part of the user or operator they are often used where ease of use and maintenance are essential.

1. Where debris may be present in the water, such as in a raw water intake, a screen filter (such as a Y-type strainer) upstream of the meter should be provided.

2. A continuous straight run of piping upstream of the meter, 10 pipe diameters if possible should be provided, to produce a smooth flow profile through the meter. This will minimize errors in the reading.
3. If it is not possible to provide at least five diameters of straight piping upstream of the meter, install straightening vanes in the pipe immediately upstream of the filter. Even with vanes, the accuracy of the meter may be compromised.
4. Five diameters of straight piping should be provided downstream, if possible.
5. If a totalizer or flowrate display is provided, they should be located so that the display is easily read.

6.1.5.2.2. Magnetic Flow Meters

Magnetic flow meters operate by applying a magnetic field around the flowing liquid and reading the voltage produced on a pair of immersed electrodes.

1. The manufacturer should be consulted regarding electrode material and liner material. The meter should operate with silt, chemicals, etc.
2. It is essential that the pipe be full of water at all times; the meter will not operate with large air bubbles in the pipe. Some small bubbles, such as are found downstream of pumps, can be tolerated.
3. A continuous straight run of piping should be provided upstream of the meter, 10 pipe diameters if possible, to produce a smooth flow profile through the meter. This will minimize errors in the reading.

Because magnetic meters read the total voltage produced across the full width of the pipe, some averaging is provided, and this makes them more resistant to turbulence than either turbine or ultrasonic meters. Less than 10 pipe diameters straight run upstream may compromise the accuracy of the meter.

1. Five diameters of straight piping should be provided downstream if possible.
2. Magnetic meters should be supplied with flowrate and flow total displays; the controller should be installed so that the display is easily read.

6.1.5.2.3. Ultrasonic Flow Meters

Ultrasonic flow meters operate by firing a sonic “pulse” through the pipe wall into the flowing liquid. A transit-time meter uses two transducers, one mounted upstream of the second, and measures the difference in travel time for a pulse from one transducer to the other. A Doppler type measures the difference in the frequency received by the transducer as the sonic pulse reflects off particles or bubbles in the liquid. In either case, the difference is directly proportional to the velocity of the liquid.

1. The manufacturer should confirm that the flow meter will operate with the pipe wall material and thickness expected.
2. Ultrasonic flow meters should not be installed where the pipe will contain large bubbles or air pockets; the sonic pulse will be disrupted so that the meter won't operate.
3. Ultrasonic meters are sensitive to the flow profile; at least five pipe diameters of straight piping should be provided (ten pipe diameters recommended) between the meter and an upstream elbow or other hydraulic disturbance.

6.1.5.3. Water Quality Instruments

The most frequently used water quality measurements are turbidity, pH, and chlorine residual. On-line turbidity measurement is relatively inexpensive and should be provided in any plant, on the raw water, flocculator or clarifier effluent (if applicable), each filter effluent, and final plant discharge lines. In larger plants, on-line pH and chlorine residual are generally used, but these can be done through lab tests in smaller plants.

6.1.5.3.1. Turbidity Instruments

Turbidity instruments usually measure the degree to which a beam of light is transmitted or scattered as it passes through a sample of the liquid being measured. A small constant flow of liquid is required to pass through the turbidimeter. It is important that the liquid be free of bubbles, which would scatter the light and produce an erroneously high reading.

1. A transmissive type flow meter should be used for low-turbidity applications such as treated water (turbidity range 0-100 NTU) and a surface-scatter model for high-turbidity applications such as raw water (range 0-5000 NTU).
2. A needle valve and rotameter should be provided to adjust the flowrate through the turbidity meter so that it falls in the range required by the manufacturer. If necessary, a pressure reducing valve should be installed upstream of the needle valve to make the flowrate adjustment easier.
3. The liquid stream is not affected by the turbidimeter; it may be returned to the process or discharged to waste.
4. The sensor element should be located as near to the sample point as practicable to minimize lag time. Where the water contains settleable material, the sample line velocity should be high enough to prevent sedimentation in the line. The use of clear piping should be avoided to reduce the possibility of algae growth.
5. Where a sample line may become plugged by silt, as in a raw water measurement, a manual flush valve should be provided with pressurized plant water to flush the silt either backward into the process line or to waste, as required. A block valve should be provided for the turbidimeter to protect it from the high-pressure flush water.

6. The sensor element may be mounted some distance from the controller. The controller should include a display and should be installed so that the display is easily read.

6.1.5.3.2. pH Instruments

pH is read by the measurement of an electric potential generated at a pair of electrodes, which are wetted by the sample stream. All pH instruments use a buffer solution, which is generally pumped to the electrodes in very small volumes by the controller. The solution must be replenished at intervals.

1. A needle valve and rotameter should be provided to adjust the flowrate past the electrodes so that it falls in the range required by the manufacturer. If necessary, a pressure reducing valve should be installed upstream of the needle valve to make the flowrate adjustment easier.
2. If the sensor element could become clogged with silt, a filter should be provided upstream. The sensor elements are generally very fragile, so flush lines should only be provided where the electrodes can be completely removed from service during flushing.
3. The liquid stream is contaminated with buffer solution during the measurement; the stream should be discharged to waste.
4. If the controller includes an alarm contact to warn of low buffer solution level, the contact should be tied into the alarm system to remind the operator to refill the controller.
5. The sense element must not be mounted far from the controller because of the very low-level signals involved. If necessary, the sample line should be routed to a location where the sense probe and the controller may be located near each other.
6. The controller should include a display, and should be installed so that the display is easily read.

6.1.5.3.3. Chlorine Residual Instruments

Chlorine residual measurements fall into two categories: amperometric, which measures a potential generated at three electrodes, and polarographic, which measures a colour change when an indicator is added to the liquid sample. Both types of instruments require periodic refilling with buffer or indicator solution.

1. A needle valve and rotameter should be provided to adjust the flowrate past the electrodes so that it falls in the range required by the manufacturer. If necessary, a pressure reducing valve should be installed upstream of the needle valve to make the flowrate adjustment easier.
2. The liquid stream is contaminated with buffer solution during the measurement; the stream should be discharged to waste.
3. If the controller includes an alarm contact to warn of low buffer solution level, the contact should be tied into the alarm system to remind the operator to refill the controller.

4. The sense element must not be mounted far from the controller because of the very low-level signals involved. If necessary, the sample line should be routed to a location where the sense probe and the controller may be located near each other.
5. The controller should include a display, and should be installed so that the display is easily read.
6. Because chlorine measurements are usually limited to treated waterlines, it is not necessary to install flush lines or filters to protect the instrument from debris.

6.1.5.4. Pressure Instruments

Pressure may be simply indicated on a gauge or transmitted (and optionally indicated as well) by a transmitter.

6.1.5.4.1. Pressure Gauges

Pressure gauges are available to read both differential and single-ended pressure. By far the most common measurements are single-ended, although differential gauges are used to read head loss on water and air filters.

1. Where a pressure gauge is reading a pressure produced by a pump (normally required) the gauge should be protected from vibration by filling it with either silicone liquid or glycerine. Silicone should be used if the ambient temperature will fall below -30°C .
2. The range of the gauge should be chosen so that it will normally operate at one-half to two-thirds of scale at normal design pressure; the gauge should not be operated full-time near the top end of the scale. This will provide some safety margin on over-pressure as well as prolonging the life of the gauge.
3. The gauge should be installed where the lens will not get damaged and where it can be read easily. Choose a gauge with a top-mounted stem where it will be installed near the ceiling so that the dial will read right-side up.
4. For water applications (both raw water and treated) a bronze or 316 stainless steel bourdon tube mechanism should be used. For applications on chemical lines, the manufacturer should be consulted for compatibility between the process and the gauge material.
5. On corrosive liquids and processes containing solids, or where the gauge material is not compatible with the process, an isolating diaphragm should be used between the process sense line and the gauge to protect the gauge.
6. A block and bleed valve should be installed between the process and the gauge, or between the process and the diaphragm, to take the gauge out of service.

6.1.5.4.2. Pressure Transmitters

Pressure transmitters are available to read either differential or single-ended pressures. The single-ended type may read either gauge pressure (the pressure relative to the atmosphere) or absolute pressure (relative to a vacuum). Absolute pressure measurements are not common. Differential measurements are commonly used to determine when a filter needs washing.

1. The range of the transmitter should be chosen so that it will normally operate at one-half to two-thirds of scale at normal design pressure; the transmitter should not be operated full-time near the top end of the scale. This will provide some safety margin on over-pressure as well as prolonging the life of the sense element in the transmitter.
2. For water applications (both raw water and treated) a bronze or 316 stainless steel sensing diaphragm should be used. For applications on chemical lines, the manufacturer should be consulted for compatibility between the process and the diaphragm material.
3. On corrosive liquids and processes containing solids, or where the sense diaphragm material is not compatible with the process, an isolating diaphragm should be used between the process sense line and the transmitter to protect the transmitter.
4. A block and bleed valve should be used between the process and the transmitter, or between the process and the isolating diaphragm, to take the transmitter out of service, and to facilitate calibration.
5. Where a pressure gauge is not installed on the same line as the transmitter, an integral display should be provided on the transmitter for local indication.

6.1.6. Process Controls

6.1.6.1. Pumping Systems

Regardless of the function of the pumping system, its control will normally be achieved through monitoring level, flow and/or pressure. The choice of control parameter(s) will depend on the system's function and features.

Controls and monitoring for the following systems is discussed:

1. Raw Water Pumping; and
2. Finished Water Pumping.

6.1.6.1.1. Raw Water Pumping

Raw water pumping is normally controlled by flow, since this sets the production rate of the treatment processes. Typically, this is achieved manually, by selecting the number of raw water pumps operating. If there are variable speed pumps, these will be controlled by flow, with their speed, and output, controlled to match a manually selected flow set point.

Alternatively, pumps may be controlled by level in the plant's treated water clearwell storage reservoirs, or in one of the open unit processes. At selected level set points, a falling water level will bring on another pump, and rising water level will shut down a pump. If variable speed pumps are used, an analog level signal can be used to control pump speed, and hence its output, and therefore maintain water level within a selected operating band.

Raw water pumping rate should be varied gradually, if possible, and only when necessary. Flowrates through the treatment processes should preferably be kept steady, as this will achieve better and more consistent treatment and water quality. This may be achieved by setting the raw water pumping rate, and hence the plant production rate, to meet the anticipated demand for the day.

On the suction side of the pump(s), pressure is monitored by level or pressure indicator. The pressure/level-measuring device will initiate low level (or pressure) alarm, and low-low level (or pressure) alarm and shut down of pumps, to protect the pumps from cavitation damage or running dry. Where the raw water source exhibits or is subject to rapid increase in free surface elevation (F.S.E.), the pressure/level-measuring device should initiate high level alarm and raw water pumps and possibly the whole plant should shut down for flood protection.

Flow monitoring may be provided on either the suction or discharge side of pumps; normally on the discharge side. Flow monitoring should indicate flowrate, and accumulated flow volume. Coagulant and pre-disinfectant (if used), should be flow paced to the flowrate signal. Pressure on the pump discharge should be monitored. The combination of flow and pressure will serve to monitor pump performance. If the pump discharge flowrate is to be controlled by a modulating valve, pressure should be monitored upstream of the valve to ensure pumps are operating within the normal process operating range, and also to ensure they are not operated outside their allowable envelope. High pressure and low pressure set points should be provided to initiate an alarm condition; high-high and low-low pressure set points will initiate pump shut down. Likewise, monitoring the valve position helps to ensure that the valve can be operated within its working range.

Flow splitting is required where two or more process trains are used. This may be through separate flow meters and flow control valves or through flow splitter boxes employing weirs.

6.1.6.1.2. Finished Water Pumping

Finished water pumping control should ensure that varying demand from the distribution system can be met while maintaining adequate pressure in the distribution system. This will be achieved by controlling flow or pressure, depending on the distribution system into which it feeds.

Flow control may be used in larger systems when the control system is essentially manual, and the distribution system has sufficient storage to accommodate the difference between varying demand and the selected pumping rate. This essentially comprises manual selection of the number of operating pumps, and will require continual operator monitoring and supervision or an automatic system to ensure distribution storage is not depleted or overflowed.

Monitoring discharge pressure is a common approach in controlling small and medium systems. Pump discharge pressure set points will start or stop pumps in a pre-selected sequence. Increased demand in the distribution system will result in falling pressure, when pressure reaches the low pressure set point, it will initiate starting the next duty pump, thereby restoring pressure to within an acceptable range. If pressure continues falling and again reaches the low pressure set point, the next duty pump will start, and so on.

On rising pressure, a pump will be shut down when the high pressure set point is reached. If pressure continues to rise again, the next pump in the sequence will drop out. The pressure set points must be selected to ensure distribution system pressures remain within acceptable limits; the pumps must be selected to ensure they can operate over the range of the operating set points.

Variable speed pumps may be used in finished water pump systems. Multiple pumps are still needed, but fewer units can be used to cover the same flow range, if some or all are variable speed. The most important advantage of variable speed pumping is the ability to maintain a constant discharge pressure into the distribution system. Control of variable speed pumps will be by pressure. Pump speed and output will vary in response to a drift in discharge pressure from the selected set point. A drop in pressure below set point will initiate incremental pump speed increases until pressure set point is restored. A rise in pressure above set point will initiate incremental pump speed decreases until pressure set point is restored. When maximum (minimum) pump speed limit is reached and pressure set point has still not been restored, another pump will start (stop), and the variable speed unit will ramp down (up) until pressure set point is restored. Correct selection and sizing of the pumps is vital to ensure the speed of the pumps remains in the recommended range.

Regardless of the control system, pressure (or level) should be monitored in the suction side to provide alarm and shut down or low pressure (level) and low-low pressure (level).

Discharge flowrate should be monitored continuously, and the accumulated volume recorded. Flowrate will be used to control the feed rate for secondary disinfectant, and where applicable, corrosion control chemicals, and pH control chemicals. Discharge pressure monitoring will also provide alarm on low or high pressure, and pump shut down on low-low or high-high pressure.

6.1.6.2. Treatment Processes

6.1.6.2.1. Travelling Screens

Two methods may be used to control the operation of travelling screens:

1. Simple manual start/stop, which requires the presence of the operator at the screen in order to start and stop the screen. This method is not recommended where sudden changes in raw water quality could result in heavy debris accumulation on the screens.
2. Automatic activation by differential level or time. This method uses the differential level across the screen to provide the start condition. The screen should run at least one complete screen cycle before stopping. The screen may be programmed to stop when the differential level is returned to the clean screen value, the final stop should be controlled using a sensor

to determine cycle completion (i.e. limit switch, proximity sensor, timer). In addition, a timer should be provided to initiate a cleaning cycle at regular intervals regardless of actual head loss. When this method is employed, there should be an alarm signal with a head loss set at a point higher than the automatic start of the travelling screen.

6.1.6.2.2. Chemical Feed Systems

6.1.6.2.2.1. Liquid Chemical Feed

The chemical dose rate should be flow paced to the plant flow in the part of the process that the chemical is to be injected into. Two methods are typically used to achieve this: metering pump, or flowmeter and flow control valve on the chemical feed:

1. Metering Pump Feed Control - Positive displacement type (diaphragm, peristaltic or progressive cavity) pump should be used. The output of the pump is directly controlled by a 4-20 mA signal from the flow transmitter on the plant flowmeter. On plant shutdown, the flowmeter (usually the raw water flowmeter) will signal the metering pump to stop and a solenoid on the dilution water to close. A load cell or pressure (level) transmitter on the chemical storage tank should provide warning signals when chemical supply is low, and should have alarm and initiate plant shutdown on low-low level.
2. Flow Meter Control - Where the need and justification for a more accurate and positive control system exists, flow meter control may be provided, where the chemical feed rate is controlled by an in-line flow control valve. A PLC receives a 4-20 mA signal from the flow transmitter on the plant flowmeter. Using this dose rate set point, the controller will look at the flowrate on the chemical feed flow transmitter and signals the in-line flow control valve to a position that will control the feed rate to the established set point. On plant shutdown, the controller will signal the in-line control valve to close. Depending on the range of feed rates, multiple flow meters and control valves may be required. As with the metering pump system, low and low-low level alarms/shut-down should be provided on the chemical storage tank(s).

6.1.6.2.2.2. Dry Chemical Feed

Dry chemical feed systems typically include a packaged bulk storage combination feeder and mixer. The feeder can be gravimetric or volumetric, and will be controlled by a 4-20 mA signal from the flow transmitter on the plant flowmeter.

The chemical feeder discharges to a dissolving tank where it is mixed with plant service water to form a solution (slurry) suitable for dosing. Plant service water flowrate is manually set and monitored by flow indicator. The rate needs to be suitable for the range of anticipated chemical feeds and its solubility; the rate may need to be manually adjusted seasonally. For a specific plant service water flowrate, the variation in chemical feed rate creates a corresponding variation in solution strength fed to the process water. The solution is fed via a hydraulic injector (if into a pipeline under pressure), or directly by gravity into open channels or tanks. On plant shutdown a signal from the raw water flowmeter will call for the dry feeder to stop and a solenoid valve on the plant service water feed to the dissolving tank to close. If an injector is used, a solenoid valve on the plant service water will also close.

6.1.6.2.3. Rapid Mixing

Rapid mixing of coagulant and other chemicals is achieved by mechanical or hydraulic mixing. Mechanical mixing may be in a tank or in a pipe and will comprise of a propeller or impeller assembly, usually electric motor driven. Control of the rapid mixer will be simply on or off. The unit should operate continuously whenever the plant is producing.

The use of variable speed or two speed drives can be used to vary mixing energy. If used, the speed may be controlled manually, based on operating experience and/or varied proportion to the flowrate in order to reduce backmixing, if this is of concern.

Hydraulic rapid mix can be in-pipe (static mixer or pumped jet) or free-fall (weir or cascade). These systems require no controls other than on/off for the pumped jet. With the static mixer, it is useful to indicate headloss across the mixer to confirm energy level and also monitor for headloss build-up, which could be indicative of chemical accumulation.

6.1.6.2.4. Flocculation

Flocculation is achieved mechanically or hydraulically in tanks. Mechanical flocculation requires paddles, picket fences or turbines to gently mix the coagulated water to produce a settleable floc for subsequent settlement, (or if the liquid - solid separation process is flotation, to produce a fine pin-point floc for floating). Some processes, such as solids contact clarifiers, integrate flocculation into the unit process. Flocculation requirements should be addressed in terms of the unit process parameters.

Where flocculation is a discrete unit process, it is normally achieved in multiple tanks operating in trains of usually two or three stages. The mixing energy level should be optimized for the water being treated; and will vary as the water quality changes. Jar testing or streaming current monitor will indicate the appropriate chemical dose. Jar testing will also indicate the mixing energy required for optimum flocculation.

For mechanical flocculation, variable speed drives should be used on the equipment. This will allow mixing energy to be adjusted to optimize the process. Speed control will be manual, based on jar tests and operational experience.

It is important that floc size and distribution through the floc cells be observed daily, along with a check of mixer speed. No other control or instrumentation is necessary, other than the status normally required for the motor drives.

With hydraulic flocculation, mixing energy is a function of headloss (and thus flowrate) through the floc cells. Thus, the only means of controlling hydraulic flocculation is to vary the flowrate. Control of the process is limited to manual control of flowrate, or where applicable, manual manipulation of valves to control the flow through the process to increase/decrease retention time.

6.1.6.2.5. Clarification

Careful monitoring and control is most important to successful clarification. Adequate instrumentation to measure water quality parameters prior to and after clarification is essential.

6.1.6.2.5.1. Sedimentation

Sedimentation can be accomplished in horizontal flow, or up-flow solids contact clarifiers. The latter combines sedimentation with the chemical coagulation and flocculation processes.

For all the types mentioned, provisions should be made to observe the clarification process. These observations should focus primarily on the floc condition throughout the tanks. Poorly settling floc, a change in floc size, flow carryover onto the filters, are all indicators that the clarification process may not be optimal. Jar testing should be undertaken to determine if the coagulant (and polymer) dosage, flocculation energy or flowrate needs adjusting.

The operator should watch for floating sludge; algae growth on tank walls and launders; and any abnormal appearance in the process water.

For horizontal or up-flow clarifiers that are equipped with mechanical sludge removal, it is necessary to monitor sludge quality and consistency. For smaller plants this may be done manually by drawing daily samples and noting the concentration, texture and condition of the sludge. Provision should be made for this sampling. In larger installations, ultrasonic or magnetic sludge density meters should be provided. Sample points should be located at strategic depths in the sludge hopper to provide information on sludge accumulation rate. An alarm should be provided to indicate failure of the mechanical sludge removal equipment.

Information gathered from this type of monitoring plus the operator's experience will be used to maintain control of the process. Provision should be made for the operator to adjust the sludge sweep cycle, speed and duration.

Up-flow solids contact clarifiers are more complex to operate because they rely on maintaining a sludge blanket to develop and capture the floc from the rising flow. Although a very efficient clarification process, it is sensitive to hydraulic and solids shock loading and should preferably be run continuously at as steady a flowrate as possible.

Starting or restarting a solids contact clarifier (SCC) requires establishing the sludge blanket. This may take some days on initial start-up, less on restarting an operational unit, depending on the sludge condition and quality.

Monitoring of the sludge blanket position, depth and condition once it is established is critical to the operation. Typically, this can be done through manual sampling from tapings at various strategic depths within the tank. Again, the use of sludge density monitors should be used in larger installations to provide continuous monitoring of and data on the sludge blankets.

With the proper level of monitoring and the operator's experience, the SCC process variables can be controlled. These including re-circulation turbine speed, sludge scraper speed (where

applicable), sludge blow down cycle (frequency, duration), and chemical feed rates. Turbine speed and sludge scraper speed are normally adjusted manually to suit operating conditions. The sludge blow down cycle can be initiated by the volume of water processed, a timer, and/or sludge level. Again, the volume, timer and/or sludge level set points will be manually set by the operator based on raw water conditions, sludge accumulation rate and sludge condition.

6.1.6.2.5.2. Dissolved Air Flotation

The process variables in DAF are:

1. Flowrate;
2. Recycle Rate; and
3. Float Removal Cycle.

The DAF process is comprised of multiple tanks operating in parallel. To handle varying flowrates, the operator should to the extent possible match the number of units operating to the demand. The process can be shut down and restarted very easily, with the effluent quality being restored quickly (within 10-20 minutes). Shutting down units during low demand keeps the operating units performing optimally, and also reduces the amount (and cost) of recycle.

Recycle rate is set based on raw water quality and operating experience. Recycle flow is controlled by the recycle pumping rate and the nozzles through which the recycle is released into the DAF tank(s). Pressure in the recycle system upstream of the nozzles should be kept in the range 450 to 725 kPa to maintain the air in solution and provide the proper micro sized bubbles on release into the tank. Recycle flowrate can therefore be varied, provided it does not cause the pressure to fall outside the design limits. Recycle rates may be further varied by shutting down bank(s) of nozzles and/or adjusting nozzles (if applicable).

The saturation process can use either injectors or a packed bed saturator. Injectors discharge saturated water into a pressure vessel. With the packed bed saturator, the saturator itself is a pressure vessel. Within this pressure vessel, the level is monitored; this level controls the recycle system.

Variable speed recycle pumps, controlled by level in the saturator tank, are used for packed bed systems. When banks of nozzles are opened/closed, the resultant recycle flowrate change initiates a pump speed adjustment to restore the level set point. Depending on the number of pumps and control system, additional recycle pumps are brought on-line or dropped off in response to saturator tank level.

Alternatively, with injector or small packed bed systems, dedicated fixed speed pumps may be used. Each injector or tank would have its own recycle pump, which would operate whenever its DAF train comes on-line.

Float removal may be continuous or intermittent, and can be accomplished mechanically and/or hydraulically. Alarms should be provided for equipment failure or if water levels fall outside of limits.

There are various systems, some proprietary, used for water clarification. The control systems for each will not be described herein. The following provides general guidance on the recommended monitoring and control for float removal, and should be read in conjunction with manufacturer's operating instructions, where applicable. Provisions must be made for the float to be observed. This is necessary to ascertain if chemical feed and/or flocculation energy need adjustment.

Continuous float removal is achieved by a mechanical sludge skimmer, or paddle, pushing float over a weir (beach). Water level has to be maintained relatively constant for the float removal system to operate efficiently. Level is controlled either by a tank effluent weir, which is set for the design flow, and should not require adjustment unless conditions change (e.g. settlement of tankage, new design flow etc.), or by an effluent control valve with a level controller. The float removal system variables (travel/rotation speed) should have the capacity for manual adjustment. Intermittent float removal typically utilizes hydraulic methods. Water level in the DAF tank is raised, by restricting the effluent flowrate, to allow float to discharge over a weir. When the float has been discharged, the effluent flowrate is restored and water surface drops to its normal operating level. The float removal cycle (frequency and duration) should have the capacity for manual adjustment.

6.1.6.2.6. Filtration

Filtration is the most critical stage in the particulate removal process. It needs to be monitored and controlled closely to ensure treated water quality is consistent and within guidelines. The following two types of filtration are used for water treatment:

1. Rapid Gravity Filtration; and
2. Slow Sand Filtration.

6.1.6.2.6.1. Rapid Gravity Filtration

The majority of municipal water filtration plants use rapid gravity filters. Rapid gravity filters (RGF) are operated in one of two ways:

1. Constant Rate; and
2. Declining Rate.

The control systems for each are different and are described in the following sub-sections.

6.1.6.2.6.1.1. Constant Rate

Flow through a constant rate RGF is controlled by a flow-control valve on the filter effluent, or by influent flow splitting and filter level control. For the flow control type, the effluent valve position is controlled by a flowrate signal from a flow meter, usually located on the filter effluent. For the level control type, the effluent valve position is controlled by the water level in the filter.

A filter run will be terminated, and the bed backwashed on one or any of the following:

1. Run time;
2. Headloss across the bed;
3. Effluent turbidity; and
4. Effluent particle count (optional).

The termination of a filter run and start of a backwash cycle can be initiated automatically or manually. Plants that are manned continuously have this option. Plants that are not manned all the time should be designed for automatic initiation, with provision for manual override; this will ensure filters are backwashed when required, even if the operator is not there.

At a minimum, both headloss and effluent turbidity should be monitored on each individual filter. Headloss is monitored by measuring the differential pressure between the effluent line (upstream of the control valve) and the top of the filter media. The pressure signal will initiate an alarm on high level, and in a non-continuously manned plant, initiate a filter backwash cycle. On high-high level, the filter should shut down until the operator has investigated the cause of the high-high alarm and/or manually initiated a backwash.

Turbidity should be monitored by an on-line turbidimeter, and there should be one for each filter. As with headloss, a high turbidity set point can initiate an alarm (and possible backwash cycle), and a high-high turbidity set point should shut down the filter to prevent poor quality water reaching the clearwell.

The turbidimeter should be located upstream of the filter-to-waste diversion point, or a second turbidimeter should be provided for filter-to-waste if the piping is separate. Filter-to-waste duration should be based on the turbidity.

Continuous recording of effluent turbidity is required in assuring filter and plant performance.

6.1.6.2.6.1.2. Declining Rate

Flow through a declining rate RGF is not directly controlled, as is the case with constant rate RGF. The rate simply decreases as the filter plugs. An effluent valve with manually adjustable stops is set to ensure the flowrate through a clean bed is not excessive. Once set, this valve will return to the set position after backwash (or after being closed for maintenance etc).

A filter run will be terminated on one or any of the following:

1. Run time;
2. Effluent flowrate;
3. Effluent turbidity; and
4. Effluent particle count (optional).

With declining rate control, all filters have the same driving head and therefore headloss is not a useful measurement. The head over the effluent weir however is an adequate measurement of filter effluent flowrate, which will decrease gradually throughout a filter run. When flowrate measurement is provided, head over the effluent weir would typically be measured by level probe or ultrasonic level sensor, calibrated for the weir characteristics to indicate flowrate. A

low level (flow) set point would initiate an alarm, and a low-low level (flow) should shut down the filter. Alternatively, an in-line flowmeter may be used.

A continuous on-line turbidity monitor should be provided on each filter upstream of the filter-to-waste diversion, or a second turbidimeter should be provided for the filter-to-waste if the piping is separate. A high turbidity set point should alarm and/or initiate a backwash. A high-high set point should shut down the filter until the operator has investigated the cause of the high-high alarm and/or initiated a backwash.

Continuous recording of effluent turbidity is required in monitoring filter and plant performance.

6.1.6.2.6.1.3. Backwashing

Backwashing a filter can be initiated various ways, as discussed earlier.

A time-initiated backwash can be automatic. Smaller plants feeding smaller systems may benefit from backwashing overnight when demand is low, and the operator is not present. In such cases, a timer can be hard wired into the filter control panel to initiate the backwash, or alternatively, the time control can be programmed into the PLC.

If an automatic backwash on turbidity, headloss (constant rate), or flow (declining rate) is desired, care should be taken to consider plant demand and the effect of interrupting or reducing production to ensure that service and treatment are not compromised.

Before proceeding, the control system must confirm that a wash is permitted by checking source water volume, receiver volume, and that no other filter is washing or that no other process or production restraints exist. Once started, its cycle can be controlled manually by the operator, or automatically by timers and a sequencer in a PLC program. All timer settings must be adjustable.

The backwash cycle takes 20 to 40 minutes depending on whether it is a straight water backwash or includes surface wash or air scour. Backwash flow changes must be made gradually. Valve sequencing is important. Flow set points must be adjustable.

With surface wash, a typical cycle may include:

1. Draw down water level over filter;
2. Initiate surface wash;
3. Initiate backwash before surface wash ends;
4. Filter-to-waste; and
5. Return filter to service.

With air scour, the cycle may include:

1. Draw down water level over filter to approximately 50-100 mm above media;
2. Initiate air scour;
3. Combined air scour and low rate backwash on time or until level reaches within 50-75 mm of washwater waste weir;
4. Stop air scour, initiate high rate backwash;

5. Filter-to-waste until effluent turbidity is within limits; and
6. Return filter to service.

A pressure transmitter senses water level over the filter to control the opening/closing of valves and the start/stop of surface wash, air scour and low rate backwash and filter filling after high rate backwash, if required. All other control is time based.

When a filter is put back into service, water should be filtered to waste until the turbidity has dropped to a preset acceptable value. Filter to waste should be performed at approximately the same flowrate as the filter normally operates. The on-line turbidimeter monitors filter-to-waste turbidity and once the turbidity set point is reached, a signal is sent for the filter-to-waste valve to close and the filter-to-production valve to open simultaneously. Valve stroking during this changeover should be synchronized to maintain flowrate through the filter as constant as possible to avoid the turbidity spikes that can occur with a sudden change in flowrate through a filter.

Water used for backwashing must be filtered water. A backwash pump will supply backwash water typically drawing from the plant's treated water clearwell. Alternatively, backwash water can be supplied directly off the transmission main leaving the plant or from a header tank. Backwash flowrate control is critical to assure good cleaning and avoid media loss. The higher density of cold water in winter requires a lesser flowrate than the summer to achieve fluidization of the bed. This flowrate set point should therefore be adjusted seasonally to compensate for the water temperature variation. Backwash flowrate is be measured by in-line (magnetic or ultrasonic) flowmeter.

Control of the flowrate may be manual or automatic. Manual control may be used on straight backwash systems (with no air scour). Manual control requires adjustment to a throttling valve on the backwash supply until the desired flowrate, as measured by the flowmeter, is achieved. This valve should be locked in this position and adjusted seasonally to compensate for water temperature as described above. Excessive and undesirable disturbance of the media can be caused by a sudden rush of water on pump start-up or rapid valve opening. This is avoided by having a second in-line valve, typically a pilot operated globe valve, which opens slowly to bring the backwash flow gradually to the set point. Alternatively, a bypass valve that closes slowly may be used.

A backwash system that includes air scour, and consequently two backwash flowrates, is best controlled automatically by a PLC (or DCS). Backwash flowrate can be varied either by using variable speed drive on the backwash pump, using multiple pumps, or using an in-line flow control valve. For the variable speed drive and flow control valve options, a flow transmitter on the backwash supply will provide a signal to the PLC. The PLC will use this signal to control the pump speed/valve position.

For the multiple pump option, the pumps could be set up to provide the required flowrates using manually adjusted throttling valves on each pump discharge so that one pump could supply the low flow, and the other (or both in parallel) could meet high flow. As with manual control, flowrate changes should not be sudden, and an in-line pilot operated globe style valve should be used to avoid this.

6.1.6.2.6.2. Slow Sand Filtration

Although their function is the same as RGF, slow sand filters operate under different conditions. Slow sand filters (SSF) operate at much lower loading rates and rely on the formation of a thin layer, Schmutzdecke, on top of the sand medium. As well as forming a filter to remove particulates, this layer contains various microorganisms that remove bacteria and other organisms. SSF are not backwashed, rather the Schmutzdecke layer is removed occasionally (typically every 4-8 months) when headloss becomes excessive, flowrate drops off and/or quality starts to deteriorate. Because of the very slow flowrate through SSF, headloss, flowrate and effluent quality can remain very stable for many weeks.

The operator can make adjustments to the flowrate manually. When commissioned, SSFs have to mature over a period of several weeks before they can produce potable quality water. Once a filter has been brought on-line, the primary operator function is to monitor and control flowrate. Flowrate through a filter is measured either by measuring head over the effluent weir, or preferably by the more accurate method of in-line flowmeter on the filter effluent pipe upstream of the filter recycle diversion. A manual throttling valve on the effluent pipe should be adjusted to ensure flowrate through a new filter is not excessive. A manual throttling valve on the filter inlet should also be adjusted to ensure influent flowrate closely matches the effluent flowrate. These valves should be adjusted to maintain the desired water depth over the bed. Alternatively, starting and stopping the raw water pumps may control water level over the filter. As the bed clogs and headloss increases, the effluent valve should be opened to compensate.

Instrumentation should be provided to routinely monitor raw and treated water quality. A sudden increase in headloss accompanied by a reduction in flowrate signals that the filter is plugged.

6.1.6.2.7. Disinfection

Chlorine is the most common disinfectant used in potable water treatment. The following discussion provides process control guidelines for the use of chlorine in either its gaseous or solution forms.

Effectiveness of chlorine disinfection and the dosage is a function of the water temperature, pH, the contact time and the chlorine demand. The dosage is controlled on the basis of the measured residual.

Disinfection is controlled for the following reasons:

1. To meet CT requirements, which will vary with the raw water quality and the performance of the upstream processes; and
2. To ensure that chlorine residual for water leaving the plant is maintained at the set point.

Laboratory chlorine demand analysis will establish the required dose concentration. The chlorine dose rate will then be controlled by a signal from the flow transmitter on the flowmeter measuring the flow in the process where the chlorine will be injected. The chlorine residual will be monitored downstream of the process/tankage that provides the required CT. This measured

variable can be used to automatically adjust the dose concentration through feedback loop control, and/or provide an alarm status to which the operator would have to respond. Unless the plant is manned continuously, it is preferable that automatic control be provided.

Since treated water is stored at the plant for some time, its chlorine residual can diminish. The residual will thus need to be ‘topped up’ or trimmed to the proper concentration. The trim dose is controlled by the flowrate (not the plant production rate) and chlorine residual of the water leaving the plant. Feedback loop control using a chlorine residual analyzer combined with flow-pacing control from the discharge flowmeter will automatically maintain the set point residual. An alarm should be generated if the residual falls out of bounds.

Chlorine gas feed systems incorporate a low-pressure switch on the vacuum gas line to the chlorine feeder to provide an alarm signal, and where applicable, signal an automatic switch over from duty chlorine cylinder/container to standby cylinder/container. Chlorine feed rate is controlled by modulating the chlorinator. The system is started and stopped by opening or closing the plant service water valve supplying the chlorine injector. A chlorine gas flow meter or solution flow proving switch is desirable. A chlorine gas detector must be provided in the chlorine room; the detector should be connected to a remote audible and visual alarm system.

6.1.7. Design Documents

Complete design documents should be prepared to ensure that construction can be completed correctly and also to properly record the system for future reference. The following are required in the design documents:

1. Design and construction standards, specifications and installation details;
2. Panel sizing and general arrangement;
3. Control system functional requirements;
4. Control component and instrument data sheets;
5. Operator interface and control hardware and software specifications including input and output (I/O) lists; and
6. Control system programming and packaged system configuration standards, structure and scope.

6.1.8. Control System Documentation

The following documents should be provided following completion of the control system:

1. Record drawings to show any changes to the design and including any drawings produced during construction;
2. Annotated listings of control system programs and packaged system configuration;
3. Manufacturer’s literature for all control and instrumentation components;
4. Final wiring diagrams complete with wire and terminal coding;
5. Motor control schematics;
6. Instrument loop diagrams;

7. Panel wiring and layout details;
8. PLC or DCS wiring schematics;
9. Instrument calibration sheets; and
10. Operating instructions.

6.1.9. Training

Adequate training to the plant operating and maintenance staff should be provided so that the system can be operated to meet the design criteria. Safety training for chlorine and chemical handling, including spill clean-up and first aid should be included.

6.2. Sewage Works – Instrumentation and Controls

Several factors should be considered when developing a plan for the instrumentation and controls for a wastewater treatment facility. AEP monitoring requirements vary depending on the type of facility being considered and its location; this will impact on the selection and type of instrumentation being considered. Instrumentation and control requirements will also depend on the size of the plant, and as each treatment process has its own set of conditions to be monitored and controlled there will be different technical requirements to be met. In general, instrumentation and control should provide efficient and safe automatic and manual operation of all plant systems with a minimum of operator effort. Automatic systems should also be provided with manual back-up systems.

The design should have provision for local control systems where parts of the plant may be operated or controlled from a remote location. The local control stations should include provision for preventing the operation of equipment from remote locations.

When making decisions relating to instrumentation and control, the following factors should be considered:

1. Plant size and complexity;
2. Regulatory requirements;
3. Hours of attended operation;
4. Potential chemical and energy savings;
5. Primary element reliability
6. Primary element location
7. Whether controls should be manual **or** automatic; and
8. The data storage and recording requirements and whether data acquisition should be central or distributed

For effective operation of larger wastewater treatment facilities the following parameters should be measured, some may not be required for smaller facilities.

1. Flowrate for raw sewage, by-pass flows, final effluent flow;
2. Return Activated Sludge (RAS) flows, Waste Activated Sludge (WAS) flows;
3. Raw and digested sludge flow, digester supernatant flows;
4. Chemical dosage, digester gas production;

5. Hazardous gas monitoring;
6. Anaerobic digester temperature;
7. Dissolved oxygen levels; and
8. Sludge blanket levels and sludge concentrations.

6.2.1. Types of Instruments

The different types of instruments that may be required to measure the previously mentioned parameters are classified as primary element devices, which alter a signal from a physical process to make it suitable for use by a transmitter. These devices are broken down into function groups with a brief description of the process application.

6.2.1.1. Flow Measurement

6.2.1.1.1. Magnetic Flowmeters (Mag Meters)

Liner and Electrode Materials - The liner for the meter can vary depending on the application being considered. In applications where moderate amounts of abrasion are likely to occur, one of the following materials may be selected; Polyurethane, Butyl rubber, Neoprene or Polytetrafluoroethylene. In applications where corrosion is likely to occur, one of the following materials may be selected; Ceramic or Polytetrafluoroethylene. Stainless steel electrode material should be used for applications where corrosion is not likely to present a problem. Hastelloy electrode material should be used for applications where corrosion is likely to present a problem.

Installation - Installation of magnetic flow meters generally require five straight pipe diameters upstream of the meter and three down stream of the meter free of valves or fittings. Meters may be installed on horizontal, vertical or sloping lines. It is essential to keep the electrodes in the horizontal plane to assure uninterrupted contact with the fluid or slurry being metered. The operating velocity required for these meters will fall into the range or (1 to 10 m/s) for non-solids bearing liquids and (1.5 to 7.5 m/s) for solids bearing liquids. When used to meter liquids containing solids, a continuous electrode cleaner or clean out tee should be installed.

Applications - These meters are suitable for Influent Wastewater, Primary Sludge, RAS, WAS, Digested Sludge and Final Effluent. These meters should not be used for Digester Gas or liquid streams with a solids content greater than 10% by weight.

6.2.1.1.2. Ultrasonic Flowmeters

Flowmeter Construction - The flowmeter usually consists of an electronics housing, transducers and pipe section. These can in many cases be fitted to existing pipes either by drilling holes for the transducer hardware or by application of external transducers to the outside of the pipe. When installed on existing pipes, the existing pipe material should be checked to assure it will not dampen the sonic signal as this will adversely affect performance.

Installation - The installation of Ultrasonic flow meters generally require ten to twenty straight pipe diameters upstream of the meter and five down stream of the meter free of valves or fittings. Meters can be installed on horizontal, vertical or sloping lines as long as the pipe sections are always full. The operating velocity required for these meters will fall into the range of (1 to 10 m/s).

Applications - Transmittance styles are not recommended for influent wastewater, primary sludge, thickened sludge, nitrification RAS, or nitrification WAS. Reflective styles are not recommended for primary effluent, secondary clarifier effluent final effluent or process wash water.

6.2.1.1.3. Turbine Flowmeters

Flowmeter Construction - The flowmeter usually consists of meter body with rotor blades and a magnetic pickup. The pickup is often connected to electronic display units or a totalizer.

Installation - Installation of turbine flow meters generally require a minimum of ten straight and as high as fifty pipe diameters upstream of the meter and five down stream of the meter free of valves or fittings. Meters may be installed on horizontal or vertical pipelines.

Applications - Turbine flow meters are recommended for applications involving natural gas, compressed digester gas.

6.2.1.1.4. Flumes and Weirs (Parshall Flume)

Installation - The flume will be affected by upstream channel arrangement and it is recommended that there be at least ten channel widths upstream. The flume must also be installed carefully to make certain that it is level.

Applications - Flumes and weirs are customarily used to measure flows in open channels. They are recommended for applications involving open channel flow measurement.

6.2.1.2. Suspended Solids Measurement (Turbidity)

Installation - Installation details for turbidity analyzers are unique to each manufacturer. The manufacturer's recommendations should be followed.

Applications - Turbidity analyzers are recommended for applications involving suspended solids concentrations less than 100 mg/L.

6.2.1.3. Suspended Solids Measurement (Optical)

Installation - Installation details for optical analyzers are unique to each manufacturer. The manufacturer's recommendations should be followed.

Applications - Optical analyzers are recommended for applications involving solids concentrations from 20-mg/L to 8%. Examples are, RAS, WAS and mixed liquor.

6.2.1.4. Dissolved Oxygen Measurement (Galvanic)

Installation - Installation details for dissolved oxygen analyzers are usually related to the choice of placement of the analyzer in the process fluid. The analyzers generally require fairly frequent maintenance and this should be considered in determining the location for installation.

Applications - Oxygen analyzers are recommended for applications involving oxygen concentrations from 0 to 20 mg/L.

6.2.1.5. Level Measurement

6.2.1.5.1. Sonic Ultrasonic

Installation - The mounting location of the sensor is determined from restrictions established by the manufacturer. Typically the sensor must be mounted a minimum distance above the high liquid level and should be located away from tank walls or other obstructions that may cause false echoes.

Applications - This type of level element may be used in many level and flow applications; it is not recommended in locations where foam is dense and persistent.

6.2.1.5.2. Float

Installation - Float switches are normally located in a stilling well when turbulence is expected.

Applications - Float switches are commonly used for high and low level alarms and for controlling pump starts and stops.

6.2.1.5.3. Capacitance

Installation - The installation practices can vary and the manufactures recommended installation should be used.

Applications - May be used in applications that require continuous level measurement and also as switches for alarms or start/stop control.

6.2.1.6. Pressure Measurement

6.2.1.6.1. Bourdon Tubes

Installation - The installation practice should include the use of block and bleed valves.

Applications - May be used in applications that require pressure indication. Pressure range 0 to 35000 kPa.

6.2.1.6.2. Bellows

Installation - The installation practice should include the use of block and bleed valves.

Applications - May be used in applications that require pressure indication. Pressure range 0 to 2000 kPa.

6.2.1.6.3. Diaphragms

Installation - The installation practice should include the use of block and bleed valves. Transmitters should be installed according to manufacturer's recommendations. Temperature extremes should be avoided and location should be as close as possible to the process measure site.

Applications - May be used in applications that require pressure indication or transmitter output. Pressure range 0 to 3500 kPa.

6.2.1.7. Temperature Measurement

6.2.1.7.1. Thermocouples

Installation - The thermocouple should be selected with care to assure that the appropriate device is chosen for the given temperature range. Installation with a thermowell is advised.

Applications - Thermocouples are suitable for most temperature measurement applications.

6.2.1.7.2. Resistance Temperature Detector

Installation - The resistance detector should be selected with care to assure that the appropriate device is chosen for the given temperature range. Installation with a thermowell is advised.

Applications - Resistance detectors are suitable for temperature measurement applications with ranges of 0 to 300°C.

6.2.1.7.3. Thermistor

Installation - The Thermistor should be selected to assure that the device is appropriate for the temperature range. Installation with a thermowell is advised.

Applications - Thermistors are suitable for temperature measurement applications with ranges of 0 to 300°C.

6.2.1.7.4. Thermal Bulb

Installation - No special installation requirements.

Applications -Thermal bulbs are suitable for temperature measurement applications with ranges of 0 to 500°C.

6.2.2. Process Controls

6.2.2.1. Lift Stations

Lift stations require simple and dependable instrumentation and control systems. The parameters that should be monitored are level, flow, pressure, temperatures, hazardous gas levels, as well as status and alarm conditions. The monitoring and control requirements will vary for each individual case based on the size, location, and economic considerations.

6.2.2.1.1. Level Control

Lift stations vary in size and storage capacity but generally they require similar controls. The level in the wet well increases to the point where a duty pump will be required to start, a lag and follow pump may be started if the level continues to increase. Pumping continues until a pump stop level is reached at which time the duty pump stops, or a series of stop levels will be reached and the lag and follow pumps stop prior to the duty pump. The pump start/ stop control can be performed using any one of several acceptable level control devices.

When variable speed pumps are used there are several ways in which the pump can be controlled. These generally are controlled to maintain a level set point in the wetwell. This requires a feedback type of control in which the measured variable (level) is compared to a set point value and the final control element is modulated in order to maintain the set point value. Level control of this nature require reliable analog level measurement if it is to function properly. Regardless of the type of level control selected, the system should include a separate low level lockout and high level alarm.

6.2.2.1.2. Flow Monitoring

The flow metering element should be selected carefully to ensure that there are no obstructions where clogging may occur. Provision should be made so that the flow-metering element can be bypassed or isolated for routine maintenance activities. The flow-metering device should be connected to either the control system or to a recording and totalizing device or both. This provides for a record of flows out of the lift station. It can also be used to help identify possible problems in the discharge piping or force main.

6.2.2.1.3. Pressure Monitoring

Monitoring of the system discharge pressure can be useful in identifying possible problems in the discharge piping or force main and in monitoring pump performance. The pressure-metering device should be connected to either the control system or to a recording device or both.

6.2.2.1.4. Pumps and Motors

The following parameters should be monitored:

1. Pump bearing temperature;
2. Pump bearing vibration;
3. Pump speed for variable speed applications;
4. Pump discharge pressure;
5. Motor voltage and current;
6. Motor hours of operation;
7. Motor bearing temperature; and
8. Motor windings temperature.

6.2.2.1.5. Alarms

Lift stations should be alarmed as outlined in Section 5.3.15.

6.2.2.2. Mechanical Bar Screens

Three methods are used to control the operation of mechanical bar screens:

1. Simple manual start/stop, which requires the presence of the operator at the screen in order to start and stop the screen.
2. Automatic activation by differential level. This method uses the differential level across the screen to provide the start condition. The screen should run at least one complete screen cycle before stopping. The screen can be called to stop when the differential level is returned to a nil value, the final stop should be controlled using a sensor to determine cycle completion (i.e. limit switch, proximity sensor, timer). In addition, a timer should be provided to initiate a cleaning cycle at regular intervals regardless of actual head loss. When this method is employed, there should be an alarm signal with a head loss set at a point higher than the automatic start of the mechanical bar screen.

3. Automatic activation by timer with differential level as emergency start condition. This method uses the differential level across the screen to provide secondary start condition. The screen should run at least one complete screen cycle before stopping. The stop signal should be controlled using a sensor to determine cycle completion (i.e. limit switch, proximity sensor, timer). When this method is employed there should be an alarm signal with a head loss set at a point higher than the automatic start of the mechanical bar screen.

6.2.2.3. Primary Treatment

6.2.2.3.1. Raw Sludge Pumping

The raw sludge pumping should be set up to incorporate the following features:

1. Automatic or manual selection of duty pump;
2. On line sludge density metering for control and monitoring;
3. On line sludge flow monitoring and totalization;
4. On line adjustable sludge density control;
5. Individually selectable hopper pumping controls where required;
6. Manual override for automatic controls;
7. On line sludge blanket level monitoring and alarming;
8. On line sludge pump monitoring and control;
9. Sludge density feedback control for variable speed pumping with manual override;
10. On line sludge pump speed monitoring and control with manual override; and
11. On line monitoring and control of primary tank scraper mechanisms.

6.2.2.3.2. Scum Pumping

The scum pumping should be set up to incorporate the following features:

1. Automatic or manual selection of duty pump;
2. Manual override for automatic controls;
3. On line sludge blanket level monitoring and alarming;
4. Automatic controls consisting of high and low scum tank level for starting and stopping scum pumps;
5. High scum tank level alarm;
6. On line scum pump speed monitoring and control with manual override; and
7. Scum tank flushing system for scum tank cleaning

6.2.2.4. Secondary Treatment

6.2.2.4.1. Dissolved Oxygen (DO) Control

Automatic DO control systems should be used to control the rate of air supply to aeration tanks. The following methods may be used:

1. **Closed Loop Control (Feedback Control)** - Closed loop control consists of on line dissolved oxygen analyzers providing feedback control to an airflow control device. The dissolved oxygen reading is compared to the dissolved oxygen set point. The resultant error signal is used to increase or decrease the rate of air flow to the aeration tanks. Automatic dissolved oxygen control should always be equipped with manual override.
2. **Feed Forward Control** - Feed forward control consists of a fixed volume of air being delivered to the aeration tanks for a given flowrate. This system may utilize on line dissolved oxygen analyzers but these are used for monitoring only and do not provide feedback to the air flow control elements. Process status and alarms should be provided for dissolved oxygen level, blower operating parameters, air flow control elements.

6.2.2.4.2. Return Activated Sludge Control

The Return Activated Sludge pumping should be set up to incorporate the following features:

1. Automatic or manual selection of duty pump;
2. Variable speed pumping;
3. Return activated sludge flow monitoring;
4. Feedback control to match pumping rates to flow set points;
5. Individual control of sludge return rate from individual final clarifiers;
6. Manual override for automatic controls; and
7. On line monitoring of return sludge flowrate, pump speed and status.

6.2.2.4.3. Waste Activated Sludge Control

The Waste Activated Sludge pumping should be set up to incorporate the following features:

1. Automatic or manual selection of duty pumps;
2. Variable speed pumping;
3. Waste Activated Sludge flow monitoring;
4. Feedback control to match pumping rates to flow set points;
5. Manual override for automatic controls; and
6. On line monitoring of Waste Sludge flowrate, pump speed and status.

6.2.2.4.4. Chemical Control System

Chemical addition consists of a feeder or chemical metering pump that will dose at a fixed ratio to the influent or effluent flow of the plant, with no analyzer or feedback control. More specific chemical dosing may also be based on such things as return sludge flowrate. Chemical dosing requirements will vary widely depending on performance requirements and the specific process being utilized.

6.2.2.4.5. *Disinfection Control Systems (Ultra Violet)*

The disinfection of final plant effluent utilizing ultra violet light consists of a feed forward control system. This consists of a series of lamps and or lamp channels that are turned on based on effluent flow of the plant, UV transmittance analyzers may be utilized for monitoring system performance but are not generally employed in feedback control.

6.2.2.5. Control and Monitoring Systems

Control and monitoring systems can be a conventional system with recorders, indicators, switches, push buttons, indicating lights, control panels, etc. or it can be a computerized control system that utilizes various configurations of hardware and software to provide the control required. Computerized systems can be separated into two groups, PLC (Programmable Logic Controller) Systems and Distributed Control Systems.

6.2.2.5.1. *Conventional Relay Control Systems*

The conventional system is a passive system with limited automatic control, where the operator is responsible for decisions and actions that control the process.

6.2.2.5.2. *PLC Control Systems (Programmable Logic Controllers)*

The PLC based system is a multipurpose system with extensive scope for modification. The plant status, alarms, motor starters, meters and analyzers are all wired into input/output cards located in what are called racks. The racks may be mounted separately or placed in specific plant areas to reduce wiring costs. The input/output racks are associated with controllers that are programmed to perform the required process control functions. Changes can generally be made relatively easily by modification of or addition to the PLC controller programs.

Plant personnel require process information in real-time or in near real-time. The PLC systems accomplish this by means of a Man Machine Interface (MMI). The MMI may be dedicated hardware and software or may come in the form of personal computers utilizing MMI software and connected to the PLC communications system. These systems vary widely in their capabilities and performance. The selection of hardware and software should be done carefully to assure current performance and future supportability and expendability.

6.2.3. Design Documents

Complete design documents should be prepared to ensure that construction can be completed correctly and also to properly record the system for future reference. The following are required in the design documents:

1. Design and construction standards, specifications and installation details;
2. Panel sizing and general arrangements;
3. Control system functional requirements;
4. Control component and instrument data sheets;
5. Operator interface and control hardware and software specifications including input/output lists; and
6. Control system programming and packaged system configuration standards, structure and scope.

6.2.4. Control System Documentation

The following documents should be provided following completion of the control system:

1. Record drawings to show any changes to the design and including any drawings produced during construction;
2. Annotated listings of control system programs and packaged system configuration;
3. Manufacturer's literature for all control and instrumentation components;
4. Final wiring diagrams complete with wire and terminal coding;
5. Motor control schematics;
6. Instrument loop diagrams;
7. Panel wiring and layout details;
8. PLC or DCS wiring schematics;
9. Instrument calibration sheets; and
10. Operating instructions.

6.2.5. Training

Adequate training should be provided to the plant operating and maintenance staff so that the system can be operated to meet the design criteria.