
8.39 Wastewater Treatment Controls

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INTRODUCTION

This section concentrates on the description of the controls used in industrial wastewater treatment. It also covers, but in less detail, the controls used in municipal wastewater and cooling water treatment processes. The controls of water supply plants, including water softening and purification, are covered in [Section 8.40](#).

In the United States, the operations of all water treatment plants are directed by the Federal Water Pollution Act. Together with its amendments, it is known as the Clean Water Act (CWA). Water treatment plants can be privately or publicly owned. Private treatment plants can discharge into publicly owned treatment works (POTWs) if they have the proper permits.

The goal of the water treatment plants is to remove organic matter and to reduce the water's nitrogen content to less than 20 mg/l in all forms. The water quality targets for the treated plant discharge usually include BOD concentration under 5 mg/l, suspended solids concentration under 3 mg/l, PO₄ under 0.05 mg/l, and NO₃ under 10 mg/l. If the plant discharge is for golf course use, the allowable BOD concentration is under 10 mg/l and the suspended solids concentration is under 12 mg/l.

The coverage of this section overlaps with a number of other sections in this chapter. These are:

[Section 8.1](#), Aeration and DO Controls, [Section 8.31](#), ORP Controls, and [Section 8.32](#), pH Control. It is recommended to the reader that for an in-depth coverage of the control strategies available for dissolved oxygen (DO), oxidation-reduction potential (ORP), and pH control and optimization, they also refer to the above sections.

Lastly, the reader is reminded that the various sensors and analyzers used in the wastewater treatment processes are all covered in the first volume of this handbook. Their section numbers are as follows:

- 8.2 Analyzer Sampling, Process Samples
- 8.6 Biometers
- 8.7 BOD, COD, and TOD Sensors
- 8.11 Chlorine
- 8.15 Colorimeters
- 8.23 Fiber-Optic Probes

- 8.28 Ion-Selective Electrodes
- 8.36 Nitrate, Ammonia, and Total Nitrogen
- 8.38 Odor Detection
- 8.39 Oil in or on Water
- 8.41 Oxidation-Reduction Potential (ORP)
- 8.43 Oxygen in Liquids (Dissolved Oxygen)
- 8.45 Ozone in Water
- 8.48 pH Measurement
- 8.49 Phosphorus Analyzer
- 8.54 Streaming Current or Particle Charge Analyzer
- 8.58 Total Carbon Analyzers
- 8.60 Turbidity, Sludge, and Suspended Solids
- 8.65 Water Quality Monitoring
- 8.66 Wet Chemistry and Auto-Titrator Analyzers

General Considerations

Some of the processes used in the treatment of wastewater are not well suited to automatic process control. This is because many continuous analyzers are not reliable enough for the control of such processes as coagulation and flocculation of water or the biological treatment of wastewater. These processes are, for the most part, an art, not a science, still requiring some human judgment to determine chemical application rates and process control parameters.

The measurements that are reliable and in wide use are pH, oxidation-reduction potential, residual chlorine, and flow rate. Other water properties that are measured to assist the operator in controlling the system are conductivity, alkalinity, temperature, suspended solids, dissolved oxygen, and color. [Figure 8.39a](#) illustrates the design of the sampling system used when measurements obtained by inserting the sensors directly into the process are not reliable.

Water and wastewater treatment consists of unit operations that may be classed as mechanical, chemical, biological, and any combinations of these. The mechanical operations most often consist of screening, filtration, and separation by gravity.

Industrial Wastewater Treatment

Environmental regulations restrict the discharges of chlorine, heavy metals, arsenic, cyanides, biological pollutants, and excessively acidic or basic water. These regulations are

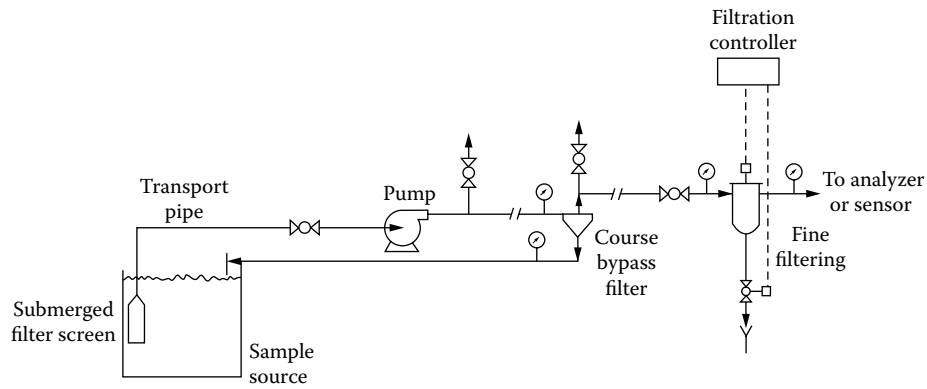


FIG. 8.39a

Schematic of a typical sample transport system.

included in the Clean Water Act and its amendments, including the effluent limitations and pretreatment standards for centralized waste treatment (CWT) facilities.

The majority of industrial wastewater treatment processes are continuous rather than batch-type operations. In the discussion that follows, the control of the following types of water treatment processes will be described: (1) chemical oxidation, (2) chemical reduction, (3) neutralization, (4) precipitation/flocculation/filtration, and (5) biological control by chlorination.

CHEMICAL OXIDATION

Wastewater is treated by chemical oxidation when the contaminant can be destroyed, its chemical properties altered, or its physical form changed. Examples of chemicals that can be destroyed are cyanides and phenol. Sulfides can be oxidized to sulfates, thus changing their characteristics completely. Iron and manganese can be oxidized from the soluble ferrous or manganous state to the insoluble ferric or manganic state, respectively, permitting their removal by sedimentation.

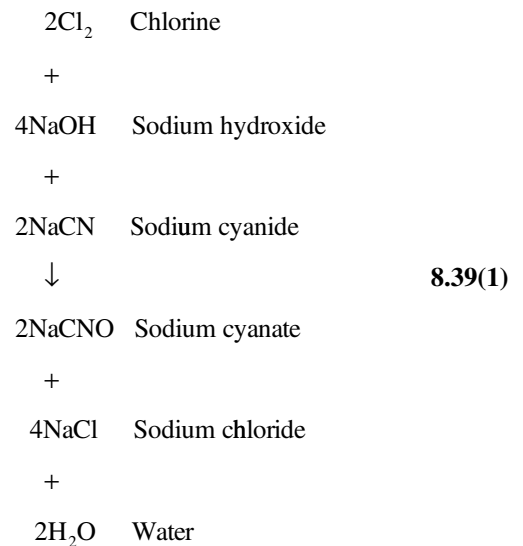
Strong oxidants, such as chlorine, chlorine dioxide, ozone, and potassium permanganate, are used. Chlorine is preferred when it can be used because it is the least expensive and is readily available. Ozone is a strong second choice and is now favored because its excess converts to oxygen, while the excess chlorine could react with industrial waste to produce cancer-causing substances.

The time required for these reactions to proceed to completion is usually pH-dependent. Most often, either residual oxidant or ORP measurement is used to control these processes.

Cyanide Destruction Process

Oxidation-reduction implies a reversible reaction. For a detailed discussion of ORP-based controls, refer to [Section 8.31](#).

Because these reactions are carried to completion and are not reversible, the term is misleading. In practice, control is by what may be called “electrode potential readings.” An illustration is the oxidation of cyanide into cyanate with chlorine, according to the following reaction:



The electrode potential of the cyanide waste solution will be on the order of -200 to -400 mV. After sufficient chlorine has been applied to complete the reaction described in Equation 8.39(1), the electrode potential will be on the order of $+300$ to $+450$ mV. The potential value will not increase until *all* cyanide has been oxidized. Control of pH is essential, with the minimum being about 8.5. The reaction rate increases as the pH rises.

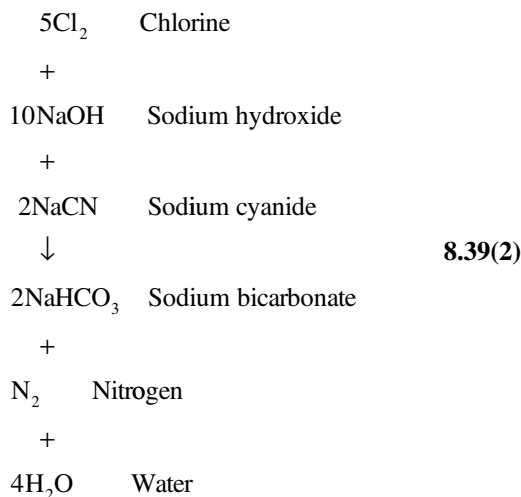
Complete oxidation (the complete destruction of cyanide) is a two-step reaction. The first step is oxidation to the cyanate level described in Equation 8.39(1). The endpoint of

TABLE 8.39b

Set Points and Operating Parameters of the Two-Stage Cyanide Destruction Process

Parameters and Set Points	Process Stages	
	First Stage: Cyanide to Cyanate	Second Stage: Destruction of Cyanate
pH set point	10–12	8.5–9.5
Reaction time (minutes)	5	45
ORP (mv) set point	+300 to +450	+600 to +750
Maximum concentration of cyanide (cyanate) that can be treated	1000 mg/l	1000 mg/l

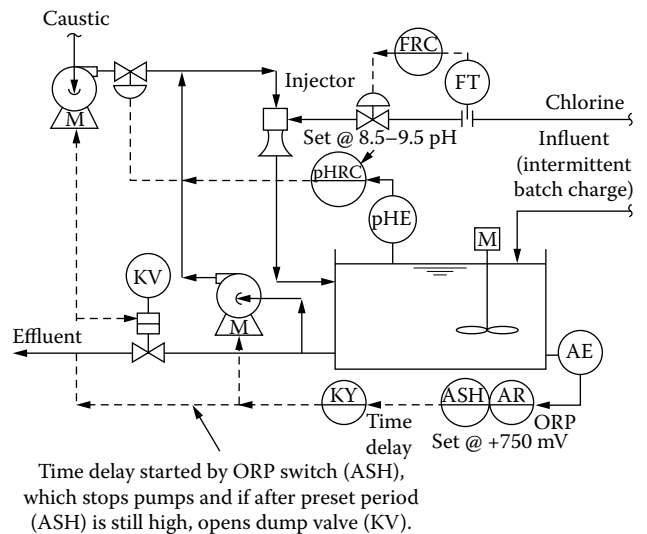
the second-stage reaction is at an electrode potential of about +600 to +750 mV. The overall reaction is



Cyanide destruction is the only chemical oxidation reactions that takes place in two steps, as described in Table 8.39b.

Batch Cyanide Control Because of the complexity of a two-stage process, the toxicity of cyanide, and the rigid requirements on waste discharge, a batch-type treatment is often recommended. Such a batch type control system has already been described in Figure 8.31i, and a slightly different one is shown in Figure 8.39c.

In Figure 8.29a, chlorine is charged at a constant flow rate (FRC), while caustic is being added under pH control to maintain the batch pH at about 8.5–9.5. When the ORP set point of +750 mV is reached, the high ORP switch (ASH) actuates a delay timer (KY) and the chemical feed systems are shut down.

**FIG. 8.39c**

Batch oxidation of cyanide waste with chlorine.

If, after a 30-min delay, the ORP of the tank contents is still at or above the +750 mV set point, the batch is discharged (by opening KV). If further reaction has been taking place during the delay period and the ORP potential value has dropped below the set point, the system is reactivated and the cycle is repeated. When this batch approach is used, additional, usually duplicate, storage tanks are required to receive the incoming waste while the batch tank is used for treatment.

Continuous Cyanide Control As was shown in Figure 8.31g, the continuous flow-through cyanide destruction control systems have the advantage of requiring less space, but this advantage is often offset by the capital cost of the additional equipment that is required.

In the control system configuration shown in Figure 8.39d, the two steps in the cyanide destruction process are separated. In the first step, the ORP controller set point is approximately +300 mV, and this ARC controls the addition of chlorine to oxidize the cyanide into cyanate. The pH in the first-stage tank is controlled by the pHRC at approximately 10 by throttling the caustic flow into the recycled effluent into the injector.

The reaction time of this first-stage process is on the order of 5 minutes. The set point for the chlorine flow controller (FRC) that charges the chlorine into the second-stage tank is ratioed (FY) to the chlorine flow into the first stage. The caustic requirement of the second stage is dependent solely on the chlorine flow rate (pH control is not necessary), and therefore the same chlorine flow signal can be ratioed (FY) to generate the set point for the caustic feed flow controller (FRC).

The ORP detector (AE) is provided to signal process failure and to actuate alarms or initiate emergency actions, if the potential level drops below approximately +750 mV.

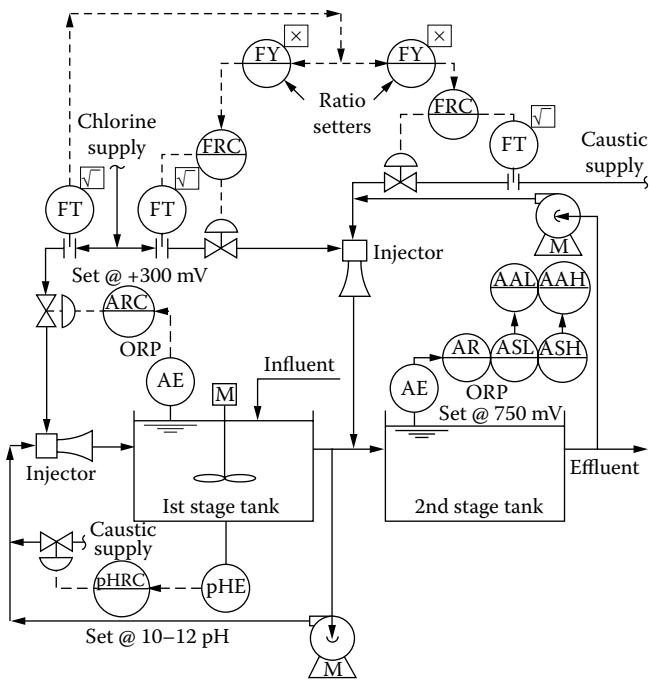


FIG. 8.39d
Continuous oxidation of cyanide waste with chlorine. Influent here has continuous constant flow rate and variable quality.

One might note that in the control system described in Figure 8.31g, an ORP controller (ORPIC) was used to charge the chlorine into the second stage. It is debatable if that is necessary, because the ratioing accuracy available between the first-stage chlorine flow rate and secondary addition (which is approximately 1:1) is, in most cases, sufficiently high. The probability is that the system shown in Figure 8.39d might apply a little more chlorine than is actually required.

In the cyanide destruction process, fixed flow rates are preferred, because they will provide constant reaction times. Residual chlorine analyzers are seldom used in this process, because the metal ions usually present in the waste interfere with their accurate operation. They are used in processes in which the presence of excess residual chlorine indicates a completed reaction. In such processes the set point is usually 1 mg/l or less.

Chlorinator, Sulfonator, and other Controls Figure 8.39e describes the main components of the feeders that can be used in chemical oxidation operations to charge chlorine, sulfur dioxide, or carbon dioxide.

The chlorinator shown in the figure has two operators, two control valves that can be throttled. One is operated in a feedforward mode (PVC) and responds to changes in the influent flow rate. The other control valve (FV) is throttled in a feedback configuration by the effluent quality controller (ARC), which can be detecting ORP, pH, residual chlorine, or other related indicators.

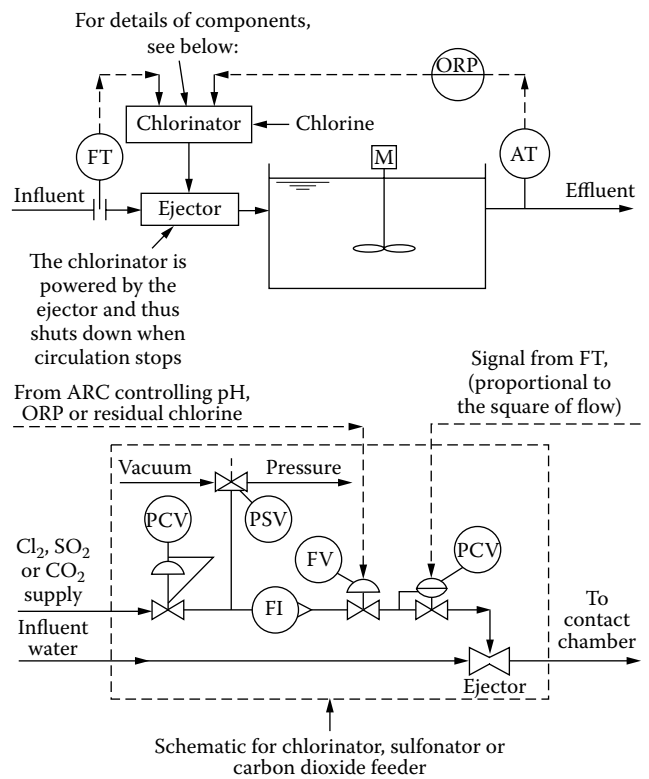
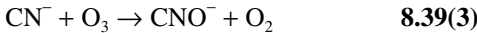


FIG. 8.39e
The lower part of this figure shows the main components of a gas feeder, such as a chlorinator. The top part of the figure shows how a chlorinator is integrated into a chemical oxidation control system.

Most reactions are completed within 5 min, and except for cyanide treatment, most all other chemical oxidation operations are carried out simultaneously with other unit operations, such as coagulation and precipitation, which govern the pH value. Thus, whereas the pH value affects the rate of reaction, it is seldom controlled solely to serve the oxidation process.

Cyanide Destruction by Ozonation The oxidation of cyanide to cyanate by ozonation is extremely fast and is carried out at a pH of 9 to 10.



The further reaction to cyanates is much slower and can be accelerated by the addition of copper (2+) salt catalysts. Figure 8.39f illustrates how cyanide oxidation by ozone can be controlled, using either a stirred reactor or a packed or sieve plate tower.

Chlorination is a better developed and more frequently utilized process than ozonation. On the other hand, ozone is faster and more powerful as an oxidizing agent and requires smaller holding and reaction tanks. Chlorine gas is also

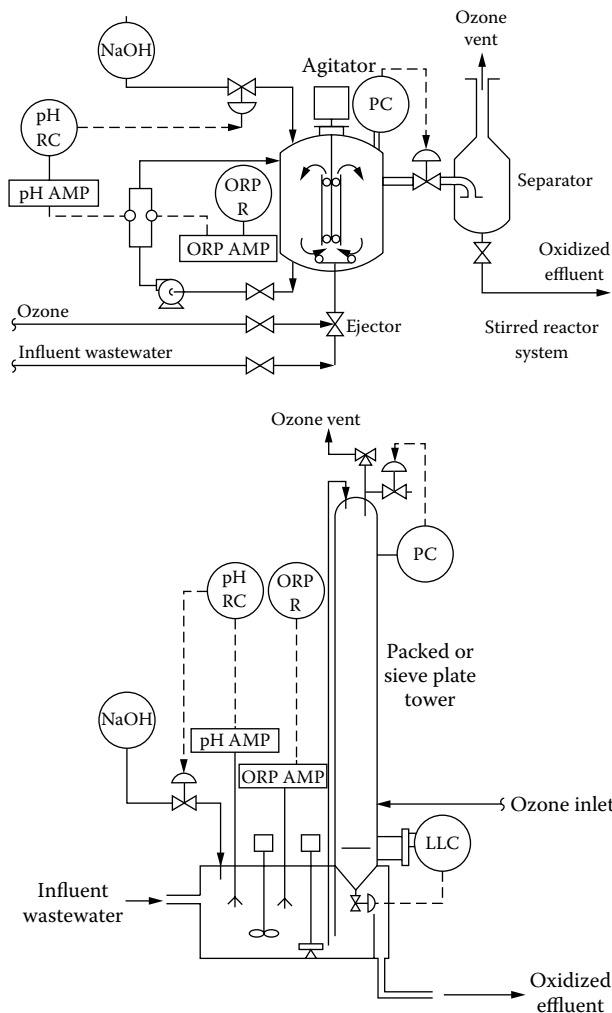


FIG. 8.39f

Control systems for the oxidation of cyanide by ozone, utilizing a stirred reactor (top) or a packed or sieve plate tower (bottom).

hazardous. In order to remove 1 lb of cyanide, one usually requires 2.7 to 6.8 lb of chlorine gas or 1.8 to 4.6 lb of ozone.

CHEMICAL REDUCTION

Wastewater treatment by chemical reduction is quite similar to chemical oxidation. Commonly used reductants are sulfur dioxide and its sodium salts, such as sulfite, bisulfite, and metabisulfite. Ferrous iron salts are infrequently used. Typical examples are reduction of hexavalent chromium, dechlorination, and deoxygenation. Table 8.39g lists some of the reduction and precipitation reactions that take place in the process of chrome treatment.

Reduction of Hexavalent Chromium

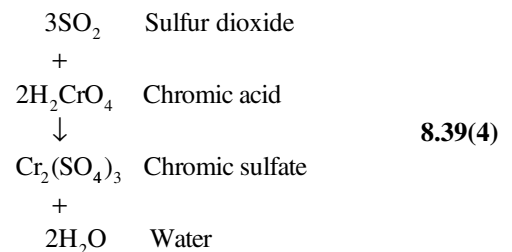
The ORP-based controls of the reduction of highly toxic hexavalent chromium into the innocuous trivalent form has

TABLE 8.39g

Chrome Reduction and Precipitation Reactions

Reducing Agent	Reaction
Ferrous sulfate (FeSO ₄)	$2\text{H}_2\text{CrO}_4 + 6\text{FeSO}_4 + 6\text{H}_2\text{SO}_4 \rightarrow$ $\text{Cr}_2(\text{SO}_4)_3 + 3\text{Fe}_2(\text{SO}_4)_3 + 8\text{H}_2\text{O}$ $\text{Cr}_2(\text{SO}_4)_3 + 3\text{Ca}(\text{OH})_2 \rightarrow$ $2\text{Cr}(\text{OH})_3 + 3\text{CaSO}_4$
Sodium metabisulfite (Na ₂ S ₂ O ₅)	$\text{Na}_2\text{S}_2\text{O}_5 + \text{H}_2\text{O} \rightarrow 2\text{NaHSO}_3$ $2\text{H}_2\text{CrO}_4 + 3\text{NaHSO}_3 + 3\text{H}_2\text{SO}_4 \rightarrow$ $\text{Cr}_2(\text{SO}_4)_3 + 3\text{NaHSO}_4 + 5\text{H}_2\text{O}$ $\text{Cr}_2(\text{SO}_4)_3 + 3\text{Ca}(\text{OH})_2 \rightarrow$ $2\text{Cr}(\text{OH})_3 + 3\text{CaSO}_4$
Sulfur dioxide (SO ₂)	$\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3$ $2\text{H}_2\text{CrO}_4 + 3\text{H}_2\text{SO}_3 \rightarrow$ $\text{Cr}_2(\text{SO}_4)_3 + 5\text{H}_2\text{O}$ $\text{Cr}_2(\text{SO}_4)_3 + 3\text{Ca}(\text{OH})_2 \rightarrow$ $2\text{Cr}(\text{OH})_3 + 3\text{CaSO}_4$

already been discussed in some detail in Section 8.31. If the reducing agent is sulfur dioxide, the following reaction takes place:



Most hexavalent chrome wastes are acidic, but because the rate of reaction is much faster at very low pH values, pH control is essential. Sulfuric acid is preferred because it is cheaper than other mineral acids. The set point of the pH controller is approximately 2.

Similarly to the treatment of cyanide, the chrome reduction reaction is not reversible, either. As shown in Figure 8.39h, the control of sulfur dioxide addition is by electrode potential level, using ORP instrumentation. The potential level of hexavalent chromium is +700 to +1000 mV, whereas that of the reduced trivalent chrome is +200 to +400 mV. The set point on the ORP controller is approximately +300 mV.

The illustrated batch treatment of chrome is controlled at a pH of 2 by feedback control of the acid addition (pHRC), while the sulfur dioxide addition is under ORP control (ARC), which feedback loop is set at 300 mV. The reaction time is about 10 min at a pH of 2, and it drops to 5 min if the pH is reduced to 1.5. The control system used in continuous chrome treatment is shown in Figure 8.31d.

The trivalent chromic sulfate is removed from solution by subsequent raising of the pH to 8, at which point it will precipitate as chromic hydroxide (see Figure 8.31d). The control system for this step can be identical with the one used in Figure 8.39v.

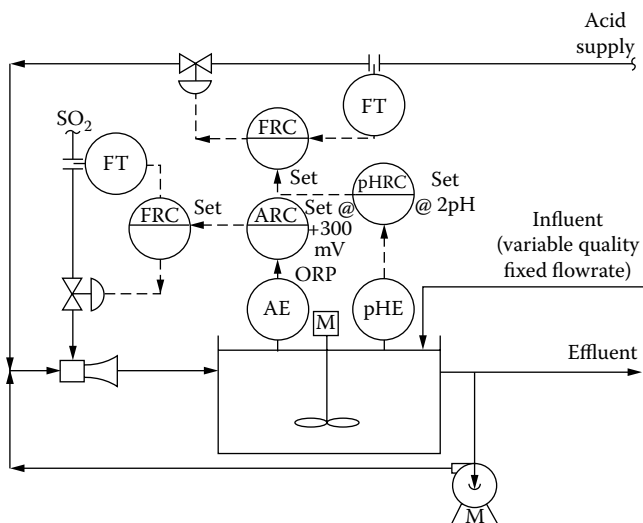


FIG. 8.39h
Batch reduction of chromium waste using sulfur oxide as the reducing agent.

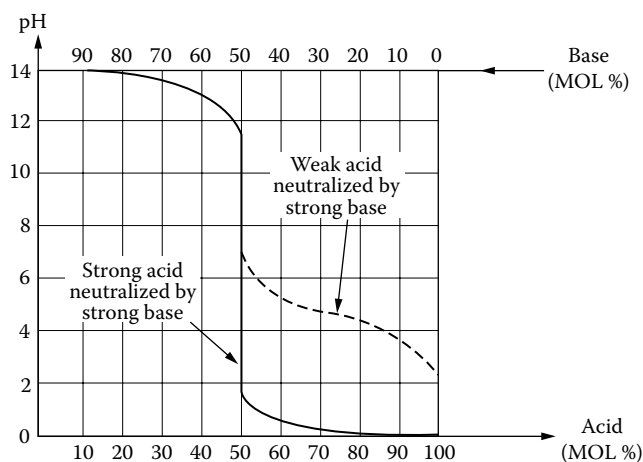


FIG. 8.39i
pH curve of strong acid neutralized by strong base (solid line) and of weak acid neutralized by strong base (dashed line).

Other Reduction Processes

In dechlorination or deoxygenation controls, the reducing agent is usually added in proportion to the oxidant concentration but by maintaining a slight excess. In most cases, a slight excess of reducing agent is not detrimental. The pH value is not critical and can be determined by corrosion control considerations.

Dechlorination to a fixed residual value is controlled, as illustrated in Figure 8.39e, except that sulfur dioxide is used instead of chlorine.

NEUTRALIZATION CONTROLS

For a detailed discussion of pH control, please refer to Section 8.32. It should be emphasized that pH is a measure of hydrogen ion activity and not acid concentration. A weak sulfuric acid solution will have a low pH value because of the high degree of hydrogen ion activity (disassociation), whereas some strong organic acids may show a pH value as high as 3 or 4.

Strong alkalis react quickly and efficiently to neutralize strong acids. The simplicity of this fact is misleading in its consequences. Acid neutralization is a common requirement in wastewater treatment, but few operations can be as complex. The information needed for the proper design of neutralization systems includes (1) flow rate and range of flow variations; (2) titratable acid content and variations in acid concentration; (3) rate of reaction; and (4) discharge requirements for suspended solids, dissolved solids, and pH range.

Figure 8.39i shows the pH values corresponding to the mixtures of a strong acid and a strong base. The slope of this pH curve near neutrality (pH = 7) is so great that there is no

likelihood of controlling such a system. Fortunately, plant effluents usually contain weak acids or bases that are neutralized by strong reagents. (The dotted pH curve shows that these are much easier processes to control.)

The slope of the pH curve is affected by the ionization constants of the acid and base involved and by buffering. Buffering compounds are those that contain no hydrogen or hydroxyl ions but are capable of suppressing the release of these ions from other solutes and, thereby, affect the solution acidity or alkalinity.

Neutralization control of wastewater is difficult because their acid or base contents can vary by several decades and because as the type or amount of buffering of acid (or base) varies, it changes the applicable pH curve. In some plants, the flow rate of the wastewater is also highly variable and the effluent itself can change from acidic to basic, in which case two reagents are required.

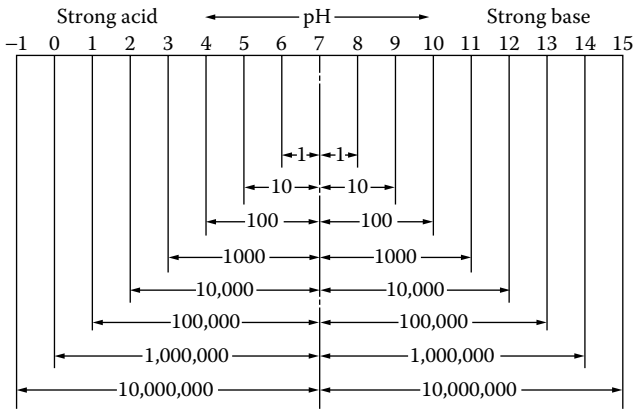
Equalization Tanks

An equalizing basin should be installed ahead of the neutralizing system whenever possible. This will tend to level out fluctuations in the wastewater flow and concentration. This point cannot be overemphasized, because the lack of such a basin has been the cause of many failures. Pumping from an equalizing basin at a constant rate eliminates the need for high rangeability flow rate instrumentation. This, in combination with reduced variations in base or acid content, reduces the reagent feed range requirements.

The obvious disadvantage is in the capital cost for large basins. Most systems are designed with as large an equalization tank as possible according to the available space. Any equalization that can be installed will pay some dividends.

In sizing the reagent equipment, the maximum capacity of the alkali feed system should be determined on the basis of the maximum acidic wastewater concentration and

	Hydrogen ion activity pH gr mols/liter	Hydroxyl ion activity gr mols/liter
	0	1
	1	0.1
	2	0.01
Acidic	3	0.001
	4	0.0001
	5	0.00001
	6	0.000001
Neutral	7	0.0000001
	8	0.00000001
	9	0.000000001
	10	0.0000000001
Basic	11	0.00000000001
	12	0.000000000001
	13	0.0000000000001
	14	0.00000000000001



Graph of reagent demand. Reagent addition units are 10^{-6} mols/liter.

FIG. 8.39j
The logarithmic nature of pH.

maximum flow rate. The minimum flow and minimum acid concentration determines the minimum capacity requirement of the reagent feed system.

Valve Rangeability Required As shown in Figure 8.39j, the reagent demand to neutralize a unit of wastewater increases tenfold every time its pH changes by a single unit. In other words, neutralizing a unit of wastewater at a pH of 3 will take 1000 times more reagent than would an effluent at a pH of 6.

As a consequence, a reagent addition rangeability of several hundred to one or more may be required. This is accomplished by the use of two or more control valves in parallel, as has already been discussed in detail in connection with Figure 8.32h.

As shown in Figure 8.39k, the smaller valve has equal percentage characteristics and is throttled by a proportional only controller (pHC). This is desirable to match the pH characteristics near neutrality with that of the valve. If the pH measurement moves outside a preset and narrow “dead zone,” this causes the second controller (pHRC) to make an adjustment in the opening of the large linear valve, thereby compensating for load changes. This second controller is

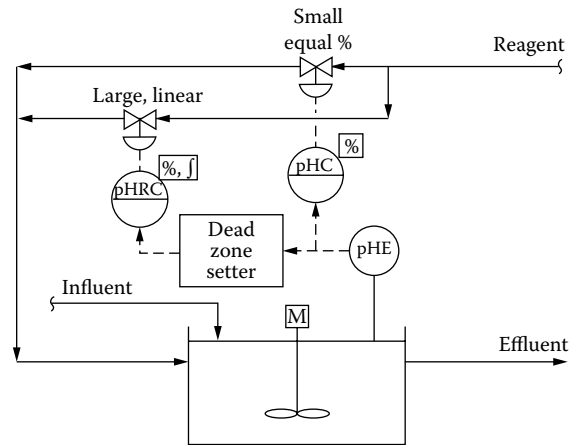


FIG. 8.39k
For accurate neutralization, the required high rangeability is provided by parallel control valves.

provided with two control modes, with the integral action serving to bring the system back to set point after a load change.

A valve position control-based method of using multiple valves in a feedback-trimmed feedforward neutralization system was shown in Figure 8.32j in Section 8.32.

Sequenced Valves A wider reagent delivery capability can be obtained by using the sequenced valve approach where the controller output can be switched to either valve by a pressure switch (PS) or its electronic equivalent. With sequenced controls, only one valve at a time is operating, while the other is closed. In this way, the overall characteristics of a pair of equal-percentage valves are still equal percentage, which is represented by a straight line on a semilog plot.

Figure 8.39l illustrates various combinations of different pairs of sequenced valves. On such sequenced valves, positioners must be used because each valve must be calibrated to stroke over only a portion of the controller output signal range.

Table 8.39m lists the various flow rangeabilities for some of the valve pairs in Figure 8.39l, assuming a constant pressure drop across the valves (equivalent to 9.5 ft, or 2.85 m, of 66° Be sulfuric acid) and assuming an individual valve rangeability of 35:1. For the four valves, the valve capacity coefficients (c_v, s) are 1.13, 0.14, 0.08, and 0.04, respectively, for CV-1, 2, 3, and 4.

The overlap between each valve pair becomes smaller as the rangeability increases. The pressure switch to transfer the valves can be set anywhere in the overlap region, because in this region the process loads can be satisfied by either valve.

Reaction Rates and Tank Sizing It is essential that reaction rates be determined so that suitable reaction tank sizes (residence time) can be calculated. Once the reaction rates are

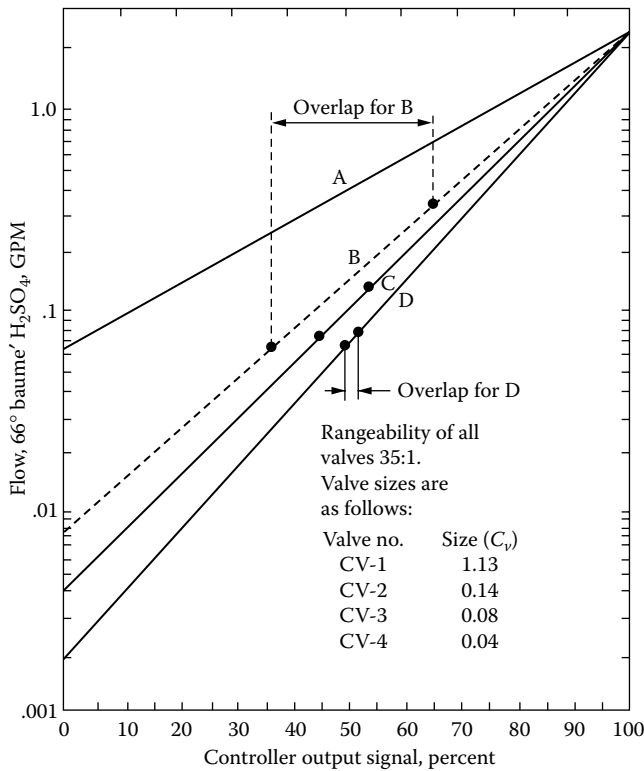


FIG. 8.39l
Delivery capability for various valve pairs.
Key: A = CV-1 alone; B = CV-1 + CV-2; C = CV-1 + CV-3; D = CV-1 + CV-4.

known, one can determine the residence time required to make sure that the reaction has time to go to completion. One obtains these rates by first determining the total amount of alkali (in case of an acid waste) that is required to neutralize a sample of the wastewater and then adding this amount to a second sample in a single dose.

Plotting the pH of that sample show the pH rise as a function of time (Figure 8.39n). The reaction vessel volume should provide at least 50% more holding time than the time it took for the sample to reach neutrality.

TABLE 8.39m
Reagent Delivery Turndown (Rangeability) for Sequenced Pairs of Equal-Percentage Valves

Valve Pair	Line on Figure 8.22hh		Log Turndown*	Valve Positioner Calibration(s) (%)
	Turndown	Turndown		
CV-1 (alone)	A	35:1	1.54	0-100
CV-1 + CV-2	B	275:1	2.44	0-63; 37-110
CV-1 + CV-3	C	570:1	2.76	0-58; 44-100
CV-1 + CV-4	D	1150:1	3.06	0-51; 50-100

* Signifies the approximate pH swing that valves will accommodate.

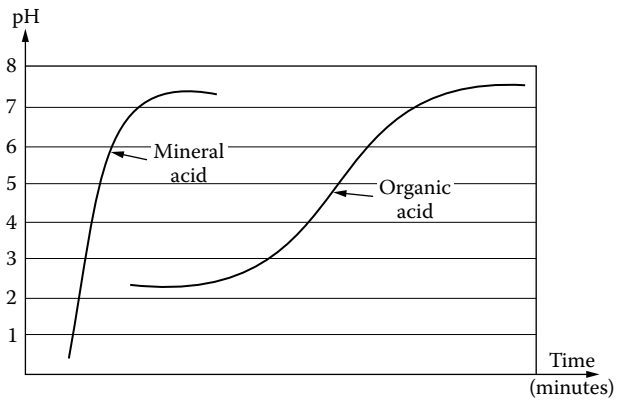


FIG. 8.39n
Acid neutralization reaction rates.

The ideal aim is obtain sufficient equalization to provide a homogeneous wastewater pH at a constant flow rate. To neutralize such a system, a lime feeder operating at a preset constant rate would suffice. Unfortunately, this seldom occurs, and provision must be made for reagent throttling.

Single Reagent Control

Figure 8.39o illustrates a system that can handle changes in both the flow and the acid concentration in the wastewater. In this equipment configuration, the equalization tank is followed by three treatment tanks, and to each of these tanks, the lime slurry feeding controls have identical capacities.

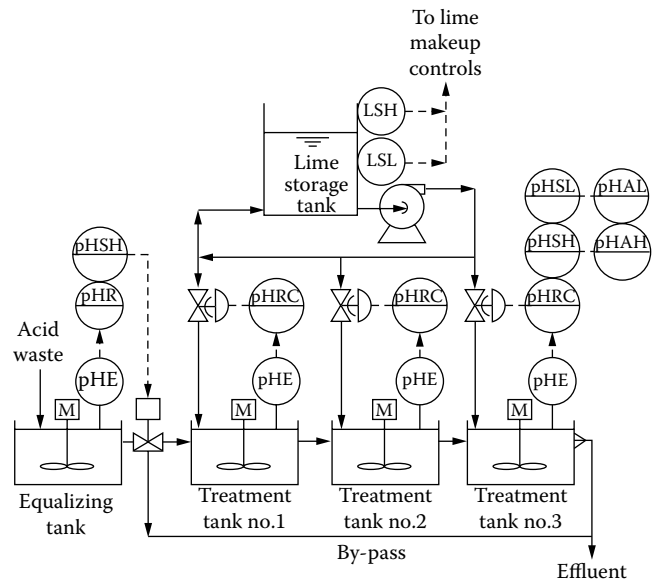


FIG. 8.39o
Simple acidic wastewater neutralization system with a 30:1 rangeability.

Assuming a 10:1 range for each lime slurry control valve, the range of the system is 30:1. Thus, it can handle any combination of flow and acid concentration within that range.

The three pH controllers are set at the same set point of usually between pH 6 and 8. At periods of low flow, or when the acid content is low, treatment tank number 1 can handle the entire neutralization load. Under other conditions, all three tanks may be required, with the first one or two satisfying a major portion of the reagent requirement and the third serving a "polishing," or final trim, function.

Each tank in this system should be sized for a minimum of 50% of the total retention time determined at maximum flow rate. Where mixtures of acids are involved, the maximum time (not average) must be used. Figure 8.39o also has a provision for the occasional case when the incoming wastewater is self-neutralizing and the treatment system can be bypassed.

High maintenance costs of pH electrodes have been reported when lime is used as the reagent, because of the formation of calcium sulfate coatings on the electrodes. For the designs of retractable and self-cleaning pH detectors, refer to Section 8.48 in Chapter 8 of the first volume of this handbook.

Two Reagent Control Systems

In some plants, the wastewater can be either acidic or basic. Figure 8.39p illustrates the two-sided feedback control system required to neutralize such wastewaters. Although only one valve for each side is shown, it would be possible to have

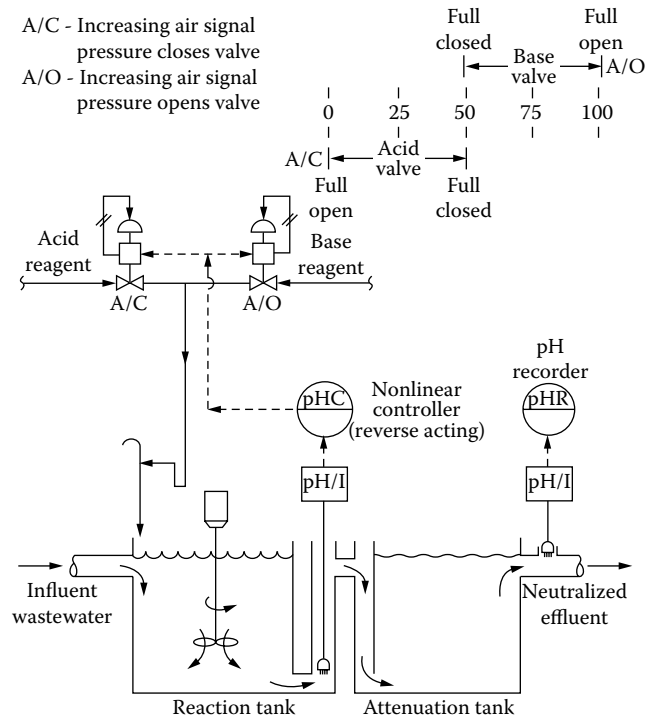


FIG. 8.39p
Two-sided feedback control of pH.

a sequenced pair for one side of neutrality and a single valve for the other, or a sequenced pair for both sides.

Because this is a feedback control system, load changes cannot be frequent or severe in order for this system to give acceptable performance. For those applications in which load changes are frequent and severe, a combination feedforward-feedback should be considered, such as the system shown in Figure 8.32j in Section 8.32.

If sequencing is used, the reagent delivery system will have a high gain characteristic, because the stroking of the pair (moving from closed to open) is accomplished with only half the controller output signal, thereby doubling their gain (making them twice as sensitive). The valve gain will vary with the turndown, and a characterizer will be required for each set of sequenced valves to provide constant loop gain.

Ratio Control

Ratio control of pH can be effective when the process flow rate is the major load variable, and the objective is to meet increased flow with a corresponding increase in reagent. Because the errors in flow measurements and because reagent concentration may vary, a means for on-line ratio adjustment must be provided.

Figure 8.39q illustrates a ratio control system in which the reagent set point is changed proportionally to changes in wastewater flow. A feedback signal supplied by the feedback controller (pHC) also adjusts the reagent flow set point proportionally to a nonlinear function of the deviation between desired and actual effluent pH.

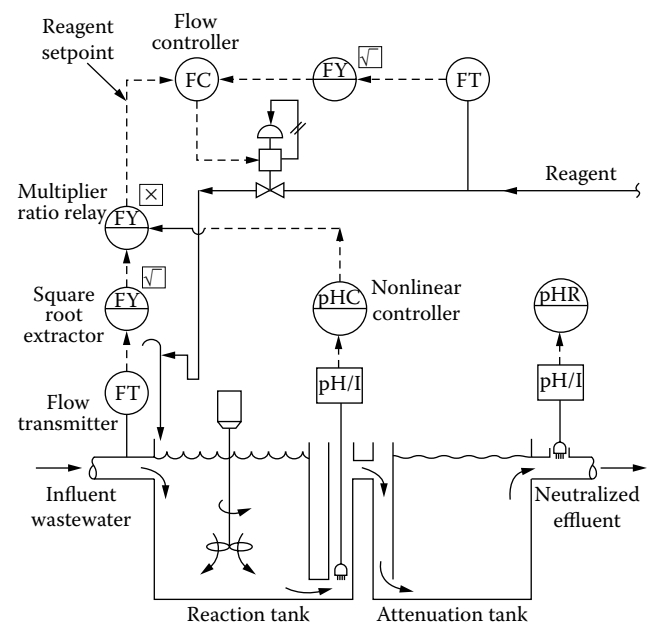


FIG. 8.39q
In this control system, the reagent flow is ratioed in a feedforward manner to the influent wastewater flow, whose ratio is feedback-trimmed by the pH controller.

Note that the rangeability of the ratio system is limited by that of the flowmeters, typically 4:1 for orifice meters to 30:1 for some turbine meters.

Cascade Control

Cascade control as applied to pH control systems can take two forms. In addition to the usual condition in which the output of one controller serves as the set point to another controller, it is also possible to have two vessels arranged in series, each with its own control system. The latter arrangement is referred to as *cascaded residences*.

The conventional cascade control system is shown in Figure 8.39r, wherein the output of controller pHC-1 is the set point of the slave, or secondary controller, pHC-2. This arrangement is particularly useful when lime is the reagent, because of the finite reaction time between the acid and reagent. The set point of pHC-2 may have to be lower than the desired pH of the final effluent, because the materials are still reacting with each other after they have left the first tank. If the set point pHC-2 is too high, the pH of the final stream will be greater than desired. When flocculation is to be carried out downstream of the pH treatment facility, stable pH values can be extremely important.

A delicate balance must be struck in this type of system with respect to the size of the first vessel. A long residence time in the first tank ensures long contact time between reagents, thereby producing an effluent pH that is close to the desired value, but at the same time it may result in a sluggish control loop around this vessel. For efficient cascade control, response of the inner loop (control loop around the first tank) must be fast.

The other control loop (pHC-2), sometimes referred to as the master, or primary, control loop, is usually tuned so as to be less responsive than the inner loop. The tuning of pHC-1 will be a result of the dead time (a delay between a change in reagent flow and the time when its effect is first felt), capacity, and process characteristics.

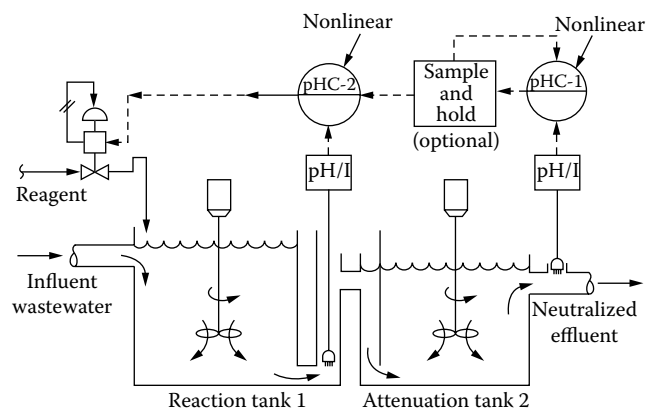


FIG. 8.39r
Cascade control of pH.

When this part of the process is dominated by dead time, the technique of sample data control may be useful in stabilizing the control system by a sample and hold device. This device may be a timer that automatically switches the controller between automatic and manual modes of operation (see Figure 2.2q in Chapter 2). This can allow the controller to be in automatic for a fraction (x) of the cycle time (t) and then can switch it to a fixed-output, manual condition for the rest of the cycle $(1 - x)t$.

Feedforward Control

In those systems in which equalizing basins or other averaging techniques cannot be applied and accurate pH control is required, control by feedback alone is insufficient, and feedforward schemes can be considered. It should be kept in mind, that feedforward based on influent pH is only recommended *if only a single specie in the wastewater must be neutralized*, because if there are several species, the relationship between influent pH and reagent demand cannot be predicted.

A feedforward control system is dedicated to initiating corrective action as soon as changes occur in process load. The corrective action is implemented using a control system that is essentially a mathematical model of the process. For example, the amount of base required to neutralize an acid can be predicted using the following formula:

$$\log(B) = \log(K) + \log(F) + (7 - \text{pHi}) \quad 8.39(5)$$

where

B is the base in normal equivalents

F is flow rate

K is a constant specific to the chemical reaction

pHi is the pH value of the influent

Ordinarily, the inclusion in the model of each and every load to which the process is subjected is neither possible nor economically justifiable. This means that a feedback control loop (usually containing the nonlinear controller for pH applications) is required in conjunction with the feedforward system. The function of the feedback controller is to trim and correct for minor inaccuracies in the feedforward model.

Feedback–Feedforward Combination Control Figure 8.39s describes a feedback-trimmed feedforward neutralization control system, using three control valves for high rangeability. In this system, the control signal to the reagent valves (X_b) is the sum of the characterized flow signal $f(F')$ of the influent wastewater and the output of the feedforward pH controller (pHC-1). Therefore, the total output signal to the sequenced pair of valves (X_b) becomes the sum given in Equation 8.39(6), minus twice the feedback controller's (pHC-2) output:

$$X_b = f(F') + \text{feedforward output} - 2(\text{feedback output}) \quad 8.39(6)$$

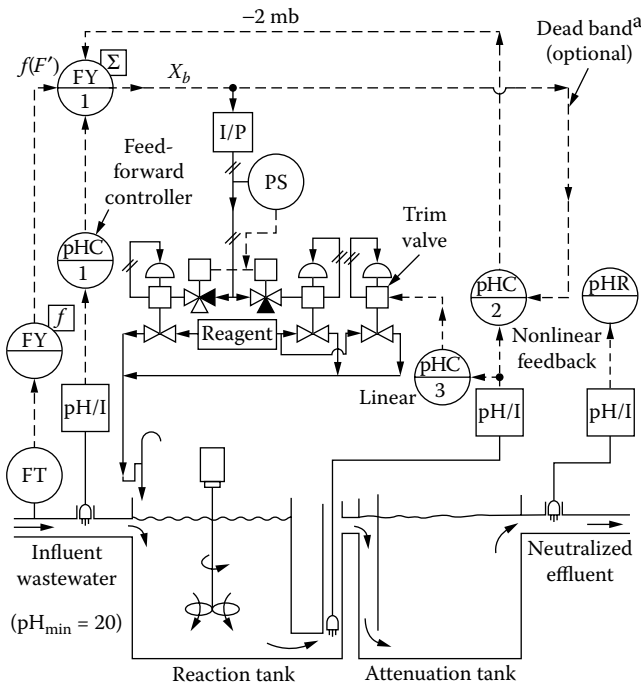


FIG. 8.39s High rangeability feedback-trimmed feedforward pH control system utilizing three control valves, which are so configured that only one is throttling at any one time.

If the total rangeability of the pair of sequenced valves is 1500:1 and if the minimum expected influent pH is 2.0, then the maximum controllable influent pH value is $pH(\max) = 2.0 + \log(1500) = 5.2$ pH. Therefore, in this control configuration, when the influent pH rises to over 5.2, both sequenced valves will be completely closed and the linear feedback controller (pHC-3) will throttle the trimming valve. Figure 8.39t describes the operating ranges of the three valves and their total rangeability in terms of reagent flow.

The nature of a neutralization system is such that the process gain (slope of the pH curve) is likely to be the highest at set point (around $pH = 7$) and it decreases as the deviation from set point increases. To compensate for this inverse relationship between process gain and deviation, the feedback controller that is trimming the feedforward model (pHC-2) should be a nonlinear one, with its gain varying (increasing) with deviation.

With this controller, the greater the deviation from set point, the larger the controller's correction, but this does not create an unstable condition, because at high deviations the process gain is low. In the control system shown in Figure 8.39s, the feedback control signal (mb), which is trimming the feedforward signals in summer FY-1, is generated by the nonlinear pHC-3 controller. This controller can be provided with a dead band around its set point, so that it does not change its output until its measurement moves outside that gap.

Figure 8.39u illustrates a similar feedforward-feedback neutralization control system, where the expected rangeability

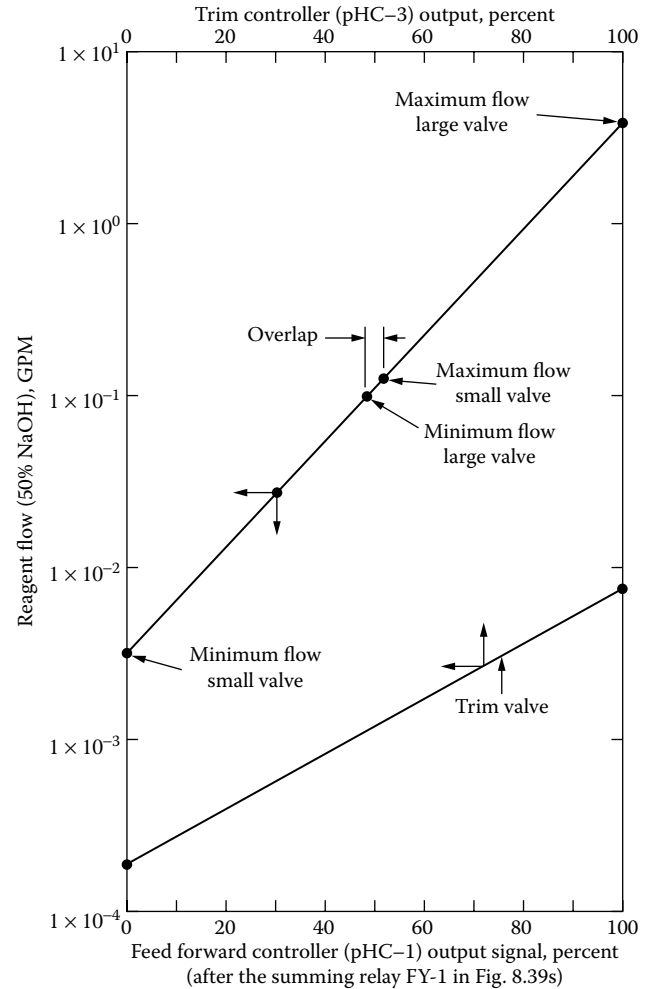


FIG. 8.39t When the influent pH is below 5.2, the sequenced large and small valves throttle the reagent (top line). When the influent pH rises above 5.2, only the trim valve is modulated (bottom line)

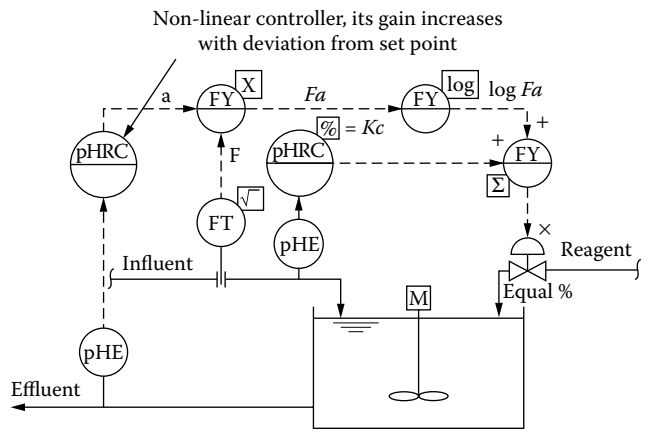


FIG. 8.39u Low rangeability feedback-trimmed feedforward neutralization control system.

requirement of the reagent is low enough to be met with a single control valve. Here, the reagent valve opening (x) is calculated as follows:

$$X = Kc(\text{setpoint-measurement}) + \log(F.a) \quad 8.39(7)$$

where

- X is the valve position signal to an equal-percentage reagent valve
- Kc is the gain of the proportional-only feedforward controller
- F is the influent flow
- a is the output signal of the nonlinear feedback controller

In this control system, the opening of the equal-percentage reagent valve is obtained by the summing of the feedforward pH controller's output signal with the logarithm of the product of the influent flow (F) and the output of the nonlinear feedback controller (a).

PRECIPITATION AND FILTERING

Precipitation is the creation of insoluble materials by chemical reactions that can then be removed through subsequent liquid-solids separation. Typical of these operations is the removal of sulfates, removal of trivalent chromium, and softening of water with lime. Iron and manganese are removed by a variation of this process, following the treatment discussed earlier in connection with the chemical oxidation process.

Lime Softening

The process of water softening and its controls are discussed in detail in Section 8.40. Figure 8.39v shows a precipitation control system that can be used for the precipitation of calcium carbonate in the process of water softening or for the precipitation of other insoluble crystals.

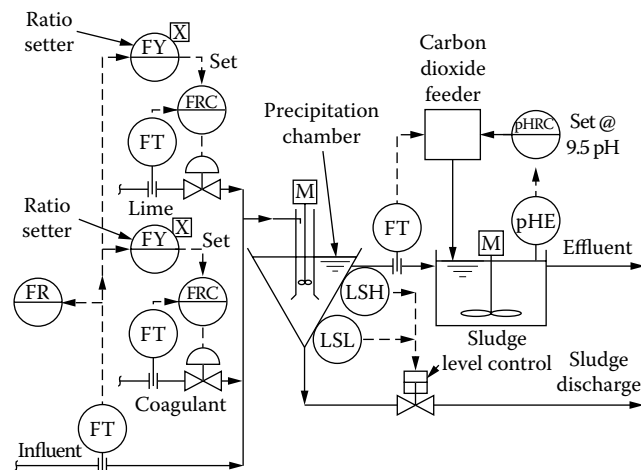


FIG. 8.39v Calcium carbonate precipitation control system. (For the details of the gas feeder refer to Figure 8.39e.)

In this process, *crystal seeding* involves the acceleration of crystal formation by the presence of previously precipitated crystals. This is accomplished in practice by passing the water being treated through a “sludge blanket” in an up-flow precipitation chamber, shown schematically in Figure 8.39v. The resulting crystals are hard, dense, and discrete; therefore, they separate readily.

When colloidal suspended material is also to be removed, which would be the case where surface waters are softened, a coagulant of aluminum, iron salts, or polymers is also added to precipitate the colloids. Dosage is variable, depending on the quantity of suspended material. Application of both coagulant and calcium hydroxide is controlled by flow-ratio modulation.

The resulting sludge, consisting of calcium carbonate, aluminum, or iron hydroxides, and the precipitated colloidal material are discharged to waste continuously. An automatic sludge-level control system is used in Figure 8.39v to keep the sludge level within an optimum range of operation.

Water softened by the excess lime treatment is saturated with calcium carbonate and, therefore, is unstable. Stability is achieved by addition of carbon dioxide to convert a portion of the carbonates into bicarbonate. This process is suited to automatic pH control as shown in Figure 8.39v. The carbon dioxide feeder has two operators; one is controlled in feedforward by the influent flow rate and the other in feedback by effluent pH control (pHRC). The set point is on the order of 9.5 pH.

Fouling of the electrodes is likely to occur as a result of precipitation of crystallized calcium carbonate. Daily maintenance may be expected, unless automated cleaners are used (Figure 8.39w). The farther downstream (from the point of carbon dioxide application) the electrodes can be placed, consistent with acceptable loop time delays, the less will be the maintenance requirement.

Hydroxide Precipitation

Precipitation is the process used to remove soluble metal ions from solutions as hydroxides. The process is pH controlled. By raising the pH with lime or sodium hydroxide, the corresponding metallic oxide precipitates out. Figure 8.39x shows the solubility curves of some heavy-metal hydroxides as a function of the pH of the solution.

As can be seen in Figure 8.39x, copper at a pH of 6 will start precipitating from the solution at a concentration of about 20 mg/l, while if the pH is raised to 8, its solubility drops to 0.05 mg/l.

Several metals such as chromium and zinc are amphoteric, being soluble at both alkaline and acidic conditions.

As can be seen in Figure 8.39x, chromium is least soluble in the range of pH 7.5 to 8.0. It is for this reason that in the second stage of chrome treatment in Figure 8.31d, the set point of the pHIC is 8 pH. For a detailed discussion of chrome treatment, refer to Section 8.31 or to the earlier paragraph in this section in connection with Figure 8.39h.

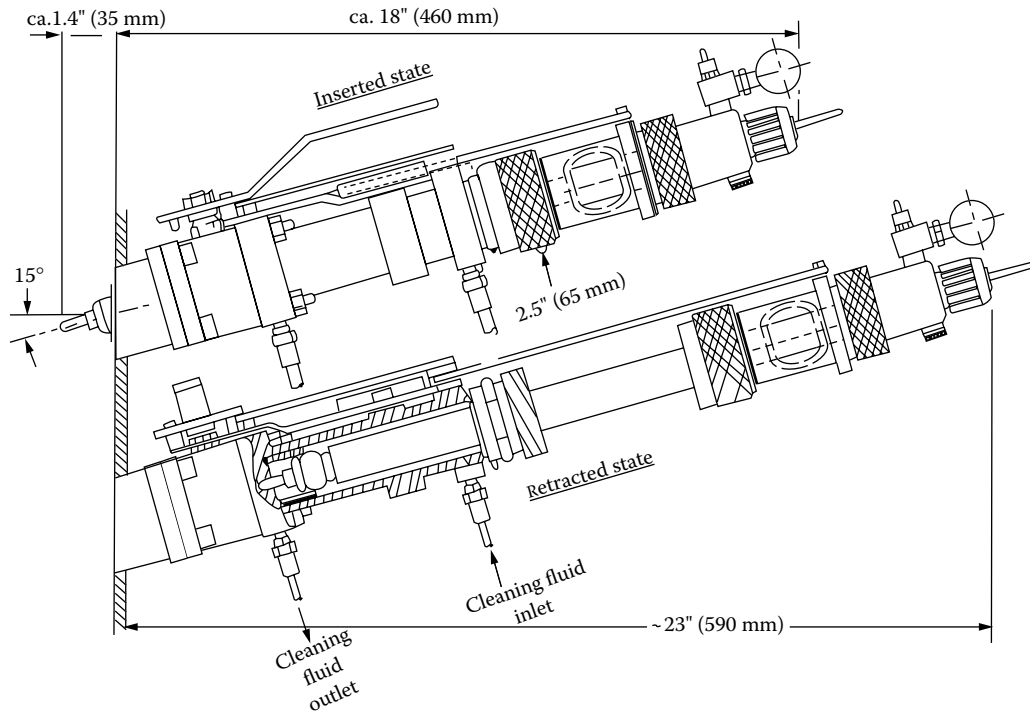


FIG. 8.39w
Self-cleaning, retractable pH probe installation.

Filtering

The solids suspended in the wastewater, including the particles generated by precipitation, can be removed by filtration. A large variety of filter designs are available, including diatomite, microstrainers, gravity, pressure, deep-bed, multilay-

ered, cartridge, moving bed, and membrane. (See Section 7.33 in Chapter 7 of the second edition of the *Environmental Engineers' Handbook* for more details.)

Figure 8.39y illustrates the design of a multilayered filter, having a flat under-drain deck with long-stem nozzles for washing with backwash and air.

Figure 8.39z describes a deep-bed, pressure type, granular filter that is in forward flow operation. *Forward flow* refers to the state of filtering, while *back flow* refers to the backwashing or wash cycle during which the collected solids are removed and the filter is prepared for another filtering cycle.

Polishing filtration packages are usually designed in duplex configurations. In such designs, under normal “pump down” operation, while one filter is active, the other is being backwashed. The system is operated in its “normal” mode, when the level in the feed buffer tank is within its allowable high and low limits. In this mode, while one filter is filtering the wastewater from the large buffer tank and, after filtering, discharges it to drain, the other filter is being backwashed. The backwash cycle can either be initiated on the basis of the total flow that has passed through the filter or on the basis of the pressure drop that has built up across the filter.

The operation is automatically reconfigured as a function of the level in the large buffering feed tank. If the level in the buffer tank reaches a high level, the normal “pump down” mode of operation is switched to a “dual pump down” mode. In this mode, both filters are operating in their filtering mode, and the discharges of both filters are being sent to drain.

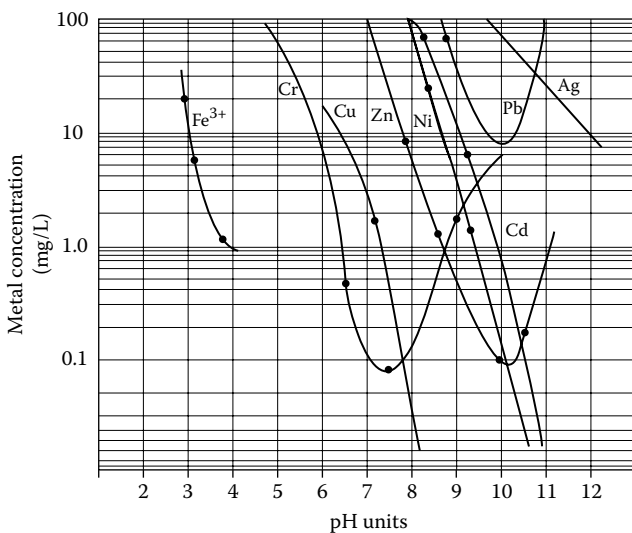


FIG. 8.39x
Solubility curves of a number of metal hydroxides at various concentrations as a function of the pH of the solution. (Courtesy of Hoffland Environmental Inc.)

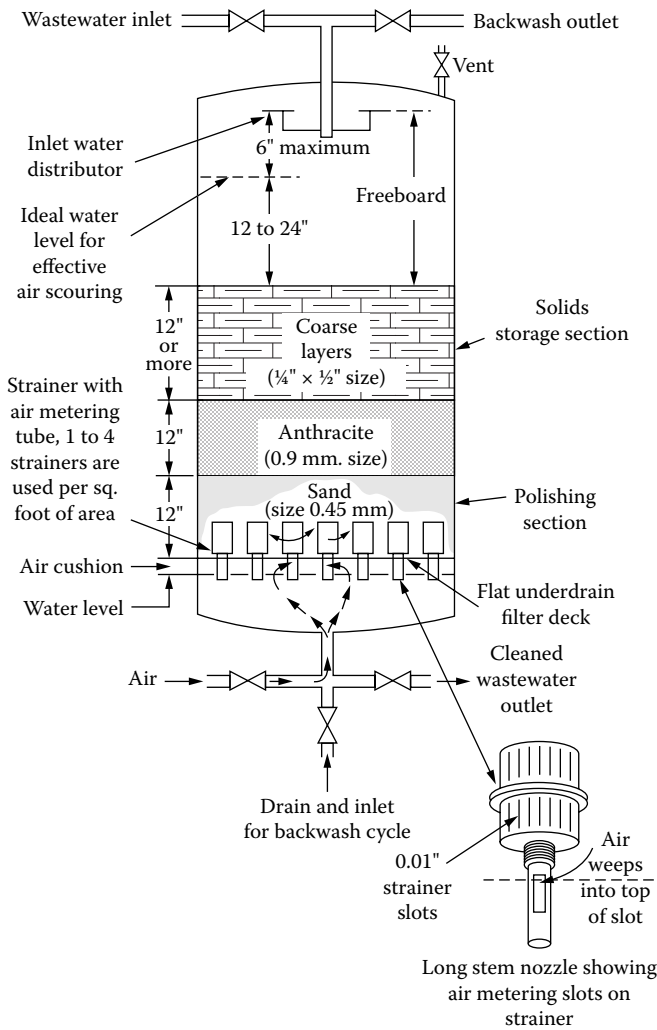


FIG. 8.39y
Construction of a multilayered filter.

The buffer feed tank has three level probes, detecting high, normal, and low levels. If, after a “dual pump down” episode, the level drops to the “normal” probe, the system is returned to the single filter pump down mode and the inactive filter is backwashed. If the level in the buffer feed tank drops further and reaches the low level probe, the filtered wastewater will no longer be drained, but is returned into the holding tank.

Superfilters The required purity of nuclear power plant boiler feed water, in terms of conductivity, is 0.05 micro-Siemens. The total organic carbon (TOC) content of such feedwaters must be under 50 ppb. Such purity can only be obtained by membrane filtration. These designs are discussed under Tertiary Water Treatment in a later paragraph in this section.

In order to prevent corrosion, oxygen scavengers such as hydrazin are also added to boiler feedwater.

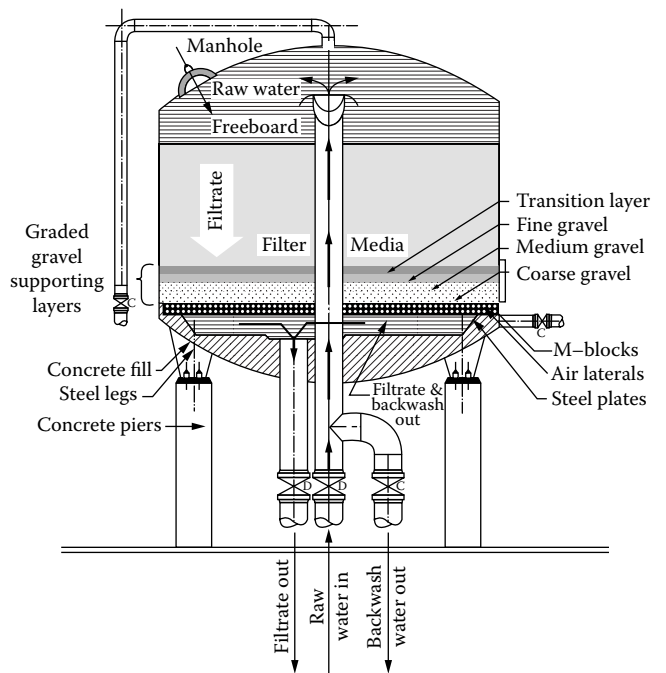


FIG. 8.39z
Construction of a deep-bed granular filter.

CHLORINATION

Nearly every wastewater treatment process uses chlorination, although drinking water chlorination is being phased out in favor of ozonation. Chlorination may be used either to reduce the possibility of pathogenic bacterial contamination of the receiving water or to prevent biological growth from interfering with other processes. Control of biological slimes that interfere with heat exchange in cooling water systems is often accomplished with chlorine, but also with biocides.

Chlorine is a strong oxidant with many other uses, as were described earlier in connection with chemical oxidation. It is a very effective bactericidal agent readily available at reasonable cost. Its effectiveness has been proved by over 75 years of use.

Several factors contribute to the complexity of chlorination for biological control. These include that the materials in the water that can be chemically oxidized cause an immediate reduction of the available active chlorine into an ineffective chloride form. Therefore, sufficient chlorine must be added to the water to account for this reaction and, in addition, to provide a residual amount, reserving sufficient chlorine for subsequent reactions. The amount of chlorine involved in the initial reduction is called *chlorine demand*. A dosage greater than this amount provides excess chlorine, which is called *residual chlorine*.

When nitrogenous material, particularly ammonia, is present in the water, the residual chlorine will be altered. Two kinds of residual chlorine are recognized: (1) free residual is that remaining after the destruction with chlorine of ammonia

or of certain organic nitrogen compounds; (2) combined residual is produced by the reaction of chlorine with natural or added ammonia or with certain organic nitrogen compounds.

Because these two compounds (free residual chlorine and combined residual chlorine) are completely different in their ability to control bacterial organisms, it is important to differentiate which of the two forms of chlorine are involved in a process. Laboratory methods are available for both the measurement and the differentiation among these two.

Continuous analyzers (see Section 8.11 in Chapter 8 in the first volume of this handbook) suitable for control are also available to measure either the level of free residual chlorine or the level of total residual chlorine, meaning the combination of the two when both are present.

The presence of residual chlorine in water does not ensure either disinfection nor biological control. A bacteriological analysis requires several hours, or even days. Through years of experience, it has been determined that measurement of residual chlorine can be a suitable inferential indicator of the effectiveness of biological control. For this reason, such processes are suitably controlled by analysis of residual chlorine.

An example of a typical control system used in the disinfection of wastewater is shown schematically in Figure 8.39aa. The chemical feed system for applying chlorine must be of sufficient capacity both to satisfy the chlorine demand of the waste and to provide sufficient residual after the contact time that is required for the disinfection action has passed. Typical of this for wastewater treatment would be a chlorine demand of 5 mg/l.

Another important factor is that the amount of residual chlorine will decline with time. There is no assurance that the initial residual concentration will persist for the length of time required for the disinfection to be accomplished. Yet, it is important that residual chlorine be present during this entire period. Typical design basis is to size the contact chamber for 30 min retention at maximum flow.

Local regulations usually require that there be a minimum of 1 mg/l of available chlorine at the end of this contact time. It is not uncommon for flows to vary over a range of 6:1. To account for these variations and for the continuing chemical

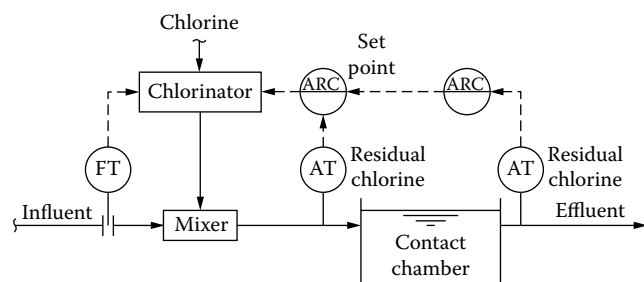


FIG. 8.39aa

Illustration of chlorination-based disinfection controls used when both the flow rate and the quality of the wastewater influent is variable. For the details of the chlorinator, refer to Figure 8.39e.

reactions, the control system must automatically control the residual after a short (approximately 5 min) fixed contact time. This is accomplished by building the 5 min retention time into the sampling system.

Feedback control of residual chlorine, in conjunction with flow-proportioning feedforward correction (Figure 8.39aa), establishes a constant residual value at the inlet of the contact chamber. Because of the variable rate at which residual decay occurs, assurance that the residual at the exit of the contact tank is maintained at a minimum value requires a second analyzer. This cascade master adjusts the set point of its slave, the inlet residual chlorine controller, as required.

The amount of residual chlorine decay varies widely as a result of variations in temperature, quality of wastewater, and detection times. It may vary from a minimum of 0.5 to 5 mg/l. To maintain an effluent residual of 1 mg/l, the set point on the controller for the chlorinator may be anywhere from 1.5 to 6 mg/l.

Chlorination of wastewater for disinfection is unique in that it is usually the final process unit prior to discharge. For this reason, detection time is provided as a part of the process. For most other biological control applications, other subsequent unit operations provide sufficient contact time, and the residual decay can be reasonably well predicted.

MUNICIPAL WASTEWATER TREATMENT

As shown in Figure 8.39bb, the conventional household sewage treatment process consists of pretreatment, primary settling, aeration, final clarification, and disinfection steps.

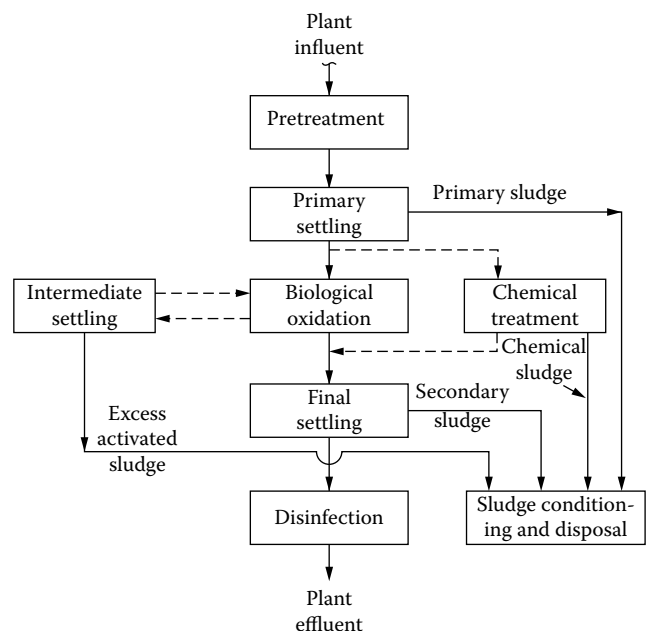


FIG. 8.39bb

The basic stages of municipal wastewater treatment.

Pretreatment equipment includes screens, grinders, skimmers, grit chambers, flow equalization, and primary settling. Traveling grates are also used to remove large debris. Plugging is detected by level differential across the grate. Older systems use bubbler tubes with d/p transmitters for this measurement; newer ones use noncontact ultrasonic level transmitters.

The second step usually is biological oxidation, which can be done either in aeration tanks or in aeration ponds. The aeration process is controlled by dissolved oxygen (DO) analyzers. See Section 8.43 in Chapter 8 of Volume 1 of this handbook for the description of the submersed platinum electrodes operating under diffusing Teflon membranes that are used for this measurement. The biological oxidation step is usually combined with chemical treatment and intermediate settling, which respectively produce chemical and excess activated sludge.

The aerated water is allowed to settle in a settling tank, which is also referred to as a clarifier or a thickener. Figure 8.39cc illustrates a circular basin-type clarifier. Other designs include horizontal flow, solids contact, and inclined surface versions. RF capacitance probes and ultrasonic sludge interface detectors are both often used to detect the sludge blanket level in the clarifier (Sections 3.3 and 3.20 in Chapter 3 Volume 1). The settled sludge is pumped to sludge digester or sludge conditioning units.

Microwave-type density sensors are often used to detect the consistency of the secondary sludge from the final settling tank (see Chapter 6 in the first volume of this handbook). The purpose of the sludge density measurement is to make sure that

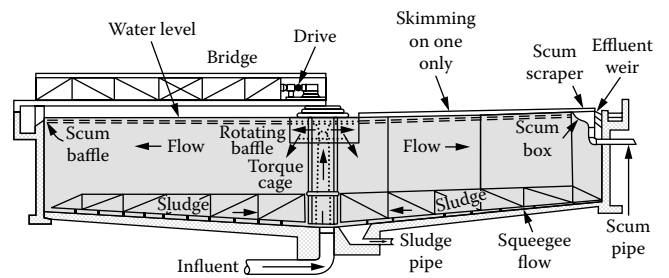


FIG. 8.39cc
Circular basin-type clarifier design.

the secondary sludge that is being pumped to sludge conditioning or sludge digestion is thick enough in its solids content.

Either prior to, after, or in parallel with biological oxidation, treatment chemicals such as ferrous chloride or soluble polymers are added to cause flocculation. Figure 8.39dd describes a combined coagulation and settling apparatus used for such dual purposes.

The flocculant and coagulant chemicals are usually added by metering pumps, having either variable-stroke or variable-speed adjustments. The flocculant flow through these pumps is ratioed to the sewage influent flow, so that the chemical dosage is maintained constant. The sewage influent flow is usually measured by a magnetic flowmeter (Figure 8.39ee) if a pipe is used. In open channels, Parshall flume or ultrasonic flow detectors are used (see Chapter 2 in Volume 1 of this handbook).

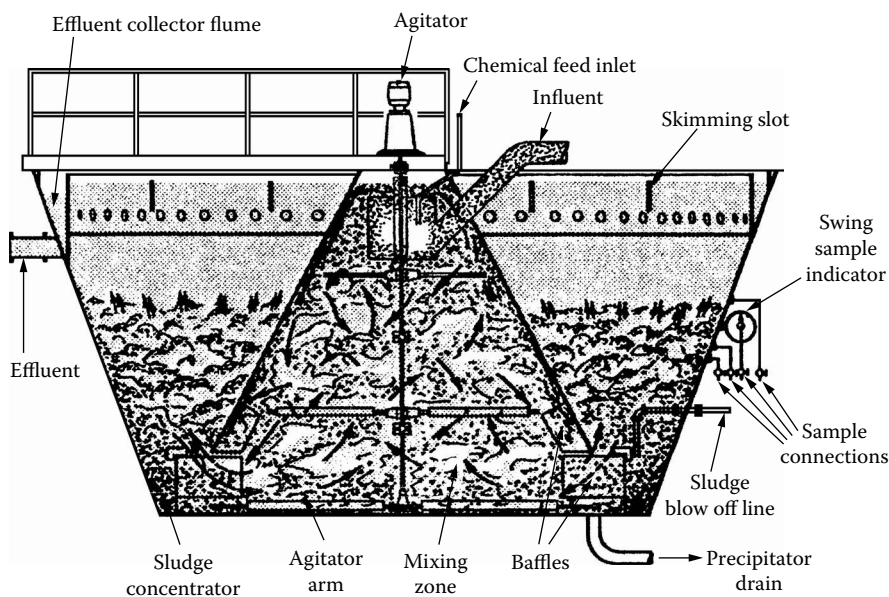


FIG. 8.39dd
Apparatus for the combined processes of coagulation and settling.

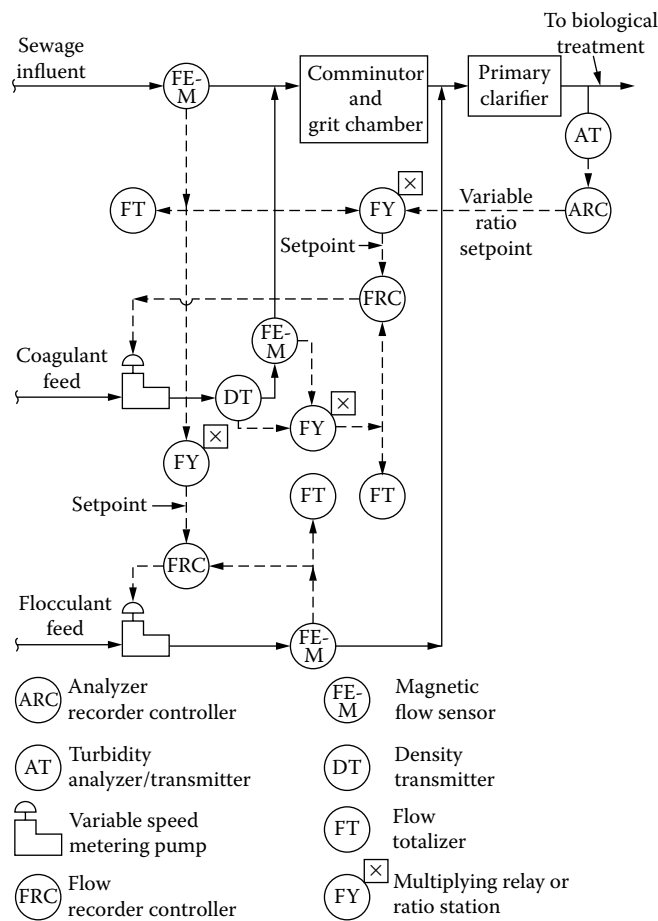


FIG. 8.39ee
Control system for automatic flocculant and coagulant additions.

The coagulant flow is also ratioed to the sewage influent, and the ratio is modulated by the cascade master (ARC in Figure 8.39ee), which keeps the turbidity level of the clarifier effluent constant. If the pH is under 7.5, caustic solution is also added under pH control by a positive displacement pump, because good flocculation requires that the pH in the tank exceed 7.5.

Final settling is usually followed by disinfection and filtration steps, which were discussed in connection with Figures 8.39y and 8.39z. The sand filters are backwashed either on the basis of time or on the basis of totalized flow through them. The clarity of the filtered water is monitored by light-scattering turbidity detectors (see Section 8.60 in Volume 1 of this handbook).

Disinfection While ultrafiltration removes quantities of pathogens, other methods of filtration require disinfection, either by UV radiation, chlorination, or ozonation, mainly to remove coliform bacteria. While coliform tests are lab based, most water treatment plants also use nephelometric turbidity meters to bring the purity to 0.06 turbidity units. Chlorination is controlled by residual chlorine analyzers. They measure free chlorine or total chlorine (which includes, e.g., NH_2Cl).

Tertiary Wastewater Treatment

Tertiary treatment is used for the water reclamation where the purification process is followed by disinfection. Membrane filtration separates the influent into two streams. The stream that has passed through a semipermeable membrane will have less solids than the one that did not. The designs used include reverse osmosis (RO), nano-filtration (NF), ultrafiltration (UF), and microfiltration (MF), which is the separation of submicron particulates from dissolved material.

Reverse osmosis uses hollow fiber membranes to route ions into one side and pure water into the other side of the membrane. Pumps generate the RO pressure, which usually exceeds 900 psig. In the RO process pH is monitored to prevent the precipitation of alkaline salts and the water purity is detected by conductivity and ion selective electrodes (see Sections 8.17 and 8.28 in Chapter 8 in the first volume of this handbook).

Nano-filtration separates monovalent salts from multivalent and uncharged organic molecules. NF is used for desalting and for concentrating dyes.

Ultrafiltration is used in paper mill, oily, and latex effluent streams. It can also be used as a pretreatment to ion exchange to prevent particulate fouling of the resin bed.

Microfiltration uses ceramic and polymeric membranes for processing liquids in the pharmaceutical and chemical industries, as well as for separating wastewater effluents.

Deionization Ion exchange is mostly used to soften water by the removal of calcium and magnesium. These units can remove not only water hardness, but also other mineral salts and silica. They can provide 2 ppb purity. Ion exchange purified water can be further cleaned by reverse osmosis, combined with ultrafiltration.

Ion exchangers are vessels filled with resins that are saturated with Na^+ during regeneration by a salt solution. When the cycle is switched to deionization, the resin captures Ca^{++} and Mg^{++} while releasing Na^+ . When Na^+ is exhausted, the resin is backwashed (Figure 8.39ff). During the first phase of regeneration, Ca^{++} and Mg^{++} are purged to waste.

The sequencing of the run, regeneration, purge, and backwash phases of the operating cycle are usually PLC controlled, and these phases are started either on the basis of elapsed time or because a conductivity sensor indicates an ion-breakthrough.

When the removal of Cl^- or sulfate is also required, mixed-bed ion exchangers are used that contain both anionic and cationic resins. The anionic resins are regenerated by HCl , which saturates the H^+ ions. Conductivity sensors are used to initiate the regeneration of the exhausted unit while switching the water to the stand-by unit.

The sludge from the settling and treatment steps is usually dewatered in rotary filters and is then dried for disposal as soil supplement or is sent to aerobic or anaerobic digesters for fermentation. The H_2S in the generated digester gases is usually monitored by infrared analyzers (see Section 8.26 in Chapter 8 in Volume 1 of this handbook).

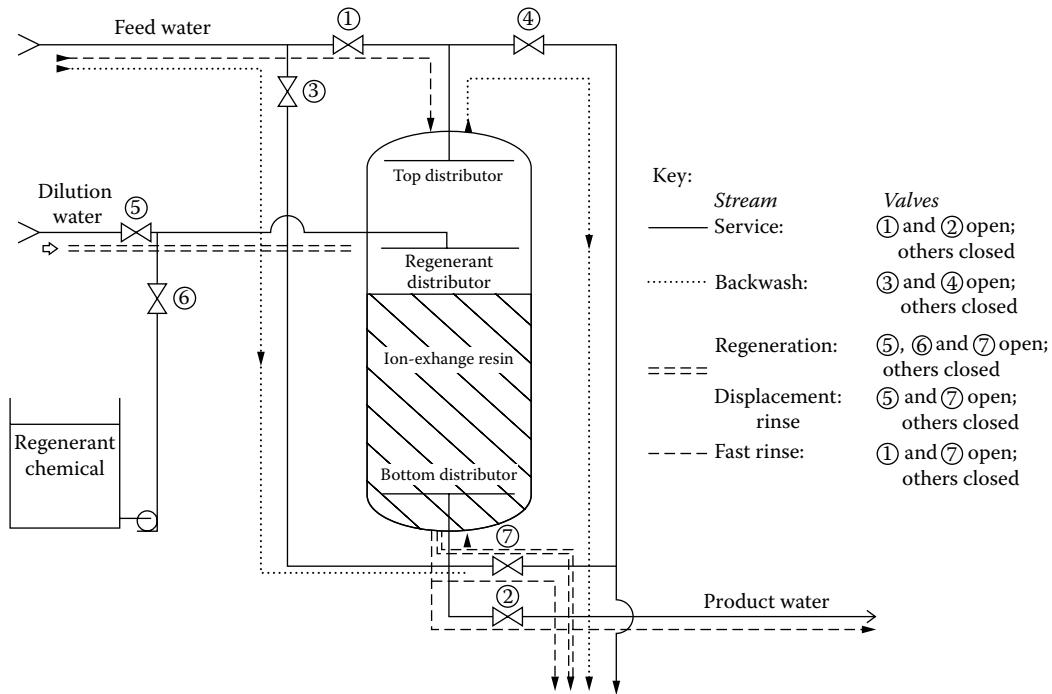


FIG. 8.39ff

Simplified ion-exchange operations cycle. The water used for backwash, dilution water, or displacement rinse can be feed water, softened water, decationized water, or DI water depending on the ion-exchange resin used and the quality of water produced in the service cycle. (Reprinted with permission from Owens, 1985, p. 89.)

Safety

If the treatment plant is in a closed building, the air in the building has to be monitored for toxic H₂S, for combustibles in explosive concentrations, and for oxygen deficiency. The low-oxygen alarm is usually set at 19.5% of oxygen in the air. Combustibles can be detected either by infrared sensors or by catalytic combustion detectors (for details see Section 8.16 in Chapter 8 in Volume 1 of this handbook).

The safety monitoring sensors actuate both local and central alarms. Figure 8.39gg illustrates the remote head-type safety monitoring installation.

In remote and unattended installations, radio transmission in the 920 MHz band is used. The radios can receive both analog and on/off contact signals, and their receivers can transmit them to SCADA, PLC, or PC devices, using Ethernet or Modbus protocols.

COOLING WATER TREATMENT

For a detailed discussion of cooling tower controls and optimization, refer to Sections 8.16 and 8.17.

Cooling systems can be once-through, cooling tower, or closed-loop cooling systems. Most power plants and refineries use cooling towers with water recirculation, but evaporation losses will cause concentration of scaling compounds such as calcium and magnesium carbonates. Also, biological

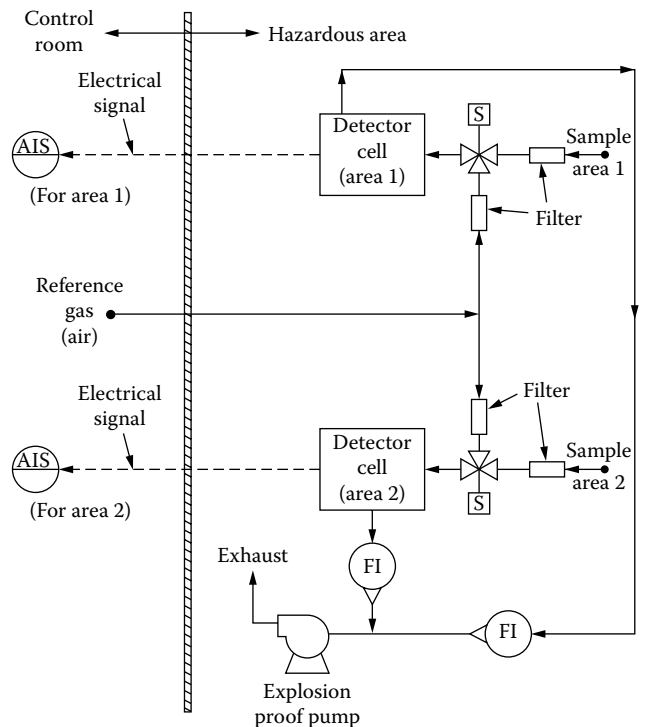


FIG. 8.39gg

Safety monitoring installation using remote detector cells located in the monitored area.

TABLE 8.39ii

Control Instrumentation Applicable to Various Wastewater Treatment Systems

Treatment Process	Instrumentation			Residual Chlorine
	Flow	pH	ORP	
Chemical oxidation of				
Cyanide		✓	✓	
Iron	✓			✓
Manganese	✓			✓
Hydrogen sulfide	✓			✓
Chemical reduction of				
Chromium		✓	✓	
Residual chlorine	✓			✓
Precipitation of				
Chromium	✓	✓		
Iron	✓	✓		
Manganese	✓	✓		
Hardness	✓			
Neutralization of				
Acid and alkali	✓	✓		
Alkalinity (recarbonation)	✓	✓		
Biological control	✓			✓

reactions dictate the design considerations. The most critical of these involve (1) pH, (2) reaction rates, (3) ratios (chemical dosage), (4) concentration, and (5) temperature.

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