CHAPTER 6

WASTEWATER TREATMENT PROCESSES

6-1. Preliminary and Primary Wastewater Treatment Processes

a. Introduction. Preliminary treatment of wastewater generally includes those processes that remove debris and coarse biodegradable material from the waste stream and/or stabilize the wastewater by equalization or chemical addition. Primary treatment generally refers to a sedimentation process ahead of the main system or secondary treatment. In domestic wastewater treatment, preliminary and primary processes will remove approximately 25 percent of the organic load and virtually all of the nonorganic solids. In industrial waste treatment, preliminary or primary treatment may include flow equalization, pH adjustment or chemical addition that is extremely important to the overall treatment process. Table 6-1 liss the typical effluent levels by degree of treatment. This section of the manual will discuss the various types of preliminary and primary treatment processes available.

b. Preliminary treatment. An important part of any wastewater treatment plant is the equipment and facilities used to remove items such as rags, grit, sticks, other debris, and foreign objects. These interfere with the operation of the facility and often cause severe problems. Methods of removing these materials prior to primary and subsequent treatment are part of a pretreatment or preliminary treatment. While a summary discussion of the commonly employed unit operations follows, a more complete description of design criteria which must be used is contained in TM 5-814-3.

(1) Screening and comminution. Screening and comminution are preliminary treatment processes utilized to protect mechanical equipment in the treatment works, to aid downstream treatment processes by intercepting unacceptable solids, and to alter the physical form of solids so they are acceptable for treatment. Screening or comminution shall always be used for military domestic wastewaters.

(a) Screening. Screening devices remove materials which would damage equipment or interefere with a process or piece of equipment. Screening devices have varied applications at wastewater treatment facilities, but most often are employed as a preliminary treatment step. Screens are classified as fine or coarse and then further classified as manually or mechanically cleaned. Coarse screens are used in preliminary treatment, while fine screens are used in lieu of sedimentation preceding secondary treatment or as a step in advanced wastewater treatment. Fine screens as a preliminary or primary treatment are more applicable to process or industrial wastes. TM 5-814-3 provides detailed descriptions of these units and design considerations.

(b) Comminution. A comminutor acts as both a cutter and a screen. Its purpose is not to remove but to shred (comminute) the solids. Solids must be accounted for in subsequent sludge handling facilities. Comminutors, like most screens, are mounted in a channel and the wastewater flows through them. The rags and other debris are shredded by cutting teeth until they can pass through the openings. Some units require specially shaped channels for proper hydraulic conditions, resulting in more expensive construction. Treatment. plant design manuals, textbooks, and manufacturer's bulletins provide detailed information on these units. A bypass channel is required for all comminutors to permit maintenance of equipment.

(2) Grit removal. Grit represents the heavier inert matter in wastewater which will not decompose in treatment processes. It is identified with matter having a specific gravity of about 2.65, and design of grit chambers is based on the removal of all particles of about 0.011 inch or larger (65 mesh). For some sludge handling processes, it may be necessary to remove, as a minimum, grit of 0.007 inch or larger (100 mesh). Grit removal, compared to other unit treatment processes, is quite economical and employed to achieve the following results:

- Prevent excessive abrasive wear of equipment such as pumps and sludge scrapers.
- Prevent deposition and subsequent operating problems in channels, pipes, and basins.
- Prevent reduction of capacity in sludge handling facilities.

Grit removal facilities shall be used for combined sewer systems or separate sanitary systems which may have excessive inert material. Grit removal equipment should be located after bar screens and comminutors and ahead of raw sewage pumps. Sometimes it is not practical to locate

Table 6-1. Typical effluent levels of principal domestic wastewater characteristics by degree of treatment (mg/L unless noted otherwise)

Parameter	Average Raw Wastewater	Wastewater Treatment				
				Advanced[a]		
		(1) Primary	(2) Secondary	3 (1)+(2)+NR[b]	(4) (3)+PR[c]	(5) (4)+SSOR[d]
BOD	300	195	30[e]	15	5	1
COD	600	400	150	100	45	12
Suspended Solids	300	120	30[e]	20	10	1
Amnonia (as N)	25	25	28	3	3	3
Phosphate (as P)	20	18	14	13	2	1
pH (units)	7	6-9	6-9[e]	6-9	6-9	6-9
Fecal Coliform (no. /100 mL)	1,000,000	15,000	200[e]	200	200	100

[a]Reasonable levels but not necessarily minimum for all constituents.

[b]NR = Nitrogen Removal or Conversion

[c]PR = Phosphorus Removal

[d]SSOR = Suspended Solids and Organics Removal

[e]Environmental Protection Agency, Secondary Treatment Information, 40 CFR, Part 133, Federal Register, Monday, 30 April 1973.

the grit removal system ahead of the raw sewage pumps because of the depth of the influent line. Therefore, it may be required to pump the wastewater containing grit. If this mode is selected, pumps capable of handling grit should be employed.

(a) Horizontal flow grit chambers. This type of grit chamber is designed to allow wastewater to pass through channels or tanks at a horizontal velocity of about one foot per second. This velocity will allow grit to settle in the channel or tank bottom, while keeping the lighter organic solids in suspension. Velocity control and other design features are covered in TM 5-814-3.

(b) Detritus tanks. A grit chamber can be designed with a lower velocity to allow organic matter to settle with the grit. This grit-organic matter mixture is referred to as detritus and the removal devices are known as detritus tanks. When detritus tanks are employed, the organic matter is separated from the grit by either gentle aeration or washing the removal detritus to re-suspend the organic matter. Several proprietary systems are available to accomplish this, and the advantage over other types is that the configuration of the tank is simple and the system allows for continuous removal of grit.

(c) Aerated grit chambers. As the name implies, diffused air can be used to separate grit from other matter. A secondary benefit to the aeration method is that is also freshens the wastewater prior to further treatment; quite often it is used in conjunction with a preaeration facility. The different types of grit removal facilities employed are described in TM 5-814-3.

(3) Preaeration. Methods of introducing supplemental oxygen to the raw wastewater are sometimes used in preliminary treatment. This process is known as preaeration and the objectives are to:

—Improve wastewater treatability.
—Provide grease separation, odor control, and flocculation.
—Promote uniform distribution of suspended and floating solids to treatment units.
—Increase BOD removals in primary sedimentation.

This is generally provided by either separate aeration or increased detention time in an aerated grit chamber. Provisions for grit removal are provided in only the first portion of the tank (125).

(4) Equalization. Equalization has limited application for domestic wastes, but should be employed for many industrial discharges including some of those from military industrial manufacturing processes as discussed later in this chapter. Equalization reduces fluctuations of the influent to levels compatible with subsequent biological or physical-chemical processes. A properly designed facility dampens the wide swings of flow, pH, BOD, and other parameters to levels such that downstream systems operate more efficiently and economically, and can be constructed at a reduced capital investment. Proper equalization will also minimize system upsets and more consistently provide a better quality effluent. A graphical example of how an equalization facility can stabilize a wastewater having significant cyclic pH variations is illustrated in figure 6-1. While there are definite primary benefits for equalization, a facility can also be designed to yield secondary benefits by taking advantage of physical, chemical, and biological reactions which might occur during retention in the equalization basin. For example, supplemental means of aeration are often employed with an equalization basin to provide:

—Better mixing.
—Chemical oxidation of reduced compounds.
—Some degree of biological oxidation.
—Agitation to prevent suspended solids from settling.

If aeration is not provided, baffles or mechanical mixers must be provided to avoid stratification and short circuiting in equalization basins. The size and shape of an equalization facility will vary with the quantity of waste and the patterns of waste discharge. Basins should be designed to provide adequate capacity to accommodate the total volume of periodic variation from the wastewater source (125) (130).

(5) pH control. Similarly to equalization, the use of pH control as a preliminary treatment step is usually limited to treatment of industrial process wastes. It is necessary to regulate pH since treatment processes can be harmed by excessively acidic or basic wastes. Regulation of this parameter may be necessary to meet effluent levels specified for secondary treatment. Control of the pH at elevated levels is usually required to precipitate certain heavy metals and/or alleviate an odor producing potential.

(6) Flotation. In preliminary treatment, flotation is sometimes used for wastes which have heavy loads of grease and finely divided suspended solids. These are mainly systems having large industrial discharges and may apply to military installations with significant oil and grease quantities from manufacturing or laundry

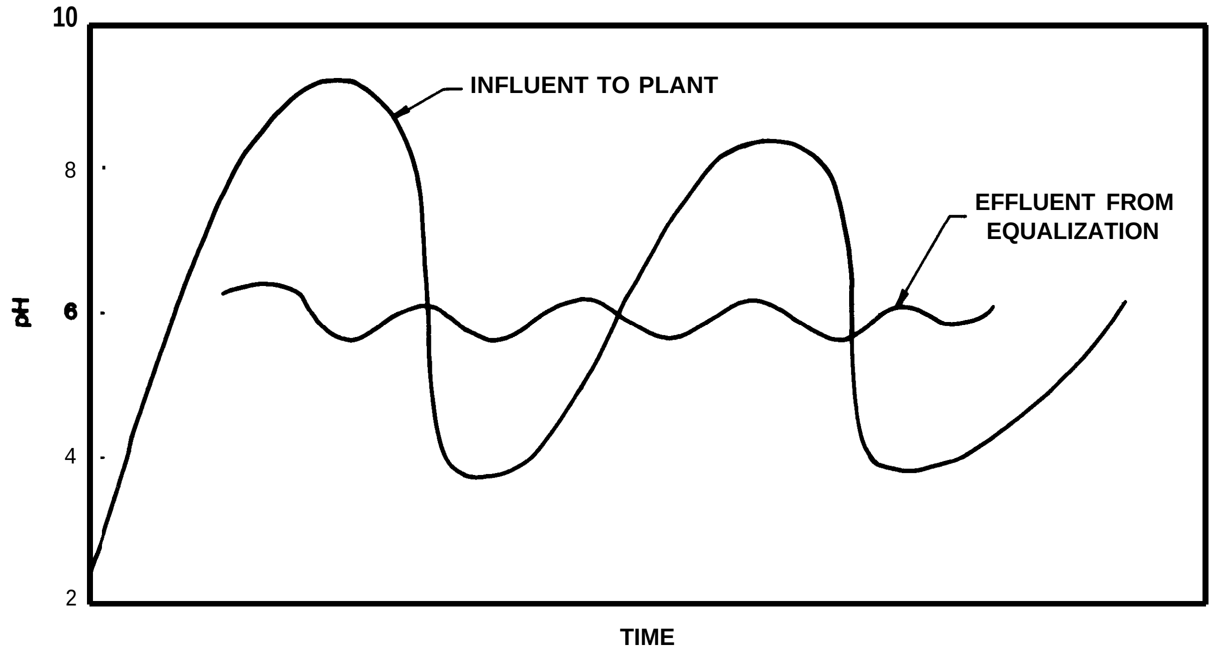

Figure 6-1. The effect of equalization on a wastewater with variable pH.

operations. Domestic waste may also contain large quantities of grease from food preparation. Use of air to float materials may relieve scum handling in a sedimentation tank and lower the grease load to subsequent treatment units. Grit removal is often incorporated with a flotation unit providing sludge-removal equipment. Flotation design guidelines are available, but bench testing is desirable to finalize the criteria and expected performance.

(7) Other methods. Other preliminary treatment steps include coagulation and chlorination. Coagulation is a part of sedimentation as presented later in this chapter. Chlorine additions are often made to the plant influent for odor control (120). Two other operations which usually precede any treatment process include pumping and flow measurement. Wastewater bypasses must also be provided.

(a) Pumping. Pumping facilities may be employed to gain sufficient head for the wastewater to flow through the treatment works to the point of final disposal. Pumping is also generally required for recirculation of all or part of the flow around certain units within the plant. Pumping facilities are classified as influent, effluent, or recirculation stations and perform a critical function. Provisions shall be made for reliability to ensure the facility is operable at all times. This means the largest pump has a standby duplicate so that pumping capacity is available to meet peak flows. It also means duplicate sources of power and/or standby power must be provided. U.S. EPA requires this flexibility for municipal facilities. Guidelines for pumping facilities are available in TM 5–814-3.

(b) Flow Measurement. Metering and instrumentation devices in numerous sections of a wastewater treatment facility are necessary for adequate plant control and operating flexibility. Proper monitoring of effluent characteristics is required to comply with NPDES permits. Use of devices such as Venturi meters, weirs, and Parshall flumes predominate. Parshall flumes are the preferred flow measuring method for military installations. TM 5-814-3 provides a description of sizing and design considerations. The need for other meters and instrumentation throughout the treatment facility will be dictated by the size of the facility, complexity, and need for recordkeeping and operator control of the process. In small installations, where maintenance and availability of spare parts may be difficult, metering can be a problem. Reference should be made to publications (120) for guidelines on types of measurement systems available, limitations, and preliminary design criteria. Also standard textbooks and literature from equipment manufacturers should be investigated thoroughly prior to selection of type and degree of plant measurement and instrumentation.

(c) Wastewater bypasses. Piping arrangements and duplicate treatment units may be provided to the maximum practical extent so that an inoperative unit, such as a clarifier, may be bypassed without reducing the overall treatment

efficiency of the plant. Bypassing of the entire wastewater treatment plant through an emergency overflow structure during periods of extraordinarily high flow must be provided. In all cases, this diverted flow shall be disinfected and screened, and the quantity of flow measured and recorded. The appropriate regulatory agency shall be notified of every bypass occurrence. When the wastewater is discharged to a waterway which could be permanently or unacceptably damaged by the quantity of bypassed wastewater, such as shellfish waters, drinking water reservoirs, or areas used for water contact sports, provision shall be made to intercept the bypassed flow in a holding basin. The intercepted flow shall then be routed back through the treatment facility as soon as possible. Bypasses for diversion of flow around treatment plants will be locked in a closed position. The bypass must be controlled by supervisory personnel.

c. Primary treatment. Primary treatment for the purposes of this manual will be limited to sedimentation with and without chemical addition. Other unit processes are usually combined with sedimentation as a part of “primary treatment”, including some degree of preliminary treatment, sludge treatment and disposal, and chlorination as a disinfection step. For many years, water quality criteria specified only the use of primary treatment for domestic wastewaters. Primary treatment is no longer acceptable as the total wastewater treatment step prior to discharge to a receiving body of water and secondary treatment must now be employed to meet regulatory criteria. Therefore, the discussion presented herein on primary treatment shall be utilized by military personnel concerned with:

—Alternatives that must be considered for existing treatment facilities which are to be upgraded to meet effluent limitations and water quality criteria.

—Design factors and alternatives that must be considered when planning a new wastewater treatment facility.

(1) Plain sedimentation. Wastewater, after preliminary treatment, undergoes sedimentation by gravity in a basin or tank sized to produce near quiescent conditions. In this facility, settleable solids and most suspended solids settle to the bottom of the basin. Mechanical collectors should be provided to continuously sweep the sludge to a sump where it is removed for further treatment and disposal. Skimming equipment should be provided to remove those floatable substances such as scum, oils, and greases which accumulate at the liquid surface. These skimmings are combined with sludge for disposal. Removals from domestic wastewaters undergoing plain sedimentation will range from about 30 to 40 percent for BOD and in the range of 40 to 70 percent for suspended solids. With optimum design conditions for sedimentation, BOD and suspended solids removal efficiency is dependent upon wastewater characteristics and the proportion of organics present in the solids. One of the most important design parameters if the overflow rate, usually expressed in gal/day/sq ft, which is equal to the flow in gal/day divided by the settling surface area of the basin in square feet. Usually average daily flow rates are used for sizing facilities. The flow rates, detention time, and other factors which shall be employed for design purposes are documented in TM 5-814-3.

(a) Secondary treatment sedimentation facilities. It should be recognized that design principles of secondary sedimentation tanks are significantly different than those for primary tanks, the fundamental difference being in the amount and nature of solids to be removed. Primary sedimentation facilities are basically designed on overflow rate alone; secondary units must be designed for solids loading as well as overflow rate. Reference should be made to TM 5–8 14–3 for design criteria.

(b) High-rate settlers. In recent years, the development of high-rate settlers has proven quite promising for both primary and secondary sedimentation applications. These have been used primarily to improve performance and to increase treatment capacity of existing plants and should receive attention for upgrading military facilities. The theory is that sedimentation basin performance can be improved by introducing a number of trays or tubes in existing facilities, since efficiency is independent of depth and detention time. Until recent years, use of trays or tubes was unsuitable on a practical basis because of difficult sludge collection and removal. These problems have been largely overcome although slime growths may cause flow restrictions and require periodic cleaning. The principal advantage of the settlers is their compactness which reduces material costs and land requirements. For most military installations, the land savings is not critical but cost reductions will be important. Settlers do not improve the efficiency of primary sedimentation facilities that are already achieving reasonably high removals of suspended solids. Available data indicate that where the settlers have been installed in existing units, it has been possible to increase the surface overflow rate of both primary and final sedimentation systems

from 2 to 5 times the conventional rate while still maintaining about the same suspended solids effluent level. Manufacturer's bulletins and U.S. EPA Technology Transfer series documents provide data on design criteria.

(2) Sedimentation with chemical coagulation. Sedimentation using chemical coagulation has been implied mainly to pretreatment of industrial or process wastewaters and removal of phosphorus from domestic wastewaters. Chemical usage as a pretreatment step for industrial wastes and phosphorus removal is discussed later. The use of chemical coagulating agents to enhance the removal of BOD and suspended solids has not been used extensively on domestic wastewaters, since it is not usually economical or operationally desirable. However, special applications may exist at some installations. Advantages of increased solids separation in primary sedimentation facilities are:

- –A decrease in organic loading to secondary treatment process units.
- –A decrease in quantity of secondary sludge produced.
- –An increase in quantity of primary sludge produced which can be thickened and dewatered more readily than secondary sludge.

Chemicals commonly used, either singularly or in combination, are the salts of iron and aluminum, lime, and synthetic organic polyelectrolytes. It is desirable to run jar studies to determine the optimal chemicals and dosage levels. The use of a given chemical(s) and effluent quality must be carefully balanced against the amount of additional sludge produced in the sedimentation facility. Design information and guidance is contained in the U.S. EPA Technology Transfer series documents.

(3) Other methods. For some industrial wastes which contain large amounts of floatable and finely suspended matter, flotation may be used in lieu of sedimentation as a cost-effective means of primary treatment. Some wastewater treatment alternatives, including ponds and extended aeration, do not require primary treatment as a distinct process step. Other secondary treatment processes could operate without primary treatment but it is cost-effective to remove the suspended organics physically rather than biologically.

6-2. Biological Wastewater Treatment Processes

a. Introduction. Biological treatment processes are those that use microorganisms to coagulate and remove the nonsettleable colloidal solids and to stabilize the organic matter. There are many alternative systems in use and each uses biological activity in different manners to accomplish treatment. Biological processes are classified by the oxygen dependence of the primary microorganism responsible for waste treatment (125). In aerobic processes, waste is stabilized by aerobic and facultative microorganisms; in anaerobic processes, anaerobic and facultative microorganisms are present. The discussion of biological treatment processes has been further divided into the following two categories:

- —Suspended growth processes.
- —Fixed growth processes.

(1) Suspended growth processes refer to treatment systems where microorganisms and wastewaters are contained in a reactor. Oxygen is introduced to the reactor allowing the bilogical activity to take place. Examples of suspended growth processes include ponds, lagoons and activated sludge systems.

(2) Fixed growth processes refer to systems where a biological mass is allowed to grow on a medium. Wastewater is sprayed on the medium or put into contact in other manners. The biological mass stabilizes the wastewater as it passes over it. Examples of fixed growth processes include trickling filters and rotating biological contractors.

b. Suspended growth processes.

(1) Ponds. Ponds have found wide-spread usage in the U.S. In 1968, 34.7 percent of the nearly 10,000 secondary treatment systems operating in the U.S. were in the category of stabilization ponds (49). Waste treatment ponds can be divided into three general classifications: aerobic ponds, aerobic-anaerobic (facultative) ponds, and anaerobic ponds. Ponds are sized on an average BOD loading or detention time basis and are quite sensitive to climate and seasonal variations.

(a) Aerobic ponds. Photosynthetic ponds are 6 to 18 inches deep with BOD loadings ranging from 100 to 200 lb per acre per day and detention times of 2 to 6 days. These are usually mixed intermittently, generally by mechanical means, to maximize light penetration and algae production. A very high percent of the original influent BOD is removed, but due to algae growth and release to the effluent, overall removals are in the 80 to 95 percent range. Suspended solids in the effluent are also mainly due to algae. Lower efficiencies occur during warmer periods of the year due to algal growths, and during extremely cold periods due to decreased biological activity and freezing. Aerated aerobic ponds uti-

lize oxygen mixed with the wastewater either from diffused air or mechanical means, with photosynthetic oxygen generation not playing a major role in the process. These ponds are 6 to 20 feet deep with BOD loadings ranging from 100 to 300 lb per acre per day and detention times of 2 to 7 days. BOD and suspended solids removals in the range of 80 to 95 percent are obtained if a quiescent cell is provided to effect solids removal after aeration. Aerated aerobic ponds may be considered for military applications where flow is variable or land is precious. Without the aerators operating, the system might function as an aerobic-anaerobic (facultative) pond during low loads.

(b) Aerobic-anaerobic (facultative) ponds. These ponds consist of three zones: a surface zone of algae and aerobic bacteria in a symbiotic association; an intermediate zone populated with facultative bacteria (aerobic or anaerobic); and an anaerobic bottom zone where settled organic solids are decomposed by anaerobic bacteria. The ponds, operated in natural aeration mode, are 3 to 8 feet deep with BOD loadings ranging from 10 to 100 lb per acre per day and detention time of 10 days to 1 year. BOD removals of 80 to 95 percent are obtained with proper operation and loadings, but suspended solids removals vary because of algal carryover. These ponds may also be partially mixed using mechanical or diffused aerators to supply some oxygen. Mechanically mixed ponds normally have BOD loadings ranging from 30 to 100 lb per acre per day; detention times of 7 to 20 days; operational depths of 3 to 8 feet; and, BOD removals of 90 to 95 percent.

(c) Anaerobic ponds. These ponds have BOD loadings in the range of 10 to 700 lb per acre per day and can provide removals of 50 to 80 percent. Detention times range from 30 days to 6 months and operational depths range from 8 to 15 feet. Anaerobic ponds have been used principally in industrial waste applications and particularly in meat packing wastes. Due to the nature of the pond environment, these treatment units generally produce severely offensive odors. They are normally not used by themselves and in order to produce a higher quality effluent, must be followed by an aerobic pond. Anaerobic ponds should not be utilized for military wastewaters except under special circumstances.

(d) Other considerations. In treatment of principally domestic wastes, there are additional factors to consider (44)(154). Aside from not meeting effluent criteria, operating problems include odors, colored effluent, high effluent suspended solids, mosquito and insect problems and weeds. A study (154) indicated that of 21 different pond installations studied, none would consistently meet the secondary treatment effluent requirement of 30 mg/L BOD. Similarly, of 15 installations reporting effluent suspended solids values, none would consistently meet the 30 mg/L effluent limit. New wastewater treatment pond designs and existing installations being upgraded must recognize and provide methods which will achieve required effluent levels. Definitive design criteria for all situations are beyond the scope of this manual. EPA Technology Transfer series documents and similar publications should be consulted when planning a new wastewater treatment pond facility or when assessing alternatives for upgrading an existing pond system. Locally applicable design criteria considering the effect of climate should be used when planning new or upgrading existing facilities. Wide variations in criteria are followed in the U.S. in terms of loading rates, detention times, depths and number of cells required. While most States in the midwest relate to a BOD design loading criteria in pounds BOD per acre per day, the principal design factor in northern states is retention time, primarily because of the extreme winter temperatures. In terms of organic loading, pounds of BOD per acre per day, State design criteria range from less than 20 in the northern states to as high as 75 in the southern, southwestern or western states, reflecting temperature effects on performance.

(2) Activated sludge. Activated sludge is an efficient process capable of meeting secondary treatment effluent limits. In recent years, this process has undergone significant changes and improvements from the conventional activated sludge process. For further information on the process itself or its modifications, reference should be made to TM 5-814-3. The principal factors which control the design and operation of activated sludge processes are:

—Detention time.

—BOD volumetric loading.

—Food to microorganism (F/M) ratio.

—Sludge age or solids retention time (SRT).

While all of these parameters have been used to size facilities, the most commonly used are the F/M ratio and the SRT. Reference should be made to textbooks or TM 5-814-3 for further explanation and limitations to be considered when dealing with these parameters. Secondary sedimentation is particularly important for activated sludge systems. The design of these units is based on overflow rate and solids loading. Design criteria for various size plants and process modifications are available (152). A number of variations of the conventional activated sludge process were developed to achieve greater treatabilit y, to minimize capital and/or operating costs or to correct a problem. While not all of the variations are mentioned herein, the following should be evaluated when considering a new facility, or upgrading an existing primary or secondary facility:

–Completely-mixed.
—Step aeration.
—Contact stabilization.
—Extended aeration.
—Pure oxygen system.

Summary characteristics on design criteria, removal efficiencies and basic applications of the modifications are described in table 6-2. Based on the overall BOD removal efficiency reported, most variations are able to achieve a high degree of treatment. The extended aeration system is a flexible system, but is more cost-effective for small populations. Extended aeration and contact stabilization are most applicable as package plants and are described under that heading. Activated sludge systems are commonly designed to accomplish two or more of the operating modes to accommodate flexible operational requirements. An example is the completely-mixed and step aeration systems. From the data in table 6-2, it can be seen that depending upon volumetric loading, F/M or detention time, selection of one variation over another can result in significant differences in the size of the aeration basins. The information presented in table 6-2 covers the range which has been experienced.

(*a*) Conventional. The conventional activated sludge process employs long rectangular aeration tanks which approximate plug-flow although some longitudinal mixing occurs. This process is primarily employed for the treatment of domestic wastewater. Return sludge is mixed with the wastewater prior to discharge into the aeration tank. The mixed liquor flows through the aeration tank during which removal of organics occurs. The oxygen utilization rate is high at the entrance to the tank and decreases toward the discharge end. The oxygen utilization rate will approach the endogenous level toward the end of the tank. Principle disadvantages of conventional activated sludge treatment in industrial application are:

—The oxygen utilization rate varies with tank length and requires irregular spacing of the aeration equipment or a modulated air supply.
—Load variation may have a deleterious effect on the activated sludge when it is mixed at the head end of the aeration tanks.
—The sludge is susceptible to slugs or spills of acidic, caustic or toxic materials.

(*b*) Completely mixed. In the completely mixed process, influent wastewater and recycled sludge are introduced uniformly throughout the aeration tank. This flow distribution results in a uniform oxygen demand throughout the aeration tank which adds some operational stability. This process may be loaded to levels comparable to those of the step aeration and contact stabilization processes with only slight reductions compared to the removal efficiencies of those processes. The reduced efficiency occurs because there is a small amount of short circuiting in the completely mixed aeration tank.

(c) Step aeration. The step aeration process is a modification of the conventional activated sludge process in which influent wastewater is introduced at several points in the aeration tank to equalize the F/M, thus lowering the peak oxygen demand. The typical step aeration system would have return activated sludge entering the tank at the head end. A portion of the influent also enters near the front. The influent piping is arranged so that an increment of wastewater is introduced into the aeration tank at locations down the length of the basin. Flexibilityof operation is one of the important features of this system (125). In addition, the multiple-point introduction of wastewater maintains an activated sludge with high absorptive properties. This allows the soluble organics to be removed within a shorter period of time. Higher BOD loadings are therefore possible per 1000 cu ft of aeration tank volume.

(*d*) Contact stabilization. The contact stabilization process is applicable to wastewaters containing a high proportion of the BOD in suspended or colloidal form. Since bio-adsorption and flocculation of colloids and suspended solids occur very rapidly, only short retention periods (15-30 minutes) are generally required. After the contact period the activated sludge is separated in a clarifier. A sludge reaeration or stabilization period is required to stabilize the organics removed in the contact tank. The retention period in the stabilization tank is dependent on the time required to assimilate the soluble and colloidal material removed from the wastewater in the contact tank. Effective removal in the contact period requires sufficient activated sludge to remove the colloidal and suspended matter and a portion of the soluble organics. The retention

Table 6-2. Summary characteristics of the activated sludge process variations

Process Variation	Volume Loading lb BOD/1,000 cu ft/day	Food/Micro-organism Ratio (F/M) lb BOD/lb MLVSS/day	Mixed Liquor Suspended Solids (MLSS) mg/L	Detention Time, hr	Overall BOD Removal Efficiency, percent	Comments
Conventional (plug flow)	20-40	0.2-0.5	1,000-3,000	4-8	85-95	Applicable to low-strength domestic waste, susceptible to shock loads.
Completely-Mixed	50-120	0.2-0.6	3,000-6,000	3-6	85-95	General application, resistant to shock loads.
Step Aeration	50-60	0.2-0.4	2,000-3,500	3-6	85-95	Applicable to wide range of wastes.
Contact Stabilization	60-75	0.2-0.6	1,000-3,000; 4,000-8,000	0.2-1.5[a] 3-6[b]	80-90	Flexible system; expansion of existing systems or package plants.
Extended Aeration	10-25	0.05-0.2	3,000-6,000	18-36	75-90	Applicable to small communities and package plants, flexible.
Pure Oxygen System	100-250	0.3-1.0	4,000-8,000	1-10	85-95	General application but more so for high-strength wastes.

[a] Contact Unit.

[b] Stabilization unit.

time in the stabilization tank must be sufficient to stabilize these organics. If it is insufficient, unoxidized organics are carried back to the contact tank and the removal efficiency is decreased. If the stabilization period is too long, the sludge undergoes excessive auto-oxidation and loses some of its initial high removal capacity. Increasing retention period in the contact tanks increases the amount of soluble organics removed and decreases required stabilization time.

(e) Extended aeration. The extended aeration process operates in the endogenous respiration phase of the growth curve, which necessitates a relatively low organic loading and long aeration time. Thus it is generally applicable only to small treatment plants of less than 1 mgd capacity (125). This process is used extensively for prefabricated package plants. Although separate sludge wasting generally is not provided, it may be added where the discharge of the excess solids is objectionable.

(f) Pure oxygen system. The variations set forth in table 6-2, with the exception of the pure oxygen system, represent flow models which are based on plug flow or completely mixed systems. Some systems use a diffused air system, others are more applicable to mechanical aeration, and some variations are adaptable to either aeration system. All of the systems, with the exception of the pure oxygen system, use air as the source of oxygen. The principal distinguishing features of the pure oxygen system are that it utilizes high-purity oxygen as a source of oxygen and employs a covered, staged aeration basin for the contact of the gas and mixed liquor (49). To date, the system has demonstrated its greatest applicability and cost-effectiveness for treatment of high strength industrial wastes and for large plants treating domestic wastes. Thus, pure oxygen systems for military wastewaters have limited application.

(g) Continuous loop reactors. The continuous loop reactor (CLR) is best described as an extended aeration activated sludge process. The process uses a continuously recirculating closed loop channel(s) as an aeration basin. The reactor is sized based upon the wastewater influent and effluent characteristics with emphasis given to the hydraulic considerations imposed by the basin geometry. hydraulic detention times range from 10 to 30 hours and the mixed liquor concentration in the basin is typically 4,000 to 5,000 mg/L. To provide the necessary oxygen to the system and impart a horizontal velocity, several pieces of equipment are available. These include:

—Brush aerators.

—Low speed surface aerator as used in the Carrousel system.

—Jet aeration.

—Diffused aeration with slow speed mixers.

Clarification can be accomplished using a conventional clarifier or by using an integral clarifier as with the Burns and McDonnell system (159). Advantages of the CLR process include:

–The ability for the system to handle upset loading conditions.

–Produces low sludge quantities.

–Can provide for vitrification and denitrification.

–Typically produces very good and stable effluent characteristics.

–Simplicity of operation.

The major disadvantages include the potential washout of the system by excessive hydraulic flows and the large land area and basin sizes that are required due to the typically high detention times.

(h) Nitrification. The kinetics and design criteria for this system are already well defined. Two important considerations are maintenance of a proper pH and temperature. Nitrification is a very temperature-sensitive system and the efficiency is significantly suppressed as the temperature decreases. For example, the rate of vitrification at pH of 8.5 and 50 degrees F is only about 25 percent of the rate at 86 degrees F. Treatment facilities located in northern climates must be sized at the appropriate loading rate to accomplish the desired effluent level if required to provide year-round vitrification. The loading rate significantly affects the capital costs for construction of the nitrification tanks. The optimum pH has been determined to range between 8.4 and 8.6. However, for those wastewaters where it would be necessary to provide chemical-feeding facilities for pH adjustment, the cost-effective alternative may be to provide additional tankage to allow for the reduced biological activity when the pH is not optimum.

(i) Biological denitrification. As with nitrification, denitrification is a process which involves further removal of the nitrogen by conversion of the nitrate to nitrogen gas. This represents a process for the ultimate removal of nitrogen from wastewater. As with vitrification, there are a number of system configurations that have been developed for denitrification. The most promising system alternatives include suspended growth and columnar systems (46). While there are advantages and disadvantages to either alternative, the more feasible system for military installations

will depend somewhat on effluent criteria. Where suspended solids are critical, a columnar unit may also serve as a filter. In other instances, the suspended growth system will usually be most appropriate.

c. Fixed film processes.

(1) Trickling filters. This type of treatment method has proven very popular over numerous years in the U.S. In 1968, more than 3,700 trickling filter installations existed in this country. In the past, the use of the trickling filter has been considered as the ideal method for populations of 2,500 to 10,000. The principal reasons for its past popularity have been cost, economics and operational simplicity as compared to the activated sludge process.

(a) Types. The trickling filter process is well documented in TM 5-814-3 and will not be repeated herein. The types of trickling filters used and their basic design criteria are set forth in table 6-3. BOD and hydraulic loadings are based on average influent values. Filters at military installations have either been low or high rate single stage facilities. One advantage of most low rate filters is that the longer solids retention time (SRT) in the unit allows for production of a highly nitrified effluent, provided the climatic conditions are favorable. By comparison, intermediate and high rate filters, which are loaded at higher organic and hydraulic loadings, do not achieve as good an overall BOD removal efficiency and preclude the development of vitrifying bacteria. The other classification of filters are those termed as super rate. These employ synthetic media and have been shown to be able to sustain much higher loadings than a stone medium unit. As a result, the super rate filters, in addition to normal applications for domestic and industrial wastewaters, have found applications as roughing filters prior to subsequent treatment facilities. The large surface area per unit volume (specific surface area) and high percent voids of synthetic media allow higher organic and hydraulic loadings. The greater surface area permits a larger mass of biological slimes per unit volume. The increased void space allows for higher hydraulic loadings and enhanced oxygen transfer due to increased air flow.

(b) Performance. Most existing trickling filter installations must be upgraded to meet the new secondary treatment requirements. Decreasing hydraulic or organic loading at existing facilities will not produce a significant increase in BOD removal above original design values; instead, additional treatment operations will be needed to achieve greater BOD removals. Performance of trickling filters is dependent upon several other factors including: wastewater characteristics, filter depth, recirculation, hydraulic and organic loading, ventilation and temperature. While all of these factors are important, wastewater temperature is the one which is most responsible for secondary effluent criteria not being met during winter operating conditions. Based on data from several high rate filters in Michigan, filter performance was observed to vary 21 percent between summer and winter months. Covering trickling filters or providing an additional stage should be considered for improving and maintaining performance.

(2) Rotating biological contractors. Another type of biological secondary treatment system is the rotating biological contactor. This system has been used in Europe, particularly West Germany, France and Switzerland. Manufacturers indicate 1000 installations in Europe treat wastewaters ranging in size from single residences to 100,000 population equivalent. Domestic, industrial and mixtures of domestic and industrial wastewaters have been treated. In the process, the large diameter corrugated plastic discs are mounted on a horizontal shaft and placed in a tank. The medium is slowly rotated with about 40 percent of the surface area always submerged in the flowing wastewater. The process is similar in function to trickling filters since both operate as fixed film biological reactors. One difference is that the biomass is passed through the wastewater in the biological contactor system rather than the wastewater over the biomass as in a trickling filter unit. No sludge or effluent recycle is employed. The system has several advantages, including:

- Low energy requirements compared with activated sludge.
- Small land area requirement compared with trickling filters.
- A high degree of vitrification can be achieved.
- A more constant efficiency can be achieved during cold weather than with trickling filters since the units are easily covered. The covers allow sufficient ventilation, but minimize the effect of low ambient air temperatures.

While the system has achieved high BOD removal efficiencies on domestic wastewaters in the U. S., pilot testing should be performed for any industrial application. A recent U.S. EPA study (42) on an industrial waste showed the biological contractors could not perform at the anticipated loading rate and achieve required removal efficien-

Table 6-3. General trickling filter design criteria

Filter Type	Organic Loading lb BOD/1000 cu ft/day		Hydraulic Loading mgad	Depth, ft	
	Literature	TM 5-814-3 Design Criteria		Literature	TM 5-814-3 Design Criteria
Low Rate (Standard)	10-20	up to 14	2-4	5-7	6
Intermediate	15-30	--	4-10	--	--
High Rate	up to 90	up to 70	10-30	3-6	3-6
Super Rate (Synthetic Media)	--	--	Less Than 50	--	--

ties. It also demonstrated that the activated sludge process was better able to handle shock loads. Although the system may not be applicable for certain industrial waste applications unless pretreatment is provided, it should be considered for upgrading existing military treatment plants treating primarily domestic wastewater. The process has potential as a second stage unit with existing trickling filters to improve performance and also as a vitrification unit. The rotating biological contractor can be considered as an option, however, the use may be limited to add-on or advanced wastewater treatment capacity for nitrogen removal until the RBC equipment reliability and economics have been improved.

(3) Activated biological filter. An activated biofilter (ABF) is a tower of packed redwood or other media which supports the growth of attached microorganisms. Influent wastewater is mixed with recycled solids from the clarifier and returned mixed liquor. The mixture is sprayed over the media and flows through the tower. Oxidation occurs in both the falling liquid film and in the attached growth. Less sludge is produced from ABF treatment, diminishing the size of the final clarifier. Reduced life-cycle and land costs, compensate for high capital cost. ABF treatment achieves the same degree of effluent quality as activated sludge process (39). Biological towers can be designed and operated with the same parameters as activated sludge systems. ABF's are used for both domestic and industrial applications.

(4) Anaerobic denitrification filter. Denitrification in attached growth anaerobic reactors has been accomplished in a variety of column configurations using various media to support the growth of denitrifying bacteria. In the denitrification column, the influent wastewater is evenly distributed over the top of the medium and flows in a thin film through the medium on which the organisms grow. These organisms maintain a balance so that an active biological film develops. The balance is maintained by sloughing of the biomass from the medium, either by death, hydraulic erosions or both. Sufficient voids are present in the medium to prevent clogging or pending. The denitrification column must be followed by a clarification step to remove sloughed solids. The various types of denitrification columns currently available are summarized below:

–Packed bed, nitrogen gas void space, high porosity media.

–Packed bed, liquid voids, high porosity media.

–Packed bed, liquid void, low porosity media.

–Fluidized bed, liquid void, high porosity fine media (sand, activated carbon).

Most denitrification work has been conducted on submerged columns wherein the voids are filled with the fluid being denitrified. The submerged columns can be further subdivided into packed bed and fluidized bed operations. Recently, a new type of column has been developed in which the voids are filled with nitrogen gas, a product of denitrification.

d. Miscellaneous Biological Systems.

(1) Package plants. A number of so called "package plants" have been developed to serve the wastewater treatment needs of small installations. Many of these units are available from a number of manufacturers. The small ones are all factory fabricated and shipped as nearly complete units except for electrical connections and other minor installation requirements. These will serve a maximum population of 300 to 400. Larger sized package plants are partially constructed in the factory and then field erected. These types of facilities generally will serve larger installations, up to about 1 mgd. Package plants are available as biological treatment facilities and some new units have been developed for physical-chemical treatment applications. Nearly all of the biological units use the activated sludge process, principally extended aeration and contact stabilization modifications. The small physical-chemical package plants have been developed mainly as "add on" units to existing biological facilities to provide additional removal of organic and inorganic constituents. Physical-chemical package units are available for multi-media filtration, phosphorus removal, nutrient removal and activated carbon operations. For widely varying flows at small installations, a battery of physical-chemical units might be employed. The on-off operation of these installations would not be satisfactory for biological units.

(2) Batch activated sludge. A batch activated sludge system utilizes a single tank reactor. The typical treatment cycle consists of:

—fill, in which the wastewater is received.

—react, which allows treatment reactions to be completed.

— settle, which separates the sludge from the effluent.

–draw, in which the effluent is discharged.

—idle, the time period between discharge and refill.

A batch activated sludge system combines the reactor and clarifier into a single unit. Sludge wastage can take place at either the end of the react cycle or after the settling cycle, prior to draw off of the effluent. If required, a higher wastage concentration can be obtained through draw off of the settled solids. Effluent quality can be considered essentially equal to conventional treatment, with its benefits being seen mainly with smaller sytems requiring a relatively low flow of wastewater for treatment.

(3) Sequencing batch reactors. The sequencing batch reactor system (SBR) uses two or more tanks with various functions operating in a sequence. The typical treatment cycle consists of the same steps as a single batch activated sludge treatment system, fill, react, settle, draw, and idle. The tanks fill in sequence in a multiple tank system, allowing for a joint reactor-clarifier unit. As with the batch activated sludge system, sludge wastage can occur from each reactor during either the react or settle mode. Vitrification and dentrification are possible through system modifications. The SBR system is capable of meeting effluent requirements, with operational and maintenance cost roughly equal to, and initial cost less than or equal to conventional systems (74).

(4) Septic system with recirculating sand filters. A septic system with a recirculating sand filter utilizes a conventional septic or Imhoff tank with a sand filter instead of a tile field (166). The system also includes a recirculation tank which receives effluent from the septic system as well as underflow from the sand filter. Effluent from the recirculator tank is pumped to the filter on a time basis. Float controls may also be required to keep the recirculation tank from overflowing. The purpose of the recirculation tank is to keep the sand filter wetted at all times. This system eliminates the odor problem common with intermittent filters. This system is applicable for small domestic facilities, recreational areas, etc.

(5) Overland flow. This technique is the controlled discharge, by spraying or other means, of effluent onto the land with a large portion of the wastewater appearing as run-off. Soils suited to overland flow are clays and clay silts with limited drainability. The land for an overland flow treatment site should have a moderate slope.

e. *Biological system comparisons.* Table 6–4 provides a comparison of the key wastewater treatment processes which must be considered for pollution control programs at military installations. These comparisons include major equipment required, preliminary treatment steps, removal efficiency, resource consumption, economics and several other factors which must be considered.

6-3. Physical and Chemical Wastewater Treatment Processes

a. Introduction. Physical and chemical processes may be categorized as treatment for the removal pollutants not readily removable or unremovable by conventional biological treatment processes. These pollutants may include suspended solids, BOD (usually less than 10 to 15 mg/L), refractory organics, heavy metals and inorganic salts. In domestic wastewater treatment, a physical-chemical process may be required as tertiary treatment to meet stringent permit applications. In industrial applications, physical-chemical treatment is frequently used as a pretreatment process in addition to its use as a tertiary process. The primary physical-chemical processes included in this manual are:

—Activated carbon adsorption.

–Chemical oxidation.

–Solids removal (clarification, precipitation).

Each of the treatment alternatives above, as well as, other less common physical chemical processes are discussed in this section.

b. Activated carbon adsorption.

(1) Description. Carbon adsorption removes many soluble organic materials. However, some organics are biodegradable, but not adsorbable. These will remain in the effluent from physical-chemical systems. While carbon adsorption is used in physical-chemical secondary treatment systems, its most significant application is as part of an advanced wastewater treatment system employing numerous schemes for additional constituent removal or as part of a system treating an industrial wastewater stream.

(2) Applications. Carbon adsorption has been adequately demonstrated in numerous pilot and full scale facilities as a system which can achieve a high degree of organic removal to satisfy water quality standards. The carbon adsorption process can be readily controlled and designed to achieve various degrees of organic removal efficiency. This feature makes it unique as an advanced wastewater treatment step. The activated carbon system is utilized to treat certain industrial process wastewaters from military installations including munitions wastes.

(3) Design considerations. Both the powdered and granular forms of activated carbon can be used. However, powdered carbon currently cannot be justified economically due to problems associated with regeneration of the material; thus, the present state-of-the-art in activated carbon

Table 6.4. Summary of primary and biological wastewater treatment processes

	Unit Process	Purpose	Major Treatment Equipment. Required	Preliminary Treatment Steps	Application
A.	Primary Sedimentation	Remove settleable suspended inorganic and organic solids.	Primary sedimentation tank with sludge collecting mechanism and skimming device.	Screening and usually grit removal .	Almost all domestic wastewaters. Must precede trickling filter. Does not have to precede activated sludge, but usually most economical method of reducing BOD and suspended solids.
B.	Trickling Fil ter Systems	Biologically convert dissolved and nonsettleable organic material and remove by sedimentation.	Trickling filter, settling tank and sludge collector, recirculation pumps (high rate units), and piping.	Must have primary treatment.	Removal of carbonaceous BOO. Under certain environmental conditions may achieve considerable nitrification.
c.	Activated Sludge System	Biologically convert dissolved and unsettleable suspended organic material and remove by sedimentation.	Aeration tank, aeration equipment, settling tank, sludge collector, sludge return pumps, and piping.	Usually primary treatment although not necessary.	Removal of carbonaceous BOO. Usually little nitrification unless designed for long solids retention time.
D.	Ponds	Combines the purposes of primary and secondary biological treatment as well as sludge treatment and disposal into one unit process.	Earthen pond with inlet and outlet structures.	None.	Small facilities where adequate land area is available. Good for intermittent wastewater discharge, but will not meet U.S. EPA-defined secondary treatment standards.
E.	Vitrification (Nitrogen Conversion)	Biologically oxidize ammonia to nitrates.	1. Suspended Growth System - vitrification tank, aeration equipment, settling tank and sludge collector. sludge return pumps, and piping. 2. Tricklinq Filter System - low-rate filter, settling tank and sludge collector. 3. Rotating Biological Contactor System - several RBC stages, settling tank and sludge collector.	Usually secondary treatment; although in many cases with proper design and operation, nitrification can be part of secondary treatment.	Where ammonia conversion or nitrogen removal is required.
F.	Denitrification	Biological removal of nitrogen by reduction from nitrates to nitrogen gas.	1. Suspended Growth system - denitrification tank with mixing equipment, final settling tank with sludge collection equipment, return sludge pumps and piping, chemical feed system, and possibly small aerated basin for release of nitrogen gas. 2. Columnar System - structure containing media similar to deep bed filter (gravity or pressure system), backwash and chemical feed equipment.	Most be preceded by vitrification step.	Where complete nitrogen removal is required and vitrification facilities are installed. Potential for combining with filtration step is good.

wastewater treatment is limited to granular carbon. Both upflow and downflow carbon contractors can be used. Upflow units more efficiently utilize carbon since counter-current operation is closely approached. Downflow contractors are used for both adsorption and some suspended solids filtration. Dual-purpose downflow contractors offset capital cost at the expense of higher operating costs. The following basic factors should be considered when evaluating an activated carbon system (l)(127):

—To avoid clogging, the influent total suspended solids concentration to the activated carbon unit should be less than 50 mg/L.

–Hydraulic loadings and bed depth are important design parameters, but contact time is the most important factor in carbon systems.

–For some domestic and certainly all industrial applications, treatability studies, (laboratory and pilot scale) must be conducted. This is essential since the carbon removes the dissolved trace organics from wastewaters by a combination of adsorption, filtration and biological degradation. Treatability studies will assist in evaluating these factors to optimize design criteria for the particular wastewater under consideration.

c. *Chemical oxidation.*

Table 6-4 (Cont'd). Summary of primary and biological wastewater treatment processes

	Removal Efficiency	Economics	Resource Consumption	Operation	Side Streams	Aesthetic Problems
A.	Removes 40 to 60% of suspended solids and 30 to 40% of BOO.	Capital costs are generally lower than secondary treatment. O&M costs are low.	Very small power consumption for sludge collection mechanism.	Simple to operate and maintain. Most operational labor associated with sludge removal.	Sludge-solids content 3 to 6%.	Severe odor problems if sludge is not removed periodically.
B.	Overall BOD removal (including primary sedimentation) about 85%. Effluent suspended solids 30 to 50 mg/L. Unless covered, removals drop off considerably In winter.	O&M costs are quite low.	Minimal power costs.	Relatively simple and stable operation. Not as easily upset as activated sludge systems. Tends to pass rather than treat shock loads.	Sludge - humus that sloughs off filter medium is generally returned to primary sedimentation.	Filter flies that breed in filter medium. Potential odors if overloaded or improperly maintained.
C.	Generally can remove 90+% of carbonaceous BOD. Effluent suspended solids usually are less than 30 mg/L.	O&M costs are considerably higher than trickling filter system.	High electrical power consumption to operate aeration equipment.	Requires more skilled operation than trickling filter. Subject to upsets with widely varying organic load, but can handle and treat shock loads.	Sludge - considerably more than trickling filter system. Low solids content (0.5 to 1.0%).	None if properly operated. Potential odors if improperly operated.
D.	Removes 99+% of original BOD, but algae in effluent may result in suspended solids (100 mg/L) and BOD (30 mg/L). High vitrification during warm weather. Must provide winter storage; no treatment during ice cover.	Relatively low construction cost and very low O&M costs.	None except land.	Minimal operation. Close effluent lines during ice cover and retain all wastewater until spring thaw.	None.	Odor problems during spring thaw as pond is turning from anaerobic to aerobic conditions.
E.	Greatly dependent on environmental factors such as temperature and pH. Can reach effluent ammonia Concentrations down to 1 to 2 mg/L. Also removes much of the carbonaceous BOD remaininq from secondary treatment.	Costs similar to the appropriate secondary treatment system (activated sludge, trickling filter, RBC).	High power consumption in suspended growth system.	Generally requires supervision equivalent to the appropriate secondary treatment process.	Almost negligible sludge production.	None if properly operated.
F.	Nitrates (as nitrogen) can be reduced to below 1 mg/L. Columnar system with fine grain media also can double as filter with appropriate suspended solids removal.	High construction costs. O&M costs relatively high due to carbon source such as methanol that usually is added to system.	Chemical use such as methanol; miminal power consumption.	Requires skilled operation, careful control of methanol feed, and system monitoring.	A relatively small amount of waste sludges are generated in suspended growth system and coarse grain columnar system. Backwash water in fine grain columnar system.	None apparent at time.

(1) Chlorination. Chlorine is the principal chemical utilized for disinfection in the U.S. Chlorine dosages vary, but for secondary treatment effluents the normal range is from 5 to 15 mg/L with requirements for a chlorine residual of not less than 0.2 to 1.0 mg/L after a 15 minute detention time at maximum flow rate (108). Regulatory requirements may differ in various States and consultation with the appropriate agency is recommended. Disinfection must meet the U.S. EPA fecal coliform level of 200/100 mL. General practice is to provide the chlorine feed either as gaseous chlorine, normally vaporized from liquid storage, or from a calcium hypochlorite solution feeder. Other than for extremely small plants, the gaseous chlorines more economical. However, many of the large metropolitan areas, such as New York and Chicago, have converted to the use of hypochlorite solutions due to the potential hazards involved in transporting chlorine through populated areas. Where treatment facilities are remotely located, such as many military installations, gaseous chlorine will be acceptable provided suitable safety precautions are taken with shipping and handling. Possible disadvantages of chlorine disinfection are the toxicity of the chlorine residual to aquatic life and the potential of the chlorine combining with organic material in the effluent or the receiving stream to form cancer-causing compounds. Some States and the U.S. EPA have proposed limitations on the residual chlorine concentration in both effluent and streams. Thus, for some chlorination systems additional detention time, addition of a reducing agent (sodium bisulfite or sulfur dioxide), or passage through activated

carbon may be required to reduce chlorine residuals prior to discharge.

(2) Alkaline chlorination. Use of breakpoint chlorination to oxidize ammonia to nitrogen gas, which is released to the atmosphere, has been used in water treatment for numerous years. the process requires large chlorine dosages (8 to 10 mg/L chlorine for each mg/L of ammonia oxidized) resulting in high operating costs. Adjustment of pH is often required and formation of complex organic-nitrogen-chlorine compounds have been harmful environmental effects. Application will be limited to removal of trace ammonia after some other ammonia removal process.

(3) Ozonation. An alternative to chlorine is use of another disinfectant such as ozone. Manufacturer's literature indicate over 500 water treatment plants in Europe use ozone for disinfection. Chlorine, however, remains the predominant disinfectant for portable water in the U.S. Although ozone has had limited application in wastewater treatment, equipment manufacturers and other literature report many pilot studies have been and are currently being conducted. Results indicate ozone is an effective disinfectant for wastewater effluents. Use of ozone avoids the problems with aquatic life and disinfects at a faster rate than chlorine. Ozone, however, is 10 to 15 times as expensive as chlorine and on-site generation is necessary (80).

(4) Hydrogen peroxide oxidation. Hydrogen peroxide (H_20_2) is a strong oxidizer but has only limited application in the disinfection of wastewater. This is primarily because three to four hours of contact time is required to accomplish disinfection and it tends to leave a distinctive taste. The primary use of hydrogen peroxides is in industrial applications where it is extremely effective in oxidizing a wide variety of pollutants. Uses include destruction of cyanide which is generated from electroplating and destruction of organic chemicals including chlorinated and sulfur containing compounds and phenols. Hydrogen peroxide is clear, colorless, water like in appearance and has a distinctive pungent odor. Hydrogen peroxide is not a hazardous substance and is considerably safer to handle and store than chlorine gas.

(5) Ultraviolet radiation. Ultraviolet radiation is a very effective alternative to chemical oxidation. This method consists of exposure of a film of water up to several inches thick to quartz mercury-vapor arc lamps emitting germicidal ultraviolet radiation. This technique has been reported to have been used on small systems in Europe for over 100 years. Although this alternative is receiving attention as an alternate, it remains unattractive due to high capital and operating costs for other than very small systems.

(6) Ionizing radiation. Application of ionizing radiation as an alternative to chlorine or ozone for disinfecting wastewater and as an alternative to heat for disinfecting sludge is now in the development and demonstration stage in the U.S. and in Europe. Both gamma rays and high energy electrons are being evaluated. The technical feasibility has been established but data to assess the cost-effectiveness are not yet available. Experience to date with ionizing radiation indicates that applications will be characterized by relatively high capital costs and moderate-to-low operating costs. In addition to destroying microorganisms in wastewater and sludge, ionizing radiation has shown capabilities of reducing concentrations of phenol and surfactants, increasing settling rates and destroying chlorine in wastewater, and improving physical characteristics of sludge. Engineers concerned with either upgrading existing wastewater treating facilities or designing new facilities should be aware of this developing area of potentially applicable technology. Reference to available literature or contact with HQDA (DAEN-ECE-G) WASH DC 20314, is suggested, Authority to apply this emerging technology in any waste treatment process must be obtained from DAEN-ECE-G.

d. Solids removal.

(1) Chemical precipitation phosphorus removal.

(a) Description. Phosphorus removal is needed because it is a major nutrient for algae and other aquatic vegetation. The sources of phosphorus in a typical domestic wastewater for a military facility are associated with human excretions, waste foods and laundry products. While conventional wastewater treatment techniques, i.e., primary sedimentation and secondary treatment, will remove about 10 to 40 percent of influent phosphorus, it often becomes necessary to provide for additional removal to meet effluent or water quality criteria. Numerous States in the U.S. have developed water quality criteria and/or effluent standards for phosphorus. Typical limitations are 1 to 2 mg/L. However, recent standards being considered by regulatory agencies indicate levels for given situations may become more stringent. The U.S. EPA should be contacted for requirements when wastewater treatment facilities alternatives include phosphorus removal.

(b) Application. Some biological techniques for removing phosphorus have been identified,

but no large scale or long term demonstrations of the process have been undertaken. The common method of removal is by chemical treatment usually employing alkaline precipitation with lime or precipitation using minerals (iron or aluminum salts). The process can be accomplished in numerous ways either in the primary system, secondary system or as a separate system. The particular method to employ at a given installation is a matter of numerous constraints. The two predominant methods are mineral addition to the primary clarifier and lime clarification after secondary treatment, although addition of minerals or lime to the final clarifier of trickling filter systems has been successful. Mineral additions to the primary or secondary clarifier will not usually provide quite as low a phosphorus level as lime precipitation. All precipitation processes increase sludge quantities which must be handled. Recalcination of lime will not be economical at most military facilities. Design considerations for the various phosphorus removal alternatives are presented in TM 5-814-3 and the U.S. EPA Process Design Manual for Phosphorus Removal.

(2) Sedimentation.

(a) Process description. Sedimentation is the separation of suspended particles that are heavier than water from water by gravitational means. It is one of the most widely used unit operations in wastewater treatment. This operation is used for grit removal; particulate-matter removal in the primary settling basin; biological-floc removal in the activated sludge settling basin; chemical-floe removal when the chemical coagulation process is used; and for solids concentration in sludge thickeners. Although in most cases the primary purpose is to produce a clarified effluent, it is also necessary to produce sludge with a solids concentration that can be easily handled and treated. In other processes, such as sludge thickening, the primary purpose is to produce a concentrated sludge that can be treated more economically. In the design of sedimentation basins, due consideration should be given to production of both a clarified effluent and a concentrated sludge (125).

(b) Clarifier design. Clarifiers may either be rectangular or circular. In most rectangular clarifiers, scraper flights extending the width of the tank move the settled sludge toward the inlet end of the tank at a speed of about 1 ft/min. Some designs move the sludge toward the effluent end of the tank, corresponding to the direction of flow of the density current. Circular clarifiers may employ either a center feed well or a peripheral inlet. The tank can be designed for center sludge withdrawal or vacuum withdrawal over the entire tank bottom. Circular clarifiers are of three general types. With the center feed type, the waste is fed into a center well and the effluent is pulled off at the weir along the outside. With a peripheral feed tank, the effluent is pulled off at the tank center. With a rim-flow clarifier, the peripheral feed and effluent discharge are also along the clarifier rim, but this type is usually used for larger clarifiers. The circular clarifier usually gives the optimal performance. Rectangular tanks may be desired where construction space is limited. The circular clarifier can be designed for center sludge withdrawal or vacuum withdrawal over the entire tank bottom. Center sludge withdrawal requires a minimum bottom slope of 1 in/ft. The flow of sludge to the center well is largely hydraulically motivated by the collection mechanism, which serves to overcome inertia and avoid sludge adherence to the tank bottom. The vacuum drawoff is particularly adaptable to secondary clarification and thickening of activated sludge. The mechanisms can be of the plow type or the rotary-hoe type. The plow-type mechanism employs staggered plows attached to two opposing arms that move about 10 ft/min. The rotary-hoe mechanism consists of a series of short scrapers suspended from a rotating supporting bridge on endless chains that make contact with the tank bottom at the periphery and move to the center of the tank.

(3) Microscreening. The use of microscreening or microstraining in advanced wastewater treatment is chiefly as a polishing step for removal of additional suspended solids (and associated BOD) from secondary effluents. The system consists of a rotating drum with a peripheral screen. Influent wastewater enters the drum internally and passes radially outward through the screen, with deposition of solids on the inner surface of the drum screen. The deposited solids are removed by pressure jets located at the top of the drum. The backwash water is then collected and returned to the plant. The screen openings range from about 23 to 60 microns depending upon manufacturer type and material. However, the small openings themselves do not account for the removal efficiency of the unit. Performance is dependent on the mat of previously trapped solids which provide the fine filtration. Thus an important factor in design is the nature of the solids applied to the system. The strong biological floes are better for microscreening; weak chemical floe particles are not efficiently removed. Depending upon the influent wastewater characteristics and the microfabric, suspended solids removals have

ranged from about 50 percent to as high as 90 percent. Maintenance of the units can be costly, since they require periodic cleaning. For further information, the U.S. EPA "Process Design Manual for Suspended Solids Removal", and "Process Design Manual for Upgrading Wastewater Treatment Plants".

(4) Filtration. Secondary effluents normally contain minerals which range from the easily visible insoluble solids to colloids. Filtration is one means of removing the suspended solids (and the BOD associated with the suspended solids) remaining after secondary sedimentation to a level which will meet effluent or water quality criteria. Filtration methods most applicable to military facilities are the multimedia filter and the diatomaceous earth system. For information on design criteria and operating considerations, the U.S. EPA Process Design Manual for Suspended Solids Removal should be consulted.

(a) Multi-media. Recently, dual-media, mixed-media and multi-media filtration units have basically replaced the conventional single medium filter otherwise known as the "rapid-sand filter" for wastewater applications. These filters, widely utilized in advanced wastewater treatment, are sometimes referred to as "deep-bed" filters. Single medium filters have a fine-to-coarse gradation in the direction of flow which results from hydraulic gradation during backwash. This gradation is not efficient, since virtually all solids removal must take place in the upper few inches of the filter with a consequent rapid increase in headloss. A coarse-to-fine gradation, as used by multi-media units, is more efficient since it provides for greater utilization of filter depth, and uses the fine media only to remove the finer fraction of suspended solids. The multi-media filter is capable of producing effluents with suspended solids of less than 10 mg/L from typical feed concentrations of 20 to 50 mg/L. This also reduces the BOD since about one-half of the BOD of a secondary effluent is normally associated with the suspended solids. The feed concentration must be kept below 100 mg/L of suspended solids for practical backwash cycles. A typical multi-media system consists of three or more materials, normally anthracite (coal), sand and garnet, with carefully selected specific gravities. Dual-media filters usually utilize anthracite and sand. The filtering system is supported by a few feet of gravel or other support means. Addition of small amounts of coagulant chemicals such as alum or polymer enhances filtration. Multi-media filtration is a process normally associated either with physical-chemical wastewater treatment or as a polishing step after biological treatment. It is particularly applicable for removal of the weaker chemical floe particles while surface straining devices such as rapid-sand filters and microstrainers work well with the stronger biological floes. Use of the filters for the dual purpose of solids removal and as a fixed media for denitrification should also be considered where both processes are necessary. A summary of information on effluent suspended solids to be expected from a multi-media filtration system is indicated in table 6-5.

*Table 6-5. Expected effluent suspended solids from multi-media filtration of secondary effluent**

Effluent Type	Effluent Suspended Solids, mg/L
High-Rate Trickling Filter	10-20
Two-Stage Trickling Filter	6-15
Contact Stabilization	6-15
Conventional Activated Sludge	3-10
Extended Aeration	1--5

*Adapted from the U.S. EPA "Process Design Manual for Suspended Solids Removal".

(b) Diatomaceous earth. Filtration by diatomaceous earth consists of mechanically separating suspended solids from the wastewater influent by means of a layer of powdered filter aid or diatomaceous earth, applied to a support medium. The use of the system for clarification of domestic secondary treatment effluent has been demonstrated only at pilot scale facilities. Multimedia filters are more cost–effective for domestic wastewaters from military installations. However, the diatomaceous earth system is applicable and currently being used as part of a treatment step in munitions wastewater treatment.

e. *Membrane processes.* Other feasible methods of advanced wastewater treatment consist of what are generally known as the membrane processes, and include electrodialysis, ultrafiltration and reverse osmosis. These processes can remove over 90 percent of the dissolved inorganic material to produce a high quality product suitable for discharge or reuse. Considerable pretreatment is required. Use of these membrane processes in the field of wastewater treatment is at the present time limited because the costs are very high and applications will be to small flows at best. For example, a possible application is the treatment for reuse of small process discharges at military field installations. Three different reverse osmosis units were evaluated at a field location by the U.S. Army Environmental Hygiene Agency (1). This study was initiated to determine the feasibility of treating and reusing wastewater from field laundries, showers and kitchens. Where it may be necessary to consider the application of a membrane process for reuse or discharge, reference should be made to appropriate design manuals or manufacturer's literature for information on design criteria.

f. Physical and chemical process comparisons. Table 6-6 provides a comparison of the key wastewater treatment processes which must be considered for pollution control programs at military installations. These comparisons include major equipment required, preliminary treatment steps, removal efficiency, resource consumption, economics and several other factors which must be considered.

6-4. Industrial process wastewater treatment

a. Introduction. Except at those facilities where the principal function is manufacturing, processing or equipment maintenance, the major portion of wastewater produced at a military installation will be domestic waste similar in characteristics to that produced in a residential area. However, for those installations with industrial facilities, certain process wastes produced on-site require separate consideration. The following are examples of these waste producing processes:

–Munitions manufacturing, loading, assembling and packing.
–Metal plating.
–Washing, paint-stripping and machining operations.
–Photographic processing.
–Laundry.

Other process waste sources include hospitals and blowdown from cooling towers, boilers and gas-scrubber systems. Chapter 3 of this manual describes typical industrial waste producing pro

Table 6-6. Summary of physical and chemical wastewater treatment processes

	Unit Process	Purpose	Major Treatment Equipment Required	Preliminary Treatment Steps	Application
A.	Breakpoint Chlorination for Ammonia Removal	Removes nitrogen by chemi - tally concerting to nitrogen gas. Process also serves as disinfection step.	Chlorine contact basins and chlorination equipment may require carbon adsorption step to remove potentially toxic chloro-organic compounds formed.	At least secondary treatment. Nitrogen must be in ammonia form. The higher the degree of treatment, the less chlorine required to reach breakpoint.	Nitrogen removal . Hiqh chemical costs and side effects make process most attractive as a back-up system in case of failure of primary nitrogen removal process and for removal of remaining trace ammonia concentrations.
B.	Lime Clarification	Primary purpose is to chemically precipitate phosphorus. Secondary purpose is to remove suspended solids and associated BOO.	Clarifier, usually solids contact up-flow type, with sludge collection equipment; chemical feed equipment; and recarbonation facilities. Low alkalinity wastewaters may require two-stage system with two clarifiers. Lime recal - cining furnace and related equipment may be used for large facilities.	Usually secondary treatment although lime clarification of raw wastewater is practiced in physical-chemical plants.	Where standards require over 90% phosphorus removal, or phosphorus concentrate ions below 0.5 mg/L, or as an additional step for suspended sol ids removal. Recalcination of lime sludge generally uneconomical in plants under 10 mgd capacity.
C,	Mineral Addition to Primary Sedimentation	Primary purpose is to chemically precipitate phosphorus. Secondary purposes are increased suspended sol ids and BOO removal in primary sedi - mentation, thereby decreasing the load on secondary treatment facilities.	Chemical feed equipment, mixing and flocculating basins for existing primary sedimental ion basins.	Screening and usual1 y grit removal.	Where standards require 80 to 90% phosphorus removal. Phosphorus removals over 90% usually cannot be achieved by this process. Upgrading existing treatment plants where secondary treatment facilities are overloaded.
D.	Multi-Media Filtration	Suspended sol ids remova 1.	Filters and backwash equipment.	Generally at least secdary treatment.	Where a high degree of suspended solids removal is required. Particularly applicable following chemical clarification because of "in depth" filtration characteristics.
E.	Microscreening	Suspended sol ids removal.	Microscreens and tanks.	Seconary treatment.	Removal of suspended solids from secondary effluents. Works best with strong biological floc particles. Not used for chemically clarified effluents because weak chemical floc particles will break through screen.
F.	Granular Carbon Adsorption	1. AWT-remove non-biodegradable dissolved organics following secondary treatment 2. PCT - remove organic material instead of by biological treatment.	Carbon contractors, carbon regeneration furnance, and carbon storage facilities	1. AWT - secondary treatment followed by filtration for down-flow contractors. Filtration not necessary for up-flow contractors. 2. PCT - chemical coagulation of raw wastewater.	1. AWT - to remove trace organic and produce high quality effluent. 2. PCT - remove carbonaceous BOD as in secondary biological treatment.

Table 6-6 (Cont'd). Summary of physical and chemical wastewater treatment processes

	Removal Efficiency	Economics	Resource Consumption	Operation	Side Streams	Aesthetic Problems
A.	Can essentially remove 99+% of ammonia.	Low capital and high O&M cost.	Chlorine. Large quantities needed (from 8 to 10 mg/L for each mg/L of ammonia oxidized).	Requires careful or automatic monitoring to control dose and PH. May require addition of chemicals to control PH.	None.	Adds considerable amount of chlorides to wastewater.
B.	On secondary effluents can remove 99+% of the total phosphorus. Suspended solids levels will be in the 10 to 20 mg/L range.	Construction costs are moderate, but O&M costs are high due to chemical (lime) addition. Disposal of lime sludge must be included in costs.	Lime quantities depend on wastewater alkalinity but generally are high. If recalcination is practiced, fuel consumption will be high but lime is recovered. Power consumption is minimal.	Careful attention to chemical dosage and sludge blankets in clarifiers. Recalcination requires skilled operation.	Lime sludge. Large quantities which, if recalcined, will result in ash for disposal. If not recalcined, must be dewatered for disposal.	None with operation of clarifiers. Potential air pollution problem with recalcining furnace.
C.	Approximately 80% phosphorus removal in primary sedimentation. Overall phosphorus removal after secondary treatment will range from 85 to 95%. Increase suspended solids removal to 60 to 75% and BOD removal to 40 to 50% in primary sedimentation.	With existing primary sedimentation tank capital cost is small compared to lime clarification of secondary effluent. O&M costs are high becasue of chemicals-usually alum or an iron salt. Must consider increased quantities of primary sludge in costs	Chemicals, either alum or iron salt.	Similar to primary sedimentation except for close attention to chemical feed and flocculation.	Increased quantity of primary sludge including chemical precipitates. It may be necessary to enlarge existing sludge handling facilities. Increased primary sludge offset somewhat by reduced secondary biological sludges.	Potential sludge odor problems if improperly handled.
D.	Filter effluents with suspended solids from 0 to 2 mg/L can be obtained with chemically clarified secondary effluents. Removals for secondary effluents depend on degree of bio-flocculation, but range from 3 to 10 mg/L for activated sludge plants to 10 to 20 mg/L for trickling filter plants. Also removes BOD and phosphorus associated with suspended material.	Construction costs are high and O&M costs are moderate.	More power use than microscreening.	Reliable. Can handle shock shock loads. Relatively easy to operate and maintain.	Backwash water.	None
E.	With secondary effluents suspended solids removals will vary from 50 to 80% and BOD removals from 40 to 70% depending on size of screen openings.	Costs generally less than multi-media filtration.	Minimal power use.	Some slime growth problems on screen. Flow through screen very sensitive to solids loading.	Screen backwash water.	None.
F.	1. AWT - with biological pretreatment can get COD 10 mg/L and BOD 1 mg/L. 2. PCT - cannot remove COD and BOD to levels in AWT due to nonadsorbable biodegradable organic (sugars and alcohols).	High capital and O&M costs. One of the most expensive wastewater treatment processes.	High fuel consumption. for carbon regeneration. Power use is relatively small.	Monitoring carbon column break through and carbon regeneration requires skilled operation.	Considerable waste activated carbon without regeneration; very small-amounts with regeneration.	Regenerat on furnace potential air pollution prob em.

cesses, waste characteristics. This section describes waste reduction and treatment methodology applicable to military installations.

(1) Considerations. The need to consider industrial process wastes separately is based on the following potential effects:

—Degradation of the sewer lines by corrosion or chemical attack and/or production of an environment dangerous to maintenance and operating personnel.

–Interference with normal treatment plant processes.

–Inability of treatment plant processes to reduce a process waste constituent to a level required by regulatory constraints or other environmental considerations.

(2) Limitations. Brief descriptions of processes are included in chapter 3 to serve as a basis for consideration of the effect of such wastes on facility planning. Typical analyses of

some process wastes are also provided. The quantity and quality of process wastes produced often vary in similar installations; therefore, data presented are descriptive only. To establish basic design criteria, more detail is required. The applicability of the wastewater treatment and sludge disposal processes presented elsewhere is discussed for each special process in this section.

b. Munitions wastes. Wastes generated from the munitions industry originate from both manufacturing (MFG) plants as well as loading, assembling and packing (LAP) facilities.

(1) Explosives and propellants. The major explosive product produced is trinitrotoluene (TNT). Other explosive chemicals that are generated in military installations include:

—nitroglycerine.
—HMX and RDX.
—tetryl.
—nitrocellulose.
—black powder.
—nitroguanidine.
—lead azide.
—lead styphnate.

A description of the manufacturing process utilized for each explosive, as well as typical wastewater characteristics are included in chapter 3.

(a) Waste reduction. Process changes to include increased chemical recovery/reuse and good housekeeping are important waste reduction practices in the manufacture of explosives and propellants. For examples, as indicated in chapter 3, changing from batch-type to continuous TNT manufacturing resulted in lower chemical and water usage and reduced waste volumes (20)(23)(116). High pressure water sprays also may result in decreased cleanup water usage. Batch-dumping of process wastes and acids must be discouraged. Whenever cooling water is reasonably uncontaminated, it should be segregated from the contaminated water streams, thereby reducing the volume of waste to be treated.

(b) Sampling and gaging. Care must be taken in establishing a sampling program for explosives manufacturing wastes which will accurately represent the waste flow and characteristics. This is necessary because of the difference in waste characteristics from different manufacturing plants, even if they are making the same product. Batch dumping, periodic cleanup operations and changes in production levels all contribute to wide variations in flows and concentrations. Such variations can result in the need for added treatment capacity and/or provision for equalization storage. Cost-effective design and operation of treatment equipment depend on accurate assessment and management of waste flow and quality.

(c) Environmental impact. The blood-red color from red water produced in TNT manufacture and fish kills resulting from high acid concentrations are the most readily visible environmental impacts of improperly treated explosive wastes. High oxygen demand, excessive nitrate compounds, elevated temperature and high suspended solids also contribute to the gradual degradation of the receiving body of water.

(d) Treatability. Explosives manufacturing wastes are sometimes toxic to conventional biological treatment plants, but may be treated by physical and chemical methods and by specifically adapted biological means. Waste acids may be neutralized with lime or other alkaline material using conventional pH control methods. Activated carbon adsorption has been successful for removing color-causing TNT compounds as well as HMX and RDX (20)(116)(130). The acidic wastes must not be neutralized with lime until after carbon treatment, because color removal efficiency is greater at low pH, and precipitates formed by lime addition will encrust and clog the carbon column. Color may also be removed by ion exchange, although problems exist with resin regeneration. Wastewater from an acid plant in a TNT manufacturing complex has been successfully treated by lime precipitation followed by ion exchange (11 5). Biodegradable explosives wastes, including dynamite, nitrocellulose, HMX and RDX and TNT to some extent, may be treated by biological methods such as land irrigation or activated sludge after process proof by bench and pilot scale studies (77)(106)(107). Lead resulting from the production of lead azide and lead styphnate may be removed by chemical precipitation using sodium sulfhydrate.

(e) Red water treatment. Red water is currently one of the most difficult disposal problems. Red water has been sold to kraft paper mills when transportation costs make this economically feasible. In other cases, it has been burned in an incinerator. Where land permits, evaporation ponds have been used; care must be taken to effectively line the pond to prevent ground water contamination from leaching. Fluidized bed incineration and recycle of the resultant ash are being studied (87).

(2) Projectiles and casings. The manufacture of the lead slugs, bullet jackets and shell casings generates wastewater different in composition than from explosives manufacture. Waste constituents include heavy metals, oil and grease, soaps and surfactants, solvents and acids.

(a) Waste reduction. Waste reduction practices which should be evaluated include use of counter-current flow of successive rinse waters, separation and reuse of lightly contaminated water (such as cooling water), elimination of batch-dumping of processing solutions, recovery and reuse of metals and pickling liquor, and provisions to divert highly contaminated spills to holding tanks for individual treatment.

(b) Gaging and sampling. Due to the extreme variations in flows and characteristics encountered, careful sampling and gaging procedures must be employed in order to characterize the waste and identify peak values. Identification of peak values is helpful in tracing batch dumping and is essential to cost-effective design of treatment facilities.

(c) Environmental impact. The environmental impact of metal working wastes can be acute. Heavy metals, acids, surfactants and oils are all highly toxic to aquatic life. Serious stream degradation results from the direct discharge of insufficiently treated metal wastes.

(d) Treatability. Toxic materials present in the wastewaters from munitions metal parts manufacturing can interfere with biological treatment. Treatment methods available include neutralization with lime, heavy metal removal and recovery by precipitation or cementation, and oil removal by gravity separation. Suitably pretreated wastes will be cost-effectively treated along with domestic wastes in biological facilities (21).

(3) Loading, assembling and packing wastes. The main LAP operations are explosives receiving, drying and blending operations, cartridge and shell-filling operations and shell-renovation. The main waste sources are spillage, cleanup water, dust and fume scrubber water and waste flows from renovation operations.

(a) Waste reduction. Waste reduction which should be considered in a pollution control program can be accomplished by reuse of lightly contaminated water for air-scrubbing and shell-washout. In the shell-loading operation, the use of covered hot water baths and shell-loading funnels can reduce or eliminate explosives contamination of the water baths. High-pressure water sprays can reduce the amount of water used for cleanup. Recovery of waste explosives from shell-washout operations reduces the waste load and is an economic incentive. Proper wastewater gaging and sampling practices can be quite helpful in identifying the source of any unauthorized batch-dumps and lead to waste reduction practices.

(b) Environmental impact. The environmental impacts of LAP wastes include red coloration from TNT-containing wastewater, heavy metal toxicity, oxygen depletion and toxicity and bitter tastes from excess nitrates (11)(20).

(c) Treatability. LAP plant wastes have been treated successfully by diatomaceous earth filtration followed by activated carbon adsorption. Effluents of less than 5 mg/L of TNT are readily attainable. Suspended solids removals by the diatomaceous earth filters have, in some instances, been much less than expected. Presence of suspended solids in waste entering the activated carbon filter greatly reduces the effective life of the carbon unit due to clogging. Normally, the spent carbon is burned, although experimental work is being performed to determine the feasibility of regeneration in fluidized beds. Carbon usage varies from 2 to 7.5 lb carbon/1000 gal (11)(20). Plating wastes from renovation operations are treated in the manner described in chapter 3.

c. *Metal plating.* The major waste sources are rinse water overflow, fume-scrubber water, batch-dumps of spent acid, alkali, or plating bath solutions, and spills of the concentrated solutions.

(1) Plating waste separation. Processing solutions are often replaced on an intermittent basis; consequently, dumps of spent solutions impose a heavy short term load on treatment facilities. Therefore, separate collection of waste process solutions and rinse waters should be evaluated. Separation as to type of waste is also desirable to facilitate later treatment and to avoid the production of the toxic hydrogen cyanide gas at low pH levels. Categories for waste separation are as follows:

—Oil bearing wastes from cleaning operations.

—Acid wastes including waste pickling liquor, acid-plating solutions, and anodizing solutions.

—Alkaline wastes including cyanide-plating solutions.

(2) Waste reduction practices. There are a number of waste reduction practices which can be effective and should be considered for plating operations including: dragout reduction, process/chemical changes, and good housekeeping (35)(41)(111).

(a) Plating waste dragout reduction. Reducing the dragout from chemical baths not only reduces the contamination of successive rinse water, but it also prolongs the life of the chemical bath. Some dragout reduction practices which should be evaluated are:

- —Design special drip pans, high-pressure fog-sprays, air knives and shaking mechanisms.
- — Improve racking procedures and minimize overcrowding on the rack to facilitate drainage of process chemicals back into the chemical tank.
- —Increase drainage time over the process tank or install an empty tank upstream from the rinse operation in which the process solution can be drained and returned to the process tank.
- –Reduce the viscosity of plating agents with either water or heat.
- —Add wetting agents to process solutions to reduce surface tension and facilitate drainage.

(b) Plating process changes. Changes in process or chemicals used can result in a reduced waste volume, reduced waste strength or a waste which is more readily treatable. Process/ chemical changes include the following and should be considered in pollution control evaluations:

- —Eliminate use of breakable containers for concentrated solutions.
- —Employ a recovery step for metals from the waste stream. This adds an economic incentive to cleanup the effluent.
- —Recirculate the water used in the fume-scrubber systems.
- —Separate cyanide wastes from chromium bearing and other acid wastes to avoid production of lethal hydrocyanic acid fumes.
- —Substitute high-concentration plating solutions for low-concentration solutions, reducing the volume of waste to be treated.
- —Replace cyanide salt plating solutions with low cyanide or cyanide-free solutions.
- —Use counter-current rinse flows rather than using fresh water in all rinses.

(c) Plating waste reduction by other means. Good housekeeping steps are important waste reduction practices which should be employed for all industrial operations; those particularly important to plating include the following:

- —Curb areas which have chronic spillage or leakage problems and divert spills to a holding tank for treatment.
- — Increase inspection and maintenance of pipes, valves and fittings to prevent leaks and spills.

(3) Gaging and sampling. Because of the concentrated processing solutions used and their highly variable characteristics, proper wastewater gaging and sampling is essential in determining the characteristics and sources of batch-dumps and the resultant peaks. Sampling of effluents from the individual waste sources can be an important supplement to end-of-pipe data.

(4) Environmental impact. The extremes of pH and the high concentrations of heavy metals and cyanides are extremely toxic to all forms of life. Fish kills and even fatalities to livestock have been reported when plating wastes were fed directly to a body of water (34). The accumulation of heavy metals in sediment causes long term pollution. In addition, toxicity to micro-organisms retards the self-purification abilities of the receiving stream.

(5) Treatability. Plating wastes may be treated by conventional municipal biological processes if sufficient dilution is provided. Otherwise, the extreme toxicity of the waste will seriously interfere with the biological processes. Just as heavy metals become concentrated in stream sediments, they also accumulate in treatment plant sludge and can interfere with subsequent biological treatment processes and disposal procedures. Pretreatment of industrial wastes to reduce constituents to levels which will be compatible with biological treatment is required. Pretreatment requirements for plating wastewater to ensure successful subsequent treatment with domestic waste may require pilot scale studies (34)(76)(78). The pH control, cyanide destruction and heavy metal removal/recovery methods discussed in chapter 3 are capable of providing the required pretreatment for discharge to a biological treatment system or directly to a receiving body of water. Such treatment may also permit recycling and reuse of the water for some process needs. In many cases, it is desirable to integrate the treatment operations into the overall plating scheme (33)(109).

d. Washing, paint-stripping and machining. Washing and paint stripping of aircraft and land vehicles is performed as routine maintenance or in preparation for repairing, overhauling and machining of a part or component of the aircraft or vehicle.

(1) Waste reduction practices. The volume of washrack and paint-stripping wastewater to be treated can be reduced considerably by excluding storm water and by employing practices to reduce the amount of water used. It is reported that some U.S. commercial airlines have used hot, rather than cold, water sprays in the paint-

stripping operation, resulting in a water usage of only four gallons per gallon of stripper. Also, squeegees are used to remove the paint-stripper and paint skins onto plastic sheets which are disposed of at a sanitary landfill (29).

(2) Gaging and sampling. Care must be taken when sampling wastewaters with high oil contents, such as washrack and paint-stripping wastes, to ensure that a representative sample is obtained (15 1). The precaution is required due to the tendency of oil to float on the water surface.

(3) Environmental impact. Washrack and paint-stripping wastewaters containing high concentrations of phenols, organic solvents, chromium, oils and surfactants are extremely toxic to aquatic life. Failure to properly contain and treat these wastes can result in fish kills, stream purification inhibition and odors. All of these are unacceptable by any water quality standards (26)(29)(1 13). Oils from machining operations can be toxic and may impose a high oxygen demand on the receiving body of water.

(4) Treatment. Unless highly diluted, the raw wastewaters from machining and paint-stripping operations and washracks utilizing solvents are highly toxic to the microorganisms of biological treatment plants, interfering with both aeration and sludge digestion processes. Paint-stripping wastes are particularly toxic. A typical pretreatment system for a major facility would include the following steps:

–Gravity separation tank equipped to remove floating oils and settleable solids.

–Detention tanks with mixing to provide equalization of flow and waste strength as well as to permit evaporation of volatile solvents.

–Chemical addition in a rapid mix tank followed by slow mixing in a separate tank to promote flocculation, break emulsions and agglomerate solids.

–Final treatment in an air flotation unit to remove flocculated particles.

For smaller facilities, where washrack wastes are only a small part of the total waste flow, an alternate approach can be used. A storage tank, arranged to receive this waste and equipped with air mixing and adequate air emission controls, would provide for evaporation of a part of the volatile solvents and permit pumping to the main sewer at a controlled rate. At the main treatment plant, the primary settling tank preceding biological treatment will have adequate oil and solids removal capacity.

e. *Photographic processing.* Because of the widespread use of photography in military operations, the military services operate many photoprocessing facilities. The size of such facilities varies greatly, with waste flows of 10,000 to 1,000,000 gallons per month. Liquid wastes originate from the discharge of spent processing solutions and associated rinse or washwaters. Approximately 90 percent of the liquid waste produced is from the rinse operations.

(1) Waste reduction practices. Waste reduction practices include recovery of silver, regeneration of ferrocyanide and other chemicals, chemical bath reuse and the use of squeegees to reduce the carryover, or dragout, of chemicals from one step to another.

(a) Silver recovery. Because of the high market value of silver, it can be economically recovered from the spent bleach and fixer solutions as well as from the final washwater. Such recovery reduces the impact of silver as a pollutant and in some cases allows the fixer solution to be reused, reducing chemical replacement costs. Silver recovery is most often accomplished by passing the waste effluent through a proprietary steel-wool-filled canister where silver is exchanged for iron. Silver can also be removed by precipitation with sodium sulfide or by electrolysis.

(b) Bleach regeneration. The bleach solution may also be reused by regenerating ferrocyanide from the spent ferrocyanide using oxidizing agents such as persulfate and ozone. One manufacturer offers a packaged bleach regenerator material (123). Regeneration provides a cost savings as well as pollutant reduction. Methods of complete cyanide destruction are discussed later in this chapter.

(c) Equalization. Equalization is very important if photographic wastes are treated biologically, particularly when the photographic processing operation occurs during only part of the day. Daily variations in flow and concentration can cause serious operating difficulties at the treatment plant.

(2) Gaging and sampling. To define wastewater quality and quantity for a new installation, sampling and gaging data from a similar operating facility is valuable. The presence of a large amount of free silver metal will inhibit biological action and yield unreliable BOD test data. Large amounts of thiosulfates from the fixing bath will exert an oxygen demand. Care must be taken to prepare appropriate waste dilutions to avoid these interferences with the BOD tests.

(3) Environmental impact. The environmental impact of discharging improperly treated photographic waste can be severe due to high concen-

trations of toxics. Heavy metals such as silver are toxic to aquatic life and can accumulate in sediments. Cyanides, strong reducing agents and constituents with high oxygen demands are all capable of seriously degrading water quality.

(4) Compatibility with domestic wastewater treatment. Experimental work has shown that photographic processing wastewater is treatable by biological means. One survey (30) indicated that almost 80 percent of Air Force base photographic facilities discharge all or part of their wastes to sanitary sewers. The Air Force Environmental Health Laboratory at Kelly AFB recommended disposal of desilvered photographic wastewater in trickling filter or activated sludge plants in proportions not exceeding 0.05 percent of the total waste influent. It is further specified that the plant should discharge to a stream providing a dilution of at least ten to one hundred times, to account for the conversion of ferrocyanide to toxic cyanides. Mohanro, et al., (75) chemically treated photographic wastes with alum to reduce the COD by 40 percent, then polished the effluent in activated sludge units. With roughly a two to one ratio of domestic sewage to chemically treated photographic waste, 90 percent BOD reductions were obtained. Dagon (70) reported on a 20,000 gal/day package activated sludge plant operating totally on raw photographic wastewater and obtaining as much as 85 percent BOD reduction. However, problems were experienced with poor sludge settling. Therefore, it is generally recommended that photographic wastes be treated witih domestic sewage in a biological plant after providing silver recovery and bleach regeneration; the photographic waste portion should be kept to less than 20 percent of the total. Bench scale or pilot plant testing may be required to define the treatment approach in some instances.

f Laundries. Central laundering facilities are provided at most military facilities. At facilities engaged in industrial-type operations, additional pollution problems may result from the laundering of the employees' work clothes.

(1) Waste reduction practices. In recent years a variety of different synthetic laundry detergents have been used. Biodegradable detergents have replaced "hard" detergents. In some areas, low phosphate or non-phosphate detergents have replaced the established high phosphate compounds. The type of detergents used does warrant some consideration because of treatment requirements to meet regulations covering effluent characteristics.

(2) Gaging and sampling. Gaging and sampling of laundry wastewaters present no particular problems. However, due to the differing characteristics of the various laundering processes and wash cycles within a process, some care must be taken in order to obtain representative wastewater samples.

(3) Environmental impact. The older "hard" synthetic detergents such as alkyl benzene sulfonates (ABS) were resistant to degradation by biological means. Thus, they were discharged untreated to bodies of water, causing foaming problems. Currently used biodegradable detergents such as linear alkylbenzene sulfonate (LAS) have eliminated this problem. These detergents are biodegradable and exert a BOD in addition to that of the soil, grease, starch and other materials washed from the soiled garments.

(a) Phosphate. There has been a great amount of controversy about the contribution of detergent phosphate compounds toward the eutrophication of lakes and rivers. Some states and cities have banned the use of phosphate-containing or high-phosphate detergents. The environmental effects of phosphates or the elimination thereof are still unresolved.

(b) Explosives. In explosives manufacturing or LAP facilities, the laundering of employees' work clothes can create "pink water" conlamination of the laundry effluent, with the resultant toxic effects and undesirable aesthetic conditions.

(4) Treatability. Laundry wastewaters may generally be treated with domestic sewage by conventional biological systems. Due to the high levels of emulsified grease, BOD and phosphates, special primary treatment, or pretreatment at the laundry, may be required depending on the relative proportion of laundry flow to total plant flow. Chemical precipitation and flotation have been used successfully as pretreatment (103)(130). Because surfactants (ABS and LAS) interfere with oxygen transfer, special care should be taken to ensure that biological processes are receiving a sufficient oxygen supply. When phosphorus removal is required, chemical precipitation processes should be employed.

(a) Unacceptable treatment. Laundry wastewaters should not be treated anaerobically, as in a septic tank-drainage field system. The synthetic detergents are not broken down and are therefore more likely to enter water supplies. There is evidence that the detergents may also facilitate the movement of coliform bacteria through the soil (25).

(b) Treatment and recycle. Laundry wastewaters may be treated in commercially available physical-chemical units with the possibility of recycling the effluent. One system involves chemical precipitation with alum, followed by sand filtration, carbon adsorption and ion exchange. Another system consists of chemical precipitation and diatomaceous earth filtration. About 94 percent phosphate removal, 90 to 98 percent ABS removal, 60 to 80 percent COD reduction and 60 to 70 percent BOD reduction can be obtained (35).

g. *Other generators.* Other wastewaters typical of some military facilities include hospitals discharges, boiler water blowdown, cooling water system blowdown, blowdown from boiler flue gas-scrubber systems and vehicle washing facilities.

(1) Hospitals. Hospital wastewaters require special attention because of several factors. The diurnal peaks and minimums of both flow and concentration may be different from those normally associated with domestic wastewaters due to the unique hospital patterns of activity. Pathogenic organisms will probably be present in higher than normal concentrations; however, modern biological or physical-chemical secondary treatment plants with post-chlorination should eliminate excess pathogens in the effluent. Conservative design of chlorination facilities is encouraged. Operating personnel must exercise special care to reduce the possibility of infection. Ample design and maintenance of screening equipment should be exercised to eliminate most problems caused by excessive quantities of gauze, rags and bandages in the wastewater. Average sewage flows from hospitals are estimated at about 100 gallons per resident per day in TM 5-814-1, while other sources estimate as high as 200 gallons per bed per day. These values are quite similar to those for normal domestic sewage. Resident population includes patients and full time employees.

(2) Boilers. This waste is normally hot, up to 210 degrees F, and contain phosphates (30 to 60 mg/L), sulfite (30 to 60 mg/L), organic matter and some suspended material. Normally, blending this water with other wastes reduces various constituents to a level which will not inhibit subsequent biological treatment. Direct discharge of blowdown to a receiving stream would require treatment to reduce phosphate and sulfite concentrations. In addition, cooling would be required for direct discharge.

(3) Cooling water systems. Cooling water systems can be classified in these general categories:

–Once-through systems.

–Closed systems.

—Evaporative recirculating systems.

(a) In once-through systems, the cooling water is obtained from a lake or stream and returned to the same stream with little or no treatment. Periodic additions of biocides are sometimes required to prevent fouling of the cooling water equipment. Chlorine is the most commonly used biocide. In some instances, the water may require de-chlorination prior to return to the stream.

(b) Closed cooling systems are used where the composition of the cooling water is critical, such as in the cooling of high temperature surfaces. The cooling water rejects heat to an air-cooled radiator or through a heat exchanger to a once-through or evaporative recirculating system. Blowdown or other losses from a closed system are small but contaminated. Corrosion inhibitors sometimes contain chromate, zinc, sodium nitrate, and borax which must be removed prior to biological treatment or stream disposal.

(c) The evaporative recirculating system uses a cooling tower or spray pond to dissipate heat by evaporation of a part of the flow. Although limited by blowdown, this results in an increase in the concentration of dissolved solids to a level of 3 to 5 times that found in the makeup water. To avoid corrosion, scale and biological problems, acid, inhibitors and biocides are added to the system. Treatment of the blowdown is sometimes necessary for removal of any chromate, zinc compounds or other materials used as an inhibitor.

(4) Scrubber systems. Scrubbers are used to avoid air pollution. Airborne wastes, accumulated by the recirculating liquid, require that the liquid be periodically or continuously treated for removal of wastewater constituents. In scrubbing of boiler stack gases, fine ash and sulfur oxides must be removed or neutralized. Other scrubbing systems have similar treatment requirements.

h. Treatment methods. Special treatment processes are required for some industrial wastewater constituents. These processes may be employed to provide for pretreatment prior to mixing with other wastes for complete wastewater treatment and discharge, or for recovery of special constituents.

(1) pH control. For discharging wastewater to a biological treatment process or directly to a receiving stream, pH must generally be maintained in the range of 6.0 to 9.0; although limits may be much closer in certain instances. Treatment processes to destroy cyanides, to reduce hexavalent chromium and to precipitate heavy metals also require pH control.

(a) Acid waste neutralization. Neutralization of an acid waste (low pH) can be accomplished by adding alkaline materials such as crushed limestone, lime, soda ash or sodium hydroxide to the acidic waste. Limestone ($CaCO_3$) neutralization of a waste containing sulfuric acid forms a salt of limited volubility ($CaS0_4$) which cn cause adherent deposits on equipment surfaces and piping. Hydrated lime ($Ca(OH)_2$) or quicklime (CaO) are more commonly used, since these materials have more neutralizing capacity per pound than limestone. However, lime may also form calcium sulfate sludges. Strong bases such as soda ash (Na_2C0_3) or sodium hydroxide (NaOH) quickly neutralize strong acids, forming soluble salts and virtually eliminating the sludge problem, although increasing the dissolved solids content of the water. Strong bases require special equipment and handling and are four to eight times as expensive as lime or limestone.

(b) Alkaline waste neutralization. Neutralization of an alkaline or basic wastewater (high pH) can be accomplished by adding acidic materials such as carbon dioxide (CO_2) or sulfuric acid (H_2S0_4). Carbon dioxide may be added by passing boiler flue gas or bottled CO_2 gas through the alkaline waste, forming carbonic acid (H_2CO_3) which then neutralizes the base. Sulfuric acid readily neutralizes bases, although it is highly corrosive and requires special equipment and handling. Other strong acids, such as hydrochloric acid (HC1), can be used depending on acid costs.

(2) Heavy metal removal and recovery. Heavy metals which are of most concern are silver (Ag), cadmium (Cd), chromium (Cr), copper (Cu), iron (Fe), mercury (Hg), lead (Pb), nickel (Ni), tin (Sri), and zinc (Zn) because of their toxicity and/or high market value (86). Military sources of heavy metals include munitions production, metal plating, aircraft and motor vehicle washing, paint-stripping and metal-working, photographic processing and cooling water system blowdown. The most commonly used heavy metal removal techniques are chemical precipitation, metallic replacement, electrodeposition, ion exchange, evaporation, and reverse osmosis, although solvent extraction, activated carbon adsorption and ion flotation are being developed and are applicable in some situations (32)(33)(39)(86).

(a) Chemical precipitation. the most commonly used removal method, particularly when metal recovery is not a consideration, is precipitation. This process is based on the fact that most metal hydroxides are only slightly soluble and that some metal carbonates and sulfides are also only sparingly water soluble. The typical precipitation process using sodium hydroxide or lime as a reactant is generally applicable to copper, zinc, iron or nickel removal with no special modifications.

–Chromium exists in wastewater in both the highly toxic hexavalent and the less toxic trivalent forms. To precipitate chromium, the hexavalent form must first be reduced to the trivalent form using reducing agents such as sulfur dioxide, ferrous sulfate, metallic iron, or sodium bisulfite. The reaction is best performed in an acidic solution with a pH of 2.0 to 3.0. The trivalent chromium is precipitated as chromium hydroxide by raising the pH with lime or sodium hydroxide (34)(39)(86).

–Cadmium hydroxide precipitation by lime occurs at high pH. If cyanide is also present (as inplating waste), it must be eliminated first by adding sodium sulfide. The proprietary "Kastone" process is a hydrogen peroxide oxidation-precipitation system which simultaneously oxidizes and precipitates cadmium as cadmium oxide which can be recycled to some process solutions (130).

–Lead may be precipitated by substituting soda ash for lime in the conventional lime precipitation scheme. Both mercury and silver as well as lead may be precipitated as sulfides with the addition of combinations of sodium sulfide, sodium thiosulfate or sodium hydroxide (21)(86). The precipitated sulfide sludge may be sold to a refinery for recovery (130).

(b) Metallic replacement. The metallic replacement or displacement process is used when metal recovery is desirable, such as silver recovery from photographic wastes and copper recovery from brass-working wastes. In this process, a metal which is more active than the metal to be recovered is placed into the waste solution. The more active metal goes into solution, replacing the less active metal which precipitates (or plates) out and is recovered. Zinc or iron, in the form of either dust or finely-spun wool, is often used to recover silver or copper (30)(86). A proprietary spun-iron cartridge is used to recover silver from waste photographic fixing solutions in normally a continuous operation (111). The treated fixing solution may still contain at least 1,000 mg/L of silver as well as the ionized iron and cannot be

reused because the iron is a contaminant in the fixing process. The high residual concentration of potentially toxic metal also requires that bench and/or pilot scale studies be used to establish the treatability of the waste by conventional biological systems.

(c) Electrodeposition. Like metallic replacement, electrolytic recovery is used to recover valuable metals such as silver or copper from photographic processing, brass pickling or copper-plating wastes. When a direct electrical current of the proper density is passed through the wastewater solution, the metal in solution plates out in a pure form on the cathode. The electrolytic method may be operated continuously or batch-wise, is effective over a range of 1000 to 100,000 mg/L of influent metal and may produce an effluent as low as 500 mg/L of metal. However, close supervision is required in order to maintain proper current density (30)(86)(130). Again, the residual metal concentrations are high enough to limit biological treatment of the waste.

(d) Ion exchange. Ion exchange technology has been developed for treating chromium wastes from plating processing to include chromium detoxification or recovery, water reuse and heat recovery from hot rinses. This is normally a continuous flow process rather than a batch-type operation. Mixed wastes of chromium and cyanides can be treated first by a cation exchanger to remove metals from complex metal cyanides generating hydrogen cyanide, and then by an anion exchanger to remove the liberated cyanide. The concentrated solution formed by regenerating the exchange resins can be a source of recoverable product in many cases (34). Ion exchange is also being investigated for the recovery of silver from photographic processing wastes, chromate from cooling water system blowdown (115) and cadmium from plating solutions.

(e) Evaporation. Evaporation is used to recover heavy metals particularly chromate from some plating solutions. Evaporation by applying heat or vacuum to the solution may be employed. The distilled water from evaporation is reused as process rinse water (129). Rinsing with high purity water results in low rinse water use.

(f) Reverse osmosis and ultrafiltration. Reverse osmosis and ultrafiltration processes have been rapidly improved in recent years, and are used in several cases to treat plating rinse waters. Use of membrane processes for treatment of cooling water blowdown for dissolved solids and chromate removal has also been reported (45)(50)(92).

(3) Cyanide destruction. Cyanides are found principally in metal plating wastes (including those wastes from metal-renovation operations) and photographic processing wastewaters. The most toxic form of cyanide is hydrogen cyanide (HCN), while the complex iron cyanides $(Fe(CN_6)^{-4}$ and $(Fe(CN)_6)^{-3}$ and the cyanate $(CNO)^-$ are less toxic by several orders of magnitude. The most widely used cyanide destruction process is alkaline chlorination. Other treatment processes which have been used in actual practice include oxidation using hydrogen peroxide (including the proprietary "Kastone" process), and ion exhange (32)(33)(34).

(a) Alkaline chlorination. Alkaline chlorination involves oxidation of the cyanide to carbon dioxide and nitrogen gas using chlorine in a high pH solution. This is normally a single-step reaction requiring about 4 hours with a solution pH of 11. A two-step operation consists of cyanide conversion to cyanate at pH of 11, requiring about 30 minutes, followed by complete destruction of cyanate to carbon dioxide and nitrogen gas at pH of 8, requiring another 30 minutes. About 5 mg/l of excess chlorine is maintained (129). Vigorous agitation is required, especially when metal-cyanide complexes are present, to prevent precipitation of untreated cyanide salts (34)(130). Generally, flows smaller than 20,000 gallons per day use batch treatment in two tanks, in which one tank of waste is treated while the other is filling. A continuous treatment scheme requires instrumentation to control the chemical additions, and is normally uneconomical for small flows. Either chlorine gas or hypochlorites may be used as the chlorine source, depending on economics and particular preference. Either sodium hydroxide or lime is used to raise the pH (34)(109).

(b) Hydrogen peroxide oxidation. Cyanides may be oxidized to cyanate by hydrogen peroxide. This process is used in Europe and has the advantage of not introducing an additional pollutant (residual chlorine) into the water (33). The proprietary "Kastone" process is basically a hydrogen peroxide-formaldehyde method of cyanide oxidation. Formaldehyde reacts with the cyanide to form formaldo-cyanohydrin which is readily oxidized by the hydrogen peroxide. This process is particularly advantageous for plating waste treatment because the hydrogen peroxide also precipitates bevy metals as oxides (124).

(c) Ion exchange. Ion exchange using a strong base anion exchange resin can remove cyanides effectively from plating wastes, although not always from photographic wastes due to resin poisoning by the iron cyanide complexes. Wastewater is first passed through a cation exchanger to remove metals, breakup complex metal cyanides, and free the cyanide for removal by the successive anion exchanger. The anion resin may be regenerated with caustic, recovering the cyanide as sodium cyanide. The volume of the recovered cyanide solution is only 10 to 20 percent of the original waste volume (34)(109)(111).

(4) Oil removal. Wastewater from munitions metal parts manufacturing and flows from aircraft and vehicle washing, paint-stripping and metal-working operations may contain large quantities of oils in any of three forms: free floating oil, emulsified oil or soluble oil. Physical, chemical and biological treatment steps may be used in various combinations in order to reduce oil concentrations to levels required by water usage or regulatory criteria.

(a) Free oils. Free oils readily float to the water surface to be removed by gravity separators such as conventional primary clarifiers with surface skimming devices or separators designed according to American Petroleum Institute (API) criteria. The effectiveness of these and other means of removing free oil from wastewater varies depending on the type of oil, temperature of the waste, and other factors. As a guide, however, some generalizations can be made. Gravity separation devices are effective in reducing oil concentrations to about 150 to 200 mg/L. Dissolved air flotation, similar to that used to thicken sludge, is effective in reducing oil levels to 50 to 100 mg/L. Granular media filters, preceded by gravity or flotation separators, can reduce oil concentrations to 10 to 20 mg/L. Chemical coagulation and precipitation, followed by gravity separation or dissolved air flotation, can remove all but about 5 mg/L of oil (95)(129)(156).

(b) Emulsified oils. Emulsions can be either oil-in-water or water-in-oil types. The more common oil-in-water emulsions are dispersions of tiny droplets or oil suspended in water. Emulsifying agents such as soaps, sulfated oils and alcohols and various fine particles enhance the stability of the dispersed oil, preventing the droplets from merging together into larger droplets which could be removed from the water (95). Prepared emulsions are used as coolants and lubricants in machining operations. Emulsions are also formed when oily wastewater comes in contact with steam, soaps, caustic or agitation. The emulsion must first be broken, then the oil released is removed as a free oil. Emulsion cracking is the term used to describe treatment of wastewater containing large amounts (2 to 7 percent) of emulsified oils, such as emulsions used in machining operations. Cracking involves addition of chemicals such as sulfuric acid, iron salts, alum, calcium chloride, or proprietary organic compounds, followed by heating to 100 to 140 degrees F. This is followed by two to four hours of coalescence. The effluent may still contain a few hundred mg/L of emulsified oil, and should be further treated, along with other waste streams having a similar level of oil content, by adding coagulating salts to lower the oil concentration. Wastewaters with less than 500 to 1000 mg/L of emulsified oil, or the effluent from the cracking step, may be treated by adding iron or aluminum sulfate salts, forming a metal hydroxide-oil sludge (95)(108)(129). A typical treatment scheme is shown on figure 6-2.

(c) Soluble oils. Soluble oils, such as certain animal and vegetable oils, may be readily removed by conventional biological treatment processes (89)(120). In general, oils derived from petroleum are neither readily soluble nor biodegradable, although biological systems can be developed to provide treatment of some of the soluble fractions of petroleum oils. Domestic sewage helps to provide inorganic nutrients essential for the biological degradation of the high BOD oils.

(5) Deep well injection. Pumping waste liquids into deep wells which tap porous rock formations has been used to dispose of “untreatable” or hard-to-treat organic and inorganic wastes from various industries.

(a) Pretreatment requirements. Wastes must be pretreated to remove any suspended solids which could clog the pores of the receiving rock formation. In addition, biological growth (and the resultant slime formation or corrosion) must be inhibited with the addition of biocides. Typical pre-injection treatment is costly and includes chemical addition, neutralization, oil removal, clarification and multi-stage filtration.

(b) Geological requirements. Careful geology and soils investigations must be undertaken to find a deep strata which is confined so that waste fluids will never reach a fresh water aquifer (92). The underground disposal area must also have satisfactory reservoir storage (107). The waste must not be capable of reaction with the brine at disposal level to form an insoluble material. Extreme care must be taken in drilling, constructing, and sealing the well to prevent any contamination of groundwater in other subterranean formations (37). Well casings must be highly

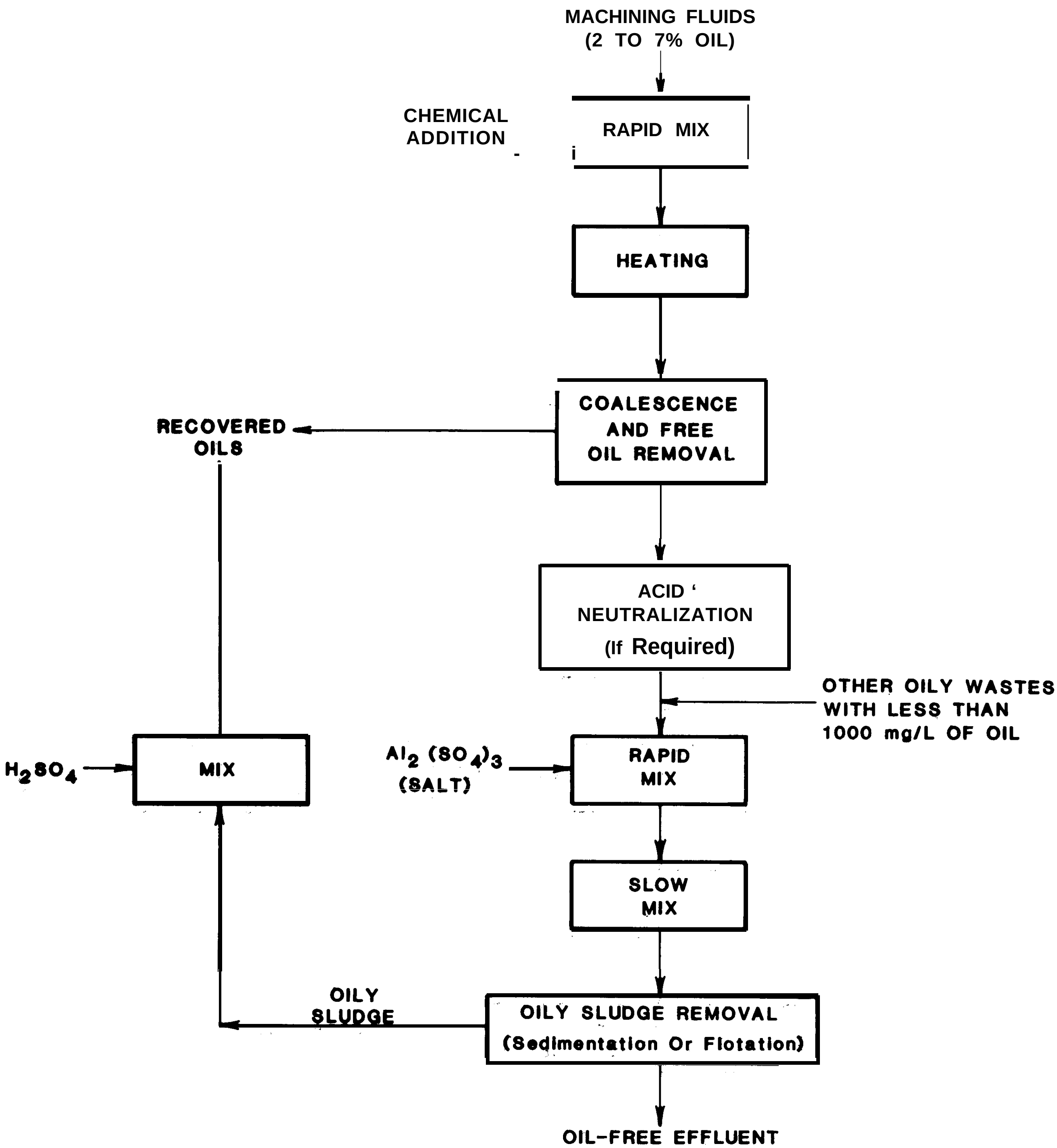

Figure 6-2. Emulsified oil removal by cracking and chemical coagulation.

corrosion-resistant to prevent leakage from corrosion caused by high pressure injection of acids and salts. Duplicate wells should be drilled if there is no alternative treatment or holding capacity in case the disposal well should fail. In addition, a number of sample wells must be drilled and maintained in order to monitor any leakage into ground water (72)(107). Trace leakage may be impossible to identify.

(c) Application to military wastes. Due to the extreme need for providing a fail-safe system, deep well injection is an expensive undertaking. Because of uncertainties with deep well operations (well leaks or clogging), careful comparison should be made of all other possible treatment alternatives prior to initiating a deep well system. Present U.S. EPA and Army policies discourage deep well disposal. The U.S. EPA requires proof that no adverse environmental impacts will result from construction or operation of the well (99)(102). This can often require involved, and expensive, research effort. In general, deep well injection is an unacceptable process for handling military installation wastewaters.