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STUDY ON INDUSTRIAL WASTE WATER POLLUTION CONTROL IN THE ARAB REPUBLIC OF EGYPT

CONCISE MANUAL FOR INDUSTRIAL WASTEWATER TREATMENT PRACTICES

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CHIYODA-DAMES & MOORE CO., LTD.
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CONCISE MANUAL FOR INDUSTRIAL WASTEWATER TREATMENT PRACTICES

Completed as Part of the
STUDY OF INDUSTRIAL WASTE WATER POLLUTION CONTROL IN THE ARAB REPUBLIC OF EGYPT

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LIST OF ACRONYMS

API	American Petroleum Institute
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
DO	dissolved oxygen
GAC	granular activated carbon
ha	hectares
JICA	Japan International Cooperation Agency
kg	kilograms
m	meters
M	million
mg/L	milligrams per liter
MLSS	mixed liquor suspended solids
O&M	Operation & Maintenance
ORP	oxidation reduction potential
RBC	Rotating Biological Contactor
rpm	revolutions per minute
ThOD	Theoretical Oxygen Demand
THM	trihalomethane
TSS	Total Suspended Solids
UASB	Upflow Anaerobic Sludge Blanket
µm	micrometers

VOCs	volatile organic compounds
VSS	volatile suspended solids

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MISCELLANEOUS ENGINEERING DESIGN DATA

1.0 INTRODUCTION

This manual presents an overview of industrial wastewater treatment practices and case study examples for selected industries. The manual was prepared on behalf of the Japan International Cooperation Agency (JICA) for use by engineers and operators who require specific information related to managing industrial wastewater. This section describes the background, purpose, methodology, and report organization.

1.1 Background

Egyptian Environmental Affairs Agency (EEAA) has been conducting policy measures including regulatory enforcement since its establishment.
The preservation of the Nile River have been identified as a top priority issue for the year 1998, that requires immediate action to minimize the negative aesthetic, hygienic and environmental impacts associated with improper waste management. Waste results mainly from residential, commercial and institutional sources, together with demolition and construction waste, street sweepings & garden wastes.

Egyptian regulations specify allowable pollution discharge levels for several discharge locations. Wastewater discharge regulations in Egypt are described in Section 2. By implementing wastewater treatment projects in strategic locations around the country to meet the current and future discharge criteria, desired improvements to local surface water conditions can be realized. This process would serve to initiate long-term improvements to overall environmental conditions in the affected surface water bodies.

Industrial sector is expected to achieve sound management of industrial effluent.

1.2 Purpose

Industrial facilities generate wastewater as part of routine plant operations that can often pose significant risks to human health and the environment. Treating wastewater generated at industrial facilities is an important part of a comprehensive program to protect human health and natural resources. Programs designed to reduce the types and concentrations of certain chemicals present in the wastewater are typically developed by local and national authorities responsible for environmental protection. The objectives of local or national protection programs will affect the requirements faced by a given industry and specific industrial facility to implement appropriate treatment or control measures. Many industrial facilities lack adequate wastewater treatment capability or capacity. Discharge of untreated or under-treated wastewater from industrial sources has adversely affected Egyptian surface water bodies. Such conditions pose aesthetic problems and possible human health effects.

1.3 Methodology

To conduct this study, an in-country data collection mission and subsequent in-house data analysis were completed. Available information related to industrial wastewater practices for a variety of manufacturing and processing facilities was compiled. The information presented in this document can be used by engineers at industrial facilities for purposes of initiating design and implementation of wastewater treatment programs.

To objectively evaluate the need for implementing a treatment program and its applicability to a given industrial facility, the engineer should use the following criteria:

- Will current and future discharge limits for the chemical parameters established by local and national authorities be met with the proposed project?
- Is the lowest cost and most appropriate engineering solution being considered to the specific conditions at the facility?
- Does the proposed project provide improvements to human health and environmental conditions?

Potentially applicable wastewater treatment approaches can be identified and evaluated using this manual. The most appropriate treatment approach may then selected, and planning/basic design can be initiated.

1.4 Report Organization

This report is organized into six sections as follows:

Section 1	Introduces the purpose and methodology used to prepare this manual, and the report organization.
Section 2	Summarizes the types of treatment methods used for industrial wastewater.
Section 3	Summarizes specific unit operation and unit processes used for treating various types of industrial wastewater.
Section 4	Presents information related to industrial wastewater design practices, including establishing the design basis, conceptual design, chemical characterization data, treatability testing requirements, and some tips to perform
Section 5	Identifies and evaluates case studies for selected industries and their wastewater management techniques. Advantages and disadvantages of the technologies used at existing facilities are discussed.
Section 6	Presents reference documents used in the manual.
Appendices	Includes selected internet reference sites for wastewater treatment practice, equipment, and supplies, and miscellaneous engineering design data.

2.0 INDUSTRIAL WASTEWATER TREATMENT PROCESSES

The type of wastewater treatment system designed for an industrial facility will be based on the characteristics of the wastewater and the required characteristics of the treated wastewater. Wastewater characteristics are a function of the type of industry and its specific manufacturing or production processes and the manner. The treatment approach used will be based on discharge levels permitted by the Egyptian regulations prior to discharge to a surface water body, a municipal wastewater plant, land application in the desert, or for reuse within the facility.

Industrial wastewater treatment practices are broadly defined as either physical/chemical or biological treatment technologies. Within these two broad categories there are numerous technologies, known as unit operations and unit processes, that can be used to treat a specific type of wastewater. The engineer evaluates the applicability of the various unit operations and processes needed to effectively treat the type of industrial wastewater for a facility. The results of the evaluation are then used to prepare a conceptual design for a wastewater treatment system.

Unit operations describe methods that apply physical forces for treatment (e.g., flow equalization, sludge dewatering). Unit processes refer to methods of treatment that use chemical or biological reactions (e.g., precipitation, activated sludge treatment). Most industrial wastewater treatment systems use a combination of both unit operations and unit processes to meet the treatment objective. In many cases with industrial wastewater that contains no organic pollutants the treatment system will consist of only physical/chemical technologies. In other cases a physical/chemical system may precede a biological treatment system to remove certain pollutants as a pre-treatment step, or to remove chemicals potentially harmful to a biological treatment process.

Both physical/chemical and biological treatment categories consist of conventional technologies that are well understood and commonly used at many facilities. Conventional technologies are selected because of their proven performance capabilities to meet specific treatment objectives and are often the most cost-effective. However, in some cases the use of advanced treatment technologies may be appropriate to meet more stringent discharge limits or to reduce operation and maintenance costs.

A brief discussion of physical/chemical, biological, and advanced treatment technologies is provided in the following subsections. More detailed discussions of specific unit operations and unit processes are provided in Section 3. Figure 2-1 summarizes the most common unit operations and unit processes used for industrial wastewater treatment. Table 2-1 summarizes wastewater discharge regulations in Egypt that pertain to industrial effluent limits for industrial facilities.

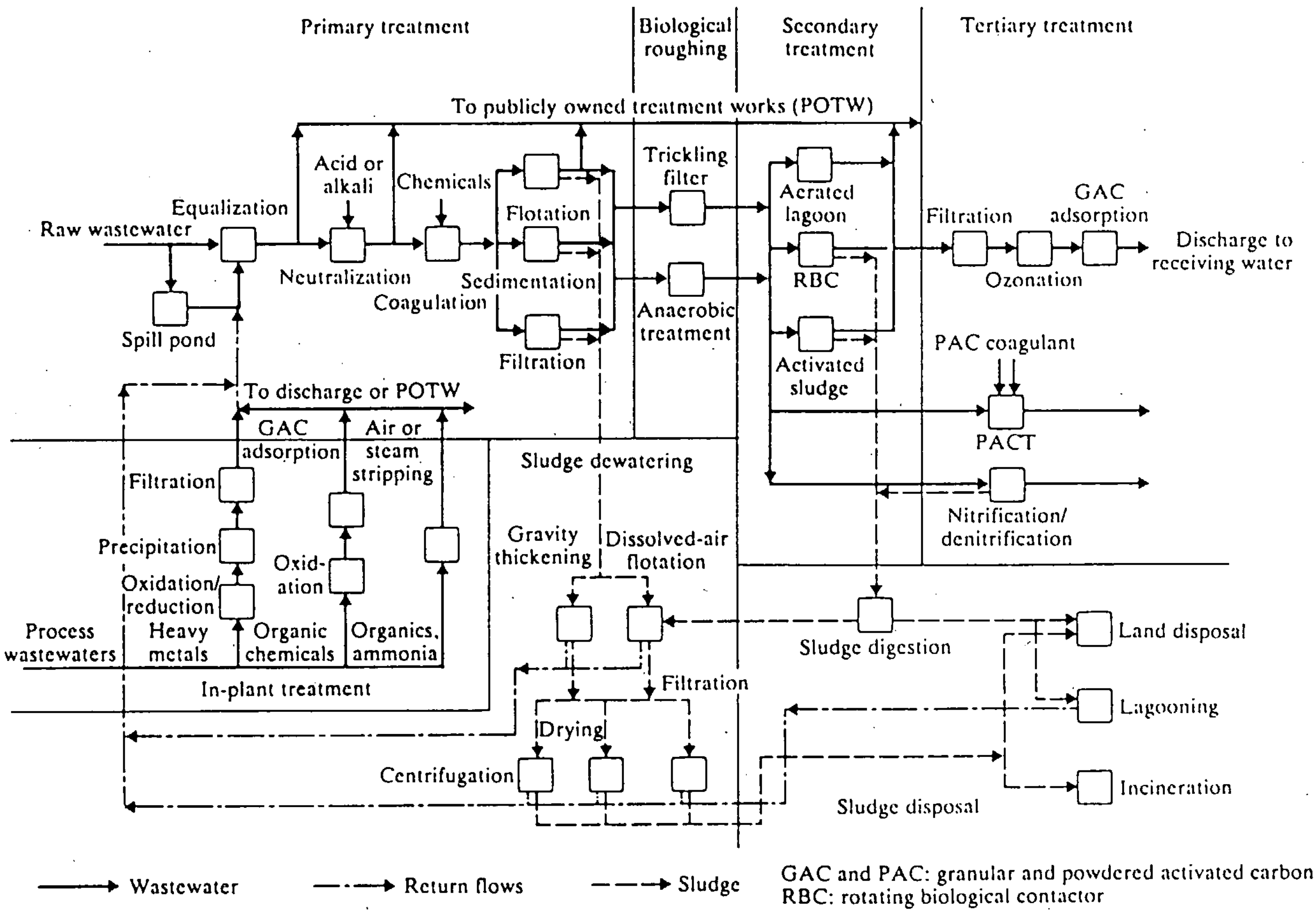

Figure 2-1 Summary of Unit Process operations and Processes

Table 2-1 Wastewater Discharge Regulation in Egypt

Parameter ppm or mg/L (unless otherwise noted)	Law 4/94: Discharge to Coastal Environment	Law 93/62: Discharge to Sewer System		Law48/82			
		as modified by Decree 9/89	as modified by Decree 44/2000	Underground Reservoir & Nile Branches /Canals	Nile (Main Stream)	Non Potable Surface Water: Municipal	Non Potable Surface Water: Industrial
BOD (5 day, 20℃)	60	<400	600	20	30	60	60
COD (Permananate)	n/a	350		10	15	40	50
COD (Dichromate)	100	<700	1100	30	40	80	100
pH (units)	6-9	6-10	6-9.5	6-9	6-9	6-9	6-9
Oil & Grease	15	<100	100	5	5	10	10
Temperature (℃)	10 C>temp of receiving body	<40	43	35	35	35	35
TSS total Suspended Solids	60	<500	800	30	30	50	60
SS Settable Solids (ml/l)	n/a	n/a	10min - 8 30min - 15	n/a	n/a	n/a	n/a
TDS Total Dissolved solids	2000	2000		800	1200	2000	2000
PO_4	5	30	25 (Total Phosphorous)	1	1	n/a	10
NH_3-N (Ammonia)	3	<100		n/a	n/a	n/a	n/a
NO_3-N (Nitrate)	40	<30	100 (Total Nitrogen)	30	30	50	40
Total Recoverable Phenol	1	<0.005	0.05	0.001	0.002	n/a	0.005
Fluoride	1	<1		0.05	0.05	n/a	0.5
Sulphide	1	<10		1	1	1	1
Chlorine	n/a	<10		1	1	n/a	n/a
Surfactants	n/a	n/a		0.05	0.05	n/a	n/a
Probable counting for colon group/100 cm^3	5000	n/a		2500	2500	5000	5000
Aluminum	3	n/a		n/a	n/a	n/a	n/a
Arsenic	0.05	n/a	2.0	0.05	0.05	n/a	n/a
Barium	2	n/a		n/a	n/a	n/a	n/a
Beryllium	n/a	<10		n/a	n/a	n/a	n/a
Cadmium	0.05	<10		0.01	0.01	n/a	n/a
Chromium	1	Total metals: <10, <50 m^3/d <5, >50 m^3/d		n/a	n/a	Total concentration for these metals should be <1 for all flow streams	
Chromium Hexavalent	n/a		0.5	0.05	0.05		
Copper	1.5		1.5	1	1		
Iron	1.5			1	1		
Lead	0.5		1.0	0.05	0.05		
Manganese	1			0.5	0.5		
Mercury	0.005	<10	0.2	0.001	0.001	n/a	n/a
Nickel	0.1	<10	1.0	0.1	0.1	n/a	n/a
Silver	0.1	<10	0.5	0.05	0.05	n/a	n/a
Zinc	5	<10		1	1	n/a	n/a
Cyanide	0.1	<0.1	0.2	n/a	n/a	n/a	0.1
Total Metals	n/a	Total metals: <10, <50 m^3/d <5, >50 m^3/d	5	1	1	1	1
Organic Compounds	0	0		0	0	0	0
Pesticides	0.2	0		0	0	0	0
Colour	None	None		None	None	None	None

n/a = not applicable

2.1 Physical/Chemical Technologies

Physical/chemical technologies can be used alone or in combination with biological technologies. Industrial facilities that generate wastewater primarily with inorganic chemicals will often require wastewater treatment using physical/chemical technologies. If the wastewater contains both inorganic and organic pollutants, a physical/chemical pre-treatment system is commonly used to reduce the concentration of pollutants that may be harmful to biological processes.

Physical/chemical technologies most commonly used for industrial wastewater treatment include:

Flow equalization
Neutralization
Coagulation/flocculation
Sedimentation
Flotation
Chemical Precipitation
Sludge dewatering

Some or all of these treatment technologies may be part of a treatment system, based on wastewater characteristics and required effluent limits. Table 2-2 summarizes physical/chemical wastewater technologies, the types of wastes treated, typical modes of operation, and the degree of treatment provided by a specific treatment technique.

Table 2-2 Physical/Chemical Wastewater Treatment Technologies

Treatment Technology	Waste Types Treated	Mode of Operation	Degree of Treatment	Comments
Flow equalization	No treatment performed	NA	No treatment performed	Required for high-strength wastes and variable flow conditions
Neutralization	High or low pH wastewater	Batch or continuous	Adjusts pH for subsequent treatment processes	
Sedimentation	Solids removal	Batch or continuous	Gross solids removal	Solids separation depends on type of settling and solids load rate
Filtration	Solids removal	Batch or continuous	Polishing solids removal	Follows sedimentation operation
Flotation	Oils, greases, small suspended particles	Batch or continuous	Excellent separation achieved	May require chemical aids to improve performance
Oxidation/reduction	Toxic and refratory organics	Batch or continuous ozone or catalyzed hydrogen peroxide	Partial or complete oxdation	Partial oxidation to render orgaics more biodegradable
Coagulation/flocculation	Paperboard, Refinary, Rubber, Paint, Textile	Batch or continuous treatment	Complete removal of suspended and colloidal matter	Flocculation and setting tank or sludge blanket unit; pH cotrol required

The information contained in Table 2-2 can be used as a general guide to select an appropriate technology type or types for the wastewater being generated at the facility.

2.2 Biological Treatment Technologies

Similarly to physical/chemical technologies, biological technologies can be used alone or in combination. If the wastewater potentially contains constituents that are harmful to the microbes in the biological treatment system, a laboratory investigation may be needed to evaluate the need for pre-treatment.

Biological technologies most commonly used for industrial wastewater treatment include:

Aerobic Lagoons
Facultative Lagoons
Activated Sludge Treatment
Rotating Biological Contactors (RBCs)
Trickling Filters
Anaerobic Treatment

Table 2-3 summarizes biological wastewater technologies, typical modes of operation, the degree of treatment provided, land area requirements, and equipment requirements for each treatment technique.

Table 2-3 Biological Wastewater Treatment Technologies

Treatment Technology	Mode of Operation	Degree of Treatment	Land Requirement	Required Equipment	Comments
Aerobic Lagoons	Continuous	80 to 90% removal of organics	160 kg BOD/ha • d typical loading rate	Influent flow control, aeartors or air diffusers	Used for low to medium-strength wastes
Facultative Lagoons	Continuous	85 to 90% removal of organics	200 kg BOD/ha • d typical loading rate	Influent flow control, surface aeartors	Used for low to medium-strength wastes
Anaerobic Lagoons	Continuous	Depends on influent strength; 50 to 85% or greater organics removal	500 kg BOD/ha • d typical loading rate	Influent flow control	Appropriate for high-strength wastes
Activated Sludge	Completely mixed or plug flow; Sludge recycle	>90% removal of organics	Varies based on process modification selected	Diffused or mechanical aerators; clarifier	Used for low to medium-strength wastes
Trickling Filters	Continuous. May employ effluent recycle	Intermediate or high, Depending on loading	5.5 - 34.4 m3/m2/d	Plastic packing or rocks 6 -12 m deep	POTW or activated sludge plant
RBC	Multistage continuous	Intermediate or high	Varies based on process modification selected	Steel or concrete tank with rotating disk assemblies	Solids separation required
Anaerobic Reactors	Continuous	Depends on influent strength; consistently 85% organics removal		Steel tank, methane collection equipment	Excellent for high-strength wastes; possible methane recovery

The information contained in Table 2-3 can be used as a general guide to select an appropriate technology for the wastewater being generated at the facility.

2.3 Advanced Treatment Processes

Advance treatment processes are available for both the physical/chemical and biological technologies. These are required for certain types of wastewater pollutants based on the requirements for the effluent quality. In some cases advanced technologies are more complex to operate and are more costly to design, build, and operate. However, depending on the needs for higher effluent quality, advanced treatment may be the only option available for a specific type of wastewater pollutant.

Selected advanced technologies that most commonly used for industrial wastewater treatment include:

Activated carbon adsorption
Ion Exchange
Membrane Filtration

Table 2-4 summarizes these selected advanced wastewater technologies, the types of wastes treated, modes of operation, and the degree of treatment provided by a specific treatment technology.

Table 2-4 Selected Advanced Wastewater Treatment Technologies

Treatment Technology	Waste Types Treated	Mode of Operation	Degree of Treatment	Comments
Activated Carbon Adsorption	Organic compounds, chlorine, and suspended solids	Batch or continuous	Excellent removal of target organics and chlorine	Granular carbon used in physical/chemical process; powdered carbon used in activated sludge systems
Ion Exchange	Dissolved inorganic ionic species	Continuous filtration with resin regeneration	Demineralized water recovery; Product recovery	One day's capacity for batch treatment;3-h retention for continuous treatment; Sludge disposal or dewatering required
Membrane Filtration	Dissolved ionic species	Batch or continuous	Excellent removal of most ionic species - high-purity water	High operation and maintenance costs, operator attention required

The information contained in Table 2-4 can be used as a general guide to select an appropriate advanced technology for the wastewater being generated at the facility.

3.0 UNIT OPERATIONS AND PROCESSES

The broad categories of physical/chemical and biological wastewater treatment described in Section 2 can be further subdivided into specific unit operations and unit processes. These various treatment technologies are used to remove pollutants from a specific industrial waste stream. The technologies used to achieve the desired pollution reduction will depend on three factors:

(1) Specific influent wastewater characteristics
(2) Influent wastewater flow rate
(3) Effluent regulations or requirements for wastewater resue.

The wastewater chemical composition is a function of the industrial process or processes from which it is generated. Manufacturing facilities in a particular industry will commonly exhibit similar wastewater chemistry. Therefore the treatment technologies required to remove the chemicals of interest for a specific type of facility are similar in many cases.

If a new manufacturing facility is to be constructed there will be no actual data available for the wastewater system design. In this case the design can be prepared using data from other similar facilities. In cases where a new wastewater treatment system will be constructed at an existing industrial facility, representative wastewater samples can be collected and used to develop specific design criteria.

For example, steel manufacturing and processing facilities employ similar production techniques, and the process water often contains higher concentrations of various dissolved metal species. These metals can be readily removed using conventional precipitation and clarification technologies to achieve suitable levels for effluent discharge. Therefore, general assumptions related to the type of treatment technologies for this industry will be based on industry-specific knowledge from other manufacturing operations.

Wastewater flow rates will vary significantly by industry type, and size of the facility. Table 3-1 summarizes typical unit flow rates of water consumed for production at various industrial facilities.

Table 3-1

Typical Water Use Rates for Various Industries

Industry	Range of flow (m^3/ton product)
Cannery	
Green beans	45 — 64
Peaches and pears	14 — 18
Other fruits and vegetables	4 — 32
Chemical	
Ammonia	91 — 272
Carbon dioxide	54 — 82
Lactose	544 — 725
Sulfur	7 — 9
Food and beverage	
Beer	9 — 15
Bread	2 — 4
Meat packing	14 — 18[a]
Milk products	9 — 18
Whisky	54 — 73
Pulp and paper	
Pulp	227 — 718
Paper	110 — 144
Textile	
Bleaching	181 — 272[b]
Dyeing	27 — 54[b]

[a] Live weight
[b] cotton
Adapted from Metcalf & Eddy, 1991

In addition to the variable flow rates indicated in Table 3-1 within a given type of industry, wastewater to be treated and the regulated effluent quality requirements vary widely. Consideration of wastewater flow rates, characteristics and effluent limits must be made to as part of the design process. Additional information related to a practical design approach for industrial wastewater treatment is presented in Section 4. The following subsections present general information and design criteria for unit operations and processes that are most commonly used for industrial wastewater treatment.

3.1 Flow Equalization

Flow equalization of the wastewater system influent is a critical component in many industrial treatment systems. Objectives of system flow equalization that include:

- Providing a mechanism to avoid large fluctuations in the influent chemistry that can impact effective treatment by creating shock loads to the treatment system
- Minimizing chemical consumption for pH control by allowing wastewater exhibiting variable pH values to mix prior to treatment
- Minimizing fluctuations to the treatment system and reducing the size of pumping and chemical addition equipment
- Providing continuous flow to biological treatment systems over a specified time period as wastewater generation rates vary during the daily production schedule, and minimize shock loading of toxic chemicals to a biological process
- Allowing even discharge rates of treated effluent.

Figure 3-1 depicts an equalization basin flow diagram. In facilities where there are known discharges of highly concentrated waste streams, a separate basin may be provided to temporarily hold the wastewater to reduce the potential for shock loading to the system.

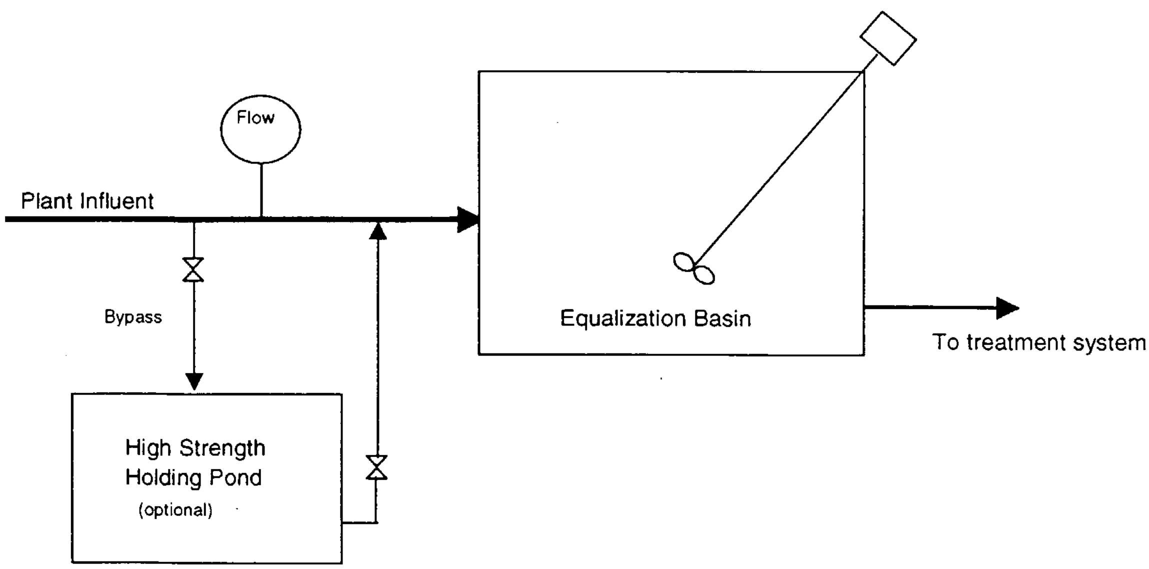

Figure 3-1 Wastewater Flow Equalization

Most equalization basins are installed with an aeration device to keep suspended solids from settling out and to maintain avoid having the wastewater becoming anaerobic prior to treatment. Aeration can be accomplished using the conventional techniques of mechanical surface aerators, or submerged coarse-bubble air diffusers. Typical design guidelines for these aeration techniques are:

Table 3-2

Equalization Basin Aeration Requirements

Aeration Technique	Requirement
Mechanical Surface (kW/m^3)	0.003 — 0.004
Submerged Air Diffusers (m^3/m^3 min)	0.02 — 0.04

Many industrial facilities discharge wastewater to a treatment facility with variable flow rates over a 24-hour period. Using flow data for the facility a graphical solution can be used to determine the proper size for the equalization basin. Table 3-3 presents sample data for an example calculation of the proper basin size. Figure 3-2 shows the graphical solution.

Table 3-3
Sample Industrial Wastewater Flow Data

Time	Flow Rate (L/min)	Hourly Total (m^3)	Cumulative Total (m^3)
8:00 AM	189	11.34	11.34
9:00 AM	348	20.87	32.21
10:00 AM	869	52.16	84.37
11:00 AM	1,172	70.31	154.68
12:00 PM	1,021	61.24	215.91
1:00 PM	529	31.75	247.67
2:00 PM	340	20.41	268.08
3:00 PM	416	24.95	293.03
4:00 PM	302	18.14	311.17
5:00 PM	567	34.02	345.19
6:00 PM	869	52.16	397.35
7:00 PM	1,153	69.17	466.53
8:00 PM	1,436	86.18	552.71
9:00 PM	756	45.36	598.07
10:00 PM	302	18.14	616.22
11:00 PM	227	13.61	629.82
12:00 AM	265	15.88	645.70
1:00 AM	208	12.47	658.17
2:00 AM	151	9.07	667.25
3:00 AM	265	15.88	683.12
4:00 AM	284	17.01	700.13
5:00 AM	170	10.21	710.34
6:00 AM	208	12.47	722.81
7:00 AM	132	7.94	730.75

Using this example data a graph is prepared showing the cumulative hourly total flows versus time over a 24-hour period. A straight line is drawn from the origin to the cumulative total endpoint. Lines are then drawn from the straight line to the point on the curve representing the maximum value above and below the straight line. The corresponding volumes associated with these lines are read from the y-axis and are added to obtain the required equalization basin volume. In this particular example, the value obtained using the graphical solution is approximately 185 m^3.

The geometry of the basin will depend upon the available area at the treatment facility and the type of mixing used. For mechanical surface aerators and submerged mixing units the depth should not be significantly greater than the horizontal dimension to avoid hydraulic dead zones where settling of solids may occur. Submerged air diffusers will maintain excellent solids suspension in deeper basins.

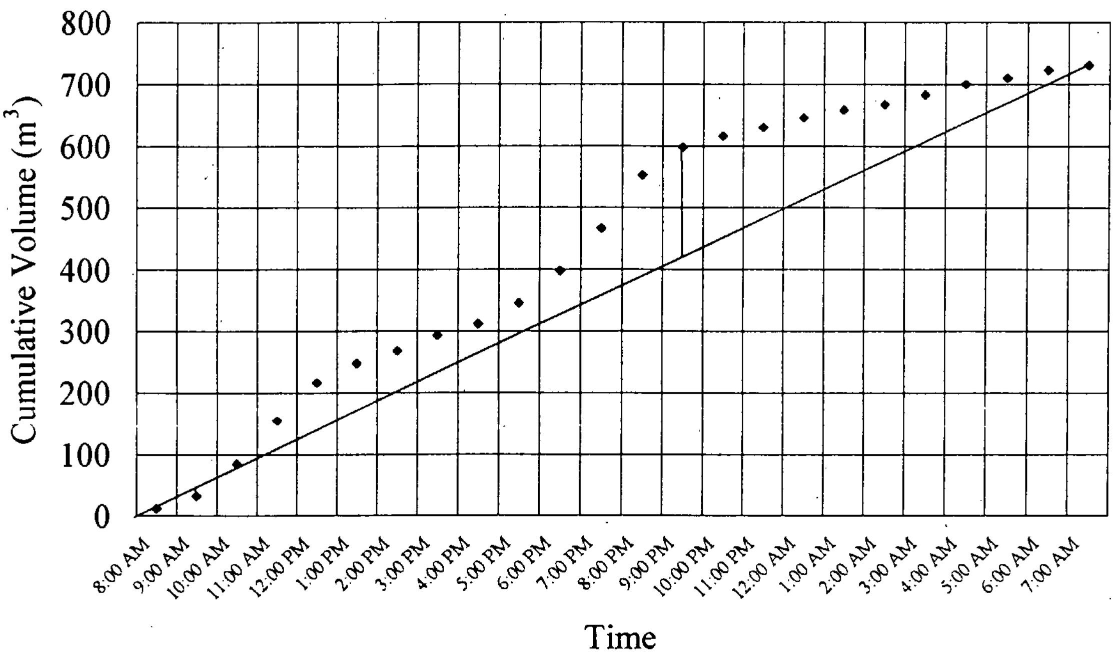

Figure 3-2 Determination of Flow Equalization Basin Size

Proper installation of an equalization basin should include the following components to ensure reliable flow to the treatment system:

- Solids strainer on the inlet line from each process waste stream
- Automatic submersible pump constructed of chemically compatible materials
- Liquid level sensors and controllers
- Access.

If a separate tank is needed to temporarily store high-strength wastes, a closed top tank is recommended its capacity should be based on plant information of process flow rates. In some cases existing tanks at a facility may be available for use with flow equalization basins. If an existing tank is used the unit must be cleaned of potentially harmful chemicals. Ideally the following items should be included with the tank:

- 200 micron or equivalent strainer, on the incoming fill line
- Exhaust vent at the top of the tank (if closed top tank)

- Drain valve at the lowest point of the tank
- An overflow line near the top of the tank, use a pipe with at least a one (1) inch greater diameter than the incoming fill line
- A high level alert and shut-off.

3.2 Neutralization

Numerous industrial wastewater streams exhibit very acidic or alkaline properties. In the case of physical/chemical systems pH adjustment is required for effective wastewater treatment. Biological treatment systems require a pH range of 6.5 to 8.5 in order to maintain the optimum biological activity. Therefore, a neutralization step is often used to adjust wastewater pH prior to a physical/chemical or biological treatment system. Final pH adjustment is also required at some treatment plants the wastewater treatment process to meet regulatory requirements for discharge.

If the industrial process generates both acidic and alkaline waste streams, mixing of these two discreet wastewater flows in an equalization basin can be used to achieve some neutralization. The degree of neutralization that can be accomplished by simple mixing of waste streams is determined by one of three approaches:

(1) performing laboratory titration tests using the actual facility wastewater streams, if available
(2) conducting titration tests using surrogate waste streams prepared based on specific knowledge of the manufacturing process
(3) using information available from other similar facilities.

If the facility does not generate acidic and alkaline waste streams, neutralization is accomplished by the addition and mixing of neutralizing agents. Strongly acidic wastes are most commonly neutralized using calcium hydroxide or sodium hydroxide (caustic). Less commonly used bases are calcium oxide (unslaked lime), sodium carbonate, and ammonium hydroxide. The disadvantages of unslaked lime are the requirement to mix the product with water prior to use, and its handling safety hazards.

Strongly alkaline wastewater is most commonly neutralized using hydrochloric acid or sulfuric acid. Determination of the chemical agent to be used for neutralization will be based on local availability of the chemical and its associated cost.

The neutralization reaction rate for acids and bases is essentially instantaneous. However, process control to achieve and maintain the target pH is the greatest concern for design. Ideally neutralization is accomplished in a multiple step process as depicted in Figure 3-3. The first stage of neutralization should bring the wastewater to approximately 40% to 50% of the desired endpoint. The second stage can be used to reach the endpoint and maintain additional detention time to ensure a stable pH before water is directed to the other unit operations. Laboratory titration tests are useful to predict the required chemical dosages in order to size chemical storage tanks, feed pumps and tank mixers for each neutralization stage. Based on the required flow rates as determined through testing, a factor of safety of 1.2 should be applied for sizing tanks and pumps for the neutralization process. Detention time can range from 5 to 30 minutes detention to achieve proper neutralization. However, treatability tests can be used to confirm the actual detention time for purposes of sizing the reactor.

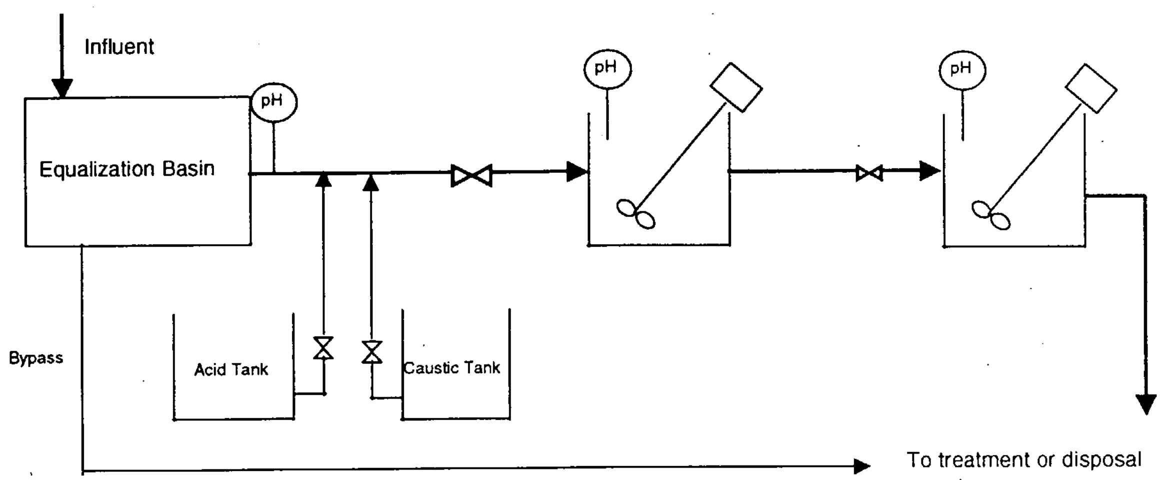

Figure 3-3 Typical Flow Scheme of Neutralization

3.3 Sedimentation

Sedimentation is the process by which solid particles in the wastewater are separated and removed from the stream by gravity. The sedimentation process operates continuously, and most commonly uses rectangular or circular shaped tanks. The tanks are sloped on the bottom to allow for easy removal of the collected solids. Sedimentation occurs in one of three types:

(1) discreet particle settling
(2) flocculent settling
(3) zone settling.

Depending on the particular industrial wastewater characteristics, one or more of these types of settling basin will be required. A description of each is given in the following subsections.

3.3.1 Discreet Settling

This unit operation is used at facilities having significant quantities of suspended solids and as a pre-treatment step to biological treatment units. This process is also referred to as grit removal. Depending on the source of the wastewater the collected solids may contain some putrescible organic materials that may result in odor generation.

Discreet particle settling is used to remove inert materials, typically having specific gravity values of approximately 2.65 and with a diameter of 0.2 mm or greater. A primary goal of suspended solids removal is for protection of pumping equipment caused by abrasion from the suspended materials. In some cases the removal is required to maintain optimum treatment efficiency for down stream unit operations. If significant suspended solids are present in the influent wastewater this unit operation may need to be placed hydraulically upgradient of a flow equalization basin to protect pumping equipment.

Design of rectangular channel-type sedimentation facilities for discreet particles is based on the particle settling velocity and fluid velocity through the tank. The average settling velocity for such inert materials is approximately 0.023 m/s. The desired fluid flow velocity is 0.30 m/s. This results in a length to depth ratio of 13.2. If the tank is placed before a flow equalization basin fluid velocity though the tank is controlled by designing the cross-sectional area of the tank to accommodate the maximum instantaneous flow rate. For sedimentation tanks that have hoppers on the bottom to collect the solids, a minimum of 1 minute detention is required for effective removal. In either case the inlet structures to these tanks should dissipate inlet fluid velocity and provide for uniform flow in the tank.

3.3.2 Flocculent Settling

Flocculent settling occurs as part of a coagulation/flocculation unit operation where specific chemicals are added to and mixed with the wastewater to remove pollutants. Flocculent settling basins are part of the coagulation/flocculation unit operation that is many times included with a metals precipitation process. Metals precipitation through oxidation/reduction processes is discussed further in Section 3.8.

The coagulation/flocculation process is depicted in Figure 3-4. After a coagulant is added to the wastewater a rapid mix process is performed to provide complete mixing of the chemical with the wastewater influent. Rapid mixing detention time is typically 1 to 5 minutes. The water is then directed to a flocculation tank where additional slow mixing is performed and to allow floc formation to occur. Detention time in the slow mix tank typically range from 10 to 30 minutes. The individual flocs formed will begin to agglomerate into larger particle masses. After slow mixing the fluid is directed to a settling tank for solids removal. Supernatant is drawn from the settling tank and continues on to the remaining treatment system unit operations. Solids are drawn off of the tank bottom and directed to a dewatering operation.

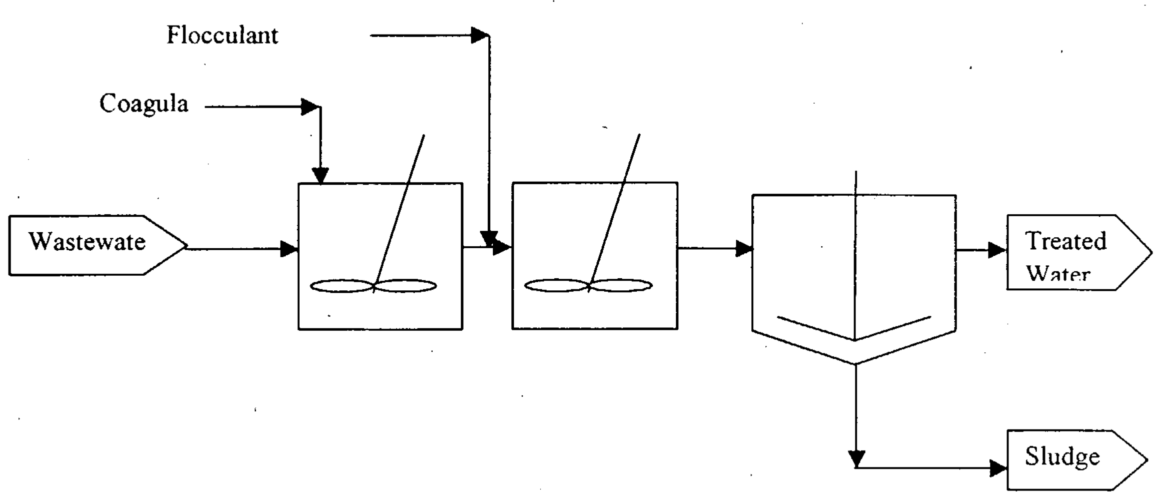

Figure 3-4 Typical Flow Schematics of Coagulation/Sedimentation

Since there is no mathematical relationship to describe the flocculation process and the associated settling properties, laboratory settling tests are required to size the clarifier unit.

Typically a maximum effluent suspended solids concentration is specified for the clarification process and experimental data are obtained using wastewater samples to design the clarifier. An example calculation using sample data from a pulp and paper mill laboratory test is given in Section 4. This example demonstrates how site-specific design criteria for the settling basin is developed.

3.3.3 Zone Settling

The mixed liquor from activated sludge systems will typically exhibit suspended solids concentrations exceeding 1,000 mg/L. Suspended solids from this type of a system will exhibit zone settling characteristics. Similar settling basins as those used for flocculent settling are used to remove suspended solids from this type of process, however the detention times are typically greater to achieve superior solids removal. The settling characteristics of this type are well understood when compared to those generated from a conventional coagulation/flocculation unit operation. These clarifiers are generally circular, since rectangular tanks can allow hydraulic dead zones to develop and affect the solids settling effectiveness.

Table 3-4
Typical Clarifier Design Data

Treatment Type	Overflow rate ($m^3/m^2/D$)		Solids Loading ($kg/m^2/h$)		Depth (m)
	Average	Peak	Average	Peak	
Settling following activated sludge	16 – 32	40 – 50	3.9 – 4.9	9.8	4 – 6
Settling following extended aeration	8 - 16	24 – 32	0.97 – 4.8	6.8	4 – 6
Settling following trickling filters	16 - 24	40 – 50	2.9 – 4.8	7.8	3 – 5
Settling following rotating biological contactor	16 - 32	40 – 50	3.9 – 4.9	9.8	3 – 5

Adapted from Metcalf & Eddy, 1991

The tank diameters for clarifiers will range from 10 to 40 meters, though both smaller and larger units have been used based on facility-specific flow and loading conditions. Generally the tank radius should not exceed five times the sidewater depth. In biological systems the settled solids are withdrawn constantly to maintain a constant depth in the unit, and to provide for necessary make-up solids for the mixed liquor in the aeration basins.

3.4 Flotation

Dissolved air flotation (DAF) is used to remove non-aqueous phase liquids and suspended solids matter commonly found in industrial wastes. Applications of the DAF technology include the pulp and paper, de-inking, food and textile industries, and petroleum processing facilities. DAF units can also be used to thicken sludge from biological treatment plants to improve the sludge dewatering process. For many industrial wastewater types treatment using DAF units can reliably achieve clarification to below 50 mg/L of filterable solids and a thickened float consistency of 2-4%.

A typical DAF unit is depicted in Figure 3-5. The major system components include the flotation cell, an air compressor, chemical feed pumps for polymer dosing (if required), a sludge pump, and a float skimmer mechanism. A portion of the clarified effluent is pressurized with air from a compressor such that the liquid is saturated with respect to air. This pressurized air/liquid mixture is returned to the DAF tank and released into the influent wastewater. The pressure differential causes micro-fine bubbles to form in solution and rise to the tank surface. A rotating skimmer mechanism removes the float from the DAF cell and directs it to a sludge holding tank. DAF units can be either rectangular or circular in their configuration.

The operating variables are air pressure, wastewater recycle ratio, detention time, air/solids ratio, solids and hydraulic loading rates, and chemical aid dosing rates. The bubble size generated from the air distribution line is controlled by the pressure differential. Higher pressures result in smaller bubble size, while lower pressures will increase their size.

Pressurization of the clarified effluent can range from approximately 140 to 550 kPa. These pressures will generate bubbles with average diameters of 30 to 120 μm. Bubbles that are too large are less effective at attaching to the solid particles present in the wastewater. Typical design data for solids loading to a DAF unit range from approximately 9 to 19 $kg/m^2 \cdot hr$, a hydraulic loading rate of 40 $L/m^2 \cdot min$, an effluent recycle rate of 30 to 150%, and a detention time of 20 to 30 minutes.

Treatability testing using wastewater from the facility is recommended to optimize DAF performance. However, basic information regarding the wastewater characteristics can be used to size the DAF cell and associated equipment. If pilot studies are not performed, the design should include a provision for a polymer feed system to assist the flotation process. On-site testing of a new DAF installation will be required to determine key operating parameters for the specific wastewater stream being treated.

DAF application testing for a new installation can be performed by the equipment vendor. In the case of DAF units, vendor-supplied design data will be the most reliable when specifying its use at a wastewater treatment facility. Design standards issued by the American Petroleum Institute (API) should be used by the selected DAF vendor to ensure compliance with critical issues such as materials of construction and testing procedures used to determine equipment sizes.

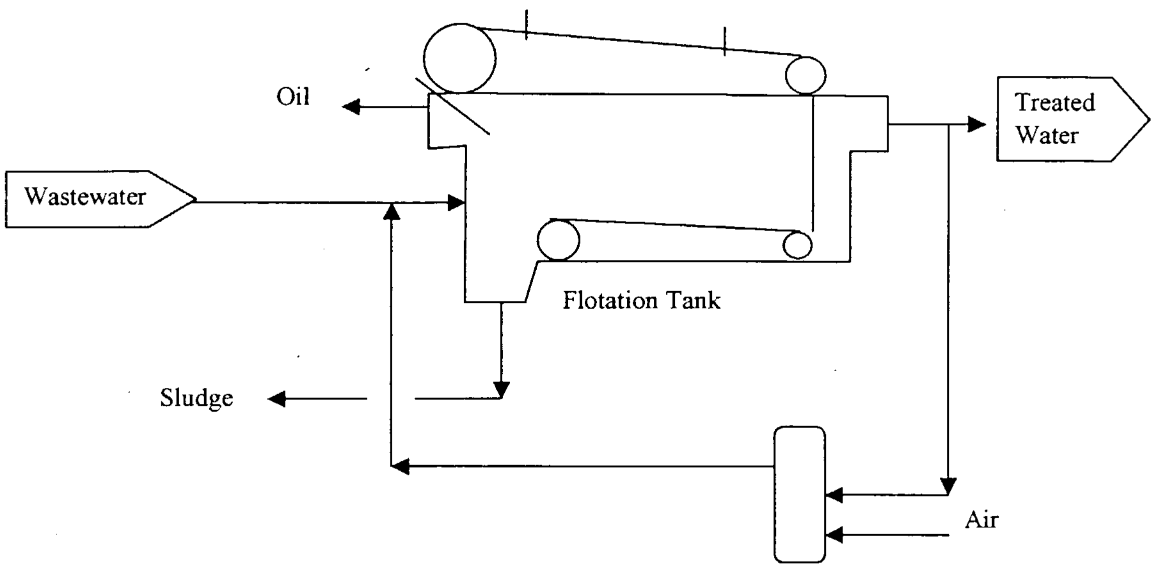

Figure 3-5 Typical Flow Scheme of Dissolved Air Flotation

3.5 Filtration

Liquid filtration of liquids is performed for the entire range of particles, from sediments that can be seen with the naked eye to ionic-sized particles. The most efficient type of filtration device will depend upon the types of particles to be removed. For purposes of this manual the term filtration will refer to removing suspended solids from the wastewater stream. Dissolved solids can be removed using membrane filtration or separation techniques. Membrane filtration is discussed in Section 3.11.

Filtration is performed on clarified effluent from coagulation/flocculation operations, or as a form of tertiary treatment following biological wastewater processes. The filtration devices operate gravity or low pressure. The suspended solids removed using conventional filtration methods range in size from 50 μm to 1000 μm. Examples of particles in this size range include beach sand, granular activated carbon, pollen and milled flour.

Solids are removed from the wastewater by either sorption or straining. Sorption may occur when the suspended solids exhibit an electrical charge and are attracted to filtration media of the opposite charge. However, sorption is not typically considered to be the primary removal mechanism in filtration operations. Straining of suspended solids occurs when particles become physically trapped within the pore spaces of the filter media. A certain portion of the suspended solids will pass through a media filtration device. The efficiency of the filter to remove the suspended solids is based on:

(1) the type and concentration of the suspended solids in the influent
(2) the type of filter media used and its depth
(3) the use of filtration aids
(4) the method of filter operation.

A typical low-pressure filtration device is shown in Figure 3-6. For treatment systems that operate continuously, the filter systems most commonly consist of two or more filter devices. This arrangement allows for one filter device to be removed from service at any given time for backwashing. The degree of backwashing required for filter operation is a function of the suspended solids concentration expected to be passed through the filters. As solids are removed head loss through the filters increases to a point where the design flow cannot be filtered. Figure 3-7 indicates a typical relationship of head loss to solids loading in a gravity filter. Head losses can increase significantly beyond those shown in Figure 3-7 if filtration aids are added to increase the solids removal efficiency.

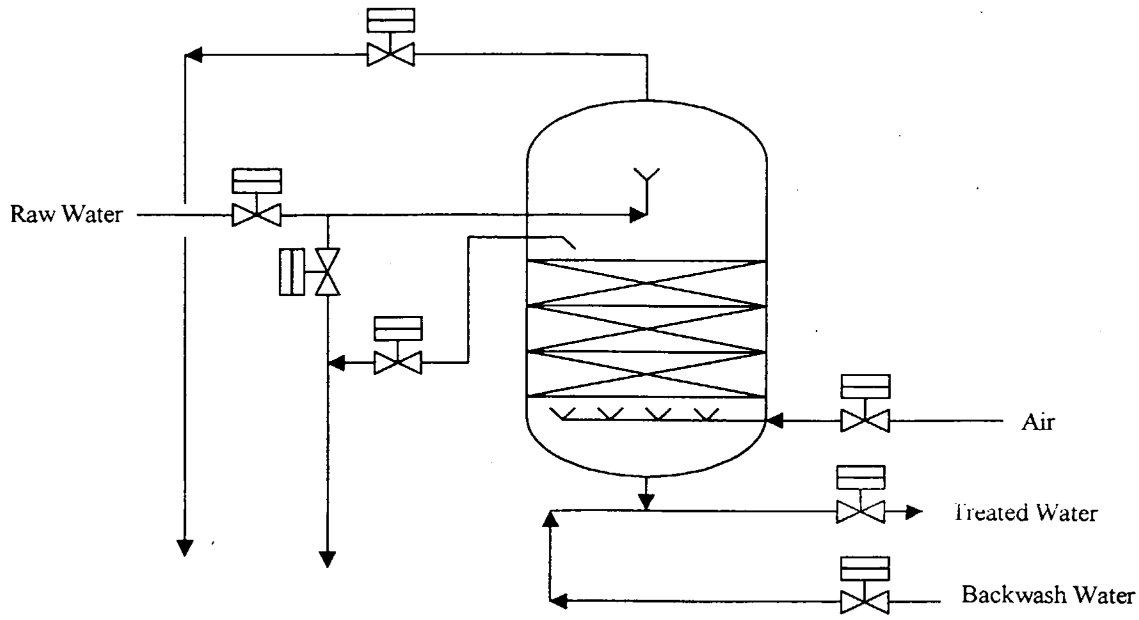

Figure 3-6 Typical Flow Scheme of Pressure Filtration

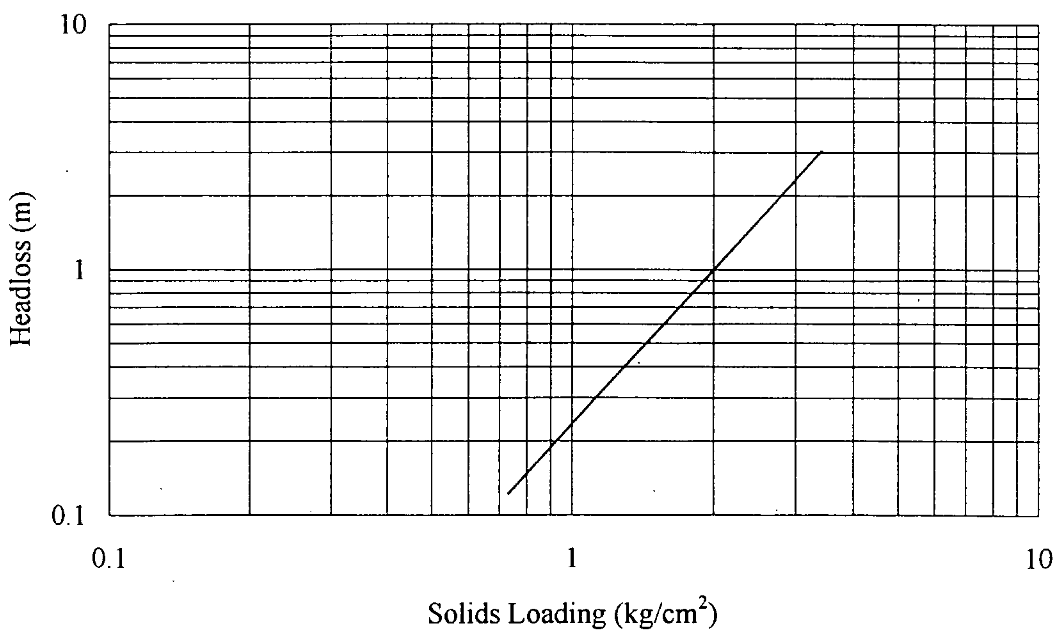

Figure 3-7 Sample Filter Head Loss as a Function of Solids Loading

Filtration can be accomplished using one, two, or three media placed in the filtration device. Table 3-5 presents the types of filtration media commonly used in gravity or low-pressure filtration configurations and typical hydraulic loading rates.

Table 3-5 Typical Filtration Media Types and Hydraulic Loading

Media Type	Material	Size (mm)	Depth (cm)	Hydraulic Loading ($m^3/m^2 \cdot min$)
Monomedia				
Fine	Sand	0.35 — 0.60	25 — 50	0.12
Coarse	Anthracite Coal	1.3 — 1.7	90 — 150	
Dual Media	Sand	0.45 — 0.60	25 — 30	
	Anthracite Coal	1.0 — 1.1	50 — 75	0.20
Multimedia	Garnet	0.25 — 0.4	5 — 10	
	Sand	0.45 — 0.55	20 — 30	0.20
	Anthracite Coal	1.0 — 1.1	45 — 60	

Adapted from Eckenfelder, 1989

The hydraulic loading rates will vary depending on the influent suspended solids concentrations and particle sizes. Of these types of filtration used, multi media filtration has become widely accepted as a standard in high rate, high performance filtration technology. Multi media uses a combination of three or more materials to approach the coarse-to-fine grain configuration of the ideal filter. The media grain size decreases uniformly in the direction of flow. This configuration provides an infinite series of progressively finer "screens" which remove increasingly smaller particles and redistribute the captured solids throughout the entire depth of the bed. Multi media filters use materials that typically range in size from 0.25mm to 1.7 mm and with specific gravity values from 1.6 to 4.0.

Backwashing the filters can be initiated manually based on observations related to filter run-cycles at for a specific application. An automated control system can also be used for backwashing which initiates the cycle using pressure gages in the unit that measure its head loss constantly. Table 3-6 summarizes typical backwash hydraulic loading and velocity requirements for gravity and low-pressure filters. Backwashing time requirements will vary by the site-specific conditions, such as the solids loading rate, and particle sizes of suspended solids removed. However, backwash times typically range from 15 to 20 minutes.

Provisions must be made in the design for a sufficient clean water supply and pumping capacity for routine backwash cycles.

Table 3-6
Typical Backwash Requirements for Low Pressure Filters

Filter Type	Hydraulic Loading ($m^3/m^2 \bullet min$)	Fluid Velocity (m/min)
Monomedia	1.8 – 2.0	1.8 – 1.9
Dual Media	0.8 – 1.2	0.76 – 1.22
Multimedia	0.8 – 1.2	0.76 – 1.22

Adapted from Metcalf & Eddy, 1991

Other types of filter devices used for industrial wastewater treatment include screen-, and bag-type filters. Screen filters use a coarse screen to filter out large particles in the influent waste stream. These filters are subject to blinding and build-up of excessive head loss. Bag filters are constructed of non-woven media such as polypropylene in the shape of a bag. Fluid is directed into the bag filter unit under pressure and the impurities are captured on the media. As solids build up in the unit the bags will require changing. Granular activated carbon may be used for physical filtration, although its use is more commonly applied to organic compound removal using the sorption phenomenon. The sizing of these types of filters is made by the equipment vendors using the wastewater characteristics and flow information for the facility.

3.6 Aerobic Biological Treatment

Aerobic biological treatment refers to the process where wastewater is introduced into a reaction tank and the resident microbial population stabilizes the pollutants in the presence of oxygen. Wastewater can also be treated using anaerobic biological techniques. Anaerobic treatment is typically used for high-strength industrial wastewater applications. Anaerobic treatment is discussed further in Section 3.8.

Aerobic biological treatment is performed using either suspended-growth or attached-growth systems. This refers to the means in which the microbes contained in the treatment system are maintained; either suspended within the aeration tank through mixing, or attached to certain types of treatment media that sustains biological growth over which the wastewater is passed. Representative process options of suspended-growth and attached-growth systems are described in the following subsections.

3.6.1 Suspended Growth Systems

Suspended growth systems provide treatment by maintaining biomass (microorganisms) used for converting waste materials suspended in a reactor and in direct contact with the waste to carbon dioxide and water. Suspended growth systems require mixing techniques to maintain proper biomass suspension and contact with organic wastes. Mixing is often achieved by mechanical means or through delivery of diffused air or oxygen to the reactor. Air diffusion within a reactor provides oxygen transfer concurrent with the required mixing.

Suspended growth systems maintain relatively high microorganisms concentrations in the reactor by recycling biological solids. Descriptions of several aerobic suspended-growth treatment systems are described in the following subsections.

Activated Sludge

The activated sludge process is the most commonly used suspended growth system for secondary wastewater treatment. There are many variations of the basic process, all of which contain certain fundamental operating principles. Organic-bearing wastewater is directed to a reactor where a consortium of aerobic microorganisms is suspended through mechanical mixing or diffused aeration. The liquid present in the aeration reactor is termed mixed liquor. In addition to providing continuous mixing within the aeration reactor, the mechanical mixers or air diffusers provide for the required oxygen transfer to maintain microbial growth.

Mechanical mixers lift the mixed liquor into the air to drive oxygen into the fluid; the diffused aeration devices provide oxygen transfer through rising air bubbles from diffusers located at the bottom of the reactor. A general process flow diagram for the activated sludge process is shown in Figure 3-8.

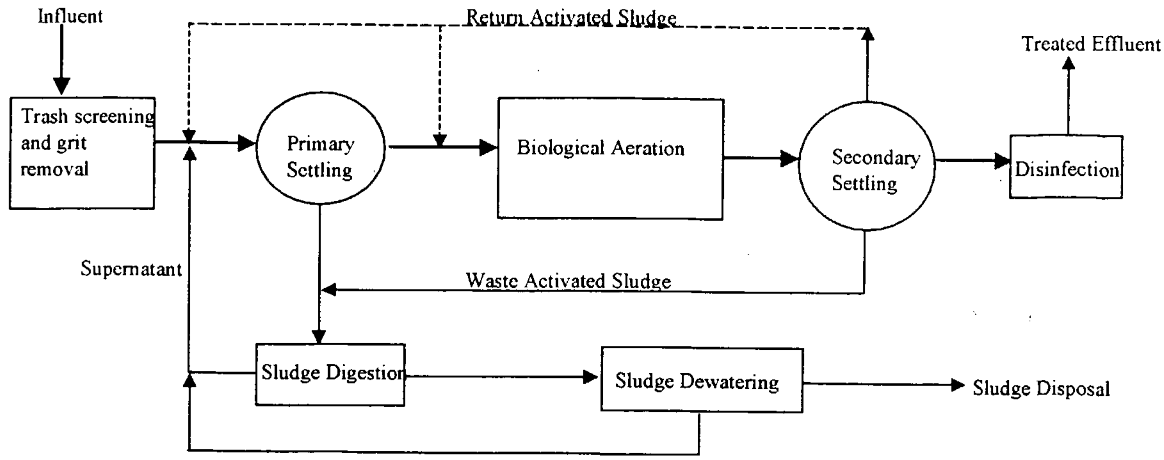

Figure 3-8 Activated Sludge General Process Flow Diagram

Aerated wastewater from the reactor is directed to a clarifier for solids settling. A portion of the settled sludge is returned to the aerobic reactor to maintain biological activity needed for organic waste degradation. The remaining sludge is directed to a stabilization reactor to reduce the number of pathogenic organisms present. This stabilized sludge is dewatered prior to its disposal. Sludge stabilization can be performed either aerobically or anaerobically.

The activated sludge process is well-understood and well-established for use in treating low to intermediate-strength wastewater. With several variations to the basic process design, a suitable approach can be developed for specific application to an industrial facility. The activated sludge process is more complex than lagoon treatment systems, however, the facilities can be automated to require little operator attention beyond routine maintenance activities. Table 3-7 summarizes the variations of the activated sludge process that have been developed. Selection of the process for an application will depend upon the specific wastewater characteristics at the facility.

Table 3-7 Description of activated-sludge processes and process modifications

Process or Process modification	Description	Process or Process modification	Description
Conventional plug-flow	Settled wastewater and recycled activated sludge enter the head end of the aeration tank and are mixed by diffused-air or mechanical aeration. Air application is generally uniform throughout tank length. During the aeration period, adsorption, flocculation, and oxidation of organic matter occurs. Activated-sludge solids are separated in a secondary settling tank.	Extended aeration	Extended aeration process is similar to the conventional plug-flow process except that it operates in the endogenous respiration phase of the growth curve, which requires a low organic loading and long aeration time. Process is used extensively for prefabricated package plants for small communities.
Complete-mix	Process is an application of the flow regime of a continuous-flow stirred-tank reactor. Settled wastewater and recycled activated sludge are introduced typically at several points in the aeration tank. The organic load on the aeration tank and the oxygen demand are uniform throughout the tank length.	High-rate aeration	High-rate aeration is a process modification in which high MLSS concentrations are combined with high volumetric loadings. This combination allows high F/M ratios and low mean cell-residence times with relatively short hydraulic detention times. Adequate mixing is very important.
Tapered aeration	Tapered aeration is a modification of the conventional plug-flow process. Varying aeration rates are applied over the tank length depending on the oxygen demand. Greater amounts of air are supplied to the head end of the aeration tank, and the amounts diminish as the mixed liquor approaches the effluent end. Tapered aeration is usually achieved by using different spacing of the air diffusers over the tank length.	Kraus process	Kraus process is a variation of the step aeration process used to treat wastewater with low nitrogen levels. Digester supernatant is added as a nutrient source to a portion of the return sludge in a separate aeration tank designed to nitrify. The resulting mixed liquor is then added to the main plug-flow aeration system.
Step-feed aeration	Step feed is a modification of the conventional plug-flow process in which the settled wastewater is introduced at several points in the aeration tank to equalize the F/M ratio, thus lowering peak oxygen demand. Generally three or more parallel channels are used. Flexibility or operation is one of the important features of this process.	High-purity oxygen	High-purity oxygen is used instead of air in the activated-sludge process. Oxygen is diffused into covered aeration tanks and is recirculated. A portion of the gas is wasted to reduce the concentration of carbon dioxide. pH adjustment added is about four times greater than the amount that can be added by conventional aeration systems.
Modified aeration	Modified aeration is similar to the conventional plug-flow process except the shorter aeration times and higher F/M ratios are used. BOD removal efficiency is lower than other activated-sludge processes.	Oxidation ditch	The oxidation ditch consists of a ring- or oval-shaped channel and is equipped with mechanical aeration devices. Screened wastewater enters the ditch, is aerated, and circulates at about 0.8 to 1.2 ft/s (0.25 to 0.35 m/s). Oxidation ditches typically operate in an extended aeration mode with long detention and solids retention times. Secondary sedimentation tanks are used for most applications.
Contact stabilization	Contact stabilization uses two separate tanks or compartments for the treatment of the wastewater and stabilization of the activated sludge. The stabilization activated sludge is mixed with the influent (either raw or settled) wastewater in a contact tank. The mixed liquor is settled in a secondary settling tank and return basin to stabilize the organic matter. Aeration volume requirements are typically 50 percent less than conventional plug flow.	Sequencing batch reactor	The sequencing batch reactor is a fill-and -draw type reactor system involving a single complete-mix reactor in which all steps of the activated-sludge process occur. Mixed liquor remains in the reactor during all cycles, thereby eliminating the need for separate secondary sedimentation tanks.

Reactor sizing in activated sludge systems is variable, and usually designed as a function of waste load rates, hydraulic load rates, and required treatment performance. The design can be modified to provide greater control over the oxygen supply, and significantly reduces the area requirements for effective treatment. These systems have been successfully used for industrial wastewater treatment. However, activated sludge is not an effective approach for treating high-strength wastewater.

Design considerations can be made using one of two variables, the mean cell residence time (MCRT), or the food:microorganism (F/M) ratio. The F/M measures the influent wastewater strength to the hydraulic detention time and existing microorganism concentration in the aeration reactor. The MCRT is the amount of time an microorganisms remains in the system. Table 3-8 summarizes typical design values for the activated sludge process. The *Ten States Standards* specifies that air requirements for all activated sludge processes except extended aeration shall be 93.5 m^3/kg BOD for peak organic loading to the system. The extended aeration process requires 125 m^3/kg BOD.

Table 3-8
Typical Activated Sludge Design Values

Process Type	MCRT (days)	F/M (kg BOD/kg VSS •d)	Volumetric Loading (kg/m3 •d)	Detention Time (hours)
Conventional	3 – 15	0.2 – 0.5	0.32 – 0.64	4 – 8
Complete-mix	1 – 15	0.2 – 1.0	0.80 – 1.92	3 – 5
Step-feed	3 – 15	0.2 – 0.5	0.64 – 0.96	3 – 5
Modified Aeration	0.2 – 0.5	1.5 – 5.0	1.2 – 2.4	1.5 – 3
Contact Stabilization	5 – 15	0.2 – 0.6	0.96 – 1.2	3 – 6
Extended Aeration	20 – 30	0.05 – 0.15	0.16 – 0.40	18 – 36
High-rate Aeration	5 – 10	0.4 – 1.5	1.6 – 16	2 – 4
Kraus Process	5 – 15	0.3 – 0.8	0.64 – 1.2	4 – 8
Oxygen Process	3 – 10	0.25 – 1.0	1.2 – 2.4	1 – 3
Oxidation Ditch	10 – 30	0.05 – 0.3	0.08 – 0.48	8 – 36
Sequencing Batch Reactor	NA	0.05 – 0.3	0.08 – 0.24	15 – 50
Single-Stage Nitrification	8 – 20	0.1 – 0.25	0.08 – 0.32	6 – 15
Multi-Stage Nitrification	15 – 100	0.05 – 0.2	0.05 – 0.14	3 – 6

Adapted from Metcalf & Eddy, 1991

These design values can be used to initiate the design process and obtain information about major equipment sizes. Design engineers and equipment vendors should be consulted in order to select the most appropriate activated sludge process modification for the specific application.

The most common operational problem with activated sludge plants is the excessive growth of filamentous organisms that cause poor solids settling in the secondary clarifier. This is also called 'bulking sludge' and results in effluent with high suspended solids and BOD levels. One method of controlling the filamentous organism growth is by providing a separate mixing chamber upstream of the main aeration reactor, where mixing of the influent and the return activated sludge can occur. A relatively short hydraulic detention time of 10 to 30 minutes in this separate basin can achieve the desired results. The organic loading rates will be greater than the main aeration reactor. A minimum F/M in this contact basin should be 2.25 kg BOD/kg mixed liquor suspended solids (MLSS), although F/M ratios may be as high as 20 to 25 kg COD/kg MLSS.

Other factors which can contribute to bulking sludge include nutrient deficiencies, which are common in many industrial wastewater streams. Low dissolved oxygen (DO) content in the aeration basins can cause bulking, and DO levels should be maintained at approximately 2mg/L under normal loading conditions. If the MCRT the F/M values exceed the plant design values, adjustments to the sludge wasting rate may be required to reduce these process variables. In extreme cases the addition of chemicals can be made to the process to control the filamentous organisms. A dose of 2 to 3 mg/L of chlorine per 1000 mg/L of volatile suspended solids (VSS) in the return activated sludge line can be made to reduce the solids loading to the aeration basin. Alternatively hydrogen peroxide can be added to the aeration basin to increase the DO levels to a stable point should the air distribution system be unable to deliver the proper amount of oxygen to the system.

Controlling sludge bulking requires a step-wise evaluation of the process variables to identify the potential cause or causes. Daily process modifications may be required to maintain the proper solids level and DO concentrations in the aeration basin through increasing or decreasing return activated sludge rates and modifying blower or aerator operations. Also, sludge depths in the clarifier may be changed by increasing or decreasing the wasting rates as appropriate. Such process changes require daily monitoring of the MLSS levels in the return sludge, the aeration reactor, the influent, and the flow rate of the influent to calculate either the MCRT or F/M ratio. With expected waste load rates and flow variations common to industrial facilities, close operator attention is typically required to maintain optimum process control.

Aerobic Waste Stabilization Ponds

This common form of wastewater treatment has been used successfully to treat municipal sanitary and industrial wastes. In general, pond systems are well understood, relatively simple to design and operate, and can be constructed with readily available local materials. Pond systems have been successfully used for most wastewater treatment applications, although their applicability is related directly site-specific conditions. Advantages of pond systems to activated sludge treatment includes operational simplicity and lower capital and O&M costs. However, the significant disadvantages include lower treatment performance, reduced control of the treatment process, and greater land area requirements.

These ponds are classified by the dominant type of biological activity and include: aerated ponds, aerobic ponds, and facultative ponds. Each pond type is summarized below.

Aerated Ponds — Aerated ponds use mechanical surface aerators or submerged air diffusion devices to mix wastewater and supply oxygen to the system. These ponds may be used for industrial wastewater pretreatment, or for municipal sanitary wastewater treatment. Depending on the pond system configuration and biosolids recycle rates, these ponds can be made to operate similarly to the more advanced mechanical activated sludge systems. Additional aeration may be passively provided to these ponds in warmer climates by photosynthesis that occurs during daylight; however, this is not the primary oxygen source. Pond depths range from 2 m to as much as 4 m. Organic waste design loading rates may be as high as 320 kg BOD_5/ha • d.

Treatment effectiveness of these ponds is dependent on the influent wastewater strength and hydraulic detention time. While organic waste reduction effectiveness in aerated ponds may be as high as 95 percent, high-strength wastewater would not be effectively treated using aerated ponds.

Aerobic Ponds — Aerobic ponds are distinguished from aerated ponds in that oxygen levels in the treatment system are maintained relatively constant over the entire pond depth through photosynthesis. Thus, these ponds are comparatively shallow, ranging from 30 to 45 cm in depth. Mixing may be needed to expose all the algae in the pond to sunlight and to prevent anaerobic conditions from occurring. These ponds are typically used as a polishing step to treat effluent from other biological treatment processes. Acceptable design waste load rates are as much as 160 kg BOD_5/ha • d.

Aerobic ponds are effective for soluble organic waste reduction; however, these systems often have higher TSS levels in the treated effluent, ranging from 80 to 140 mg/L. These ponds have lower maximum waste loading capacities than aerated ponds, and would not meet effluent discharge criteria. Thus, greater land area would be required than for aerated ponds with no additional treatment benefit.

Facultative Ponds — Facultative ponds are the most common type of waste stabilization pond. They are characterized by an aerobic layer on top of the pond, underlain by an anaerobic zone. Facultative ponds are typically used to treat sanitary municipal wastewater, or for a polishing treatment step for effluent from other biological processes. Oxygen is supplied to the aerobic layer through mechanical surface aerators and by photosynthesis; anaerobic conditions in the lower portion of the pond allow for biosolids stabilization. The stabilization process serves to reduce the volume of biosolids in the system, as well as reduce the concentration of pathogenic organisms present.

These ponds typically have depths of 1 m to 2.5 m, with organic loading rates of up to 200 kg BOD_5/ha •d. Depending on influent wastewater strength and hydraulic retention time in these ponds, BOD_5 reductions of up to 95 percent are attainable. Effluent TSS concentrations can range from 40 to 60 mg/L.

3.6.2 Attached Growth Systems

Attached growth systems affect treatment by providing a surface for microorganisms to grow where a constant exposure to wastewater and the atmosphere exists. These systems have become more common in the last 20 years. Two representative process options of this treatment approach are trickling filters and rotating biological contactors (RBCs). These are discussed in the following subsections.

Trickling Filters

Trickling filters are typically circular reaction tanks filled with a specified media (e.g., large rocks, wood, or plastic) to provide necessary surface area for attached biomass growth. Primary treatment of raw wastewater is needed to remove larger suspended materials and thus prevent the filter pore spaces from clogging. Wastewater is applied by dosing the filter surface through a perforated radial arm which rotates around the top of the filter arm. As a result of wastewater application, biomass will grow on the filter media, which then remove organic wastes through adsorption and assimilation in and on the biomass surface. A portion of the filtered effluent is recycled to the influent line to maintain performance. The recycle rate must be adjusted for the wastewater type being treated, and can vary from 0 to 3 times the influent flow rate.

Aerobic conditions are maintained through either natural or forced aeration of the filter, where air passes through the natural voids in the media. Clarification of the treated wastewater is needed to settle any biological solids which pass through the filter. A significant disadvantage of trickling filters is that anaerobic conditions may form if waste loads rates are too high. This results in reduced treatment performance and noticeable odor problems near the filter.

There is no universal design process for trickling filters. However, observations of trickling filter performance at a wide range of facilities have been used to develop an empirical equation to size the major equipment. The empirical design equation and representative values for specific industrial facilities is shown in Appendix. Table 3-9 presents some typical trickling filter loading and performance data for various types of wastewater.

Table 3-9
Typical Trickling Filter Performance Data

Wastewater Type	Hydraulic Loading ($m^3/m^2 \cdot d$)	Depth (m)	Recycle Ratio	BOD Loading (kg/m^3)
Municipal	187	6.5	1.5	4.2
Citrus	122	6.5	2.5	6.5
Kraft Mill	196	6	0	NA
Black Liquor	110	5.5	0	7.3

NA = Not available
Adapted from Eckenfelder, 1989

As with activated sludge processes, these values are typical of those expected from a trickling filter for industrial wastewater treatment. However, design engineers and equipment vendors should be consulted in order to select the most appropriate trickling filter design for the specific wastewater treatment application.

Rotating Biological Contactors

The first RBCs were capable of improved treatment performance compared to trickling filters, used less energy, and mitigated anaerobic conditions from becoming established within the treatment system. They were developed to enhance the oxygen transfer and wastewater contact with the attached biomass by using plastic media formed into a circular disc that rotates through a tank filled with untreated wastewater. The circular plastic disks are mounted on a horizontal shaft which rotates at about 1 to 2 rpm. Approximately 40 percent of the disks are continuously immersed in wastewater. The wastewater flows through the reactor by gravity and displacement by the disks. Disk rotation ensures that the attached biomass is alternately exposed to the atmosphere for oxygen transfer and to the wastewater for organic waste adsorption and assimilation.

Process difficulties can occur if organic loading rates are variable and disk rotation speeds are not adjusted to account for the differences. Biomass may build up on the disks excessively or unevenly, causing potential structural problems with the shaft. While RBCs are capable of achieving effective treatment performance for sanitary and intermediate strength industrial wastes, this technology is often susceptible to process operational difficulties.

The high-density polyethylene media used for the RBC disks has a surface area of approximately 121 m^2/m^3, with single disks having a diameter of 3.7 m and a length of 7.6 m. This arrangement provides for an effective surface area of 9290 m^2. Different treatment levels can be achieved by adding multiple contactor units in the reaction basin. Table 3-10 summarizes typical design information for RBCs that achieve varying degrees of treatment performance.

Table 3-10
Typical Rotating Biological Contactor Design Information

Item	Secondary Treatment	Combined Nitrification	Separate Nitrification
Hydraulic Loading ($m^3/m^2 \cdot d$)	0.08 – 0.16	0.03 – 0.08	0.04 – 0.10
Total Organic Loading ($kg/m^2 \cdot d$)	0.010 – 0.017	0.007 – 0.015	0.001 – 0.003
NH3 Loading ($kg/m^2 \cdot d$)	–	0.001 - .0015	0.001 – 0.002
Hydraulic Detention Time (hr)	0.7 – 1.5	1.5 – 4	1.2 – 2.9
Effluent BOD (mg/L)	15 - 30	7 – 15	7 – 15
Effluent NH3 (mg/L)	–	<2	1 – 2

Adapted from Metcalf & Eddy, 1991

As with activated sludge processes, these values are typical ranges of expected performance. However, design engineers and equipment vendors should be consulted in order to select the most appropriate RBC design for the specific wastewater treatment application.

3.7 Anaerobic Biological Treatment

Anaerobic treatment mineralizes organic wastes to methane and carbon dioxide in the absence of oxygen, and has been used extensively as an effective method for treating high-strength industrial organic wastewater. High-strength organic wastes are most common to the food processing industry.

In some cases the effluent from anaerobic systems is directed to an aerobic biological treatment system for polishing. Anaerobic treatment can be accomplished in open, deep lagoons, or within controlled reactor vessels that limit the presence of oxygen. This section describes these two approaches.

3.7.1 Anaerobic Lagoons

Anaerobic ponds are most commonly used for treating higher-strength industrial wastewater. These ponds are open to the atmosphere, although the treatment occurs in the deep area of the pond. Unlike aerated, aerobic, and facultative lagoons, there is no external mixing performed in these units. The high-strength wastewater influent directed to the treatment system tends to be oxygen-depleted, and thus typically prevents an aerobic zone from forming within the pond system. Anaerobic lagoons require relatively small design volumes and are thus less expensive to construct than aerobic systems. These lagoons can mineralize significantly more organic matter per unit volume than aerobic lagoons.

Anaerobic ponds have typical depths of 2.5 to 5 m and accommodate an organic waste loading rate of up to 500 kg BOD_5/ha •d. Reduction of BOD_5 concentrations of 50 to 85 percent is typical. Thus, a subsequent polishing treatment step is usually required prior to treated wastewater discharge. Concentrations of TSS in the effluent are relatively high, and can exceed 160 mg/L, thus requiring polishing filtration or clarification.

The treatment process results in the generation of methane gas by the anaerobic microorganisms. This gas is usually not captured in pond systems due to physical constraints, and is vented to the atmosphere. Mixing within the pond system is generally achieved by wastewater flow through the ponds and from the methane gas generation.

Disadvantages to anaerobic lagoons include sensitivity to sudden changes in temperature and loading rates, and can produce some septic odors as a result. The lagoons work best during summer and in warmer climates since higher temperatures improve organic decomposition.

3.7.2 Anaerobic Reactors

There are several types of anaerobic reactors used for industrial wastewater, including anaerobic contact chambers, anaerobic filters, upflow anaerobic sludge blanket (UASB) reactors, and fluidized bed reactors. The UASB type is quite common for use with high-strength wastes. A commonly used anaerobic reactor vessel is the upflow anaerobic sludge blanket (UASB) system. This type of treatment has been significantly refined over the past 25 years to treat high-strength industrial wastewater.

An enclosed reactor is used to maintain anaerobic conditions. Biological sludge from an activated sludge plant is placed in the reactor before the UASB process is initiated to assist with the start-up process. Wastewater enters at the base of the reactor vessel and passes up through the sludge blanket, where the microorganisms adsorb and assimilate the organic wastes. The sludge blanket thickens as the process continues, enhancing treatment performance, until a steady-state is achieved by controlling the influent flow rates. Treated effluent flows out near the top of the reactor, along with some biological solids. The solids must be removed through clarification, a portion of which will be returned to the reactor. The effluent then is directed to a polishing treatment process. Methane gas is typically recovered and used for heating the reactor system.

The UASB technology has been proven to effectively reduce strong industrial waste levels by up to 85 percent with much lower area and hydraulic retention time requirements of anaerobic ponds. Thus, a UASB system would require polishing treatment prior to treated wastewater discharge.

Advantages of the UASB process other than comparatively low area requirements include a lower volume of waste solids generation, methane gas formation which can be used for energy production, and a relatively stable operation, even after dormant periods of reactor use. This technology has been installed at numerous beet-sugar processing facilities in Europe and the United States. This level of development over the past 25 years for high-strength wastewater treatment indicates its applicability to meet the requirements for those industries which have such wastewater issues. In addition, the treatment facilities can be constructed using readily available materials.

Table 3-11
Typical UASB Waste and Hydraulic Loading Data

Wastewater Type	Waste Loading (kg COD/m^3 • d)	Hydraulic Detention Time (hr)
Skimmed Milk	71	5.3
Potato	25 – 45	4
Sugar	22.5	6
Sugar Beet	10	4
Brewery	95	-
Champagne	15	6.8

Adapted from Eckenfelder, 1989

While the UASB technology is proven for treating high-strength wastes, a variation of this technique provides similar, and possibly improved treatment results with lower area requirements and improved methane gas production. This treatment variation is the internal circulation (IC) reactor. The fundamental difference between the IC and the UASB reactor is that contact between the biomass and influent wastewater is increased significantly, achieving similar treatment performance at greater waste loading rates. This also results in more efficient methane gas generation rates. The circulation of wastewater within the vessel can be achieved by either mechanical mixing, or by a reactor configuration that uses the upward methane gas and influent wastewater flow to establish a dynamic mixing regime.

As with the aerobic biological treatment processes, the design data for the selected food industry wastes are given as typical for the UASB technology. However, design engineers and equipment vendors should be consulted in order to select the most appropriate type of anaerobic reactor for the specific wastewater treatment application, and to determine the need for additional aerobic processes for wastewater polishing steps.

3.8 Chemical Precipitation

Chemical precipitation techniques are commonly used in many wastewater treatment applications where dissolved metal species must be removed. This treatment approach takes advantage using pH adjustment to modify the chemical stability of the metals of interest. By controlling pH to specific ranges the target metal can be precipitated from solution. In many cases the precipitation reaction is performed with lime to generate the insoluable hydroxide form of the metal. Other treatment chemicals include sulfides and aluminum sulfate.

In many cases the precipitates formed do not settle readily from solution under gravity, and chemical enhancement using specialized polymers may be needed to assist in the settling or clarification process.

Since wastewater generated by industrial processes may contain a variety of non-metal contaminants that can affect chemical precipitation, wastewater containing certain non-aqueous solvents, excessive surfactants and or solids, cyanide, or hexavalent chromium will require pre-treatment prior to their introduction to an oxidation system. For example, hexavalant chromium must be reduced to the trivalent state before precipitation, and excessive surfactants can interfere with particle flocculation thereby reducing filtering efficiency.

Hexavalent chromium is very stable and will not precipitate from solution by conventional chemical precipitation methods. The reduction of hexavalent chrome is accomplished by the addition of a reducing agent which donates three negatively charged electrons to the hexavalent chrome ion thus reducing the chromium charge by 3 to its trivalent state. Reducing agents include sodium metabisulfite, ferrous sulfate, or sulfur dioxide. The reduction reaction occurs instantly at a pH of 3 or less. Once the hexavalent chrome has be reduced to the trivalent state, the chrome ion can then be precipitated as a chromium hydroxide by raising the pH of the wastewater to a pH of 8.0 to 8.5.

The typical oxidation reduction treatment process can operate as a batch treatment system in which the wastewater is collected in a tank and then treated as a single batch. Depending on flow rates in the system, and the use or availability of flow equalization tanks, the process can be performed on a continuous basis. However, continuous systems require greater control features and may result in variable treatment effectiveness. A batch system can be operated in a fully automatic mode with reagents injected under electrode control to ensure accurate dosing.

The typical treatment system consists of the following major components.

- Conical bottom HDPE reaction tank

- Circulation pump
- System controls including electrodes, switches, relays, and main control device
- Reagent dosing pumps
- Polish filter module (optional).

The basic process description is as follows:

(1) pH Adjustment

The pH electrode continuously signals its controller, which monitors the signal and compares it to the preset pH value. When the solution pH value differs from the preset pH set point, the controller will start an acid or base delivery pump. The reagent will be added to the stream until the set point is achieved. Should the pH value drift from the set point, the metering pump activates until the pH set point is achieved.

(2) Chemical Reaction

After the pH is properly adjusted, the reduction reaction process can proceed. An oxidation/reduction potential (ORP) electrode continuously signals a controller that monitors this signal and activates feed rate of a reducing or oxidizing reagent pump. The reagent is added to the stream until the ORP set point (or end point) is reached.

(3) Precipitation Reaction

The precipitation cycle begins by adjusting the pH again. This is performed automatically using the same controller and electrode described above. Caustic or acid reagent is added until a preset set point is achieved. If the pH has not been fully reached, the caustic pump injects additional reagent until the preset pH set point is achieved and maintained. When an End Point Delay timer reaches a set time, the system shuts down automatically and indicates the batch reaction is complete.

The treated water is clarified and filtered as required to remove the suspended solids from solution. Table 3-12 summarizes treatment levels that may be achieved using chemical precipitation processes.

Table 3-12
Typical Treatment Levels for Chemical Precipitation

Metal	Effluent Concentration (mg/L)	Technology
Arsenic	0.05	Sulfide precipitation/filtration
	0.06	Carbon adsorption
	0.005	Ferric hydroxide co-precipitation
Barium	0.5	Sulfate precipitation
Cadmium	0.05	Hydroxide precipitation
	0.05	Ferric hydroxide co-precipitation
	0.008	Sulfide precipitation
Copper	0.02 – 0.07	Hydroxide precipitation
	0.01 – 0.02	Sulfide precipitation
Mercury	0.01 – 0.02	Sulfide precipitation
	0.01 – 0.01	Alum co-precipitation
	0.0005 – 0.005	Ferric hydroxide co-precipitation
	0.001 – 0.005	Ion exchange
Nickel	0.12	Hydroxide precipitation
Selenium	0.05	Sulfide precipitation
Zinc	0.1	Hydroxide precipitation

Adapted from Eckenfelder, 1989

Application of this technology to a specific waste stream requires laboratory treatability testing. An example of how to obtain design criteria for chemical precipitation using laboratory data is shown in Section 4.

3.9 Carbon Adsorption

Granular activated carbon (GAC) is most often used to remove refractory organic compounds from wastewater, as well as certain inorganic pollutants such as chlorine, nitrogen, and sulfides. The GAC internal structure allows it to fully use its surface area to sorb pollutants of interest and remove them from solution. Macropores, or larger openings with a diameter greater than 1000 Å, provide an entrance into the inner structure of the carbon particle. Adsorption takes place due to intra-molecular attraction between the carbon surface and the substance that is being adsorbed. The force of the attraction can be altered by increasing the density of the carbon or by reducing the distance between the carbon surface and the substance being adsorbed (typically by reducing the median pore size).

As the fluid passes over and through the carbon, the attractive forces between the compounds that are the most attracted to the carbon are adsorbed onto the surface. The compounds that are the most highly attracted are typically organic compounds (which can cause taste, odor and appearance problems), volatile organic compounds (VOCs) and trihalomethane (THM) compounds. Pores with a diameter of less than 1000 Å are where adsorption takes place. The effective surface area for adsorption for a particular species depends on its size and the available surface area of the pores it can enter. A wide variety of activated carbons are available to fit particular applications.

Backwash of the units is required to remove suspended particles that are trapped within the system by physical filtration and prevent short-circuiting of the filter media. Sampling of the effluent is required on a periodic basis to monitor when the sorption capacity of the GAC is reached. When all sorption sites on the carbon are filled with the target chemical(s), the carbon must be replaced with fresh material. The spent carbon can be disposed of, or possibly regenerated at a dedicated reclamation facility. Regenerated carbon can be reused in the treatment process, though its efficiency will not be as great as fresh GAC. The use of fresh versus reactivated carbon can be evaluated for a specific application based on a cost evaluation of all operating parameters. Figure 3-9 depicts a typical GAC process flow schematic.

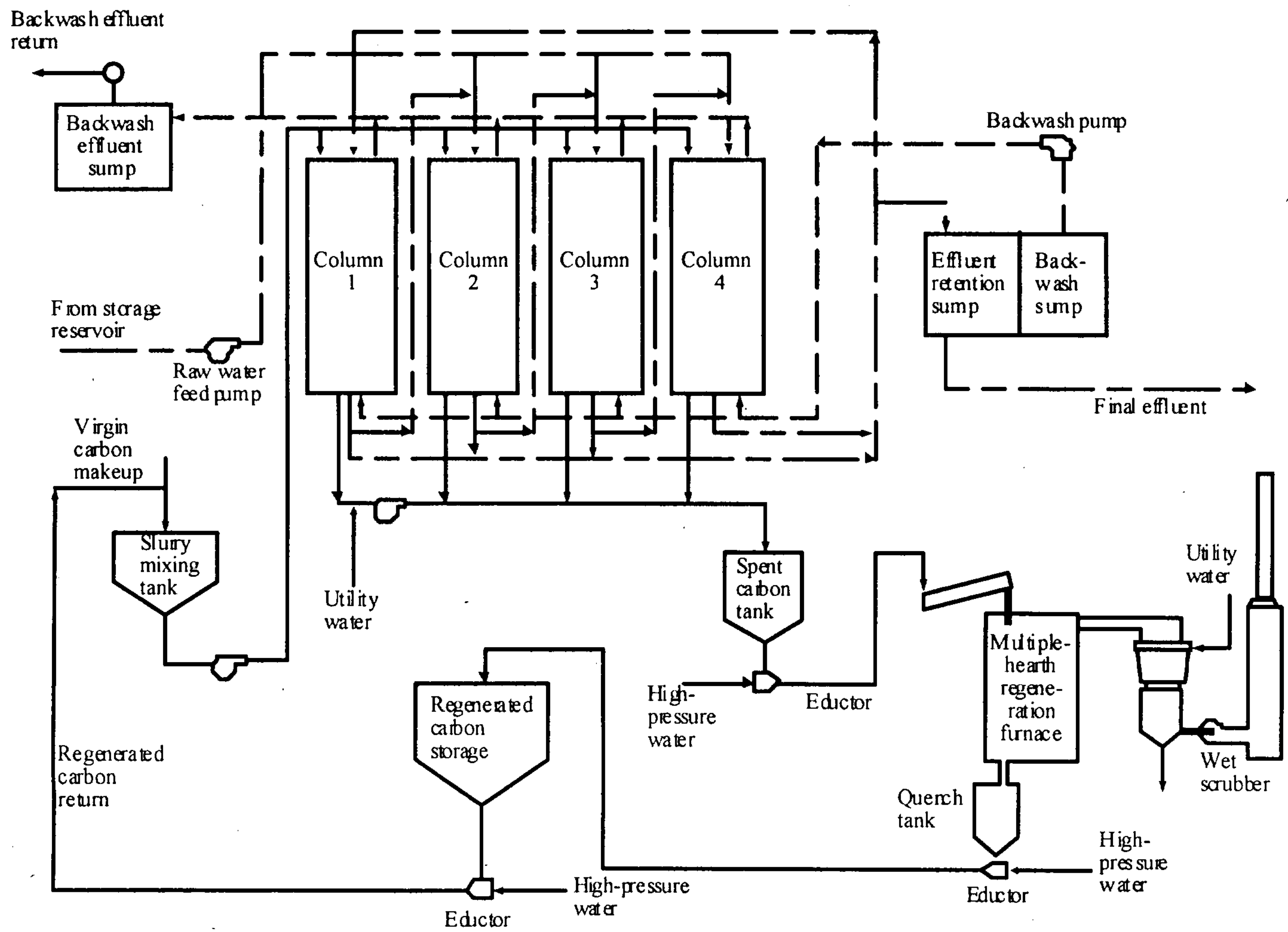

Figure 3-9 Typical GAC Process Flow Schematic

In many cases a multimedia filter bed is placed before the GAC unit to remove high concentrations of suspended solids. The design of GAC filter vessels typically include an upper baffle combined with slotted lateral distributor for low pressure drop and good flow distribution into the unit. GAC reactor sizing is based on four factors:

(1) desired contact time
(2) hydraulic loading rate
(3) carbon bed depth
(4) number of reactors in system.

The contact time and type of carbon specified will be based on the type of wastewater treated. For example, wastewater containing VOCs will require different carbon specifications than needed for activated sludge effluent polishing. Table 3-13 summarizes key design parameters for GAC systems.

Table 3-13
Typical Design Parameters for GAC Reactors

Carbon Dosage Tertiary Treatment Physical/Chemical Process	 0.024 - 0.048 kg/m^3 0.06 – 0.22 kg/m^3
Contact Time	10 – 50 min
Hydraulic Loading	0.08 – 0.41 m^3/m^2 • min
Backwash Rate	0.61 – 0.81 m^3/m^2 • min
Flow Configuration	Upflow or downflow; single or multi-stage
Contactor Configuration	Gravity or low-pressure

Adapted from Viessman & Hammer, 1985

Adsorption capacities of various organic compounds is given in Appendix as a reference. Since the selection of carbon types is specific to the individual chemical pollutants in the wastewater, equipment vendors and carbon suppliers should be contacted to obtain key design parameters for an application. In some cases treatability work will not be required to properly size a GAC system. However, simple laboratory isotherm tests can be performed by the carbon supplier to evaluate more complex wastewater streams.

3.10 Ion Exchange

Ion exchange operates on a similar principle as GAC. Chemicals of interest are sorbed to the surface of a resin, a solid material that is coated with the replacement ions that are released when the chemical of interest is sorbed. Water softening is an example of ion exchange. In this case the resin is coated with Na^+ and Cl^- ions which are released when the calcium and carbonate ions are sorbed to the resin surface. Another example is deionization where resins are coated with H^+ and OH^- ions which are released to solution after the positively and negatively charged particles are sorbed to the resin.

The resin is exhausted when all of the replacement ions have been used in the chemical replacement. In order to regenerate the resin a strong solution of the replenishment ions must be applied to the system. This replaces the ions that were removed from the influent wastewater stream came from the water and regenerates the resin for continued use. Concentrated acids and bases are used to regenerate spent resins.

Positively charged metals or metal salts that are removed from solution with cationinc resins include:

Aluminum	Ammonium	Barium
Cadmium	Calcium	Chromium
Cobalt	Copper	Ferric Iron
Ferrous Iron	Lead Lithium	Magnesium
Manganese	Mercury	Nickel
Potassium	Sodium	Strontium
Zinc		

Negatively charged metals or metal salts that are removed from solution using anionic resins include:

Bicarbonate	Boron	Bromine
Carbonate	Chloride	Hexavalent chromium
Cyanide	Fluoride	Gold
Iodide	Nitrate	Phosphate
Silver	Sulfate	Sulfide
Sulfite		

The most common application for ion exchange technology in industrial wastewater treatment is for solutions with high dissolved metals concentrations. Plating wastes can be effectively treated using this technology. Figure 3-10 presents a schematic diagram of a chromate removal and wastewater reuse process using ion exchange technology.

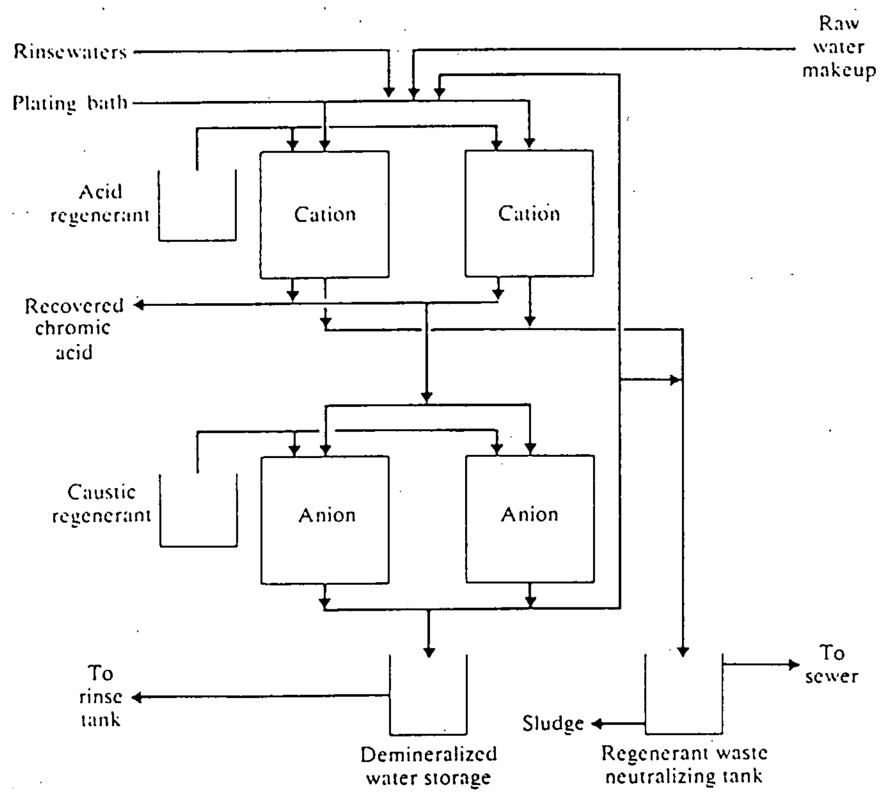

Figure 3-10
Chromate Removal and Wastewater Reuse Schematic Using Ion Exchange

Capacities of specific resins for the pollutants present in the wastewater will vary significantly. As with GAC specification for a given wastewater stream, equipment vendors should be contacted to obtain key design parameters for an application. In some cases treatability work for an ion exchange resin will not be required to properly size a treatment system. However, simple laboratory capacity tests can be performed by the resin supplier to evaluate a specific wastewater stream.

3.11 Membrane Separation

Membrane separation refers to the range of treatment techniques that use higher pressure devices to remove specific chemicals of interest. The types of membrane separation techniques include reverse osmosis (RO) nanofiltration (NF) and ultrafiltration (UF). These three types operate at successively lower pressures. Therefore, RO treatment operates at the highest pressure and ultrafiltration at the lowest pressure. Figure 3-11 depicts a process schematic diagram for a membrane filtration system.

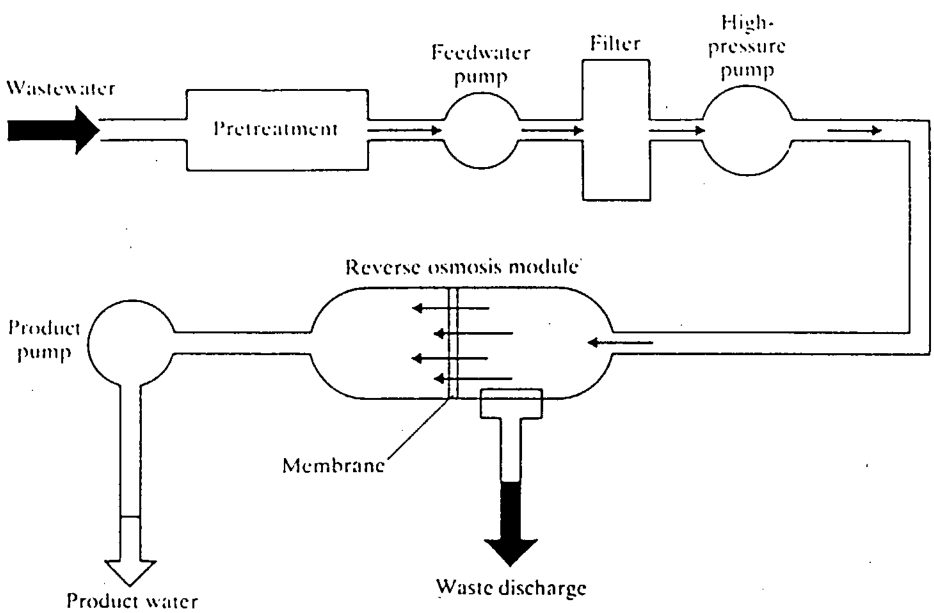

Figure 3-11 Typical Membrane Separation Process Schematic

There is a direct correlation between the operating pressure of the membrane and the size of the particles removed from solution. The greater the pressure the smaller the particle removed. For example, and RO system is capable of removing particles in the range of 0.00005 μm to 0.05 μm, which are only visible with a scanning electron microscope. Nanofiltration will allow some salts through the membrane and ultrafiltration will allow passage of all salts and larger molecular weight particles.

The RO, NF, and UF membranes are semipermeable to allow passage of water and retain the chemical of interest present in the wastewater. The systems are arranged in various configurations, including tubular, hollow fiber, plate and frame or spiral-wound. The spiral-wound configuration is the most common configuration for the crossflow or tangential filtration used in many industrial wastewater applications.

A pressurized flow of feedwater is passed across the surface of the membrane. A portion of the feed passes through pores in the membrane becoming the permeate, and the balance of the feed is passed across the outer surface of the membrane becoming the concentrate, or reject solution. The flow of water across the membrane forms a turbulent cleaning action, which keeps the membrane from fouling. Capital costs are relatively similar for the different types of membrane separation. However, as the pores in the membrane get smaller the cost of operation increases.

Generally, UF is used for fine filtration and removal of various organic contaminants. Examples of particles in this size range include: paint or ink pigment, asbestos, carbon black viruses, gelatin, colloidal silica, tannins and lignins (color components found in surface waters). Occasionally NF is used if particle sizes are exceptionally small yet still beyond the ionic range. Different membrane media is used for different size particles. Ultrafiltration is used in many applications including: pretreatment for other purification systems such as ion exchange.

Nanofiltration is used for particles in the molecular range of 0.05 μm to 0.005 μm and include sugar, synthetic dyes, as well as smaller particles of gelatin, colloidal silica, viruses and larger charged ions such as calcium carbonate (hardness).

Reverse osmosis is used to remove ionic species with sizes that are 0.002 μm diameter and smaller. Particles in this size range include aqueous salt, metal ion, and smaller particles of sugars, synthetic dye and endotoxins/pyrogens. Applications for RO include boiler feed water, potable water, car wash rinse water, glass rinsing, electronics rinsing, plating rinse makeup, pure water for dialysis, beverage makeup, and pharmaceutical water.

Due to the specialty nature of all membrane separation techniques, laboratory or pilot-scale treatability testing is required to design a treatment system for a specific application. The capability of the membrane to achieve the required effluent limits, and the need for pre-treatment are determined with the treatability tests. Equipment vendors should be contacted to perform the treatability testing and obtain key design parameters for sizing major membrane separation equipment.

3.12 Sludge Dewatering

Most of the unit operations and processes described in this section result in some form of sludge generation. Biological sludge is first stabilized using aerobic or anaerobic techniques to reduce pathogenic organism concentrations prior to dewatering and disposal. Sludge generated from physical/chemical processes is directed from the process to a dewatering step without pre-treatment. Figure 2-1 in presented in Section 2 identified several sludge dewatering operations for both biological and physical/chemical treatment systems.

The dewatering process selected for a given sludge will depend its the chemical and physical characteristics, and disposal options available locally for the resulting filter cake. There are several dewatering techniques available for use in an industrial wastewater treatment system. Table 3-14 summarizes various approaches for dewatering and thickening sludge generated at industrial wastewater facilities.

Since sludge dewatering operations are developed for each individual facility, equipment vendors should be contacted to obtain basic sizing data for the application. A review of the options available can be made based on anticipated dewatering effectiveness and associated costs for operation and maintenance, and with respect to local disposal considerations.

Table 3-14
Wastewater Sludge Dewatering and Thickening Techniques

Sludge Equipment	Sludge Type	Loading	Cake Solids (%)
Thickening			
Gravity	Waste activated sludge	30 $kg/m^2 \cdot d$	3
Gravity	Pulp and paper	122 $kg/m^2 \cdot d$	6
DAF	Waste activated sludge	18 $kg/m^2 \cdot d$	4.8
Solid Bowl Centrifuge	Waste activated sludge	0.33 m^3/min	6
Basket Centrifuge	Citrus	0.13 m^3/min	9.5
Solid Bowl Centrifuge	Paper mill	0.38 m^3/min	11
Solid Bowl Centrifuge	Chemical plant	-	8
Dewatering			
Basket Centrifuge	Citrus	0.13 m^3/min	9 – 10
Basket Centrifuge	Paper mill	0.23 m^3/min	11
Belt Press	Chemical plant	-	13 – 15
Belt Press	Deinking	0.50 m^3/min	37
Belt Press	Kraft linerboard	0.08 m^3/min	19

Adapted from Eckenfelder, 1989