Pollution Abatement in the Fruit and Vegetable Industry

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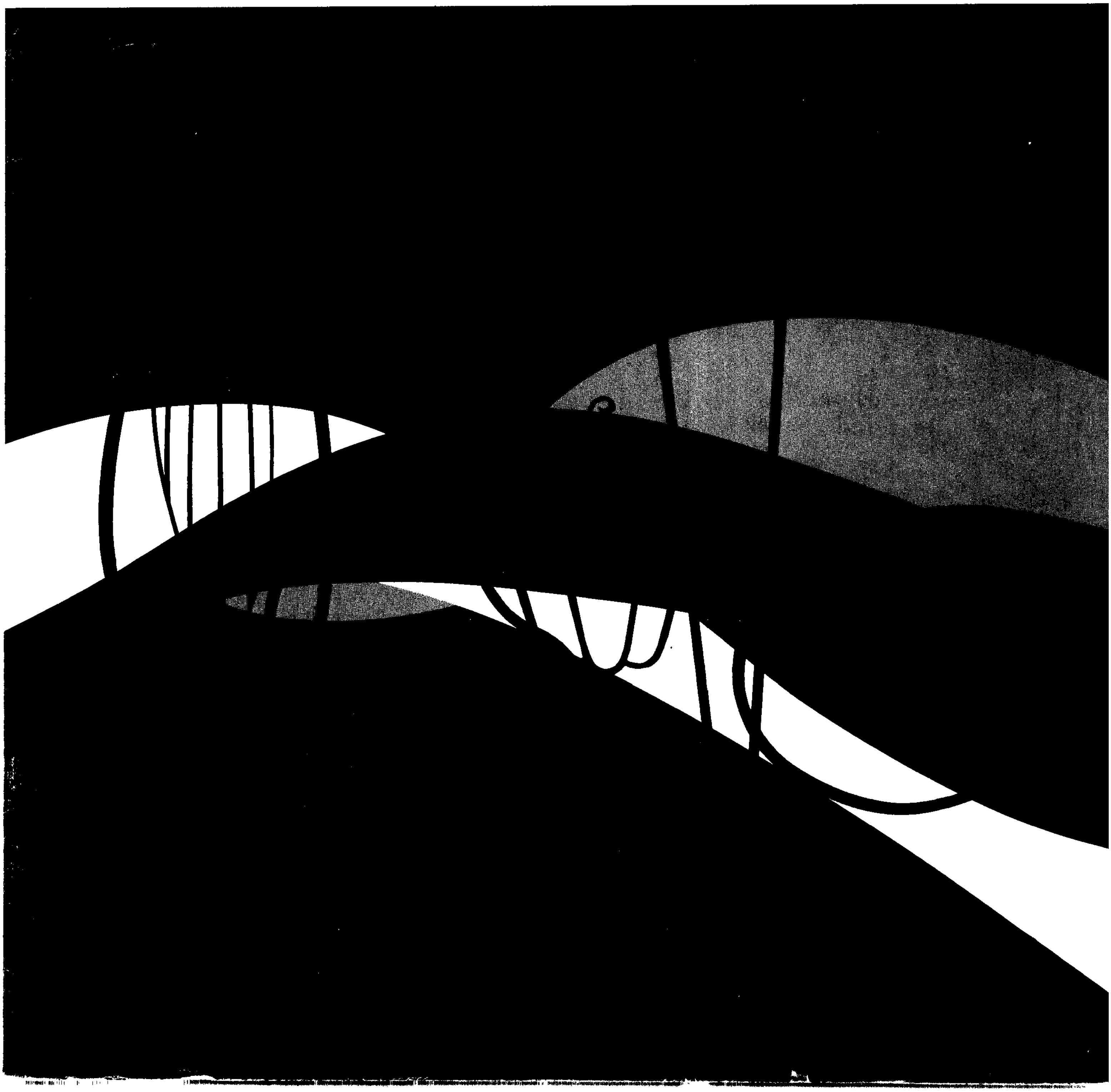
Wastewater Treatment

PA Technology Transfer Seminar Publication



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POLLUTION ABATEMENT IN THE FRUIT AND VEGETABLE INDUSTRY

Wastewater Treatment

ENVIRONMENTAL PROTECTION AGENCY
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Chapter I

INTRODUCTION/BACKGROUND

INTRODUCTION

This publication offers to fruit and vegetable processors a general understanding of wastewater treatment technology that will enable processors to deal more effectively with regulatory agencies and their own waste disposal situations. The material will give an understanding of the following topics:

1. Important Waste Characteristics
2. EPA and State Regulations
3. Sewer Ordinances
4. Pretreatment Technology
5. Treatment Technology Required to Meet Present and Future Effluent Requirements
6. Land Treatment Disposal Methods
7. General Costs of Pollution Control
8. Sludge and Solid Residuals Disposal Methods

The information presented is based on general engineering practice in the fruit and vegetable processing industry. More detailed and specific information for the theory of treatment processes and design systems can be found in textbooks and other EPA publications. Current reviews can be found in publications from state agencies and associations such as the National Canners' Association (NCA). An annual review of literature on fruit and vegetable processing waste is found in the *Journal of the Water Pollution Control Federation.*

For reference purposes, general design criteria are presented in task form throughout the text. This information can help processors determine the adequacy of proposed systems to handle waste, or to develop preliminary sizes for treatment units, but it should not be used for design. Cost summaries are also given for the more significant treatment processes discussed. The costs were developed for a hypothetical fruit and vegetable processing plant, producing one million gallons per day (mgd) of wastewater, and operating for 90 days each year. The estimates are presented to illustrate the relative magnitude of various treatment processes, and should not be used to project actual construction costs.

BACKGROUND

GENERAL

The first step of a pollution control program is to characterize the wastewater. In this chapter we present typical wastewater characteristics for various products and common parameters used to characterize wastewater. These characteristics and the reduction quantity required determine the type and cost of pollution control. Chapters II through V give the methods for treating wastes associated with the fruit and vegetable industry. The current federal effluent requirements for this industry are given in this chapter.

Fruit and vegetable processing wastewater has as one of its characteristics a seasonal variation which causes major problems in treatment. Each raw product has a processing season that may vary from year to year, from field to field, and from beginning to end of the pack. Processors with treatment systems are aware of these variations.

Each processing plant is unique. Plants operated by the same corporation and producing the same product can have significantly different wastewater characteristics. Therefore, wastewater quality data must be developed for each plant. Waste quantities for new plants, or for expansions of existing plants, are usually estimated by assuming a proportional (on the basis of production capacity) waste from similar plants or processes. Possible expansion and product changes must be considered when determining waste loads.

WASTE CHARACTERISTICS

Scientists and engineers have developed many parameters to characterize wastewater. Common parameters are as follows:

- Biochemical oxygen demand (BOD) -
  BOD is used to size treatment systems or to determine sewer service charges when an industry is discharging to a public treatment system. The acclimated seed used for the BOD test should not contain nitrifying bacteria. If it does, the tests will yield high results because nitrogenous BOD as well as carbonaceous BOD will be measured. Special test procedures can be applied to avoid the problem.

- Chemical oxygen demand (COD) -
  COD can be used as a fast way to estimate the BOD for most food processing waste by empirically determining a ratio of BOD to COD. A few cities use COD to assess sewer service charges. For a majority of cannery wastes, the BOD is 60 to 80 percent of the COD. For many wastes it is also possible to develop a useful correlation of volatile solids to BOD.

- Total suspended solids (TSS) -
  TSS is used to calculate the amount of waste solids resulting from treatment. TSS is also used to determine sewer service charges.

- Volatile suspended solids (VSS) -
  The volatile fraction of total suspended solids is needed to help determine the volume of biodegradable waste solids.

- Nutrients -
  A balance of nitrogen and phosphorus is needed for successful biological treatment. In unusual cases, other trace elements (Mg, Fe, etc.) may also be critical nutrients. Many food processing wastewaters are deficient in nutrients for biological treatment. If a deficiency exists, nutrients can be added. Adequate nutrients are often present in a joint treatment system with a city because domestic waste contains excess nutrients.

- pH -
  Local sewer ordinances usually limit the allowable pH range. The city may also require that waste be neutralized before treatment or land application.

- Alkalinity and acidity –
  Alkalinity and acidity are measured to determine the resistance of wastewater to pH changes. This information is used to design neutralization systems or to determine the stability of pH during biological treatment.

- Temperature -
  Wastewater temperature is important in sizing biological treatment units. Process stability, even in physical-chemical systems, can be adversely affected by wide ranges in waste temperature. Municipal ordinances usually limit maximum waste temperature.

- Toxicity -
  Food processing waste usually is not toxic, but some discharge requirements include toxicity limits. The most common causes of wastewater toxicity are excessive amounts of free ammonia, residual chlorine from disinfection, discharges of detergents (from cleanup) or other toxic materials such as paint, solvents, and biocides.

In the future, the following tests may be required: chlorinated hydrocarbons; chlorine residual; color; heavy metals; and phenolic compounds. Table I-1 shows common wastewater parameters that will be required for the three possible waste disposal methods.

Table I-1.—*Common wastewater parameters for fruit & vegetable processing*

Characteristics	Discharge to sewer[a]	Discharge to own treatment plant	Discharge to land
Flow	X	X	X
pH	X	X	X
Temperature	X	X	
Dissolved oxygen			X
BOD	X	X	X
COD (use as a check or guide for BOD)	X	X	X
Total suspended solids	X	X	X
Volatile suspended solids		X	X
Oil and grease	X	X	X
Total dissolved solids		X	X
Nitrogen		X	X
Phosphorus		X	X
Settleable solids	X	X	X
Specific ions[b]			X

[a]Typical requirements are set forth in sewer-use ordinances.
[b]See table IV-4.

Sampling, Testing, and Flow Measurement

A program for sampling, testing, and measuring flow is important to waste characterization. It provides basic information to calculate sewer service charges, to compare the economics of in-plant waste reduction versus "end of pipe" treatment, and to help select and size treatment processes.

The EPA's *Monitoring of Industrial Wastewater*[1] is a good reference on the practicalities of waste characterization and on methods of sampling and analysis. The reader should also utilize the EPA's *Methods for Chemical Analysis of Water and Wastes*[2] as a reference on analytical procedures and preservation of samples.

Building, staffing, and maintaining a wastewater analysis laboratory is costly. The use of an outside laboratory for wastewater testing may be less costly, particularly for difficult tests. Many states require that data submitted to regulatory agencies be analyzed by a state-certified or approved laboratory. The EPA and the states require the use of the latest edition of standard methods[3].

The single most important wastewater characteristic is flow. Flow is the primary criterion used to size many treatment units. Several different wastewater flows must be known for efficient treatment design: (1) average flow, (2) maximum instantaneous flow, and (3) peak daily flow. Other wastewater characteristics are measured only in concentration. The mass (pounds per day) for these characteristics can only be determined if flow is known. Concentration alone is of little value.

Selection of a point and method of measuring flow is important. The following factors should be considered:

- Reliability of automatic flow-measurement equipment
- Nonclogging characteristics of flow-measurement equipment
- Accuracy required
- Maintenance required
- Costs
- Accessibility of the flow-measurement station

Sampling points must be carefully selected to obtain representative samples. As a result of solids separation, the waste strength may vary from the top to the bottom of the flow in a large sewer. Sampling points should be selected where the waste is thoroughly mixed.

Variations in processing activities will change wastewater characteristics. Therefore, samples should be taken during each operating shift and during different stages of the finished-product and raw-product runs. Flows should be monitored continuously, even during cleanup and on weekends.

The amount of testing varies according to plant operation and the purpose of testing. Requirements are difficult to generalize, but if the purpose of testing is to establish the waste load for a product, reasonable accuracy should be achieved by taking flow proportion composite samples daily for 8 to 20 days.

The sampling program should include monitoring waste during the peak processing period. The remainder of the sampling will probably be done on two 2-week periods. The first 2-week period could be in the first half of the processing season, and the second during the latter half of the season. Flow measurements should include instantaneous flow and peak daily flow during the periods of monitoring. Flows for these two-week periods should be measured and recorded continuously; samples should be taken at least hourly for each day (24 hours) and composited in proportion to flow.

Typical Wastewater Characteristics

Table I-2 summarizes typical wastewater characteristics for many fruits and vegetables. The range between minimum and maximum values is large. These numbers are combinations of data from EPA and NCA. The sources do not indicate if the values are for raw or screened waste. The characteristics in table I-2 are given in unit loadings such as thousand gallons (or pounds) per ton of raw product. Typical concentrations (mg/l) for BOD and suspended solids can be calculated from these relationships:

$$\text{concentration (mg/l)} = \frac{\text{mass (lbs/day)}}{\text{flow (million gal/day)} \times 8.34}$$

or

$$\text{concentration (mg/l)} = \frac{\text{mass (lb/ton)} \times 120}{\text{flow (1,000 gal/ton)}}$$

Changes in Waste Strength

Many factors cause changes in waste strength (table I-3). Length of season affects wastewater characteristics. If a crop is harvested over a long period of time (potatoes, for example), the wastewater quality and quantity may differ significantly from beginning to end of season. Changes in waste strength may also occur from shift to shift. For example, waste flows during a cleanup shift will be different than those coming from a processing shift.

Daily or seasonal shutdown and startup of a processing plant usually causes wastewater characteristics to vary greatly. This variation often causes problems in a treatment system. Biological treatment systems perform best on a uniform supply of a given source of food (BOD). If the food supply changes greatly, the biological process may not be able to adjust to the change. The impact of frequent shutdowns and startups on a treatment system should be carefully evaluated.

REGULATIONS

Fruit and vegetable processors must meet the discharge requirements of one or more governmental agencies: (1) federal, (2) state, and (3) local. Each industry discharging to a receiving waterway must have a permit under the National Pollutant Discharge Elimination System (NPDES permit). Industries discharging to land or to municipal sewers may require additional discharge permits from the EPA, state or city. Although the EPA guidelines focus on process wastes, permits set restrictions on all discharges — cooling water, sanitary waste and storm drainage.

Table I-2.—*Typical raw wastewater characteristics for canned and preserved fruits and vegetables*[4,5,6]

Crop	Flow 1,000 gal/ton raw product			BOD lb/ton raw product			TSS lb/ton raw product		
	Min.	Mean	Max.	Min.	Mean	Max.	Min.	Mean	Max.
Apples	0.2	2.4	13	3.9	18	44	0.4	4.5	21
Apricots	2.5	5.6	14	18	40	80	5	9.9	19
Asparagus	1.9	8.5	29	0.9	4.9	22	4.3	7.5	13
Dry beans	2.5	8.8	33	15	60	182	2.6	43	99
Lima beans	2.4	7.7	22	9.3	48	175	4.6	39	231
Snap beans	1.3	4.2	11.2	1.6	15	81	0.8	6.1	46
Beets	0.3	2.7	6.7	28	53	127	7.3	22	64
Broccoli	4.1	9.2	21	5.8	20	61	4.6	17	61
Brussels sprouts	5.7	8.2	12	4.2	7.5	14	2.9	15	79
Berries	1.8	3.5	9.1	11	19	40	1.4	7.1	22
Carrots	1.2	3.3	7.1	17	30	53	4.5	17	53
Cauliflower	12	17	24	5.5	16	36	2.8	7.8	22
Cherries	1.2	3.9	14	21	38	78	1.0	2.0	3.8
Citrus	0.3	3.0	9.3	0.9	9.6	26	0.7	3.7	14
Corn	0.4	1.8	7.6	12	27	64	3.6	10	27
Grapes	0.6	1.5	5.1	6.4	9.0	13	1.5	1.7	2.0
Mushrooms	1.8	7.8	28	7.7	15	28	5.1	7.3	12
Olives	–	8.1	–	–	27	–	–	27	–
Onions	2.5	5.5	10	57	57	58	5.3	17	55
Peaches	1.4	3.0	6.3	17	35	70	3.4	8.6	21
Pears	1.6	3.6	7.7	19	50	126	3.6	12	33
Peas	1.9	5.4	14	16	38	87	3.8	11	38
Peppers	0.9	4.6	16	5	32	50	1	58	170
Pickles	1.4	3.5	11	26	42	75	3.0	8.2	23
Pimentos	5.8	6.9	8.2	39	55	76	4.1	5.8	8.1
Pineapples	2.6	2.7	3.8	13	25	45	5.2	9.1	17
Plums	0.6	2.3	8.7	6.5	10	14	0.6	2.1	4.3
Potato chips	1.2	1.6	2.2	17	25	38	22	32	48
Potatoes, sweet	0.4	2.2	9.7	39	93	217	40	57	117
Potatoes, white	1.9	3.6	6.6	42	84	167	39	128	423
Pumpkin	0.4	2.9	11	9.2	32	87	2	67	12
Sauerkraut	0.5	0.9	3.0	4.6	5.6	15	–	1.0	2.6
Spinach	3.2	8.8	23	5.7	14	31	1.8	6.1	21
Squash	1.1	6.0	22	–	20	–	–	14	–
Tomatoes, peeled	1.3	2.2	3.7	6.3	9.3	14	5.8	12	26
Tomatoes, product	1.1	1.6	2.4	2.2	4.7	9.7	5.6	10	19
Turnips	2.4	7.3	18	–	–	–	–	–	–

NOTE.—These figures represent two different types of samples: screened and unscreened. This increases the range of values shown.

Table I-3.—*Factors contributing to raw-waste load variabilities*

• Fruit or vegetable processed
• Product mix
• Raw-product condition (ripeness, damage)
• Product-conveying systems (countercurrent vs. single pass fluming, dry conveying, pneumatic conveying)
• Process methods (blanching, peeling)
• Cleanup methods (dry vs. wet, detergent, disinfectant)
• Batch dump frequency (brine, caustic)
• Frequency, duration of shutdowns
• Type and condition of equipment
• People

Federal Requirements

The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) required EPA to establish guidelines for all industrial wastewater discharged to receiving waters. "Phase I" and "Phase II" guidelines have been completed.[4,5] The guidelines originally covered the following characteristics: fecal coliform count; BOD; Total Suspended Solids (TSS); pH; and grease and oil. However, the fecal coliform limitation has been deleted.[7,8] Processors and government agencies should refer to the *Code of Federal Regulations* for effluent guidelines and standards.[9]

Table I-4 gives the allowable mass emissions of BOD and TSS. The effluent pH limit is 6 to 9.5 for both 1977 and 1983 for all fruit and vegetable processing.

An additional oil and grease limitation of 20 mg/l for 1977 and 10 mg/l for 1983 has been set for the following products:

- Added ingredients
- Baby foods
- Chips (potato, corn, tortilla)
- Ethnic foods
- Jams/jellies
- Mayonnaise and dressings
- Soups
- Tomato-starch-cheese canned specialties

Table 1-4.—*Federal effluent limitation guidelines*[8]

[pounds allowed per ton raw product]

Commodity	1977 Daily max BOD	1977 Daily max TSS	1977 30-day avg BOD	1977 30-day avg TSS	1977 Annual avg BOD	1977 Annual avg TSS		1983 Daily max BOD	1983 Daily max TSS	1983 30-day avg BOD	1983 30-day avg TSS	1983 Annual avg BOD	1983 Annual avg TSS
Added ingredients[a]	1.90	0.00	1.10	0.00	0.72	0.00	M	1.560	---	1.100	---	0.460	---
							L	1.560	---	1.100	---	0.460	---
Apple juice	1.20	1.60	0.60	0.80	---	---		0.40	0.40	0.20	0.20	---	---
Apple products (except juice)	2.20	2.80	1.10	1.40	---	---		0.40	0.40	0.20	0.20	---	---
Apricots	6.00	10.72	3.62	7.48	2.52	4.66	M	2.522	4.556	1.876	2.618	0.970	1.972
							L	2.522	2.522	1.876	1.876	0.970	0.970
Asparagus[b]	---	---	---	---	---	---		---	---	---	---	---	---
Baby food[a]	2.46	4.46	1.46	3.10	1.02	1.90	M	1.678	3.002	1.222	1.630	0.580	1.172
							L	1.678	1.678	1.222	1.222	0.580	0.580
Beets	2.02	3.76	1.42	2.94	1.14	2.24	M	1.364	2.484	1.096	1.704	0.722	1.444
							L	1.364	1.364	1.096	1.096	0.722	0.722
Broccoli	7.66	13.56	4.42	9.14	2.94	5.30	M	3.788	6.684	2.674	3.342	1.114	2.228
							L	3.788	3.788	2.674	2.674	1.114	1.114
Brussels sprout[b]	---	---	---	---	---	---		---	---	---	---	---	---
Caneberries	1.54	2.76	0.92	1.90	0.64	1.16	M	0.364	0.656	0.268	0.368	0.134	0.274
							L	0.364	0.364	0.268	0.268	0.134	0.134
Carrots	3.52	6.38	2.22	4.60	1.64	3.08	M	1.932	3.512	1.458	2.092	0.794	1.618
							L	1.932	1.932	1.458	1.458	0.794	0.794
Cauliflower[a,b]	---	---	---	---	---	---		---	---	---	---	---	---
Cherries (sweet)	2.24	4.02	1.38	2.86	0.98	1.84	M	0.896	1.626	0.674	0.958	0.362	0.736
							L	0.896	0.896	0.674	0.674	0.362	0.362
Cherries (sour)	3.54	6.40	2.22	4.60	1.62	3.04	M	2.204	4.026	1.678	2.450	0.944	1.924
							L	2.204	2.204	1.678	1.678	0.944	0.944
Cherries (brined)	5.74	10.36	3.56	7.36	2.56	4.76	M	1.526	2.876	1.242	2.026	0.846	1.744
							L	1.526	1.526	1.242	1.242	0.846	0.846
Chips (potato)[a]	6.92	12.50	4.34	8.98	3.16	5.94	M	3.366	6.064	2.488	3.428	1.258	2.548
							L	3.366	3.366	2.488	2.488	1.258	1.258

Table 1-4.—*Federal effluent limitation guidelines*[8] —Continued

[pounds allowed per ton raw product]

Commodity	1977 Daily max BOD	1977 Daily max TSS	1977 30-day avg BOD	1977 30-day avg TSS	1977 Annual avg BOD	1977 Annual avg TSS		1983 Daily max BOD	1983 Daily max TSS	1983 30-day avg BOD	1983 30-day avg TSS	1983 Annual avg BOD	1983 Annual avg TSS
Chips (corn)[a]	3.16	5.80	2.80	4.34	1.60	3.06	M	2.284	4.234	1.796	2.772	1.714	2.286
							L	2.284	2.284	1.796	1.796	1.114	1.114
Chips (tortilla)[a]	4.82	8.68	3.00	6.22	2.18	4.08	M	3.330	6.050	2.506	3.578	1.352	2.754
							L	3.330	3.330	2.506	2.506	1.352	1.352
Citrus	1.60	2.40	0.80	1.70	---	---		0.28	0.40	0.14	0.20	---	---
Corn (canned)	1.42	2.64	0.96	2.00	0.76	1.46	M	0.892	1.674	0.720	1.760	0.480	0.988
							L	0.892	0.892	0.720	0.720	0.480	0.480
Corn (frozen)	2.90	6.26	1.68	4.60	1.12	3.14	M	1.974	3.664	1.556	2.408	0.970	1.988
							L	1.974	1.974	1.556	1.556	0.970	0.970
Cranberries	3.42	6.12	2.06	4.28	1.46	2.68	M	1.240	2.248	0.930	1.320	0.496	1.010
							L	1.240	1.240	0.930	0.930	0.496	0.496
Dehydrated onion/garlic	4.90	8.86	2.92	6.04	1.96	3.52	M	2.318	4.134	1.674	2.204	0.774	1.562
							L	2.318	2.318	1.674	1.674	0.774	0.774
Dehydrated vegetables	5.96	10.60	3.52	7.30	2.42	4.42	M	3.562	6.356	2.576	3.398	1.196	2.412
							L	3.562	3.562	2.576	2.576	1.196	1.196
Dried fruit	3.72	6.68	2.26	4.68	1.60	2.96	M	1.466	2.674	1.112	1.610	0.616	1.254
							L	1.466	1.466	1.112	1.112	0.616	0.616
Dry beans	5.00	8.96	3.02	6.26	2.14	3.94	M	2.806	5.018	2.042	2.726	0.972	1.962
							L	2.806	2.806	2.042	2.042	0.972	0.972
Ethnic foods[a]	4.78	8.46	2.82	5.82	1.92	3.46	M	3.176	5.652	2.286	2.982	1.040	2.092
							L	3.176	3.176	2.286	2.286	1.040	1.040
Grape juice (canning)	2.20	3.98	1.38	2.88	1.02	1.92	M	1.532	2.798	1.166	1.698	0.652	1.332
							L	1.532	1.532	1.166	1.166	0.652	0.652
Grape juice (pressing)	0.44	0.80	0.28	0.58	0.20	0.36	M	0.222	0.406	0.170	0.246	0.094	0.194
							L	0.222	0.222	0.170	0.170	0.094	0.094
Jams/jellies[a]	0.84	1.52	0.52	1.08	0.38	0.72	M	0.374	0.684	0.284	0.416	0.160	0.328
							L	0.374	0.374	0.284	0.284	0.160	0.160
Lima beans	7.36	13.12	4.38	9.06	3.02	5.52	M	3.506	6.234	2.516	3.266	1.132	2.276
							L	3.506	3.506	2.516	2.516	1.132	1.132

Table 1-4.—*Federal effluent limitation guidelines*[8] —Continued

[pounds allowed per ton raw product]

Commodity	1977 Daily max BOD	1977 Daily max TSS	1977 30-day avg BOD	1977 30-day avg TSS	1977 Annual avg BOD	1977 Annual avg TSS		1983 Daily max BOD	1983 Daily max TSS	1983 30-day avg BOD	1983 30-day avg TSS	1983 Annual avg BOD	1983 Annual avg TSS
Mayonnaise and dressings[a]	0.74	1.34	0.48	0.98	0.34	0.66	M	0.420	0.772	0.326	0.490	0.194	0.396
							L	0.420	0.420	0.326	0.326	0.194	0.194
Mushrooms	6.02	10.72	3.56	7.36	2.44	4.44	M	2.376	4.244	1.724	2.292	0.812	1.640
							L	2.376	2.376	1.724	1.724	0.812	0.812
Olives	10.88	19.58	6.68	13.84	4.78	8.88	M	4.570	7.852	3.212	4.382	1.592	3.226
							L	4.570	4.570	3.212	3.212	1.592	1.592
Onions (canned)	6.18	11.02	3.66	7.56	2.50	4.56	M	3.438	6.270	2.610	3.786	1.452	2.960
							L	3.438	3.438	2.610	2.610	1.452	1.452
Peaches	3.02	5.44	1.86	3.86	1.34	2.52	M	1.532	2.794	1.166	1.688	0.648	1.320
							L	1.532	1.532	1.166	1.166	0.648	0.648
Pears	3.54	6.42	2.24	4.64	1.66	3.10	M	1.710	3.150	1.328	2.006	0.794	1.624
							L	1.710	1.710	1.328	1.328	0.794	0.794
Peas	4.84	8.72	3.00	6.22	2.16	4.04	M	1.990	3.636	1.516	2.216	0.854	1.742
							L	1.990	1.990	1.516	1.516	0.854	0.854
Pickles (fresh pack)	2.44	4.38	1.50	3.08	1.06	1.98	M	1.278	2.278	0.922	1.212	0.426	0.858
							L	1.278	1.278	0.922	0.922	0.426	0.426
Pickles (process pack)	2.90	5.26	1.84	3.82	1.36	2.56	M	1.304	2.416	1.022	1.568	0.626	1.286
							L	1.304	1.304	1.022	1.022	0.626	0.626
Pickles (salt stations)	0.36	0.66	0.24	0.50	0.18	0.36	M	0.168	0.326	0.144	0.250	0.108	0.226
							L	0.168	0.168	0.144	0.144	0.108	0.108
Pimentos[b]	---	---	---	---	---	---		---	---	---	---	---	---
Pineapples	4.26	7.70	2.66	5.52	1.92	3.62	M	2.952	5.362	2.222	3.170	1.198	2.440
							L	2.952	2.952	2.222	2.222	1.198	1.198
Plums	1.38	2.48	0.84	1.74	0.58	1.08	M	0.566	1.008	0.408	0.540	0.190	0.382
							L	0.566	0.566	0.408	0.408	0.190	0.190
Raisins	0.86	1.56	0.56	1.14	0.42	0.78	M	0.408	0.760	0.326	0.514	0.210	0.434
							L	0.408	0.408	0.326	0.326	0.210	0.210
Sauerkraut (canning)	1.00	1.78	0.60	1.26	0.42	0.80	M	0.520	0.940	0.388	0.540	0.200	0.408
							L	0.520	0.520	0.388	0.388	0.200	0.200

Table 1-4.—*Federal effluent limitation guidelines*[8] —Continued

[pounds allowed per ton raw product]

Commodity	1977 Daily max		1977 30-day avg		1977 Annual avg			1983 Daily max		1983 30-day avg		1983 Annual avg	
	BOD	TSS	BOD	TSS	BOD	TSS		BOD	TSS	BOD	TSS	BOD	TSS
Sauerkraut (cutting)	0.16	0.28	0.10	0.22	0.08	0.16	M	0.092	0.174	0.076	0.128	0.054	0.112
							L	0.092	0.092	0.076	0.076	0.054	0.054
Snap beans	3.02	5.34	1.74	3.60	1.16	2.08	M	2.096	3.716	1.494	1.910	0.652	1.306
							L	2.096	2.096	1.494	1.494	0.652	0.652
Soups[c]	8.28	14.76	4.92	10.18	3.38	6.20	M	5.532	9.868	4.000	5.276	1.858	3.744
							L	5.532	5.532	4.000	4.000	1.858	1.858
Spinach	4.74	8.38	2.72	5.62	1.82	3.28	M	2.352	4.150	1.660	2.076	0.692	1.222
							L	2.352	2.352	1.660	1.660	0.692	0.692
Squash	1.80	3.28	1.18	2.46	0.92	1.74	M	0.590	1.068	0.440	0.614	0.228	0.464
							L	0.590	0.590	0.440	0.440	0.228	0.228
Strawberries	3.56	6.38	2.12	4.40	1.48	2.70	M	1.238	2.210	0.898	1.188	0.420	0.846
							L	1.238	1.238	0.898	0.898	0.420	0.420
Sweet and white potatoes	1.80	3.38	1.32	2.74	1.10	2.18	M	1.144	2.180	0.952	1.606	0.684	1.414
							L	1.144	1.144	0.952	0.952	0.684	0.684
Tomatoes	2.42	4.30	1.42	2.96	0.98	1.80	M	1.048	1.866	0.756	0.990	0.346	0.698
							L	1.048	1.048	0.756	0.756	0.346	0.346
Tomato-starch-cheese specialties[a]	2.74	6.62	2.16	4.46	1.44	2.60	M	1.962	3.490	1.410	1.836	0.638	1.286
							L	1.962	1.962	1.410	1.410	0.638	0.638

[a]Lb/ton final product

[b]Guidelines have not been established as of April 1976

[c]Lb/ton raw ingredients

NOTES — Medium *(M)* and large *(L)* food processing plants have the same guidelines for 1977, but they are separated for 1983. Small processing plants are not subject to these guidelines.

Large is defined as a plant that processes more than 10,000 tons per year.

Medium is defined as a plant that processes between 2,000 and 10,000 tons per year.

Small is defined as a plant that processes less than 2,000 tons per year.

The guidelines for 1983 have been divided according to size of plant (medium *(M)* or large *(L)*, as shown in table I-4). The *Federal Register* of April 16, 1976, stated that, "Industry plants with less than 2,000 tons per year production remain excluded from the regulation. While these plant groups are not covered by these effluent limitations due to potential economic impacts, permitting authorities have sufficient information in the Development Document to regulate the discharges from these excluded plants on a case-by-case basis."[8] A "medium" plant is one that processes between 2,000 tons and 10,000 tons per year. "Large" is defined as greater than 10,000 tons per year.

The EPA guidelines are based on what is attainable with current treatment processes, not on what is required to protect water quality. For 1977, the effluent standards are based on what is defined as the "Best Practicable Control Technology Currently Available (BPCTA)." By 1983, the effluents are to conform to limits that are achievable by the "Best Available Technology Economically Achievable (BATEA)."

Although the EPA guidelines are written for waste discharged into receiving waters, they also affect processors discharging into a municipal sewer. The law requires that all industries meet the guidelines. Fruit and vegetable processors discharging to a sewer meet their treatment obligations through the use of the joint city-industry treatment plant operated by the city. If the city's treatment plant does not adequately treat the waste, processors may be forced to provide treatment facilities to make up the difference.

State Requirements

Each state with an EPA-certified pollution control program issues NPDES permits. The EPA issues permits in states without a certified program under guidelines that represent the minimum standard or the maximum permissible discharge. The states must consider water quality of receiving waters when establishing additional limits; therefore, many state requirements are more restrictive than EPA guidelines. Some states require a state discharge permit even for industries discharging to publically owned treatment works.

Local Requirements

Local requirements are primarily in the form of sewer ordinances that apply to sewer users. These ordinances are intended to prevent blockages and damage of the collection system, hazards to workers in the sewers and at the treatment plant, or interferences with the treatment process. They contain specific limits on heavy metals, toxic compounds, oil and grease, temperature, pH, and other characteristics. Ordinances set the basis for sewer user charges and requirements for flow measurement, sampling, sample storage, and testing. Copies of sewer ordinances are always available to industrial users.

Processors discharging to municipal systems are subject to local sewer service charges. Generally, cities charge for the use of their sewers and treatment plants. The base and amounts of charges do (and will for some time to come) vary greatly from city to city. The largest contributing factor to this variation is the body of regulations set by EPA for federally assisted treatment construction projects. If a city is not receiving federal funds, then the sewer charge can be nominal, perhaps covering only a fraction of the operation and maintenance of the treatment plant. Charges vary from a flat rate to a charge proportional to the flow or floor area of the plant.

However, if a facility is receiving federal funds for treatment plant construction, service charges usually rise. EPA requires that industry pay its "fair share" of the operation and maintenance, and the capital cost of the treatment plant. Industry's "fair share" is calculated in proportion to the amount of waste loading (usually flow, BOD, and suspended solids) it contributes to the treatment plant. Processors must understand the city's ordinance and determine the effect of EPA grant regulations (if any) on charges.

TREATMENT

There are two basic reasons for treating waste: one, to reduce sewer user charges, and two, to comply with an effluent standard set by EPA, the state, or the city.

Once the treatment need is established, three possible options can be used:

- Install pretreatment; discharge to city sewer.
- Install full treatment; discharge to stream.
- Discharge to land.

Unless the processor is building a new plant, all of these options are not usually available. The remainder of this text is devoted to discussion of the various techniques available under each option. Each is discussed separately in its own chapter. The techniques of meeting a treatment need are listed along with general design and operational considerations.

COSTS

In each cost estimate, the cost of capital was based on an amortization period of 10 years and an interest rate of 12 percent. This results in a cost of 17.7 percent of the capital per year.

The costs are for October 1975 and assume competitive bids by contractors. The estimates are "order of magnitude" estimates. It was assumed that significant site grading would not be required and that good soil conditions existed. Costs were not included for site acquisition or for separate fencing, yard lighting, access roads, and laboratories. In the examples, a plant producing 1 mgd of wastewater and operating 90 days per year has been assumed. The costs associated with startup and shutdown have not been included.

The cost range from $0.18 per 1,000 gallons to $3.21 per 1,000 gallons is for systems which operate 90 days per year. A total system will likely cost more since the financing of screening, primary treatment, and secondary treatment, if required, would be additive.

Table I-5 summarizes the costs from the text, and gives costs for 180 and 360 days of operation, as well as 90 days. Other assumptions for each example are either listed on the tables or given in the text. The operating and maintenance costs, as presented, are only major direct costs. They do not include any general or corporate overhead or equipment replacement costs.

Generalized cost curves are also given in the two EPA effluent guideline development documents for the fruit and vegetable industries. These are good references for comparative system costs.[4,5]

COMMUNICATIONS

Communications between the processing plant staff and municipal treatment plant operators cannot be over-emphasized. Good communications will improve public relations and assist the treatment plant operators in handling occasional upsets or unusual conditions. Treatment plant operators need to know, as much in advance as possible, when the plants will start up or when the product mix will be changed. Early notification of planned wastewater "dumps" of an unusual nature, or immediate notification of accidental spills, can be invaluable to treatment plant operators. Make an effort to know the people and system that serve your plant.

Table I-5.—*Summary of estimated costs for fruit and vegetable processing*

		Number of operating days per season					
		90 Days		180 Days		360 Days	
		Annual cost	¢/1,000 gal.	Annual cost	¢/1,000 gal.	Annual cost	¢/1,000 gal.
II-1	Flow measurement and screening	$ 15,900	17.7¢	$ 19,100	10.6¢	$ 25,500	7.1¢
II-2	Neutralization	$ 41,300	45.9¢	$ 64,900	36.0¢	$112,100	31.1¢
[a] III-3	Aerated lagoon	$112,100	125¢	$132,600	73¢	$173,600	48.2¢
III-5	Activated sludge without sludge concentration	$289,150	321¢	$364,150	202¢	$814,150	226¢
III-6	Activated sludge with sludge concentration	$255,850	284¢	$314,350	175¢	$431,350	120¢
III-9	Filtration	$ 51,960	57.7¢	$ 55,960	31.1¢	$ 63,960	17.8¢
III-10	Chlorination	$ 9,525	10.6¢	$ 12,325	6.8¢	$ 17,925	5.0¢

[a] Based on capital costs as given on Table III-5.

Chapter II

PRETREATMENT

INTRODUCTION

Most fruit and vegetable processing plants discharging to a city sewer system use some method of pretreatment. In the broadest sense, pretreatment is the treatment applied before discharge to a treatment system. However, pretreatment usually refers to gross solids removal, soil removal, or neutralization. Common pretreatment steps are screening, neutralization, and flow equalization. Frequently, more extensive treatment, such as gravity sedimentation or dissolved air flotation, is used.

The reasons for pretreatment are as follows:

- Meet municipal ordinance requirements.
- Reduce costs.
- Accommodate production increases.

ORDINANCE REQUIREMENTS

Pretreatment is often required by city ordinance, of which screening is almost always a requirement. Neutralization, flow equalization, and soil removal are also usually required.

REDUCE COSTS

Despite the apparent high rates charged by some cities for using their sewers, it is usually difficult to economically justify treatment for sewer charge reduction. The main reason for this difficulty is the high cost of solids disposal and the high cost of building and operating small treatment systems. Because of the high cost of industrial capital, the short processing season, and other factors, the cost for comparable treatment by fruit and vegetable processors alone is considerably higher. Because of the federal grant program regulations, industries participating in joint treatment essentially receive a 30-year, interest-free loan for the EPA-funded share of the joint treatment facilities, and a low-interest (7%±), long-period (20 to 30 years) loan for the remaining share, which is financed by state or local bonds.

A decision to provide extensive pretreatment or separate treatment should be based on a thorough, after-tax analysis of the costs. If a processor can irrigate part or all of the plant effluent onto nearby land, the cost can be favorable when compared to treatment by a municipality in a mechanized plant.

Presently, recovery of fruit and vegetable processing by-products is usually less than a "break-even" proposition. For this reason, recovery is usually only practical if it responds to other requirements for pretreatment or helps to defray some of the pretreatment operating costs. For certain products in live-stock-producing areas, screenings and treatment sludges can be recovered and used in animal (cattle, poultry, hogs) feeding operations. If by-product recovery is to be practiced, all sanitary waste must be separated.

PRODUCTION INCREASES

Extensive pretreatment is often required as a result of plant expansions. Plants discharging to public systems frequently reach their allocated treatment capacity as a result of increasing waste loads. Presently, the time required to expand a public treatment plant is about 5 years. The ability of the municipal plant to meet its own discharge limitations might prevent additional waste discharge from increased production. Few processors can wait for a city to provide additional capacity. One option is to pretreat the waste so that the processor's contribution to the public system does not increase as a result of the expansion.

PRETREATMENT PROCESSES

SCREENING

In almost all canning plants, discrete waste solids (such as trimmings, rejects, and pits) are effectively and economically separated from liquid wastes by screening. Screening has several objectives including recovery of useful solid by-products; a first stage primary treatment operation; or pretreatment for discharge to a municipal wastewater treatment system.

Screens are often characterized by the size of the openings. There are several methods of designating the open area in a screen. Wire screen openings are usually measured in meshes per inch, and are available in increments of the Tyler Standard Sieve sizes. For example, the popular 20-mesh screen has a standard wire diameter which is woven in a rectangular grid with 20 wires per linear inch. A second method of screen size measurement describes the clear opening between screening elements (usually flat or wedgewire in shape), either in millimeters or mils. For example, a 0.76 mm opening is equal to 30 mils (0.030 in) and approximately equivalent to a 40-mesh screen. Bar screens, because of their very large openings, are measured by their clear opening, usually in centimeters.

The following are typical examples of screens:

Manufacturer	Remarks
SWECO	135-mesh are possible; 50-or 60-mesh are more common. Few blinding problems with cannery waste.
Link Belt	Some blinding on 20-mesh screens. Recommended 6-to 10-mesh for canning waste.
Dorr Oliver	No blinding with equivalent 20-mesh (1.5 millimeters).

Screening prevents the spray nozzle from plugging. Removal of grease or neutralization may be required to prevent soil or crop damage. Certain ions may have to be removed to prevent soil or crop damage or ground-water contamination.

Screens should be located as close as possible to the process producing the waste. The longer the solids are in contact with water and the rougher the flow is handled, the more material will pass through the screens and the more solids will be dissolved. Keep the contact time and agitation to a minimum before and during screening.

The following are often considerations in purchasing screens:

- Initial cost
- Hydraulic capacity
- Hydraulic head required
- Solids captured
- Blinding potential
- Moisture of screenings
- Operating and maintenance costs
- Space required.

Four types of screens are commonly used in the fruit and vegetable industry. Vibratory screens are very common. Two variations are the circular center-feed units (in which solids may be discharged in a spiral toward the center or periphery) and the rectangular, end-feed variation (in which solids are discharged along the screen toward the lower end). These units are shown on figures II-1 and II-2.

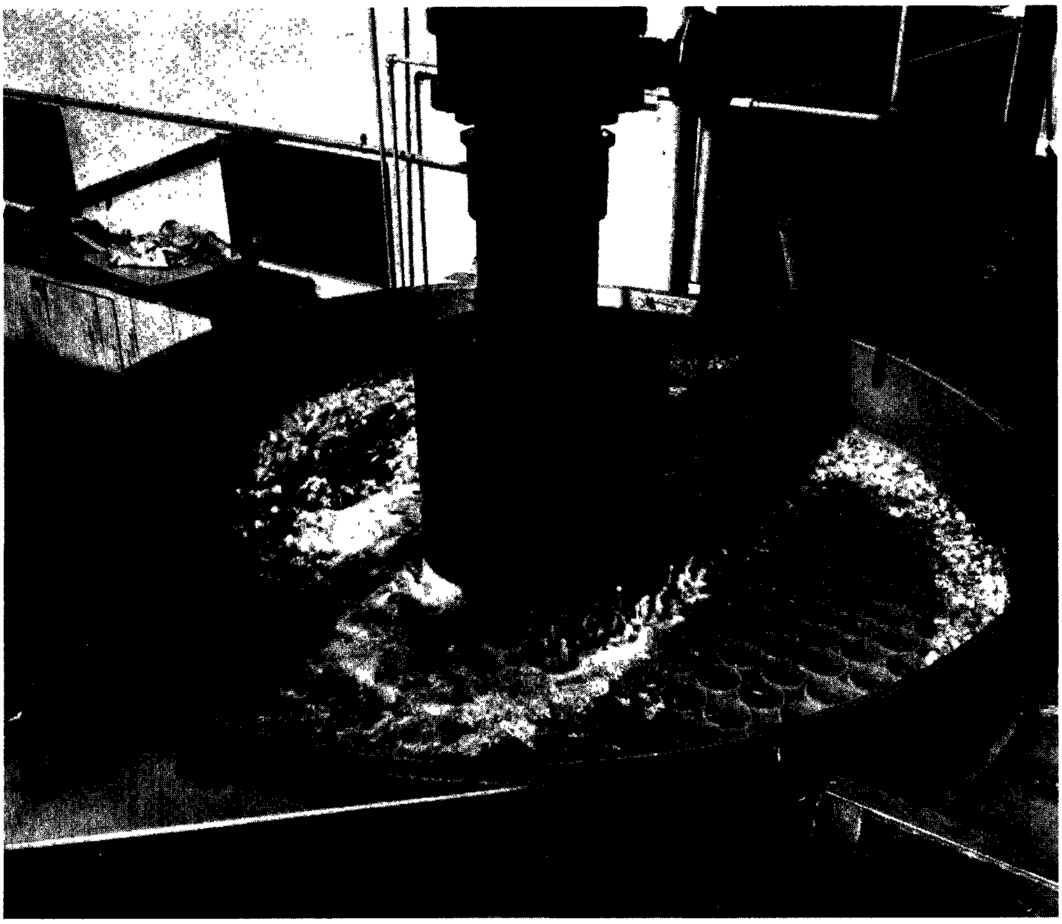


Figure II-1. Circular center-feed vibratory screen. (Courtesy of SWECO, Inc.)

Figure II-2. Rectangular end-feed vibratory screen. (Courtesy of CH_2M Hill)

The rotary drum screen is also common. These screens may be designed so that the flow is from the inside of the drum toward the outside, or the reverse. If the flow is from the inside, then the solids are collected inside the screen and removed by augers, or a trough. In units where the flow is from the outside to the center, the solids are retained on the outer surface of the drum and are removed by a doctor (or scraper) blade. A drum screen is shown on figure II-3.

Tangential screens (figure II-4) are also commonly used. The water flows down and through a parabolic screen, but the solids are retained on the surface of the screen and discharged from its lower en

A recent derivation of the tangential and drum screens is illustrated in figure II-5. The wastewater is introduced behind the slotted drum, which rotates forward at the top. Solids are retained on the surface of the drum and scrapped off by a blade. The screened waste falls through the drum and backwashes the underside before being discharged.

Rotating centrifugal or collar screens can be used when high-solids capture is required. The screens can be very fine, up to 400 mesh. The waste is sprayed under pressure onto the inside of the rotating drum. The water passes through the screen and the solids are collected on the inside of the collar. The solids typically have a high-moisture content.

Successful application of screens depends on many variables. Screens ordinarily achieve a high removal of settleable and floatable solids, but variable amounts (up to 70 percent) of the suspended solids. Proportional amounts of BOD are ordinarily removed with the solids.

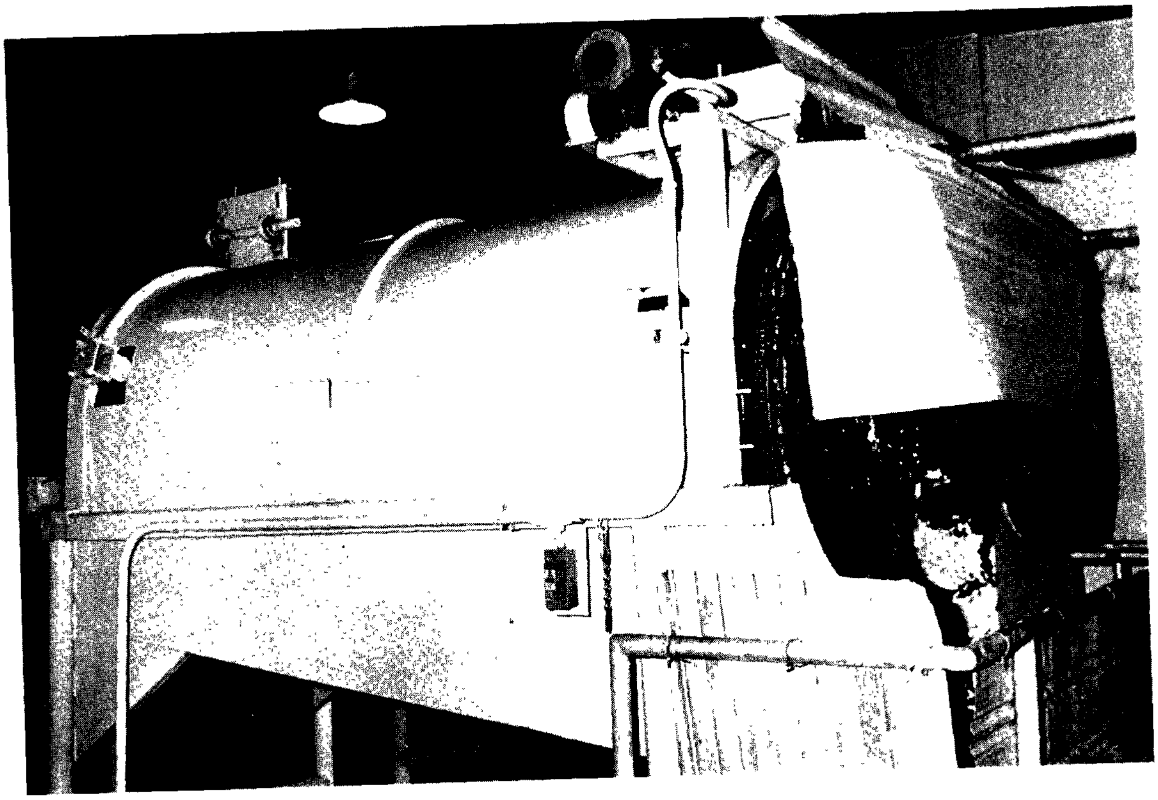


Figure II-3. Rotary drum screen. (Courtesy of CH_2M Hill)

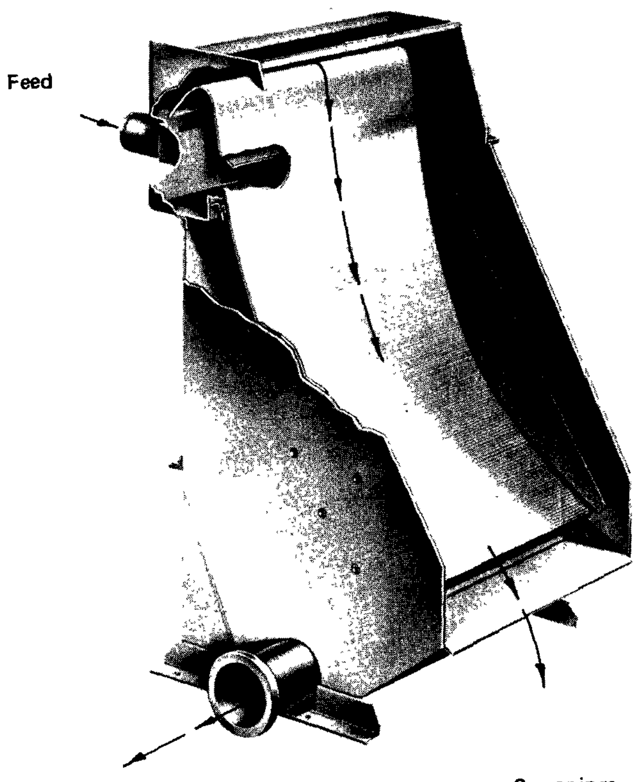


Figure II-4. Tangential screen (45°). (Courtesy of Dorr Oliver)

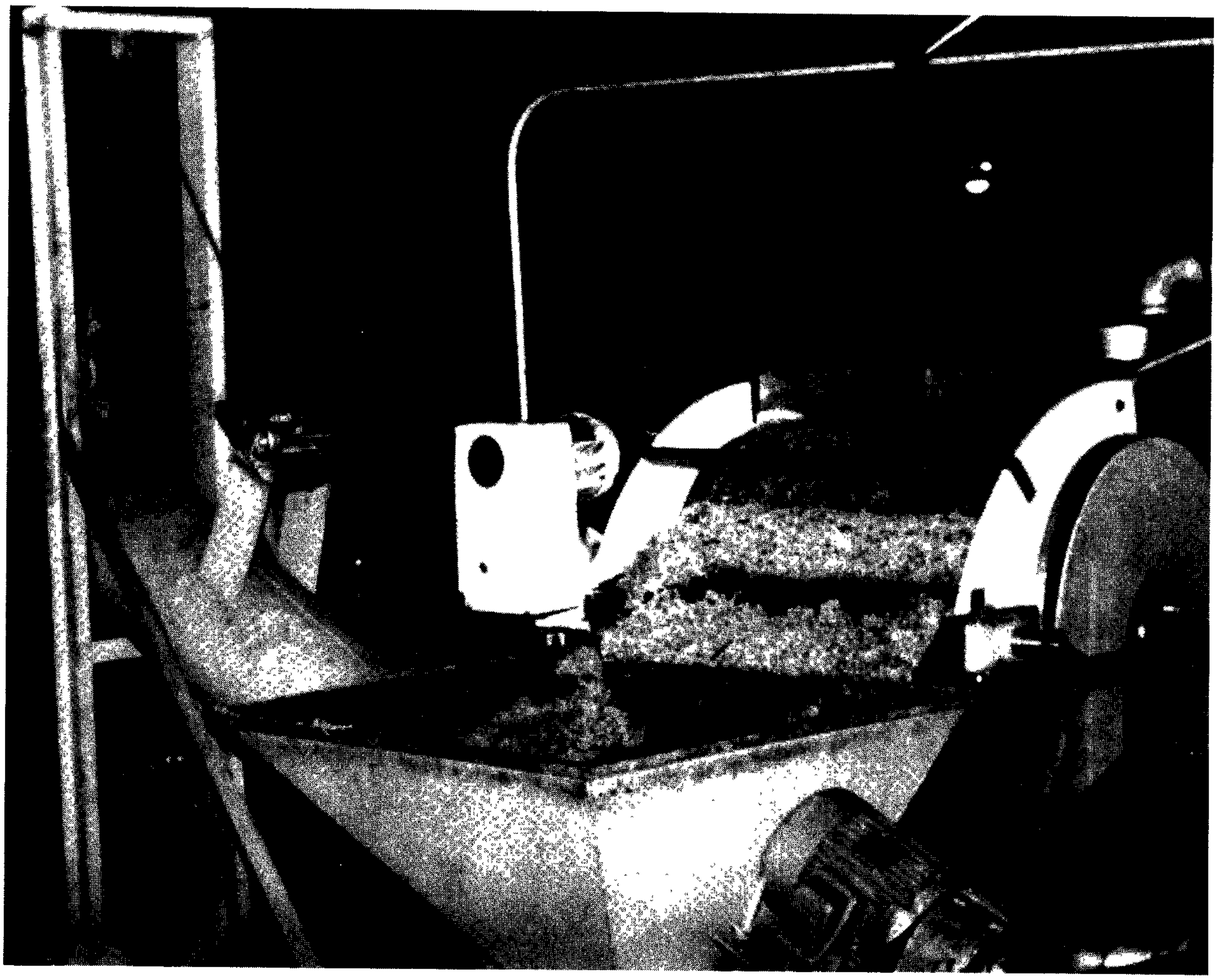


Figure II-5. Slotted drum screen. (Courtesy of Hydro Cyclonics Corp.)

Location of the waste screen is very important. One option is to collect wastewater in a sump below the floor level of the plant, and then pump the wastewater to the screen. Many screens are located above the solids hopper. These require pumping, but usually avoid the need for a solids conveyor. Pumping may reduce screening efficiency by reducing the particle size of suspended solids. Pumps, valves, and piping should be designed to minimize agitation. Another option is to place the screens below the level of the plant drains (if the elevations permit). After screening, the solid waste can be conveyed up to the waste hopper.

Screening is an inexpensive method for removing large solids (greater than about 60 mesh) from wastewater. A good screen may remove the same amount of solids at less cost than in-plant dry cleanup. Compared to other pretreatment methods, screens require only a small space, and they can usually be installed in an existing plant.

Screening efficiency is affected by the following:

1. Mechanical features

   - Wastewater flow rate

   - Area of screen

- Screen inlet and outlet locations
- Screen motion
- Screen opening size
- Screen fabric (wedgewire, flat, or round).

2. Wastewater properties

- Discrete particle dimensions
- Concentration of discrete materials
- Shape of discrete material (irregular, round, fibrous)
- Consistency of discrete material (hard, soft, sticky).

An estimate of the costs for screening is given in table II-1. These costs are for October 1975 and assume a 20-mesh tangential screen. The estimate assumes that the plant floor drains will not have to be modified to collect all waste at one point.

NEUTRALIZATION

It is sometimes necessary to install pH control systems to treat wastes from the fruit and vegetable processing industry. Typically, municipal ordinances require wastes discharged to its sewers to be between pH 6 and 9, and many biological treatment systems cannot tolerate wide ranges in raw waste pH. Wastes with low pH result from processing of acidic fruits, e.g. plums, and wastes with high pH result from the use of lye during peeling such as typical peach peeling operations.

Depending on the daily operating mode of the processing plant, variations in instantaneous flow can be from very small to very great (a maximum of four times the minimum). Each plant is obviously different, but large variations in flow may be smoothed with a surge tank of about 10 to 20 percent of the total daily flow volume. Settling of solids will be a significant problem in a tank of this size; so the tank must either be mixed or some means provided for solids removal. If solids accumulate, odor will result.

SOIL REMOVAL

Root crops (potatoes, carrots and beets) and machine harvested crops (tomatoes) introduce, along with the raw product, large amounts of field soil to a food processor's waste stream. Since the present incentive for field cleaning is slight, each processor has to handle and/or remove the soil. Municipal plants usually are not built to deal with large quantities of soil. The abrasive material accelerates equipment wear, settles in pipelines and accumulates in the treatment plant's solids handling system (i.e., the sludge digester).

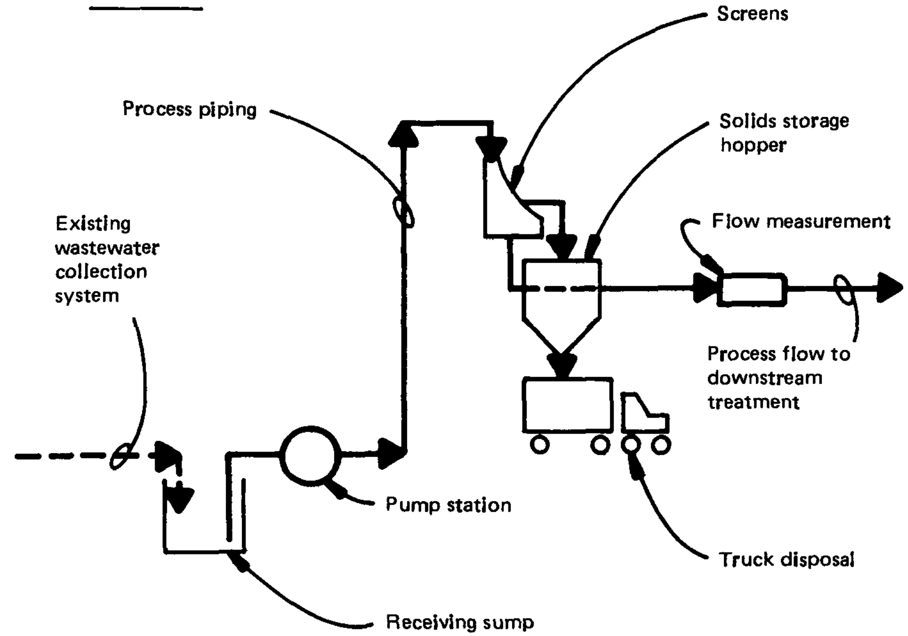
Some city ordinances are now being written to require fruit and vegetable processors to remove a majority of the soil from their waste. Soil may also have to be removed from waste before it is irrigated.

Table II-1.—*Cost summary for flow measurement and screening*

Criteria

- Flow: 1 mgd average; 2 mgd peak
- BOD: 1000 mg/l
- TSS: 1000 mg/l
- pH: 4.5
- Season: 90 days
- Amortization: 10 years at 12%
- Engineering, legal and contingency costs included at 25% of construction cost
- Labor at 7.00 (including overhead) ~ 1 hr/day
- October 1977 dollars

Schematic



Assumptions

- Solids hauling and disposal at 4 dollars/cy (approximately 700 lbs/day at $80/ton)
- Use of 20-mesh screen (tangential)

Costs

Capital	Operation and maintenance	
$71,600	Labor	$ 700/yr
	Disposal	2,500/yr
	Total	$3,200/yr

Amortized capital plus O&M	$15,900/yr
unit cost	17.7¢/1000 gal

Settling lagoons have and can be used for soil removal. Provisions must be made for draining the ponds to remove the solids. Odor is a potential problem if organic suspended matter is present; however, the extent of odor production cannot be forecast. In general, it is better to have fewer organics, a higher pH and a shorter detention time. The effluent from settling ponds is often high in BOD and suspended solids.

A reliable neutralization system has two or three mixed tanks, in series, in which an acid or base is added. The acid or base is automatically added, using a metering system controlled from effluent pH readings.

A consistently alkaline waste can be neutralized by using carbon dioxide (CO_2). Boiler stack gas may be a source of CO_2.

A cost estimate for a neutralization system is given in table II-2. The costs are for October 1975 and include two mixed tanks, an instrumentation and control system, and chemical storage. It was assumed that tomato processing waste is acidic and is neutralized with caustic. Facilities for neutralization with lime or sulfuric acid will differ only in chemical storage and delivery.

Rarely will a fruit and vegetable processing plant produce a waste that exceeds both alkaline and acid limits. In cases where limits are exceeded, the storage, feed and control system must provide for either an acid or base addition. This system is both more complicated and expensive.

If it is necessary for the individual plant to install a pH control system, it will generally be found that the automatic control of pH for the neutralization of waste streams can present problems including:

1. The relationships between the amount of reagent needed and the controlled variable (pH being non-linear).

2. The pH of the wastewater can vary rapidly over a range of several units in a short period of time.

3. The flow will change while the pH is changing since the two variables are not related.

4. The change of pH at neutrality can be sensitive to the addition of a reagent so that even slight excesses can cause large deviations in pH from the initial setpoint.

5. Measurement of the primary variable, pH, can be affected by materials which coat the measuring electrodes.

6. The buffer capacity of the waste has a profound effect on the relation between reagent feed and pH and may not remain constant.

7. A relatively small amount of reagent must be thoroughly mixed with a large volume of liquid in a short period of time.

FLOW CONTROL

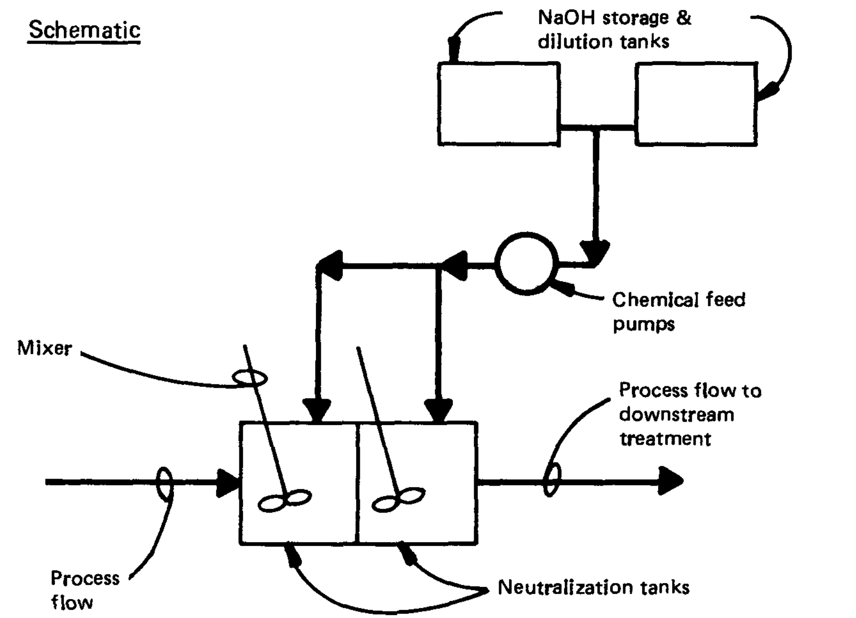
Control of surges in effluent flow is usually not required as a pretreatment measure. However, if flow variations can be smoothed out and accidental spills contained and controlled, screens can be smaller, and effluent pH control will be simpler.

Table II-2.—*Cost summary of neutralization (for acid waste)*

Criteria

- Flow: 1 mgd average; 2 mgd peak
- pH: 4.5
- Season: 90 days
- Amortization: 10 years at 12%
- Engineering, legal and contingency costs included at 25% of construction cost
- October, 1975 dollars
- Labor at $7.00/hr (including overhead)

Schematic



Assumptions

- Neutralization with 20% NaOH at 200 mg/l NaOH average application rate (216 gal 50% NaOH per day)
- NaOH cost at 165 dollars per anhydrous ton (.08¢/lb)
- Tank truck shipping cost at 3 cents/100 lb liquid/mile with 100-mile shipping distance ($60.00/ton)
- Two neutralization tanks in series with 15-minute average retention

Costs

Capital	Operation and maintenance	
$100,000	Labor	$ 1,000/yr
	Caustic (50%)/day	22,600/yr
	Total	$23,600/yr

Amortized capital plus O&M	$41,300/yr
unit cost	45.9¢/1000 gal

Where space and disposal of solids is a problem, circular clarifiers (figure II-6) can be used to settle and thicken the soil. Typically, circular clarifiers will produce a mud two or three times thicker than could be obtained in plain settling ponds. This means that the amount of mud to be disposed of is proportionally less.

Grit-removing cyclones have also been tried at some plants. The units are relatively inexpensive, but they must be run at a constant flow to achieve their design efficiency. Cyclones are not as efficient as a well-designed clarifier, and they tend to produce a dilute mud. The system must be designed to withstand abrasion.

Fine screens (to 400 mesh) have also been applied to remove soil. The application is similar to screening. Several screens can be used in series to concentrate the solids. These units approach the efficiency of clarifiers, but are considerably more difficult to operate and maintain, and are usually more expensive.

FURTHER PRETREATMENT

If additional removal of suspended solids or BOD is needed, more complex process units must be used. These processes and others are discussed in complete detail in Chapter III.

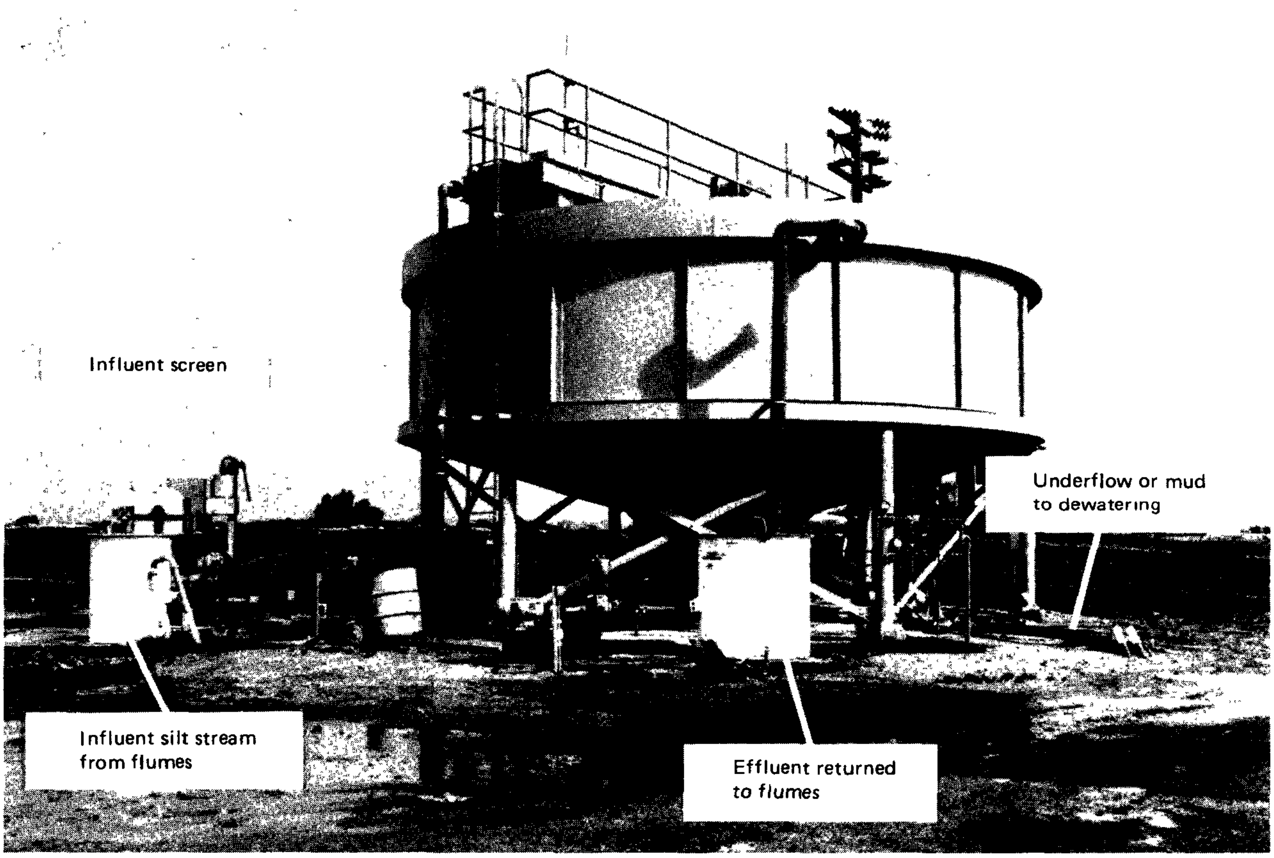


Figure II-6. Silt clarifier. (courtesy of CH_2M Hill)

Chapter III

PRIMARY, SECONDARY & ADVANCED TREATMENT

INTRODUCTION

Discharge to public waters (streams, lakes) requires treatment beyond pretreatment. Moreover, additional treatment may be required for land disposal or discharge to a city sewer.

Treatment processes are divided into three broad categories, based on their ability to remove increasing amounts of pollutants: (1) primary treatment, (2) secondary treatment, and (3) advanced waste treatment (tertiary treatment). The processes commonly thought of as being under each of these three categories are listed in table III-1. For the treatment of fruit and vegetable processing waste, primary treatment is used to remove a portion of the suspended solids in the wastewater; secondary treatment is used to remove a portion of the dissolved and suspended solids material; and advanced, or tertiary, treatment is used to remove additional amounts of these constituents as well as other constituents not removed by the secondary treatment. These same processes are used to treat domestic sewage.

Table III-1.—*Treatment unit processes for fruit and vegetable processors*

Primary treatment	Secondary treatment	Tertiary treatment
Grit removal Silt removal Plain sedimentation	Stabilization ponds	Chemical clarification
Dissolved air flotation	Aerated lagoons	Filtration (mixed bed of sand)
Chemical treatment	Activated sludge	
	Anaerobic systems Anaerobic ponds Anaerobic contact process Anaerobic filters	Reverse osmosis
	ABF/activated sludge	
	Trickling filters	Carbon adsorption
	Rotating biological contactors (RBC)	Ion exchange

Figure III-1 is a graphical representation of how BOD and suspended solids are removed in various treatment processes. The length of the bars in the figure is semi-quantitative. The sum of a pair of bars represents the total amount of solids (or BOD) in the waste. The length of the BOD bars should not be compared with the length of the solids bars. BOD is an effect, or demand, exerted by the solids, and may not be in proportion to the mass of solids.

It should be noted, however, that figure III-1 is not correct in all cases. The dissolved solids would decrease in activated sludge aeration and sedimentation. The dissolved solids may be either increased or decreased in chemical clarification depending on the coagulant used and the method of operation. The most common chemicals used are lime, alum, and iron salts. Before choosing a coagulant, a thorough study of both clarification and solids dewatering is essential.

Treatment is accomplished by the removal or conversion of solids. All treatment processes result in sludge which must be disposed. Treatment of this sludge is discussed in Chapter V.

REQUIREMENTS FOR TREATMENT

In nearly every case the amount of treatment is established by local, state, or federal effluent standards. However, treatment in excess of governmental regulations could be required as a result of law suits brought by people who claim to be adversely affected by the discharge or operation of a treatment system. Common causes for litigation are odor (air pollution), noise, and ground-water contamination.

EPA GUIDELINES

The Environmental Protection Agency has established discharge guidelines for fruit and vegetable processors who have their own discharge to public waters. Secondary treatment is required for all plants that discharge into the nation's waterways by mid-1977. By mid-1983, the EPA guidelines may mandate advanced treatment. The guidelines are given in table I-4.

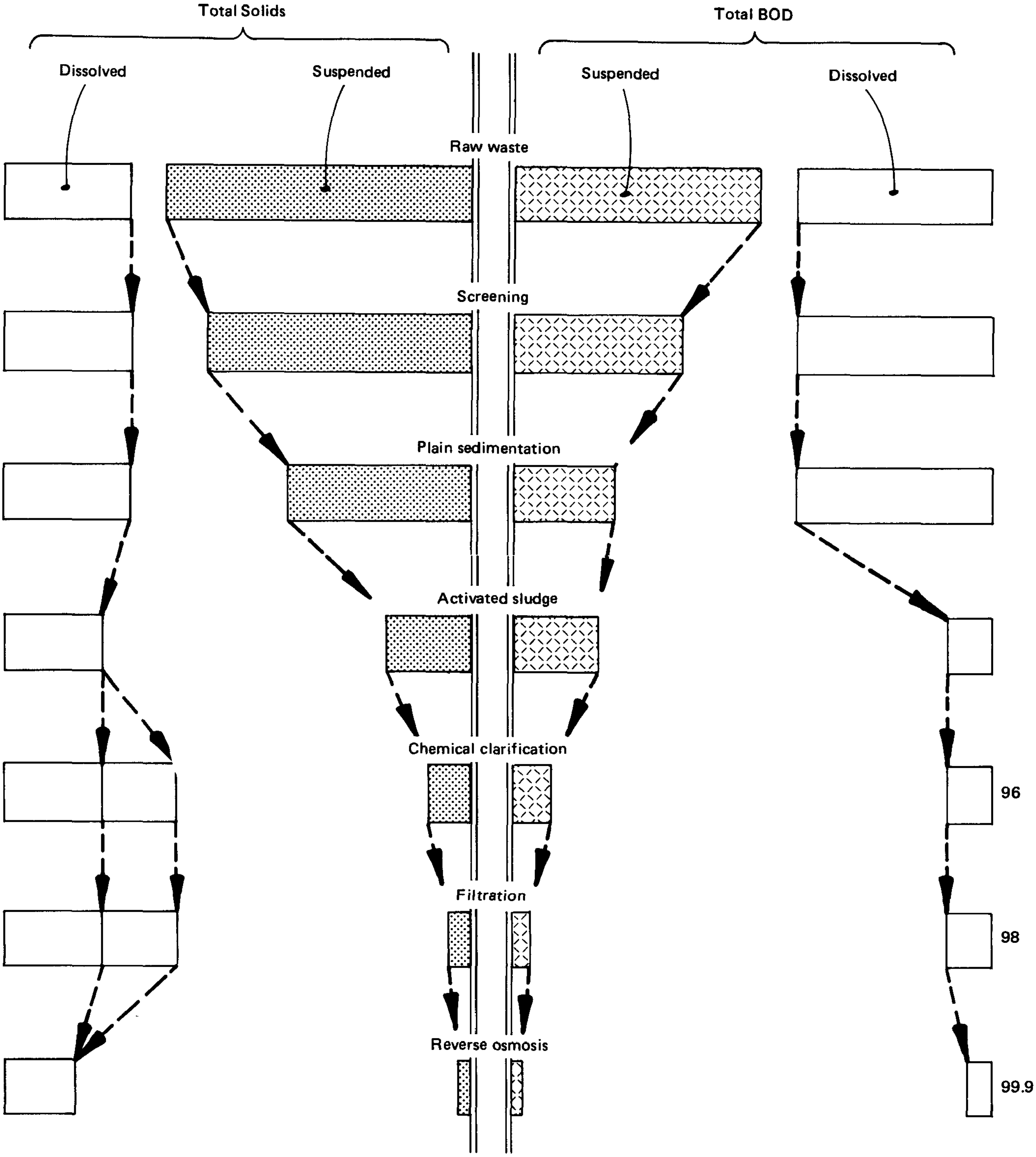
The 1977 guidelines for the apple, citrus and potato processing industries are to be met with secondary treatment. Exemplary secondary treatment plants studied by EPA included the following processes: activated sludge, trickling filter and aerated ponds, multiple aerated ponds, and anaerobic—aerobic ponds. The potato processors that were studied used primary clarifiers ahead of secondary treatment.[4] The 1983 guidelines are assumed to be met through the use of in-plant controls, the addition of more aerated lagoons or a sand filter, and chlorination.

The effluent guidelines[5] assume that processors of all products other than apple, citrus and potato products will meet the 1977 requirements with one of two kinds of secondary treatment, i.e., either aerated ponds or activated sludge. The 1983 guidelines are assumed to be met by reducing the load on the treatment plants through in-plant processing changes. However, large plants may have to add multi-media filtration.

Thus, for the future, primary treatment alone will probably be used only for discharge to some kind of land treatment system or for pretreatment. Primary treatment can be used as a first step in secondary treatment installations if the influent waste is high in settleable suspended solids (tomatoes, carrots, potatoes, etc.).

OTHER CONSIDERATIONS

Treatment may be needed to allow in-plant water re-use, ground-water recharge, or to extend the life of a land treatment system. The State of California, for example, is setting standards for waste applied to land.



NOTE: Bars indicate relative magnitude (percent) removal for each additional step in the treatment process chain.

Figure III-1. Effect of treatment on solids & BOD.

Water used for irrigation has to meet the quality requirements outlined in Chapter IV. Treatment prior to agricultural use may be required. Minerals such as boron, sodium, and calcium play an important role in determining the feasibility of agricultural re-use. These constituents are seldom restricted in discharges to receiving waters.

If a fruit and vegetable processing plant discharges to a city sewer system, the plant manager should understand the workings of treatment processes, even though the plant may only be required to perform pretreatment. The opening of the processing season is usually a significant day for the operators of a city treatment plant. If a plant manager understands the effect wastewater has on the operation and performance of the city treatment plant, he is in a better position to communicate with the city staff and maintain good relations.

A basic understanding of the treatment processes will make it possible for fruit and vegetable processors to judge the adequacy of proposed municipal systems which are intended to treat their processing wastes.

PRIMARY TREATMENT

Primary treatment is used to remove both inorganic and organic solids. Solids removal can be by gravity (or by skimming, in the case of flotables) and may be assisted by chemicals (lime, alum or polymer) to make the particles settle faster. Removal can also be accomplished by mixing the waste with dissolved air and chemicals to make the solids float to the top.

Primary treatment of domestic sewage usually removes 40 to 60 percent of the influent suspended solids and 30 to 35 percent of the BOD. These removals are usually not achieved in fruit and vegetable processing waste. Typically, much of the BOD in these wastes is in a dissolved form that will not settle or float. Potato waste is an exception because 40 to 60 percent of BOD is removed with primary treatment.

Suspended solids reductions that are achievable in primary treatment vary widely with raw and finished products. Significant suspended soils reductions are attainable with primary treatment in products like potatoes, tomatoes, beets, or carrots. Little reduction is achieved in products like corn, peas, peaches, or pears. Primary treatment is seldom used for apple juice waste because there are few settleable solids. The waste consists primarily of dissolved fruit sugars. Tomato processing waste is typically high in settleable solids from field soil, so primary treatment is effective. Primary treatment of potato waste can remove up to 75 percent of the suspended solids.

SEDIMENTATION

Primary treatment systems using gravity sedimentation are sized on the theoretical settling or falling rate of the slowest particles to be removed. This settling rate is expressed as gallons treated per day divided by the surface area in square feet of the clarifier (gpd/sf). Typical values are between 300 and 1000 gpd/sf, which is equivalent to settling rates of 0.33 and 1.11 inches per minute, respectively (see table III-2). These settling rates can be determined by special laboratory tests. Clarifiers are usually at least 10 feet deep to allow for uneven flow distribution, sludge storage, and flow surges. In addition, primary clarifiers can also thicken these solids. The solids loading on a clarifier determines the degree of sludge thickening. Solids loading is the total pounds of solids settled divided by the surface area of the clarifier. High solids loadings can also hinder the settling rate of solids. Typical values for solids loadings are given in table III-2.

Chemicals such as lime, alum or polymers may be added to the primary sedimentation tanks. This increases the rate of settling of the suspended particles by coagulating smaller particles together into larger particles. Because of fluctuations in chemical requirements, chemical coagulation systems can be extremely difficult to operate on food processing waste effluents, especially if consistently high removals are required.

Table III-2.—*Primary treatment design criteria of fruit and vegetable wastewaters*

Sedimentation Clarifier type Bottom slope	 Circular or rectangular with width equal to 1/4 to 1/3 of length. 1-2 inches per foot for light sludge. 3-4 for heavy sludge.
Overflow rate Common municipal waste Silt and clay Lime floc Alum floc	 800 gallons/day/sq ft (gpd/sf) 300 gpd/sf 900-1,000 gpd/sf 600 gpd/sf
Side-water depth	10 feet minimum; 12 feet best.
Rake speeds	Rectangular tanks: 2-4 fpm Circular tanks: 2-4 fpm at the tip, but should be 10-15 fpm for silt and clay.
Scum removal	Should be on all clarifiers. Scum trough should be on downwind side of clarifier.
Solids loading	10-30 lbs/sf/day for light organics. 80-100 lbs/sf/day for silt and clay.
Sludge piping	Preferably 6 inches in diameter. Flow velocity should be about 2-5 fps.
Dissolved air flotation Overflow Air-to-solids ratio Recycle ratio Solids loading Pressure	 1,000-5,000 gpd/sf 0.01-0.1 lbs air/lbs solids 30-100 percent 0.3-1.3 lbs/hr/sf 50-60 psi

Figure III-2 is a cross section of a typical circular gravity clarifier. Common loadings for gravity clarifiers are given in table III-2.

FLOTATION

For certain wastes, dissolved air flotation clarifiers can be used effectively. Removal of suspended solids depends on the fine air bubbles that attach to each solids particle, thereby providing buoyancy. The buoyant solids are then skimmed off after they rise and form a blanket, or float, on the top of the clarifier. Solids that settle are removed by either an auger or rake.

The most common type of air flotation is dissolved air flotation. A portion of the waste, usually the effluent, is pressurized and air is injected. When the air and solids mixture is released into the open tank, the air comes out of solution in small bubbles, which attach to the solids and cause the solids to float.

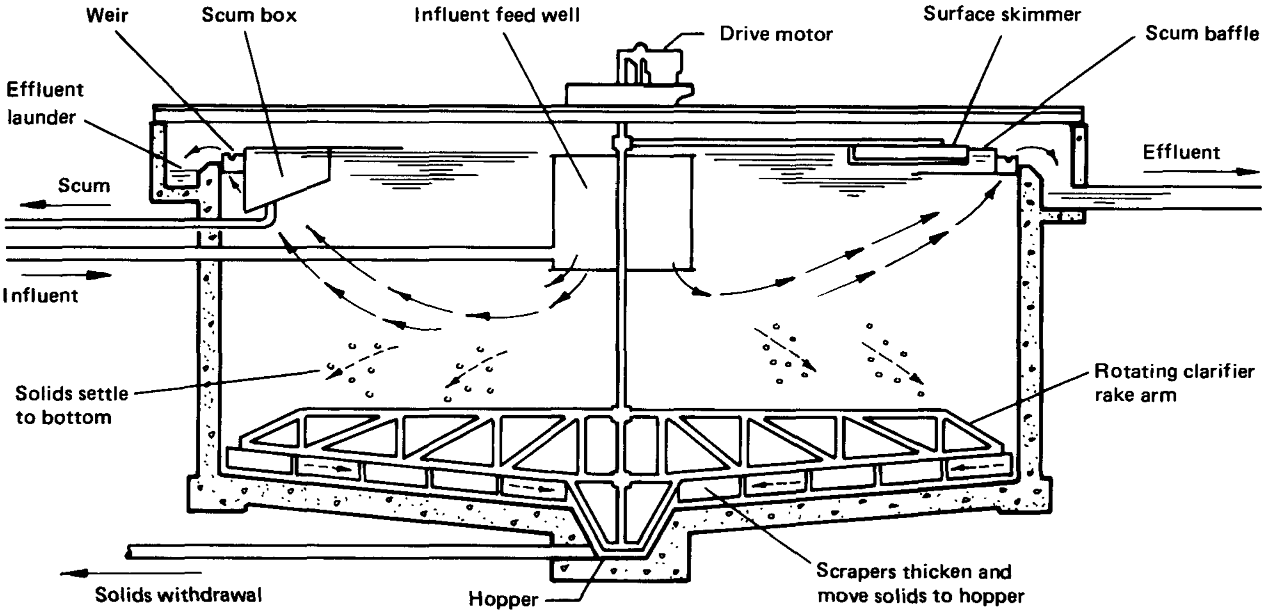


Figure III-2. Clarifier.

Dissolved air flotation units must be designed empirically from pilot experiments for a given waste. Several criteria must be examined in the pilot studies. These criteria are hydraulic loading, solids loading, air-to-solids ratio, and chemical dose requirements (if used).

Figure III-3 shows a typical, rectangular, dissolved air flotation clarifier. This clarifier is equipped to remove solids from both the top and bottom. Common loadings in dissolved air flotation units are given in table III-2.

COMPLETE PRIMARY SYSTEMS

Figure III-4 is a schematic of a complete primary system. In addition to the criteria that must be met in the design of the clarifier, it is vitally important that the sludge handling and treatment systems be well matched.

The clarifier must be sized to store sludge until it can be accepted by the dewatering equipment (a vacuum filter or centrifuge). If the vacuum filter or centrifuge is undersized, the clarifier will fill with sludge. Some sludge becomes septic when stored. This usually causes a reduced dewaterability of the sludge, requiring more chemical additions, and can also cause process failure and odors. Dewatering equipment is discussed in Chapter V. Systems having a dewatering unit must be designed to accept the recycled flow and solids from the unit as well as any wash or seal water used on the unit. These flows can be from 10 to 20% of the influent flow to the primary treatment system, and the solids from 5 to 20% of the influent solids.

Primary treatment systems operating on waste from root crops, (or other wastes, like tomato) may have special problems with field soil (mud). Some clays and silts are thixotropic, which means that they will solidify unless constantly agitated. If the sludge does solidify, it must be manually removed from the clarifier. Most mud will settle and thicken in clarifiers to 30 to 40% total solids (by weight), depending on the fractions of sand, silt and clay. At these concentrations, the head loss in pump-suction pipelines is so great that special pumping provisions must be made. The sludge pump can be located beneath the clarifier near the center, or dilution water can be added to the sludge at the center hopper of the clarifier.

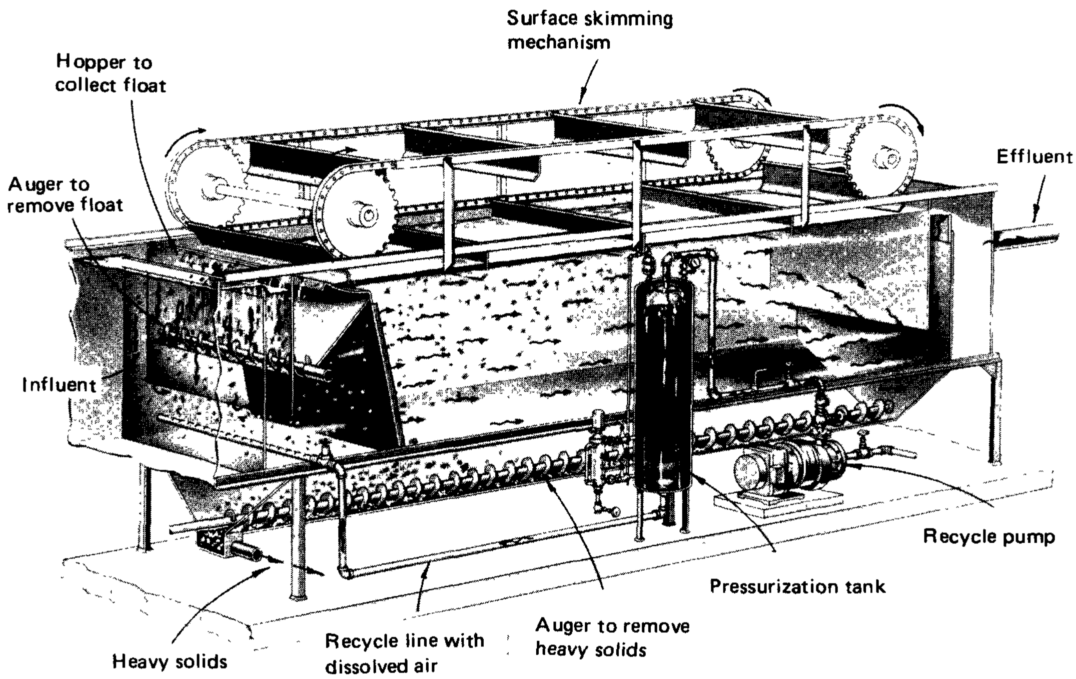


Figure III-3. Dissolved air flotation clarifier.

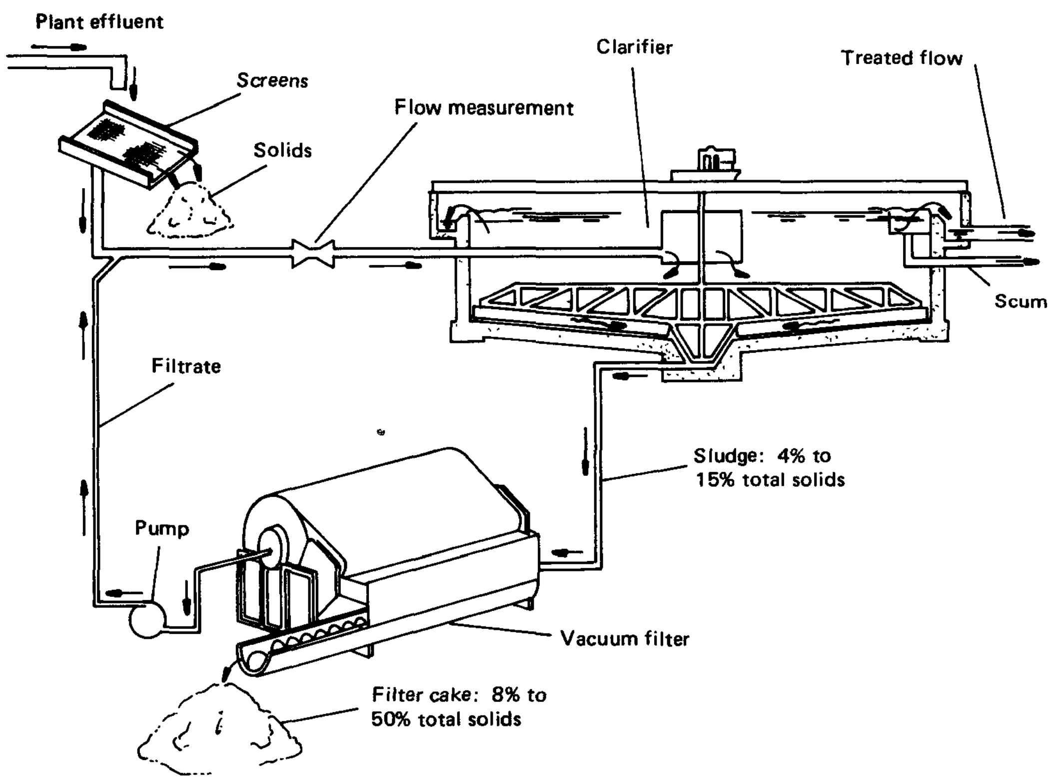


Figure III-4. Primary treatment plant.

BIOLOGICAL SECONDARY TREATMENT

While primary treatment is used to remove settleable solids, secondary treatment removes soluble organic material (BOD) and settleable solids (figure III-1). Biological secondary treatment may be (1) aerobic, which means that the biochemical reactions are carried out in the presence of oxygen, or (2) anaerobic, in which case different biochemical reactions are carried out in the absence of oxygen.

ANAEROBIC SYSTEMS

Principles

Anaerobic treatment is most commonly used in city treatment plants to digest sludges. A generalized equation for the biochemical reaction characterizing anaerobic treatment is:

food (BOD) + nutrients (N, P, etc.) → cells + methane gas

The mass, or yield of cells generated per pound of BOD stabilized, is from 0.04 to 0.06 which is considerably less than in aerobic treatment. Much of the carbon in the food source (BOD) is converted to methane gas. Anaerobic digestion requires little power. The process reduces the sludge weight and stabilizes it for disposal.

Reaction rates of anaerobic treatment increase with temperature. Sludge digesters are often heated to about 90 degrees Fahrenheit. The methane gas generated by the digestion is often used for this purpose. The anaerobic process is not often used to treat total industrial effluent. However, anaerobic ponds and anaerobic filters are of use for processing fruit and vegetable wastes.

Ponds

Anaerobic ponds followed by some kind of aerobic process (like an aerated pond) are common in the meat packing industry and achieve high removals. Processors of potatoes, corns, and apples have also used anaerobic ponds.

Anaerobic ponds are typically deep (15 to 20 feet) and have a retention time of 2 to 20 days. COD removals of 75 to 80% have been reported in the potato industry.[10] However, anaerobic processes often produce odorous gasses. Consequently, if a natural floating cover of grease and solids does not form, an artificial cover may have to be constructed.

Filters

A recent innovation is the anaerobic filter. Physically, the filters are covered tanks filled with large rock or other open media. The waste is passed through the tanks and the generated methane gas collected. The methane gas can be used to heat the incoming waste or it can be burned. These filters have been used as a pretreatment device for a wheat starch waste. Removals of COD have been high (up to 80%) with a net retention time of 2 days in the tanks.

Once the anaerobic growth is fully developed and attached to the rock, if the filter can be shut down for a period of months and restarted with only minor losses in efficiency, it is a substantial advantage for fruit and vegetable processors. Filters can be used as a pretreatment unit on selected waste (containing high dissolved organics, and low suspended solids) before discharging to a municipal system.

AEROBIC SYSTEMS

Principles

Aerobic systems are the most common type used for waste treatment. The general relation characterizing the biochemical reaction is:

$$\text{food (BOD)} + O_2 + \text{nutrients (N, P, etc.)} \rightarrow \text{cells} + CO_2 + H_2O$$

As opposed to anaerobic treatment, typical cell yields range from 0.3 to 0.6 pounds per pound of BOD oxidized. Depending on how the treatment system is operated, the requirements for applied oxygen will vary from 0.5 to 1.14 times the amount of BOD removed. Methods of getting this oxygen to the cells are discussed later.

Nutrients, especially nitrogen and phosphorus, can be critical in the performance of aerobic systems. The exact point at which nutrients become critical depends on the type of treatment process, and how it is operated. More discussion on this is found in the section on nutrients.

The basic treatment unit in aerobic systems is a biological reactor (aerated basin, pond, trickling filter). This reactor provides an environment for the conversion of soluble organic material into insoluble micro organism cells. The subsequent unit is a secondary clarifier or pond where the cells are allowed to settle. The settled cells, or sludge, may be either returned to the biological reactor cell mass (the mixed liquor), wasted from the system (waste sludge), or stored. As the result of biological growth, large volumes of organic solids are generated in secondary treatment processes. These solids are typically very wet (0.5 to 1.0 percent solids by weight), voluminous, and are difficult to dewater. In addition to the sludge resulting from biological growth, sludge also results from the removal of suspended solids that are not biodegraded.

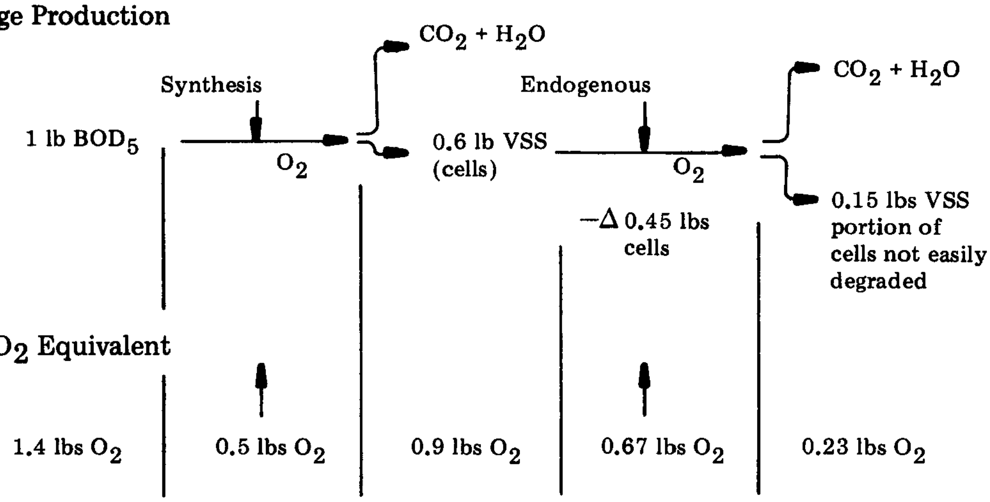
Several different biological systems are used to provide secondary treatment. In all cases, the secondary treatment units must provide an environment suitable for the growth of biological organisms. These treatment units depend on having enough oxygen to support aerobic decomposition of the organic matter. Most removals are given in terms of 5-day BOD removal which will range from 80- to 99-percent removal depending on a great range of variables, including waste characteristics, treatment flow pattern, treatment environment, system loading, and operating conditions. A summary of design factors for each process discussed is included in table III-3.

The following characterizes the aerobic conversion of waste (including a generalized scheme of this conversion):

- BOD_5 is *a* measure of oxygen required.
- BOD_5 is *not* a direct measure of O_2 required to treat waste.
- BOD_5 does *not* measure the total amount of O_2 required to treat a waste.
- BOD_5 x 1.4 is about equal to the total O_2 needed to treat a waste.
- BOD_5 is a way to measure the O_2 required to stabilize a mixture of organic compounds.

$$\text{Organic Compounds} + \text{Oxygen} + \text{Nutrients} \rightarrow \text{End Products}$$

Sludge Production



- Minimum O_2 theoretical = 0.5 # O_2/3 BOD_5
- Maximum O_2 theoretical = 0.5 + 0.67 = 1.17 #O_2/#BOD_5
- Minimum sludge production = 0.15 #/#BOD_5
- Maximum sludge production = 0.6 #/#BOD_5
- Non-biodegradable solids in the waste add directly to the amounts produced by biodegradation of organics.

Aeration Methods

An artificial aeration system is required for nearly all aerobic treatment systems. These aeration systems can be classified according to two approaches: (1) bubbling compressed air into the waste through the use of diffusers (diffused aeration), and (2) entrainment of air in the waste through agitation of the surface (mechanical aeration).

The following aerators are used in these systems:

Types of aerators	Description
Mechanical surface	
Low speed	Rotor, gear box drive
High speed	Propeller, direct drive from motor
Diffused air	
Fine bubble	Socks, stones
Large bubble	Holes in pipe
Sparge air	Combines mechanical and diffused
Hinde tubes	Small tubes with slits

Types of aerators	Description
Helical	Spirial static diffuser
Brush	Rotating brush
Aspirator (Penberthy)	Venturi aspirator
Inka grid	Low pressure system

Aeration equipment is rated at standard conditions: 20 degrees centigrade, zero dissolved oxygen in water being aerated, transfer rates and solubilities for tap water (clean water), at sea level.

Actual operating conditions will likely be: 4 degrees to 30 degrees centigrade, 0.5 to 2.0 mg/l dissolved oxygen, reduced transfer rates and solubility for wastewater above sea level.

The actual net transfer under field conditions for all types of aeration systems will range from 45 to 60 percent of the rated condition.

Blowers in diffused-air systems compress air to about 8 psi. The compressed air then enters the waste through diffusers, which are mounted close to the bottom of the aeration basin. Many methods exist to diffuse air into solution with an efficiency of only about seven percent. Diffusers clog easily from particles in the waste or from deposits that build up on the diffuser pores. Diffusers should be mounted so they can be easily removed for cleaning. As a rule, to maintain complete mixing, 20 to 30 cfm (cubic feet per minute) should be applied to each 1,000 cubic feet of basin volume. Diffused-air systems deliver around 1.0 pound of oxygen per horsepower hour at field conditions. There are a great variety of diffused air systems which have differing transfers.

A typical mechanical aerator is shown on figure III-5. These aerators may be either rigidly mounted in a tank or installed with floats, so they can rise and fall with the water level, as illustrated. The amount of power to maintain complete mixing with these units is one-half to one horsepower per 1,000 cubic feet of basin volume.

Nutrient Requirements

In addition to air and waste, a biological system needs nutrients to maintain a healthy state. Microorganisms need about the same trace minerals that humans do, but the lack of these is rarely a serious problem in waste treatment. The most common deficiencies in fruit and vegetable processing wastes are nitrogen and phosphorus. The amount of these nutrients required for a given microorganism depends on its age. However, the amount of nutrients required for a treatment process depends both on the age of the organisms and the numbers of cells generated during the reduction of BOD. A BOD/nitrogen/phosphorus ratio of 100:5:1 is usually adequate. However, high-rate systems with no available nitrogen or phosphorus in the waste could require a ratio of 100:10:2. As seen in table III-4 most fruit and vegetable processing wastes have a nutrient deficiency. Ratios lower than 100:5:1 may be adequate for aerated ponds and systems with a very long sludge age. In rare cases, nutrients such as iron and magnesium must be added. All nutrients need to be in a soluble form to be used by the microorganisms.

Table III-3.—*Secondary treatment design criteria for fruit and vegetable wastewaters*

Conventional activated sludge	
Aeration basin	
Mixed liquor suspended solids (MLSS)	2,000 – 4,000 mg/l
Food/micro-organism ratio (F/M)	0.1 – 0.5 lb BOD removed/lb MLSS
Sludge age (days)	3 – 10 days
Aeration time	16 – 48 hours, but controlled by sludge age, F/M, and MLSS concentration
Depth	10 – 20 feet
Aeration type	Floating mechanical aerators or diffused aeration
Returned sludge	25 – 100% of incoming plant flow
Secondary clarifiers	Typical overflow rate is 400 gpd/sf. Solids or floor loading 15 – 25 lb/sf/day based on influent plus recycle flow Most secondary clarifiers are circular
Pure oxygen activated sludge aeration basin	
Aeration basin	
Mixed-liquor concentration (MLSS)	3,000 – 5,000 mg/l
Food/micro-organism ratio (F/M)	0.5 – 0.7 lb BOD removed/lb MLSS
Sludge age (days)	6 – 10 days
Aeration time	8 – 24 hours, but controlled by sludge age, F/M, and MLSS concentration
Depth	15 feet
Aeration type	Diffused, high-purity oxygen in mechanically agitated covered tanks
Returned sludge	25 – 100% of incoming plant flow
Secondary clarifiers	Same as conventional activated sludge except floor loading 25 – 40 lb/sf/day
Aerated ponds	
Depth	7 – 15 feet
Hydraulic retention time	20 – 45 days
Aeration	1.1 – 1.3 lb O_2/lb BOD applied (~ 40 lb O_2 per hp/day)
Mixing	Minimum – 8 – 10 hp/mg Maximum – 14 – 20 hp/mg

Table III-3.—*Secondary treatment design criteria for fruit and vegetable wastewaters*—Con't.

Activated biofilter	
Filter tower	
Height	20 feet
Configuration	Circular with rotating waste distributors, or rectangular with stationary distributor
Hydraulic loading	1 – 2 gpm/sf of tower area including recycle
BOD loading	0.15 – 0.3 lb BOD per cubic foot of filter media
Media type	Redwood slats or various plastic shapes
Aeration basin	Same criteria as an activated sludge aeration basin. Assume that 40 – 60% of the influent BOD has been removed by the tower
Clarifier	Same criteria as an activated sludge clarifier. Sludge can be returned to both the aeration basin and the filter tower. Floor loading 15 to 25 lb/sf/day
Trickling filter (high rate)	
Filter	
Depth	3 – 8 feet
Configuration	Circular with rotating distributor
Hydraulic loadings	20 – 90 gallons/sf/day
BOD loading	20 – 50 lbs BOD/1,000 cf
Recirculation	100 – 400% of influent flow
Media type	Rock media: 1 – 3 inches diam. Plastic media now being used
Clarifier	Overflow rate 400 – 600 gpd/sf Floor loading of 20 – 35 lb/sf/day
Rotating biological contactor	
Contactor	Size to be determined by pilot testing
Clarifier	Overflow rate 400 – 600 gpd/sf Floor loading 20 – 35 lb

NOTE:—Clarifiers for trickling filters and RBS units are usually controlled by the overflow rate rather than floor loading because these systems do not use mix liquor as a part of the process. Overflow rates of 400 to 600 gpd/sf are common.

Table III-4.—*Available nutrients for fruit and vegetable wastewaters*[5]

Commodity	BOD/N/P ratio	Commodity	BOD/N/P ratio
Apricots	100/1.6/.23	Onions	100/3.1/.5
Artichokes	100/4.4/.8	Peaches	100/1.4/.3
Asparagus	100/6.5/1	Pears	100/1/.01
Beans	100/4.4/.8	Peas	100/6/.7
Beets	100/3.1/3.9	Pickles (avg. sweet & dill)	100/1/.2
Blueberries	100/.9/.1		
Broccoli	100/7.2/1	Pimentoes	100/2.8/.3
Brussels sprouts	100/7.2/.7	Pineapples	100/.6/.1
Caneberries	100/1.8/.2	Plums	100/.6/.1
Carrots	100/2.3/.5	Potato chips	100/1.1/.2
Cauliflower	100/6.8/.9	Potatoes	100/2.4/.4
Cherries	100/1.7/.2	Prunes	100/.7/.2
Corn	100/2.8/.5	Raisins	100/.7/.2
Cranberries	100/.7/.1	Rhubarb	100/3.0/.5
Dry beans	100/5.4/.6	Sauerkraut	100/4/.5
Dehydrated onions	100/2.1/.004	Spinach	100/7.7/.6
Figs	100/1.3/.2	Squash	100/3.7/.7
Grapes	100/1.6/.1	Strawberries	100/1.6/.3
Jams & jellies	100/.1/.01	Sweet potatoes	100/1.3/.2
Lima beans	100/5.4/.6	Tomatoes	100/4/.6
Mushrooms	100/7/1.9	Zucchini	100/5/.8
Okra	100/5/.6		
Olives	100/1.2/.1		

NOTE:—Domestic waste ratio is 100/20/2

The values in table III-4 are taken from the EPA effluent guidelines report[5] and presumably were developed from analyses for total nitrogen and phosphorus. Because most of the nitrogen found in fruit and vegetable processing wastes is in the form of insoluble organic nitrogen, it is not readily available for microorganism use. Thus a greater amount of supplemental nitrogen is needed than table III-4 would indicate.

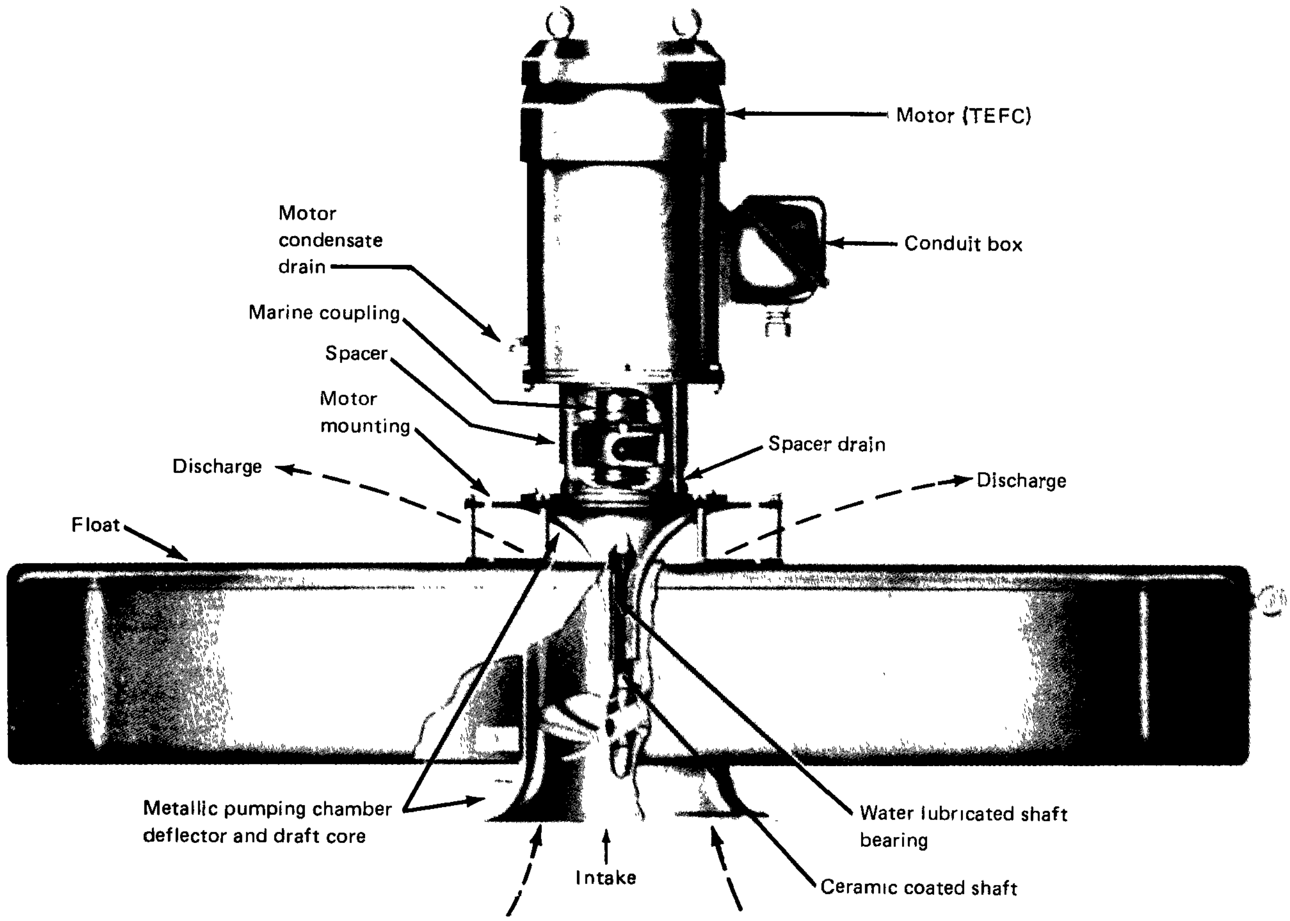


Figure III-5. Floating mechanical aerator (high speed)

Stabilization Ponds

Stabilization ponds are large, usually 3 to 6 feet deep, and retain the wastewater for a period of 60 days or longer. Oxygen needed for biological action comes primarily from the action of photosynthetic algae, although some oxygenation occurs as a result of the contact between the pond surface and the atmosphere (wind action). Depending on the degree of treatment desired, waste stabilization ponds may be designed to be operated in a variety of ways, including series and parallel operations. In some cases, treatment may include tertiary ponds for algae removal prior to effluent discharge.

Because of the high strength of fruit and vegetable processing wastes, BOD loadings determine the necessary size of the ponds. The loading should be kept at 20 to 40 pounds BOD per acre per day. A lagoon area of about 300 acres would be required for a 1-mgd flow with a BOD of 1,000 mg/l. Stabilization ponds can cause several problems that result in their being abandoned:

- Growth of algae (resulting in high effluent suspended solids and BOD).
- Odors, especially during startup.

Several algae removal systems are under study and some are under construction; however, there is no full-scale, long-term operating experience.[11]

Aerated Lagoons

Aerated lagoons are similar to stabilization ponds except that oxygen is artificially added either by compressed-air diffusion or by mechanical agitation (figure III-5). Supplemental aeration allows the pond volume to be greatly decreased and the depth increased, although ponds are seldom deeper than 12 feet with special provisions for mixing. They can thus reduce surface area and heat loss. The biological life in an aerated lagoon will contain limited numbers of algae and will be similar to that found in activated sludge.

Adequate mixing must be provided in aerated lagoons to distribute oxygen (8 to 15 horsepower per million gallons). However, the mixing should not be over 15 horsepower per million gallons or sludge will be suspended. The exact limits depend on the type of aeration as well as the depth and configuration of the lagoon. At least 0.2 pounds of sludge are produced for each pound of BOD removed. These solids will accumulate and must be removed or they will discharge in the effluent. Lagoons in series are often used for solids separation. The second lagoon serves as a polishing pond.

Table III-5 is an estimated cost of an aerated lagoon for a 1-million gallon-per-day wastewater flow. In addition to the assumptions given in table III-5, the following should be noted:

- Lagoon depth is 10 feet.
- Inside slope 3:1; outside 2:1.
- Mechanical aerators: 12 at 40 HP each, and one at 20 HP; all moored to the bottom.
- Total land for both lagoons is 11 to 12 acres.
- Material used in dike construction comes from the lagoon excavation.

It was assumed that the 30 mg aerated pond would have to be excavated below the ground. This results in 150,000 yards of excavation. Assuming a cost of $4 per yard for excavation and if the pond could be constructed with a balance of cut and fill, the excavation cost would be about $144,000. It is assumed the settling pond would be lined with concrete. The estimated liner cost is $7,500.

The liner assumed is 30 mil hypolon, 440,000 ft^2 at $\$.44/ft^2$ = $178.800.

If the pond could be constructed without a liner and with balanced cut and fill, the estimated cost would be $517,700.

This would reduce the amortized capital cost of $91,600.

Activated Sludge

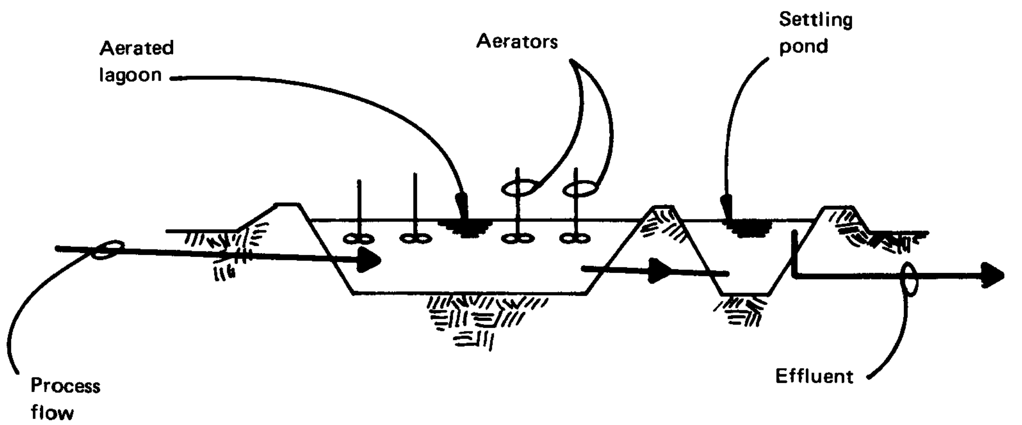
In activated sludge, waste is discharged into an aerated basin. The presence of abundant organic food, nutrients, and oxygen is favorable to sustaining a large concentration of microorganisms. Ordinarily, dissolved-oxygen levels are kept at 1 to 2 mg/l. The combination of the waste flow and microorganisms is called mixed liquor. The mixed liquor flows from the aeration basin to clarifiers where the microorganisms settle from the liquid. The settled microorganisms (activated sludge) are returned to the aeration tank to maintain the mixed-liquor concentration. The excess microorganisms produced and non-biodegraded materials removed in secondary treatment are wasted from the system (waste activated sludge). A schematic of an activated sludge plant is given in figure III-6. Design criteria for activated sludge processes are given in table III-3. Figures III-7 and III-8 are photographs of activated sludge plants treating potato wastes.

Table III-5.—*Cost summary for aerated lagoon system*

Criteria

- Flow: 1 mgd average; 2 mgd peak
- Season: 90 days
- Amortization: 10 years at 12%
- Engineering, legal and contingency costs included at 25% of construction cost
- Excavation and disposal cost at $4/cy
- October 1975 dollars

Schematic



Assumptions

- Both aerated lagoon and settling pond are lined earthen basins
- 30-day detention time in aerated lagoon
- 400 gpd/SF overflow rate in settling pond
- No nutrient addition for this example. (However, practice may require nutrient addition. See table III-6.)
- Power cost at 2 cents/kW-hr
- Labor at $7.00 (including overhead)

Costs

Capital	Operation and maintenance	
$517,700	Labor	4,500/yr
	Power (500 hp)	16,000/yr
	Total	$20,500/yr

Amortized capital plus O&M	$112,100/yr
Unit cost	125¢/1000gal

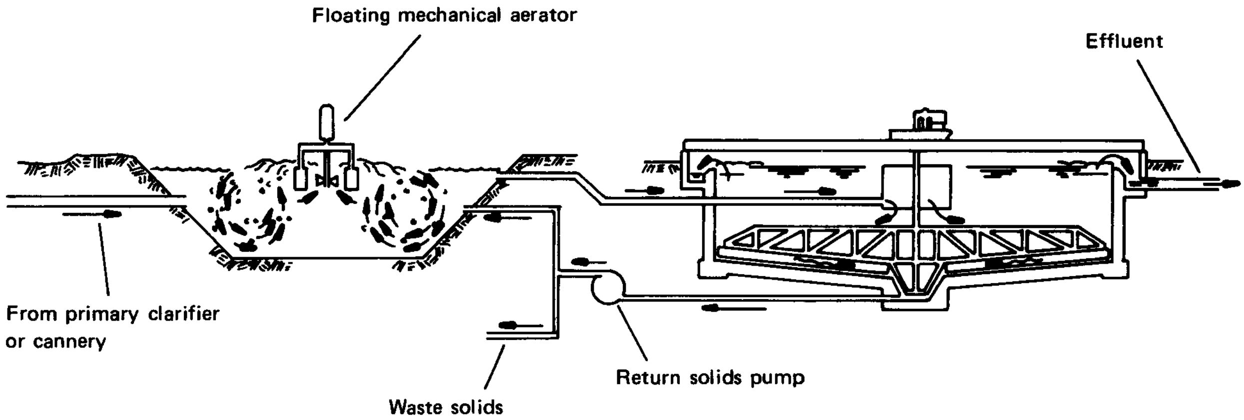


Figure III-6. Activated sludge plant.

An operational problem with activated sludge plants is bulking. Sludge bulking is the inability of the activated sludge to settle or thicken in the secondary clarifier. This occurs commonly in plants treating wastewater containing a high percentage of carbohydrates (corn, apples, etc.) because of the formation of filamentous, or stringy, bacteria. Unless carefully designed and operated, plants will develop filamentous growth and consequently not perform efficiently.

There are many variations of activated sludge processes; however, all operate basically the same. Unit arrangements and methods of introducing air and waste into the aeration basin account for the variations. A small, compact, prefabricated activated sludge plant is shown in figure III-9.

Tables III-6 and III-7 give cost estimates for an activated sludge plant (1.0 mgd), both with, and without, sludge digestion and dewatering. In addition to the assumptions listed in the tables, the following should be noted:

- Activated sludge food to micro-organism ratio (F/M) is 0.2, where:

  F = pounds BOD in influent per day, and
  M = pounds of mixed liquor under aeration

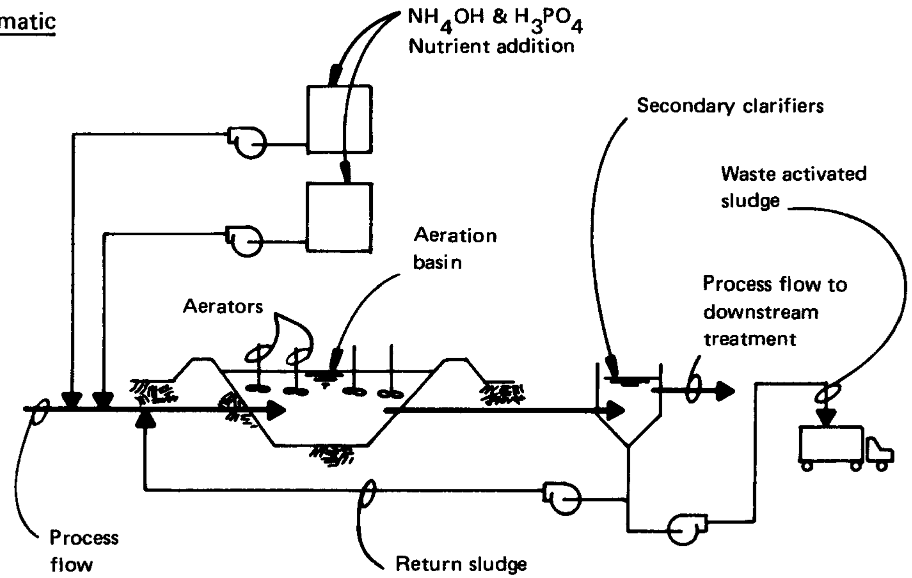
- Aeration basin sludge age: 6.5 days
- Aeration basin mechanical aerators: 10 to 50 HP each
- Two 40-foot diameter clarifiers
- Area requirements for activated sludge alone: about 2 acres
- Area requirements with digestion, dewatering: about 3 acres
- Aerobic digester sludge age: 15 days
- Two gravity dewatering units for waste sludge concentration
- Raw-waste activated sludge to truck: 95,000 gal/day at 0.8% solids

Table III-6.—*Cost summary for activated sludge system*

Criteria

- Flow: 1 mgd average; 2 mgd peak
- Season: 90 days
- Amortization: 10 years at 12%
- Engineering, legal and contingency costs included at 25% of construction cost
- October 1975 dollars

Schematic



Assumptions

- Lined earthen aeration basin with 2-day detention time $F/M = 0.2$
- Two conventional secondary clarifiers with 400 gpd/sf overflow rate
- Cost of NH_4OH at $184/ton (100% basis) cost of H_3PO_4 at $0.215/lb SOL'N.
- Power cost at 2 cents/kW-hr
- WAS disposal cost at 1.5 cents/gal for 20-mile haul
- Labor at 9 hrs/day at $7.00/hr.

Costs

Capital	Operation and maintenance	
$645,000	Labor	$5,000/yr
	Nitrogen	2,900/yr
	Phosphorous	5,000/yr
	Power (500 HP)	16,000/yr
	Waste sludge[a] disposal	130,000/yr
	Miscellaneous	16,100/yr
	Total	$175,000/yr
Amortized capital plus O&M		$289,150/yr
Unit cost		321¢/1000 gal

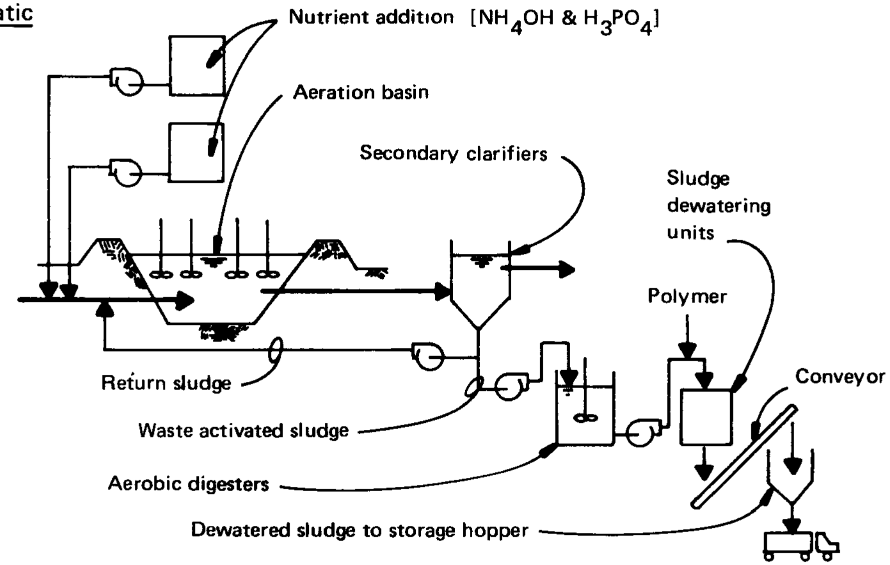
[a]Normally, the sludge from the clarifier is further thickened and then dewatered. See table III-7.

Table III-7.—*Cost summary for activated sludge with aerobic digestion and dewatering*

Criteria

- Flow: 1 mgd average; 2 mgd peak
- Season: 90 days
- Amortization: 10 years at 12%
- Engineering, legal and contingency costs included at 25% of construction cost
- October 1975 dollars

Schematic



Assumptions

- See assumptions for activated sludge system (table III-6)
- Dewatered sludge trucking costs at \$3.70/ton dry solids/mile (Approximately 30 mile haul at 20% solids)
- Polymer addition at 6 lb/ton solids
- Polymer cost at \$2.25/lb
- Unit dewatering rate at 1000 gph for digested sludge
- Labor at 10 hrs/day @ 7.00/hr.

Costs

Capital	Operation and maintenance	
\$1,115,000	Labor	\$6,300/yr
	Nitrogen	2,900/yr
	Phosphorous	5,000/yr
	Polymer for sludge	3,000/yr
	Power (575 H.P.)	18,500/yr
	Dewatered sludge disposal	17,000/yr
	Miscellaneous	5,800/yr
	Total	\$58,500/yr
Amortized capital plus O&M		\$255,850/yr
Unit cost		28¢/1000gal

Figure III-7. Activated sludge plant. (Courtesy of CH_2M HILL)

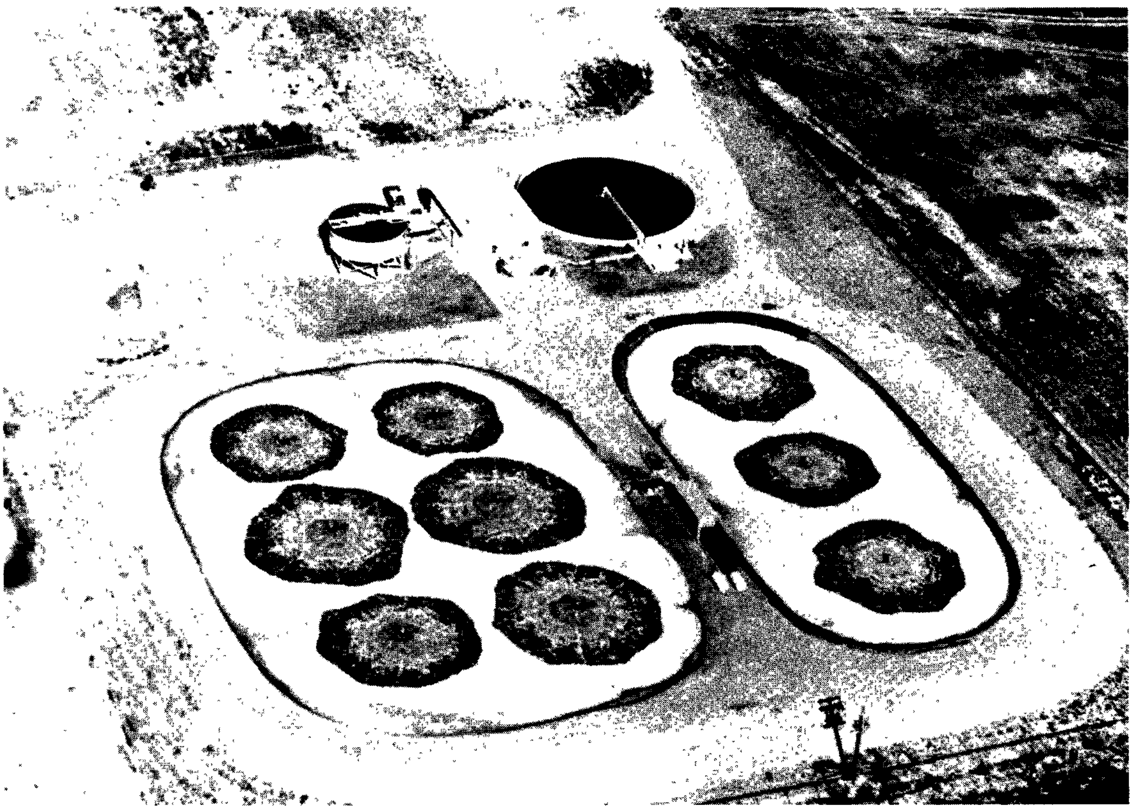


Figure III-8. Activated sludge plant. (Courtesy of CH_2M HILL)

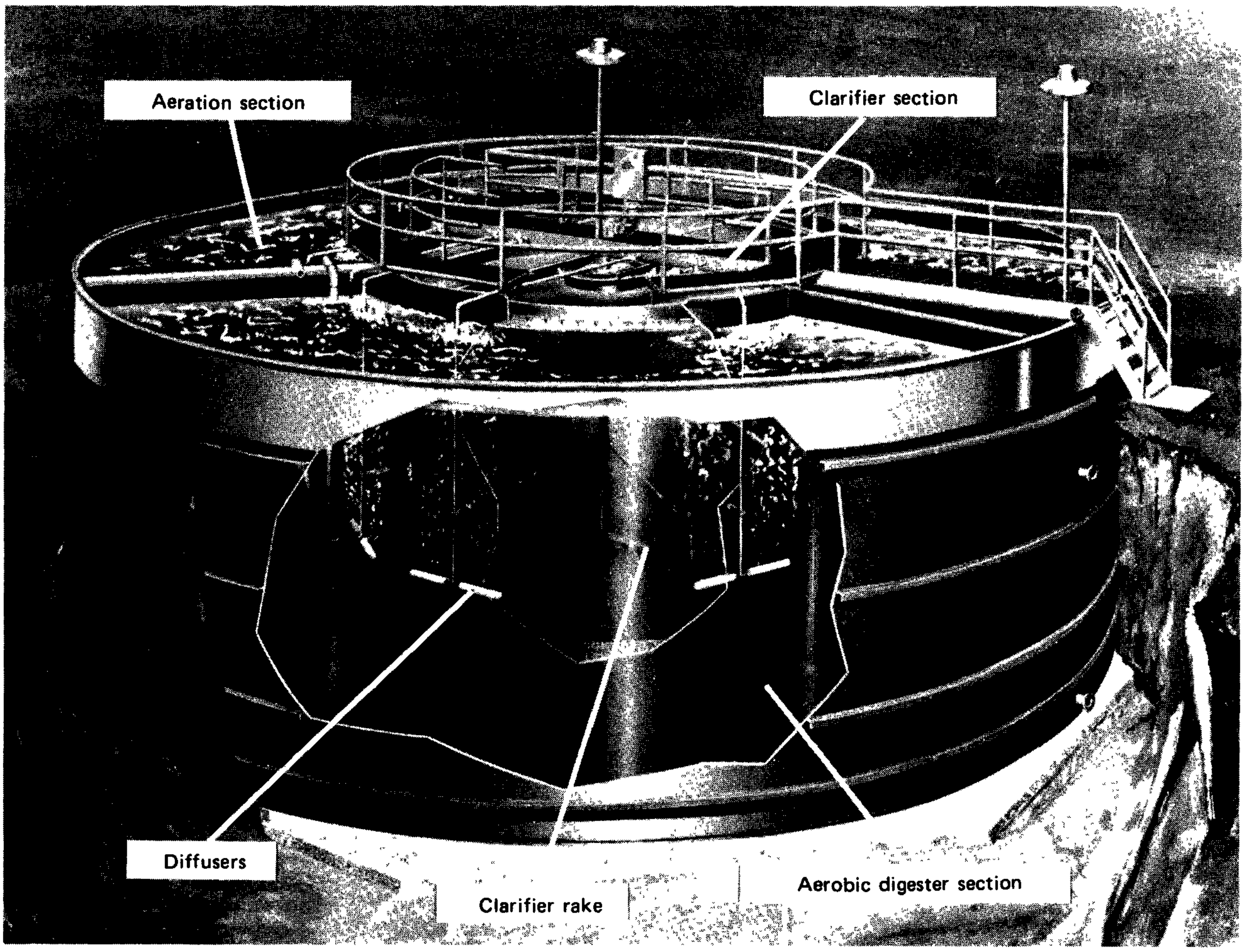


Figure III-9. Package activated sludge plant. (Courtesy of Cantex)

- Digested, dewatered, waste activated sludge to truck: 35 cubic yards/day at 9% solids
- Small building for motor control center and pumps
- Small building to house dewatering units.

Oxygen Activated Sludge

The activated sludge process that uses high-purity oxygen (HPO) merits discussion. This system uses covered multi-stage (3 to 5 stage) aeration basins into which oxygen-rich gas is fed. Oxygen utilization is approximately 90 percent. Oxygen concentration varies from above 90 percent in the inlet gas to about 50 percent in the exhaust gas. Mechanical mixers project through the roof to mix the basin contents and entrain the oxygen. Dissolved oxygen concentrations can be maintained at high levels (7 to 15 mg/l, versus 1 to 2 mg/l in conventional plants) in the wastewater flow. The basin effluent is clarified in standard secondary clarifiers and sludge is returned to the first stage aeration basin. Excess sludge is wasted as it is in a conventional activated sludge plant.

Current knowledge of fruit and vegetable processing waste and the high-purity oxygen, activated-sludge process suggests that when compared with more conventional activated sludge systems, this modified process results in the following advantages:

- A sludge more settleable in secondary clarifiers, resulting in lower secondary effluent suspended solids and BOD levels. This has been observed in the treatment of other high-strength carbohydrate wastewaters. It is believed to be related to the high dissolved oxygen concentration within the system.

- Retention of wastewater heat necessary for effective treatment in cold climates.

- Less land area.

The capital cost of a high-purity oxygen system is usually greater than conventional systems, but it should be considered where the need for biological secondary treatment is indicated. Commonly used design criteria for HPO processes are given in table III-3.

Activated Biological Filter (ABF)/Activated Sludge

Activated bio-filtration (ABF) was developed in recent years to take maximum advantage of artificial filter media characteristics. Plastic and redwood biological filter media have high void-to-total-volume ratios and high surface-to-total-volume ratios. These characteristics make high organic loadings possible.

In the original ABF system, secondary clarifier underflow is combined with the secondary plant influent and pumped to the bio-filter. Bacteria grow on the filter media and in the wastewater flow. Portions of the bacterial mass, which continuously slough from the media, join the bacteria growing in the wastewater and settle out in the secondary clarifier. Most of the bacterial mass settled in the secondary clarifier is returned to the filter influent to maintain a high concentration of bacteria in the flow through the filter. The flow scheme has the appearance of activated sludge, which gives rise to the name of activated bio-filtration.

A recent modification of the ABF process has been the insertion of an activated sludge aeration tank between the ABF tower and the final clarifier. The effluent from the tower is sent through the aeration basin for further treatment. The aeration basin is designed to assimilate 40 to 60 percent of the organic loading to the tower. The return sludge from the final clarifier is usually returned to the tower. At least one of the suppliers of plastic media has recently indicated that there will be better performance if the sludge is not returned to the tower. In this case, the filter would simply be a roughing filter ahead of the activated sludge units.

This ABF-activated sludge process has shown great promise in successfully treating high carbohydrate wastewaters (potatoes) without developing the sludge bulking problems of activated sludge. The process is also resistant to shock loadings. Figure III-10 shows a circular ABF tower operating on combined domestic and potato waste. The towers (about 20 feet high) may also be square or rectangular. Figure III-11 is a schematic of the ABF-activated sludge process. Design criteria for ABF-activated sludge plants are given in table III-3.

Rotating Biological Contactors (RBC's)

This system has many large diameter, lightweight discs mounted on a horizontal shaft in a semi-circular shaped tank. The discs are rotated slowly with the lower half of their surfaces submerged in the wastewater. Bacteria and other micro organisms grow on the disc surfaces and in the tank. In rotating, the discs carry a film of wastewater into the air where it absorbs oxygen. The mixing created by the disc rotation also transfers oxygen to the tank contents. Shearing forces cause excess bacterial growth to slough from the discs and into the wastewater. The sloughed solids flow out with the treated waste to the secondary clarifier for separation and disposal.

Figure III-10. Activated biological filter tower. (Courtesy of CH_2M HILL)

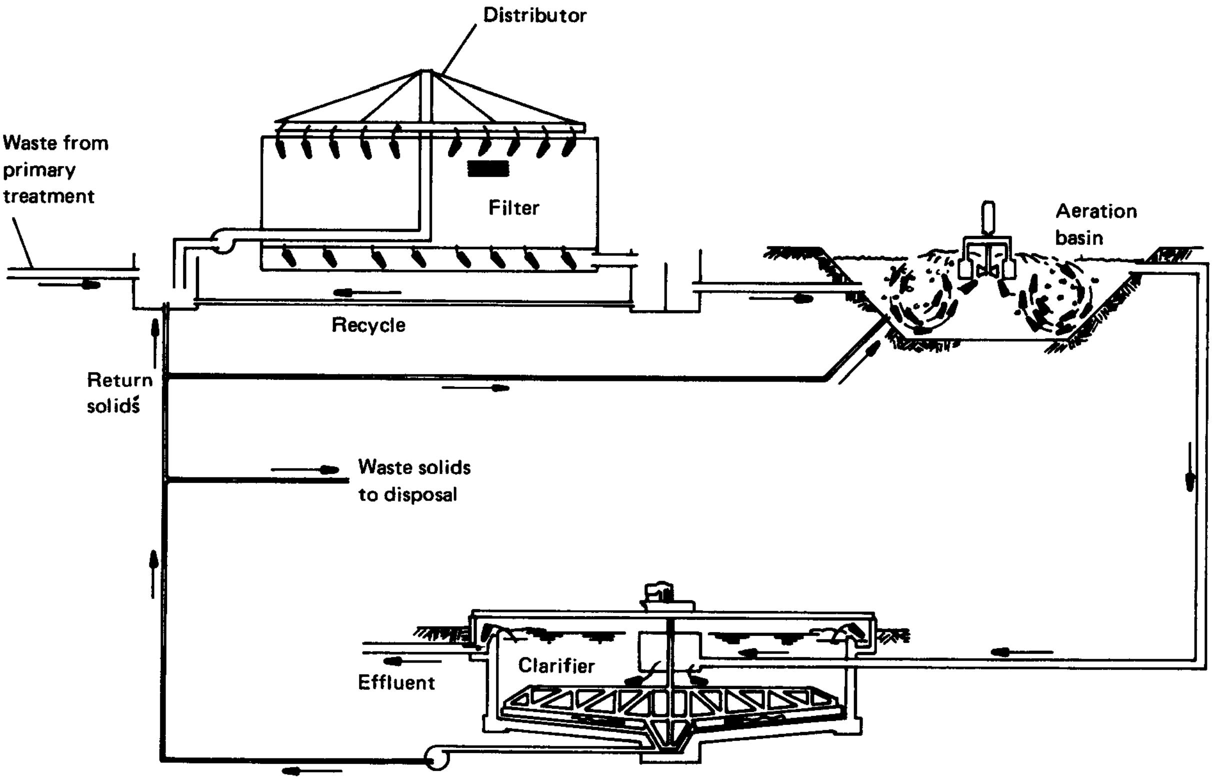


Figure III-11. Activated biological filter activated sludge plant.

Rotating biological contactors have been successfully applied to municipal and some industrial waste. Operation is simple and power requirements are low, but the capital costs of the discs are high. Before this system is applied to the treatment of fruit and vegetable processing waste, pilot plant testing and economic analysis should be done to answer the following questions:

(1) Effect of wastewater pH.

(2) Effect of wastewater strength.

(3) Temperature of waste.

(4) BOD and suspended solids removal efficiency related to BOD and suspended solids unit loadings.

(5) Capital and total costs compared to alternative systems.

Trickling Filters

One of the oldest biological treatment systems is the trickling filter. Typically, the filter is a 6-foot deep bed of 2-1/2 to 4 inch rock over which the wastewater is distributed. Atmospheric oxygen moves naturally through the void spaces in the rock. In the environment thus created, biological slimes (consisting mainly of bacteria) flourish and colonize on the rock surfaces. As the waste trickles over the surface of the growths, organic matter is removed. As the growths become more and more concentrated, their attachment to the media surface is weakened and they are washed from the filter. The solids are then removed by sedimentation as in other high-rate processes. See figure III-12 for a diagram of this process.

There are a number of variations of the biological filter process, depending on the waste loadings applied to the filters, the arrangement of the units, and the number of filters employed. Trickling filters are very stable and easier to operate than activated sludge plants. Removals of BOD seldom exceed 80 percent, and the effluent contains a higher level of suspended solids than the activated sludge process. For this reason, no new trickling filter plants are now being designed to meet the new EPA requirements. Common design parameters for trickling filters are given on table III-3.

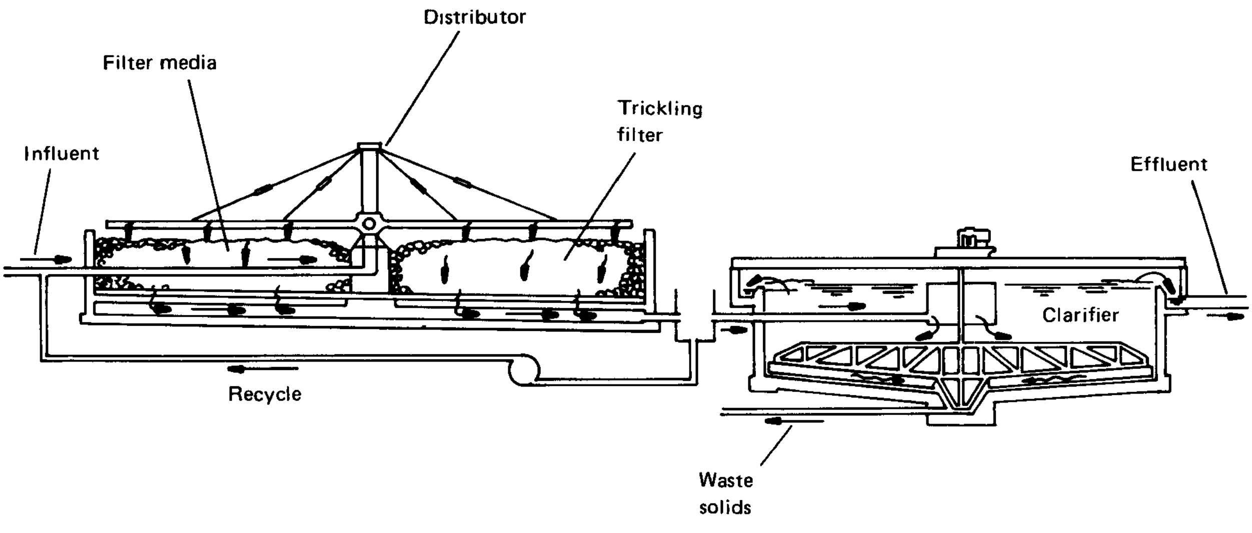


Figure III-12. Trickling filter plant.

TERTIARY (ADVANCED) WASTE TREATMENT

With the exception of two or three rapid-sand filter installations, tertiary treatment is not being practiced by the fruit and vegetable processing industry[4,5]. Only those processes with the greatest possible applicability are discussed here (table III-8). These processes are: chemical precipitation, filtration, carbon absorption, ion exchange, and reverse osmosis. In this discussion, it is assumed that any advanced waste treatment process is treating effluent from a secondary treatment plant.

CHEMICAL PRECIPITATION AND SEDIMENTATION

The primary application for this step as a tertiary process is the removal of suspended solids that escape secondary treatment. The process involves the use of a coagulant to (1) form a precipitate with the waste that settles out, and (2) form a metal precipitate which "sweeps" out other colloidal matter. The coagulants commonly used are lime, alum, or ferric chloride. Polymers are sometimes used as a primary coagulant, but most often as an aid.

Simplified chemical reactions illustrating the action of these coagulants are given below:

Lime

$$Ca(OH)_2 + Ca(HCO_3)_2 \rightarrow 2CaCO_3 (\downarrow) + 2H_2O$$

Alum

$$Al_2(SO_4)_3 + 6HCO_3 \rightarrow 3SO_4 + 2Al (OH)_3 (\downarrow) + 6CO_2$$

Ferric Chloride

$$FeCl_3 + 3H_2O \rightarrow Fe (OH)_3 (\downarrow) + 3H^+ + 3Cl^-$$

(($\downarrow$) indicates a solid material or precipitate that settles out.)

Table III-8.—*Tertiary waste treatment applications*

Process	Pollutant to be removed				
	COD	BOD	Suspended solids	Dissolved salts	Refractory organics
Carbon adsorption	X	X	X		X
Chemical precipitation	X	X	X	X	May remove some refractory compounds
Filtration	X	X	X	X	
Ion exchange	X	X		X	X
Reverse osmosis	X	X		X	X

The overflow rate on the chemical clarifier can be from 500 to 2,000 gpd/sf, depending on the coagulant used. Expected solids concentration in the sludge varies from 3 to 7 percent. If lime is used as a coagulant, the floc is very dense and settles easily. The use of alum increases sulfates in the water, and this floc is more difficult to settle and dewater than lime. The use of iron increases the chloride concentration in the water and can cause low pH problems. Chemical precipitation, however, is the most efficient way to prevent deterioration of effluent during biological plant upsets.

FILTRATION

Filtration reduces suspended solids of colloidal size—those that will not settle out. Historically, a single media was used with a filtration rate of 0.05 to 0.13 gpm/sf, and has been termed slow-sand filtration. Rapid-sand filtration, now in use, has a filtration rate of 1 to 5 gpm/sf. In addition to single-media filters, dual- and tri-media filters are also used.

Filters may be classified by five parameters as follows:

(1) Direction of flow

(2) Type of media

(3) Flow rate

(4) Gravity or pressure

(5) Cleaning method.

Today the filters used most successfully on wastewater are downflow filters using dual- or tri-media. A filtration rate of 2-1/2 to 5 gpm/sf is common. Cleaning is by hydraulic backwash, commonly at a rate of 15 gpm/sf. This backwash may be preceded by air backwash and assisted by surface wash. Often a filtration aid like polymer or alum is added to the feed to strengthen floc and improve solids removal. Figure III-13 shows a small package mixed-media pressure filter installation.

Single-media filters can achieve high removals but ordinarily remove only 70 percent of the influent solids under ideal conditions. Seventy-five to ninety percent of the head loss occurs in the first inch of this media, which indicates that filtration is really a surface phenomenon. In addition, single-media filters tend to "blind off" at the surface, reducing filter runtime, and thus necessitating more frequent backwashing.

Mixed-media (dual- or tri-media) filters generally give longer runs and better removals, even though the media is slightly more expensive. The idea behind mixed-media is to provide a constant gradation of pore size in the filter from coarse on the surface to fine on the bottom. The gradation in pore size allows filtration and storage of solids throughout the depth of the bed, as opposed to a single-media bed in which filtration takes place in the top.

As a rule, filters cannot be used when the influent suspended solids exceeds 100 mg/l or when the size distribution of solids changes rapidly so that selection of media type or mix is impossible. It is usually uneconomical to use filters if the required backwash volume exceeds 10 percent of the incoming flow. A better choice would be a chemical clarifier. A key to successful operation of filters is adequate backwash. There must be provisions to break up surface slime and caking.

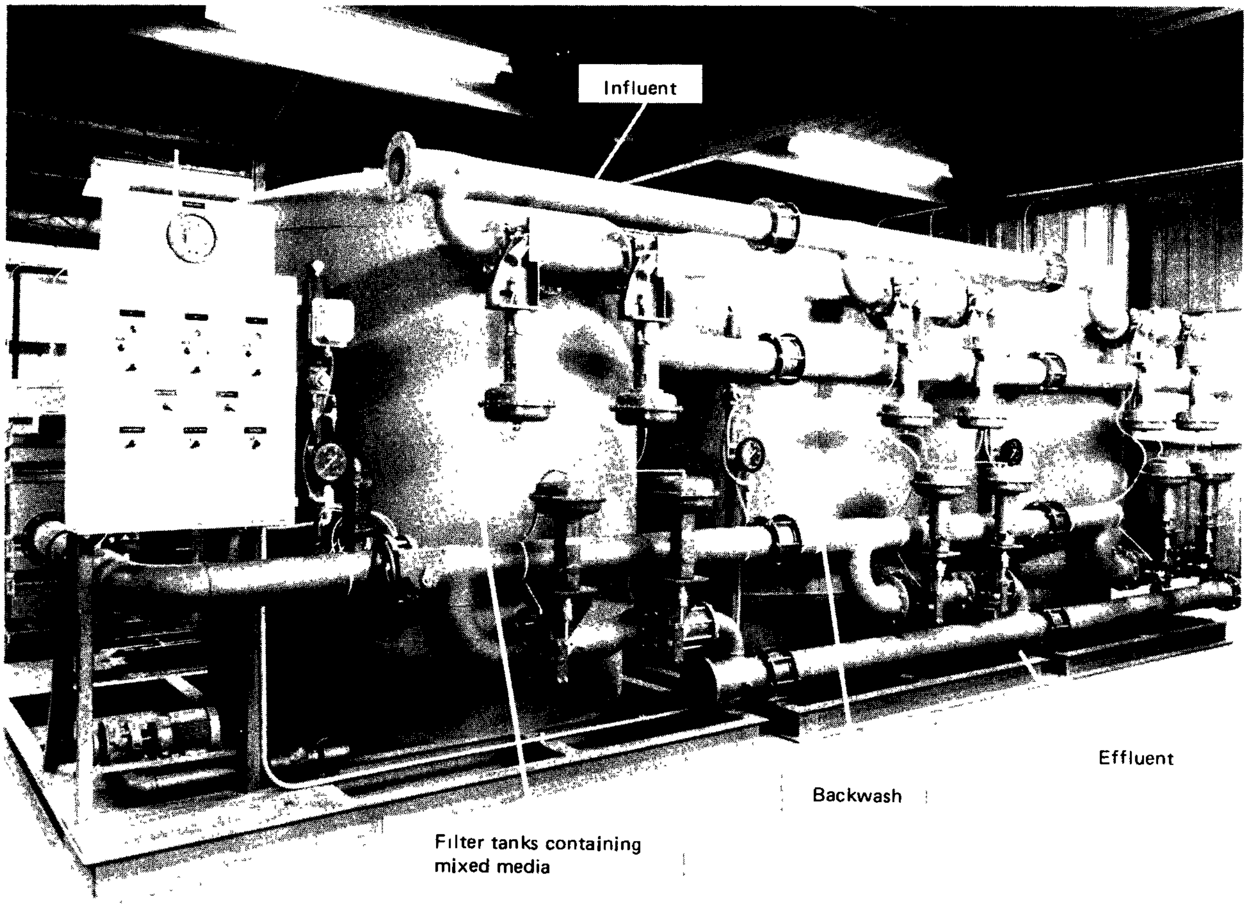


Figure III-13. Pressure filter. (Courtesy of Neptune Microfloc)

Table III-9 gives a cost estimate for mixed-media filtration of 1 mgd of secondary effluent. It is assumed that filtration is a workable option for additional removal of suspended solids, although this is not always the case. Secondary effluent suspended solids may be high enough to "blind off" filters after a short-run time (less than 6 hours). When this happens, filter backwash volumes become so large that the secondary plant capacity must be significantly increased to handle the backwash return flow.

In addition to those shown on table III-9, the following assumptions in the development of the estimates should be noted:

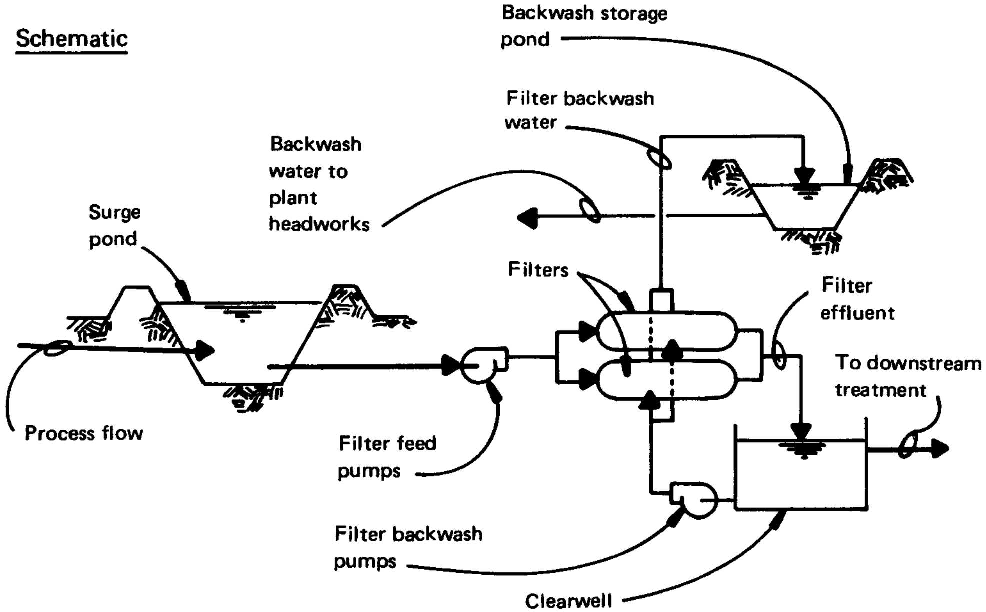
- 2 horizontal pressure filters
- Filter rate: 2.5 gpm/sf
- 150,000 gal lined earthen surge pond ahead of filters
- 60,000 gal concrete clearwell
- 60,000 gal backwash return surge pond
- Polymer dose: 1 mg/l.

Table III-9.—*Cost summary for filtration*

Criteria

- Flow: 1 mgd average, 2 mgd peak
- Season: 90 days
- Amortization: 10 years at 12%
- Engineering, legal and contingency costs included at 25% of construction cost
- October 1975 dollars

Schematic



Assumptions

- Two pressure filters with 2.5 gpm/ft^2 application rate
- 18 gpm/ft^2 backwash rate
- Lined earthen surge pond
- Concrete clearwell
- Labor 3 hrs/day at 7.00/hr
- Chemicals: 1 ppm poly at $2.25/lb.

Costs

Capital	Operation and maintenance	
$271,000	Labor	$2,000/yr
	Polymer	1,700/yr
	Miscellaneous	300/yr
	Total	$4,000/yr

Amortized capital plus O&M	$51,960/yr
Unit cost	57.7¢/1000 gal

CARBON ADSORPTION

Carbon adsorption removes refractory organic compounds like those causing taste and odor (tannins, lignins, and ethers). It also removes residual COD, BOD, insecticides, herbicides, and related components. However, few tests have been run with activated carbon treating fruit and vegetable processing wastewater.

Carbon adsorption can be accomplished either by granular or powdered activated carbon. Powdered carbon still has many problems, not the least of which is its recovery for reuse. However, the technology of granular activated carbon in columnar beds is well developed.

The influent to a granular carbon process must be low in BOD, COD, and suspended solids. The effluent from carbon adsorption can go to ion exchange, or reverse osmosis, and/or disinfection.

A design criterion is to use upflow expanded bed columns with a contact time of 20 minutes. The hydraulic rate should be between 6 to 7 gpm/sf and the granular carbon used should be an 8 x 30 mesh.

Carbon adsorption is the only method to remove refractory organics, with the exceptions of reverse osmosis, distillation, or freezing (but these are not competitive).

As a rule, activated carbon cannot be expected to remove reducing sugars from fruit and vegetable processing wastes. However, some organic acids can be removed.

If the influent contains high concentrations of BOD and COD, the column can become anaerobic and produce hydrogen sulfide. This is generally not a problem with filtered secondary effluent. The problem can be solved by frequent backwashing, chlorination, or the addition of sodium nitrate.

ION EXCHANGE

There are many applications of ion exchange, ranging from the selective removal of specific substances such as ammonia, phosphates, or nitrates, to the complete demineralization of water. Ion exchange to remove calcium and magnesium is currently practiced by many processors for boiler water treatment. The regenerant for these softeners is sodium chloride.

The simplified equations below show the action of a typical cationic ion exchange resin, during both use and regeneration. R indicates the resin.

Use: $R\text{Na}_2 + \text{Ca}^{++} \rightarrow R\text{Ca} + 2\text{Na}^+$

Regeneration: $R\text{Ca} + 2\text{NaCl} \rightarrow R\text{Na}_2 + \text{CaCl}_2$

Demineralization of wastewater requires both cationic and anionic resins to remove cations (like sodium) and anions (like phosphates), respectively. These can be mixed in a single bed, but more often, they are set up in a series of separate beds. Since 1965, pilot tests on ion exchange have been run in Pomona, California, where carbon column effluent is used as the feed water. The system contains four resin beds in series: two cationic and two anionic. The cationic resins are regenerated with sulfuric acid and the anionic with ammonia. Historically, removals have been as follows:

COD	63.0%
Total dissolved solids	86.7%

Thirteen percent of the volume treated becomes a waste brine.

Pilot work by Rohm and Haas, Inc., using their modified Desal ion exchange process on disinfected secondary effluent, gave the following removals:

COD	83.3%
TDS	approximately 90%

No full-scale, long-term installations of ion exchange for dissolved solids reduction have been operated on wastewater. Little work has been done on a pilot scale to test dissolved solids removal in food processing wastewater.

Three of the largest problems in the use of ion exchange are (1) in achieving efficient regeneration of the resin, (2) the disposal or recovery of the waste regenerant solution, and (3) the length of the resin life.

REVERSE OSMOSIS

The natural process of osmosis has been known since the middle of the eighteenth century, but it was not until the 1950's that experiments were conducted in reverse osmosis. If fresh and saline water are separated by a semipermeable membrane, the natural tendency is for the fresh water to migrate through the membrane into the saline water until the concentrations of the salts on both sides of the membrane are equal. The driving force to accomplish this appears as a pressure differential called osmotic pressure. In reverse osmosis, this osmotic pressure is overcome by pumping to reverse the process, which leaves the salts behind and makes fresh water from saline water.

The semipermeable membrane is now commercially made of a cellulose acetate. While reverse osmosis is applied in the reclamation of sea water and brackish water, its use on wastewaters has fouled the membrane. In theory, reverse osmosis has the capacity to remove more than 90 percent of inorganic ions, and most organic matter.

The most extensive experience in reverse osmosis has been gained from pilot plants in Pomona, California. These plants achieved the following removals from domestic activated sludge effluent:

COD	88.5%
TDS	92.1%

Twenty-five percent of the volume treated went to waste as brine, but this fraction can be reduced to 15 percent. The flux, or flow rate, through the membrane is about 10 gpd/sf. Pressure used was 750 psi.

Some low-molecular weight organic compounds like amines, alcohols, and acids are not removed by reverse osmosis. *Reverse osmosis has the greatest potential for technological improvement of any process for removing dissolved solids.* Currently, however, reverse osmosis is costly. Work is continuing to increase the flux and the product-to-waste ratio, and to develop methods of disposal of the highly concentrated brine.

CHLORINATION

Disinfection by chlorination is often practiced in domestic water and waste treatment. Disinfection is required because disease carrying organisms, or pathogens, are present in the water or waste. Chlorination is also used in the fruit and vegetable processing industries for odor and slime-growth control in flumes and process units.

As long as sanitary or domestic waste is kept separate from processing wastewater, there will be no need for final disinfection for pathogen removal, except where it is required to meet water quality standards. However, some fruit and vegetable processors are disinfecting the effluent from their secondary treatment plants.

If a local requirement is based on total coliforms then disinfection will be required. A cost estimate for chlorination of 1.0 mgd of secondary effluent is given in table III-10. The critical assumptions in the estimate are given in the table.

Chlorine also oxidizes BOD and some organic compounds. The additional chlorine demand of these compounds must be satisfied before adequate disinfection can occur. This has proved to be a major problem in stabilization pond effluent, where the algae exerts a high-chlorine demand.

OPERATION AND MAINTENANCE

Every treatment system requires regular care and attention, regardless of the skill of the designer and the nature of the treatment process. Adequate operation and maintenance are paramount in achieving the greatest possible efficiency from a treatment system. The person responsible for the operation must have a thorough understanding of the basic theory of waste treatment. A complete and current operation and maintenance manual is a must for any system. Monitoring and testing must be adequate to give the operator all needed data to determine system performance and to judge the need for changes in operation.

The staff responsible for operating treatment systems should receive special training. Training is available from the state and also from many community colleges. Membership in the Water Pollution Control Federation also offers valuable exposure to operating information through literature and local meetings.

Regulatory agencies increasingly recognize the need for proper operation and maintenance. A requirement in the future may be that every industrial treatment plant operator be certified by a state agency. Some states now require certification. In addition, laboratories performing tests to be submitted to regulatory agencies may also require state certification.

An aid to determining staffing requirements is the EPA's *Estimating Staffing for Municipal Wastewater Treatment Facilities.*[12] As stated in the title, this manual is oriented toward municipal treatment facilities. Frequently, in an industrial setting, fewer operating man hours are required, because the plant can be operated as one portion of the total processing plant. The industrial plant can usually share maintenance crews, cleanup crews, supplies, office and laboratory space, technical staff and other items.

Finding adequate qualified staff can be particularly difficult in the seasonal fruit and vegetable processing industry. Two options to staffing your own plant are:

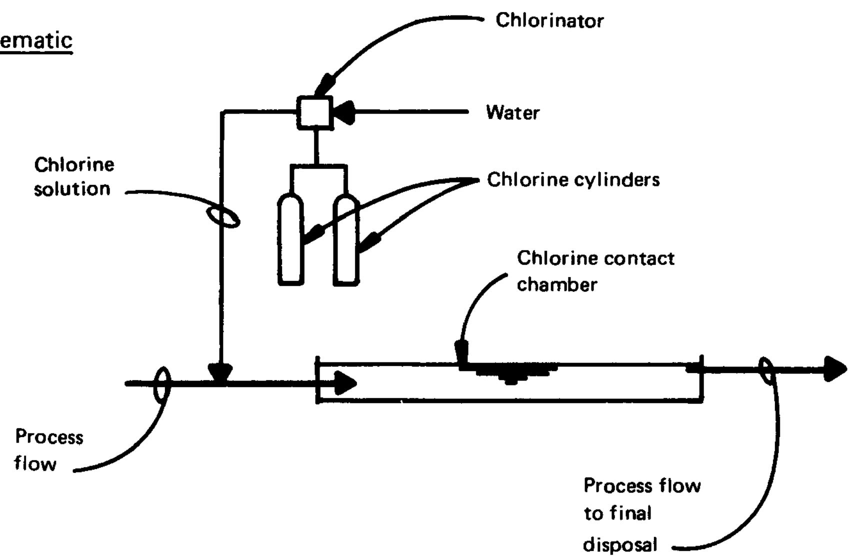
- Use an outside consultant with operating staff.
- Contract the local public agency for operation of your treatment facility.

Table III-10.—*Cost summary chlorination system*

Criteria

- Flow: 1 mgd average; 2 mgd peak
- Season: 90 days
- Amortization: 10 years at 12%
- Engineering, legal and contingency costs included at 25% of construction cost
- October 1975 dollars

Schematic



Assumptions

- Concrete chlorine contact chamber with 1 hour detention time at average flow
- Chlorine dosage at 10 mg/l
- Chlorine cost at 27.5 cents/pound
- Small chlorination building included
- Labor at $7.00/hr 1 hr/day

Costs

Capital	Operation and maintenance	
$38,000	Labor	$ 600/yr
	Chlorine	2,200/yr
	Total	$2,800/yr

Amortized capital plus O/M	$9,530/yr
Unit cost	10.6¢/1000gal

Chapter IV
LAND TREATMENT AND DISPOSAL

INTRODUCTION

Land disposal or treatment is the application of wastewater onto land by a conventional irrigation procedure. Treatment is provided by natural processes (chemical, physical and biological) as the effluent moves through the "filter" provided by the cover crop and soil mantle. Part of the water is lost to the atmosphere through evapotranspiration, part to surface water by overland flow, and the remainder percolates to the ground water system. The method of application, the site, and the loading rate determine the percentage of flow to each destination.

Land treatment is deceptively simple. Although there are successful systems, there are many which have, and will fail as a result of, misapplications and increasing restrictions on groundwater quality, surface runoff, air quality, and other environmental factors.

System failures do not usually occur in the first few years. Failure is more likely to occur after five years or more. The common symptoms and causes of failure are:

Symptom	Cause
Runoff resulting from decreased soil permeability	Solids build-up on or in soil. Physical and chemical changes in soil.
Runoff resulting from organic overload	Slime layer forms on surface of ground. Root zone becomes anaerobic.
Increase in ground water nitrate	Accumulation of nitrogen in soil and percolation to ground water.
Decreases in cover crop quality	Nutrient imbalance.
Mounding of water under the site resulting in cover crop loss	Horizontal movement of water in soil not adequate to keep ground water below root zone.
Salt build-up in soil resulting in in crop loss	Salts from waste flow concentrated in soil as result of evaporation and transpiration.

These problems can be avoided or corrected with good engineering and system management.

PROCESSES

Land treatment is done in several ways (see figure IV-1). For discussion, these have been divided into four processes: overland flow, irrigation, high-rate irrigation, and infiltration-percolation (see table IV-1). Most fruit and vegetable processors use some kind of high-rate irrigation by spray nozzles.

The objectives and characteristics of each of the four processes are distinctly different. The most suitable process depends on the characteristics of the site, the type of waste to be applied, and environmental regulations. Overland flow is especially suited to the treatment of wastewaters high in BOD and suspended solids, such as from tomato processing. Removal efficiencies greater than 90 percent have been reported for processing plants using overland flow.

The infiltration-percolation process is least suited to treatment and disposal of high BOD and suspended solids wastes because most of the wastewater, with its pollutants, may enter the ground water untreated.

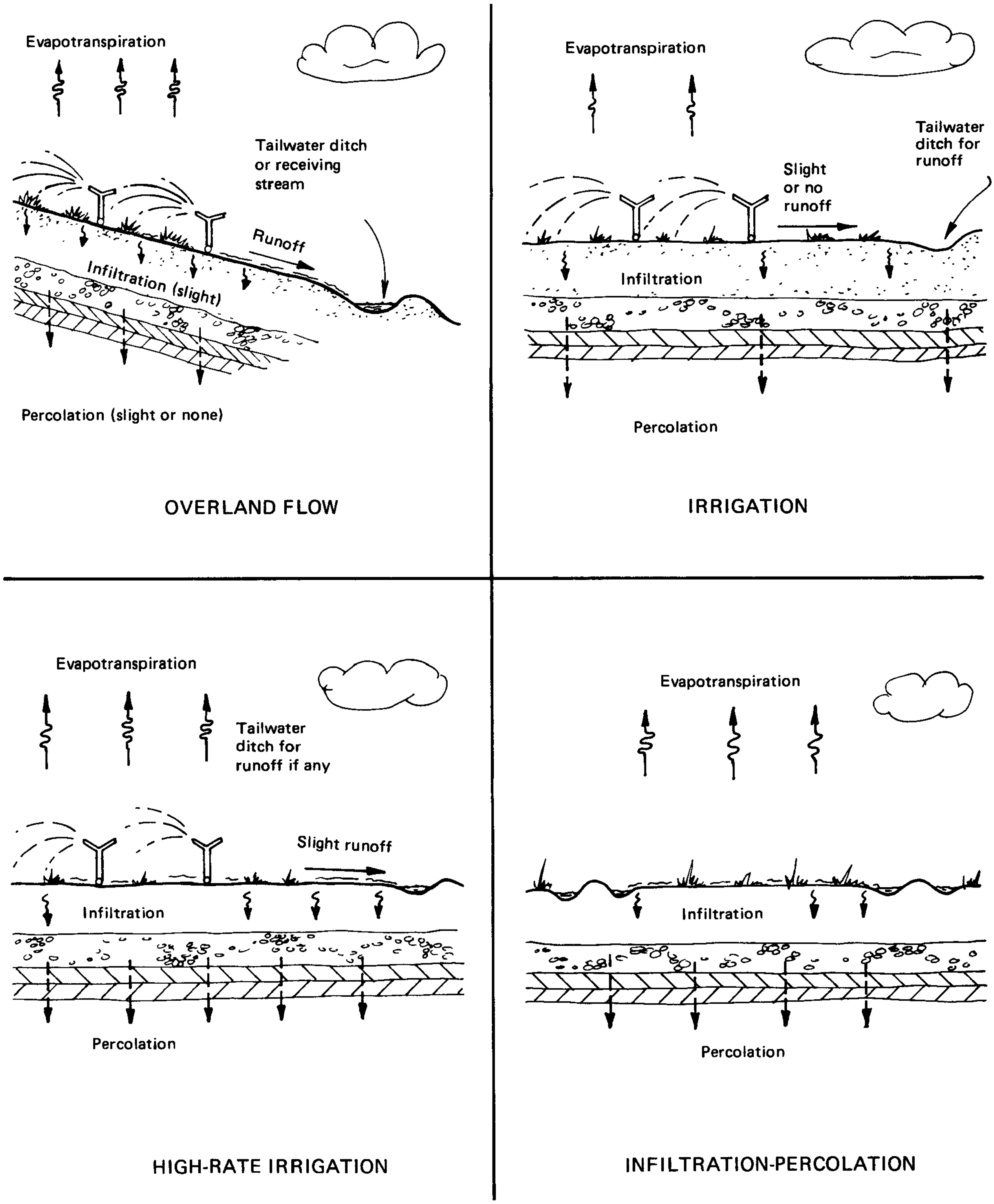


Fig. IV-1. Land treatment processes

Table IV-1.—*Land treatment and disposal processes*

Process	Objective	Suitable soils	Typical annual application	Dispersal of applied water	Impact on quality of applied waste
Overland flow	Maximize waste treatment. Crop is incidental. Allow runoff.	Low permeability and/or high-water table.	60–300″	Most to surface runoff. Some to evapotranspiration and ground water.	BOD and SS greatly reduced. Nutrients reduced by fixation and crop growth. TDS increased in runoff.
Irrigation	Maximize agricultural production.	Suitable for irrigated agriculture.	12–60″	Most to evapotranspiration. Some to ground water; little or no runoff.	BOD and SS removed. Most nutrients consumed in crop or fixed. TDS greatly increased in percolated water.
High-rate irrigation	Maximize waste treatment by evapotranspiration and percolation without runoff crop production a side benefit.	More permeable soils suitable for irrigated agriculture; may use marginal soils if coarse texture.	24–120″	Evapotranspiration and ground water; little or no runoff.	BOD and SS mostly removed. Nutrients reduced. TDS substantially increased in percolated water.
Infiltration-percolation	Recharge ground water or filter water; crop may be grown with little or no benefit.	Highly permeable sands and gravels.	240–6000″	To ground water some evapotranspiration; no runoff.	BOD and SS reduced. Little change in TDS of percolated water.

Some nutrients are used by crops in overland flow, but most will be carried away in the runoff water. Most of the nutrients are carried into the ground water or subsurface drainage system in the infiltration-percolation process. Few, if any, plants are grown on the site for nutrient uptake.

The irrigation process is most effective for removing the nutrients in wastewater. The application rate is limited so the nutrient loading does not exceed the crop nutrient requirement. The nutrients are removed from the site by crop harvest.

PRETREATMENT REQUIREMENTS

Some pretreatment of wastewater is necessary before land application. The waste is usually screened to avoid plugging the distribution system. Screens (10 to 20 mesh) are necessary to prevent clogging of the sprinkler nozzle. Silt and other suspended particles that may hinder operation of the distribution and application system should be removed. The pH of the wastewater must be controlled for application on land because pH outside the range of 6.4 to 8.4 may render some nutrients inaccessible to plants.

Design modification may be needed to remove oil and grease, avoid soil sealing, remove specific ions (such as sodium) and avoid loss of infiltration capacity or poisoning of plants.

APPLICATION METHODS

Three methods are commonly used for application of wastewater: (1) sprinkler irrigation, (2) surface irrigation, and (3) drip (or trickle) irrigation. In sprinkler irrigation, water is sprinkled onto the land to simulate rainfall (figure IV-2). Sprinkler and surface irrigation are most commonly used for wastewater application. Water is distributed in furrows or small channels, or by flooding in surface irrigation. With drip irrigation, water is applied through small holes (emitters), spaced along the supply line. Drip irrigation is impractical for use with fruit and vegetable process wastewater because suspended material can clog the holes.

Figure IV-2. Spray irrigation system. (Courtesy of CH_2M HILL)

The selection of an irrigation method depends on soil characteristics, crop, operation, maintenance, topography, costs, water supply, weather, and need for control of runoff. Each method has distinct advantages.

Distribution of water by sprinkler irrigation is controlled by the selection and design of the equipment used. Surface irrigation depends on soil permeability and soil uniformity for an even distribution of wastewater. If soil conditions are suitable, surface irrigation normally offers economic advantages in power and hardware requirements. Both sprinkler and surface methods have been used in freezing conditions.

SYSTEM SELECTION

The various processes and application methods are not necessarily interchangeable. The process selected will depend on the specific waste, site, and discharge limits. Some waste characteristics influencing the selection are solids, BOD, nutrients, salts, and pH.

Location

Site characteristics that will influence selection are as follows:

- Soil and topography must be suitable for the disposal process (overland flow, sprinkling, ponding).
- Areas with continual winds (greater than 10 mph) cannot be used without great allowances for sprinkler droplet drift.
- Slopes must not exceed 15 percent.
- The site must not have shallow ground-water depths (less than 4 to 5 feet)
- The site should be a short distance from the processing plant, and it must be easily accessible.
- The site should allow for buffer zones, sight screens, roads, etc.
- The site preparation requirements must not be prohibitive.
- The site must be properly zoned.
- The site should be situated to allow for expansion.

Discharge limits that will influence selection are as follows:

- Permissible nitrate in ground water
- Limits on runoff
- Limits on constituents in applied waste or harvested crop.

Loadings

The amount of liquid that can be applied depends upon the infiltration and percolation capacity of the soil. Quality discharge limits placed on deep percolation to ground water or return flow to surface streams may require a limited loading rate or extensive pretreatment. A soil-crop system has a finite capacity for removal of various pollutants. If this capacity is exceeded, the system will eventually fail, odor will develop, and pollution of ground water or a nearby stream can result.

The various constraints on loading may be classified as hydraulic, treatment, and chemical as follows:

Hydraulic constraints:

- Infiltration capacity of the soil
- Permeability of the root zone
- Permeability of the underlying soil

Treatment constraints:

- Capacity of the soil to remove and oxidize BOD
- Capacity of the soil to filter and assimilate suspended solids

Chemical constraints:

- Capacity of the soil to remove major plant nutrients (nitrogen, phosphorus and potassium)
- Sensitivity of the soil to other wastewater characteristics such as salt content, sodium-adsorption ratio, and pH.

Hydraulic Constraints

The infiltration capacity of a soil is the rate at which water can be applied without runoff. Previous erosion or lack of a dense vegetative cover will reduce infiltration capacity and require a reduction in application rates. The infiltration capacity of the soil will influence the choice of irrigation methods. Infiltration rates limit the instantaneous (daily or hourly) rate of application, but rarely will it limit the total seasonal application.

Permeability of the soil determines the allowable percolation rate. It will establish the total effluent and precipitation that can be applied. In a year with high rainfall, the amount of effluent which can be applied must be reduced.

Three to five feet of aerated soil are required in the root zone to provide sufficient treatment of the applied effluent. If the permeability of the site is not adequate for the amount of waste applied, the ground water will rise into a root zone and drown the cover crop, causing treatment failure.

If no runoff is allowed, the maximum hydraulic loading is the sum of the soil moisture depleted by evapotranspiration, plus the quantity of waste that can be transmitted through the root zone. Maximum hydraulic loadings, less evapotranspiration under ideal conditions for different soils, are given in table IV-2. Daily loadings should not exceed the rates given in the first column in inches per day. The average loading throughout the season should not exceed the rates given in the right-hand column. One inch is approximately equal to 27,000 gallons per acre.

Table IV-2. *Estimated maximum hydraulic loading of wastewater effluent for various soil textures (ideal conditions)*

Soil root zone	Movement through the soil root zone[a]	
	Infiltration rate inches/day[b]	Percolation rate inches/year[c]
Fine sandy	15.0	300
Sandy loam	7.5	180
Silt loam	3.5	90
Clay loam	1.5	40
Clay	0.5	10

[a] Does not include evapotranspiration

[b] Rate not to be exceeded on any one day. Reduce if site is sloped

[c] Rate not to be exceeded in a growing season (or year)

To avoid runoff, or ponding on the surface, the instantaneous sprinkler-application rate should not exceed the infiltration rate (measured in inches per hour). The following are typical infiltration rates for these soil types:

- Fine sand — 1.0 + inches/hour
- Sandy loam — 0.5 – 1.0
- Silt loam — 0.3 – 0.7
- Clay loam — 0.2 – 0.4
- Clay — 0.1 – 0.2

The allowable loading rate for infiltration-ground-water recharge depends on the soil and surface geology. Recharging a water-bearing aquifer also depends on the permeability of the aquifer itself.

Treatment Constraints

BOD is associated with both suspended solids and dissolved organic material. The BOD associated with suspended solids will remain close to the surface where the soil organisms have access to atmospheric oxygen to break the material down. The BOD in the dissolved organic material will percolate through the unsaturated zone of the soil and, under aerobic conditions, be removed during percolation. If the loading is too great, the soil will become anaerobic, and the crop and treatment process will fail. Table IV-3 lists typical BOD loading rates of various soil conditions for processes that rely on an aerobic root zone for BOD removal. Experience indicates that higher loadings are possible if the site is irrigated for only a few weeks each year and is well maintained.

Clogging of soil is most often due to incomplete biological breakdown of organics in an anaerobic environment. Aerobic conditions can be maintained by intermittent application of the allowable amount of waste. A day of application followed by several days of rest is typical.

Table IV-3.—*BOD loading rates*

Process	Lbs/acre/hr	Average summer summer season lbs/acre/day
Irrigation and high-rate irrigation		
Fallow soil with no fresh organics	1–2	36
Fallow soil following addition of organic residues	2–4	72
Soil with growing plants	3–6	108
Estimated recommended maximum BOD load to be added on well aerated soil [13]	–	100
Overland flow	–	40–100
Infiltration/percolation	–	600

If the soil becomes sealed with inert suspended solids, such as silt, it can usually be opened by harrowing or disking. The amount of silt which can be accepted without a loss of permeability can be estimated from an analysis of the soil and the inert solids.

Suspended solids of up to 200 lbs/acre/day[14] have been applied. However, a loading limit of about 70 pounds per acre per day is more typical.

Chemical Constraints

Typically, the total nitrogen found in fruit and vegetable wastewaters is mostly organic nitrogen. All of this nitrogen is not immediately available for plant use. The "mineralization rate" of organic nitrogen to nitrate is such that 20 to 30% of it becomes available for plant use in the first year, 5% in the second, 2% in the third, and so on. These figures were developed from domestic sewage sludge (primary and secondary), but recent information indicates that up to 40 per cent of the nitrogen in fruit and vegetable processing waste will mineralize in the first year.[13]

Nitrate is the only form of nitrogen used by crops. Removing the grown crops is a major method of removing nitrate from the soil.

Irrigation systems that allow no runoff or percolation to the ground water should have an applied rate of total nitrogen controlled to match the nitrogen removed in the crop. The nitrogen removed is 100 to 300 pounds per acre per year, depending on the extent of irrigation, climate, crop, soil, temperature, etc., plus the amount lost through nitrification-denitrification.

If nitrogen application is not controlled, the excess nitrogen (beyond that removed by the crop, nitrified-denitrified) will enter the ground water or receiving stream as nitrate. The nitrification-denitrification mechanism will only work if an anaerobic soil layer is present below the aerobic surface layers (a condition which is not controllable).

Caustic peeling processes used for commodities such as potatoes and peaches may result in high sodium wastes. If the sodium content is high compared to the calcium and magnesium content, it will be absorbed by the soil and replace the calcium and magnesium salts present. As the exchangeable sodium increases, the soil becomes more alkaline, and adverse growing conditions will occur. These can reduce permeability in some clay bearing soils. The potential effect of sodium on the soil is measured by the sodium-adsorption ratio, SAR, of the waste.

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

where Na, Ca, and Mg, are measured in equivalents per liter.

Generally, the SAR must not exceed 6.0 to 9.0, depending on the soil. Gypsum ($CaSO_4$) can sometimes be applied to the soil to increase the amount of sodium that can be applied. If the SAR of the waste is high, additional soil analysis will be necessary to determine if the waste can be applied directly, or if the sodium should be eliminated from the wastewater.

Some wastewater may contain certain constituents that retard plant growth or present potential health hazards. Table IV-4 lists recommended concentration limits of these constituents for continuous irrigation on all soils. These limits are for non-sandy, non-acidic soils.

Table IV-4.—*Recommended maximum limits of inorganic constituents for irrigation water*[15]

Inorganic constituents	Recommended limit for irrigation on all soils
Aluminum, mg/l	5.0
Arsenic, mg/l	0.10
Beryllium, mg/l	0.10
Boron, mg/l	0.50
Cadmium, mg/l	0.01
Chloride, mg/l	70.0
Chromium, mg/l	0.10
Cobalt, mg/l	0.05
Copper, mg/l	0.20
Fluoride, mg/l	1.0
Iron, mg/l	5.0
Lead, mg/l	5.0
Lithium, mg/l	2.5
Manganese, mg/l	0.20
Molybdenum, mg/l	0.01
Nickel, mg/l	0.20
Selenium, mg/l	0.02
Vanadium, mg/l	0.10
Zinc, mg/l	2.0
Sodium-adsorption ratio	6.0 - 9.0
pH	6.4 - 8.4

OPERATION AND MANAGEMENT

The major tasks involved in operating a land treatment system include: (1) maintaining the proper application rate and frequency, (2) managing the soil and cover crop, and (3) monitoring the performance of the system. Scheduling wastewater applications will depend on the weather. During wet months, the amount that can be applied will depend on daily precipitation. Applications will also have to be coordinated with harvest. For the most efficient operation of the system during wet months, irrigation should be scheduled on a daily basis to incorporate the daily measurement of precipitation and not exceed the application criteria. Thus, a storage pond is often required to hold the wastewater during times when it cannot be disposed. This pond must be adequately aerated to prevent odors.

Experience with potato wastewaters has shown that spray irrigation facilities can be operated during winter months when the field ices. Ice accumulates during the winter and melts in the spring. The thaw is usually gradual enough that BOD loading rates are not greatly exceeded and odors do not occur. If the thaw is too fast, ground water pollution and odor can result.[10]

Proper soil management is required to maintain the infiltration rate and prevent erosion. To accomplish this, a healthy cover crop should be established and general soil conservation practiced.

Grasses and other crops keep the infiltration rate high by preventing droplets from sprinkler irrigation from puddling and sealing the surface. A good cover crop is also necessary to remove nutrients from the soil treatment system. The crops must be periodically harvested and removed from the site. Monitoring the wastewater characteristics, soil, crop, ground water and runoff are very important for successful operation of a land treatment system. Monitoring also gives advance warning of developing problems. Failure in any part of the system, in wastewater quality, soil infiltration, crop growth, or ground water drainage can eventually cause failure of the whole treatment and disposal system.

COSTS OF ALTERNATIVE APPLICATION METHODS

Costs for different land wastewater treatment systems are compared in table IV-5. This table is an update of table 28 in the EPA's *Wastewater Treatment and Re-Use by Land Application*.[16] In that EPA report, several assumptions were made which are not consistent with those made for the cost summaries in this report. Thus, the costs in table IV-5 are only useful in illustrating the comparative costs of the three land treatment systems. They should not be compared with the other cost estimates in this report.

Table IV-5.—*Comparison of capital and operating costs for 1-mgd systems*[16,a]

	Spray irrigation	Overland flow	Infiltration-percolation
Liquid loading rate, in/wk	2.5	4.0	60.0
Land use, acres	103	64	––
Land required, acres[b]	124	77	5
Capital costs			
Earthwork	$ 12,700	$ 79,100	$ 12,400
Pumping station	61,800	61,800	––
Transmission	163,200	163,200	163,200
Distribution	178,000	79,000	6,200
Collection	––	7,400	37,100
Total capital cost	$415,700	$390,600	$218,900
(excluding land)	$ 3,352/acre	$ 5,072/acre	$ 43,780/acre
Amortized cost[c]	$ 73,600	$ 69,100	$ 38,700
Annual operating cost			
Labor	$ 12,400	$ 12,400	$ 9,300
Maintenance	24,000	14,800	4,300
Power	7,200	7,200	2,200
Total operating cost	$ 43,600	$ 34,400	$ 15,800
Total equivalent annual cost	$117,200	$103,500	$ 54,500
Total cost, ¢/1,000 gal.[d]	$ 130.2	$ 115.0	$ 60.6

[a]Updated estimate for October 1975 dollars, ENR index 2300, from 1973 ENR of 1860.

[b]20% additional land purchased for buffer zones and additional capacity.

[c]12%, 10 year life.

[d]90-day season assumed; hence annual flow is 90 million gallons.

Chapter V

SOLIDS DISPOSAL

SOURCES AND NATURE OF SOLIDS

Because of the nature of fruits and vegetables, a great many solids are generated during processing. These solids, or residuals, may exceed the mass of solids generated by treatment of the effluent.

The handling and disposal of in-plant and waste treatment solids or sludges varies not only with the characteristic of each, but also with the governmental classification of the solids. Currently, transportation and final disposal of waste solids from treatment plants are more closely regulated than waste solids from fruit and vegetable processing.

IN-PLANT SOLIDS (RESIDUALS)

Only about 20 to 30 percent of many vegetables are finally used for human consumption. Some of this residue is left in the field during harvest, but a large portion is generated in processing. Table V-1 lists estimates, developed in 1971, of the percentages of raw products that show up as solid waste, or residuals, in fruit and vegetable processing. The table also shows the amount of total solid waste that is used as a by-product and the amount that is finally handled and disposed of as a waste. By-product utilization is primarily for animal feed. None of the waste is reprocessed and used for human consumption.

The use of residuals in livestock feed is not possible for most fruit and vegetable processors. Most of the residuals used for feed come from citrus, corn, pineapple and potato processors. These four alone produce about 75 percent of the nation's waste used for animal feed.

It is worth noting why the processors of these four items can use these residuals in livestock operations:

1. The residuals are generated over a long season (up to a year). The exception is corn, but corn can be stored for later use. Most other commodities are processed over a very short season, and the waste cannot be stored for any reasonable length of time without decomposing.

2. The products are processed in cattle raising areas.

3. With the exception of potatoes, all the wastes from these four commodities are produced dry. Potato screenings and primary clarifier sludge are used as cattle feed in some areas.

In the Salinas Valley of California, trimmings from local vegetables are used as cattle feed. Such items as asparagus, broccoli, lettuce, and artichoke trimmings and process screenings are used. However, most food processors must resort to some type of land disposal for their residuals.

Table V-1.—*Percentage of solid waste produced in fruit and vegetable processing*[17]

Product	Percent total waste produced	Percent utilized as by-product	Percent handled as solid waste
Apples	28	19	9
Beans, green	21	10	11
Beets, carrots	41	21	20
Citrus	39	38	1
Corn	66	62	4
Olives	14	12	2
Peaches	27	9	18
Pears	29	9	20
Peas	12	8	4
Potatoes (white)	33	29	4
Tomatoes	8	2	6
Vegetables (misc.)	22	9	13

NOTE - These are average percentages of total incoming raw products.

TREATMENT PLANT

Depending on the processes used and the extent of treatment, solids generated in waste treatment can be quite significant. Table V-2 lists the types of treatment and the characteristics of the general types of solids produced. Two main categories are screenings and sludges. Sludges are generated in primary, secondary, and, to a minor extent, tertiary treatment processes.

Table V-2.—*Treatment plant solids characteristics for fruit and vegetable wastewaters.*

Type of treatment	Sludge characteristic
Primary	Percent solids: 1 - 5%. A higher percentage of silt in the sludge can raise the percentage of solids to 20 - 40%.
Biological sludge	0.5 - 1% solids from the clarifier underflow.
Pure-oxygen activated sludge	1 - 2% solids.
Lime clarifier sludge (Tertiary)	7% solids.

Screenings

The amount of screenings varies according to the nature of the waste and screen mesh size. Screenings are wet and will drain if allowed to stand. Draining the water does not reduce the volume of screenings to be hauled away, but makes them easier to handle and more acceptable by landfill sites.

Primary Treatment Sludge

Primary treatment wastes are in the forms of sludge from the bottom of the clarifier, scum from the top of the clarifier, and float from the top of dissolved-air flotation units.

Dissolved-air flotation float commonly has a total solids concentration of about four to six percent, and is not difficult to pump. Sludge from the bottom of clarifiers can be very difficult to pump, depending on the product being run. For example, field dirt from tomatoes and potatoes can be thickened to about 40 percent solids, which can then be pumped with only positive displacement pumps. This same mud will only settle and concentrate to about 20 percent solids in a tank or pond without a thickening rake. An organic sludge from a primary clarifier will probably not exceed a concentration of three to five percent solids.

The actual mass (pounds per day) of sludge or float from primary treatment will be a function of the raw product. The volume (gallons per day) will be a function of both the product run and the primary treatment process used.

Secondary Treatment Sludge

The masses of sludges from the secondary treatment processes are a result of the process used, the BOD load, and the inert suspended solids load. The biological processes used in secondary treatment all produce sludge. In biological treatment, dissolved BOD is transformed into microorganism cellular matter, which then settles in the final or secondary clarifier. The largest sludge producing processes are the high-rate processes described in Chapter III. Of these, the activated sludge process produces the most sludge. Stabilization ponds and aerated ponds accumulate sludge on the bottom of the ponds.

An activated sludge plant, operating at a high rate (or low sludge age) will produce 0.5 to 1.0 pounds of microorganisms for each pound of BOD treated. In addition to the production of up to 0.5 pounds of microorganisms per pound of BOD removed, added sludge results from the non-biodegradable suspended solids, both volatile and nonvolatile, in the influent to secondary treatment. Consequently, it is not uncommon for the total secondary sludge production to be 0.8 to 1.0 pounds per pound of BOD removed. Sludge from secondary treatment systems is still biologically active and will putrefy. This can cause an intolerable odor. If the sludge contains no domestic wastes, it may be possible to spread and dry the sludge quickly on a disposal site or agricultural land, and then plow it into the soil.

Secondary sludge is difficult to dewater. Raw, undigested secondary sludge has a total solids content of only one-half to one percent. In addition, the cellular matter in the sludge is only fifteen percent solids.[6] Unless the cell membranes are ruptured, microorganisms cannot be dewatered to greater than ten percent solids. Cells can be ruptured by heating or slow freezing although natural freezing can be used in some climates. Commercially available heat treatment systems which have been used for municipal waste activated sludge are costly and have not been used in the fruit and vegetable processing industry.

Tertiary Treatment Sludges and Concentrates

With the exception of chemical clarification, none of the tertiary treatment processes discussed earlier generates a solid waste. Reverse osmosis and ion exchange produce a waste brine or concentrate, which is probably best handled by evaporation and disposal in a landfill. Spent carbon in columns, if not regenerated, becomes a solid waste that is usually acceptable for disposal in a sanitary landfill. Backwash water from filters is usually stored and pumped at a constant rate back to the treatment plant headworks.

Sludge from tertiary chemical clarifiers varies in handling ability according to the coagulants used in the treatment process. Lime sludge is quite dense (about seven percent solids) and can be dewatered rather well with vacuum filters or centrifuges. Lime sludge lines should be oversized to allow for scaling in the lines and cleaning. Alum sludge, however, is quite light, gelatinous, and difficult to dewater. Ferric chloride sludges are usually not difficult to dewater, but they are messy. Vacuum filters are usually used on ferric sludges. Unless a secondary plant is upset, tertiary chemical clarifier sludge will contain few organics and does not require further stabilizing the sludge to prevent putrefaction.

SLUDGE HANDLING

Table V-3 lists the available options most commonly used in handling waste treatment sludges. Treatment and disposal of waste treatment solids require a substantial portion of the cost of treatment (tables III-6 and III-7).

DIGESTION

There are two types of biological sludge digestion processes: anaerobic and aerobic. Anaerobic digestion has been practiced for many years at municipal treatment plants across the country. Anaerobic systems are prone to upset and must be heated to 90°F for good operation. The tanks must be covered to collect the generated gas, which usually contains about 65 percent methane and can be used as a fuel.

A well-operating anaerobic digester will destroy about 50 to 60 percent of the volatile, or organic fraction, in the sludge. It operates well on domestic primary sludge alone, although few process sludges have been digested alone. The required retention time of sludge in a digester is 20 to 80 days when maintained at 90°F.

Aerobic digestion is more practical than anaerobic digestion for seasonally operated plants treating only food processing waste. Aerobic digestion allows the metabolic processes of the microorganisms used in treatment to continue, but in the absence of food (BOD). The organisms continue metabolizing at decreasing rates (termed "endogenous respiration") in the digester. Aerobic digestion will reduce the organic content of sludge up to 40 percent. Detention time of the sludge in aerobic digestion is 10 to 20 days. Enough air is supplied in the open digester, either by diffusion or mechanical means, to satisfy the oxygen requirements of the organisms.

Regardless of the method of digestion chosen, the digester must be kept operating after the end of the processing season to stabilize the remaining sludge.

Table V-3.—Solids handling options

Digestion	Thickening	Dewatering	Disposal
Anaerobic	Gravity	Vacuum filter	Sanitary landfill
Aerobic	Dissolved air flotation	Centrifuge	Disposal on soil
	Centrifuge	Pressure filter	Animal feeding[a]
		Dewatering belts	Composting
		Drying beds	

[a]Use of waste activated sludge for animal feeding operation is not approved by the U.S. Food and Drug Administration.

THICKENING AND DEWATERING

Thickening is used to reduce the volume of sludge to enable the use of a smaller dewatering device or to control sludge solids concentration for optimal operation of the dewatering devices.

Three units are commonly used for thickening sludge: gravity thickeners, flotation thickeners, and centrifuges. Flotation thickeners are the same as air-flotation clarifiers, but operated at higher solids loading rates. Gravity thickeners look like ordinary clarifiers, except the clarifier rake is rotated faster to convey and agitate the sludge blanket. Representative design criteria for thickeners are given in table V-4.

Dewatering lowers water content of sludges to facilitate disposal, whether by landfill or by incineration. Before sludge can be hauled in open trucks, it should be dewatered so that it does not flow. Several kinds of dewatering units are available. The most common are vacuum filters and centrifuges; however, filter presses and capillary action devices may also be used.

Vacuum Filters

A common type of vacuum filter is shown in figure V-1. The sludge is pumped into a vat or pan at the base of the filter. The sludge level is usually high enough to submerge the filter drum to about 30 to 40 percent of the diameter of the drum. A vacuum applied to the drum (about 10 to 20 inches of mercury) picks up the sludge and forms a cake during the time the drum is submerged. As the drum rotates out of the sludge, air is pulled through the sludge cake, drying it so it falls or can be scraped from filter cloth. The yield, or rate of sludge dewatering by this method, is about one to ten pounds of dry sludge per hour for each square foot of filter drum area.

Many sludges must be conditioned with chemicals before they can be filtered. The addition of chemicals will usually increase the filter yield. A key to good filter operation is the solids concentration in the filter feed.

Vacuum filters have a high capital cost and are difficult to operate. Sometimes they require a full-time operator.

Centrifuges

Three types of centrifuges are now commercially available. The solid bowl centrifuge (figure V-2) is more suitable for the dewatering of inorganic sludges. Disc nozzle (figure V-3) and basket centrifuges (figure V-4) work better on organic sludges, but the disc nozzle type tends to clog at high concentrations of sludge, or when proper sludge pretreatment (grit removal, screening) is not provided. Several basket centrifuges installations are now operating on secondary sludge.

Other Methods

Filter presses or pressure filters work well on some sludges. They are, however, quite expensive and can be difficult to operate and maintain.

About three different units on the market use a combination gravity and capillary action to dewater sludge. These units rely on a porous cloth to suck water from the sludge as it is squeezed between rollers. These units are easy to operate but have a low capacity. They cannot be universally applied to different sludges, and appear to work best on waste activated sludges from domestic treatment plants.

Table V-4.—*Design criteria for solids handling devices for fruit and vegetable wastewaters*

Digestion	
Anaerobic	
Retention time	20 - 30 days, depending on whether the digester is heated
Ideal temperature	90 - 100°F
Volatile solids reduction	50 - 60%
Methane production	8 - 12 cf/lb volatile solids destroyed
Solids loading	Standard Rate: 0.03 - 0.10 lb volatile solids/cf/day High rate: 0.1 - 0.4 lb volatile solids/cf/day
Aerobic	
Retention time	10 - 20 days, depending on the sludge age of the activated sludge system and the ambient temperature
Solids loading	0.1 - 2.0 lb volatile solids/cf/day
Oxygen requirement	1.5 - 20 lbs/lb of volatile solids destroyed
Volatile solids reduction	Up to 40%
Thickening	
Gravity	
Solids loading	4 - 15 lbs solids/sf/day, depending on the concentration of the incoming sludge
Overflow rates	400 - 900 gpd/sf
Dissolved-air flotation	
Solids loading	1.5 - 2 lbs/sf/hour
Overflow rates	1,400 - 5,000 gpd/sf
Unox sludge	3 lbs/sf/hour
Air-to-solids ratio	0.01 - 0.1 lb/lb
Recycle rate	50 - 800%
Pressure	60 - 70 psi
Dewatering	
Vacuum filters	
Common yields	1 - 4 lbs of dry solids/hour per sq ft of drum area for organic primary sludge 8 - 10 lbs/hr/sf for properly conditioned silt and clay
Cake total solids content	11 - 13% for primary sludge 20 - 70% for silt or clay. Not applicable for biological sludges
Solids capture	85 - 95%
Centrifuges	
Cake total solids content	For primary sludges 4 - 25%, depending on the use of chemicals and type of centrifuge. For waste activated sludge Solid bowl type: 6 - 10%, w/poly Disk nozzle type: 4 - 5%, w/o poly Basket type: 7 - 10%, w/o poly; 9-12%, w/poly
Solids capture	60 - 70% without chemicals Up to 95% with chemicals
Common capacities	10 - 300 gpm

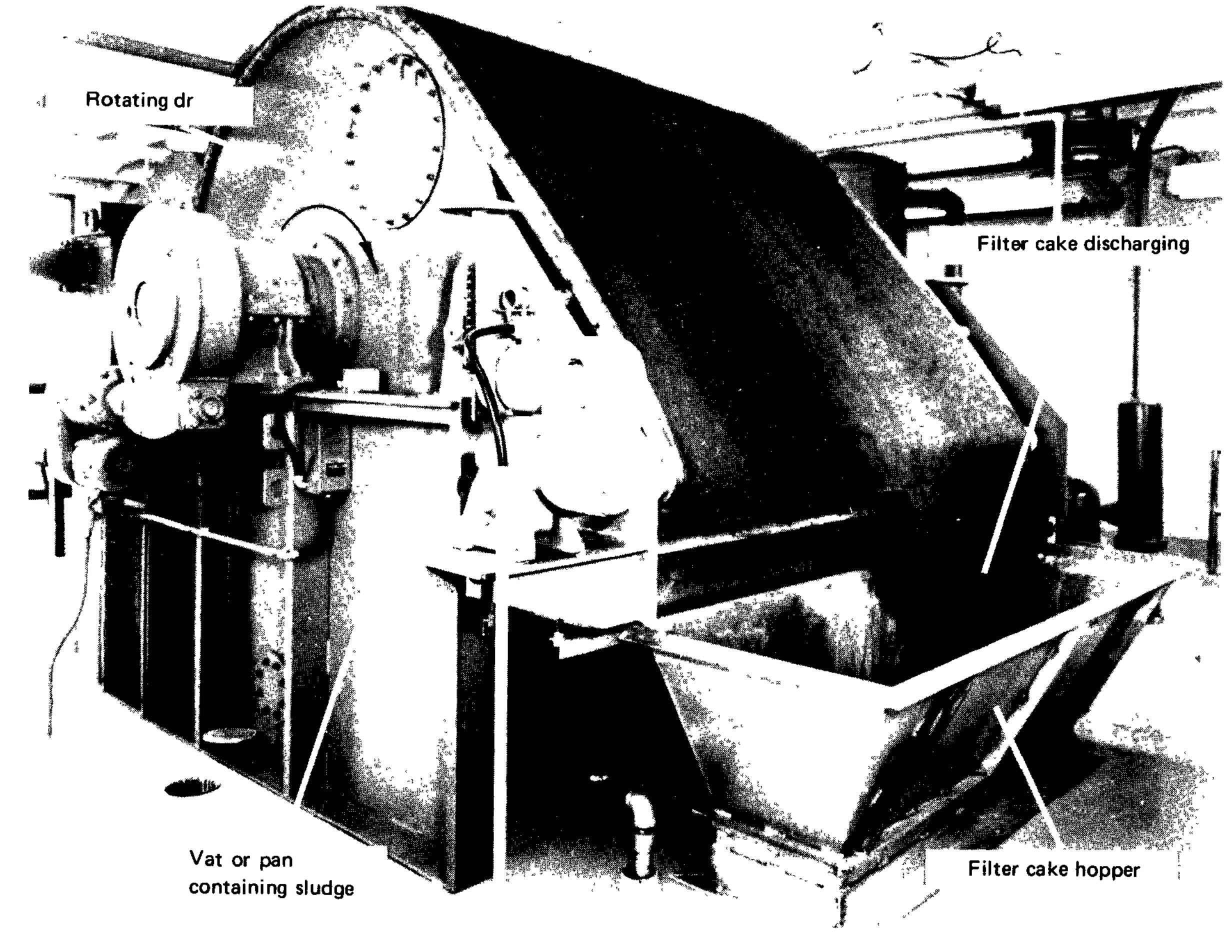


Figure V-1. Vacuum filter. (Courtesy of Envirex)

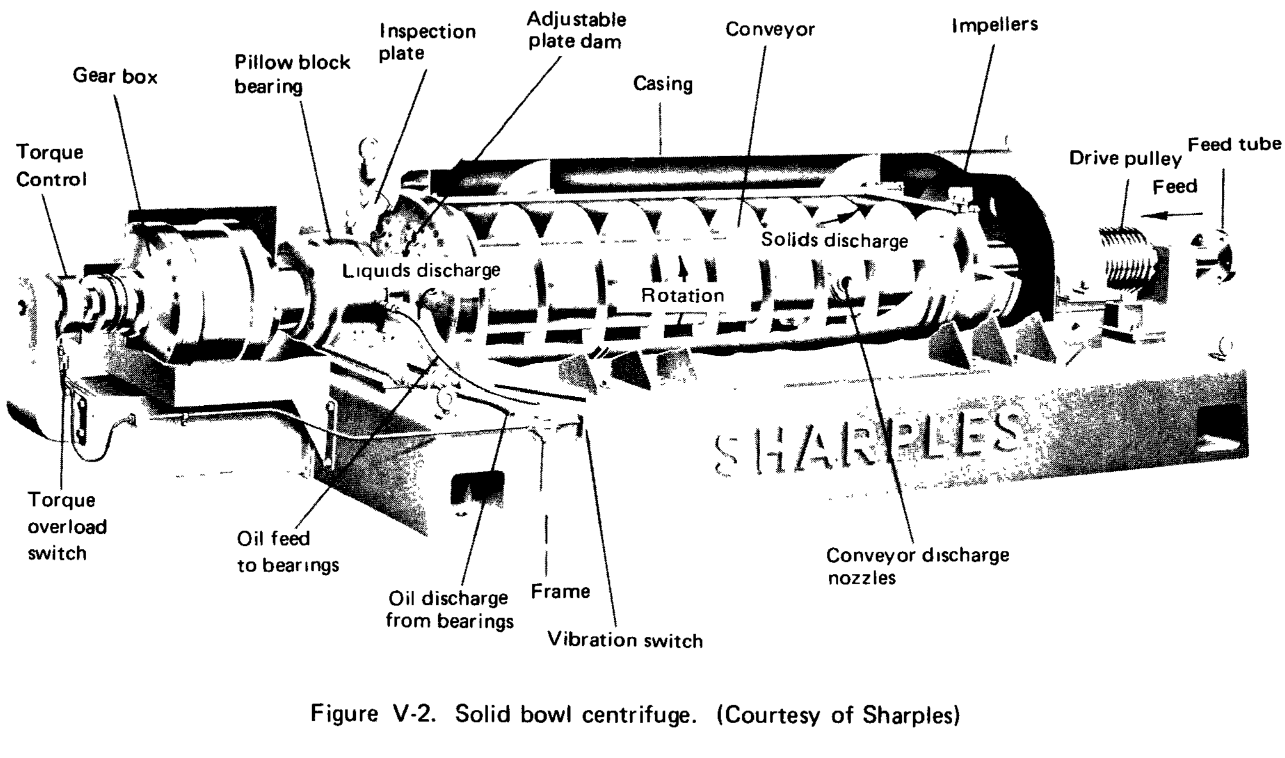


Figure V-2. Solid bowl centrifuge. (Courtesy of Sharples)

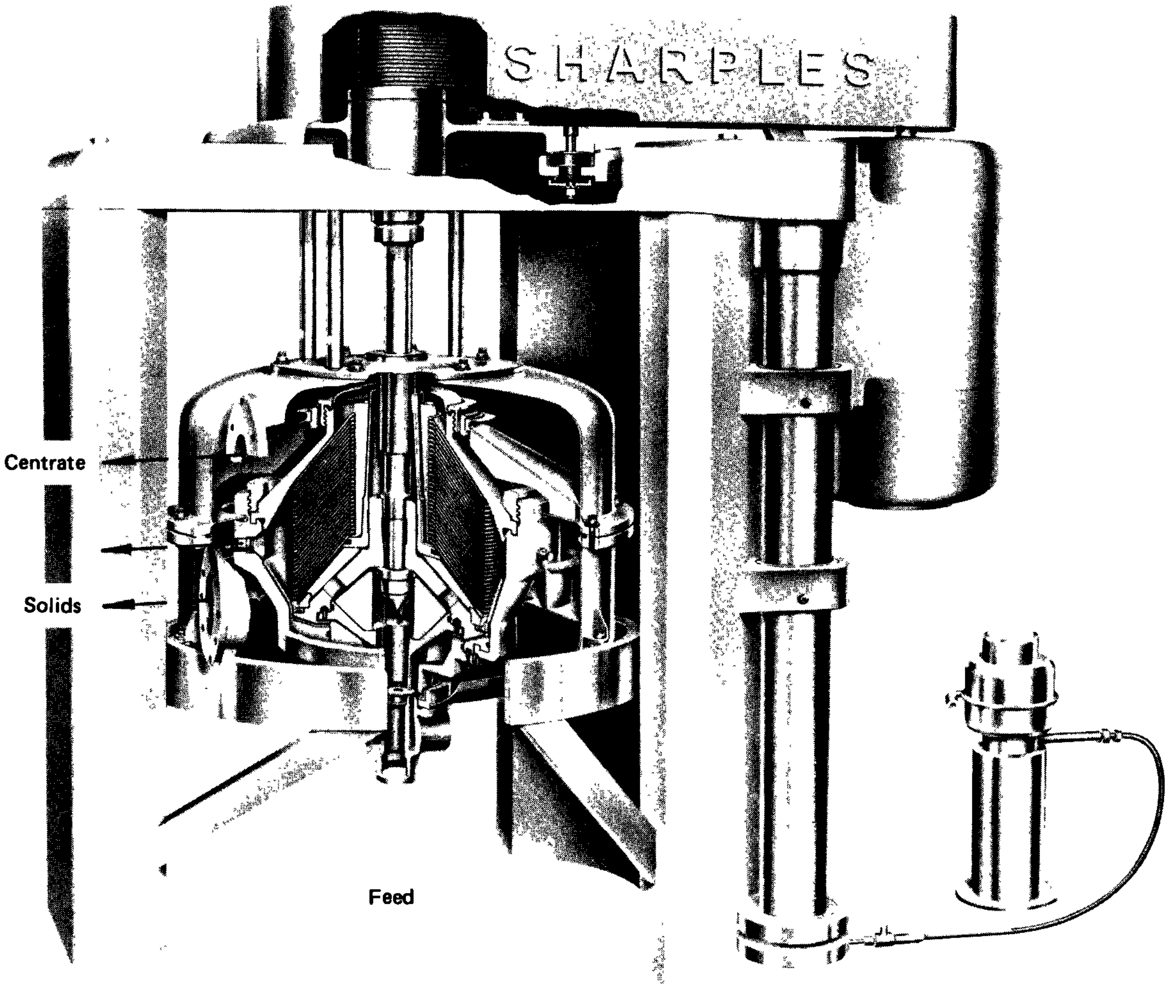


Figure V-3. Disc nozzle centrifuge. (Courtesy of Sharples)

Sludge Drying Beds and Lagoons

In areas with dry weather during the processing season, sludge drying beds and sludge lagoons may be effectively used to dewater digested sludge for disposal. Drying beds are constructed with sand bottoms and an underdrain system to capture water that percolates down through the sludge. Digested sludge is pumped to each bed until the depth reaches about 18 inches; then new sludge is pumped to another bed. Water evaporates from the sludge surface and also percolates down through the bed. The drained water is returned to the treatment plant headworks and when the sludge is sufficiently dry, it is taken out with a skip loader. Drying beds will have only a slight musty odor, provided the sludge is adequately digested.

Sludge lagoons differ from beds in that they are deeper (about two or three feet), and do not have a sand blanket with underdrains. If sufficiently dry, the sludge may be taken out with a skip loader; otherwise it must be removed with a drag-line or dredge.

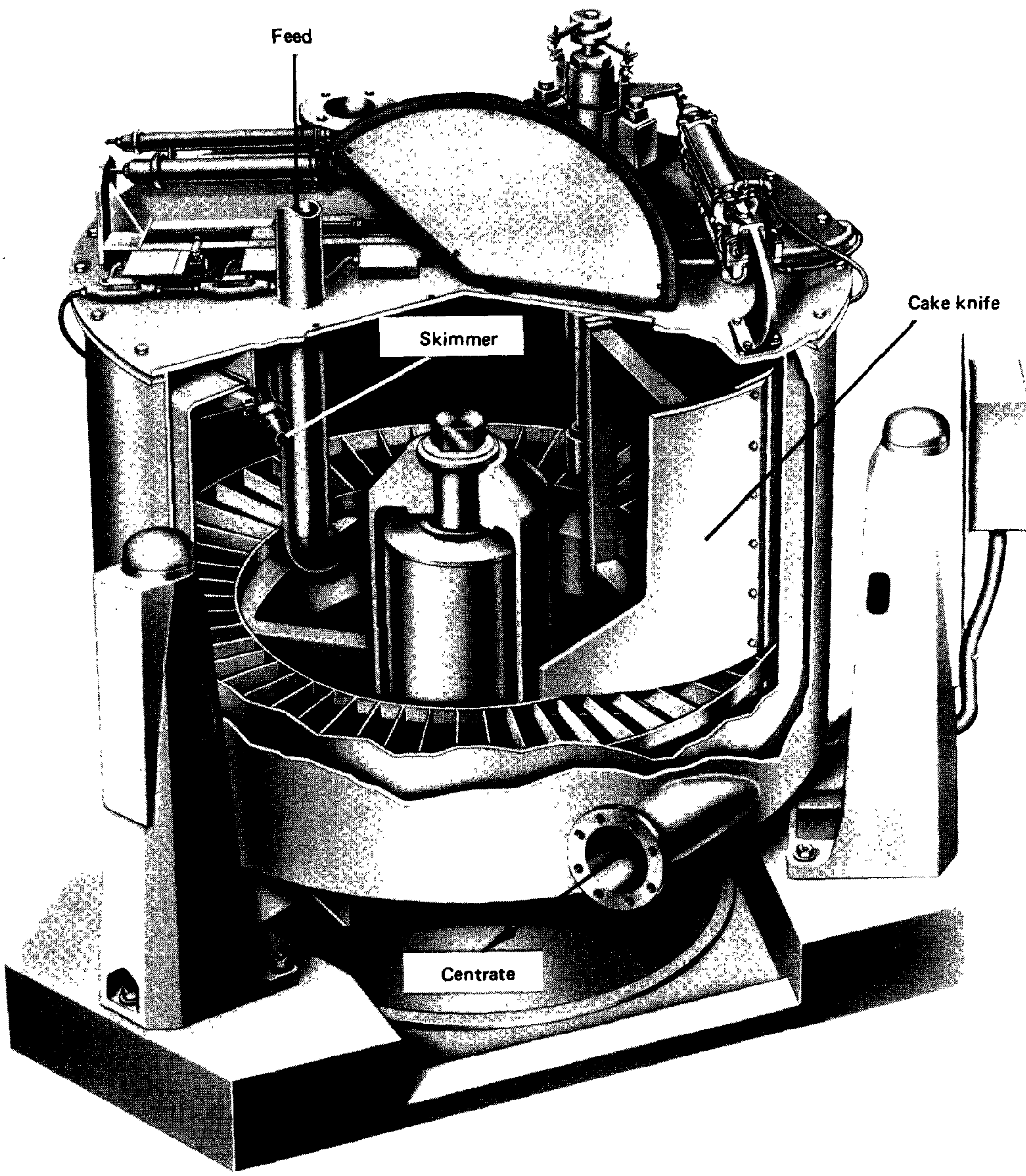


Figure V-4. Basket centrifuge. (Courtesy of Sharples)

METHODS OF SOLIDS DISPOSAL

The ultimate disposal of solids is becoming quite a problem. Most municipal treatment plants are now disposing dewatered digested sludge in landfills. In-plant residuals from most fruit and vegetable processing plants are disposed in landfills, usually owned by a public agency. As these sites are filled, the processors are often asked to go elsewhere with their residuals, screenings, and sludge. Some fruit and vegetable processors are now operating their own land disposal system for residuals and treatment plant sludges.

Many processors are able to dispose of some portion of the solid wastes, usually screenings, to animal feeding operations. Due to the relatively low food value of screenings, they must be mixed with grains or other common feed to provide a balanced diet for animals. Because of the specific dietary requirements of many animals and the variability of goals of feeding (egg versus meat production for poultry, for example), feeding requirements should be studied before starting such a program. As a rule, the lack of nutrients in fruit and vegetable processing waste, coupled with the seasonality of waste production, does not make the program attractive to animal feeders. Transportation costs also make this option unattractive. Year-round operations (like potato processing, for example) have been successful in setting up operations with local feed lots to accept screenings and primary sludge.

LAND DISPOSAL OF WASTE SOLIDS

Residuals that are not converted to a by-product or animal feed are a major problem. Some form of land disposal is usually the only option. Local regulations on land disposal are becoming more stringent. Present practices should be carefully reviewed to avoid problems. In the future, land disposal sites will have to be selected and operated with greater care. The following is a general discussion of the factors to consider.

Silt, screenings, primary treatment sludges, and other dry waste can usually be incorporated in a landfill or tilled into the soil. However, sludges from secondary and advanced waste treatment would not be allowed in a landfill unless they were concentrated to a semi-solid. This conversion is usually too costly to be practical. Therefore, the usual option for disposal of dilute sludge is land spreading as a fertilizer. The limits for application of fruit and vegetable waste solids to land are much less defined than for irrigation of liquids.

Land application of waste solids can be grouped into two methods: (1) fertilizer and (2) disposal. The fertilizer method maximizes crop production while using the waste solids for nutrients and soil conditioning. The loading rates are relatively low when compared to the disposal method. Any soils suitable for high-production agriculture will generally be suitable for application of waste solids. Clay soils or other soils with low-organic matter will receive special benefit from residuals. Loading rates are about three to ten tons of dry solids per acre per year.

The disposal method maximizes disposal by incorporating large amounts of the solids into the soil. This process is essentially a sanitary landfill, and most are now publically owned and operated. A crop is maintained mainly to enhance site appearance, minimize wind erosion, take up moisture, or use some of the nutrients in the residuals. Loading rates are about 5 to 50 tons per acre per year. The leachate from landfills is a substantial problem because it is odorous, high strength, and must be irrigated or treated for discharge.

Pretreatment Requirements

Waste solids vary greatly in character and pretreatment requirements, depending on the food being processed, method of processing and method of treatment. Adjustment of the pH will be required before land application if it is below 6.4 or above 8.4. These limits will vary, depending on the texture and buffering capacity of the soil and the loading rate. The solids may need to be stabilized by biological treatment so that rapid degradation and odor do not result when they are applied to land. The solids may need to be ground to allow better incorporation into the soil and better operation of application equipment. Dewatering of solids may be advantageous to a land disposal system. It will result in less volume and a smaller disposal site.

Application and Incorporation Methods

Waste solids can be applied to land by several methods. As a liquid, they can be injected or plowed under the surface, spread by truck or tractor, or sprayed. As a solid, they can be spread by equipment such as manure spreaders. The selection of the suitable method depends upon soil characteristics, crop, labor requirements, maintenance, topography, and costs.

In general, the solids must not be allowed to remain on the soil surface for a long time because of odor, insect, wind, and water erosion problems which often result. Insect problems may develop even when liquid waste solids are immediately incorporated into the soil. This has been prevented by spreading the solids in a thin layer and allowing them to remain on the surface just long enough to dry before tilling into the soil.

Site Selection Criteria

The criteria for site selection are generally the same as those listed for a waste effluent irrigation site with the following exceptions:

- Hydraulic loading will not be as great; therefore, the subsurface permeability is not as important.
- Because of the appearance of solids and the nature of the operation, a remote or concealable site should be selected.

Application Rate Constraints

The application rate will be limited by several constraints.

- Nutrient balances
- BOD
- Nitrogen
- Solids loading rate
- SAR
- pH

All of the above-mentioned factors vary greatly between types of food processed and the method of processing and waste treatment. The loading rate must be studied carefully in each case. The hydraulic loading limits, infiltration capacity, root-zone permeability, and geologic permeability are not usually limiting because only small amounts of water will be applied with the solids. Solids must be incorporated into the soil as applied, or very shortly thereafter. Limits exist on how much organic solids can be physically incorporated into the soil, and on the soil's ability to decompose solids without causing plant toxicity problems. Limits on BOD, nitrogen, SAR, dissolved salts, etc. áre approached the same as for irrigation of effluent.

Management and Operation

Proper management and operation of a solids disposal system is as important as for a waste effluent treatment and disposal system. A major factor for successful operation is the timing of land application.

In a fertilizer application system, where crop production is optimized, waste solids cannot be applied and tilled into the soil while the crop is growing. Tillage would kill most crops. Cropping areas and disposal areas can be alternated. The method of disposal used—either fertilizer or disposal—will depend greatly on who owns the site and who operates the system. A farmer will want to maximize crop production, and a food processor will want to maximize residual disposal. Other practices, such as crop and soil management and monitoring, are also important as noted in the discussion of waste effluent treatment and disposal.

Cost of Residuals Delivery and Application

The cost of disposing of residuals onto land can vary greatly depending on the amount of liquid in the residuals, the distance to be transported, and the method of delivery and application. Some typical recent costs for hauling are given in table V-5. Actual costs vary considerably due to differences in disposal sites, government regulations, availability of trucking firms, and pretreatment requirements. The costs given in the table do not include pretreatment or site preparation costs.

Table V-5.—*Cost ranges of hauling and disposal*

Hauling of liquid sludge (4 - 15% TS) to ponding site (20 mi haul)	4 - 5 cents/gallon includes disposal fee of 3-1/2 cents/gallon
Hauling of liquid sludge (4% TS) to farm land (35 mi haul)	2 cents/gallon or $3.70/ton-mile
Hauling of screenings, mud to land fill	$4.00/cubic yard — includes disposal fee of $1.00/cubic yard
Hauling, spreading of dewatered sludge to disposal site (5 mi haul)	$1 - $2/ton-mile
Hauling, spreading of liquid sludge to disposal site (5 mi haul)	$3 - $4/ton-mile
Hauling of hazardous waste (acid, caustic) to evaporation ponds	8 - 10 cents/gallon includes disposal fee

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[4] *Development Document for Effluent Limitations Guidelines and New Source Performance Standards for the Apple, Citrus and Potato Processing Segment of the Canned and Preserved Fruits and Vegetables Point Source Category*, U.S. Environmental Protection Agency, Office of Air and Water Programs, Washington, D.C., Mar. 1974.

[5] *Development Document for Interim Final and Proposed Effluent Limitations Guidelines and New Source Performance Standards for the Fruits, Vegetables and Specialties Segment of the Canned and Preserved Fruits and Vegetables Point Source Category*, U.S. Environmental Protection Agency, Office of Water and Hazardous Materials, Washington, D.C., Oct. 1975.

[6] "Management of Solid Residuals," *Proceedings, 1971 Research Highlights Meeting*, National Canners Association, Berkeley, Calif., Nov. 1971.

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[10] "Waste Disposal," *Potato Processing*, Chapter 21, AVI Publishing Company, Inc., 1975.

[11] *Proceedings, Fourth National Symposium on Food Processing Wastes*, U.S. Environmental Protection Agency, EPA-660/2-73-031, Dec. 1973.

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[15] *Guidelines for Interpretation of Water Quality for Agriculture*, University of California Extension, January 15, 1975.

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[17] *Waste Disposal Control in the Fruit and Vegetable Industry*, Noyes Data Corporation, 1973.

METRIC CONVERSION TABLES

Recommended Units

Description	Unit	Symbol	Comments	Customary Equivalents*
Length	meter	m	*Basic SI unit*	39 37 m = 3 281 ft = 1.094 yd
	kilometer	km		0.6214 mi
	millimeter	mm		0.03937 in
	micrometer or micron	μm or μ		3.937 X 10^{-5} in = 1 X 10^{4} Å
Area	square meter	m^2		10 76 sq ft = 1 196 sq yd
	square kilometer	km^2		0 3861 sq mi = 247 1 acres
	square millimeter	mm^2		0 001550 sq in
	hectare	ha	The hectare (10,000 m^2) is a recognized multiple unit and will remain in international use	2 471 acres
Volume	cubic meter	m^3		35.31 cu ft = 1.308 cu yd
	litre	l		1.057 qt = 0 2642 gal = 0.8107 X 10^{-4} acre ft
Mass	kilogram	kg	*Basic SI unit*	2 205 lb
	gram	g		0 03527 oz = 15 43 gr
	milligram	mg		0 01543 gr
	tonne	t	1 tonne = 1,000 kg	0 9842 ton (long) = 1 102 ton (short)
Force	newton	N	The newton is that force that produces an acceleration of 1 m/s^2 in a mass of 1 kg.	0.2248 lb = 7 233 poundals
Moment or torque	newton meter	N-m	The meter is measured perpendicular to the line of action of the force N. Not a joule	0.7375 lb-ft 23 73 poundal-ft
Flow (volumetric)	cubic meter per second	m^3/s		15 850 gpm = 2,119 cfm
	liter per second	l/s		15 85 gpm

Recommended Units

Description	Unit	Symbol	Comments	Customary Equivalents*
Velocity linear	meter per second	m/s		3 281 fps
	millimeter per second	mm/s		0 003281 fps
	kilometers per second	km/s		2,237 mph
angular	radians per second	rad/s		9 549 rpm
Viscosity	pascal second	Pa-s		0 6722 poundal(s)/sq ft
	centipoise	Z		1 450 X 10^{7} Reyn (μ)
Pressure or stress	newton per square meter or pascal	N/m^2 or Pa		0 0001450 lb/sq in
	kilonewton per square meter or kilopascal	kN/m^2 or kPa		0 14507 lb/sq in
	bar	bar		14 50 lb/sq in
Temperature	Celsius (centigrade)	°C		(°F−32)/1 8
	Kelvin (abs.)	°K		°C + 273 2
Work, energy, quantity of heat	joule	J	1 joule = 1 N-m where meters are measured along the line of action of force N	2 778 X 10^{-7} kw-hr = 3.725 X 10^{-7} hp hr = 0 7376 ft-lb = 9.478 X 10^{-4} Btu
	kilojoule	kJ		2 778 X 10^{-4} kw-hr
Power	watt	W	1 watt = 1 J/s	44 25 ft-lbs/min
	kilowatt	kW		1.341 hp
	joule per second	J/s		3.412 Btu/hr

Application of Units

Description	Unit	Symbol	Comments	Customary Equivalents*
Precipitation, run-off, evaporation	millimeter	mm	For meteorological purposes, it may be convenient to measure precipitation in terms of mass/unit area (kg/m^2). 1 mm of rain = 1 kg/m^2	
Flow	cubic meter per second	m^3/s		35 31 cfs
	liter per second	l/s		15 85 gpm
Discharges or abstractions, yields	cubic meter per day	m^3/d	1 l/s = 86 4 m^3/d	0.1835 gpm
	cubic meter per year	m^3/year		264 2 gal/year
Usage of water	liter per person per day	l/person/day		0 2642 gcpd

Application of Units

Description	Unit	Symbol	Comments	Customary Equivalents*
Density	kilogram per cubic meter	kg/m^3	The density of water under standard conditions is 1,000 kg/m^3 or 1,000 g/l or 1 g/ml	0 06242 lb/cu ft
Concentration	milligram per liter (water)	mg/l		1 ppm
BOD loading	kilogram per cubic meter per day	$kg/m^3/d$		0 06242 lb/cu ft/day
Hydraulic load per unit area, e g., filtration rates	cubic meter per square meter per day	$m^3/m^2/d$	If this is converted to a velocity, it should be expressed in mm/s (1mm/s = 86 4 m^3/m^2/day)	3 281 cu ft/sq ft/day
Air supply	cubic meter or liter of free air per second	m^3/s l/s		
Optical units	lumen per square meter	$lumen/m^2$		0 09294 ft candle/sq ft

*Miles are U S statute, qt and gal are U.S liquid, and oz and lb are avoirdupois

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