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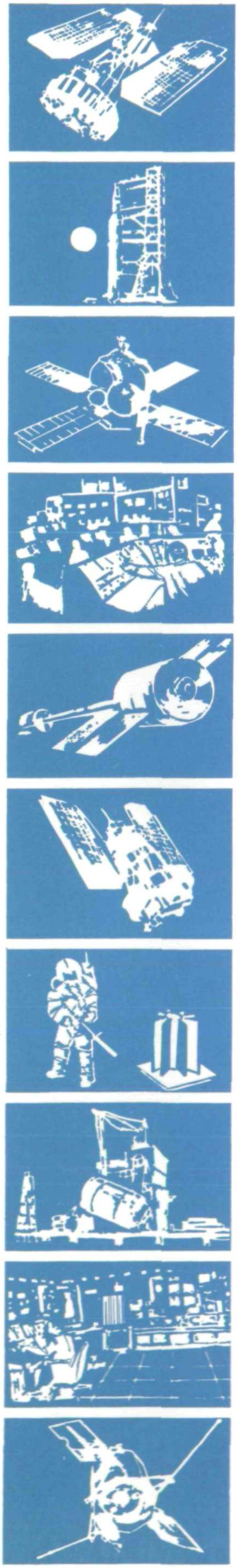
SPACE
DIVISION

CONTRACT NO. NAS 9-12505
DRL NO. T-644
LINE ITEM NO. 3
DRD NO. MA183T
GE DOCUMENT NO. 73SD4236



WATER RECOVERY AND SOLID WASTE PROCESSING FOR AEROSPACE AND DOMESTIC APPLICATIONS

MAY 21, 1973

Volume II
Appendices

GENERAL ELECTRIC

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Appendices

SUBMITTED BY: R W Murray
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GENERAL ELECTRIC

Acknowledgement

I would like to take this opportunity to acknowledge the significant contributions made by Donald R. Glenn, General Electric Reentry and Environmental Systems Division and Edward J. Glanfield, General Electric Space Division, in the preparation of this report.

R. W. Murray
Program Manager

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APPENDIX A

HOUSEHOLD HYDROGRAPH

1. HOUSEHOLD HYDROGRAPH (INSTANTANEOUS FLOW)

START TIME	USE	GPM		MINUTES
		HOT	COLD	
700	Toilet		3	1.67
703	Shower	3.75	1.25	4.00
715	Toilet		3	1.67
715	Cooking		4	.06
718	Shower	3.75	1.25	4.00
730	Toilet		3	1.67
732	Lavatory		3	.17
735	Toilet		3	1.67
737	Lavatory		3	.17
740	Lavatory		3	.17
743	Lavatory		3	.17
800	Garbage Disposal	3.14		.73
815	Cooking		4	.075
1000	Toilet		3	1.67
1030	Cleaning	2.25	.75	.83
1045	Drinking		1	.1
1200	Cooking		4	.075
1240	Lavatory		3	.17
1245	Garbage Disposal	3.14		.73
1255(1/2 days)	Dishwasher	3		3.33
1300	Toilet		3	1.67
1400	Cleaning	2.25	.75	.83
1430	Drinking		1	.1
1500	Clotheswasher	3		5.83
1515	Clotheswasher	3	3	2.92
1525	Drinking		1	.1
1530	Drinking		1	.1
1530	Toilet		3	1.67
1535	Toilet		3	1.67
1600	Toilet		3	1.67
1715	Drinking		1	.1
1730	Cooking		4	.12
1735	Cooking		4	.12
1740	Cooking		4	.06
1745	Garbage Disposal	3.14		.73
1800	Toilet		3	1.67
1801	Lavatory	2	1	.17
1803	Toilet		3	1.67
1804	Lavatory	2	1	.17
1806	Toilet		3	1.67
1807	Lavatory	2	1	.17
1835	Lavatory		3	.17
1840	Lavatory		3	.17
1845	Lavatory		3	.17
1845	Garbage Disposal	3.14		.73
1850	Lavatory		3	.17
1900	Toilet		3	1.67
1900	Dishwasher	3		3.33
1930	Drinking		1	.1
1945	Drinking		1	.1

HOUSEHOLD HYDROGRAPH (INSTANTANEOUS FLOW) (Continued)

START TIME	USE	GPM		MINUTES
		HOT	COLD	
1955	Toilet		3	1.67
2000	Shower	3.75	1.25	4.00
2005	Toilet		3	1.67
2030	Bath	3.75	1.25	4.00
2100	Toilet		3	1.67
2155	Lavatory		3	.17
2200	Toilet		3	1.67
2205	Lavatory		3	.17
2210	Toilet		3	1.67
2255	Lavatory		3	.17
2300	Toilet		3	1.67
2305	Lavatory		3	.17
2310	Toilet		3	1.67

2. HOUSEHOLD HYDROGRAPH (15 MINUTE FLOWS)

	GALLON BLACK	GALLON GREY-HOT	GALLON GREY-COLD
700-715	5	15	5
715-730	5	15	5.25
730-745	10	-	2.0
745-800	-	-	-
800-815	-	2.29	-
815-830	-	-	.30
830-1000	-	-	-
1000-1015	5	-	-
1015-1030	-	-	-
1030-1045	-	1.87	.63
1045-1100	-	-	.10
1100-1200	-	-	-
1200-1215	-	-	.30
1215-1230	-	-	-
1230-1245	-	-	.50
1245-1300	-	12.29	-
1300-1315	5	-	-
1315-1400	-	-	-
1400-1415	-	1.87	.63
1415-1430	-	-	-
1430-1445	-	-	.10
1445-1500	-	-	-
1500-1515	-	17.5	-
1515-1530	-	8.75	1.85
1530-1545	10	-	.10
1545-1600	-	-	-
1600-1615	5	-	-
1615-1715	-	-	-
1715-1730	-	-	.10
1730-1745	-	-	1.25
1745-1800	-	2.29	-
1800-1815	15	1.0	.50
1815-1830	-	-	-
1830-1845	-	-	1.00
1845-1900	-	2.29	.50
1900-1915	5	10.00	-
1915-1930	-	-	-
1930-1945	-	-	.10
1945-2000	5	-	.10
2000-2015	5	15	5
2015-2030	-	-	-
2030-2045	-	15	5
2045-2100	-	-	-
2100-2115	5	-	-
2115-2145	-	-	.50
2145-2200	-	-	-
2200-2215	10	-	.50
2215-2245	-	-	-
2245-2300	-	-	.50
2300-2315	10	-	.50

APPENDIX B
MANUFACTURER'S ADDRESSES

MANUFACTURER'S ADDRESSES

1. AES Automated Environmental Systems
   135 Crossways Pk. Drive
   Woodbury, N. Y. 11797

2. Agricultural Control Systems, Inc.
   Redwood City, California

3. Analytical Measurements, Inc.
   31 Willow Street
   Chatham, N. J. 07928

4. Aqua Test Corporation
   Arlington, Mass.

5. Aquatronics, Inc.
   Philadelphia, Pennsylvania

6. Beckman Instruments, Inc.
   2500 Harbor Blvd.
   Fullerton, California 92634

7. BIF
   345 Harris Avenue
   Providence, R. I. 02901

8. Calgon Corporation (Subsidiary Merck & Company)
   Pittsburgh, Pennsylvania

9. Cambridge Scientific Industries
   Cambridge, Maryland

10. Capital Controls Company, Inc.
    Advance Lane
    Colmar, Pennsylvania 18925

11. Carl G. Brimmekamp & Company
    San Francisco, California

12. Delta Scientific Corporation
    120 East Hoffman Avenue
    Lindenhurst, N. Y. 11757

13. Delta Technical Laboratories
    Arcadia, California

14. Fischer & Porter Company
    Warminster, Pennsylvania

15. Foxboro Company
    Neponset Avenue
    Foxboro, Mass. 02035

MANUFACTURER'S ADDRESSES

16. Gam Rad, Inc.
16825 Wyoming Avenue
Detroit, Michigan 48221

17. Hach Chemical Company
Box 907
Ames, Iowa 50010

18. Honeywell Industrial Division
1100 Virginia Drive
Fort Washington, Pennsylvania 19034

19. Hydrodyne, Inc.
Indianapolis, Indiana

20. Hydrolab Corporation
Austin, Texas

21. Industrial and Mill Supply Company
Division Kernco Instruments, Inc.
Huntington Station, N. Y.

22. Ionics, Inc.
65 Grove Street
Watertown, Mass. 02172

23. Jacoby-Tarbox Corporation
Yonkers, N. Y.

24. KDI Poly-Technic, Inc.
10540 Chester Road
Cincinnati, Ohio 45215

25. Keene Corporation, Water Pollution Control Division
1740 Molitor Road
Aurora, Illinois 60507

26. Leeds and Northrup Company
Sumneytown Pike
North Wales, Pennsylvania 19454

27. Lehigh Systems, Inc.
Syracuse, N. Y.

28. Limnetics, Inc.
6132 West Fond Du Lac Avenue
Milwaukee, Wisconsin 53218

29. Martek Instruments, Inc.
Newport Beach, California

MANUFACTURER'S ADDRESSES

30. Myron L. Company
656 First Street
Encinitas, California 92024

31. Oceanography International Corporation
College Station, Texas

32. Parkson Corporation
Fort Lauderdale, Florida

33. Phipps & Bird, Inc.
Richmond, Virginia

34. Photomation, Inc.
Mountain View, California

35. Photronic, Inc.
411 Cheltena Avenue
Jenkintown, Pennsylvania 19046

36. Precision Scientific
Chicago, Illinois

37. R.M.A. Development, Inc., Products Division
P. O. Box 1222
Fond Du Lac, Wisconsin

38. Robertshaw Controls
Aeronautical and Instrument Division
Anaheim, California

39. Technicon Corporation
Tarrytown, N. Y. 10591

40. Union Carbide Corporation, Instrument Department
5 New Street
White Plains, N. Y. 10601

41. Universal Interloc, Inc.
17401 Armstrong Avenue
Santa Ana, California 92705

APPENDIX C

WATER AND SEWAGE TREATMENT - WORST CASE

APPENDIX C

Water & Sewage Treatment - Worst Case

A. Package Plant Cost:

total cost equation: (Dorr-Oliver, ref. 31)

$$\log (¢/KG) = 2.58 - 0.53 \log (KG)$$

$$= 2.58 - 0.53 \log (25.5)$$

$$¢/KG = 67. \text{ (mid '67 price level)}$$

total cost includes:

capital amortization
power
labor
chlorine
maintenance

performance:

95 - 98% BOD removed
$<$ 5 ppm suspended solids effluent

B. Sewer Construction Cost

41,100 ft. estimated sewer length
x 2.90 $/ft. (10" asbestos cement-installed cost, ref. 33)

$119,000

Manholes:	$275 @ precast 4' diameter, 5' deep
	105 @ cover & frame
	$380 total installed cost

41,100' ÷ 400 ft. intervals (ref. 7) =

105 manholes
x 380
$40,000

$119,000 - sewer mains
40,000 - manholes
$159,000 - total capital cost
x .0634 (6% - 50 years)
10,100 $/year amortization
÷ 9,300 KG/yr. = 1.09 $/KG
(mid 1972)

C. Sewer Maintenance:

41,100 ft.
x .06 $/yr/ft. (ref. 7)
2,500 $/yr.
9,300 KG/yr. = .27 $/KG
(mid 1969 price level)

D. Sewer System Overhead:

customer service & accounting	1.20 $/capita/year
general & administrative	2.40
	3.60 $/capita/year

3.60 $/capita/year
x 4 capita/home
14.40 $/home/yr.
÷ 93 KG/home/yr.
.16 $/KG (mid 1969 price)

E. Sludge Disposal Cost:

from Seymour (ref. 9):

9 wk. - average sludge removal frequency
1600 gal. - sludge removal volume

∴ assume: 1000 gal/mo. sludge removal

6/24/72 vendor quote: $35/1000 gal. sludge
= $35/mo.
÷ 765 KG/mo. flow
= .046 $/KG (mid 1972 price)

F. Water Softening Cost:

regeneration:

7 lbs. NaCl/lb. $CaCO_3$ equiv. - regeneration requirement
(ref. 21)

500 ppm $CaCO_3$ hardness level assumed

500 ppm $CaCO_3$ hardness
= .00417 lbs/gal
x 255 gal/day
1.06 lbs/day $CaCO_3$ removed
x 7 lbs, NaCl/lb " "
7 lbs/day NaCl - regeneration

$4/100 lb NaCl - vendor quote 6/16/72

7 lbs x 4 ¢/lb = 28¢/day
28 ¢/day ÷ .255 KG/day = 1.10 $/KG
(1972 price)

capital:

$325 purchase - vendor quote - 6/16/72
90 installation (ref. 33)
$415
x .149 (8% - 10 yr.)
$ 62/yr. = $.17/day ÷ .255 KG/day = .67 $/KG
(1972 price)

regeneration cost -	1.10 $/KG
capital amortization -	.67 $/KG
total softening cost -	1.77 $/KG (1972 price)

APPENDIX D

PRICE ADJUSTMENTS

APPENDIX D

Price Adjustments

1)	average water rate - 25,000 pop.	.42$/KG	(1960) x 1.785	$ .75
2)	water rate - 100 homes	2.67$/KG	(1967) x 1.49	3.76
3)	sewage rate - 25,000 pop.	.33$/KG	(1969) x 1.34	.44
4)	packages plant treatment	.67$/KG	(1967) x 1.49	1.00
5)	sewer line maintenance	.27$/KG	(1969) x 1.34	.32
6)	sewer G&A	.16$/KG	(1969) x 1.34	.21

All adjustments based on U.S. Bureau of Labor Statistics Index for Residential Water Sewage Services.

APPENDIX E

BASELINE HARDWARE COST

APPENDIX E

BASELINE HARDWARE COST

ITEM	MATERIAL	INSTALLATION	TOTAL
1	49.95	70.00	
2	34.00	6.50	
3	44.50	22.00	
4	59.95	30.00	
5	40.85	21.00	
6	121.00	62.00	
7	96.50	50.00	
8	135.50	70.00	
9	3.29	2.00	
10	9.41	-	
11	28.00	14.00	
12	15.00	8.00	
13	40.00	-	
14	36.00	18.00	
15	30.00	15.00	
16	9.10	34.00	
17	25.20	47.00	
18	3.70	-	
19	5.50	-	
20	1.65	-	
	789.10	469.50	$1311.70

APPENDIX F

ADDITIONAL PIPING CONNECTIONS

CONNECTION	PIPE LENGTH (ft)	SIZE (in)	NUMBER OF CONNECTIONS
Additional Piping-Connections			
C.W. supply to storage tank	2	1/2	2
Clothes. W. Int. Rec. line to strainer	5	1	4
Strainer to H.W. tank		1	1
H.W. tank to pump to tee		1/2	3
Tee to C.W. h.w. line	5	1/2	4
Tee to dishwasher h.w. line	5	1/2	4
H.W. tank to strainer 2	1	1	2
Strainer to chlorinator		1	2
Chlorinator to F.W. tank	1	1	2
F.W. tank to pump to filter		1/2	2
Filter to water closets (1 floor + 2 floor)	18	1/2	3
Dishwasher to line to strainer 1	15	1	4
Tub & lav (2 floor) + lav. (1 fl.) to line to strainer -2	18	1	4
Shower flow control		1/2	2
Clotheswasher to above line	2	1	1

CONNECTION	PIPE LENGTH (ft)	SIZE (in)	NUMBER OF CONNECTIONS
F.W. tank to waste line	2	1	2
Deletions			
Clotheswasher to waste line	2	1	1
Tub, lav sinks to waste line	6	1	4
C.W. supply to W.C's	4	1/2	2

Total piping length above conventional
1/2" pipe - 26'
1" pipe - 36'

connections - above conventional - 34

a)	1/2" line	18
b)	1" line	17

a)	straight-in	18
	T	0
b)	straight-in	14
	T	3

R +	bends		Add. connections
	1/2"	2	4
	1"	4	8

Total added connections

1/2"	straight-in	22
1"	straight-in	22
1"	T	3

Electrical Connections

Clothes W. to 2 way solenoid valve norm closed
Clothes W to 2 way solenoid valve norm open
Clothes W to 3 way solenoid h.w. inlet
Clothes W to H.W. T. pump
Dishwasher to 2 way solenoid valve norm closed
Dishwasher to 2 way solenoid valve norm open
Dishwasher to 3 way solenoid valve H.W. inlet
Dishwasher to H.W.T. pump

APPENDIX G

SOLIDS REMOVAL

APPENDIX G

SOLIDS REMOVAL

INTRODUCTION

Solids removal serves several primary purposes in leading to a final effluent quality. Solids within a residential wastewater stream comprise approximately 60 to 70% of the influent BOD. In addition, the effluent clarity is directly related to the residual suspended solids (sizes and quantity measured as turbidity). Solids removal is roughly defined as primary treatment. As shown in the following table, the solids from 1 - > 100 microrns (μ) constitutes the average primary treatment target. The remaining "solids" require more sophisticated physical, chemical or combinations of both methods to fully remove all residuals resulting in a tertiary treated wastewater effluent.

		Organic		Inorganic	
Type of solid	Size range	mg/l	%	mg/l	%
Settleable	> 100 μ	90	30	30	10
Supra Colloidal	1 - 100 μ	55	18	25	8
Colloidal	1 mμ - 1 μ	30	10	10	4
Soluble	< 1 mμ	125	42	235	78
		300	100	300	100

Solids removals are accomplished by any of the following processes, singly or in trains, depending on the solids content, particle sizes and processing rates with respect to the required effluent requirements.

1. Separation -
   a. Settlement
   b. Flotation
   c. Vortex devices
   d. Centrifuges

2. Filtration
    a. Mechanical grates and screens
    b. Diatomaceous earth
    c. Bed filters (rapid-sand, multi-media)
    d. Membranes (ultrafiltration, reverse osmosis)
3. Chemical Process
    a. Coagulation enhancement
    b. Precipitate reactions
    c. pH Control

1. SEPARATION PROCESSES

The distinction between separators and filters lies in the manner in which the solids are accumulated with respect to the water carrier. In general, separation devices do not concentrate the solids removed as well as filters, excepting the centrifuge. Their advantage lies in the fact that most separation schemes are passive systems requiring infrequent maintenance therefore resulting in an operating reliability and performance, limited by the specific dynamic design conditions of its application.

1.1 SETTLEMENT (SEDIMENTATION)

Obviously, settlement is based on the difference between the specific gravity of the liquid and the carried solids. A basic settling basin is shown in Figure 1. The settling velocity of the smallest settleable solid (settling zone) determines time-tank volume relationships.

The basin is divided into four zones, inlet, outlet, settling and sludge. The inlet zone must dissipate the kinetic energy of the feed stream and provide a uniform distribution of the flow entering the settling zone without creating excessive turbulence. The outlet zone is less critical to basin performance, but low approach velocities to effluent weirs must be maintained for maximum sedimentation efficiency. The difficulties in obtaining optimum inlet and outlet conditions vary with basin shape and flow patterns.

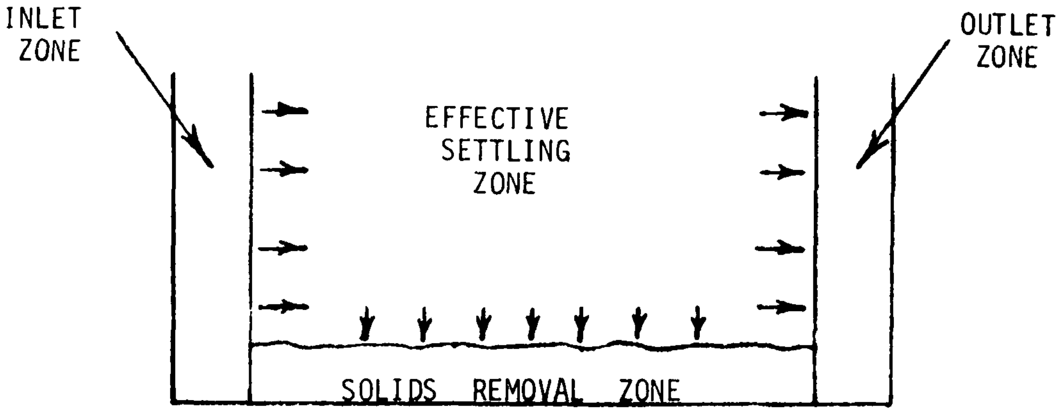


Figure 1. Functional Zones in an Idealized Sedimentation Basin

The basic objective of the flow streamlines is to minimize resuspension of settled solids or create turbulence through the flow cross-section thereby countering gravimetric settling. The sludge zone serves the two-fold function of retaining the solids so that a minimum of resuspension occurs and providing sufficient time for compaction, thereby minimizing sludge pumping requirements. In most cases mechanical scrapers are utilized to slowly move the sludge to the pump drawoff area. An alternative device uses suction to remove the sludge at its deposition point, thereby eliminating the need for displacement prior to removal. Clarifiers are essentially settlement basins but require different designs depending on the application. The principles governing design of secondary sedimentation tanks are significantly different from those used for a primary clarifier. The major reason for the difference lies in the amount and nature of the solids to be removed. While primary settlers are designed on the basis of overflow rate alone, secondary clarifiers must be designed on the basis of overflow rate and solids loading. The greater concentration and lighter nature of the mixed-liquor suspended solids requires that the underflow concentration be considered in design. Settling rates are slower, as hindered settling prevails instead of free settling which occurs in primary basins. Since particle settling velocity determines tankage volumes, it is apparent that by reducing the vertical dimension required, less space (horizontal area) and time is required. This has promoted other types of settlement methods.

It has been recognized that solids removal by settling could be accomplished within a few minutes if shallow basins could be used, but early prototypes of such equipment were not successful because of problems with flow distribution and sludge removal. Improvements in design have been made, and now two basic types of high-rate settlers are being applied in the treatment of wastewater. These are the tube settlers which consist of modules of inclined tubes with small hydraulic radii suspended in a basin, and the Lamella Separator which consists of suspended, inclined plates. Operating data for wastewater treatment application are limited. Satisfactory operation is indicated for most installations, although there are reports of unresolved problems with buildup of slime growths which may constrict the shallow passages through which the water must pass. Periodic cleaning may therefore be necessary and equipment should be designed to permit ready access to the settling units. The Lamella Separator is recommended for waste water solids removal only in conjunction with chemical coagulation.

1.1.1 Tube Settlers

In the basic tube settler system, wastewater carrying suspended solids is subjected to clarification by particle sedimentation as it moves from an influent well or distribution chamber, upward through small tubes and into a collection gallery, clearwell or launder. The basic configuration for the installation of tube settlers uses the steeply-inclined (45-60°) tubes. When the tubes are installed in this position, continuous gravity drainage of the settleable solids in the tubes is achieved. The incoming solids settle to the tube bottom and then exit by sliding downward as shown in Figure 2. In this flow pattern the solids settling to the tube bottom are trapped in a downward flowing stream of previously settled and concentrated solids.

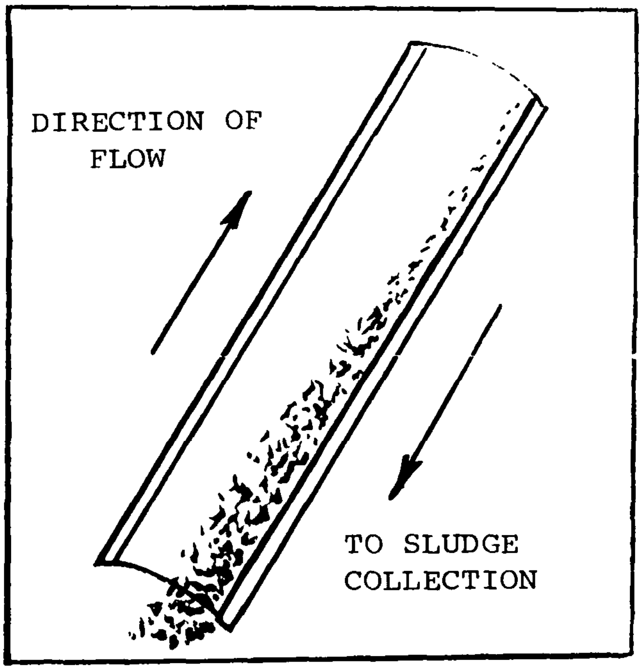


Figure 2. Tube Settlers - Flow Pattern

The tube cross section may be circular, square, rectangular, hexagonal or other suitable shape.

Tests to determine the optimum angle of inclination for tubes showed that, tube efficiency at 60° was comparable to that obtained at 5°. It appeared that, when the angle of inclination exceeded the angle of repose of the settled sludge, additional flocculation occurred as the heavier floc settled and collided with the smaller, upward moving floc, contributing to increased efficiency. A continuing increase in angle eventually results in the tube acting as an upflow clarifier. These settlers, when fabricated as modular sections, Figure 3, can result in loading rates of to 5 times that used for conventional settling basins.

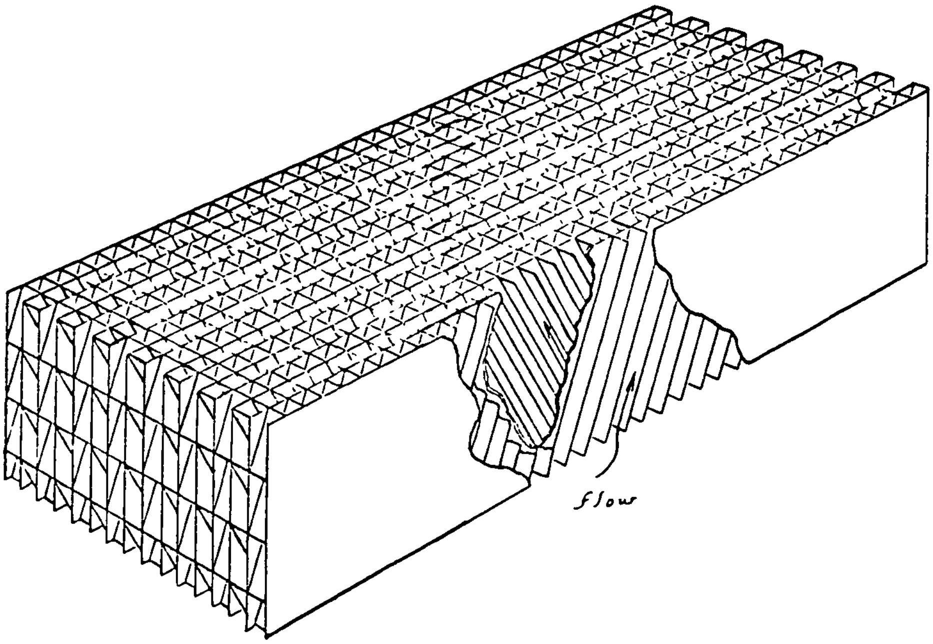


Figure 3. Module of Steeply Inclined Tubes

1.1.2 Lamella Separators

The Lamella Separator shown in Figure 4 consists of a nest of parallel inclined plates through which the suspension is passed, each plate having an effective settling area equal to its projection onto a horizontal plane. By putting the plates in very close proximity, it is possible to obtain a high settling capacity in a very small volume.

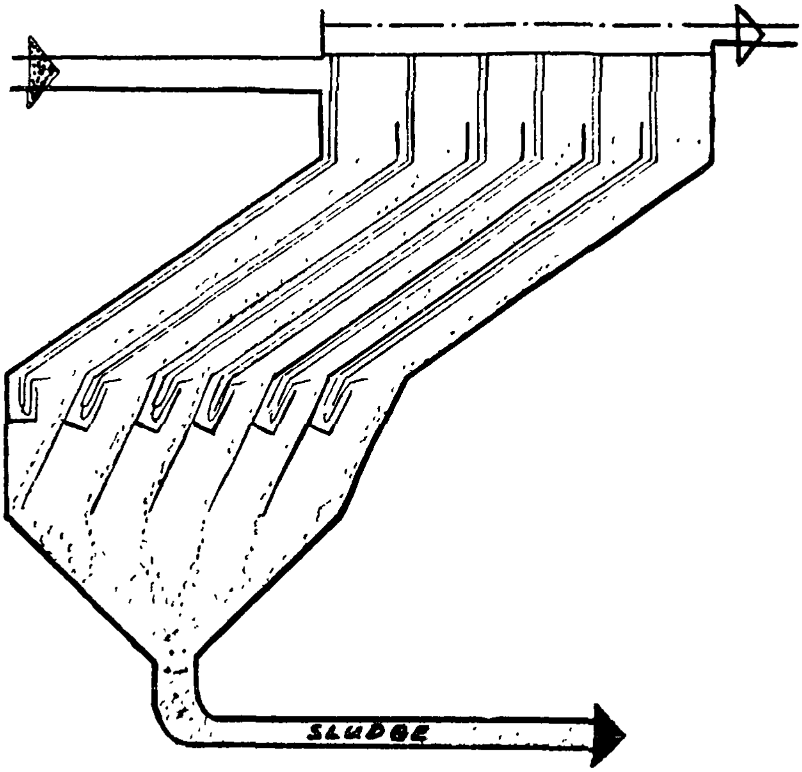


Figure 4. Lamella Settler

(The term "Lamella" refers to the liquid layer between adjacent plates.) The basic difference between the Lamella Separator and tube settling units, which also utilize the principle of multiple inclined surfaces, is that the Lamella Separator is fed from the top whereas the tubes are fed from the bottom. Flow of the liquid is thus cocurrent with the sludge, so that the frictional drag of the liquid and the force of gravity work in conjunction to transport the sludge down the plates. In addition, with the liquid and sludge flowing in the same direction, less shear at the interface and less probability for re-entraining sludge has been claimed.

Although the basic concept of the Lamella Settlers is not new, a number of problems had to be overcome before the idea could be reduced to practice. Of particular importance, the possibility of secondary flows has been reduced by the use of flow stabilizing devices in the inlet to the lamella and by dividing the unit into many compartments. The exit of the clarified effluent is accomplished by a tube network which collects the liquid uniformly across the width of the plate with return through a center tube to prevent recontaminating or disturbing the liquid being clarified.

1.2 FLOTATION

This method is the opposite of sedimentation in that it uses air (dispersed or dissolved) within the clarifier vessel, to float suspended solids which are removed by skimming or vacuum operated ports. The clarified effluent exits below the froth surface to prevent interference. This process is not well suited to small, varying load rates as handling the frothy sludge and providing adequate detention time to float the solids is a major challenge to the small flow system.

1.3 VORTEX DEVICES

The General Electric Comapny has been instrumental in developing sewage vortex chambers to provide gross removal of solids (interceptor) before the sewage reaches the treatment plant. This device, by inducing eddy currents causes heavier solids to migrate toward the center where a baffle separates the solids concentrate stream from the liquid carrier with the cleaned liquid exhausted over a weir (See Figure 5).

1.4 CENTRIFUGES

These machines have enjoyed increased use as both a solids separator and sludge concentrator.

There are three families of centrifuge configurations, basket, disc, conveyor, each having unique as well as overlapping performance features. The ultimate selection usually involves actual testing with the media requiring separation/concentration. This, because of the lack of knowledge of solid/liquid chemical-physical suspensions in solution. These centrifuges and their broad applications functions are presented in Figure 6.

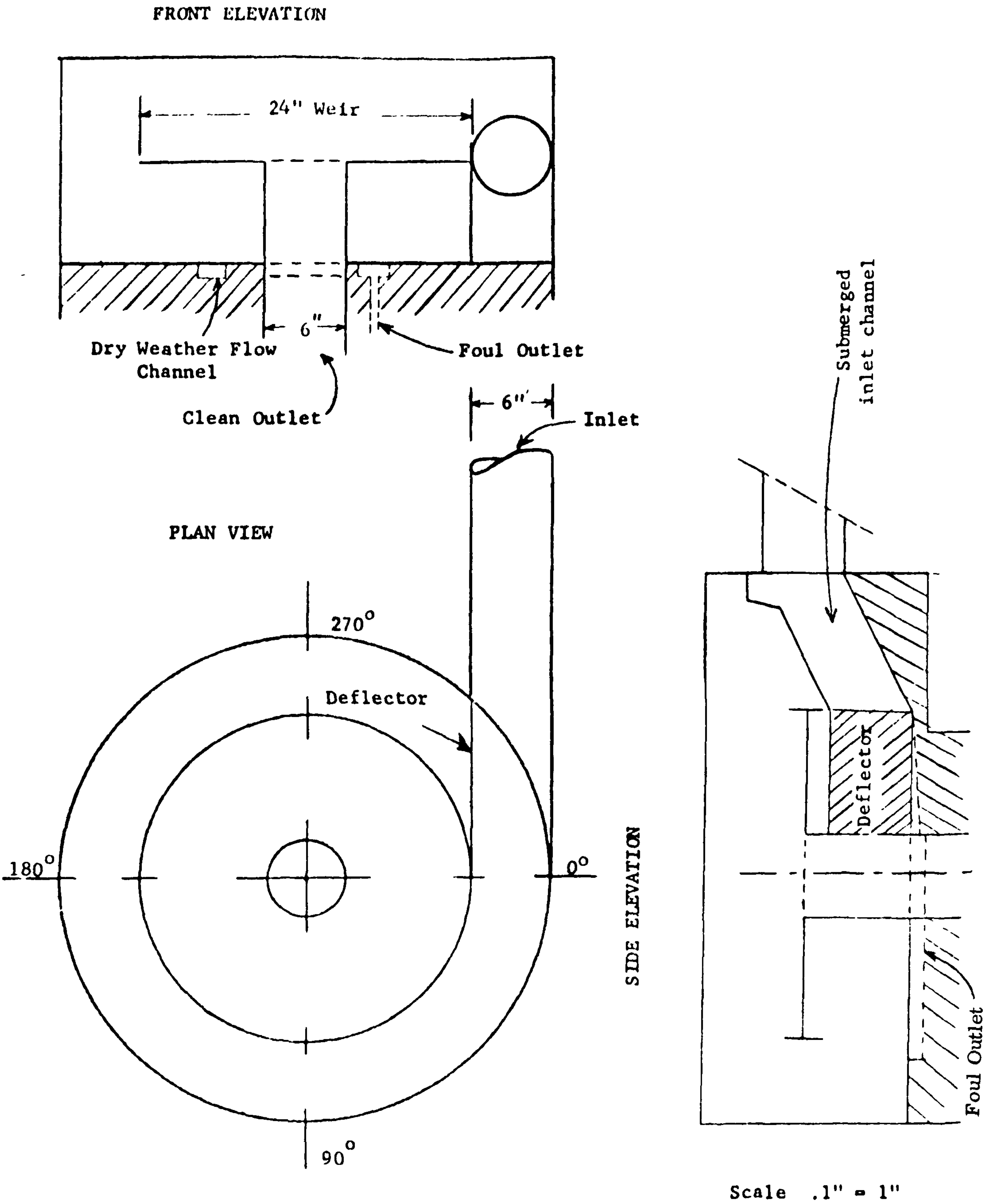
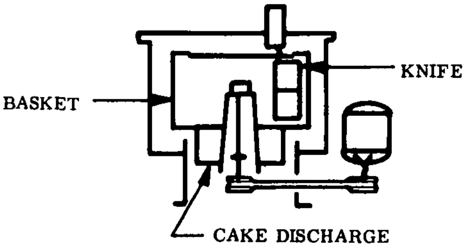
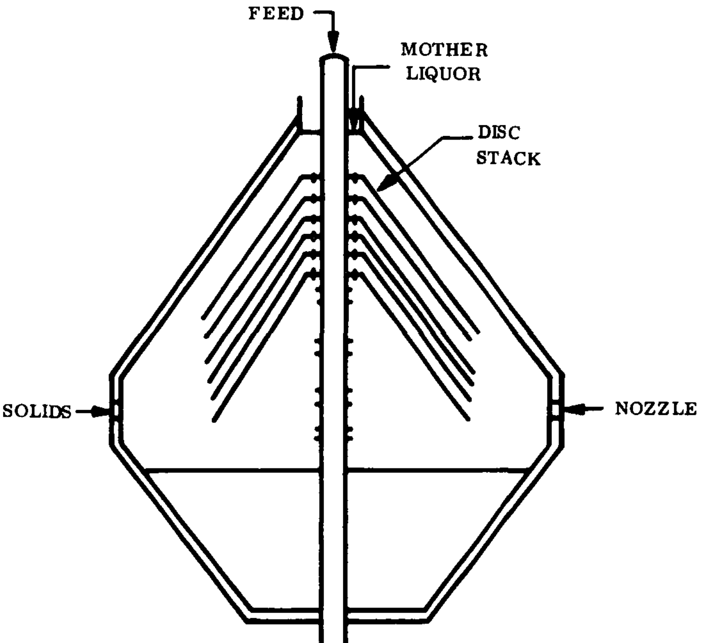


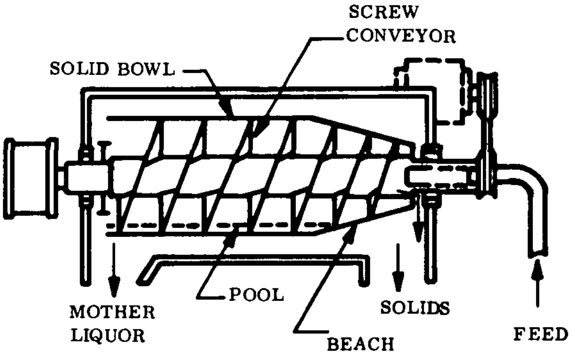
Figure 5. Diagram of Swirl Chamber



a. Basket Centrifuge



b. Disc Centrifuge



c Conveyor Centrifuge

CENTRIFUGE	DEWATERING	CLASSIFICATION	CLARIFICATION	APPLICATION
a. BASKET				
PERFORATE	VERY GOOD	GOOD	POOR	COARSE SOLIDS
IMPERFORATE	FAIR	POOR	GOOD	FINE AND COARSE SOLIDS
b. DISC	POOR	GOOD	VERY GOOD	FINE SOLIDS
c. SOLID BOWL (CONVEYOR)	GOOD	FAIR	FAIR TO GOOD	FINE AND COARSE SOLIDS

Figure 6. Centrifuge Types for Wastewater Applications

1.4.1 Basket

The operation of this device involves several time sequenced steps:

1. Load at selected speed
2. Accelerate to full speed
3. Purge cake at full speed (optional)
4. Declerate to unload speed
5. Unload

Unloading is accomplished by activating a knife, or plow, and displacing it outward towards the basket wall capturing the retained cake and routing it to the discharge. (See Figure 6a) There are two versions of the basket, perforate and imperforate. The perforate basket centrifuge finds applications in handling uniform coarse solids at high slurry concentrations where the cake is washed and/or dryed. The imperforate basket, a semi-continuous machine, can produce good clarification of fine solids but limited dewatering. It finds application in dilute concentration of fines. The unit operates at lower speeds and generates lower centrifugal forces.

1.4.2 Disc

The disc type centrifuge is a continuous processing device with self-cleaning capability when coupled to automatic variable discharge nozzles. The nozzle ejecting feature permits programmed removal of solids from the conical chamber using either a time base or sludge density (back-pressure) sensing control scheme.

Viewed in cross-section (Figure 6b), the disc centrifuge looks like a stylized Christmas tree. The discs are mounted on a vertical shaft, are spaced 0.025 to 0.075 in. apart, and make an angle of 35 to 45 deg. with the shaft. The angle is critical, being steep enough to shorten the settling distance but not so steep that it prevents the cake from sliding out of the disc stack and into the centrifuge body. Disc spacing is important also because, if too wide, it unnecessarily increases settling time and, if too narrow, causes untimely plugging of the disc stack.

The design of this centrifuge permits it to capture and to polish slurries containing very fine solids. The high G forces available make this an excellent clarifying unit. However, the disc centrifuge is not a good dewatering unit. Clarification, thickening, emulsion breaking, and some washing and fines classification are all prime functions of this centrifuge. Typical applications have been cream-milk separation, oil-water-solids separation, thickening of starch, and clay-silt classification.

1.4.3 Conveyor (decanter)

The solid cylindrical bowl has a tapered end, also called the beach, where final dewatering (i.e., decanting) takes place (See Figure 6c). Inside the bowl a screw conveyor (scroll) rotates slightly slower or faster than the bowl in order to push collected sediment out of the machine. Becuase the solid cake must pass through the liquid/solid interface without collapsing, not all sludges can be handled by this equipment; some cakes are too "soft" to withstand the trip up the beach and out of the liquid. Since the time available on the beach for drainage is limited, the entrained liquor content of the solids is higher thereby resulting in a "dryer" sludge or in other words, less fines to wetten the discharged solids. The conveyor centrifuge can classify, dewater or clarify the influent despite its lower developed centrifugal force. Typical applications are drilling mud classification, coal dewatering, antibiotic clarification, lime mud classification, and dewatering of pulp and paper mill wastes and wastewater sludges.

A summary of these centrifuge capabilities and fundamental operating mechanisms are presented as Tables 1 and 2.

Some applications data, from existing installations, reveals the actual performance attained from each type as summarized in Table 3.

There are several operating parameters influencing the final removal (concentration) attained including bowl speed (g's), feed rate (residence time), solids ejection frequency (percent concentration), influent suspended solids (average particle size and size distribution), and use of cationic flocculant aids. Mechanically, the disc centrifuge variables are nozzle

Table 1. Centrifuge Capabilities*

	Tubular bowl (Batch or continuous)	Disc (Batch or continuous)	Decanter (Continuous)	Solid-bowl basket (Batch)
Bowl diam (in.)	4-5	8-32	6-60	12-60
Flow rate, feed (gpm)	2-20	10-300	1-200	up to 100
Solids in feed	<0.1	0.1-10	**	0.1-3.0
Discharged solids	10 lb per batch	20 lb per batch (10-3000 gal/hr)	<1-15 tons/hr	up to 1050 lb
Temperature range (°F)	up to 450	−40-+300	−100-+400	up to 450
Pressure range	up to 5 in. water	−28 in. Hg to 150 psig	−28 in. Hg to 150 psig	up to 5 psig
Speed (rpm)	up to 15,000	4500-10,000	1000-6000	up to 2500
Gravity (G forces)	up to 13,000	up to 12,000	up to 3200	up to 2100
Motor power (hp)	2-5	10-125	5-250	up to 100
Particles removed	<1µ	<1-1000µ	2µ to .25 in.	1+µ

* For machines found in water and waste treatment plants

** Any liquid or slurry that can be pumped

Table 2. Fundamental Operating Mechanisms

	Mechanism of Primary Liquor Separation	Mechanism of Solids Dewatering	Mechanism of Solids Discharge
Manual discharge batch centrifugal filter	Drainage from static bed	Centrifugal drainage in static bed	Manual discharge
High speed batch automatic centrifugal filter	High centrifugal force	Centrifugal drainage in static bed	Automatic knife discharge at full operating speed
Multispeed batch automatic centrifugal filter	Drainage from static bed during acceleration part of cycle	Centrifugal drainage in static bed	Automatic knife discharge at low speed
Self-discharging centrifugal filter	Drainage from dynamic bed	Centrifugal drainage in dynamic bed	Self discharge from conical centrifugal filter bowl
Pusher discharge centrifuge	Preconcentration in conical filter section followed by drainage from dynamic bed	Centrifugal drainage in dynamic bed	Pusher discharge
Scroll discharge centrifugal filter	Drainage from dynamic bed	Centrifugal drainage in dynamic bed	Scroll discharge mechanism
Solid bowl scroll discharge centrifugal sedimentor	Centrifugal sedimentation	Centrifugal compaction and drainage	Scroll discharge mechanism
Scroll discharge centrifugal sedimentor/filter	Centrifugal sedimentation	Centrifugal drainage in dynamic filter bed	Scroll discharge mechanism

Table 3. Applications of Centrifuges

Application		Solids		Cake (% solids)	Polymer added* (lb/ton)
Effluent	Treatment	As fed	As discharged		
SOLID-BOWL SCROLL CENTRIFUGE					
Paper mill, paper	Primary; primary, secondary	Coarse, fibrous, claylike	Relatively dry	23–40	None
Municipal	Primary raw	Coarse, fibrous, claylike	Relatively dry	30–40	1.5–2.5
Municipal	Primary digested, mixed digested	Coarse, fibrous, slimy	Slimy to dry, depends on primary-secondary ratio	20–30	3-6
Municipal	Primary raw, secondary	Coarse, fibrous, slimy	Slimy to dry, depends on primary secondary ratio	18-22	4–6
Refinery	...	Gritty, coarse	Dry to pudding	20–25	None
Paper mill, municipal	...	Slimy, thickened	Thick pudding	18–22	10-20
Paper mill, water treatment	Lime sludge, water softening	Claylike	Dry	40–60 (depends on % magnesium hydroxide)	None
Steel mill	Pickle liquor, neutralized	Some floccy, some clay	Very thick pudding (can be shoveled)	20–30	1–2
DISC-TYPE CENTRIFUGE WITH NOZZLES					
Paper, municipal	Waste activated	Slimy	Thickened (for further dewatering or digestion)	6–7	None (or <1)
Refinery	Liquid liquid solids	Oil-water emulsion; some fine claylike solids	Oil water emulsion split, solids concentrated	Oil (<1% water), solids (7–10%)	None
Water treatment plant	Alum floc	Slimy, floccy	Thin, floccy	5-7	<1
SOLID-BOWL BASKET (IMPERFORATE) CENTRIFUGE					
Municipal	To improve recovery†	Floccy, slimy	Thick pudding	10–14	None
Water treatment chemical waste	Alum floc, hydroxide sludges	Floccy	Very thick pudding	15-25	None (or <1)

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*Recovery, 85–90%

†Following solid bowl scroll

size, disc spacing, method of introducing feed to the disc stack and, if used, sludge recycle. For the conveyor machine the mechanical variables are bowl speed, differential scroll speed and pool (or pond) depth. Finalized design is not presently feasible without pilot tests because of the complicated interrelationships (and unknowns) of these values, the specific characteristics of the influent sludge and the desired quality (density, wetness) demanded of the thickened output. General operating characteristics and approximate machine response limitations are shown in Table 4.

Table 4. Operating Characteristics of Solid Dewatering Centrifuges

Operating Characteristic	**Manual-Discharge Batch Centrifugal Filter**	**High-Speed Batch Automatic Centrifugal Filter**	**Multispeed Batch Automatic Centrifugal Filter**	**Self-Discharging Centrifugal Filter**	**Pusher Discharge Centrifugal Filter**	**Scroll Discharge Centrifugal Filter**	**Solid Bowl Scroll Discharge Centrifugal Filter**	**Scroll Discharge Centrifugal Sedimentor/Filter**
Dependence on mean particle size of feed solids	Generally down to 25μ	Generally down to 100μ, but less in special cases	Generally down to 50μ, but less in special cases	Generally $>100\mu$	Generally $>100\mu$	Generally $>100\mu$	Generally $>10\mu$	Generally $>10\mu$
Dependence on particle size of feed solids	No limitation	No limitation	No limitation	Dependence on fines tail	Dependence on fines tail	Dependence on fines tail	No limitation	Dependence on fines tail
Approximate lower size limit of solids which centrifuge is capable of handling	Down to about 2μ	Generally down to 50μ, but down to 10μ in special cases	Generally down to 25μ, but less in special cases	Generally down to 60μ	Generally down to 60μ	Generally down to 60μ	Down to 1μ in special cases	Generally down to 10μ
Dependence on particle shape of feed solids	Largely independent excepting effect on capacity	Gives exceptionally low capacities on needle or plate-like particles	Largely independent excepting effect on capacity	Independent	Independent	Independent	Needle or plate-like particles will cause inferior performance, e.g., loss to filtrate	
Dependence on density differential between solids and liquor in feed	Independent	Independent	Independent	Independent	Independent	Independent	Solids must be of greater specific gravity	Solids must be of greater specific gravity
Approximate lower limit of feed solids concentration which centrifuge can handle	Zero	Zero	Zero	5 to 10% weight	15% weight	5 to 10% weight	Zero	Zero
Dependence of performance on constant feed solids concentration	Independent	Independent since the feed time is controlled by cake thickness		Sensitive with dilute feeds	Sensitive with dilute feeds	Independent	Independent	Independent
Loss of solids to filtrate	Zero	Small	Small except at beginning of cycle, but smaller per unit capacity than H.S. type	Loss of about 50% of material below 100μ		Loss of about 66% of material below 100μ	Negligible (dependent on size particle)	Negligible (dependent on size particle)
Liquor content of solid product	Minimal with considerable operating flexibility	Minimal with great operating flexibility	Minimal with great operating flexibility	Small due to discharge at high 'g'	Wetter due to discharge at low 'g'	Small due to discharge at at high 'g'	Wetter due to incomplete drainage ability	Small due to drainage ability plus high 'g'
Limiting purity of solid product	No limit great flexibility	No limit great flexibility	No limit great flexibility	Limited wash effect possible, little flexibility	High wash efficiency due to thick bed	Moderate wash efficiency due to thin bed, little flexibility	Moderate wash efficiency, little flexibility	High wash efficiency due to wash on already 'dry' solids
Wash liquor consumption for given washing performance	High due to inconsistencies in cake thickness	Low due to regularly reproduced cake conditions	Low due to regularly reproduced cake conditions	High due to uneven cake formation	Low due to even cake formation	Moderate due to uneven cake	Moderate due to incomplete drainage	Low due to wash on already 'dry' solids
Ability to keep separate drained wash liquor and mother liquor	Excellent	Excellent	Excellent	Difficult	Possible but incomplete	Some difficulty	Unable	Excellent
Solids breakage	None	Appreciable	Very slight	Appreciable	Slight	Moderate	Moderate	Moderate

2. FILTRATION

For purposes of distinction in solids removal processes, filtration is defined as any interruption of a slurry (two-phase) flow caused by a mechanical interference designed to segregate the solids from the liquid carrier. All filter processes generally strain the desired solids from the liquid carrier, until the mesh, grating or bed is clogged impairing further liquid pass-through (high pressure drop across filter media) at which time flow is ceased, or diverted and the filter cleaned.

2.1 MECHANICAL GRATES AND SCREENS (STRAINERS)

In most conventional waste treatment systems, the first operating element is a bar screen (grate) to remove large objects not readily amenable to the slower flow rates usually characteristic of following treatment stages (e. g. the sewer flow rates are much higher than the treatment plant unit process flow rates). This type of hardware is not particularly noteworthy in a discussion of waste treatment processes state-of-the-art-status. Further information can be found in most basic texts of conventional system design.

Advanced mechanical filtration devices include: microscreening, vacuum and pressure filters. A cursory selection chart (Table 5) shows some basic slurry requirements and filter types basically compatible to the ranges of each parameter.

2.1.1 Microscreening

Microscreening consists of a rotating drum with a fine screen covering the cylindrical periphery of the drum (See Figure 7). Feedwater enters the drum through the open end and passes radially through the screen with concomitant deposition of solids on the inner surface of the screen. At the top of the drum, pressure jets of effluent water are directed onto the screen to remove the mat of deposited solids. The portion of the backwash stream which penetrates the screen and the dislodged solids are captured in a waste hopper and are removed through the hollow axle of the unit.

Table 5. Filter Selection vs. Application

Slurry characteristics	**Fast Filtering**	**Medium Filtering**	**Slow Filtering**	**Dilute**	**Very Dilute**
Cake formation rate	ins /sec.	ins /min.	0.05 to 0.25 in./min.	<0.05 in./min.	no cake
Normal concentration	>20%	10 to 20%	1 to 10%	<5%	<0.1%
Settling rate	rapid, difficult to suspend	fast	slow	slow	—
Leaf test rate, lb./hr./sq. ft.	>500	50 to 500	5 to 50	<5	—
Filtrate rate gal./min./sq. ft.	>5	0.2 to 5	0.01 to 0.02	0.01 to 2	0.01 to 2
Filter Application					
Continuous vacuum filters:					
Multicompartment drum	—	—	—		
Single-compartment drum	—				
Dorrco	—				
Hopper Dewaterer	—				
Top feed	—				
Scroll-discharge	—	—			
Tilting-pan	—	—			
Belt	—	—			
Disk		—	—		
Precoat				—	—
Continuous pressure precoat				—	—
Batch vacuum leaf		—	—	—	—
Batch nutsche	—	—	—	—	—
Batch pressure filters:					
plate-and-frame		—	—	—	—
vertical leaf		—	—	—	—
tubular		—	—	—	—
horizontal plate	—	—	—	—	—
cartridge, edge					—

Screens employed in microscreening have extremely small openings and are made from a variety of metals and plastics. Individual manufacturers each have specific designs and sizes for the peculiar needs of any potential installation. Some examples of microfabrics available from various manufacturers are:

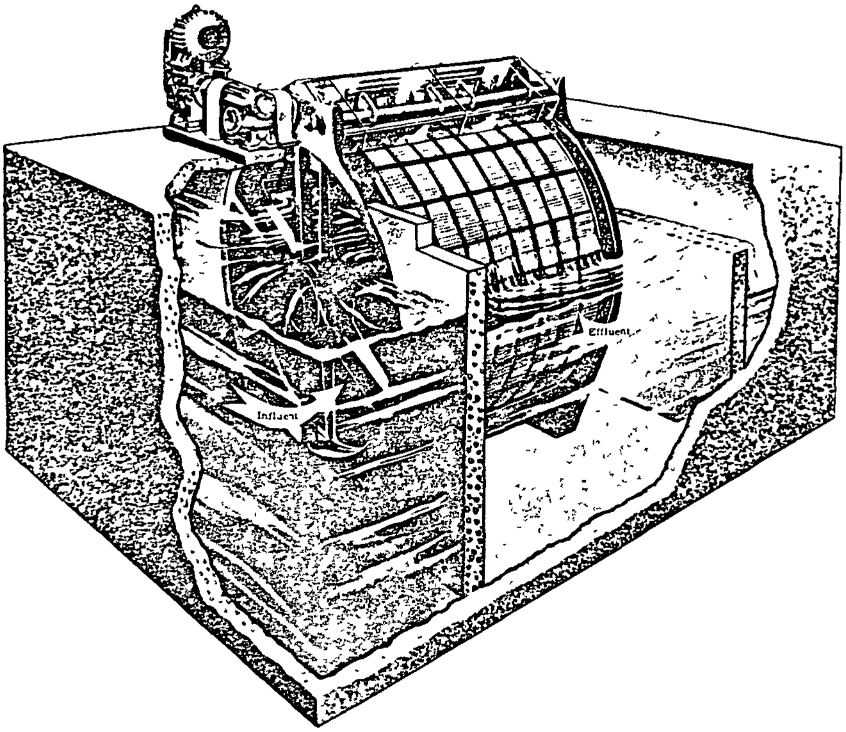


Figure 7. Typical Microscreen Unit

Opening (Microns)	No./In^2	Manufacturer
23	144,000	Crane Co., King of Prussia, Pa.
25	-------	Walker Equipment Co., Chicago, Ill.
35	80,000	Crane Co., King of Prussia, Pa.
35	120,000	Zurn Industries, Inc., Erie, Pa.
40	-------	Walker Equipment Co., Chicago, Ill.
60	58,000	Crane Co., King of Prussia, Pa.

The weave and shape of individual fabric wires are such that they allow the water from the backwashing jets to penetrate and detach the solids mat which forms on the inside of the screen during its passage through the feed stream. Although the microscreens have small openings, they cannot account for the removal efficiency of the unit. Actually, the mat of previously-trapped solids provides the fine filtration which characterizes the unit performance. Slimes form over a period of time on the screen surfaces that require periodic removal. Several automatic methods have been employed to provide this cleansing including steam and/or hot water jet sprays. The frequency of backwashing or screen cleaning of grease, and fat coatings is dependent upon the specific characteristics of the influent. These devices are usually employed to secondary or tertiary effluent. One of the advantages of using microscreens is their low heat requirement. It is feasible, therefore, and advantageous to conduct secondary effluent without pumping to a tertiary microscreening installation in order to minimize the shear forces imparted to the biological floc. Chlorination immediately ahead of microscreening units should be avoided to protect the screens. Typical performance of these devices installed as a post tertiary treatment filter is shown in Table 6.

Table 6. Tertiary Treatment by Microscreeners

Location	Screen Size (Microns)	Plant Size (MGD)	S S. (Rem. %)	BOD (Rem. %)	Backwash (%)	Manufacturer
Luton, England	35	3.6	55	30	3.0	Crane
Bracknell, England	35	7.2	66	32	N.A	Crane
Harpendon, England	35	0.3	80	N.A.	N.A.	Crane
Brampton, Ontario	23	0.1	57	54	N.A.	Crane
Chicago, Illinois	23	2.0	71	74	3.0	Crane
Lebanon, Ohio	23	Pilot	89	81	5.3	Crane
	35	Pilot	73	61	5.0	Crane
Miami, Florida (S. Gulf Utilities)	N.A.	N.A.	N.A.	N.A.	N.A.	Zurn
Islip, New York	N.A.	0.165	99	96	N.A.	Zurn
Murfreesboro, Tennessee	N.A.	N.A.	N.A.	N.A.	N.A.	Zurn
Howell Twp., New Jersey	N.A.	N.A.	N.A.	N.A.	N.A.	Walker
Columbia, South Carolina	N.A.	N.A.	N.A.	N.A.	N.A.	Walker
Macomb, Illinois	N.A.	N.A.	N.A.	N.A.	N.A.	Walker

N.A. = Not available

Rotary screens, similar in principle and appearance to microscreeners, are available for more gross solids removal. Also, vibratory self-cleaning screens are being used for similar purposes. Their major use is generally in industrial waste treatment to remove the coarser solids prior to disposal or further treatment. Recently, these self-cleaning rotary and vibratory screens have been utilized for treatment of combined sewer overflows with some success. Their advantage in such applications is owed to their compact size and their ability to operate on a start and stop mode. Suspended solids removals for these systems have generally ranged from 20 to 40 percent.

2.2 DIATOMACEOUS EARTH FILTERS

Diatomaceous earth (DE) filters have been applied for the clarification of secondary effluents at pilot scale. No full-scale installations have been characterized in the literature. DE filtration utilizes a thin layer of precoat formed around a porous septum to strain out the suspended solids in the feedwater which passes through the filter cake and septum. The driving force can be imposed by vacuum from the product side or pressure from the feed side. As filtration proceeds, headloss through the cake increases due to solids deposition until a maximum is reached. The cake and associated solids are then removed by flow reversal and the process is repeated. In the cases where secondary effluents have been treated by this process, a considerable amount of diatomaceous earth (body feed) has been required for continuous feeding with the influent in order to prevent rapid buildup of head-losses and subsequent uneconomically short filter runs. Generally, the DE filtration process is capable of removing suspended solids, but not colloidal matter. A schematic drawing of a DE system during operation is shown in Figure 8. A wide variety of diatomaceous earth (diatomite) grades are available for use. As might be expected, the coarser grades have greater permeability and solids-holding capacities than do the finer grades which will generally produce a better effluent. Fly-ash has been used as body feed, also. Some grades of diatomite are pretreated to change their characteristics for improved performance.

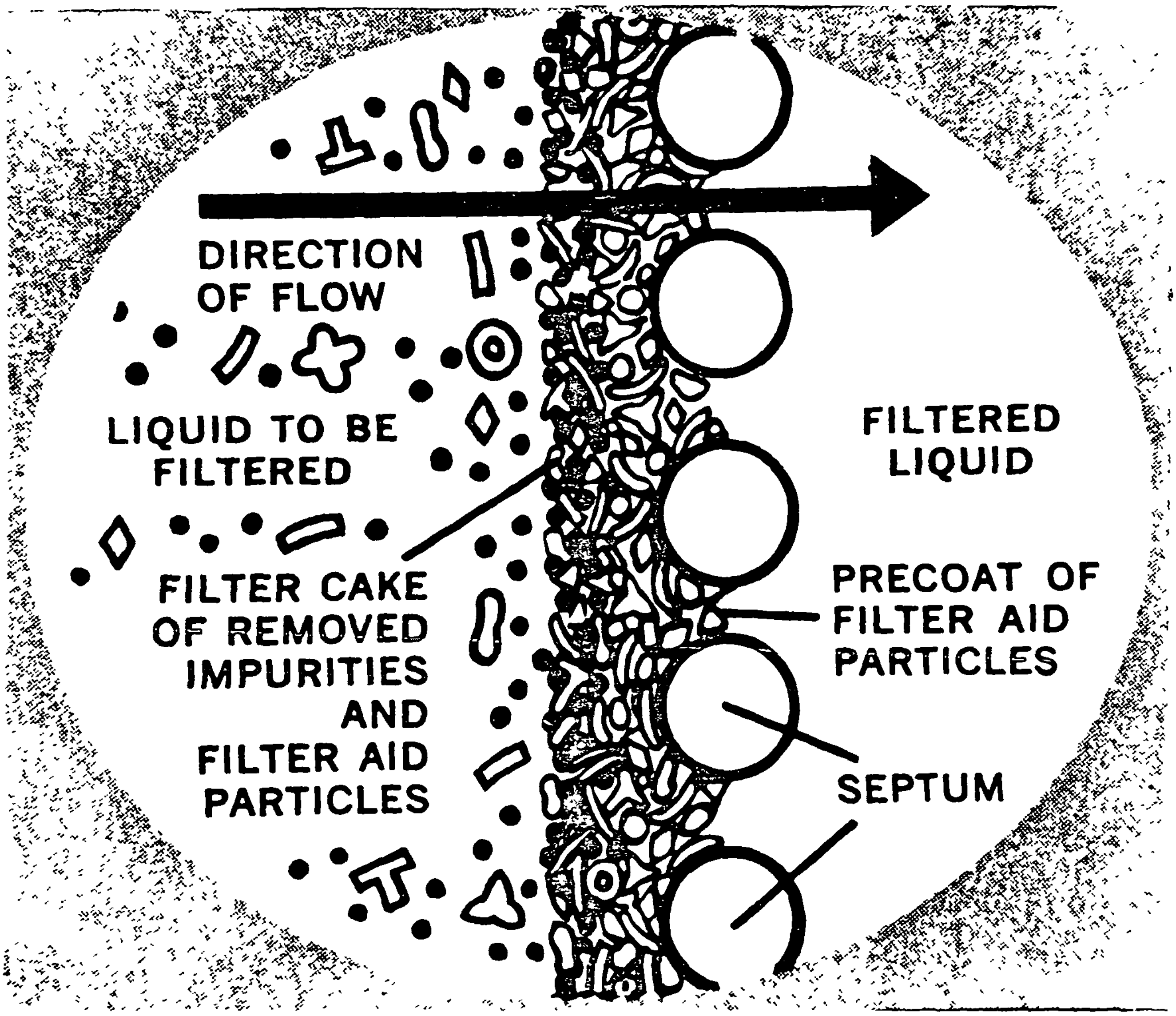


Figure 8. Diatomite Filtration System Detail

The filtration cycle can be divided into two phases, run time and down time. Down time includes the periods when the dirty cake is dislodged from the septum and removed from the filter and when the new precoat is formed. Most of the difficulties involved in these operations are dependent upon the equipment design of the individual manufacturer. Run time commences when the feed is introduced to the filter and ends when a limiting headloss is reached or an effluent quality degradation occurs. The single most important problem with secondary effluent filtration by DE filters is the amount of body feed required during the filtration or run time. These devices are operated similar to the microscreeners except that vacuum or pressure assist is employed to force the influent through the precoat and body feed constrained by the septum. Results of a coordinated pilot test (Ref. No. 61) using secondary effluent is presented in Tables 7 and 8. Comparisons indicate the vacuum machine was more effective in five solids removals and in shorter run-lengths. A vacuum filter is shown in Figure 9.

2.3 DEEP BED FILTRATION

The unit process of deep-bed filtration encompasses exhaustion of the bed followed by a regeneration. Water containing suspended solids is passed through a bed of granular material resulting in deposition of the suspended solids in the bed. Eventually the pressure drop across the bed becomes excessive or the ability of the bed to remove suspended solids is impaired. Thereupon filtration is stopped and the bed is cleaned prior to being placed back in service. The most common type is the "rapid sand" type as shown in Figure 10.

Table 7. Vacuum Diatomaceous Earth Filtration of Secondary Effluent

Flow Rate (gpm/ft^2)	Filter Aid	Body-feed Conc (mg/l)	No of Runs	Run-length (hrs)	Turbidities (JTU)* Feed	Turbidities (JTU)* Product
0.53	Celite 545**	42	5	19.5	5.5	0.8
0.75		33	3	10.7	5.2	0.8
1.0		19	1	5.4	4.4	0.4
0.51	Celite 503**	36	2	8.0	10.5	3.3
0.75		29	1	3.0	9.2	0.7
1.0		21	1	1.2	8.0	0.75
0.54	Hyflo Super-Cel **	35	6	12.7	4.6	0.85
0.75		21	2	4.4	5.8	0.8

Precoat - 0.1 lb/ft^2
Headloss at end of run – 18 in. Hg
*Jackson Turbidity Units
**Product of Johns-Manville, New York, N.Y. 10016

Table 8. Pressure Diatomaceous Earth Filtration of Secondary Effluent

Flow Rate (gpm/ft^2)	Filter Aid	Body-feed Conc (mg/l)	No of Runs	Run-length (hrs)	Turbidities (JTU)*	
					Feed	Product
0.50	Celite 545**	50	1	50.0	8.2	3.1
0.75		19	2	24.2	5.7	2.5
0.81		42	2	28.4	8.3	3.9
1.0		20	2	7.3	6.4	2.1
1.0		45	3	31	7.5	3.0
0.76	Celite 503**	18	1	14.5	7.0	4.0
0.78	Hyflo	21	1	22.3	8.1	4.9
1.2	Super-Cel **	29	1	9.7	6.5	3.8

Precoat – 0.1 lb/ft^2
Head loss at end of run 35 psi

*Jackson Turbidity Units
**Product of Johns-Manville, New York, N Y 10016

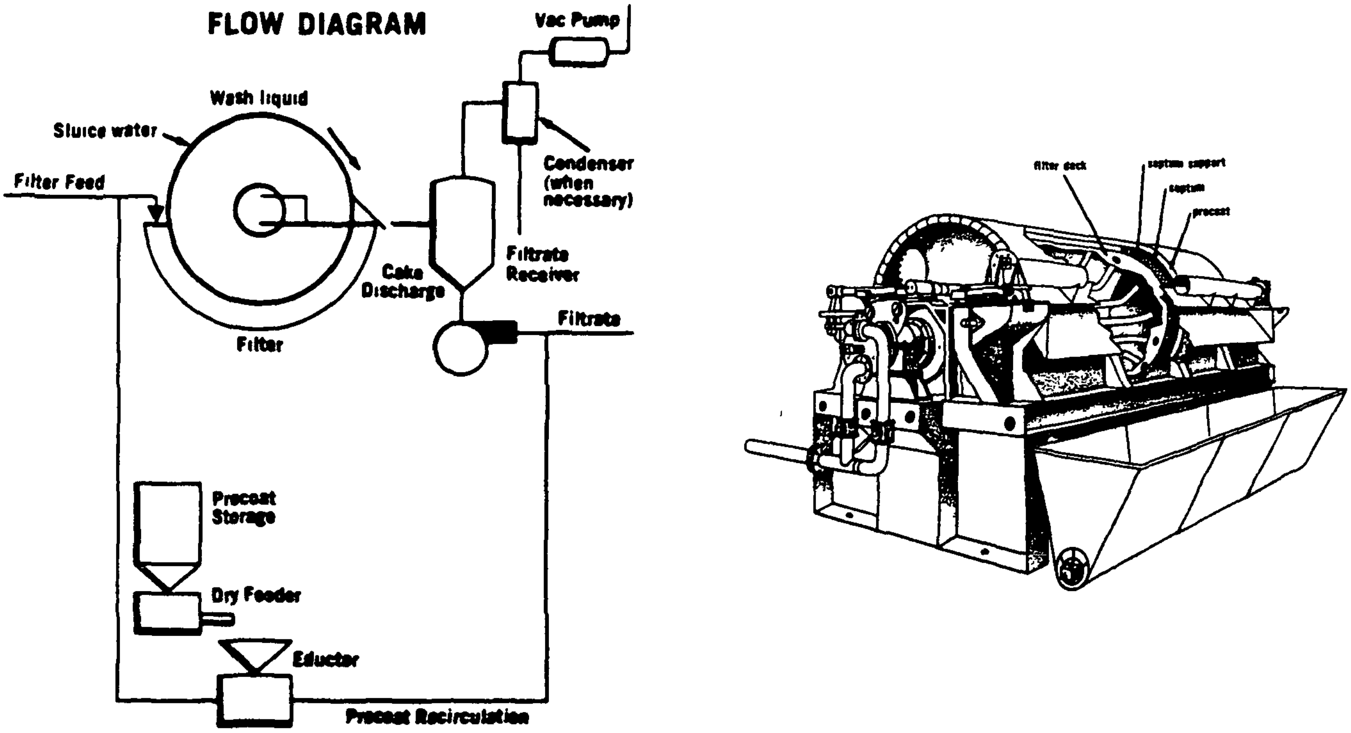


Figure 9. Rotary Vacuum Precoat Filter

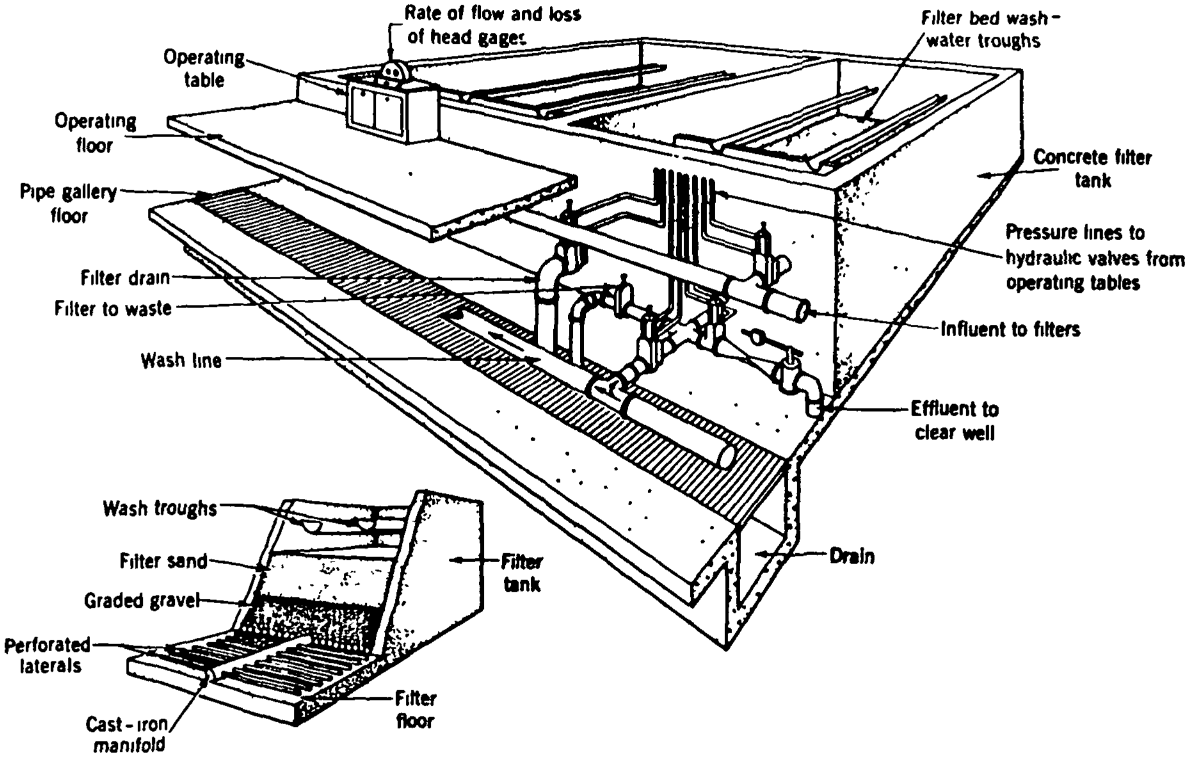


Figure 10. Typical Rapid Sand Filter

In essence the filter is a box containing filter media, an underdrain system, a backwash system, flow control systems and various conduits for bringing feedwater and wash water to and conveying filtrate and used wash water away from filter. There is little difference between the pressure and gravity flow filters except for the pressure housing. Because of size restrictions on pressure filters they are equipped with a simpler wash water collection trough system than gravity filters. A pressure in-depth filter is shown in Figure 11 and its operation described below.

The dirt-laden liquid enters the center of the filter bed through the inlet conductor. A portion of the liquid over-flows the inlet conductor pipe and filters down through the media, similar to conventional depth filters. The largest liquid volume flows radially outward, from the inlet conductor through the increasing media volume. The resulting velocity decrease permits easier dirt entrapment than if the velocity remained constant. The high inlet velocities drive the contaminant into the bed, minimizing surface loading. Clean liquid passes through the wedgewire outlet septums and can be recirculated or discharged to sewers and waterways.

Backwash is accomplished using unfiltered water, requiring only 2% of the filtered volume. Contaminants are separated by removing the media from the filter hydraulically and pumping it through the dynamic media scrubber at velocities exceeding 20 fps. The resulting violent agitation and bombardment of particles against each other induces a thorough scrubbing action in the mass, separation oils, greases and suspended particles from the media. The mixture of contaminants, water and media passes through the scrubber and over a wedgewire septum. Internal hydraulic pressures force the contaminants and water through the septum and out of the scrubber backwash discharge pipe. Clean media flows past the septum and is returned to the filter by the scrubber pump for reuse, beginning a new filtration cycle. Filter media for any application is the most important determinant in filter design. The size, type and depth of the media is evaluated for a full scale system by initial pilot studies. Sand is the most common media followed by coal. A recent trend in filtration has been the adoption of the multi-media concept. Conventional single medium filters have a fine to coarse gradation in the direction of flow which results from hydraulic gradation during backwash. This type of gradation is not efficient as virtually all of the removal and storage must take

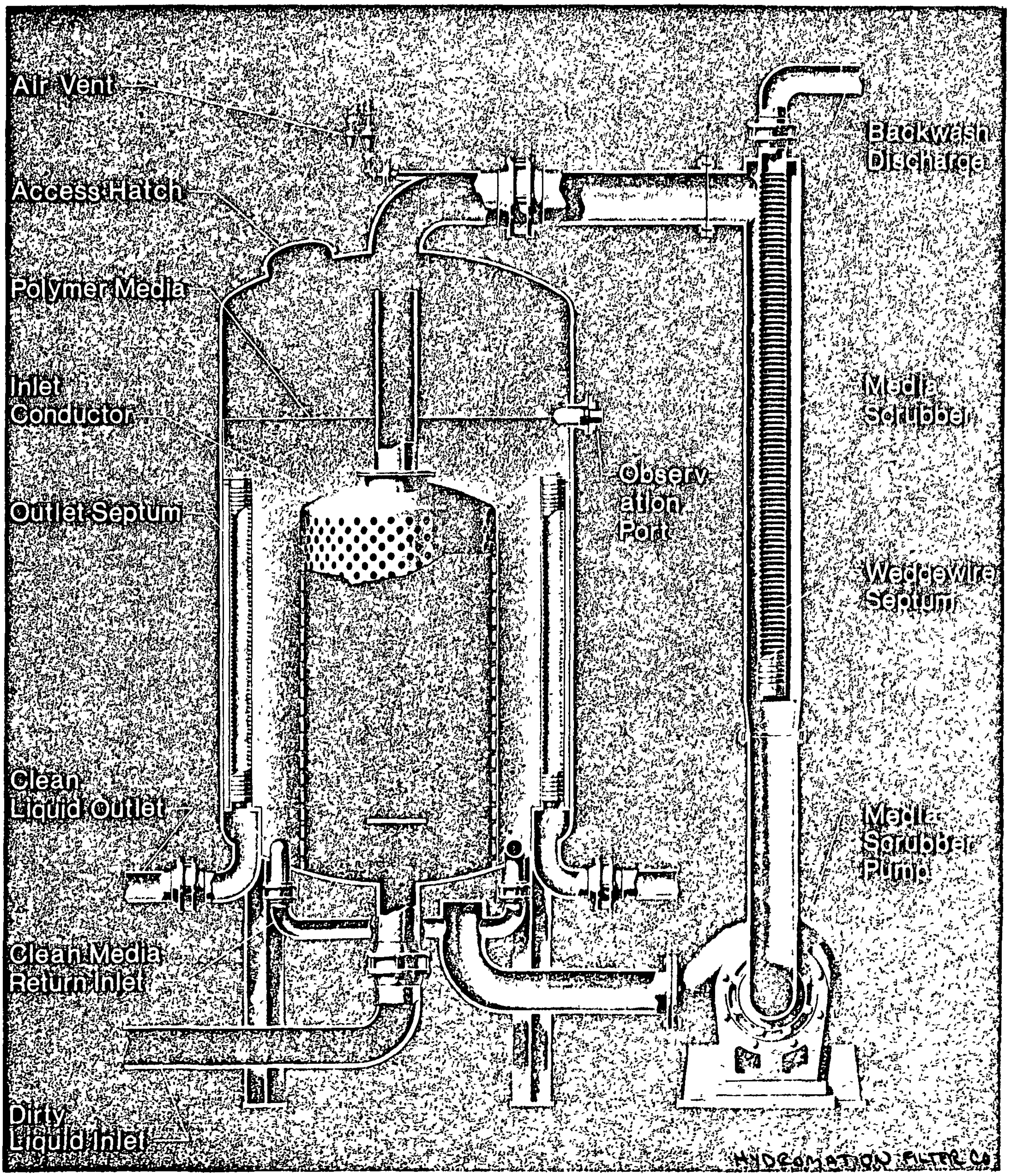


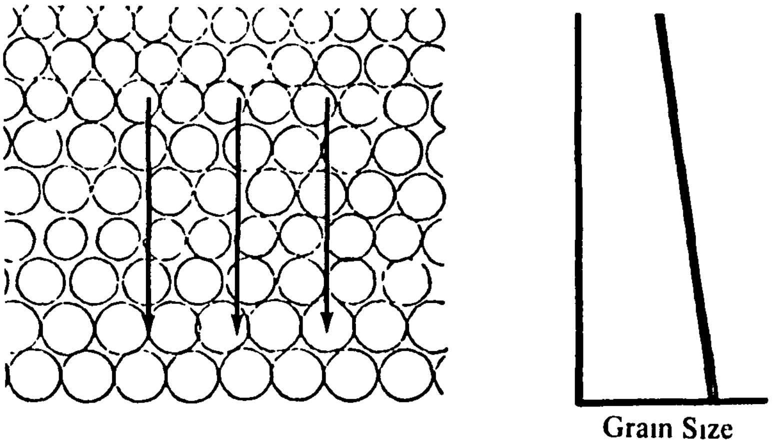
Figure 11. In-Depth Filter

place in the upper few inches of the filter with a consequent rapid increase in headloss. A coarse to fine filter gradation is much more efficient as it provides for much greater utilization of bed depth, using the fine media only to remove the finer fraction of the suspended solids.

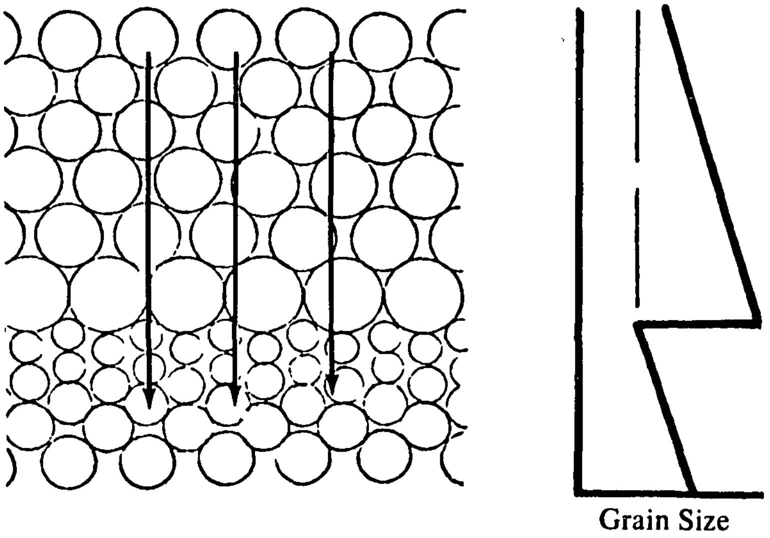
One method of obtaining a coarse to fine filter gradation is the dual-media filtration concept. This employs the use of a layer of coarse anthracite coal over a layer of fine sand. The sizes of the anthracite and sand are chosen so that the coarser but lighter anthracite (specific gravity 1.6) will remain above the heavier (specific gravity 2.65) but smaller sand during backwash. It is desirable to have the coal as coarse as possible to prevent surface blinding and the sand as fine as possible to promote high degrees of removals. However, the disparity in sizes cannot be too great or overtopping of the coal by the sand would result. In general, sand sizes much finer than 40 mesh are not utilized because the coal size required to prevent overtopping by sand during backwash would be too small to allow high filtration rates. To ascertain the degree of mixing which will occur during backwashing and its effects on subsequent filter performance, pilot column studies are best utilized.

Figure 12 illustrates several cross-sections through the depth of single and multi-media beds. As with screens, these beds require backwashing to free the trapped solids which are usually transported preceded by a surface wash and/or air scour to loosen and remove any slime and accumulated deposits on the media. The backwash cycle flushes these deposits away. These operations are available as automatic cleaning options where operator attendance is limited. Turbidimeters monitor the effluent (product water) quality and head loss across the bed is measured. Either parameter can initiate the backwash cycle. Rapid sand type filters have been used for direct filtration of secondary effluent with and without chemical treatment and raw or primary wastewater after coagulation (chemical treatment) and sedimentation. For treatment of secondary effluents, solid removals are approximately 70-90% with turbidities below 0.5 JTU. Multimedia filters remove approximately 5 to 10% more suspended solids than dual media filters. For raw sewage applications using lime addition (Ref. No. 34) followed by sedimentation then filtration, average filter effluent was 4.5 mg/1 at 70% efficiency.

Cross-Section Through
Single-Media Bed
Such as Conventional
Rapid Sand Filter



Cross-Section Through
Dual-Media Bed
Coarse Coal Above
Fine Sand



Cross-Section Through
Ideal Filter
Uniformly Graded From
Coarse to Fine
From Top to Bottom

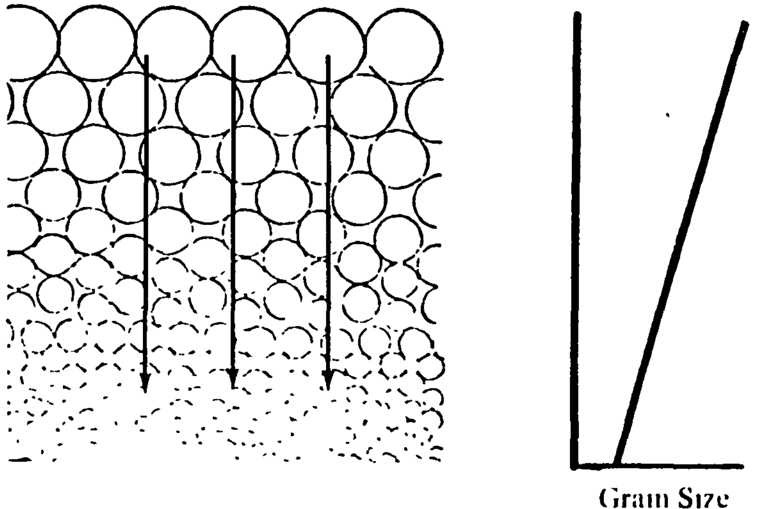


Figure 12. Media Comparisons

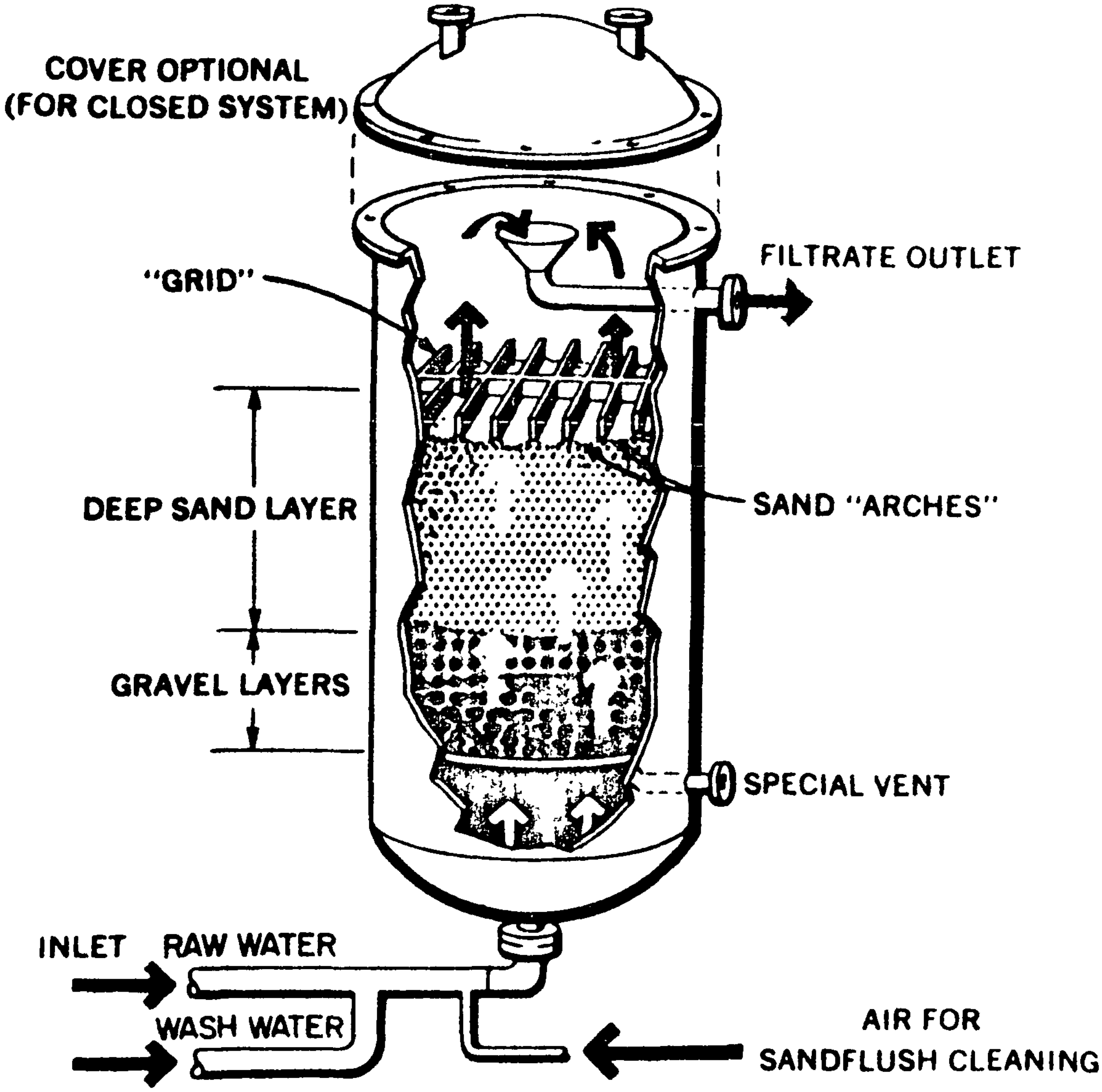


Figure 13. Cross Section of Upflow Filter

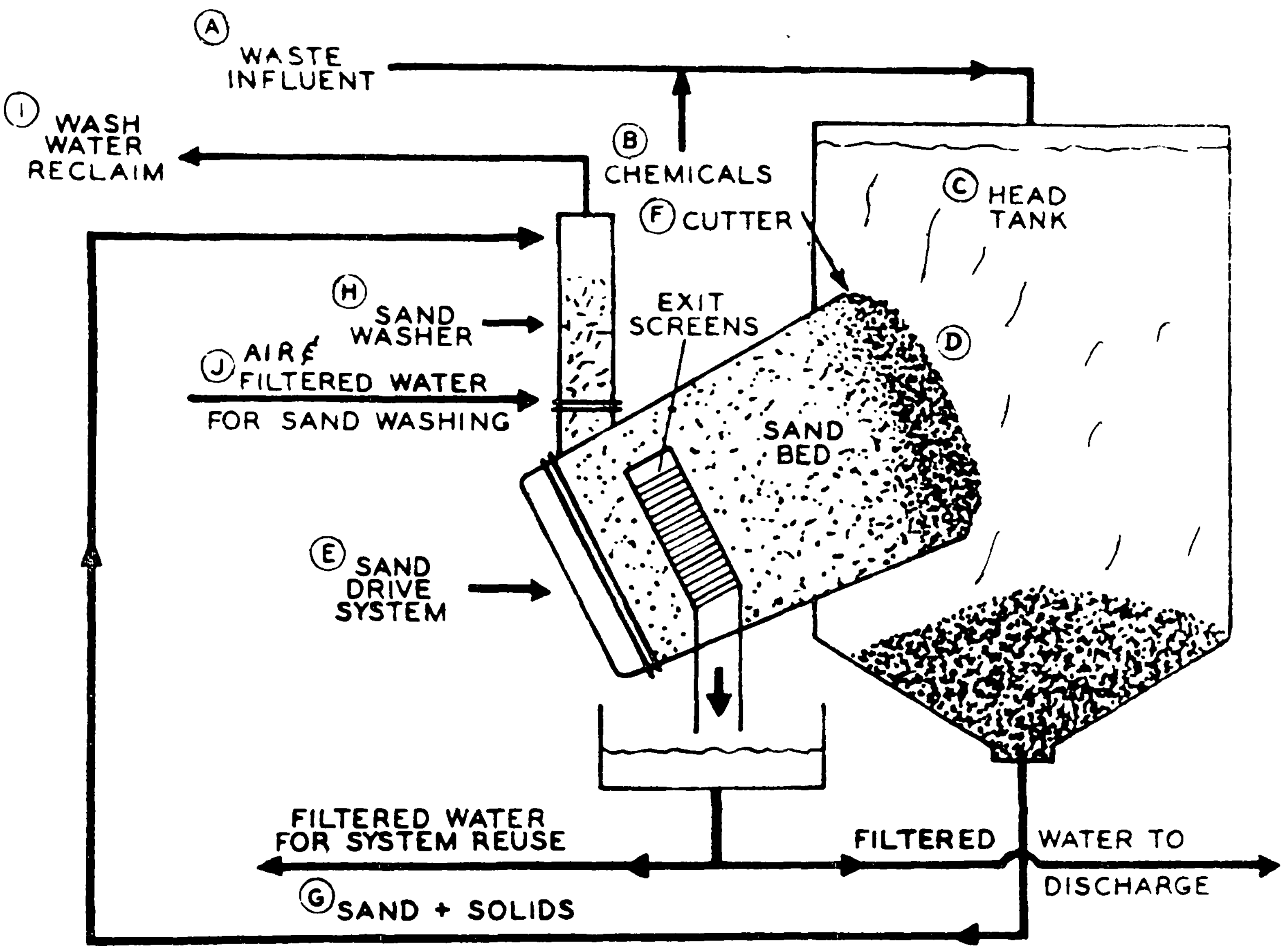


Figure 14. Schematic Drawing of the Johns-Manville Moving Bed Filter

Basic shortcomings of these downflow, static bed filters is the need to stop (or divert) the process to clean the filter medium and limited capability to accept high concentrations for suspended solids. Newer versions now use upflows to prevent redistribution of graded media during backwashing. By preserving the bed distribution, filter performance is improved 20%. An upflow filter is shown in Figure 13. A moving bed sand filter is in development capable of processing the clogged portion of the bed without process interruption. A diagram illustrating the essentials of this system is given in Figure 14. Wastewater (a) flows through the inlet pipe where chemicals, if required, are added at (b). The wastewater enters the head tank (c) and then passes through the sand bed (d). The filtered water leaves through the exit screens. When excessive headloss develops, the bed is pushed toward the heat tank by pressurizing a chamber separated from the bed by a flexible diaphragm. A mechanical cutter (f) sweeps down over the face of the bed cutting off the top layers. These then fall into the hopper (g) of the heat tank. The sludge and sand are removed from the head tank with the aid of an ejector using feedwater. The solids are hydraulically conveyed to the sand washer (h) where filtered water or air and filtered water are used to backwash the sand. Clean sand moves by gravity back to the base of the filter. The spent washwater is sent to a sedimentation tank for removal of the wastewater solids. The operation of the system is automated. This processing, using alum for phosphorous precipitation and a polymer coagulant to prevent high floc penetration, has been applied to raw wastewater, (Ref. 35) primary effluent and settled and unsettled trickling filter effluents. Results are shown in Table 9.

2.4 MEMBRANE FILTERS (ULTRAFILTRATION)

To separate dissolved materials from water, a relatively "fine" membrane with relatively high pressures and low flow rates is required. When particles in the colloidal and suspended range must be separated from water, the membrane can be somewhat more "coarse" with correspondingly lower pressures; however, the flux, or flow through the membrance, may be substantially the same as for salt separation. A problem common to both the salt and solids removal applications is that of maintaining membrane flux in the face of particulate or precipitate fouling of the membrane surface. The flux tends to decline logarithmically with time. The salt and solids removal applications have in common those aspects just discussed. In every other respect they are different. It is therefore appropriate that two

Table 9. Johns-Manville Moving Bed Filter Evaluation at Bernards Township Sewerage Authority Treatment Plant

Parameter	Final Effluent w/o Chlorination			Unsettled Trickling Filter Effluent			Primary Effluent			Raw Wastewater		
(mg/l)	In	Out	%	In	Out	%	In	Out	%	In	Out	%
Total P	9.37	0.51	95	19.1	0.99	95	14.6	1.13	93	21.5	2.16	91
Filterable P	8.03	0.11	99	14.9	0.62	96	13.2	0.58	96	18.6	0.79	96
Ortho P	7.80	0.10	99	12.4	0.53	96	9.8	0.38	96	13.2	0.57	95
BOD_5	65	12	80	55	3.8	93	67	12	82	115	19	84
Suspended Solids	50	15	70	86	7.1	91	77	11	87	156	27	83
Turbidity (JTU)	33	7	79	39	3.4	91	53	3.7	93	123	16.7	87

Alum 200 mg/l (commercial grade)

Polyelectrolyte: 0.5 mg/l anionic

different process names be applied to them. Salt removal is called reverse osmosis or hyperfiltration, while solids removal is called ultrafiltration. A basic diagram of a membrane filter is shown in Figure 15.

The geometrical configuration of the module containing the membrane is just as important as the membrane itself. The single greatest problem of ultrafiltration or any other membrane process is the fouling which causes membrane flux to decline. Such fouling is caused by slimes, precipitates and organic and microbial deposits. The membrane can be cleaned routinely with chemical or enzyme solutions, but prevention of this fouling is an important design problem. The precise nature of the fouling depends on the nature of the feedwater. Prevention of fouling may be accomplished by achievement of proper hydrodynamic conditions within the module. The feedwater velocity past the membrane surfaces serves to continually scour that surface to prevent fouling.

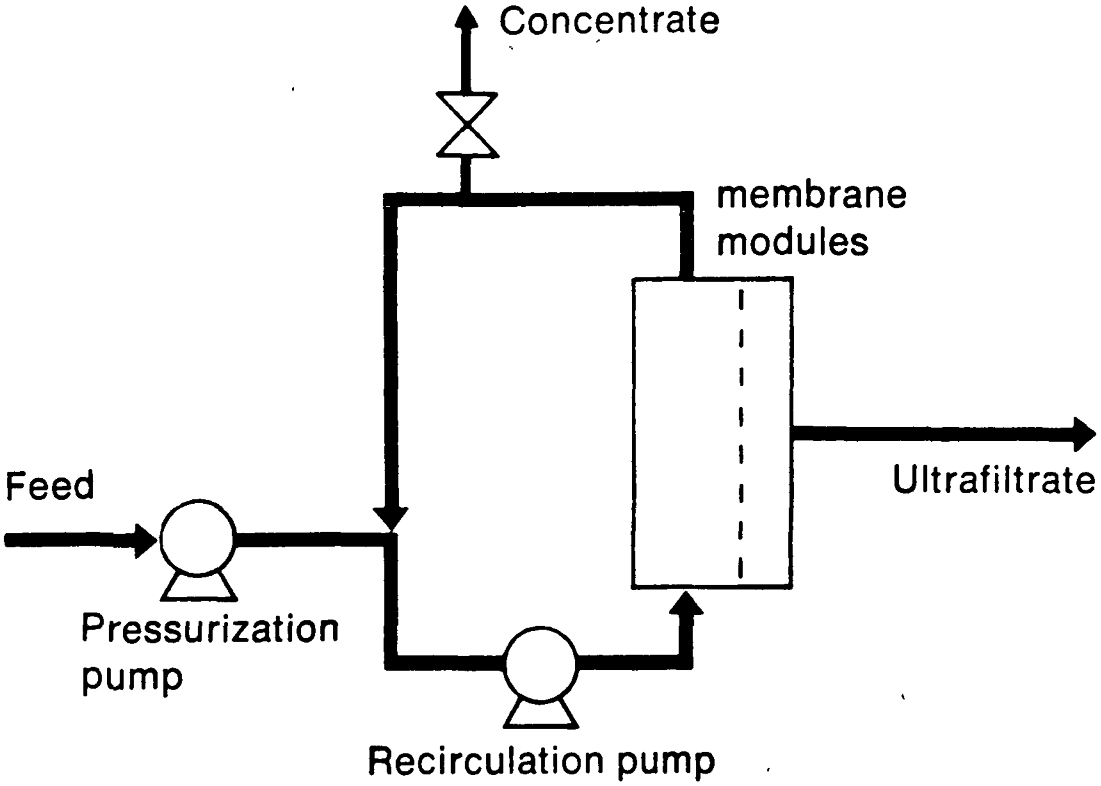


Figure 15. Ultrafiltration Flow Diagram

Another aspect of module design concerns the magnitude of membrane surface area which can be incorporated into a module. Because of the low membrane fluxes it is imperative to design the module so as to maximize membrane surface area. A successful configuration for ultrafiltration is the storage battery design (Dorr-Oliver) shown in Figure 16.

The influent passes through the membrane-plates and is collected by a manifold connecting the interiors of the various hollow plates. The design is advantageous for three reasons: (a) it is compact and incorporates a large membrane area into the module; (b) the edges of the plates function as an easily backwashed coarse filter; and (c) the flow is parallel to the membrane surface which induces scouring.

Ultrafiltration is currently competitive with other solids removal processes only in specialized situations. On account of its compactness, an ultrafiltration module can easily replace a filter or settler in a package treatment plant where space is at a premium. A package plant on top of Pikes Peak treats 21,000 gpd by a high-solids activated sludge and

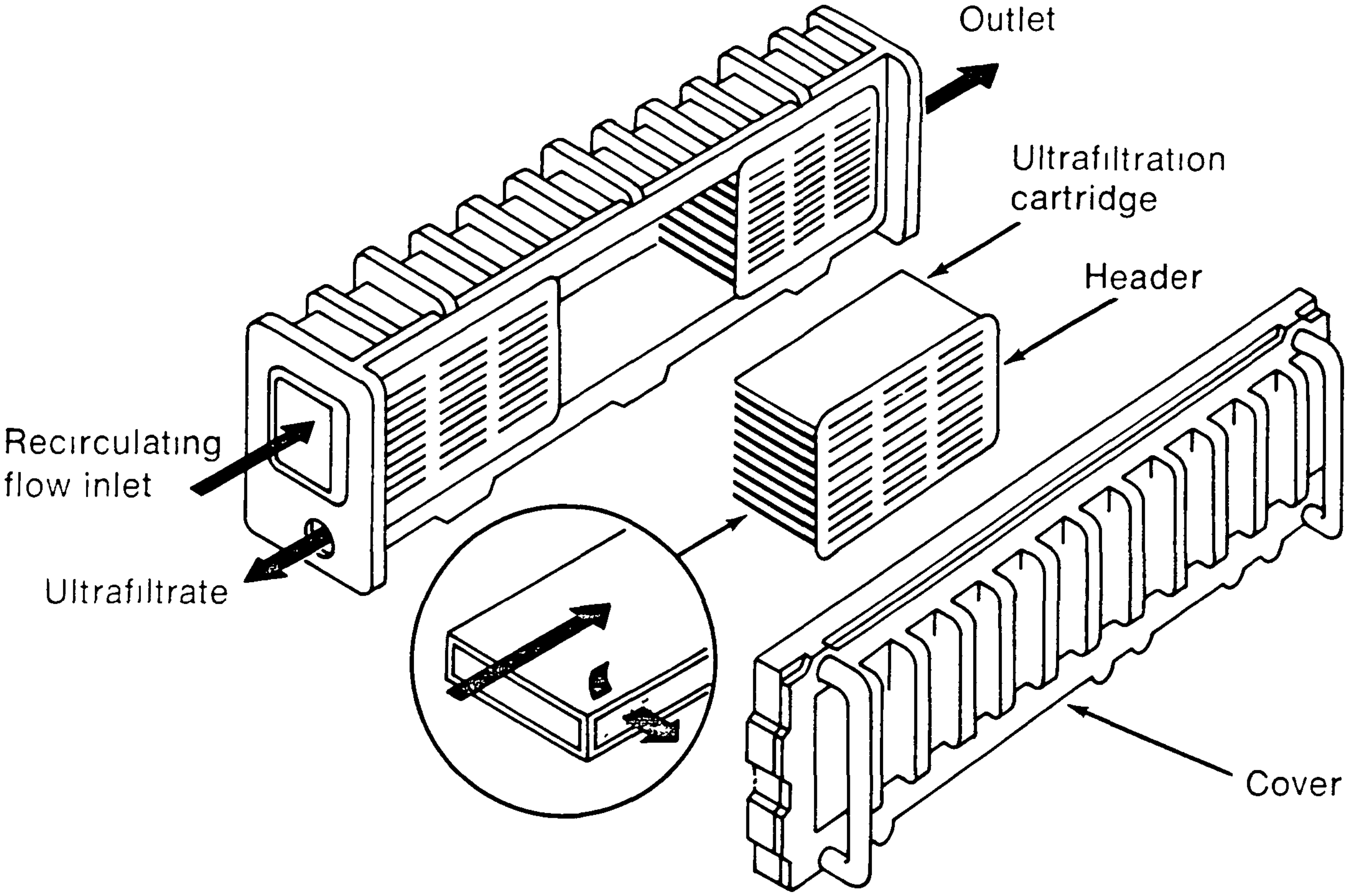


Figure 16. "Storage Battery" Membrane Modules

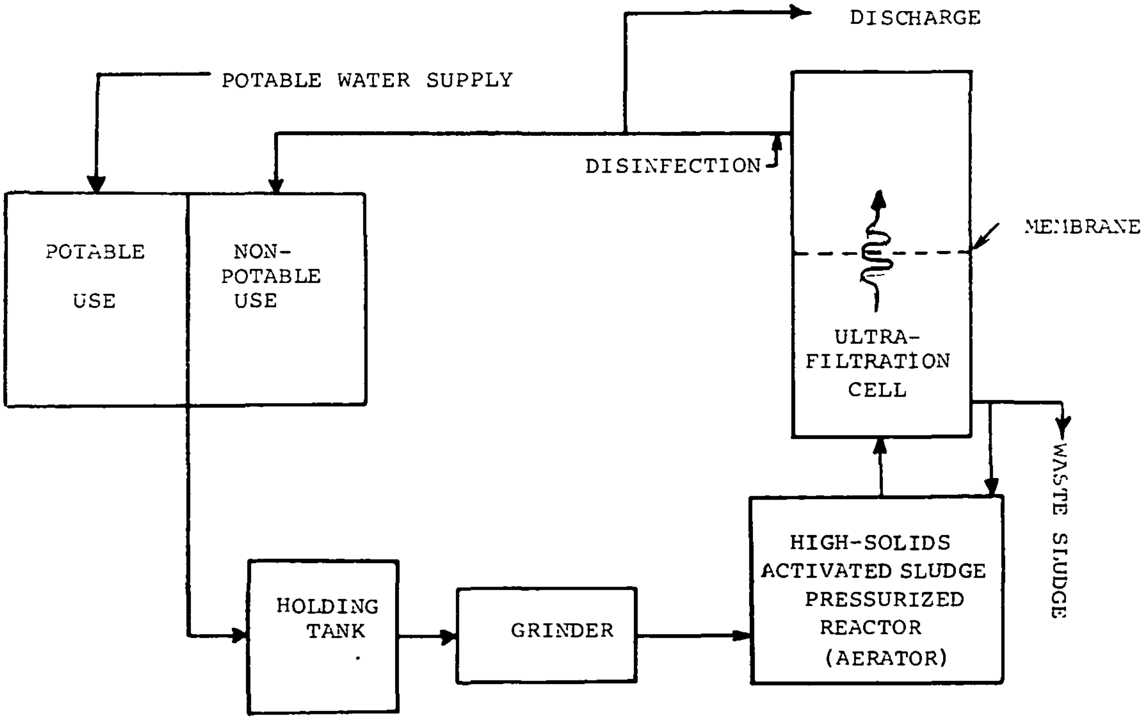


Figure 17. Schematic Flow Diagram of the Pikes Peak Treatment & Reuse System

ultrafiltration process. The concentrate from the ultrafiltration step is recycled to the aerator as shown in Figure 17. Table 10 shows the performance data collected during a brief period in 1970 after the plant was installed. The plant had not yet reached peak performance in some respects, but its chief merits are evident.

Table 10. Summary of Performance of the
Dorr-Oliver Activated Sludge-Ultrafiltration Plant Operations at
Pikes Peak

AUGUST-SEPTEMBER, 1970

Parameter	Influent (mg/l)	Effluent (mg/l)	Removal (%)
BOD	285	1	99
COD	547	32	94
TOC	136	6.6	95
Turbidity (JTU)	47	0.33	--
Color (Units)	320	40	–
TSS	129	0	100
MLSS	3954	–	–
Coliform (Per 100 ml)	–	0	100
PO_4 - P	9 1	11.1	–
pH	7 9	5.9	–
Threshhold Odor Number	--	6	–

Pressure ~ 50 psig
Average Flux - 21,000 GPD

3. CHEMICAL PROCESSES

Chemicals have been employed to wastewater treatment processing to:

1. Aid in coagulating suspended solids for rapid and more thorough solids removal
2. Chemically react with soluble components to form precipitates prior to filtration or settlement
3. Change the solution pH to permit optimum floc formation and/or precipitate reactions

Chemical addition to provide any of the above functions is dependent on the initial state of the wastewater to be treated to quantify the dosage required, however, the monitoring of performance achieved is usually the sensed process control variable. Generally, the chemical process requires a dosing means, mixing device or stimulant and a reaction (contact) time to realize the full effect of the treatment function.

The complexity of wastewater makeup and the differences between wastewater characteristics from one application to another requires detailed pilot studies to select specific chemical, dosage rate and nominal performance attainable within the process being tested.

3.1 COAGULATION ENHANCEMENT

The common flocculant aids include alum, ferrous salts and lime. Their selection is largely dependent on whether the pH of the solution must be raised or lowered following treatment processes, and economics. Use of these chemicals are covered in most basic texts. A family of chemicals, polymeric flocculants, has emerged as a significant break through in coagulating suspended solids. They are comprised of long branched chains of high molecular weight compounds.

All synthetic polyelectrolytes can be classified on the basis of the type of charge on the polymer chain. Thus polymers possessing negative charges are anionic while those carrying positive charges are cationic. Certain compounds carry no electrical charge and are called nonionic polyelectrolytes. Because of the great variety of monomers available as starting material and the additional variety that can be obtained by varying the molecular weight, charge density and ionizable groups, it is not surprising that a great assortment of polyelectrolytes are available to the wastewater plant operator. A partial list is shown in Table 11. Use of any specific polymer as a coagulant aid is of necessity determined by the size, density and ionic charge of the colloids to be coagulated. As other factors need to be considered, i.e., coagulants used, pH of the system, techniques and equipment for dissolution of the polyelectrolyte, etc., it is mandatory that extensive jar testing be performed to determine the specific polymer that will perform its function most efficiently.

Table 11. Dry Polyelectrolytes

Polyelectrolyte	Type Table 3	Bulk Density lb/cu ft			Flow Table 4	Time to Disperse into a Coll. Solution Hour(s)	Solution-Room Temp.				Percent Max Solution Concentration Recommended
		Loose	Pack	Work			Percent	Visc. cp	Sp gr	pH	
Aquafloc 409*	AP	25	34	28	CNKL	1-2	1	2350	1	4-5	1
Aquafloc 411*	AP	42	53	45	CNKL	1-2	2	480	1	4-5	2
Aquafloc 414	NP	48	59	61	CNKL	1-2	2	660	1	7	2
Aquafloc 418	CP				DPKL	1-2	2	23	1	2 4	2
Aquarid 49-702	CM	33	44	36	E S	1-2				7-9	
Calgon C-2256	CP	30	43	34	DLKP	1/2	1	75	1	6.4	1.5
Calgon C-2260	CP	24	35	28	DLKP	1/2	1	40	1	6.7	1.5
Calgon C-2270	CP			25	DPL	1/2	1	35	1	7.3	1.5
Calgon C-2300	NP	10	16	13	BLN	3/4-1	0.5	24	1	7	0.5
Calgon C-2325	AP	10	16	13	BLN	3/4-1	0.5	275	1	7	0.5
Calgon C-2350	AP	11	19	14	BLN	3/4-1	0.25	425	1	7	0.25
Calgon C-2400	AP	10	16	13	ALKM	3/4-1	0.25	740	1	7	0.25
Calgon C-2425	AP	16	28	22	BLKN	3/4-1	0.25	800	1	7	0.25
Calgon WT-2600	CP	23	34	27	DKLP	1/2	1	38	1	4	1.5
Calgon WT-2630	CP	29	42	33	DKLP	1/2	1.5	20	1	4	1.5
Calgon WT-2660 (ST-260)	CP	27	39	31	DKLP	1/2	0.5	20	1	4	0.5
Calgon WT-2690	NP	9	16	12	ALM	1/2	0.5	23	1	7	0.5
Calgon WT-2700	AP	10	18	14	DLP	1/2	0.25	80	1	7.5	0.25
Calgon WT-2900	AP	8	13	10	AKLN	1/2	0.25	160	1	7.5	0.25
Calgon WT-3000	AP	16	29	22	AKLN	1/2	0.25	250	1	7.5	0.25
Hamaco 196*	S	20	25	21	DLP	1/2-1	1	< 50	1	<6-7	2
Hercofloc 810	CP	22	31	25	EKLR	1-2	0.5	400	1	<6-7	0.5
Hercofloc 812	CP	21	31	24	EKLR	1-2	0.5	250	1	<6-7	0 5
Hercofloc 818	AP	30	40	33	DKLN	1-2	0.5	1000	1	<8-9	0.5
Ionac NA-710	AP	38	47	40	CNL	1/2-1	0.2	150	1	5-6	1
Jaguar Plus	CG	31	40	22	FLPR	1-2	1	800	1	8-9	1
Magnifloc 530C	CP										0.5
Magnifloc 820A	AD	34	40	35	CLP	1-2	1	160	1	4 2	1
Magnifloc 835A	AD	30	42	34	DKP	1/2-1	0.1	450	1	6-7	0.1
Magnifloc 836A	AD	27	35	29	CKP	1/2-1	0.1	360	1	6-7	0.1
Magnifloc 837A	AD	28	36	30	DLP	1/2-1	0.5	620	1	5	0.5
Magnifloc 865A	AD	40	42	50	CLN	1-1/2-2	1	130	1	4.1	1
Magnifloc 870A	AD			28		1/4	0.5	38	1	7.5	1
Magnifloc 875A	AD			28		1/4	0.5	38	1	7.5	1
Magnifloc 880A	AD			26		1-2	0.5	20	1	5.5	1
Magnifloc 900N	ND	32	40	33	CLN	1-2	1	150	1	4.7	1
Magnifloc 901N	ND					1-2	1	300	1	4.7	1
Magnifloc 902N	ND					1-2	1	200	1	4.7	1
Magnifloc 905N	ND	27	35	29	CLN	1-2	1	500	1	4.7	1
Nalcolyte 610	P	26	40	31	DKLP	1/2-1	0.5	700	1	5.1	1
Nalco 633-HD	CP	42	68	52	DJLN	1/4-1/2	2	190	1	3	2
Nalco 636-HD	CP	45	53	47	DLN	1/4-1/2	1.5	33	1		1.5
Nalco 635	AP	38	50	41	DLN	3/4-1	0.25	2500	1	8.5	0.25
Nalco D-2339	AP	39	53	43	DJLS	1/2-1	0.3	2000	1	7.0	0.5
Nalcolyte 675	AP	35	50	40	DLN	1/2-3/4	0.25	2500	1	8.5	0.25
Polymer F3	AG	32	40	34	DLN	1-2	4	800	1	9.5	4
Polyfloc 1100	AD	34	40	35	CKN	1-2	0.5	2000	1	8.5	0.5
Polyfloc 1110	AD	36	42	37	CKN	1-2	0.5	2400	1	7.5	0.5
Polyfloc 1120	AD	36	42	37	CKN	1-2	0.5	3500	1	8.8	0.5
Polyfloc 1130	AD	35	48	39	DKP	1-2	1	3000	1	8.8	0.5
Polyfloc 1150	AD	33	45	36	FJR	1/2-1	1	1000	1	6-7	1
Polyfloc 1160	CD	34	40	35	CJN	1/2-1	1	1300	1	5-6	1
Purifloc A-23	CD	42	53	45	BKP	1-2	0.1	950	1	10	0.5
Superfloc 128	ND	28	33	29	CLN	1-2	1	750	1	6-7	1
Tychem 8024*	ND			40		1-2	1.0	200	1	5.5-6	1.0
Tychem 8013	ND	33	43	36	CLN	1-2	1.0	750	1	6	1
Zeta Floc C*	BC[1]	48	68	54	EKR	1/4-1/2				8.2	1
Zeta Floc O*	BN[1]	52	74	59	EJR	1/4-1/2				8.2	1
Zeta Floc K (+KMnO^2)*	BC[1]	48	68	54	EKR	1/4-1/2				8.5	1
Zeta Floc S	BC[1]	54	78	61	E S	1/4-1/2					1
Zeta Floc WA*	BA[1]	54	78	61	E S	1/4-1/2					1
Zeta Flox WN	BN[1]	54	78	61	E S	1/4-1/2					1

*Approved by USPHS for potable water use.

[1] Aluminum Slicate added.

Table 11. Dry Polyelectrolytes (Cont)

Polyelectrolyte	Type Table 3	Solution Strength percent	Sp gr Room Temp (about)	Viscosity-cp Room Temp	pH (about)	Dilution
Aquafloc 403	AH	Full	1.12	100	9.6	4-1
Aquafloc 405	CH	Full	1.06	1,000	6.3	10-1
Aquafloc 407	NH	Full	1.00	10,000	4.3	10-1
Aquafloc 408*	AH	Full	1.01	1,500	3-4	10-1
Aquafloc 410	CH	Full	1.03	1,000	10.2	10-1
Aquafloc 412	CH[1]	Full	1.25	50	1.0	4-1
Aquafloc 415	AH	Full	1.03	1,000	11.5	10-1
Aquarid 49-700	CM	Full	1.1	100-500	7-8	10-1
Aquarid 49-701	CM	Full	1.1	25-150	7-8	10-1
Aquarid 49-703	AH[3]	Full	1.2	200-500	11.5	20-1
Cat-Floc (WT-2870)*	CH[2]	Full	1.025	2,000	4.2	< 10-1
Magnifloc 521-C	CH	Full	1.15	225-325	4-5	< 10-1
Nalcolyte 603	CH	Full	1.6	80	8	< 10-1
Nalcolyte 607	CH	Full	1.17	50	7.5	< 10-1
Natron 86, 18 percent	CH	Full	1.06	300-500	3	< 0.5
Polyfloc 1170	H	Full	1.06	50	9	
Polyfloc 1175	H	Full	1.08	700	9	

*Approved by USPHS for potable water use

[1] Plus a primary coagulant.

[2] A linear homopolymer of diallyldimenthyl ammonium chloride.

[3] Polyaromatic.

TYPES

A - Anionic
As - *Slightly Anionic*
B - Bentonite Clay or Clay, natural, colloidal-like type
b - plus Bentonite
C - Cationic
D - Polyacrylamide, Synthetic, High M W., Polyelectrolyte Polymer
E - Polyacrylonitrile, Synthetic Polyelectrolyte
F - Sulfonated Polymer
G - Guar Gum, Polysaccharide, Natural Polymer
H - High M W , Organic Polymer
J - Alkyl Guanidineamine Complex
K - Sodium Alginate or Algin Derivative, Natural Polymer
L - Leguminous Seed Derivative, Natural Polymer
M - Polyamine, Synthetic, High M.W , Polyelectrolyte Polymer
N - Nonionic
P - Synthetic High M.W., Polyelectrolyte Polymer
R - Polyacrylamide and Carboxylic Group
S - Starch, derivative, modified, etc., Natural Polymer
T - Synthetic Polymer and Caustic Soda
U - Sodium Carboxymethylcellulose, Natural Polymer
X - Ethylene Oxide Polymer
Y - Carboxyl Polymer
2 - Biocolloid + Inorganic Coagulant + Caustic Soda
3 - Hydrophylic Colloid + Pregelatinized Starch in Alkalai
4 - Aluminum Hydroxide + Complex Organic Polymer
5 - Alumina + Polymer + Caustic Soda
6 - Polyacrylic Acid or Polyacrylate of Sodium or Ammonium
7 - Aluminum Hydrate + Caustic Soda
8 - Alkalai Concentrate + Metallic Ions
9 - Chemically Modified Natural Polymer

FLOW

A. Soft flakes, may hang up if packed excessively in a *confining area, otherwise free flowing* Usually will not need aid (vibration or agitation)
B Powdered, soft flakes, hang up if packed excessively in a confining area, may or may not need aid according to rate of feed, etc
C Soft granules, sometimes fibrous or flattish, may hang up if packed excessively in a confining area, otherwise free flowing Usually will not need aid.
D. Powdered, soft granules, sometimes fibrous or flattish, hang up if packed excessively, may or may not need aid, according to other factors
E Granular, fluid powder, will arch if packed and can be fluidized or is floodable (to very floodable). Needs aid and may need rotor, according to rate, etc
F Granules and powder, will arch and can be fluidized Needs aid and could need rotor, etc.
G Cohesive powder and granules, will arch, but will not flood. Needs aid.
H Cake up of room relative humidity
J. Tendency to cake (or mass) at higher relative humidity
K Cake at higher relative humidity.
L. Moisture absorption, may lessen flowability
M Practically no dust.
N Very little dust
P Some dust
R Dusty.
S. Very dusty

TRADE NAMES

Aquarid - Reichhold Chemicals
Calgon C - Calgon Corp.
Calgon WT - Calgon Corp.
Cat Floc - Calgon Corp
Hamco - A. E Staley Manufacturing
Hercoflac - Hercules, Inc.
Ionac NA-710 - Ionac Chemical
Natron - National Starch and Chemical Corp.
Polyfloc - Betz Laboratories, Inc.
Polymer F3 - Stein Hall
Tychem - Standard Brands Chem. Ind., Inc.
Zeta Floc - Naryon Minning and Chemical Co

It is now generally agreed that a bridging mechanism accounts for the flocculation behavior of these compounds. In its simplest form the theory postulates that the polymer molecules attach themselves to the surfaces of the suspended particles at one or more sites and that part of the long chain extends out into the bulk of the solution. The free end of the molecule is then able to absorb onto another suspended particle when contact is made, thus forming a bridge or link between two particles of suspended solids. The progressive linking of more and more particles results in an ever-increasing size of floc whose eventual size is limited by its ability to withstand the hydraulic shear gradient imposed upon it by agitation or turbulence.

Anionic polymers have proved to be most effective when used with alum or iron coagulants. The anionics have also been used as sole additives to improve removals of solids in primary treatment, but results have been marginal. Cationic polymers when used alone will frequently produce excellent clarification of raw wastewater, but generally require high dosages. The cationics find their greatest application in conditioning of sludges for dewatering.

Polymers are used in very small doses, usually less than 1 mg/l. The dosage range in which the polymers are effective is usually limited. An overdose, in addition to the increased cost of chemicals, will frequently restabilize the solids so that they cannot be settled out.

Polymers are usually shipped as dry powders and are converted to a liquid form at the plant site, although some are available as liquids. During storage, the dry powders must not be allowed to pick up moisture. The dilute solutions of polymers are viscous and must be made up according to the manufacturer's directions. In general, the polymers are non-hazardous and require only the usual protection from dust when handling the dry material. The dosage of polymer may be accurately controlled by metering pumps.

3.2 PRECIPITATE REACTIONS

Most of the flocculant aid chemicals (excepting polymeric flocculants) will precipitate phosphates (phosphorus) when the solution pH range is within the range compatible for the specific chemicals' reaction. There are no special developments under study in this area presently.

3.3 pH CONTROL

The control of pH has become a standard in systems designed for flocculation and precipitation functions. Automated systems have recently been developed to control and measure process functions with pH control requirements.

APPENDIX H

ORGANIC REMOVAL

APPENDIX H
ORGANIC REMOVAL
INTRODUCTION

After most (all) of the suspended solids are removed, the wastewaters still contain dissolved organic (and colloidal) organics dissolved plant nutrients and dissolved inorganic materials (minerals). This section describes the dissolved organic removals. The family of dissolved organics includes biodegradable and nondegradable (refractory) organics and residual colloidal suspensions ($< 1\mu$).

1. BIODEGRADABLE ORGANICS (REF. 3)

Processes usually effective for the removal of these materials are:

1. Trickling Filters
2. Chemical Treatement
3. Carbon Adsorption
4. Ozonation
5. Other Oxidation Processes

1.1 TRICKLING FILTERS

This method involves circulating the wastewater over a bed of material coated with bacterial growths that consume the organics of the flowing media. This process is detailed in most basic texts.

1.2 CHEMICAL TREATMENT

As mentioned in Paragraph 3, Appendix G, dosage of flocculant aids and/or coagulants affect not only the colloidal suspensions but also nutrients by causing precipitates to form (pH dependent) and settle or filter out of solution.

1.3 CARBON ADSORPTION

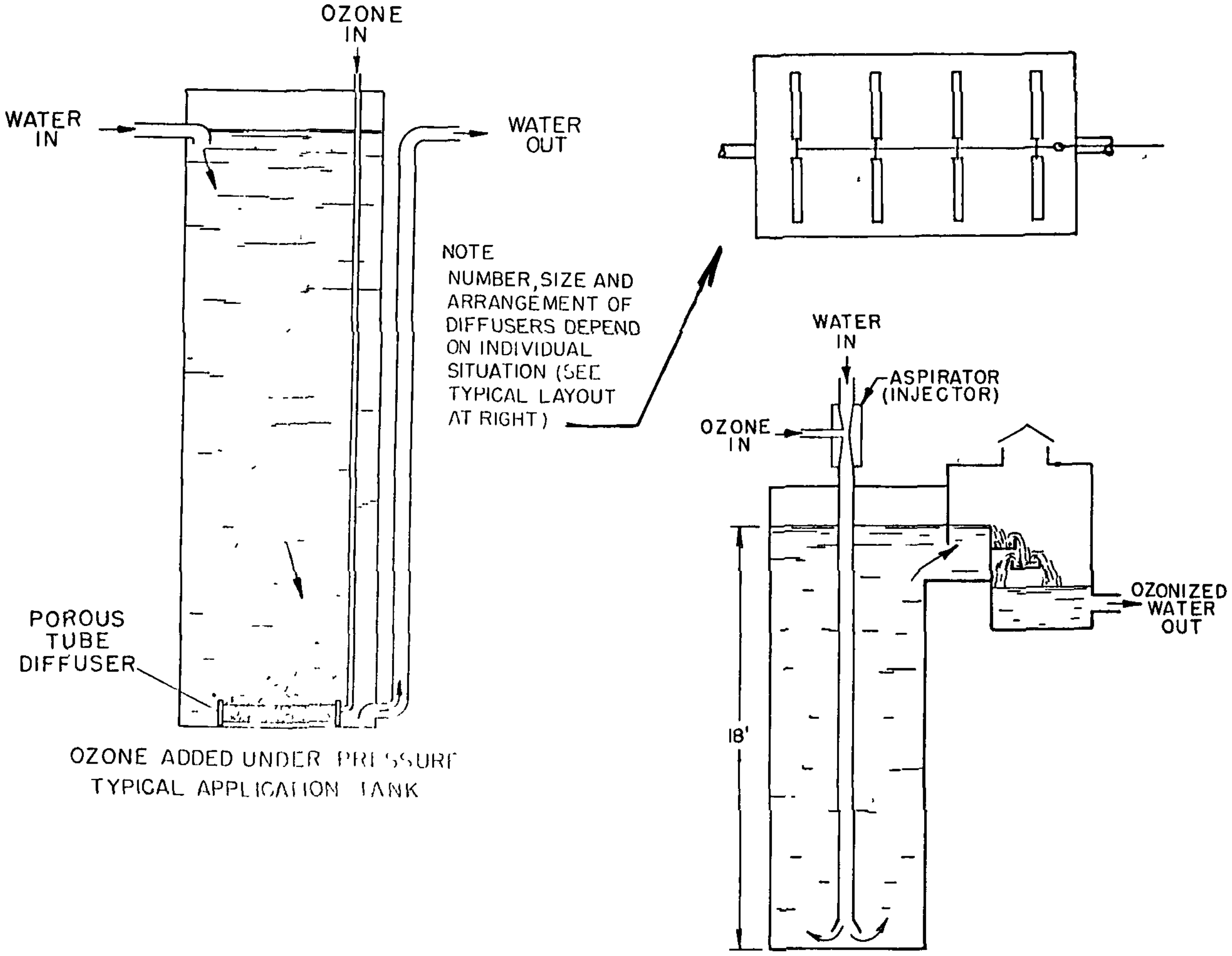
The use of charcoal, powdered and granular activated carbon has revolutionized the small capacity treatment systems market and enabled increased treatment effectiveness of organic removals in existing plants.

Granular activated or powdered carbon is used as adsorbent in wastewater treatment systems because of its high surface area (200-2,000 m^2/gram) and the chemistry of the carbon surface. Removal of organic material by activated carbon can be described as a three step sequence: (1) diffusion of the solute molecules to the carbon surface through the liquid film surrounding the carbon particle, (2) intraparticle diffusion of the solute within the channels of the carbon particle, and (3) adsorption to the internal carbon surface.

The present state of design of carbon contactors for treating municipal wastewater is rather empirical. Three important factors to be specified are: superficial approach velocity (gpm/ft^2); apparent liquid retention time (empty bed-in minutes); and average carbon exhaustion rate (pounds of carbon per million gallons of waste applied). Of these parameters the liquid retention or contact time is considered to be the most important parameter in terms of the column effluent performance and is usually between 30 - 45 minutes. Carbon exhaustion rates will of course be a function of the organic composition and concentration of the waste stream applied, and hence will vary widely. Exhaustion rates are experimentally determined by measuring both the cumulative organics removed and the cumulative wastewater volume passed through the column prior to the appearance of the breakpoint concentration in the column effluent. Breakpoint concentration is usually defined empirically as some unacceptable concentration of organic carbon in the column effluent. The weight of carbon in the column is then divided by the total flow passed through the column to breakpoint and expressed as pounds of carbon exhausted per million gallons of wastewater flow.

1.4 OZONATION

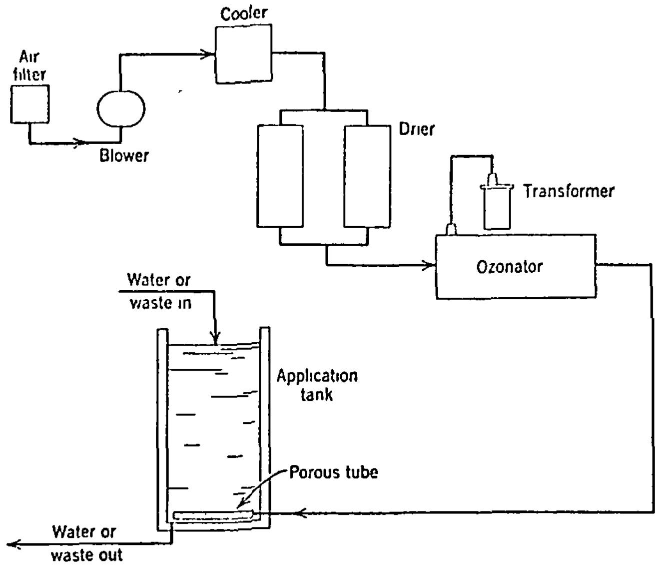
In the treatment of municipal wastewaters, ozone is normally applied following the primary and secondary sewage treatment processes. It is advantageous to use a filtration stage,



NOTE
NUMBER, SIZE AND ARRANGEMENT OF DIFFUSERS DEPEND ON INDIVIDUAL SITUATION (SEE TYPICAL LAYOUT AT RIGHT)

OZONE ADDED UNDER PRESSURE
TYPICAL APPLICATION TANK

INJECTOR METHOD
TYPICAL APPLICATION TANK
FOR
LARGE SYSTEM, E G MUNICIPAL



Ozone plant for water or waste treatment.

Figure 1. Ozonation

such as microstraining, for tertiary treatment where possible. This means that the water would be virtually free of suspended matter, and ozone would be able to act on the dissolved organics and other oxidizable substances.

There are two basic methods by which ozone is applied to water. One uses ozone under pressure and disperses it through porous diffusers in the bottom of a tank between 15 and 18 feet deep. Lower depths can be used with proper ozone dispersion. Retention time in the tank or column is in both cases about 5 minutes but may vary with the quality of water and other factors.

The other method uses an injector (venturi) principle to draw air through the ozonator and intimately mix ozone with the water. The discharge from the venturi passes through a "column of contact" into a detention chamber.

Of the two techniques, the first is more flexible, permits better control, requires less power, is more efficient in ozone adsorbed, and requires less maintenance. The two methods and a typical ozone plant schematic is shown in Figure 1.

In cases where the raw water carries organic colloidal turbidity presenting well known difficulties in coagulation by conventional treatment, it has been found that ozonation can effect fundamental changes in the nature of the colloids and make them susceptible to coagulation with minimum chemical doses producing microflocs removable by high rate rapid sand filters without the need for sedimentation. This process of colloidal modification is called Miscellization/Demicellization (the MD process). The sequence of treatment is as follows:

1. Mechanical filtration by microstraining to remove suspended solids.
2. Oxidation of the organic colloids by ozonation (the Micellization stage).
3. Coagulation using a reduced chemical dose to produce microflocs (the Demicellization stage).

4. High rate rapid sand filtration for the removal of microflocs, employing the sand bed in depth. The original microscopic suspended solids having been removed, no arcing for "schmutzdecke" is formed on the surface of the sand bed thus permitting high filtration speeds.

5. Final treatment with a sterilizing agent, which can be ozone, taken from the Micellization stage.

A simplified explanation of Micellization/Demicellization is that ozone, by oxidizing the hydrophilic organic colloids which are difficult to coagulate, effectively changes them into hydrophobic forms of inorganic nature which are readily coagulated.

Ozone will kill bacteria and viruses more quickly and thoroughly than chlorine, and with lower doses. It also reduces BOD and COD and, using higher doses, can oxidize refractory organics. The absence of a persistent residual is another advantage of ozone because contaminants are removed without producing secondary pollutants and without increasing the inorganic salt concentration. Ozone has been found effective in killing bacteria and viruses and in removing organic color, taste, and odor. Its action is virtually instantaneous, requiring no large contact tanks.

Modern ozone generators employ electrode systems made up of a series of tubes or plates equipped with insulators and provided with cooling arrangements. Specially designed transforms step up the normal mains voltage to 15,000 or 20,000 volts. Air preparation equipment comprises filters and driers using refrigeration and desiccation. The design of these units has been well established over many years, and they incorporate high quality materials completely protected by fail-safe devices. Ozone costs approximately 8 cents per pound produced from air and 3.5 cents per pound when made from oxygen. Installation costs range from $500 to $1,000 for each pound per day of ozone generating capacity.

An outstanding advantage of ozone is its immediate and effective attack on viruses in water supplies. Medical evidence shows that dilutions of polio virus can be rendered inactive in 2 minutes by a small dosage of ozone, whereas chlorine may take several hours and much higher doses. This aspect of ozone will undoubtedly bring it into more common use in this country as the search continues for higher quality water supplies.

No report on ozone would be complete without a reference to the safety aspects of using ozone, which is a toxic gas. Numerous reports on air pollution have stressed the formation of ozone in the atmosphere as a result of photochemical reactions and have indicated the long-term danger to plants and animals. As a result of this publicity, some engineers believe that ozone is a dangerous chemical to use.

The reverse is true. Ozone is, in fact, far less hazardous in water and waste treatment than the gaseous chlorine which is extensively employed. This is because the ozone is generated and used only in low concentrations and is not stored under pressure. Any escape of ozone from a treatment system can be quickly stopped by turning off the electric supply.

Ozone is self-policing. In concentrations far below harmful or toxic levels, it is immediately noticeable by the irritation it produces in the nasal passages. Concentrations up to 20 or 30 times higher than this and prolonged exposure over many hours are required before the gas can be harmful (Figure 2).

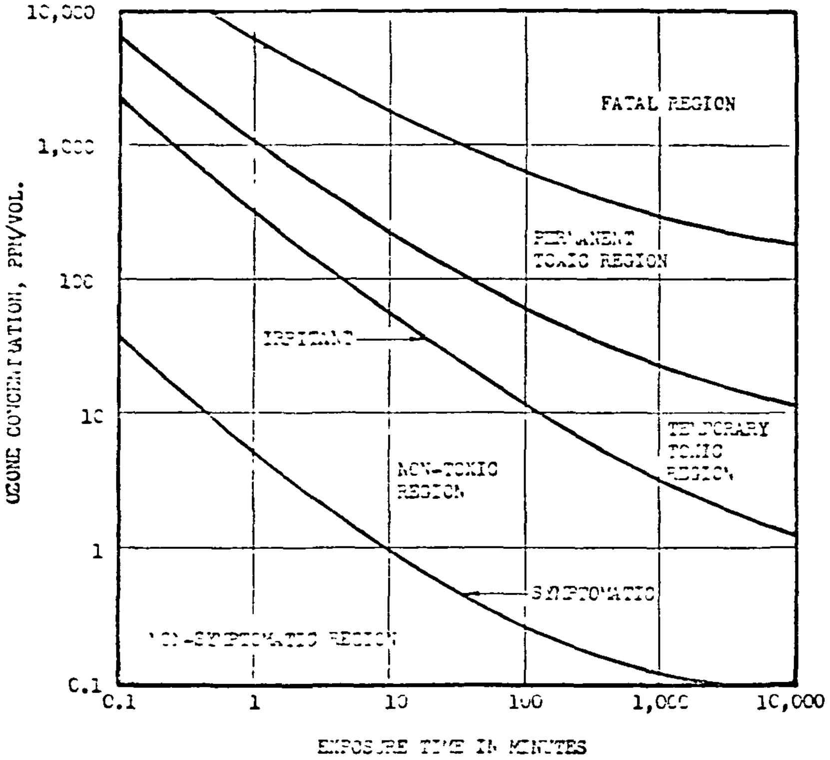


Figure 2. Ozone Toxicity

The odor of ozone can be detected in concentration as low as several parts per hundred million by volume (pphm). The American Conference of Governmental Industrial Hygienists has established 0.1 part per million by volume (10 pphm) as the maximum allowable concentration of ozone for continuous exposure. Since exposure is a product of ozone concentration and contact time, higher concentrations can be tolerated for a short time. An exposure to 1 ppm ozone for ten minutes is considered nontoxic. Ozone is generated in commercial ozonators in 1 - 2% concentration in air or oxygen. At this dilution ozone is less hazardous to handle than other gaseous compounds which are handled in 100% concentration. If the ozonators are confined in a building, all leaks must be eliminated and adequate ventilation should be provided.

Liquid ozone presents another handling problem, for in concentrations greater than 30% by weight it is extremely unstable and may explode on contact with even minute traces of organic matter. Not only all precautions for handling liquid oxygen, but also extra precautions for a sensitive explosive must be observed.

Some ozonides are so unstable that explosions occur during their preparation. During preliminary ozonolysis studies the reactors should be well shielded or barricaded, and their temperature should be controlled with a suitable cooling medium. All ozonides should be handled with extreme care; mechanical or thermal shock may produce explosion. The practice of storing ozonides or the ozonolysis products must be discouraged because of the spontaneous decomposition fo these compounds on standing.

Most ozone is generated at atmospheric pressure or at pressures not exceeding 8 to 15 psi, so that any leakage is of relatively small proportions whereas chlorine, is normally stored under pressures which produce liquefaction. If a leak develops in the chlorine containers, they are difficult and dangerous to seal because of the rapid escape of the gas. Sodium hypochlorite is now used in several large cities for water disinfection to avoid the hazard of handling and storing gaseous chlorine. Modern ozonators require very little maintenance beyond an annual cleaning. The stainless-steel structure of the ozonator has a life expectancy of at least twenty-five years.

1.5 OTHER ORGANIC REMOVAL (OXIDATION) PROCESSES

Various chemical and electronic systems have been applied to wastewater treatment exhibiting some favorable effects but have been unsuccessfully scaled to actual use because of inconsistency of performance, technical impracticality for scaling up from laboratory or pilot tests, or non-competitive cost factors. The chemicals showing some benefit are potassium permanganate and chlorine which are oxidizing agents by forming salts of oxyacids due to unreliable results with different wastewaters. Hydrogen peroxide was eliminated because of expense and limited compatibility with usual sewage treatment operating conditions. Electrical and electrochemical means have been shown to provide some benefit to oxidizing organics however, again, the projected economic outlays were too high.

APPENDIX I

NUTRIENT REMOVAL

APPENDIX I

NUTRIENT REMOVAL

INTRODUCTION

There are two basic residuals, phosphorus and nitrogen (as phosphate and nitrate ions), and ammonia, in plant effluents. As discharged in effluents to a receiving water, they disturb the natural balance of water ecology, by "fertilizing" the algae and aquatic plant life resulting in accelerated plant growth (eutrophication) in the water body and in the case of ammonia is toxic and consumes dissolved oxygen, to threaten the survival of prevalent lifeforms dependent on water quality. When algae die and decompose, dissolved oxygen is consumed to satisfy the oxygen demand of the "natural sewage", but due to the excessive rate of the algae cycle, creates an oxygen deficit in the waterbody. In combination with higher temperatures and sunlight, these factors are further catalyzed. Prolonging these conditions results in production of a variety of odorous and other objectionable substances as well as killing off all normal forms of life in the water and driving off animals depending on that water resource for nourishment. To effectively control algal growth through nutrient removal, it is necessary to pinpoint the minimum level of nutrient needed to trigger algal blooms. Unfortunately, such data are not yet available. The most widely quoted figures are those reported from a study of Wisconsin lakes which indicated that 0.30 mg/1 of inorganic nitrogen and 0.015 mg/1 of soluble orthophosphate produced nuisance algal blooms (Ref 40). Specifically, the nutrients of interest for advanced treatment are the

1. Phosphates
2. Nitrates
3. Ammoniated compounds

1. PHOSPHATE REMOVAL

In the previous sections on solids removal (Appendix G), it was shown that depending on the primary and/or secondary methods selected, phosphorus removals can be integral with the respective solids removal process. Municipal wastewaters contain about 20-30 mg/1 of phosphorus which may be present in three forms: as orthophosphate, as complex polyphosphates and as organic phosphates. Orthophosphate makes up about 25-30 percent of the total phosphates in settled raw domestic waste. The following are the processes most applicable to the advanced waste/water management design concept:

1. Chemical precipitation
2. Physical-chemical
3. Ion exchange

1.1 CHEMICAL PRECIPITATION

Chemicals can be added to either the raw waste or to the final (secondary) effluent. Chemical addition to the primary clarifier provides the following advantages: (1) it can be used with both trickling filtration and activated sludge; (2) it greatly enhances primary settling; (3) it produces BOD and suspended solids reductions as high as 60 percent and 90 percent, respectively, allowing modest reduction in the size of the aeration tank. However, due to the incomplete hydrolysis of the complex phosphates, the process can only provide moderate (60-80 percent) total phosphate removals. On the other hand, addition of chemicals to the final plant effluent produces an almost complete removal of the residual phosphorus at a higher capital cost.

The most widely used chemicals include: iron salts (ferric chloride, ferric sulfate, ferrous chloride and ferrous sulfate), aluminum salt (alum and sodium aluminate) and lime. Removal of phosphorus utilizing iron or aluminum salts has been considered a combination of chemical precipitation as well as adsorption. The two conditions most influential in the successful chemical precipitation application is control of the pH and the amounts of phosphates (as orthophosphate) in the wastewater. The optimum pH is different for iron and aluminum salts. For iron (as Fe^{III}) the pH is 4 while for aluminum (as Al^{III}) 6 is optimum. pH control about these values should be well within ± 1 unit as virtually no removals are achieved outside these bounds. The metal salts are cationic and the dosage requirement relates to the ratio of cations to orthophosphate. This ratio is 2:1 at the pH values stated for each metal salt.

When lime is used, the reaction is a function of waste bicarbonate alkalinity and the calcium hardness. pH of the wastewater must be raised by the lime to between 10.5 - 11 for best removals. Dosage rates are usually between 250 and 350 mg/1 for the pH values required. Though covered in a later section, it should be mentioned that lime recovery (recalcining) processes result in additional economy of the process. Based on pilot plant experience lime treatment, without recovery, is estimated at approximately 6 cents/1000 gallons for a 1 mgd plant.

A recent development (Ref 41) now in advanced laboratory testing uses lanthanum as a secondary effluent coagulant at a molar ratio of 1-2:1 lanthanum to orthophosphate at a pH range of 5-9. Removals well above 90 percent were recorded. The specific method chosen must consider the type of sludge handling - disposal system to be implemented as each chemical reacts with the coagulated solids to form sludges (density and "wetness") with differing characteristics. A combination of lime and iron salt addition produces the same removals as either chemical produced singly, however, the sludge volume is smaller (thicker, more dense). With good phosphorus removal, equally good clarification is obtained. In a two-stage process, lime clarification of primary effluent obtained 67.6 percent removal of COD and 75 percent removal following filtration. Similarly, the single-stage process obtained 65 percent COD removal after lime precipitation and filtration. These excellent removals of COD by precipitation and filtration compare well with secondary treatment of wastewater by trickling filters.

1.2 PHYSICAL-CHEMICAL

The chemical processes cited above can be coupled to any of several separation or filtration devices to clarify the treated wastewater for final polishing. Among the devices, microstrainers, centrifuges, deep bed filters and vacuum filters are best suited for modular systems. These are described in Appendix G.

1.3 ION EXCHANGE

The basic hardware is similar to that required for a pressure filter except that the bed materials are charged ionic groups of natural or synthetic resins. The success of ion exchange depends on the ability of the counter-ion to be replaced/or exchanged for another ion of the same charge. The ionic site must maintain electroneutrality and must associate with an ion of opposite charge (counter-ion). When the exchanges are complete (resin bed exhausted) regeneration is required, by contacting the resin bed with a concentrated solution of the original counter-ion.

Ion exchanger performance can be selectively controlled depending on the ion removals desired. A cationic resin will exchange calcium $(^{++})$, potassium $(^{+})$, ammonia $(^{+})$, sodium $(^{+})$ ions in this order. An anionic resin will operate on sulphates $(^{=})$, phosphates $(^{=})$, nitrates $(^{-})$ and chloride $(^{-})$ ions in this order. Resin beds are a matrix of styrene or vinyl benzene beads polymerized with functional groups as follows:

1. Strong acid resins contain sulfonic acid groups
2. Weak acid resins contain carboxyl or phenolic groups
3. Strong base resins carry quaternary ammonium groups
4. Weak base resins are usually amine groups ionized to the OH form.

Selective removal of phosphate ions has been performed (Ref 41) using activated alumina columns with very high removals (95-99 percent) at costs projected to be comparable to lime precipitation methods.

2. NITRATE REMOVAL

Nitrogen is present in domestic wastewaters in the range of 15-25 mg/1. The nitrogen is found as organic nitrogen 40-45 percent of the time, as ammonia nitrogen (NH_4-N) 55-60 percent of the time and in the oxidized forms NO_2-N (0-5 percent) and NO_3-N. The presence of nitrate ion, ammonia and nitrate ion with an excess of other plant nutrients has not been shown to be significant in stimulating plant growth (Ref 40). The rationale is that even if absent from waste effluents, organisms within natural water systems can supply nitrate ion in a reaction (fixation) with atmospheric nitrogen. The most serious hazard of excessive concentrations of nitrate ion in drinking water is the "blue baby" condition (methemoglobinemia). The Public Health Standards for Drinking Water limits the nitrate ion to 45 PPM maximum. As mentioned in the first paragraph of this section, nitrate ion concentrations will seldom approach the PHS limits, however, if water reuse is intended, removals may be required if successive passes are contemplated.

There are no chemical processes yet developed for nitrate ion removal. The available processes include:

1. Ion exchange
2. Ammonia removal/conversion
3. Biological nitrification - denitrification
4. Demineralization processes (see Section 4)

2.1 ION EXCHANGE

As developed in paragraph 1.3, ion exchange beds selectively exchange ions with counter-ions in a predictable order depending on the ionic strength of the charged particle. Nitrate ion is stronger than phosphate or sulphate ion and therefore is unaffected in the exchange process until these weaker ions are absorbed by the resin. Because these bed materials are not specific for nitrate ion reduction, economic feasibility is similarly disproportionate.

3. AMMONIA REMOVAL/CONVERSION

Ammonia is a special case of nitrogenous compounds present in quantities that must be removed if nitrate ion treatment is required. It is important to note that nitrate ion removal and ammonia removal/conversion are both required to control ultimate nitrogenous residuals from a treated wastewater. Ammonia, if oxidized biologically, increases the nitrate ion concentration five-fold, therefore attention to ammonia is implicit for nitrate ion control. Ammonia treatment is largely governed by the condition of the previous process effluent.

If lime precipitation, to remove phosphate ion, is employed, the high pH (10 - 12) ammonia exists in the free form (below a pH of 10 ammonia exists as the non-volatile ammonium ion) and can be stripped upon contact with air, hence the process name "air-stripping." The process uses equipment similar to cooling towers to cascade the effluent over slats and flowing large volumes of air to absorb the ammonia. Air flow requirements vary as a function of air temperature and height of tower. Towers are usually 20 - 25 feet high and air flows are 300-400ft^3/ gallons of effluent.

The air stripping process has the advantages of being simple in concept and in practice, using well known technology. Moreover, it is capable of reducing the ammonia concentration economically to very low levels. It has several disadvantages. First, efficiency falls during cold weather. Furthermore, with the high air/water ratios necessary, freezing may occur in winter months. Buildup of calcium carbonate scale, because of carbon dioxide absorption from the air, is also a problem. It has become recognized that the ammonia may be redeposited by rain and can reenter the water from which it had been removed. Air stripping is, however, the only process for ammonia removal that has passed the experimental stage and has been operated on a plant scale.

Breakpoint chlorination has been used in the treatment of water supplies for many years however the usual amounts of ammonia nitrogen in wastewater are somewhat higher than found in fresh water supplies. The efficiency of chlorine as an ammonia oxidant depends on pH, temperature, organic concentrations and chlorine contact time (Ref. 49). Solution pH should be between 7 and 8.5. The reaction forms chloramines that further oxidize to free nitrogen gas. The chemical reactions are:

$$Cl_2 + H_2O \rightarrow HO\,Cl + HCL$$

$$NH_3 + HO\,Cl \rightarrow NH_2\,Cl + H_2O$$

$$2NH_2\,Cl + HO\,Cl \rightarrow N_2 + 3HCl + H_2O$$

The effect of the added chlorine is to lower the pH hence the buffer capacity of the solution to neutralize the HCl components. Since the amounts of chlorine required depend on the ammonia nitrogen content, and not pH, caustic addition may be necessary to keep the wastewater pH at optimum value. With a 15 minute contact period the curve shown in Figure 1 results. This curve is typical for other initial ammonia concentrations. A plot of breakpoints at different initial ammonia level is presented in Figure 2. In addition to reducing ammonia-nitrogen, this process also contributes to the total chlorine dosage required for disinfection.

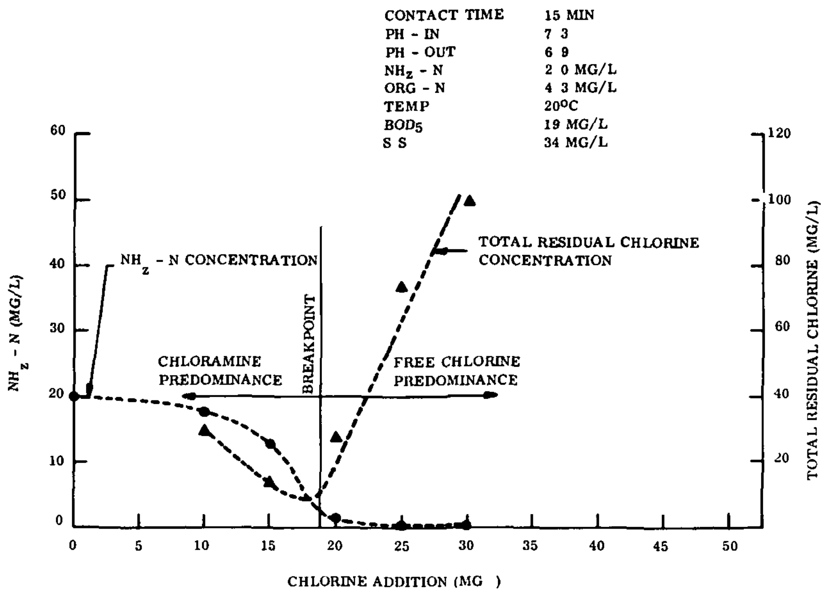


Figure 1. Breakpoint Chlorination Curve

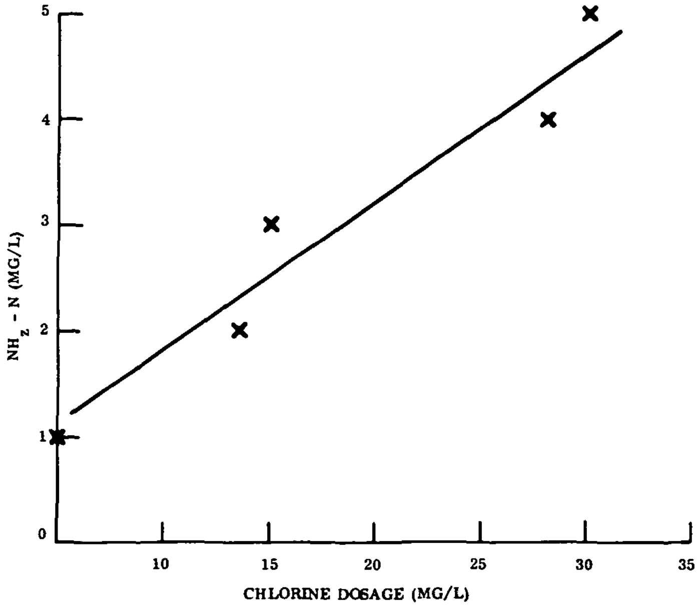


Figure 2. Chlorine Breakpoints

APPENDIX J

INORGANIC REMOVAL

APPENDIX J

INORGANIC REMOVAL

INTRODUCTION

Secondary effluents contain dissolved inorganic materials that are usually part of the natural water supplies with their concentration increased two-fold during use (about 350 PPM added/use). These are minerals whose effect produces corrosion, staining and affects taste/odor of the reused water. Discharge with excessive heavy metals content can produce poisoning or cumulative uptake by aquatic life that passes these on to their predators and so on until consumption by humans. Recent mercury poisoning has been traced to this effect. The total dissolved solids (TDS) of a water system will increase with reuse as well as due to salt water encroachment now challenging many coastal groundwaters where recharge has not been practiced. The Public Health Service Drinking Water Standards limits the TDS to 500 PPM. The materials included in "total dissolved solids" are the soluble salts of the respective minerals. The removal of these, obviously produces a brine waste solution that is in itself a troublesome treatment by-product to dispose of. This section describes those present processes capable of removing these minerals from tertiary wastewater effluent. The most promising unit processes are:

1. Ion exchange
2. Reverse osmosis
3. Electrodialysis
4. Distillation
5. Freezing

1. ION EXCHANGE

This process has been presented in Appendix I for phosphate removal. To employ this process (as well as other demineralization techniques), the influent must be essentially free of colloidal suspensions and dissolved organics in order to achieve maximum exchange efficiency of the bed materials to the mineral salts. This use of ion exchange resins is comparable to like applications in water treatment. It can be projected that the operating costs will be higher as a tertiary wastewater treatment process, due to the higher mineral concentrations, hence, an increased frequency of bed regeneration with attendant costs for regenerative chemicals.

2. REVERSE OSMOSIS (RO)

This process was developed initially for desalination. The cellulose-acetate membrane established the feasibility of freeing entrained salts and providing a high quality product water. Much activity is in progress to evaluate the membrane design dynamics (water flux, filtration limits or porosity). To induce osmotic action, high pressures (>600 psi) are required to "squeeze" the water through the membrane while capturing the minerals of interest. This performance characteristic causes rapid water flux decline and fouling. Membrane material determines the permeability and any porosity can be specified for the desired molecule capture. The mechanism of solute rejection is believed to involve hydrogen bonding of water molecules to the skin of an appropriate semi-permeable membrane. If properly designed, the membrane holds back the larger molecules of salt, while water molecules are passed, with pressure assist.

Membranes consist of two distinct layers. One a spongy porous material which accounts for 99.8% of the thickness and an active layer which accounts for all of the separation of contaminants. Surface layer is typically 0.25μ thick, porous layer 100μ thick.

Major operating problems are membrane cleaning and replacement. Fouling of the surface layer is largely due to the residual dissolved and colloidal organic materials which, due to their higher molecular sizes, restrict the passage of water and prevent efficient operation. Membrane cleaning methods include scouring and/or periodic rinsing with an enzyme solution. Membrane deterioration by chemical action of water and the contaminants as well as "permanent" fouling severely shorten membrane life, hence adversely affect operating econimics. Several different mechanical designs have been synthesized. These are:

1. Plate and frame, using flat membrane sheets in a device similar to a filter press was one of the earliest designs. Units capable of producing 100,000 gal/day have been developed by Aerojet-General. Largely used for brackish water treatment.

2. A simple tubular design consists of porous tubes which are lined with cellulose acetate membranes. Design is similar to heat exchangers. Flow is from inside the tubes at pressure and discharged from the outside surfaces of the tubes at ambient pressure.

3. To obtain a maximum of membrane area in a small volume, a "spiral-wound" design was developed by General Atomics. Several hundred feet of membrane can be accommodated in a cubic foot of pressure vessel volume.

4. The ultimate in greatest area per unit volume is approached by "hollow-fiber" design. About 20 million hollow fibers can be packed into a shell 1 foot in diameter and 7 feet long. A 12-inch permeater 7 feet long is contained in a unit only 5.5 cubic feet in volume provides about 50,000 square feet of membrane surface and will produce 7500 gal/day. Flux with these fibers is small - currently about 0.15 gal/ft^2/day. Fluxes of 1.5 gfd may be attainable but this will still be 1/10 that obtainable with other designs. This configuration can be characterized as a "very high surface area, low flux permeater."

A tabulating of the operating parameters associated with the latter three configurations follows (from Reference 30):

RO Type	$\frac{\text{ft}^2 \text{ membrane}}{\text{ft}^3 \text{ equipment}}$	Flux (gpd/ft^2)	Productivity (gpd/ft^3)
Tubular	20	32	640
Spiral wound	250	32	8,000
Hollow fiber (nylon)	5400	1	5,400
Hollow fiber (cellulose-acetate)	2500	10	25,000

From the tabulation, it would appear that the hollow fiber design provides a "best" configuration due to the high surface area/liquid volume ratio, however the hydraulic considerations (as indicated by the low flux) detract from this system in overall performance. Though a potentially valuable process, current RO systems need further development to increase fluxes, maintain flux while adversely influenced by fouling and physical-chemical changes in the membrane and increased product water to waste ratios (90% has been experimentally attained). Costs, based on flat membrane applications to treat brackish water, are estimated at about 40 cents/1000 gallons; still too high for serious competition in operational systems even though RO performance is outstanding, when on-line.

Typical RO Removals From Secondary Effluent (Ref. 30)
(Hot Membrane, 450 psi, 8 gfd)

Parameters	% Rejection
Total Organic Carbon (TOC)	90
TDS	93
Turbidity	99+
Alkalinity	90
Chloride	80-85
Phosphate	94
Nitrate	65
Ammonia	85
Organic Nitrogen	86

3. ELECTRODIALYSIS

This process is very much like reverse osmosis in that membranes are integral to the separation of dissolved minerals. Instead of pressure, electrical power is applied to poles within cells causing the minerals to polarize towards the oppositely charged terminal to the salt. The membranes are placed between the poles (See Figure 1) in pairs such that compartments are formed categorizing the process waters as dilute or concentrated. The membranes are constructed from resins with either cationic or anionic selective ion exchange sensitivity. A cation exchange resin membrane will allow only positively charged ions in a solution to pass through it, while an anion exchange resin membrane will allow passage only of negatively charged ions. A negative potential applied to an electrode immersed in the compartment sealed off by the cationic membrane, attracts positive ions

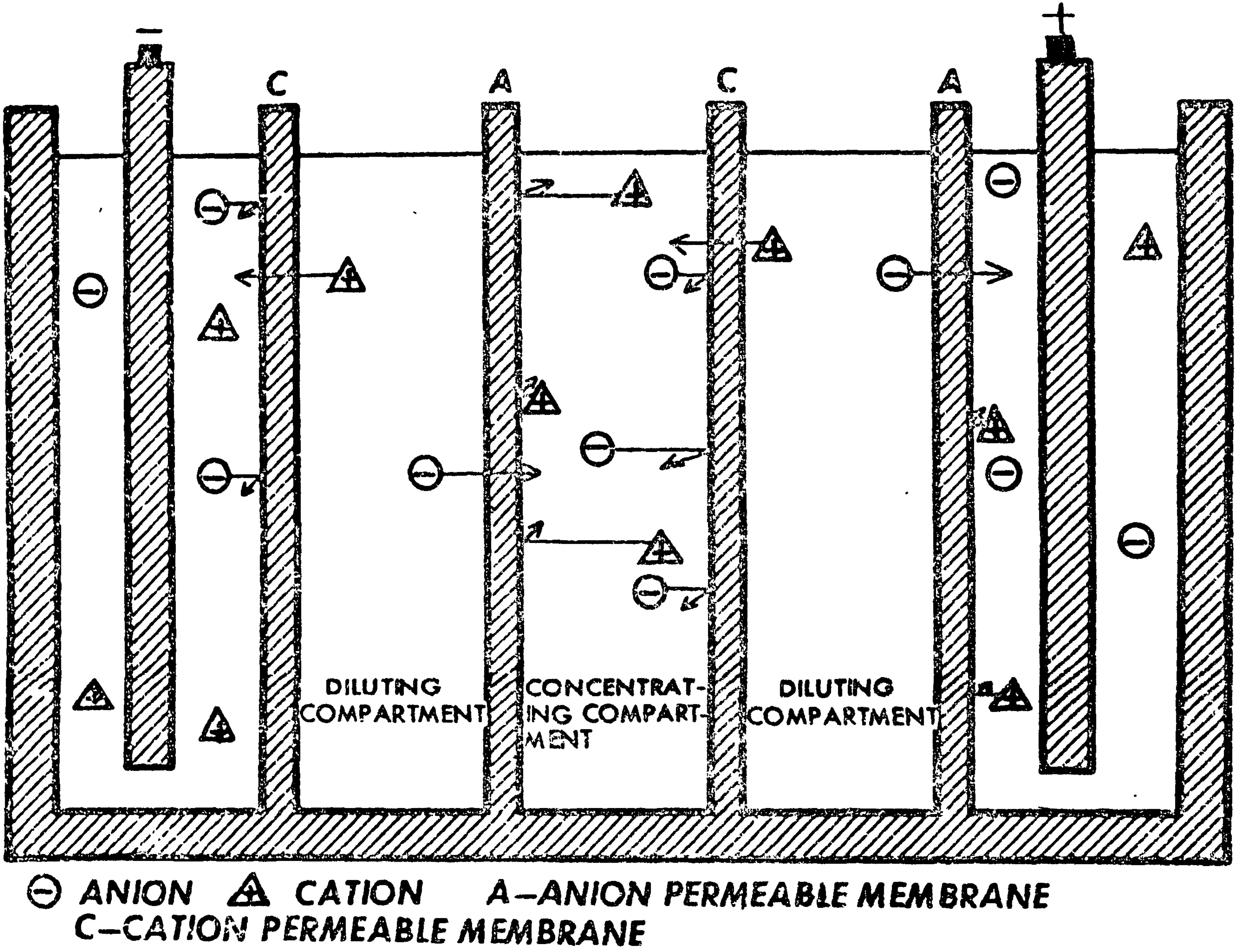


Figure 1. Electrodialysis Principle

to the electrode. These can pass through the membrane from the central compartment, depleting that compartment of positive ions. Negative ions which are repelled by the electrode cannot pass through the membrane and remain in the sealed-off compartment. A similar process occurs when a positive potential is applied to an electrode immersed in the compartment sealed off by the anion exchange membrane. If the potential is applied for a long enough time, essentially all of the ions in the dilute compartment will leave it to be concentrated in the alternate compartments. This process is termed electrodialysis.

The process can be made continuous if solution is allowed to enter one end of the compartment and be removed from the other, with de-ionized water emerging from the center compartment and a brine from the others. The degree of de-ionization then depends upon the path length, the flow rate, and the electric current density. Efficiency of the process can be increased if the membranes are stacked in alternate sheets of cationic and anionic materials with the electrodes placed at the ends of the stack, parallel to the sheets. Each sheet is separated from its opposite type neighbor by a thin porous spacer. Baffles are placed in the compartments induce mixing and thus prevent polarization, or depletion of ions, in the portions of the solution adjacent to the membrane. De-ionized water and concentrated brine are removed from alternate compartments. A single pass system can remove 40-50% of the dissolved salts. Projected costs, with a design free of membrane fouling and chemical aging, is estimated at 15-20 cents/1000 gallons, an economically attractive level. The technical feasibility of electrodialysis has been demonstrated both for brackish water desalination and wastewater demineralization. (References 42 and 43.) But, as with reverse osmosis, membrane fouling by wastewater solids and organics has deterred practical application. When applied to treatment of secondary effluent, it is necessary only to reduce the concentration of dissolved mineral matter to the Public Health Service standard. This usually requires removal of only about half of the inorganics present in the effluent in order to return it to the mineral content of the water supply which provided it, assuming that the plant nutrients and organics had been removed in earlier steps. All of the problems of reverse osmosis membranes are similarly troublesome in this process. In addition, electrolysis of water produces hydroxyl ions and hydrogen which requires an increase in power to continue the ionization flows at the same rates; pH of the concentrate stream should be 5 or less to prevent calcium carbonate scale formation on the membrane surfaces.

Electrodialysis at present is the process which would be chosen for most installations if demineralization were required. Its technology is reasonably well developed, equipment is commercially available, and its applicability to advanced waste treatment has been demonstrated. Its cost is relatively high, but is lower than the cost of alternative demineralization processes. As the need for conservation of water supplies grows in the future, electrodialysis can be expected to become even more attractive, because the increased demand can be expected to decrease manufacturing costs for equipment.

4. DISTILLATION

Distillation is now the most commonly practiced method for obtaining fresh water from sea water. Today there are 90 million gallons per day of plants in operation or under construction in various parts of the world, and this capacity is being expanded rapidly. Distilled water is a common synonym for pure water, hence it is not surprising that distillation is being considered for wastewater treatment and renovation. But distillation of wastewater is substantially different than distillation of sea water. Preliminary studies have revealed that some treatment of the distillate (product) will have to be practiced to remove carry over of volatile contaminant substances. It is also likely that the solids and organics in wastewater will pose additional problems. The concensus of investigators indicates this process is unattractive for wastewaters; however, some additional research is still continuing at the Taft Sanitary Engineering Center, Cincinnati, Ohio.

Several techniques involving low temperature distillation using air or vacuum have been investigated for aerospace applications. When combined with secondary processes such as catalytic oxidation, extremely pure effluents have been obtained from concentrated mixtures of urine and feces. These processes are discussed more fully in Section 4.3.2 of the report.

5. FREEZING

Investigation of the freezing of pure water out of secondary effluent, a process which has been applied to recovery of fresh water from saline water, showed that costs were so high relative to multiple-step purification procedures, that the method has been abandoned as a possibility. (Reference 33).

APPENDIX K

DISINFECTION

APPENDIX K
DISINFECTION

Wastewaters can contain large numbers and varieties of species of viable microorganisms, including bacteria, fungi viruses and even rickettsia, that are in most cases harmless. However, infectious types can be found. The isolation of viruses excreted [redacted] enterically [redacted] has increased to approximately 100 serotypes today, and more are sure to be discovered. Increasingly, the enteric viruses are being associated with diseases not even suspected of having a virus etiology a few years ago (diabetes mellitus and mongolism). These are in addition to a long list of conditions known for some years to be caused by enteric viruses. Unfortunately, there are no removal or destructive processes capable of selectively dealing with only the harmful strains, therefore, the total populations of microorganisms must be treated. Average levels of coliform bacteria and enteric viruses in domestic sewage are 4.6 x 10^6 to 7 virus units per ml, respectively or a coliform-virus ratio of approximately 10^6 to 10^0. From this, it can be concluded that the coliform organisms are a better indication of pollution from human sources than are enteric viruses. It is also acknowledged that these numbers can and do vary widely within a given quantity of sewage.

Disinfection is a complicated process and is dependent upon the physico-chemistry of the disinfectant, the cyto-chemical nature and physical state of the pathogens, the reaction of the two, and the physical-chemical nature of the carrier waste-water (temperature, pH, electrolytes and interfering substances). The most highly clarified and oxidized effluents are the easiest to disinfect. If good control of microorganism content is to be attained (by *chlorination), good secondary waste treatment is required. The need for high clarity (low* turbidity) was demonstrated in research (Reference 46) where coliform bacteria were constantly isolated from waters containing between 0.1 and 0.5 mg/1 of free residual chlorine and between 0.7 and 1.0 mg/1 of total residual chlorine after 30 minutes contact time. The chlorinated water in which coliform organisms were consistently found, had turbidities ranging from 3.8 to 8.4 units, and microorganism levels of 2000 per ml on occasion.

Viruses, being much smaller than bacteria, would appear to have more opportunity to become enmeshed in the organic turbidity-contributing materials and thus more opportunity to survive the disinfecting action of chemical agents. It is, therefore, advisable that turbidities in final effluents be kept well below one Jackson unit. In fact, for most effective chlorination it would be well to have the turbidity as low as 0.1 unit as recommended by A.W.W.A.* water quality goals. It should be understood that the limit of 5 Jackson Units of turbidity (JTU) specified in the Public Health Service Drinking Water Standards is meant to apply to protected watersheds and not to effluent from filtration plants. The relationship between effective disinfection dosages and effluent turbidities, for operating systems, suffers from a dirth of instrumentation capable of measuring turbidity between 0.01-1.0 JTU.

A positive coliform index means that virus may be present while an absence of coliform organisms may <u>not</u> mean that virus is absent. Some concern has been expressed regarding the fact that numerous viruses are more resistant to chlorine than the coliform bacteria. Methods of using viruses as an indicator of chlorination efficiency have not reached the stage where practical tests for routine use are available. The coliform test still remains an effective criterion for disinfection of drinking water.

Except for hepatitis, clearly defined outbreaks of virus diseases traceable to drinking water have not been reported (Reference 45). Yet entire viruses have been isolated from ground waters, surface waters and rivers around the world (Reference 69). Only epidemics of hepatitis originating in chlorinated water supplies judged satisfactory by the coliform test have been reported in instances where obvious deficiencies in chlorination were shown or suspected. From this, it has generally been considered that effluents disinfected to satisfactory coliform destruction levels are not likely to be much of a health hazard. However, in the light of recent developments in virus isolation this remains subject to question. Any future water or wastewater management systems should take this into account.

The disinfection of water for general sanitary purposes can be accomplished by application of heat (boiling), light (ultraviolet wavelengths), and a variety of chemicals (oxidizers, metallic ions, alkalies and acids, and surfactants).

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*A.W.W.A. American Water Works Assoc.

1 HEAT

The use of heat (raising the water to its boiling point and holding for 15-20 minutes) has been proven to be a safe practice usually resorted to in times of emergency. As a process, however, this approach is impractical for wastewaters in comparison to other methods.

2 LIGHT

Nautral disinfection occurs in waterbodies by direct exposure to sunlight due particularly to the ultraviolet frequencies. Ultraviolet irradiation is used in dairy and other food processing operations and other packaging industries where a measure of miniboil protection is required. The disinfection of water is accomplished by exposing water in thin films to the emanations from mercury-vapor lamps. These lamps must be encased in quartz or other special glass envelopes that are transparent to the intense, destructive, invisible light at a wavelength of 2, 537 angstrom (Å) units emitted by the mercury-vapor arc. To insure disinfection, the water must be sufficiently free from suspended matter and other substances that might shade and hence protect the organisms from the UV light. Time and intensity of exposure must also be adequate. Ultraviolet sterilizers can purify water (greater than 99% reduction) at a cost of less than 1 cent per 1000 gallons (Reference 70).

Experimentation using a gamma radiation is in the laboratory test stage and cannot be expected to be operational in the near future, even if proven to be successful.

3 CHEMICALS

There are several families of chemicals capable of providing effective disinfection. The degree of effectiveness varies with length of contact time and concentration of the chemical.

3.1 OXIDIZING CHEMICALS

The halogens (chlorine, bromine and iodine), potassium permanganate and ozone are chemicals which have been found to be particularly effective disinfectants (within their economic envelopes).

3.1.1 Chlorine

Chlorine has been and remains the most commonly used chemical disinfectant. Chlorine can be administered to treated effleunts in any of several forms---gas, liquid (as sodium or calcium hypochlorite) and tablets. For large (municipal) treatment plants, liquid chlorine forms are the most economical. Effluent dosage rates vary as a function of the specific treatment train chosen as indicated below:

Chlorine Dosage Ranges

Waste	Chlorine Dosage mg/1
Raw Sewage	6 to 12
Raw Sewage (septic	12 to 25
Settled Sewage	5 to 10
Settled Sewage (septic)	12 to 40
Chemical Precipitation Effluent	3 to 10
Trickling-Filter Effluent	3 to 10
Activated Sludge Effluent	2 to 8
Sand Filter Effluent	1 to 5

Chlorination is generally associated with conventional treatment. However, because the quality of water from advanced water treatment systems has a major effect on chlorine disinfection and the amounts needed, the operating and capital costs are reduced.

Because the chlorine demand of the final effluent is very low, instantaneous chlorine values of 2 to 3 mg/1 insure complete disinfection. To be effective for disinfection purposes, a chlorine residual of 0.2 to 1.0 mg/1 is recommended, with a contact time of not less than 15 minutes at peak flow rates. The coliform test should be considered the primary standard; the test for chlorine residual can only be considered as a secondary standard, and it is only valid to the extent confirmed by the results obtained in the coliform test. A correlation exists between chlorine residual and coliform density (coliform densities decrease with increased chlorine residuals) but the individualities of waste treatment plants and their effluents make it difficult to apply a correlation determined from one plant to other plants. Each plant must develop its own data for correlating chlorine dosage, residual, and contact time, to yield predictably, the desired reduction in the coliform count.

Though emphasis in this section is on disinfection; chlorine applications to water and wastewater have also included:

1. Destruction or control of undesirable growths of algae and related organisms in water and waste waters.
2. Destruction and prevention of growth of iron-fixing and slime-forming bacteria in pipelines and other water conduits and of slime-forming bacteria in sewers and sewage-treatment works.
3. Destruction of filter flies (Psychoda) and of ponding slime growths in trickling filters.
4. Improvement of the coagulation of water and waste waters and of the separation of grease from waste waters.
5. Control of odors in water and waste waters.
6. Stabilization of settling-tank sludges in water-purification works.
7. Prevention of anaerobic conditions in sewerage systems and sewage-treatment works, by delaying or reducing decomposition.
8. Control of odors associated with the treatment of sewage sludge, including its drying.
9. Destruction of hydrogen sulfide in water and waste waters, and the protection of concrete, mortar, and paint against the corrosive action of this gas.
10. Reduction of the immediate oxygen requirements of returning activated sludge and of digester liquor returned to the treatment plant.
11. Reduction or delay of the BOD of waste waters that are to be discharged into receiving waters.
12. Preparation at the plant of the coagulant chlorinated copperas (ferrous sulfate).

3.1.2 Bromine

Bromine, as B_{R2}, and elemental iodine, as tetroglycine hydroperiodide tablets, have been employed as a limited scale for the disinfection of small quantities of drinking water. Recently economical processes and equipment have become available for use of Bromine in swimming pools and could be applied to larger scale disinfection operations (Reference 71).

3.1.3 Potassium Permanganate

Potassium permanganate, an oxidizing agent has been effectively used in industrial treatment processes to demineralize, separate metals from solution, prevent scale and corrosion and deodorize. Its use in wastewater treatment is severely limited by its sensitivity to pH, temperature, sewage strength and presence of heavy metal ions (catalysts). Because of this and its higher costs, no practical, reliably efficient application to wastewaters is envisioned for the near future.

3.1.4 Ozone

Ozone as a unit process was discussed in Appendix H. The relatively small partial pressure of ozone in the air, the resulting difficulty of its solution in water, and the "fixing" of some residual odors in treated water have militated against the exploitation of this otherwise very promising substance. From 1 to 4 mg/1 of ozone are required for deodorizing or for disinfection. Modern ozoning plants include, besides contact tanks the following equipment for the production of ozone; air cleaners, blowers, refrigerative driers, absorptive driers, ozone generators, and cooling-water service. The power requirement for this ancillary equipment is from 25 to 35% of the power needed for the generation of the ozone. Contact tanks similar to construction to the air-diffusion units of activated-sludge tanks provide a detention of about 10 min for the absorption of the gas.

3.2 HEAVY METAL IONS

Silver ions are destructive in minute concentrations (∼ 15 g/1) however an extended contact time is required and the chemical costs are high.

Copper ions are active against algae but have little effect as a bactericide. Surface-active chemicals (detergents) are either cationic, neutral or anionic. The scale of effective destruction varies from very strong (cationic) to weak (anionic). The detergent disinfecting powers have been exploited in wash and rinse waters in various commercial/domestic products, however there is controversy over the environmental impacts of widespread use and possible toxicity effects. In general, a highly akaline or acidic solution will destroy pathogens but will most likely create a conditioning problem after functioning, of at least adjusting the pH and/or neutralizing the active elements in the additive prior to discharge or reuse.

APPENDIX L

DISPOSAL OF WASTE PRODUCTS

APPENDIX L
DISPOSAL OF WASTE PRODUCTS

INTRODUCTION

The waste products of treatment systems are primary sludge, secondary sludge, concentrated mineralized (brine) solution and any regenerants associated with backflushing, rinsing or reactivation of bed media.

The sludges of sewage are unique substances in that their behavior as a liquid/solid mixture is a function of the % moisture contained (or conversely % concentration of solids), the solids make-up (greases, organics, chemicals) and agglomerated particle size range, and age (degree of freshness). These factors interrelate and couple to affect handling, further concentration (if required) and ultimate disposal techniques. Further, sludge quantity, specific wastewater treatment processes and locality of the plant to natural resources can also influence selection of waste products disposal schemes. With the controversy over land fill and ocean dumping of municipal waste sludge, processes are being studied to convert, reduce or eliminate sludge as a waste material. A summary of current methods is presented below.

Methods of Sludge Treatment

	Disadvantages	Advantages
Composting	Large Land Requirements	Recycling
Digestion	High Capital and Operating Costs	
Heat Treatment	High Operating Costs Odor Problems	Recycling
Pressure Cooking (Wet Oxidation)	Expensive, Dangerous, Corrosive Potential Air Pollution Requires Skilled Labor	Requires Little Space Flexible
Incineration	Potential Air Pollution	Requires Little Space May be Cost Competitive with Dumping
Dumping	Large Land Requirements Odor Problems Marine Contamination	Inexpensive

The relative costs of these methods are shown in Figure 1. These costs include any sludge conditioning and treatment processes necessary to provide whatever economic advantage is available for that method and its application.

1 SLUDGE PREPARATION FOR DISPOSAL

As more and more sophisticated wastewater treating systems go into operation, the volume of sludge produced and the concentration of undesirable impurities in it will dramatically increase. All of this sludge must be treated so that it can be disposed of easily and economically without further pollution of water, air, or land. While there have been some new developments as well as some improvements in existing processes, there is still an urgent need for better and more efficient sludge treatment. The major processes now available to accomplish this can be grouped into four categories as shown on Figure 2.

Concentration and dewatering reduce the volume of sludge while digestion destroys some solids and stabilizes the remainder. Heat-drying and combustion handle the dual job of reducing volume and destroying solids. All of these approaches must be considered separately and in various combinations before coming up with the best treatment method for a given sludge.

Sludge concentrators are mainly used to thicken sludge from secondary clarifiers or mixtures of sludge from both primary and secondary treatment units.

Raw sludge is a semiliquid whose solids content varies with the source. Sludge from primary sedimentation contains 2.5 to 5% solids, that from the trickling filter contain 0.5 to 5% solids, and that from the activated sludge process contains 0.5 to 1% solids. Of these, the latter two are much more difficult to handle because they contain the excess microorganisms that proliferate in biological treatment. These organisms contain water internally and flocculate into a structure that has a strong affinity for water and retains it tenaciously. It is thus difficult and costly to reduce the volume of biological sludges by removing water in the process of preparing them for ultimate disposal.

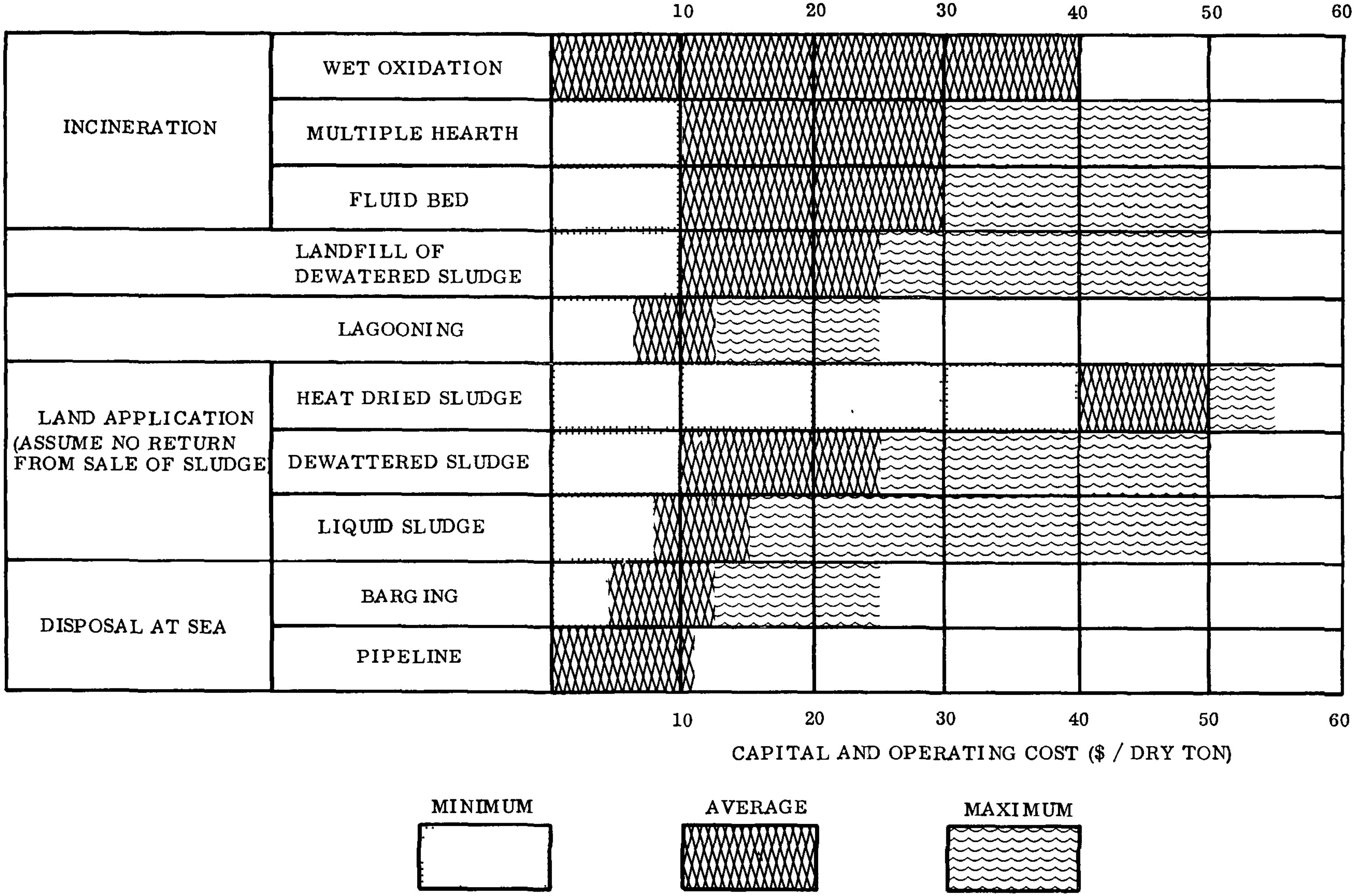


Figure 1. Sludge Disposal Costs

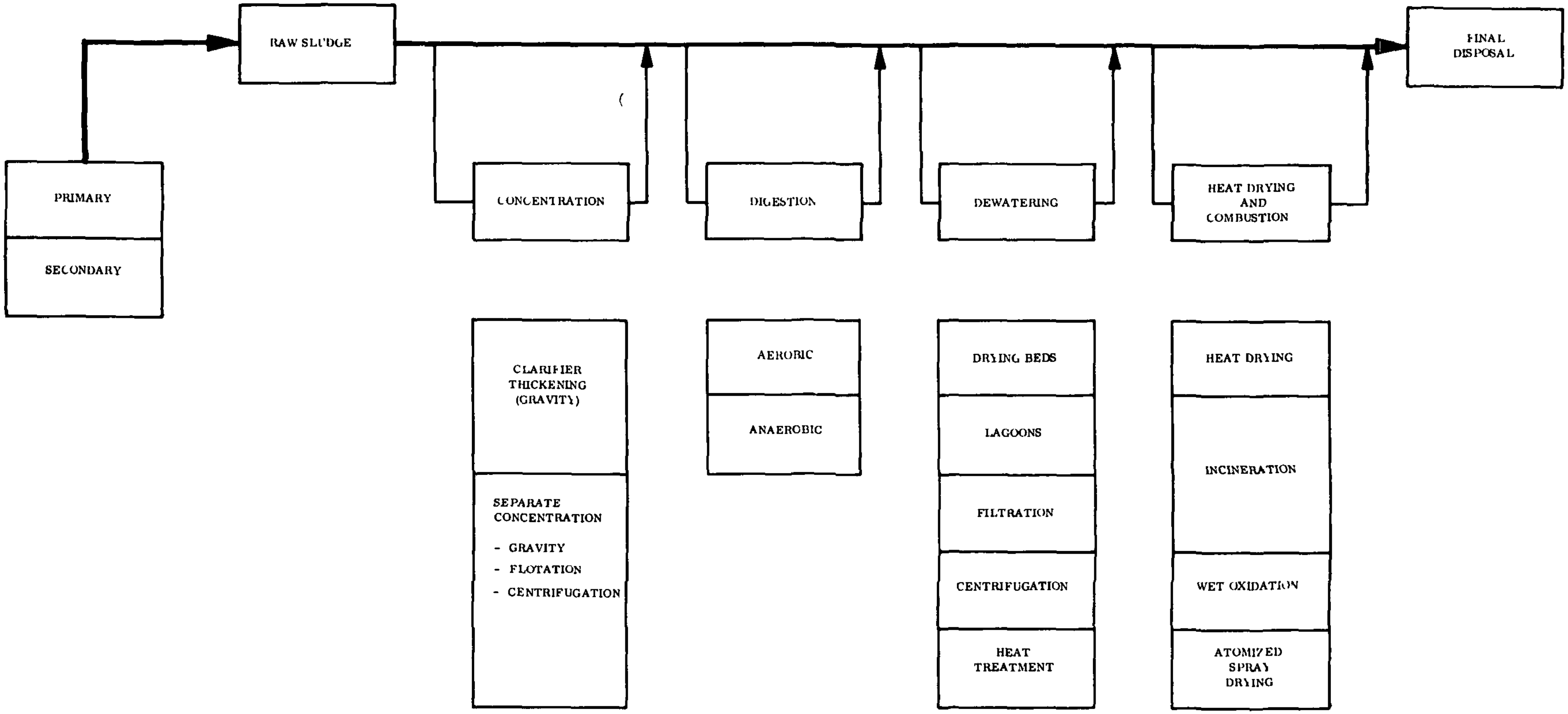


Figure 2. Sludge Treatment/Processing

Sludge handling and disposal has four general objectives:

1. To convert organic matter to a relatively stable form.
2. To reduce the volume of the sludge by removing liquids.
3. To destroy or control harmful organisms.
4. To obtain by-products whose use or sale reduces the overall cost of processing the sludge.

Of the available devices, centrifugation can yield the highest concentration (~ 10%) of secondary sludge. Primary sludges usually require some pre-treatment before a high concentration is possible.

Raw primary sludge contains approximately 25% entrained (bound) water within the settled solids. Sludge can be conditioned to release the water by chemicals or heat. The theory is that small, dispersed, charged particles can be made to coalesce by adding a chemical which ionizes in water to provide charges of the opposite sign. The chemical conditioner reduces the charge on the suspended particle and thus decreases its tendency to bind water. Settling by gravity or mechanical means is thereby enhanced.

Washing sludges with freshwater - a process known as elutriation - is sometimes done if it is desirable to lower the alkalinity of the liquid portion of the sludge. Elutriation often reduces the amount of conditioner which must be used. The most commonly used chemicals for flocculation are ferric chloride and lime, employed either separately or together depending on the type of sludge.

Synthetic polymers can also be used to promote flocculation. Such polymers are water-soluble and have end groups which ionize in solution to provide binding sites for charged sludge polymers. Polyelectrolytes can be either anionic or cationic. Sometimes nonionic polymers are used that promote settling by forming bridges between particles in suspension.

Recently, a steam-heating (Porteus) process has been substituted for chemical conditioning with promising results. The Porteus process applied heat and pressure to break down the gelatinous structure of sludge resulting in libration of bound water. After pressurization to about 250 psi, the sludge is heated, in a reactor to 350^{o} followed by steam injection into the mix for a 30 minute period. The sludge is passed through a heat exchanger to recover heat. Further dewatering by a vacuum filter, centrifuge or filter press can result in a final concentration of 50 - 55% solids content. Digesters and conditioning chemicals are not required. Of the BOD in the original sludge, 10 to 20% returns to the treatment process in the liquid from the cooker, and 60 to 80% of the nitrogen returns. Although costs and performance data on the Porteus process are not yet available for the U.S., work in England suggests that it will be competitive with alternative processes.

Fly ash has been used successfully to condition specific industrial sludges for vacuum filtration and laboratory work suggests that it would work well on municipal biological sludges. The results indicate that, besides improving the filtration characteristics of the sludge, fly ash would upgrade the quality of the filter effluent by removing significant amounts of organic material and phosphorus. Fly ash would replace more costly conditioning chemicals and would thus improve the overall economics of both municipal wastewater treatment and fly ash disposal.

Ash from the incineration of sludge is also used as a filter aid in some municipal treatment plants. As with fly ash, amounts approximately equal to the dry solids content of the sludge are used. The use of sludge ash reduces the ash disposal problem significantly and eliminates the need to transport fly ash to the treatment plant.

1.1 DIGESTION

Under anaerobic conditions sludge solids are easier to dewater and converts part of the organic matter to gaseous end products primarily methane and carbon dioxide. The methane can be stored and used for as fuel for heating or incineration functions. Sludge is pumped into an enclosed airtight vessel where the solids decompose rapidly. The rate of decomposition depends mainly on the nature of the solids, pH, temperature and the degree of mixing. Digestion can reduce the volume of sludge by as much as 50%.

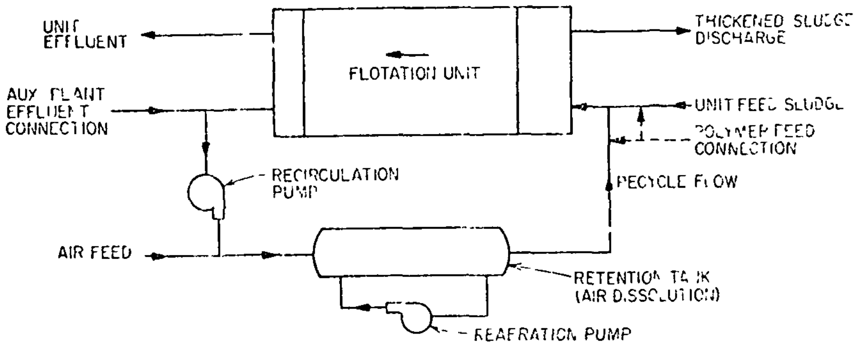
1.2 DEWATERING

Drying beds and lagoons do not lend themselves to small automated modular systems due to land required, proximity to populated areas, soil conditions and prevailing winds. The increasing costs of land and labor are leading to wider use of mechanical dewatering devices such as vacuum filters and centrifuges, followed by incineration. Incineration normally requires a sludge that contains enough solids, roughly 25% minimum, to support combustion, and mechanical dewatering is the most practical means of producing such a sludge.

Vacuum filtration has been used for some years to dewater sludges, although it fell from favor between World War II and about 1960 because of operating problems and costs. Since 1960, vacuum filtration has come back strongly because of improved filter media, higher costs for competing methods, and the growing popularity of sludge incineration. The main general shortcoming of filtration is that it involves more art than science. Required improvements include equipment that would feed sludge to the filter at a uniform rate and instrumentation that would measure sludge flow and proportion conditioning chemicals accurately. Another improvement would be filters that could adapt readily to unexpected changes in the character of the sludge.

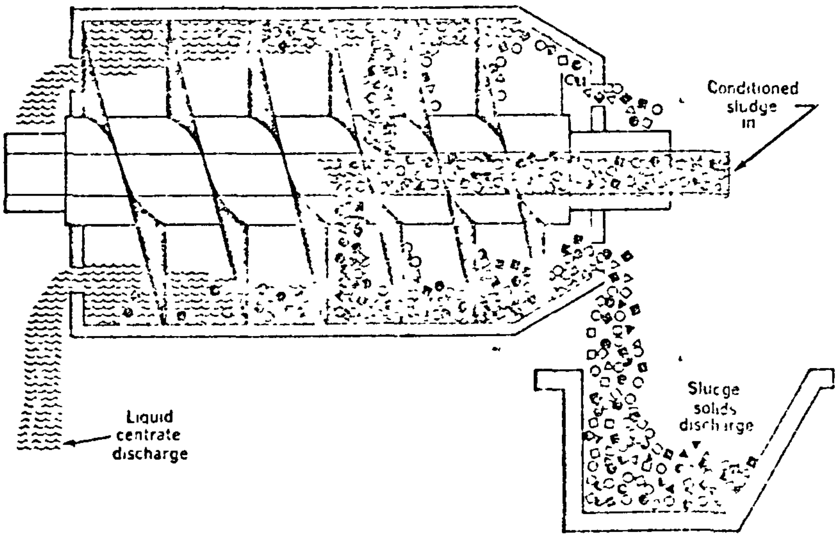
The centrifuge also has been seeing wider use in the past decade for dewatering sludges, primarily because of improved design based on the solid bowl centrifuge. Although vacuum filtration remains the predominant mechanical dewatering device, the centrifuge has certain inherent advantages, including low capital cost, moderate operating cost, and low space requirement. The chief problem with the centrifuge is that the centrate (the liquid that it returns to the wastewater treatment system) often contains undesirable amounts of fine solids that can build up in the system. The problem is greater with the biological sludges from secondary treatment, and the trend is toward more use of secondary treatment. Chemical flocculants can be used to improve the quality of the centrate, but their use can increase operating costs significantly. The centrifuge would benefit from still better design and further research on the use of chemicals and means of disposing of the centrate other than by returning it to the treatment process. Centrifuges alone do not remove enough water from activated or mixed sludges to permit them to be incinerated without using auxiliary fuel. The centrifuged sludge usually ranges from 20 to 30% solids. The vacuum filter and centrifuge are illustrated in Figure 3.

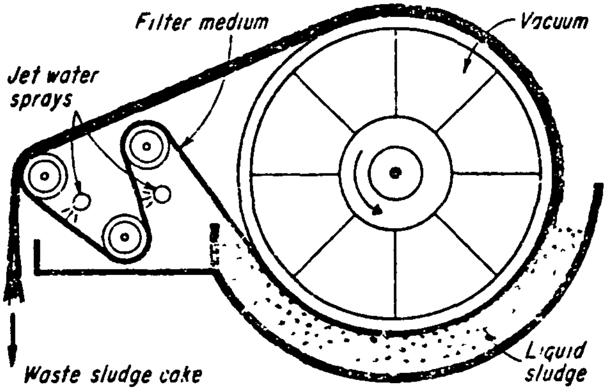
Waste activated sludge is usually about 99.5 percent water which is very difficult to separate from the associated solids. It is often helpful or necessary to thicken waste activated sludge to about 5 percent solids to prepare it for more complete dewatering in a vacuum filter or other device. Float thickeners have been used very successfully to thicken waste activated sludge to 4 - 6 percent solids. One such unit is the H-R Flotation Thickener, as manufactured by Komline-Sanderson Engineering Corporation of Peapack, N. J., shown below:



Schematic flow diagram—H-R type flotation unit (*Courtesy Komline-Sanderson Corp*)

The thickener consists of the main flotation basin equipped with a sludge removal mechanism at the water surface, a recirculation pump, a compressed air supply, an air dissolution tank equipped with a rearation pump, and a polymer feed system. The thickener operates as a dissolved-air-type flotation unit. The minute bubbles necessary for flotation of the sludge are produced by dissolving air in the recycled effluent at 50 - 70 psi. The recycled flow is mixed with the basin influent at reduced pressure. The tiny bubbles of air expand and attach to sludge particles and cause them to float to the top water surface where the sludge particles agglomerate and condense to form a thick sludge blanket. The sludge blanket is continuously removed from the water surface by the mechanical collector. High molecular weight organic polyelectrolytes are excellent flotation aids when added to the influent to the thickener unit.


Horizontal sludge centrifuge


VACUUM FILTER

VACUUM FILTER drum, covered with a porous media such as cloth, slowly rotates through liquid sludge in a slurry tank. Water is removed by filtration leaving a cake of solids which rides out on the cloth and is air-dried before final discharge

Figure 3. Mechanical Dewatering Devices

A number of unconventional methods have been studied for improving the dewatering characteristics of sludges. They include freezing and thawing, heat treatment, gamma irradiation, solvent extraction, electrical treatment, ultrasonic treatment, and treatment by bacteria. The aims of such work generally have been to increase the rate of production of dewatered sludge and to eliminate the need for conditioning chemicals.

Freezing and thawing improves the dewatering characteristics of sludge, evidently by breaking down the cell walls in the organisms that retain internal moisture. A small plant was built in England to condition water treatment plant sludge by freezing, but the operating costs appear to be impractically high for wastewater sludges. The sewage commission of Milwaukee, Wis., is currently developing a freezing process for demonstration and evaluation. The remaining methods are in very early investigation however, as is typical of new work, preliminary estimates of costs are high, efficiencies low.

2. DISPOSAL TECHNIQUES

The final disposition of municipal sludge includes sanitary land fills, ocean dumping, recycling (after composting), reclamation as new materials for construction and incineration (followed by land fill). Sanitary land fill of primary sludge is becoming extinct in most areas due to public pressures and scarcity of nearby land. Transporting over long distances increases disposal costs as indicated in Figure 4, making other type disposal methods viable. Since ultimately, disposal economics is measured in tons (or dry tons) of material, reduction of sludge mass has been uppermost in new process developments. The two basic processes are heat-drying and combustion.

2.1 HEAT DRYING

Heat drying reduces the moisture content of sludge to 10% or less by evaporation. At this moisture level, the residue can be used as fertilizer or burned as fuel in an incinerator. The flash-drying system shown in Figure 5 meets both these requirements. It converts wet sludge filter cake into: (1) cool, deodorized, ash free stack gases, (2) dry sludge containing all the original fertilizer ingredients which can be bagged for marketing as a soil conditioner,

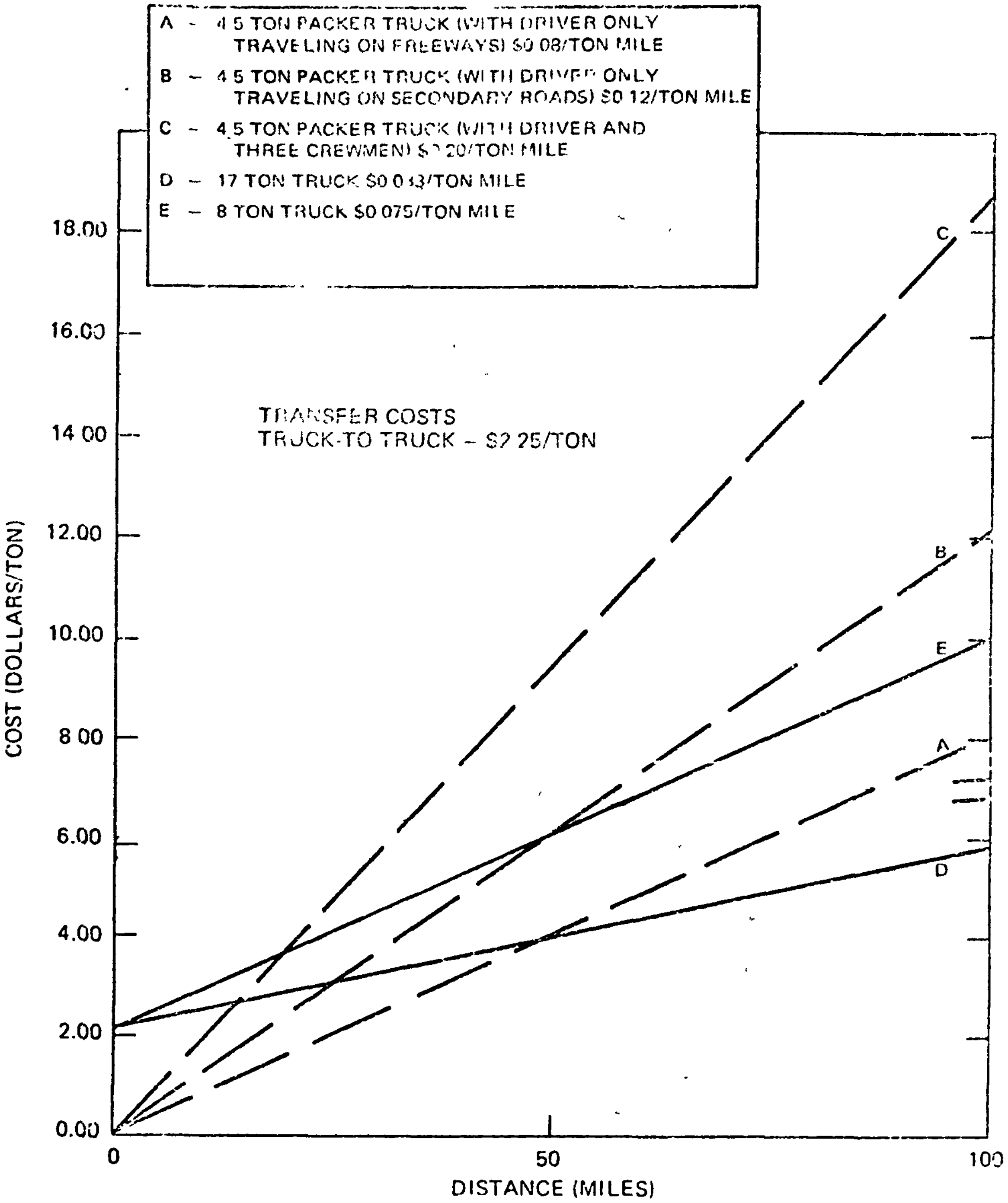


Figure 4. Trucking Costs

and (3) ash in a fine, granulated form, free from clinker or unburned organic material. The relative production of ash and dry sludge can be varied to meet local conditions. All or part of the sludge can be incinerated or converted to fertilizer. A number of wastewater treatment plants have attempted to heat-dry sludges, usually after mechanical dewatering, and sell the product as fertilizer or soil conditioner. Most have abandoned the practice in favor of incineration or landfilling. Heat-drying costs more than incineration, and limited demand for the product has made it difficult to get a high enough return to offset the increased cost. A few cities have sold large amounts of heat-dried activated sludge for some years, but generally the process is considered uneconomical.

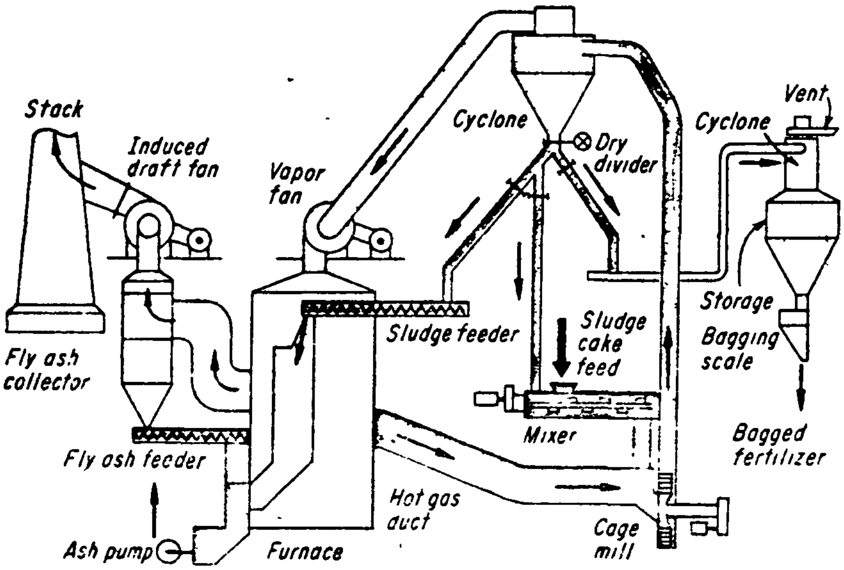


Figure 5. Flash-Drying and Incineration System

2.2 INCINERATION

Incineration has two aims, to reduce the volume of the sludge and to sterilize the organic solids. Incineration costs more than some other disposal methods, but it is gaining ground relatively as the costs of alternative methods increase. There is also a trend away from sludge digestion in plants that use incineration. About 50% of the incineration plants installed between 1934 and 1961 burned digested sludges, but only four of the 50 incineration plants built in 1961 - 67 were designed to burn digested sludge. Selection of a combustion process is largely a result of the processes used in sludge treatment. Specific sludge parameters impacting the incinerator selection (and size) are: (1) percent solids, (2) percent combustibles, (3) heat value, and (4) quantity. Sludge to be a self-supporting fuel should be concentrated to about 25% solids content. Additional benefit for combustion efficiency, is available directly if the sludge is undigested, that is, contains the maximum amounts of oxygen. Anaerobically digested sludge is bacterially broken down such that sludge volume is reduced and large amounts of methane (and carbon dioxide) gas produced. Burn value of digested sludge is approximately 6000 BTU/lb. while undigested sludge is 10,000 BTU/lb. For determining the fuel requirements to supplement the innate sludge heating value, the moisture content should be minimal, consistent with the handling and transfer system feeding the incinerator. Figure 6 shows a typical impact of moisture content on fuel costs for a raw sludge, in order to vaporize the bound water at various concentrations. Solids concentrated to above 6 - 8% are not pumpable and resist usual liquid or slurry handling procedures due to high viscosity and low shear resistance. The reduction of sludge volume as a function of solids concentration is shown in Figure 7. The important trend indicated by the curves is the asymptotic relationship of sludge volume reduction after solids concentrations of 4 - 6% are reached. Additional concentrations do not result in significant saving in sludge quantity. Incineration products are usually sterile ash and a gas exhaust expected (and generally required) to be free of noxious odors, particulate ash (carbon) and combustion pollutants. As shown in Figure 8, odors are removed by oxidizing at temperatures above 1200°F. Gas and particulate pollutants are usually removed by an exhaust gas scrubber. The incineration processes available for modular systems include:

1. multiple hearth
2. fluidized bed
3. vortex flow
4. atomized suspension
5. wet oxidation
6. combined sludge-solid wastes

2.2.1 Multiple Hearth. Referring to Figure 9a, sludge cake enters the top of the incinerator. An air cooled rotating shaft, with rakes at each hearth level, extends vertically through the unit. The sludge cake is raked in spiral path moving in and out of each successive hearth

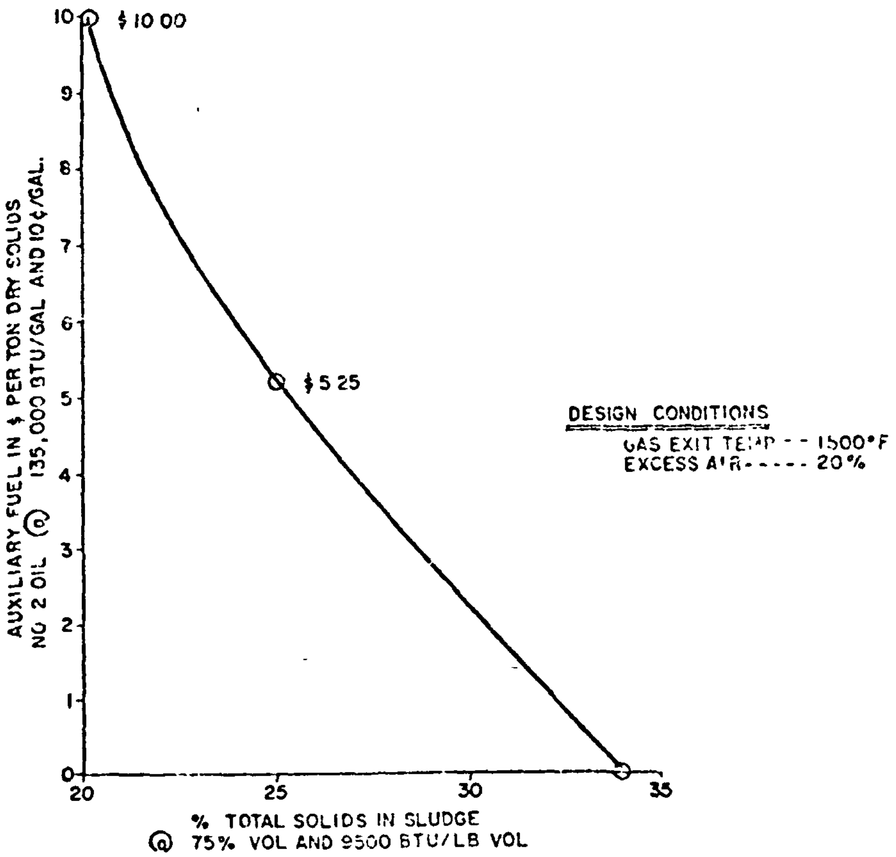


Figure 6. Moisture Content Impact on Fuel Costs

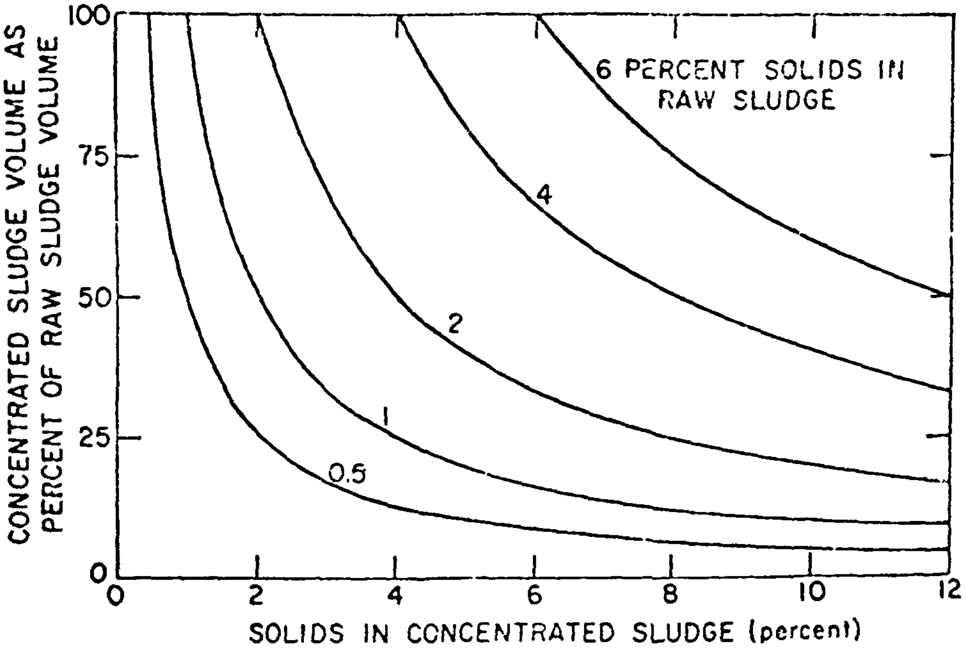


Figure 7. Effect of Increase in Sludge Solids Concentration on Reduction in Sludge Volume

through alternate drop holes. Ash discharged from the bottom hearth at 500°F is completely sterile since all the organic matter has been burned away. Combustion gases pass through a high efficiency wet scrubber to remove the fly ash. The furnace consists of 4 or more hearths, piggy-backed with combustion temperatures progressing from low at the upper hearths to high as the water is evaporated away and the remaining solids oxidized as rabble arms (plows) convey the solids to the lower levels. By including auxiliary burners at each level, combustion temperatures can be controlled for optimal incineration and for carbon regeneration where activated granular carbon is integral in the waste treatment train.

2.2.2 Fluidized Bed

Figure 9b shows the fluidized bed reactor. The dry cake, conveyed directly into the reactor, operating at 1300 to 1600°F, mixes with an inert bed of sand kept in fluid condition by an upflow of air. Rapid combustion occurs with organic solids retained in the bed until they are reduced to an inert ash and carried away by the combustion gases. Water in a wet scrubber entrains these inert solids and cools the gases. Finally, a centrifugal type liquid cyclone drops out the inert solids.

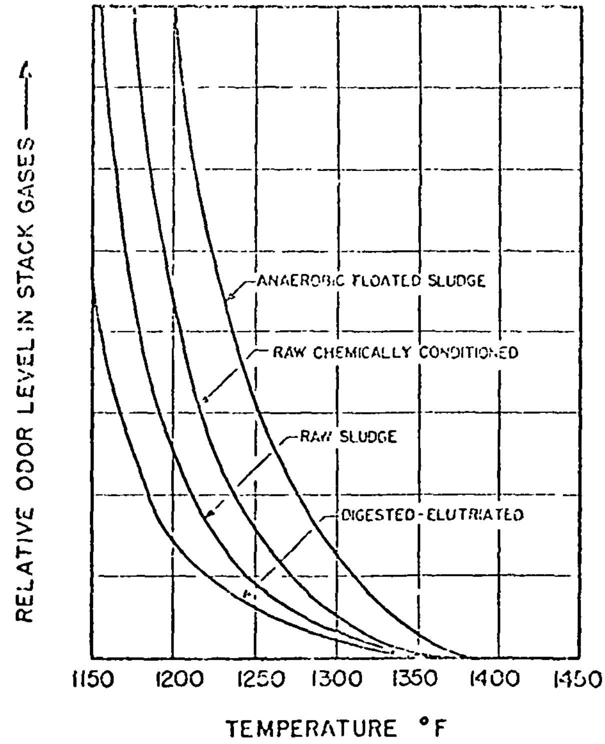
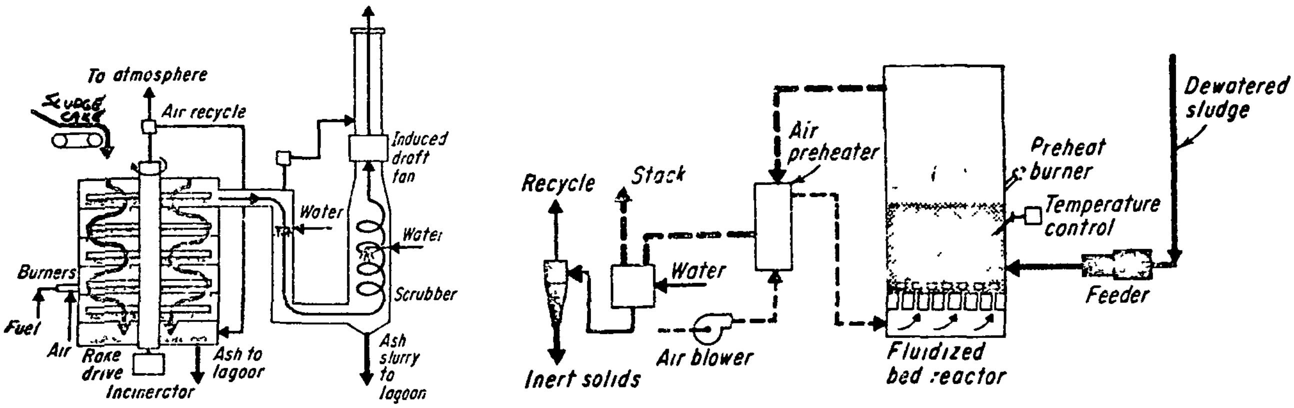
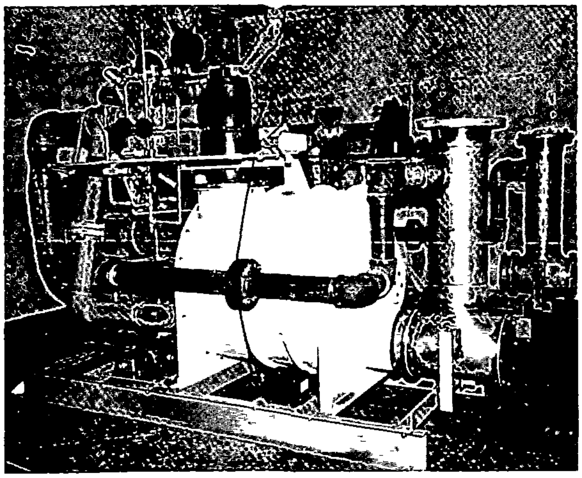


Figure 8. Relationship of Odor Level in Stack Gases to Temperature of Deodorizing Zone for Several Types of Sludges

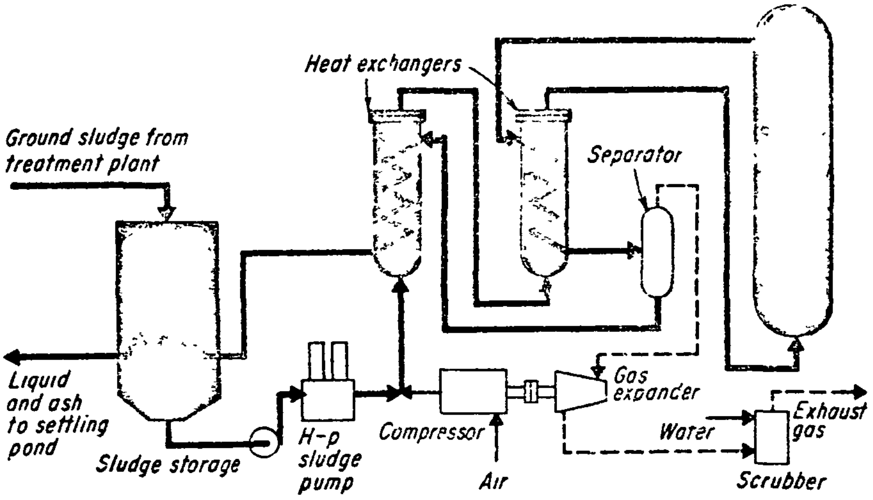


a. Multiple Hearth

b. Fluidized Bed



c. Vortex Flow



d. Wet Oxidation

Figure 9. Incineration Processes

2.2.3 Vortex Flow. Sludge, at from 1/2 to 5% concentration is aspirated into a vortex flow stream where it mixes with combustion air and is combusted within the air cooled chamber at 1700°F. Fuel is required to provide rapid time response (~ 1/2 second) and high temperatures to assure sterile ash and an odorless inert stack exhaust meeting air quality emission standards. The combustion chamber is cooled by circulating air between three shells. Sludges can be preheated by injecting the heated air into the sludge holding tank. Stack gases at 850°F offers potential for heat recovery in the treatment train to improve performance. Ash residue is collected at the base where a vacuum blower can remove any accumulations. Originally developed for shipboard applications, the present equipment can dispose of 30 gallons/hour (see Figure 9c).

2.2.4 Atomized Suspension. Atomized-suspension process involves drying and oxidizing small particles of sludge as they pass down through a reactor. The residue solids are collected in a cyclone separator and heat recovered from steam and gases. Sludge concentrated to 10% solids is atomized with pressure nozzles into the top of a vertical reactor which is heated to temperatures of 1000 - 1400°F. The entrained water flashes into superheated steam and solids are dried while falling to lower levels. Air is introduced at the midpoint of the descent to accomplish the oxidation of the solids. The condensate and entrained ash are passed through a scrubber and the liquid discharged with the treated effluent.

2.2.5 Wet Oxidation. Wet oxidation as diagrammed in Figure 9d, can be carried out without major moisture reduction. This means heat requirements of this process are significantly less. However, for the process to be thermally self-sustaining, the sludge must be sufficiently concentrated to yield about 2000 BTU/gal. A heat yield of about 3000 BTU/gal. will also generate enough heat to satisfy power requirements for pumps and other machinery to operate the process. This calls for a sludge concentration in the range of 3 to 5%. Thicker sludges, of course, provide an additional dividend of recoverable energy. Ground-up sludge is heated by oxidized sludge leaving the system. Sludge from the h-p pump and compressed air are mixed and brought up to oxidation temperature by two heat exchangers. Flameless combustion of organic matter then takes place in the reactor at 500 to 700°F. Oxidation continues spontaneously as long as there is enough air and sludge and products of combustion -- mainly carbon dioxide, nitrogen and steam - are continuously removed. Hot contents of the reactor move out to preheat incoming sludge. Gases released may be expanded to run an air compressor or electric generator. System operating pressure is 1750 psi. The solid residue is like ash from an incinerator and the liquid is biodigradable. Stack emissions are inert and odorless.

2.2.6 Combined Sludge - Solid Wastes. Incineration processes tend to be too costly for use in small communities (populations less than say, 10,000). For these applications, consideration of combined waste incineration may prove feasible. An analysis of the heat balance involved follows for an assumed mixture of 10% primary sludge (solids concentration) with municipal refuse to combust a 30% solid mixture in an incinerator capable of handling 144 tons/day (6 ton unit operating 24 hours/day).

30% x 144 tons/day = 43.2 tons solids

If s = tons of 10% sludge to be mixed then:

$0.1(s) + 1.0(144-S) = 43.2$

S = 112 T sludge
(11.2T dry solids)
+ 32 T solid wastes
144T/day
(43.2 T/day solids)

- Heat value - sludge
  Assume raw sludge @ 10,000 BTU/lb.
  10,000 BTU/lb. x 11.2 T/day x 200 lb/T = 224 MBTU/day

- Heat value - refuse
  From reference 44 (rounded off), calorific value (BTU/lb) = 6200
  ∴ 32 T/day x 2000 lb/T x 6200 = 396 MBTU/day

- Heat required for water/steam combustion
  Assume 1500°F combustion for odor removal and complete combustion and sludge temperature of 62°F

62-212°F @ 1 BTU/°F = 150 BTU
Heat of vaporization @ 212°F = 970
212-1500°F (from steam tables) = 650
1770 BTU/lb
Amount of water in 10% sludge = 112-11.2
= 100.8 T/Day
100.8 T/day x 2000 lb/T x 17770 BTU/lb = 357 MBTU/day

- Heat balance

Gains: sludge @ 224 MBTU/day
refuse @ 396 MBTU/day
620
Loss: water @ -357

TOTAL GAIN 263 MBRU/day

- Post incineration residuals

Assuming 65% combustibles in sludge=

11.2 T/day x 0.35 3.9 T/day ash

Refuse @ 20% moisture =

32 T/day x 0.8 = 25.6 T/day solids

Assuming 25% incombustibles in refuse=

25.6 T/day solids x 25% 6.3 T/day

Total disposable residual = 3.9 + 6.3 = 10.2 T/day

- Available energy for recovery

Assume 70% incineration efficiency
(30% losses through heat losses in furnace, stack)

$$0.7 \times 263 \text{ MBTU/day} \times \frac{1 \text{ day}}{24 \text{ hrs.}} = 7.66 \text{ MBTU/hr}$$

Converting to steam @ ~1050 BTU/lb =

$$\frac{7,660,000 \text{ BTU/hr}}{1050 \text{ BTU/lb}} = 7,300 \text{ lbs/hr steam}$$

Though calculated for a municipal facility, it should be obvious that there is a substantial heat recovery potential for a combined system. The case cited represents sludge from a representative population of about 115,000 (100 GPCD and sewage suspended solids @ 230 PPM) while the refuse is representative of 21,200 (4 lbs/person/day, 75% combustibles); in other words the solid waste per capita heating value can easily absorb the sludge and realize significant heat recovery benefits if designed to mix and handle the combined wastes. The mixing ratio determines the heat gain (or loss). In the example, sludge feed rate is 3.5 times the refuse feed and captures 78% of the incinerator handling capacity. Ultimate incinerator sizing must reflect the total loads of both waste sources and the desired nominal power recovery rate for the population projected for the area.

Methods of combining the two waste sources are already employed in current incineration techniques for each waste type; atomizing the sludge into a hot gas chamber where solid wastes are burning, mixing the sludge with the refuse while being conveyed to a multiple hearth furnace with the auxiliary burners and hot gas preheated at the point of entry to accelerate moisture removal and onset of autothermic combustion of the sludge.

Whenever the location of the sewage treatment plant will permit reasonable hauls, the installation of a mixed refuse incinerator at the sewage treatment plant site will permit disposal of the municipal garbage, refuse and sewage sludge at the same plant site. Such an installation permits drying or incineration of the sewage sludge with no auxiliary fuel requirements due to the heat in the waste gases from the burning of the mixed refuse.

Heat for drying the sewage sludge filter cake is supplied by the mixed refuse incinerator and the flash dried sludge may be marketed as fertilizer or incinerated at will. The dual disposal of mixed refuse and sewage sludge at the same plant site affects economics in both first cost and operating costs of the disposal equipment. For smaller communities, this system provides modern disposal facilities whereas the first cost or operational cost of the separate disposal facilities will be prohibitive. The following cities have this system in use:

Watervliet, New York

Stamford, Connecticut

Waterbury, Connecticut

Fond du Lac, Wisconsin

Bloomsburg, Pennsylvania

Louisville, Kentucky

Neenah-Menashe, Wisconsin

The success of burning the sludge with refuse depends on the type of sludge, hauling cost for refuse, etc. However, in all cases, it is important to give consideration to combined use and sludge incineration. This system may be particularly useful in small cities where hauling costs could be reasonable. For larger cities, centrally located refuse collection and sewage treatment could make this system very conducive. Improved mechanical design or incinerators and development of inexpensive refuse collection technique would encourage combined incineration.

APPENDIX M

COST DATA

APPENDIX M

COST DATA

This Appendix presents cost data used in the development of the Proposed System Economics presented in Section 4.7 of the report.

OPERATING COSTS - FINAL SYSTEM

(a) Activated Carbon:

123	ppm dosage
= 1.03	lbs/K Gal
x .085	$/lb (Acqua Nuchar-Westvaco)
.09	$ /K Gal

(b) Chlorination:

5 ppm =	.04	lbs/K Gal	
x	.95	$/lb. (Diamond Shamrock-tablets)	
	.0384	$ /K Gal	.04 $/K Gal

(c) Centrifuge:

.018	$/lb
624	lbs/day
11.20	$/day ÷ 50 K Gal/Day = .22 $/K Gal

26	lbs/hr
x 24	hrs
624	lbs/day

(d) Incinerator:

8.01	$ /ton (ref. 35)
.312	hr/day
2.50	$/day ÷ 50 K Gal = .05 $/K Gal

Assumes:

Power - 2¢
Fuel - 19¢/ gal.

NASA
ADVANCED SYSTEM EQUIPMENT COSTS

	Purchase	Installation	Total Cost	Adj: Factor	*M&S = 330 Mid-72 Total Cost
Valves	3,900		3,900		3,900
Pumps	2,400	1,440	3,800		3,800
Tankage	5,000	5,000	10,000		10,000
Clarifiers-2	13,000	30,600	43,600 (68 $)	$330/273^{(1.21)}$	52,800
Instrumentation	4,200	2,500	6,700		6,700
Pipe	110	260	400		400
Centrifuge	9,000	5,400	14,400		14,400
Conveyor	2,640	1,580	4,200 (68$)	$330/273^{(1.21)}$	5,100
Incinerator	38,500		38,500 (68$)	$330/273^{(1.21)}$	46,600
Chlorinator	180		200		200
Vibrators	450	270	720		700
Ultrafiltration	93,000		93,000 (68$)	$330/273^{(1.21)}$	112,500
					257,100

*Price adjustments made with Marshall & Swift Equipment Cost Index to Mid '72 $'s

Amortization (7% - 25 yrs) - 0.086 x 257,100 = $ 22,100 1 yr
÷ 365
60.5 $/day
÷ 50 K Gal/day = 1.21 $/K Gal

Amount	Component	Size	Material	Make & Model	Unit Cost
2	Influent Holding Tank	1320 gal.	Fiberglass	Plas. Tech. #450211	2,100
2	Clarifier	4400 gal			13,000
1	Centrifuge	6"		Solid Bowl-Est.	9,000
1	Ultrafiltration Modules	50 K6D		Dorr Oliver-Est.	93,000
4	Ion Exchange Columns	6.1 x ft^3, 9" x 1.13"	PVC	Est.	1,655
1	Fluidized Incinerator	35 lbs/hr. (dry)		Est.	33,600
3	Tablet Chlorine Dispensors			Sanural-Diamond Shamrock	180
1	Chlorination Tank			Sanural-Diamond Shamrock	
1	Screw Conveyor	4" x 15'		Est.	2,640
1	Lime Storage Tank	20 ft^2	Polyeth	Plas Tech #430207 with cover	236
1	Carbon Storage Tank	20 ft^2	Polyeth	Plas Tech #430207 with cover	236
100'	PVC Pipe	2" avc.	PVC	Est.	110
1	Lime Vibrator			EVE-800, Martin	410
1	Carbon Vibrator			DVE-07, Martin	42

Item	Description	Size	Material	Make & Model	Unit Cost
V1	Hand Valve	3"	PVC	Plas Tech Gate #201907	151
V2		3"	PVC	Plas Tech Gate #201907	151
V3		1"	PVC	Plas Tech Gate #201507	13
V4		1"	PVC	Plas Tech Gate #201507	13
V5		2"	DOES NOT EXIST		
V6		2"	DOES NOT EXIST		
V7		1/2"	PVC	Plas Tech Gate #201307	10
V8		3/4"	PVC	Plas Tech Gate #201407	12
V9		3/4"	PVC	Plas Tech Gate #201407	12
V10		1/2"	PVC	Plas Tech Gate #201307	10
V11		2"	PVC	Plas Tech Gate #201807	23
V12		2"	PVC	Plas Tech Gate #201807	23
V13		2"	PVC	Plas Tech Gate #201807	23
V14		2"	PVC	Plas Tech Gate #201807	23
V15		2"	PVC	Plas Tech Gate #201807	23
V16		2"	PVC	Plas Tech Gate #201807	23
V17		1"	PVC	Plas Tech Gate #201507	13
V18		1"	PVC	Plas Tech Gate #201507	13
V19		1"	PVC	Plas Tech Gate #201507	13
V20		2"	PVC	Plas Tech Gate #201807	23
V21		1"	PVC	Plas Tech Gate #201507	13
V22		2"	PVC	Plas Tech Gate #201807	23
V23					
V24					
V25		2"		#201807	23
CV1	Check Valve	1/2"	PVC	Plas Tech Ball #200309	15
CV2		3/4"	PVC	Plas Tech Ball #200409	18
CV3		3/4"	PVC	Plas Tech Ball #200409	18
CV4		2"	PVC	Plas Tech Ball #200809	49
CV5		2"	PVC	Plas Tech Ball #200809	49
CV6		2"	PVC	Plas Tech Ball #200809	49
RV1	Relief Valve	2"	PVC	Plas Tech Ball #200523	132
SOV1	Motor Operated Valve	3"	PVC	Plas Tech Ball #201503	273
SOV2		3'	PVC	Plas Tech Ball #201503	273
SOV3	DOES NOT EXIST				
SOV4		2"	PVC	Plas Tech Ball #201502	246
SOV5	Motor Operated Valve	2"	PVC	Plas Tech Ball	246
SOV6		2"	PVC	Plas Tech Ball	246
SOV7		2"	PVC	Plas Tech Ball	246
SOV8		2"	PVC	Plas Tech Ball	246
SOV9		2"	PVC	Plas Tech Ball	246
SOV10		2"	PVC	Plas Tech Ball	246
SOV11		2"	PVC	Plas Tech Ball	246
SOV12		2"	PVC	Plas Tech Ball	246
MV1	Modulating Valve	3/4"	PVC	Plas Tech Ball #200126	81
MV2		3/4"	PVC	Plas Tech Ball #206008	17
MV3		3/4"	PVC	Plas Tech Ball #200126	81
LC1	Level Control			Barnes 30667 - (Diaphram)	19
LC2					19
LC3					19
LC4					19
LC5					19
LC6					19
LC7					19
AI1	Ammonium Ion Sensor			Orion Research	295
AI2					295
AI3					295
PH1	pH Sensor			Universal Interloc Model 320	365
PH2					365
PH3					365
D1	Pressure Switch				
RC1	Residue Chlorine Analyzer			Capital Model 870	1,700
VT1	Vibration Transducer				
VT2	Vibration Transducer				
E1	Ejector	2	Bronze	Penberthy 166A	120
E2		2"	Bronze	Penberthy 166A	120
E3		2"	Bronze	Penberthy 166A	120
					4,173
PG1	Pump Grinders	(5 HP) 20 gpm	CPVC	GE Est	350
PG2		(5 HP) 20 gpm	CPVC	GE Est	350
PG3		(5 HP) 20 gpm	CPVC	GE Est	350
PG4		(5 HP) 20 gpm	CPVC	GE Est	350
SP1	Sludge Pump & Motor	2 gpm		Mongo FS33-V3 HP	80
SP2		2 gpm			80
SP3		2 gpm		Mongo FS22 - V3 HP	126
BP1	Booster Pump & Motor	25 gpm 1/2 HP		Flotec R5-B1-1000	201
BP2					201
BP3					201
BWP1	Backwash Pump & Motor	20 gpm 1/3 HP	Noryl	Plas Tech #190120	120
					2409

INCINERATOR COST ESTIMATE

$$\begin{array}{rl} 1,100 & \$/\text{lb/hr capacity (extrapolated from ref. 63)} \\ 35 & \\ \hline 5500 & \\ 3300 & \\ \hline 38,500 & \text{(installed)} \end{array}$$

ULTRAFILITRATION CAPITAL COST EST.

From Dorr-Oliver (1968) (ref. 54)

Capital cost estimation relationship:

$$\begin{aligned} K\$ &= 1.65\ (K6D) + 10.50 \\ &= 1.65\ (50) + 10.50 \\ &= 93\ K\$\ (1968) \end{aligned}$$

SCREW CONVEYER ESTIMATE

(From ref. 41) cost est. relationship = $\$ = 230$ (ft)

installation = 59% of purchase cost

$$\begin{aligned} \text{cap. cost} &= 230\ (15)^{.9} \\ &= 230\ (11.5) \\ &= \$\,2,640 \end{aligned}$$

ION EXCHANGE COLUMN COST EST

Size: 6.1 ft^3

Dimensions: 9' x 14"

Number: 4

Pipe cost $/

10"	8.8	Plus Task PVC Sch 40
12"	11.8	Plus Task PVC Sch 40
14"	14.8	Est
	x 36'	

535 $	535
Caps (8) x 60 $ est	480
Flanges (8) x 80 $ est	640
Purchase Cost	1,655

CLARIFIER EST

(From ref. 74)

= 6,800 f.o.b. mild steel - vertical fab.

$6,800 x 2 = $13,600 purchase cost

CENTRIFUGE COST (SOLID BOWL CONTINUOUS)

Purchase cost = 1,900 $(\text{hp})^{.73}$ (ref. 74)

Installed cost = 1.6 (purchase cost)

	(% of Purchase Cost) Installation Factor	Literature Source
Tankage	100%	(74)
Pipe (including valve installation)	240%	(74)
Instrumentation	60%	(75)
Centrifuge	60%	(74)
Conveyor	60%	(74)
Clarifiers	235%	(74)
Pumps	60%	(74)
Vibrators	60% Est.	

GENERAL ELECTRIC

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