technology transfer
design seminar
publication

SLUDGE HANDLING AND DISPOSAL

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

TECHNOLOGY TRANSFER

SLUDGE HANDLING AND DISPOSAL

This publication was prepared for use in the United States Environmental Protection Agency Technology Transfer Design Seminar Series. Emphasis is placed on technology which can be incorporated into design and practice today.

Prepared by:

Mr. John R. Harrison
Black, Crow and Eidsness, Inc.
Wilmington, Delaware

Mr. Stanley J. Mogelnicki
The Dow Chemical Company
Midland, Michigan

Dr. James E. Smith, Jr.
National Environmental Research Center
Environmental Protection Agency
Cincinnati, Ohio

December 5–6, 1972
The Copley Plaza
Boston, Massachusetts

United States Environmental Protection Agency
Technology Transfer Program
Washington, D.C.

TABLE OF CONTENTS

		Page Number	
SECTION 1	Importance of Sludge Processing and Disposal– Current EPA Programs	1 - 1	1 - 5
SECTION 2	Current and Previous Methodology	2 - 1	2 - 5
SECTION 3	Nature and Handling Characteristics of Sludges	3 - 1	3 - 10
SECTION 4	Sludge Stabilization Processes	4 - 1	4 - 9
SECTION 5A	Case Studies – Plant Results – Chemical Conditioning – Conventional Activated Sludge	5A - 1	5A - 8
SECTION 5B	Case Studies – Plant Results – Chemical Conditioning – Primary Plants with Chemical Addition	5B - 1	5B - 8
SECTION 5C	Removal of Phosphorus from Wastewater by Chemical Addition	5C - 1	5C - 7
SECTION 6A	Oxygen Activated Sludge Process	6A - 1	6A - 4
SECTION 6B	Oxygen Activated Sludge Case Study – Fairfax – Westgate	6B - 1	6B - 4
SECTION 6C	Oxygen Activated Sludge Case Study – New Orleans, Louisiana	6C - 1	6C - 4
SECTION 7	Thermal Processing of Sludge	7 - 1	7 - 10
SECTION 8	Final Disposal Processes and Case Studies	8 - 1	8 - 8
SECTION 9	Sludge Thickening and Blending	9 - 1	9 - 5
SECTION 10	Sludge Dewatering	10 - 1	10 - 6

SECTION 1 – IMPORTANCE OF SLUDGE PROCESSING AND DISPOSAL CURRENT EPA PROGRAMS

1. Introduction

- Solids removed in the processing of waters for human consumption, industrial usage, or in the case of wastewaters, for discharge to a receiving stream, present a disposal problem.

- Disposal of sludges from wastewater treatment will today account for up to 50 percent of the total treatment cost.

- Sludge is the settleable solids that are naturally present in water and wastewater or that are formed during treatment.

- Tighter effluent criteria, increasing land scarcity and population pressure combine to make sludge disposal more difficult and expensive.

2. Quantities and Characteristics of Sludge to be Handled

- Approximate amounts of sludge produced in the treatment of wastewater by simple clarification, chemical treatment and biological processes are shown in Table 1–1.

- Activated sludge process contributes large quantities of sludge for disposal.

- Sludge is a semi-liquid waste and the water content of all sludges is high, as shown in Table 1-2.

- Typical sludge masses to be handled are shown in Table 1-3.

- The quantity of sludge can be calculated from wastewater analysis and efficiency of the treatment units.

- Physical-chemical treatment means new kinds of sludges, more mass and sometimes more volume. A calculation of the increase in sludge mass when iron and alum are used at various points in the wastewater treatment sequence is presented (see Table 1-4, from Reference 7).

- The sludge produced when lime is added to wastewater in the primary or as a tertiary can be calculated from water and wastewater analysis (see Table 1-5). Measured quantities were about 20 percent higher than calculated values.

3. **Sludge Management Alternatives**

- Selection of treatment and disposal processes must consider pollution potential, aesthetics and economics. Protection and Enhancement of Environmental Quality are required by the National Environmental Policy Act of 1969 and Executive Order 11514 (Reference 8).

- Sludge can be ultimately disposed of in dry, dewatered filter cake, liquid or in the form of ash and combustion gases.

- Steps to be followed in solving a sludge handling and disposal problem are indicated in Figure 1-1.

4. **Costs of Sludge Processing and Disposal**

- Costs of sludge processing are a function of:

  Treatment sequence

  The raw sewage

  Location (the surrounding neighborhood)

  Climate

  Scale of operation

  Regulations, etc.

- Costs are sensitive to all of the above and individual author's assumptions. If possible, get all comparisons from the same unbiased source.

  The cost of some sludge handling and disposal processes is given in Table 1-6.

  The cost of some sludge handling and disposal process combinations is given in Figure 1-2.

5. **Current EPA Programs**

- Carried out primarily at the National Environmental Research Center in Cincinnati by the Ultimate Disposal Research Program.

- Objective of EPA Programs

  To develop new or improved sludge handling, disposal and utilization technology so that the municipal sector will be able to achieve compliance with present and future water quality standards. The development of methods for nonpollutional disposition of sludges resulting from treatment processes is critical to a successful water quality improvement program.

- Their implementation – by contracts, grants, and inhouse research.

  Current projects are shown in Tables 1-7, 1-8, and 1-9.

REFERENCES – SECTION 1

1. Keefer, C.E., "Sewage Treatment Works." McGraw-Hill Book Company, Inc., New York, (1940).

2. Fair, G.M., and Imhoff, K., "Sewage Treatment." John Wiley and Sons, Inc., New York, 2nd Edition, (1965).

3. Babbitt, H.E., "Sewerage and Sewage Treatment." John Wiley and Sons, Inc., New York, 7th Edition, (1953).

4. McCabe, J., and Eckenfelder, W.W., "Advances in Biological Waste Treatment." Pergamon Press (1963).

5. Burgess, J.V. *Process Biochem.*, 3, 27-30 (1968).

6. Stanley, William E., Personal communication, Washington University, St. Louis, Mo. (1967).

7. Adrian, D.D. and Smith, J.E., Jr., "Dewatering Physical-Chemical Sludges." Conference on Application of New Concepts of Physical-Chemical Wastewater Treatment, Vanderbilt University, September 18-22, 1972.

8. "Federal Guidelines, Design, Operation and Maintenance of Wastewater Treatment Facilities." FWQA, Department of the Interior, September, 1970.

9. Patterson, W.L., and Banker, R.F., "Estimating Costs and Manpower Requirements for Conventional Wastewater Treatment Facilities." Water Pollution Control Research Series 17090 DAN 10/71, Government Printing Office, Washington, D.C., 1971.

10. Smith, R., and Eilers, R.G., Personal communication, May 31, 1972.

11. Eilers, R.G., and Smith, R., "Wastewater Treatment Plant Cost Estimating Program." AWTRL of EPA, April, 1971, Internal Report (Computer Deck Available).

LIST OF FIGURES AND TABLES – SECTION 1

Table 1-1	Typical Quantities of Sludge Produced in Wastewater Treatment Processes
Table 1-2	Water Content of Sludges
Table 1-3	Sludge Masses
Figure 1-1	Considerations in the Handling and Disposal of Sludge
Table 1-4	Calculated Sludge Mass (lb/mg)
Table 1-5	Calculations of Sludge Quantity. Lime Added to the Primary
Table 1-6	Total Cost in Cents per 1,000 Gallons of Wastewater Processed for Indicated Sludge Handling Processes
Table 1-7	Recent Projects – April, 1972 – Ultimate Disposal
Table 1-8	New Projects since April, 1972
Table 1-9	In-House Activities – Ultimate Disposal
Figure 1-2	Costs of Sludge Processing and Disposal – Including Amortization

TABLE 1-1

TYPICAL QUANTITIES OF SLUDGE PRODUCED
IN WASTEWATER TREATMENT PROCESSES

Treatment	Keefer[1]	Imhoff & Fair[2]	Babbitt[3]	M&E[4]
Plain Sedimentation	2,950	3,530	2,440	3,000
Trickling Filter Humus	745	530	750	700
Chem. Precipitation	5,120	5,100	5,250	5,100
Activated Sludge	19,400	14,600	18,700	19,400

(Given as gallons/million gallons sewage treated)

[1] See Reference 2
[2] See Reference 3
[3] See Reference 4
[4] See Reference 5

TABLE 1-2

WATER CONTENT OF SLUDGES

Treatment	Percent Moisture	Pounds of Water/Pound Sludge Solids
Primary Sedimentation	95	19
Chem. Precipitation	93	13.3
Trickling Filters		
Humus-Low Rate	93	13.3
Humus-High Rate	97	32.4
Activated Sludge	98–99	~65.6
Well Digested Sludge		
Primary Treatment	85–90	~ 7.0
Activated Sludge	90–94	~11.5

TABLE 1-3

SLUDGE MASSES[1]

Treatment	Percent Suspended Solids Removal	lb/day/mg Removed	Percentage of Volatile Materials Removed	Specific Gravity Suspended Solids
Plain Sedimentation	60	1,020	65	1.33
Trickling Filter Humus	30	510	45	1.52
Activated Sludge (excess)	92	1,563	65	1.33
Imhoff Tank Dig.	60	1,020	50	1.47

[1] See Reference 6

CONSIDERATIONS IN THE HANDLING AND DISPOSAL OF SLUDGE

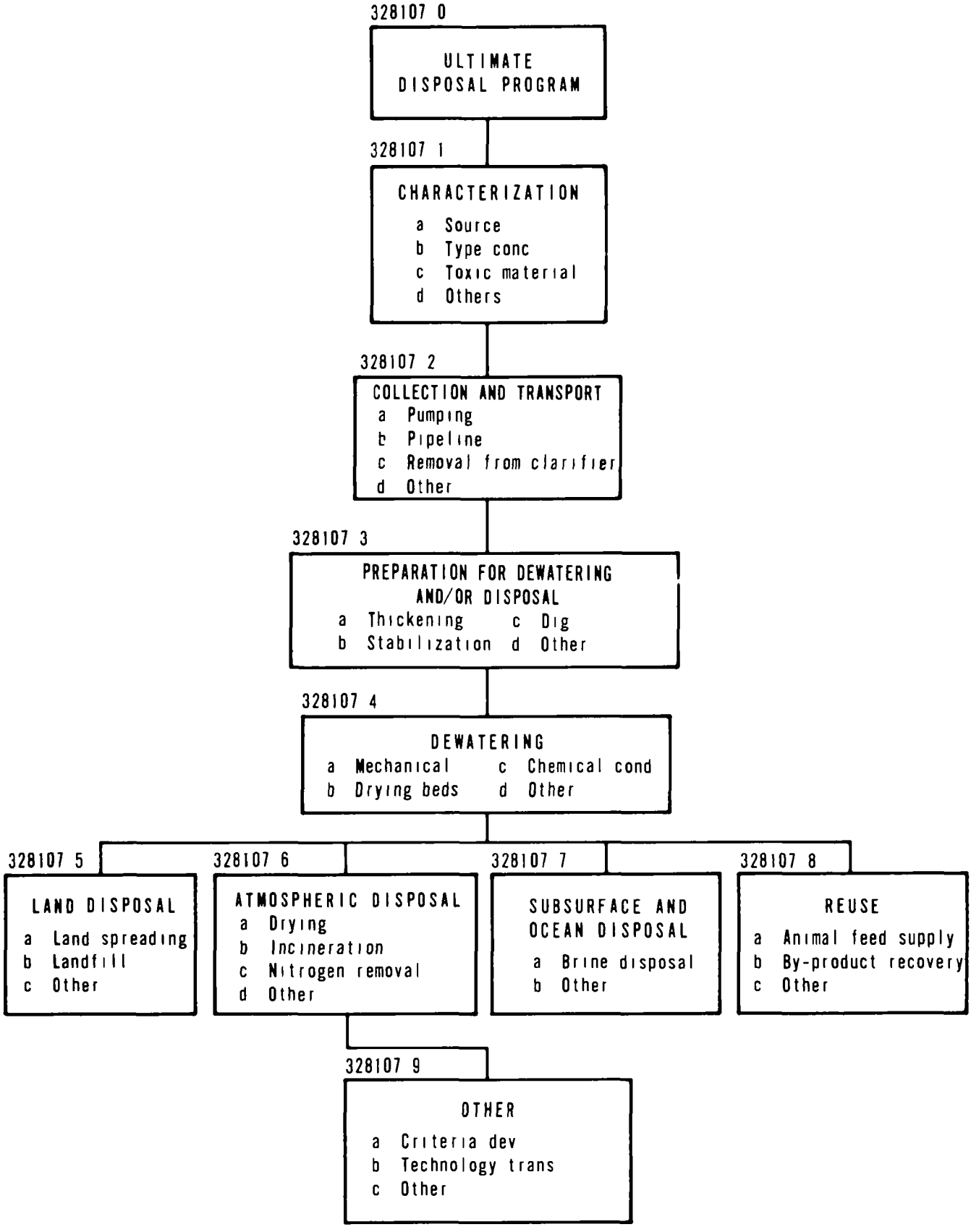


FIGURE 1 - 1

TABLE 1-4

CALCULATED SLUDGE MASS (lb/mg)

	Conventional	Fe to Primary	Fe to Aerator	Al to Aerator	Al to TF Clarifier
PRIMARY					
SS Removal	50%	75%	50%	50%	50%
Sludge Solids	1250	1875	1250	1250	1250
Fe Solids	0	605			
Al Solids	0				
Total	1250	2480	1250	1250	1250
ACTIVATED SLUDGE					
Secondary Solids	715	536	804	804	
Fe Solids			541		
Al Solids				425	
TRICKLING FILTER					
Secondary Solids	656				745
Al Solids					483
TOTALS	1965	3016	2595	2479	2478

BASIS FOR SLUDGE MASS CALCULATION

Cation/P Dose (mol/mol)	lb Chemical Sludge/lb Cation	
	lb/lb Al	lb/lb Fe
1.5	3.9	2.4
1.75	3.8	2.3

Assumptions:

Cation/P Dose = 1.5 mol/mol to aerator
Cation/P Dose = 1.75 mol/mol to primary or before trickling filter clarifier

Influent Sewage
- BOD = 230 mg/l
- SS = 300 mg/l
- P = 10 mg/l

TABLE 1-5

CALCULATION OF SLUDGE QUANTITY:

LIME ADDED TO THE PRIMARY*

Data Available — On influent and effluent: alkalinity, pH, calcium hardness, phosphorus.

Change in Ionic Content (Influent – Effluent)	mg/l
ΔHCO_3, as $CaCO_3$	223
ΔCO_2, as $CaCO_3$	14
ΔMg, as $CaCO_3$	66

Sludge Produced	mg/l
hydroxyapatite	27
$CaCO_3$	460
$Mg(OH)_2$	38
Total Calcd. Sludge	525 mg/l
Meas./Calcd.	1.25

Material Balance on Ca

$Ca(OH)_2$ dose = 390 mg/l

Input-Output = -2.9 mg/l

* Data from Run 6, Eimco's Salt Lake City Pilot Plant.

TABLE 1-6
TOTAL COST IN CENTS PER 1,000 GALLONS OF WASTEWATER PROCESSED FOR INDICATED SLUDGE HANDLING PROCESSES[1]

Process	Plant Size		
	1 mgd	10 mgd	100 mgd
Gravity thickening of primary and waste activated sludge	1.61	0.31	0.13
Gravity thickening of primary sludge above	1.47	0.22	0.08
Air flotation thickening of waste activated sludge above	2.28	1.01	0.75
Anaerobic digestion of combined primary and waste activated sludge	6.09	2.09	1.89
Dewatering of digested sludge on sandbeds	2.20	1.64	NA
Dewatering thickened raw sludges on rotary vacuum filters	8.39	5.15	3.70
Multiple hearth incineration of filter cake	13.53	5.02	1.16

[1] See References 9, 10, and 11

Costs included are capital, debt, and operation and maintenance

NA – Not applicable

TABLE 1-7

RECENT PROJECTS – APRIL, 1972

ULTIMATE DISPOSAL

Demonstration

1.	Land Reclamation through the Use of Digested Sludge (Chicago MSD)	Continuing
2.	Park Development with Wet Digested Sludge (Metro Seattle)	Completed*
3.	Microbiology of Sewage Sludge Disposal in Soil (Ohio ARS)	Completed*
4.	Development of Treatment and Disposal Methods for Septic Tank Sludges (University of Connecticut)	Completed*
5.	Utilization of Organic Matter in Waste Sludges – PB 194 784 (Foster D. Snell)	Continuing in-house
6.	Porteous Process for Heat Treatment of Sludge (Lake County, Painesville, Ohio) – plus in-house treatment of liquor	Continuing
7.	Evaluation of a Top Feed Rotary Filter (Milwaukee, Wisconsin)	Continuation pending Dec. '72
8.	D.C. Sludge Pilot Plant (District of Columbia)	Continuing
9.	Aerobic Digestion of Sewage Sludge (Hollywood, Florida)	Completed*
10.	Evaluation of Conditioning and Dewatering Sewage Sludge by Freezing – Published GPO (Milwaukee, Wisconsin) (Not economical)	Completed
11.	Sludge Slurry Pipeline and Strip Mine Reclamation (Morgantown, West Virginia)	Completed*
12.	Application of Enzymes for Sludge Dewatering (Aerojet-General) PB 207 480 (Not economical)	Completed
13.	Fly Ash Aid of Sewage Solids Dewatering and Disposal (Cedar Rapids, Iowa)	Continuing

* Work completed, Final Report not yet published.

TABLE 1-8

NEW PROJECTS SINCE APRIL, 1972

(No. 16 on)

14. Oil Flotation of Sludge (Esso)

15. Capillary Belt Filter (Westinghouse-Infilco)

16. Magnetically Assisted Dewatering of Waste Activated Sludge (R.P. Industries)

17. Lime Sludge Study (Central Contra Costa Sewage Treatment Plant, Walnut Creek, California)

18. Centrate Dewatering Study (LACSD, California)

19. Survey of Land Spreading (Battelle, Columbus, Ohio)

20. Lime Stabilization of Sludge (Battelle-Northwest, Richland, Washington)

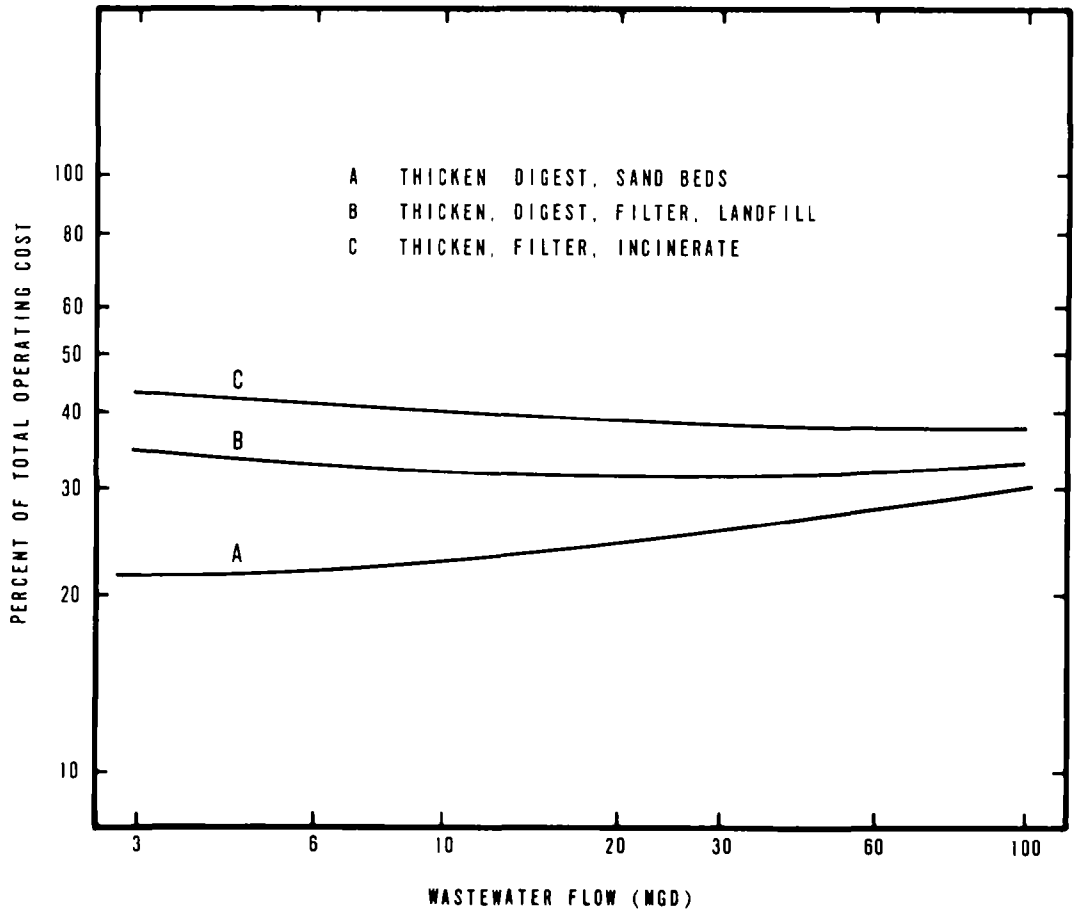
21. Phosphate Sludge Disposal in Forest Area (Ely, Minnesota)

TABLE 1-9

IN–HOUSE ACTIVITIES

ULTIMATE DISPOSAL

1. Properties of Physical-Chemical Sludges
2. Testing Pilot-Scale Dewatering Equipment
3. Aluminum and Iron Sludges Recovery and Reuse
4. Evaluating Conditioning Sludge with Sludge Ash and Polymers
5. Determining Metals Buildup with Sludge Application
6. Determining Influence of Type of Sludge and Soil on the Growth of Several Plant Types
7. Analyzing for Metals, PCB's, etc., to Determine Quantities and Fate on Disposal
8. Treatment of Liquors from Porteous Process, etc.
9. Task Force on Mercury and Other Heavy Metals in Sludge
10. Task Force on Alternatives to Ocean Dumping



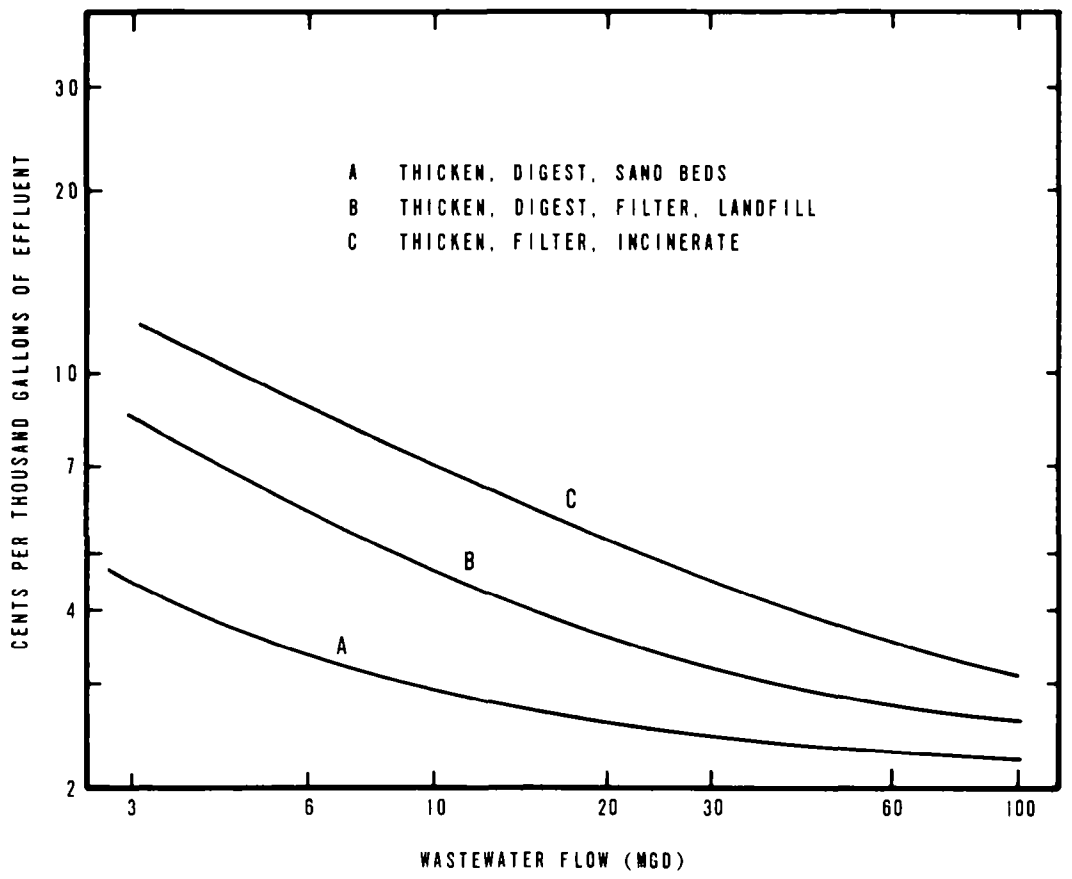


FIGURE 1-2 COSTS OF SLUDGE PROCESSING AND DISPOSAL - INCLUDING AMORTIZATION

SECTION 2 – CURRENT AND PREVIOUS METHODOLOGY

1. **Project Objectives – Wastewater Treatment Plants**

   – The way it used to be - The old climate surrounding design and startup of wastewater treatment plants.

     Partial funding for and somewhat limited role of the A/E firm.

     Divided responsibility for design of sub-systems.

     Emphasis on liquid handling R&D (Quote from agency document - Mea Culpa).

     Elastic enforcement policies (habit forming).

     Problems with sludge handling systems.

   – The way it is now - The new climate (Figure 2-1). (Ostensibly, the objectives have always been there but the new climate now makes them obtainable).

     Plants must function properly, both initially and continually.

     Both liquid and solids fractions must be processed satisfactorily.

     Effluent standards are going to be enforced.

     Capital, operating and maintenance costs must be essentially on forecast.

     The consulting engineer is increasingly responsible for preceding needs.

2. **Essential Ingredients (for a successful project)**
   (Figure 2-2)

   – Optimum Conceptual and Detailed Designs

     New standards require new processes.

     New processes mean text books are a questionable source.

     The importance of being contemporary in process engineering disciplines.

- Construction as Designed

  Increased A/E involvement, new C.M. methods.

- Proper Operation and Maintenance

  Following the Doctor's orders or he is not responsible for the results.

- Continuing Plant Service and Development

  Nobody's perfect; even naval vessels still have a shakedown cruise.

  A vital source of process improvement and future design information.

3. **Sources – Conceptual Design Information**
   (Figure 2-3)

   - Textbooks and Literature

     Must be reviewed but rarely give all the answers.

   - Laboratory and Pilot Studies

     Practically always necessary.

   - Supplier's Recommendations

     Equipment and product firms, their own R&D engineering work.

   - Previous Experiences

     All too seldom available.

   - Visitation to Other Plants

     Helpful but sometimes misleading.

   - Client's Wishes (existing plant results)

     Depends on the client's experience and capability.

4. **Special Considerations – Design Rationale**
(Figure 2-4)

- Adequacy of Available Literature

  Self serving publications.

  Strategic omissions.

  Post-paper discussions (printed in U.K., not USA)
  (Note L.A. article).

- Supplier's Recommendations

  Essential but must be sifted carefully.

  The importance of follow-up.

- Plant Data - Fact vs. Folklore

  Reliability, a function of adequacy of O&M.

  The "Shrinkage" example.

  Defending an untenable position - mistakes die hard.

- Process Engineering

  Unit operations technology.

  Biological process technology.

  Putting the whole thing together.

  Experience in other industries and in plant operations.

5. **The Total versus the Fractional Approach**
(Figure 2-5)

- A careful choice of words
  (System vs. Sub-System, actually, but, such terminology somewhat disreputable).

- The Cardinal Sin: Optimization of a sub-system must be considered in light of total system results.

– Example = Dewatering Sludge

Analysis including only operating cost, production rate, cake moisture content.

Should include complete material balance around process; effect of recycle streams on rest of system; ratio of volatile solids to moisture content (calorific value).

LIST OF FIGURES AND TABLES – SECTION 2

Figure 2-1	Objectives – Wastewater Treatment Plant Project
Figure 2-2	Essential Ingredients
Figure 2-3	Sources – Conceptual Design Information
Figure 2-4	Special Considerations – Design Rationale
Figure 2-5	The Total versus the Fractional Approach

OBJECTIVES

EFFECTIVE,RELIABLE PROCESSING OF WASTEWATER
(BOTH LIQUID AND SOLID FRACTIONS)

AT LOWEST PRACTICAL COST

CONCURRENT NON-POLLUTING EFFLUENT STREAMS
(LIQUID,SOLID AND GASEOUS)

FIGURE 2-1

ESSENTIAL INGREDIENTS

OPTIMUM CONCEPTUAL AND DETAILED DESIGN

CONSTRUCTION AS DESIGNED

PROPER OPERATION AND MAINTENANCE

CONTINUING PLANT PROCESS SERVICE AND
DEVELOPMENT

F GURE 2-2

SOURCES - CONCEPTUAL DESIGN INFORMATION

- TEXT BOOKS AND LITERATURE
- LABORATORY AND PILOT STUDIES
- SUPPLIERS RECOMMENDATIONS
- PREVIOUS EXPERIENCE
- VISITATION TO OTHER PLANTS
- CLIENTS WISHES (EXISTING PLANT RESULTS)

FIGURE 2-3

SPECIAL CONSIDERATIONS -DESIGN RATIONALE

- ADEQUACY OF AVAILABLE LITERATURE
- SUPPLIERS RECOMMENDATIONS
- PLANT DATA - FACT VS. FOLKLORE

PROCESS ENGINEERING

FIGURE 2-4

THE TOTAL VERSUS THE FRACTIONAL APPROACH

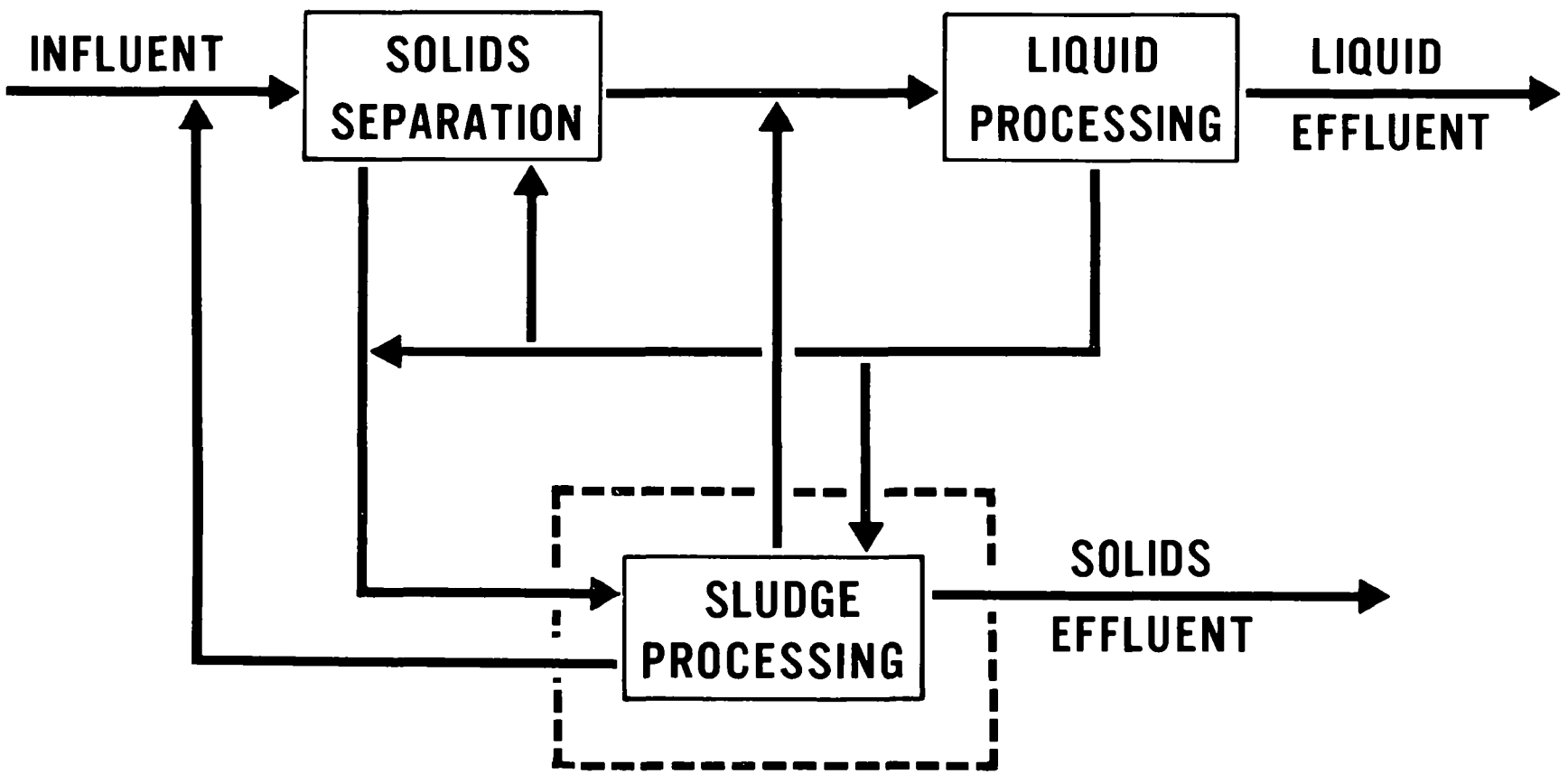


FIGURE 2-5

SECTION 3 – NATURE AND HANDLING CHARACTERISTICS OF SLUDGES

1. **Fundamental Point**

   Need – Knowledge/Insight
   Nature of Sludges/Handling Characteristics

   Potential Pitfall
   (Figure 3-1)

   "All generalities are inherently false, including this one."

   But – Methods of process study
   Knowledge of process and equipment performance at various plants.
   Supplement and guide work on a given sludge at a particular plant.

2. **Raw Primary Sludge**

   – Almost universally settles, thickens, dewaters and incinerates relatively easily.

   – Because (Figure 3-2) is usually coarse and relatively fibrous.

   – Vacuum filtration and centrifugation work well at low cost (Figure 3-3).

   – Note heavy thick cake and excellent release.

   – Costs are low and efficiencies good.
   (Table 3-1)

   – Primary sludges give slightly compressible cakes but presence of sufficient gross solids - ($\approx$ 30% $<$ 30 mesh) permits rapid formation of cake with sufficient structural matrix = good capture and rapid dewatering.

3. **Effect of Digestion (Primary Sludge)**
   (Table 3-2)

   – Anaerobic digestion, contrary to some information in the literature, makes sludges somewhat more difficult to thicken and dewater.

   – But results are still good and costs low.

   – Shear effects on particle size and increased hydration of solids.

4. **Activated Sludges (Conventional)**

- Inherently more variable

- Principal source of variation
  Configuration and mode of operation of activated sludge system involved.

- Also, Domestic/Industrial waste ratio and type, Nature of Collection System can have real effect.

- Structure
  Generally finer in particle size.
  60–90 percent cellular organic matter.
  Bioflocculated to some degree, by excretion of natural polymeric material by the microorganisms.
  Density close to density of water.

- Water Content
  (Figure 3-4)
  Biomass from conventional air systems has much associated water.

  Theoretically, if the loosely held and bound surface water disengaged, up to 29 percent solids obtained.

  Another way to overcome this problem
  Endogenous respiration (Figure 3-5, Reference 3).

  Greater degree of bioflocculation displaces extracellular water.

  Improves settling and dewatering characteristics.

5. **Summary – Activated Sludges**

- Conventional Air Aeration Systems Excess Activated Sludge requires very careful operation to give settleable sludge.

- Activated sludge is sensitive to further processing. Hydration easily and tends to float.

6. **Handling Combined Primary and Activated Sludges**

- Existing plants, many cases designed one of two ways.
  (Figure 3-6)

– A. Recirculate E.A.S. to head of plant - Primaries

Results Primary Solids Capture goes to pot.

Greater BOD load on secondary system.

More E.A.S. created than necessary.

Combined Mixed Sludge
Settles poorly in digester, another recirculation load.

When elutriated (without flocculants) sludge fractionates - another low efficiency process and recirculation load.

– B. E.A.S. mixed with Primary Sludge prior to gravity thickening
(Figure 3-7)

Results Better than recirculation to primaries but:

Dirty thickener overflow.

Activated portion will not settle in digesters or elutriation basins, so still poor.

Remedy

Combine and thicken sludges just before dewatering.

Not early in process.

7. Oxygen Activated Sludges

- Biomass from oxygen process has better settling characteristics.
(Figure 3-8, Reference 4)

- Clarifier performance, based on overflow rate (Figure 3-9) is better with oxygen process sludge (Watch bottom loading rates).

- Recycle sludge solids (Figure 3-10) are higher with oxygen activated sludge.

- Sludge volume indices are improved over air aeration sludge.

- Gravity thickening (Figure 3-11).

Admittedly different plants involved but best data available, higher underflow solids.

Chicago results from excellent article by Ettelt (Reference 13) and others.

Figure in parentheses for Chicago is for picket fence type thickener.

Summation - oxygen activated sludge appears to gravity thicken more readily.

- Flotation thickening (Figure 3-12)
  (From Reference 6 by Stamberg, Bishop, Hais and Bennett of EPA).

  These results are without floc aid use.

  Figure 3-13 - additional results with polymer usage - lower costs and greater efficiency for the O.A.S.

- Vacuum Filtration
  (Figure 3-14)

  Batavia results are from a 3 ft^2 pilot filter.

  Louisville results are from filter leaf tests on location. Representative of a workable - logical method. What could be expected in mixing primary and O.A.S. sludges.

- Centrifugation
  (Figure 3-15)

  Pilot solid bowl scroll type work by Sharples.

  Higher throughput, lower chemical cost and better capture for O.A.S.

  Need results on typical mixed sludge.

8. **Alum Use – Primary Plant – Mixed Chemical Organic Sludge**
   (Figure 3-16)

   - Work by OWRC and plant staffs (Reference 7).

   - With no chemical addition to primaries, ferric/lime conditioning, high yield and low cost.

   - With alum, primary solids level drops, amount of sludge increases, yield decreases and costs go up.

- Ferric and lime may not be best conditioning system for alum/organic sludge.

9. **Lime Use – Conventional Activated Sludge Plant – Mixed Lime/Organic Sludge (Raw)** (Figure 3-17)

   - 2.0 mgd, lime added just ahead of primaries.

   - Sludge volume almost triples, but centrifugation looks easy and inexpensive (centrate = 10–30 MG/LP).

   - Low polymer dose to clean up centrate.

10. **Alum and Lime Sludges – Windsor Little River Conventional Activated Sludge Plant** (Figure 3-18)

    - First note that normal, untreated sludge conditioning costs are abnormally high, particularly for a sludge feed to filters of 6.2 percent solids.

    - Lime usage gave a mixed sludge (with small amount of activated sludge content?) which dewatered well at a lower cost.

    - Alum lowered sludge solids concentration, decreased yield and increased conditioner costs. Cake solids were only 16 percent with alum use.

11. **Ferric Chloride/Organic Sludge at North Toronto Conventional Activated Sludge Plant** (Figure 3-19, Reference 12)

    - Use of ferric chloride for phosphorus removal.

    - Tested for many months.

    - First applied at primary basins.

    - Current application point = at end of aeration basin.

    - Chemical conditioning costs about $8/ton.

    - Reasonable production rate and cake solids content realized.

12. **Lake Tahoe Solids Handling**

    - Process flow (Figure 3-20, Reference 9)

      Two sludges handled separately in this tertiary plant.

Organic sludges (from a system which recirculates activated sludge to head of plant).

Lime sludges from tertiary type treatment.

- Organic Sludge Processing
  (Figure 3-21)

  This section of plant has two design features which, in my opinion, result in abnormal sludge handling costs.

  First is the recirculation of the excess activated sludge to the primaries which has been demonstrated to result in poor primary capture and poor activated sludge quality.

  Second is the attempt to gravity thicken a mixture of excess activated sludge and primary sludge - net result is that no thickening occurs.

  Hence feed to "Dewatering Centrifuge" is unthickened and high costs result in dewatering. (Polymer dosage is actually higher than shown because the basis is tons of dry solids to furnace which includes lime wastage).

- Lime Sludge Processing
  (Figure 3-22)

  The centrifuge serves here as a classification device.

  First centrifuge operated with high centrate loss to purge organics from lime stream to be recalcined.

  Second centrifuge, in series on centrate cleans up the more organic portion.

  Results shown are for 8 percent solids feed to lime - mud centrifuge. Cake solids equal 37 percent. Looks like a good operation.

  Cake solids from centrate centrifuge average 30 percent.

13. Aerobically Digested Activated Sludges

- Aerobic digestion is an inherently "cleaner" means of reducing the volume of activated sludge to be dewatered and to stabilize same for land disposal.

- Plant scale work current at several locations.

- Atlanta (Reference 10)

  New 6 mgd Flint River Plant tests.

  Digestion process works well.

  Sludge compacts to 2–3 percent and can be dewatered via vacuum filtration using ferric chloride.

  Yield is on the lean side.

  If aerobically digested sludge were mixed with thickened primary sludge, dewatering and incineration would be more efficient.

REFERENCES – SECTION 3

1. Reed, S.E., and Murph, R.S., ASCE Proceedings Paper 6747, August, 1969; and Discussion by Dick, et al., *ASCE Journal,* 638-646 (1970).

2. Goodman, B.L., and Foster, J.W., "Notes on Activated Sludge," Smith and Loveless. (1969).

3. Tenney, M.W., Echelberger, W.F., Coffey, J.J., and McAloon, T.J., "Chemical Conditioning of Biological Sludges for Vacuum Filtration." *Journal WPCF,* 42, No. 2, Part 2, R1-R20 (1971).

4. Private communications – Union Carbide Corporation.

5. Unox Design Information, EPA, TT Program, Metcalf and Eddy, Pittsburgh, Pennsylvania, August 29, 1972.

6. Stamberg, J.B., et al., EPA, "System Alternatives in Oxygen Activated Sludge," WPCF Meeting, Atlanta, Georgia, 1972.

7. Van Fleet, B.L., Barr, J.R., and Harris, A.J., "Treatment and Disposal of Chemical Phosphate Sludges in Ontario."

8. "Report on Phosphorous Removal," *Water and Pollution Control,* 16 (1972).

9. EPA – W.P.C.R.S. 17010 ELQ08/71 –"Advanced Wastewater Treatment as Practiced at Lake Tahoe."

10. Cameron, J., "Aerobic Digestion of Activated Sludge to Reduce Sludge Handling Costs," WPCF Conference, Atlanta, Georgia, 1972.

11. Bolek, M., and Helekal, J., "Cake Removal from R.V. Filters by Air Blast, Filtration and Separation," 146 (March, April, 1971).

12. Private communication, D.A. Clough, Director, Metro Toronto Water Pollution Control.

13. Ettelt, G.A., and Kennedy, T.J., "Research and Operational Experience in Sludge Dewatering at Chicago." *JWPCF,* 38, No. 2, 248.

LIST OF FIGURES AND TABLES – SECTION 3

Figure 3-1	Maxim – "All generalities are inherently false, including this one."
Figure 3-2	Closeup – Raw Primary Sludge Filter Cake
Figure 3-3	Release Characteristics – Raw Primary Sludge Filters
Table 3-1	Vacuum Filtration – Raw Primary Sludge
Table 3-2	Vacuum Filtration – Digested Primary Sludge
Figure 3-4	Activated Sludge – Aqueous Fluid Distribution
Figure 3-5	Effect of Aeration Time on Biopolymer Production and Dewaterability
Figure 3-6	Secondary Plant with Surplus Activated Sludge to Head of Works
Figure 3-7	Secondary Plant with Surplus Activated Sludge Mixed with Primary Sludge Prior to Thickening and Digestion
Figure 3-8	Settling Characteristics for Air and Oxygen Biomass (ISR vs. Concentration)
Figure 3-9	Typical Clarifier Performance for Air and Oxygen Sludges (at 30 percent Recycle)
Figure 3-10	Typical Clarifier Performance for Air and Oxygen Sludges (at 30 percent Recycle)
Figure 3-11	Gravity Thickening
Figure 3-12	Flotation Thickening
Figure 3-13	Flotation Thickening
Figure 3-14	Vacuum Filtration
Figure 3-15	Centrifugation, Oxygen and Conventional Aeration Sludges
Figure 3-16	West Windsor Primary Plant – Alum

LIST OF FIGURES AND TABLES – SECTION 3

(Continued)

Figure 3-17	Newmarket Conventional Activated Sludge Plant – Lime
Figure 3-18	Little River Conventional Activated Sludge Plant – Phosphate Removal
Figure 3-19	North Toronto Conventional Activated Sludge Plant – Ferric Chloride
Figure 3-20	Lake Tahoe Solids Handling System
Figure 3-21	Lake Tahoe, Organic Sludge Handling
Figure 3-22	Lake Tahoe, Lime Sludge Processing

MAXIM

" ALL GENERALITIES
ARE INHERENTLY FALSE
INCLUDING THIS ONE."

FIGURE 3-1

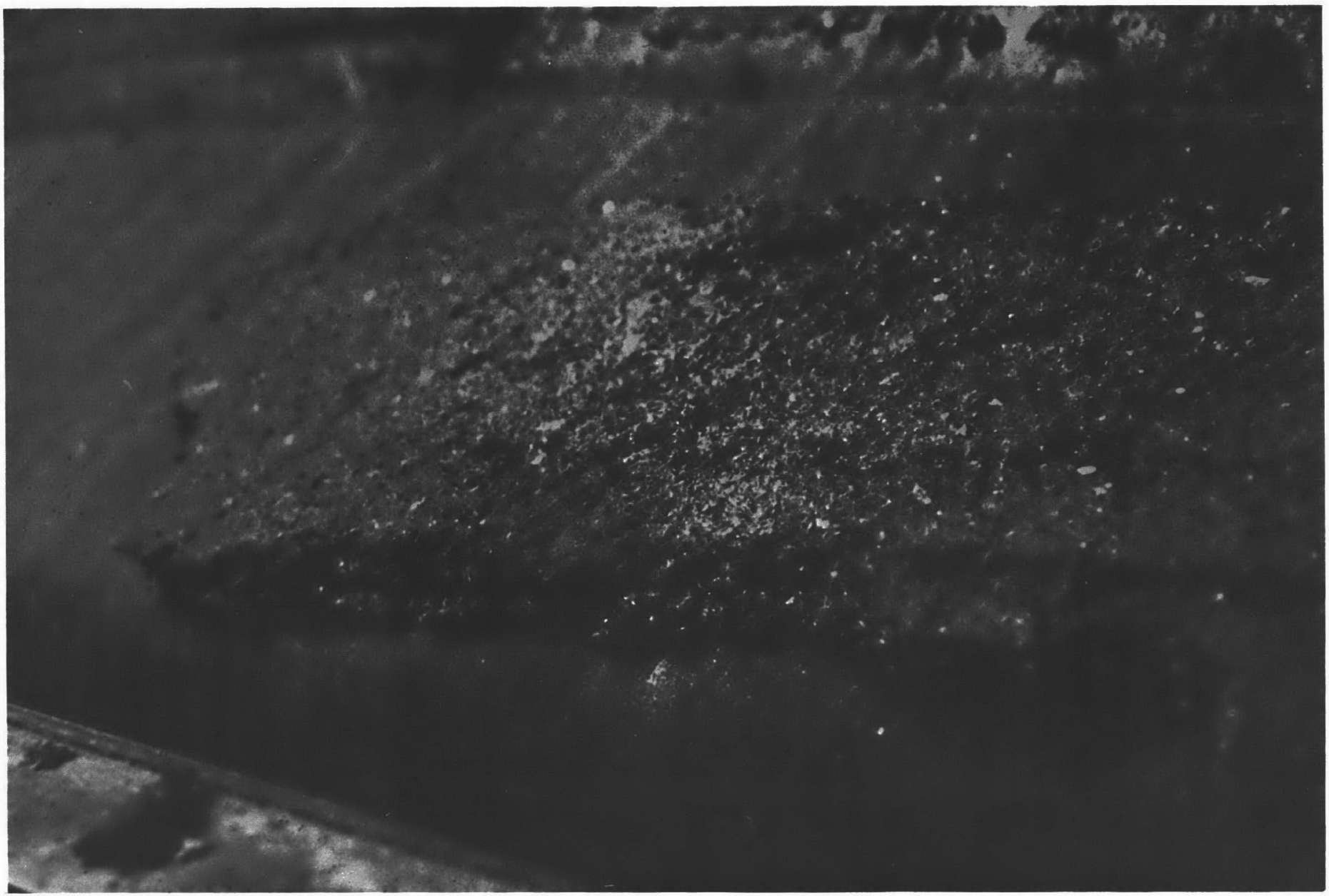


FIGURE 3-2 CLOSE–UP RAW PRIMARY SLUDGE FILTER CAKE

FIGURE 3-3 RELEASE CHARACTERISTICS – RAW PRIMARY SLUDGE FILTERS

% SLUDGE SOLIDS	CONDITIONER USED	COST ($/TON)	YIELD LB/FT^2/HR	CAKE SOLID (%)	SOLIDS CAPTURE (%)
10	CATIONIC POLYMER	1.67	10	32	90-95

TABLE 3-1 VACUUM FILTRATION – RAW PRIMARY SLUDGE

% SLUDGE SOLIDS	CONDITIONER COST ($/TON)	YIELD #/HR/FT^2	CAKE SOLIDS (%)	SOLIDS CAPTURE (%)
12.7	2.64	7.4	28	90+

TABLE 3-2 VACUUM FILTRATION – DIGESTED PRIMARY SLUDGE

ACTIVATED SLUDGE AQUEOUS FLUID DISTRIBUTION

LOCATION	PARTS	CUMULATIVE % SOLIDS
SOLIDS	1.0	100
WITHIN CELL	2.5	29
SURFACE BOUND	5.0	12
LOOSELY HELD	2.5	9

FIGURE 3-4

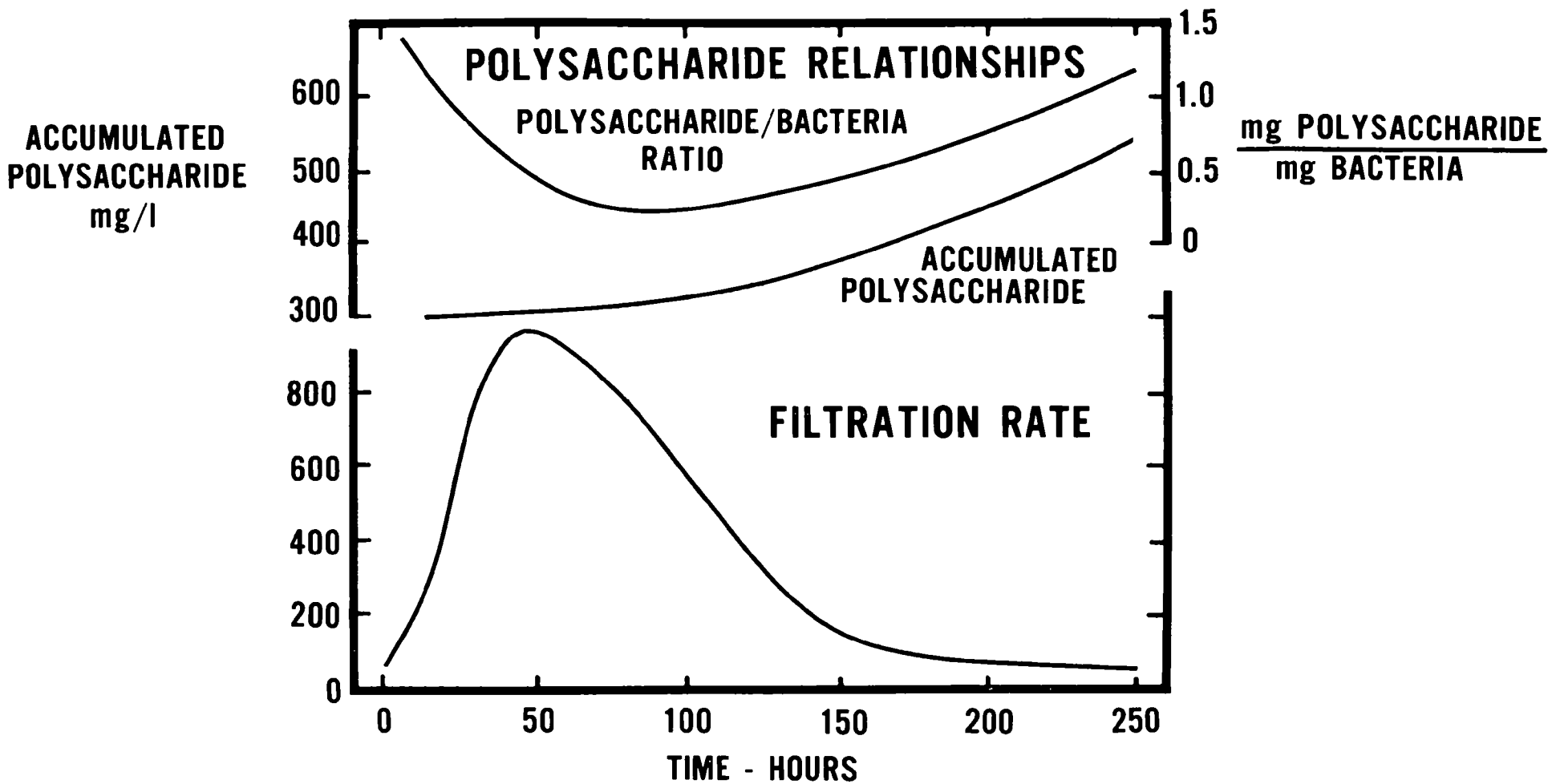


FIGURE 3-5 EFFECT OF AERATION TIME ON BIOPOLYMER PRODUCTION AND DEWATERABILITY

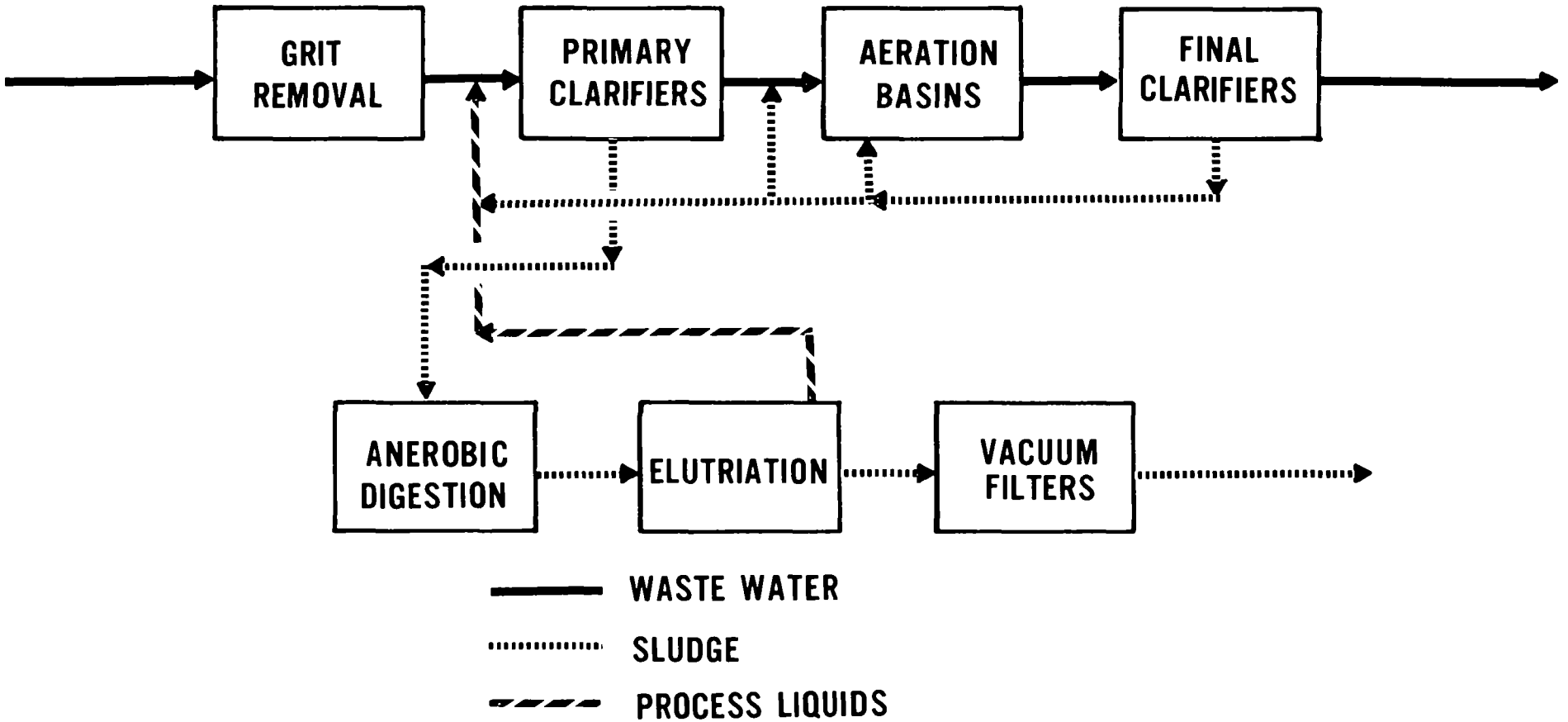


FIGURE 3-6 SECONDARY PLANT WITH SURPLUS ACTIVATED SLUDGE TO HEAD OF WORKS

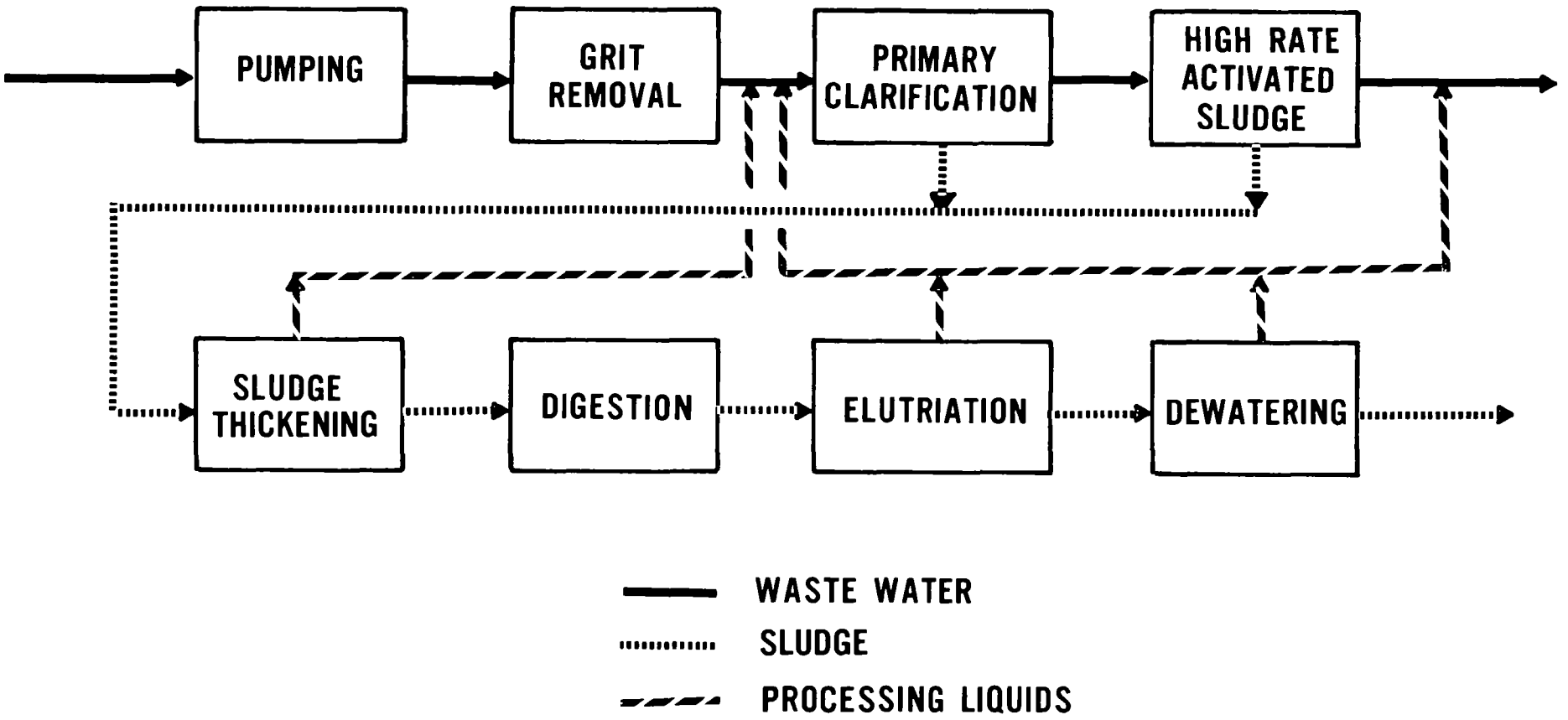


FIGURE 3-7 SECONDARY PLANT WITH SURPLUS ACTIVATED SLUDGE MIXED WITH PRIMARY SLUDGE PRIOR TO THICKENING AND DIGESTION

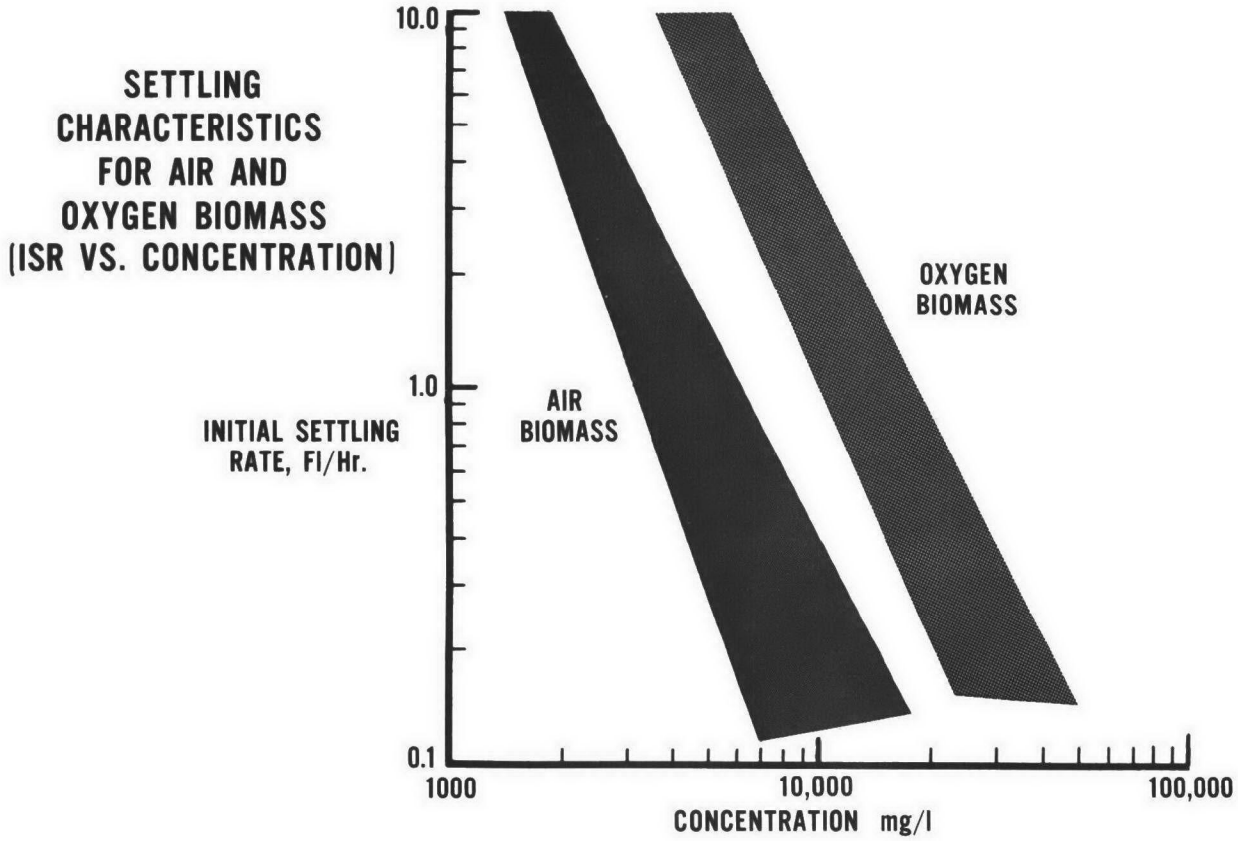


FIGURE 3-8

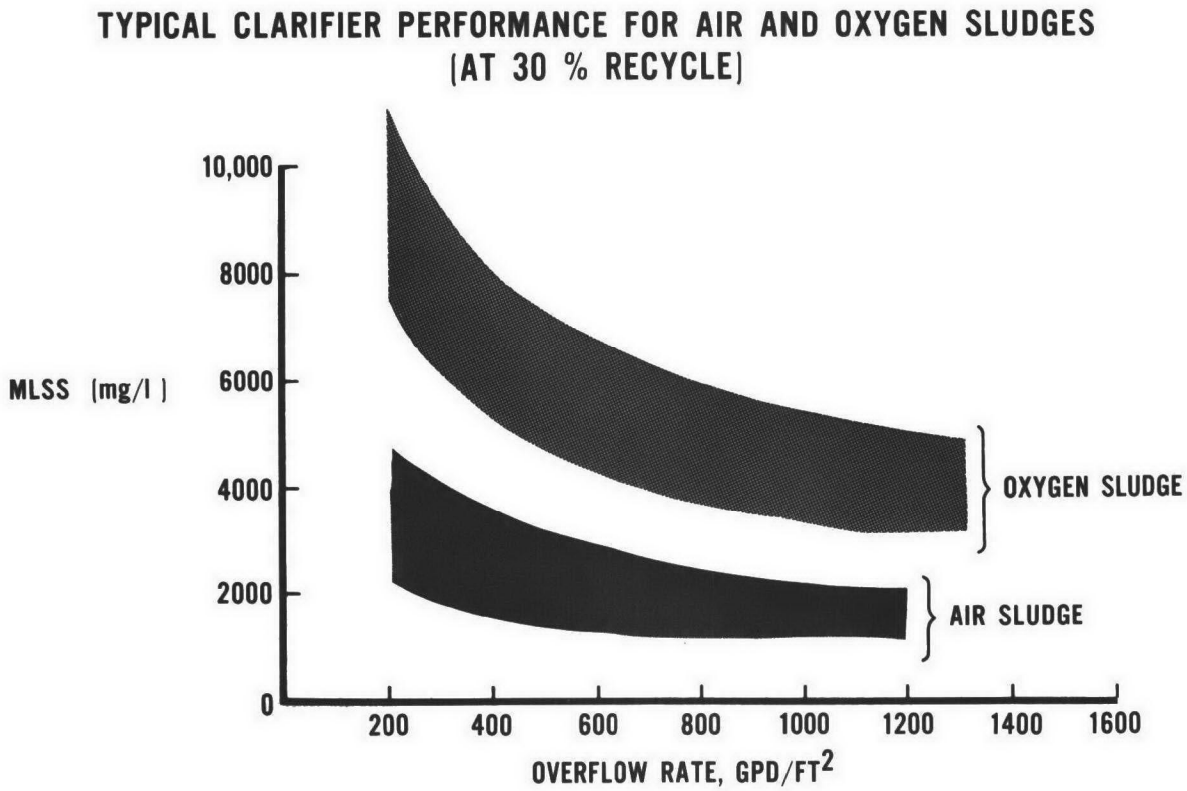


FIGURE 3-9

TYPICAL CLARIFIER PERFORMANCE FOR AIR AND OXYGEN SLUDGES

(AT 30 % RECYCLE)

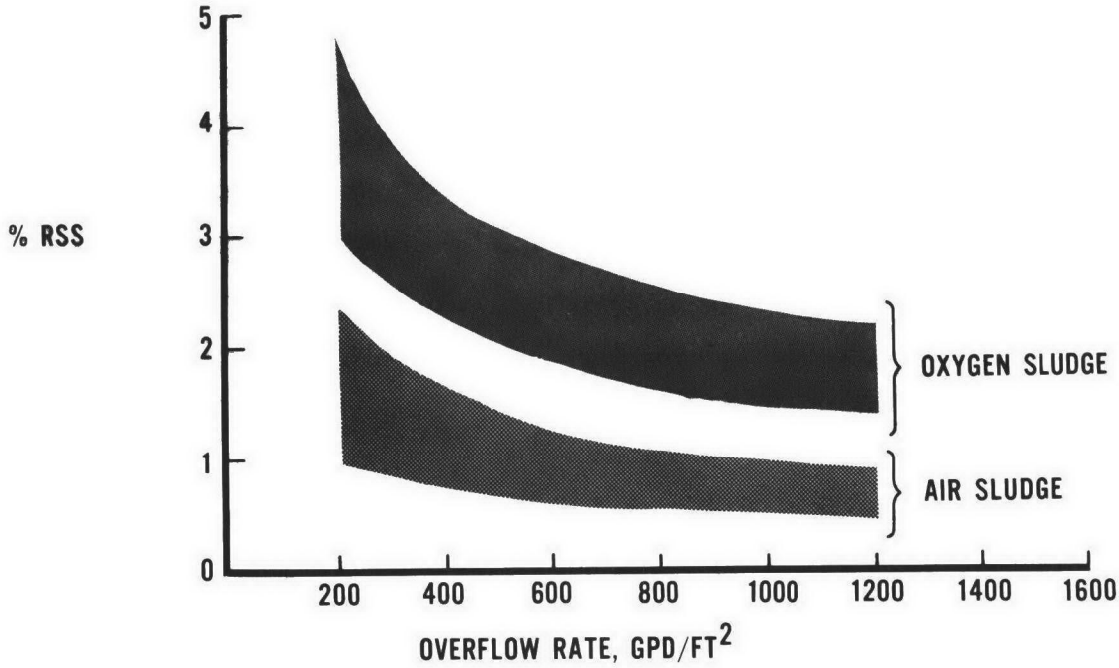


FIGURE 3-10

GRAVITY THICKENING

FEED SLUDGE		SOLIDS LOADING	UNDERFLOW CONC.	
TYPE	% SOLIDS	#/Ft.^{2}/DAY	% SOLIDS	LOCATION
OXYGEN W.A.S.	1.7	10	4.8	LOUISVILLE
AIR W.A.S.	0.9	20	1.4–2.8	CHICAGO
OXYGEN MIXED	2.3	—	5.6	MIDDLESEX
AIR MIXED	1.1	20	3.3(4.4)	CHICAGO

FIGURE 3-11

FLOTATION THICKENING

FEED SLUDGE	LOADING #/Ft.^{2}/DAY	THICKENED SOLIDS (%)
OXYGEN ACTIVATED	95	4
BLENDED OXYGEN ACTIVATED (0.3) + PRIMARY (1.0)	—	11

FIGURE 3-12

FLOTATION THICKENING

FEED SLUDGE		POLYMER	LOADING	THICKENED
TYPE	% SOLIDS	#/TON	#/Ft.^{2}/HR.	SOLIDS (%)
OXYGEN ACTIVATED	(1.7)	2.9	6.4–10.2	6.6
AIR ACTIVATED	(0.9)	9.0	2.0–4.0	4.5

FIGURE 3-13

VACUUM FILTRATION

LOCATION	FEED SLUDGE TYPE	FEED SLUDGE % SOLIDS	CONDITIONER #/TON D.S. FeCl3	CONDITIONER #/TON D.S. LIME	YIELD #/Ft.^{2}/HR.	CAKE SOLIDS %
BATAVIA	OXY.W.A.S.	4.4	200	—	5.1	14.5
LOUISVILLE	OXY.W.A.S. = 3 RAW PRIM + DIG. = 6	5.3	50	142	7.2	26.4

FIGURE 3-14

CENTRIFUGATION OXYGEN & CONVENTIONAL AERATION SLUDGES

TYPE SLUDGE	FEED % SOLIDS	FEED RATE (GPM)	POLYMER (#/TON)	SOLIDS CAP. (%)	CAKE SOLIDS (%)
OXYGEN W.A.S.	2.5	95	3	92	9
AIR W.A.S.	1.0	60	12.5	82	8.5

FIGURE 3-15

WEST WINDSOR
PRIMARY PLANT-ALUM

CHEMICAL ADDITION			PRIMARY SLUDGE	SOLIDS		$
METAL SALT	DOSE MG/L	POLYMER MG/L	% SOLIDS	TONS/M.G.	#/HR./Ft.^{2}	COND. COST
NONE	—	—	11.5	0.5	11.3	3.10
ALUM	90	0.4	7.6	1.1	5.8	9.50

FIGURE 3-16

NEWMARKET
CONV. ACT. SLUDGE PLANT-LIME

CHEMICAL ADDITION		MIXED	SOLIDS	CENTRIFUGATION		
METAL SALT	DOSE MG/L	SLUDGE % SOLIDS	TONS/M.G.	POLYMER (#/TON)	% CAKE SOLIDS	SOLIDS CAPTURE
NONE	—	3.5	0.85	—	—	—
LIME	200	10	2.45	<1	31	97

FIGURE 3-17

LITTLE RIVER
CONV. ACT. SLUDGE-PHOSP. REM.

CHEMICAL ADDITION		MIXED	SOLIDS	FILTER	$
METAL SALT	DOSE MG/L	SLUDGE % SOLIDS	TONS/M.G.	YIELD #/HR/Ft.^{2}	COND. COST
NONE	—	6.2	0.8	5.2	16
LIME	125	11.6	1.2	7.2	11
ALUM	150	5.7	1.2	4.6	18

FIGURE 3-18

NORTH TORONTO
CONV. ACT. SLUDGE-FERRIC CHLORIDE

CHEMICAL ADDITION		MIXED	COND.(lb/TON			
METAL SALT	DOSE MG/L	SLUDGE % SOLIDS	FERRIC CHLORIDE	LIME	lb/HR/Ft.^{2}	% CAKE SOLIDS
FERRIC CHLORIDE	25-35	8	104	200	3.3	21

FIGURE 3-19

LAKE TAHOE SOLIDS HANDLING

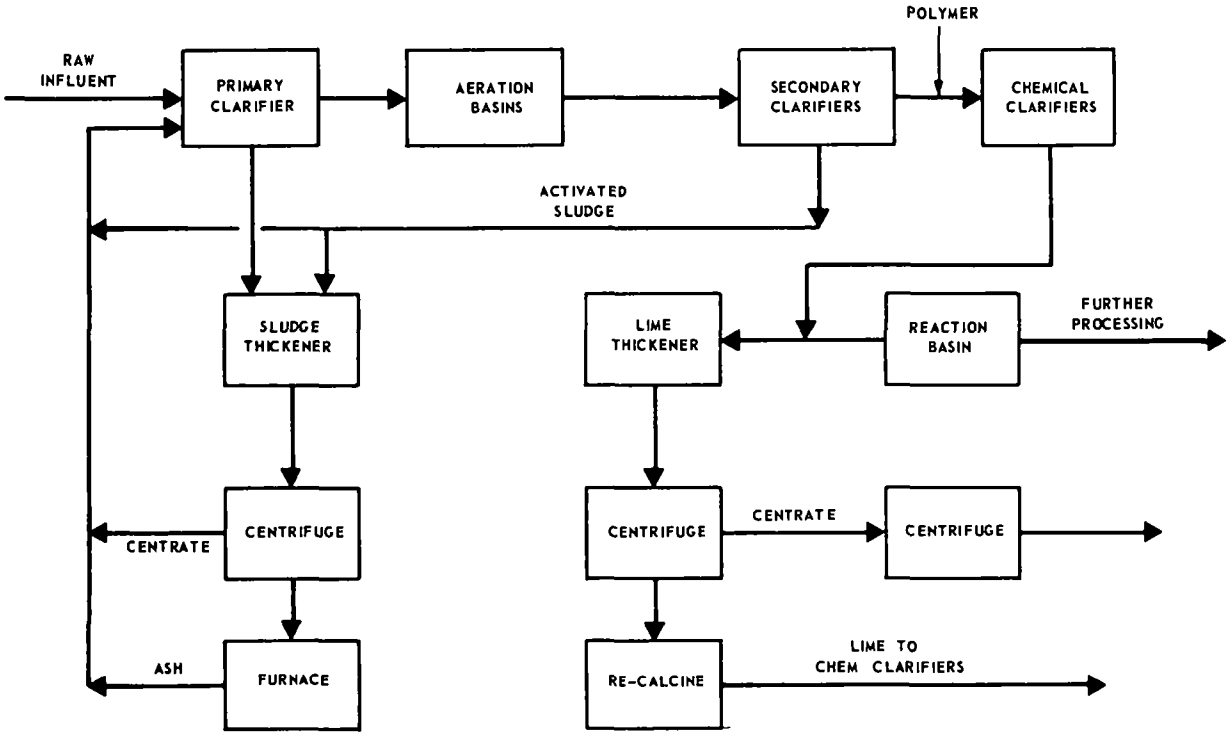


FIGURE 3-20

LAKE TAHOE
-ORGANIC SLUDGE HANDLING

% FEED SOLIDS	COND. #/TON	FEED RATE	% SOLIDS CAPTURE	% CAKE SOLIDS
2.0	5.1	—	90 +	17

FIGURE 3-21

LAKE TAHOE
-LIME SLUDGE PROCESSING

FEED RATE (GPM)	% SOLIDS CAPTURE	FRACTION LOST TO CENTRATE			
		TOTAL SOLIDS	ACTIVE LIME	PHOSPHATE	MGO
10	93	0.10	0.04	0.19	0.17
20	79	0.20	0.08	0.39	0.35

FIGURE 3-22

SECTION 4 – SLUDGE STABILIZATION PROCESSES

1. Anaerobic Digestion

- Describes the biological conversion of organic matter in the absence of molecular oxygen to simple compounds. Gas products are chiefly methane and carbon dioxide.

- Process advantages include:

  Anaerobic digestion is the most frequently employed process for sludge stabilization. When digestion operates properly, it converts raw sludge to a stable material which is inoffensive to the senses, and which has a greatly reduced pathogen content. A recent exposition of sludge digestion is available (Reference 1).

  Methane generated can be used for heating and to run generators.

  Can usually obtain a 50 percent reduction in volatile solids.

  Do not have to or want to maintain a high dissolved oxygen level.

- Process disadvantages include:

  Control is difficult because of sensitivity of micro-organisms to toxicity, especially from industrial effluents.

  Capital costs for facility construction and heating provision are high.

  Supernatant is usually high in BOD, solids, and nutrients requiring further treatment.

  Anaerobic digestion produces changes in sludge which, on the average, reduce the filter yield. If ferric chloride and lime are used, chemical demand is increased (Reference 2). If sludge density is increased (e.g., by two-stage high rate digestion), yield can by increased.

- Design criteria for anaerobic digesters

  Volume – allow 3 to 6 cubic feet per capita.

Organic loading – allow from 0.02 to 0.15 pounds of applied solids per day per cubic foot.

- Reported costs

  For anaerobic digestion followed by sand bed dewatering is approximately $25/ton dry sludge solids (Reference 3).

  For anaerobic digestion of activated sludge followed by reclamation of farm land or a strip mine is approximately $15 to $16/ton dry solids (Reference 4).

- Design of digesters at Chicago's West-Southwest and Calumet Plants is shown in Table 4-1.

  The summary of a year's operating results for the Southwest Plant's digesters is shown in Table 4-2. A similar summary for the Calumet Plant is shown in Table 4-3.

- Typical characteristics of digester supernatants are shown in Tables 4-4 and 4-5.

  Note especially high solids, BOD and alkalinity.

- Some recommended techniques for treating supernatants are given in Table 4-6.

2. Use of Aerobic Digestion

- Describes the separate aeration of:

  Waste primary sludge

  Waste biological sludge, or

  A combination of waste primary and biological sludges.

  Aerobic stabilization is usually used to stabilize waste activated sludges or the waste sludges from smaller plants which do not have separate primary clarification. See Reference 1 for a recent presentation.

- Usually designed for a 15-20 day retention.

- Biological steps include:

  Oxidation of biodegradable material.

  Oxidation of microbial cellular material.

- Process advantages include:

  Relatively simple to operate.

  Requires small capital expenditure compared to anaerobic digester.

  Does not generate significant odors.

  Reduces pathogenic organisms to low level.

  Reduces grease or hexane solubles.

  Produces a supernatant if clarified that is low in BOD, solids, and total P.

  Reduces sludge volatile solids.

  Reduces sludge respiration rate.

  Production of a highly nitrified sludge which could be denitrified if sludge is to be placed on land. (Note: nitrogen in any form can limit application rates on the land, not just in the nitrate form).

- Process disadvantages include:

  High operating cost.

  Unclear design parameters at present.

  Aerobically stabilized sludge has poor dewatering characteristics on vacuum filters although a recent publication claims otherwise (Reference 11). Ordinarily, this sludge is dewatered on sand beds or applied in liquid form to cropland.

- Important process parameters are:

  Air requirements.

  Time of aeration.

Sludge age.

Proposed method of ultimate disposal.

Temperature and heat dissipation.

- Some designs have been

  To allow for a 5-day retention, a sludge concentration of 12,000 ppm and to size at 1.4 cubic feet per capita, or

  To load at a rate of 0.1 to 0.2 lb VSS/lb solids/day.

- A 1970 Literature Survey led to the information in Table 4-7 and the following conclusions (Reference 12).

  Differences exist among investigators as to exactly what happens in the process and how it should be operated.

  Suggested loads range from 0.1 to 0.2 lb VSS/lb solids/day.

  Suggested times of stabilization range from 10 to 20 days.

  A low BOD supernatant should result from stabilization (a resultant BOD = 10-30 ppm).

  It should be possible to average a VSS reduction of 40 to 50 percent.

  The resultant ammonia level in the supernatant should be about 10 ppm.

  Resultant supernatant nitrate levels of 50 to 100 ppm or greater can be expected.

  Work by the Ultimate Disposal Research Program indicated findings in accord with the above. In addition, we found a grease reduction in about five days of 80 percent.

- A recent survey (Reference 23) of seven facilities which employ the aerobic stabilization process revealed the information given in the following tables:

  Table 4-8 describes the seven facilities.

  Table 4-9 describes the stabilizers' mode of action.

Table 4-10 describes the feed to the units.

Table 4-11 describes the sludge in the digester.

Table 4-12 gives the supernatant characteristics.

Key factors related here are:

the feed sludge
aeration
detention
solids–liquid separation
loading

3. **Chlorine Oxidation**

- The Purifax process oxidizes sludge with heavy doses of chlorine (circa 2,000 mg/l). Sludge dewaters well on sandbeds. Stability is excellent.

- Purifaxed sludges present some difficulties when they must be dewatered on vacuum filters. Chemical (or polymer) conditioning is needed, but the low pH (circa 2) interferes with the action of conditioning agents. Pilot plant tests indicate that pH must be increased to greater than 4 to get good conditioning (Reference 24).

- Supernatant and filtrate contain high concentrations of chloramines. They should not be carelessly discharged.

Lime Treatment

- Lime treatment of sludge stabilizes the sludge as long as the pH stays high (11.0 – 11.5). Kill of pathogenic bacteria is excellent (Reference 25). Sludge dewaters well on sandbeds without odor.

- Sludge filtrability is improved. Caution is advised on disposal of sludge cake to landfills to avoid thick layers. The pH could fall to near 7 before the sludge dries out, permitting regrowth and noxious conditions.

- Actual data from a recent study is shown in Tables 4-13, 4-14, 4-15, and 4-16 (Reference 25).

  Table 4-13 shows the magnitude of lime dose and the costs for treating three different sludge types.

Table 4-14 shows the bacterial response to lime addition.

Table 4-15 shows the lime requirement and cost for treating several different sludges.

Table 4-16 shows the effect of lime addition on filtrability.

- A key factor is the maintenance of a pH of 11.0 for a sufficiently long time (24 hours).

REFERENCES – SECTION 4

1. Weston, Roy F., Inc., "Process Design Manual for Upgrading Existing Wastewater Treatment Plants." EPA Report 17090 GNQ, October, 1971.

2. Teletzke, G.H., "Sludge Dewatering by Vacuum Filtration." presented at Annual Meeting of Rocky Mountain Sewage and Industrial Wastes Association, Colorado Springs, Colorado, October 24-26, 1960.

3. Burd, R.S., "A Study of Sludge Handling and Disposal." FWPCA Publication, No. WP-20-4, May, 1968.

4. Dalton, F.E., Stein, J.E., and Lynam, B.T., "Land Reclamation – A Complete Solution of the Solid Disposal Problem." *Journal Water Pollution Control Federation*, 40, (5), 789 (May, 1968).

5. Lynam, B., McDonnell, G., and Krup, M., "Start-Up and Operation of Two New High-Rate Digestion Systems." *Journal Water Pollution Control Federation,* 39, (4), 518 (April, 1967).

6. *Ibid*, No. 5.

7. *Ibid*, No. 5.

8. Maliva, J.F., Jr., and DiFilippo, J., "Treatment of Supernatants and Liquids associated with Sludge Treatment." *Water and Sewage Works, 1971 Reference Number,* R-30.

9. *Ibid,* No. 8.

10. *Ibid,* No. 8.

11. Cameron, J.W., "Aerobic Digestion of Activated Sludge to Reduce Sludge Handling Costs." 45th Annual Conference, Water Pollution Control Federation, Atlanta, Georgia, October, 1972.

12. EPA Memo from J.E. Smith, Jr. to R.B. Dean, "Aerobic Stabilization of Activated Sludge." January 4, 1970.

13. Barnhart, E.L., "Application of Aerobic Digestion to Industrial Waste Treatment." Proceedings of the 16th Industrial Waste Conference at Purdue University.

14. Private communication, Edward R. Grich, Consultant Chemist Edward R. Grich, Inc., Pequannock, New Jersey.

15. Lawton, G.W., and Norman, J.D., "Aerobic Sludge Digestion Studies." *Journal Water Pollution Control Federation*, 36, No. 4,495-503 (April, 1964).

16. Dreier, D.E., "Aerobic Digestion of Solids." Proceedings of Purdue Conference, 1963.

17. *Ibid,* No. 15.

18. Loehr, R.C., "Aerobic Digestion Factors Affecting Design." *Water and Sewage Works, Reference Number 1965,* 112, R169-R180.

19. Irgens, R.L., and Halvorson, H.O., "Removal of Plant Nutrients by Means of Aerobic Stabilization of Sludge." *Applied Microbiology*, 13, 373-386 (1965).

20. Havan, V.T., "Digesting Sludge by Aeration – Study in India." *Water Works and Waste Engineering,* (September, 1965).

21. Malina, J.R., and Burton, H.N., "Aerobic Stabilization of Primary Wastewater Sludge." Proceedings of the 19th Industrial Waste Conference at Purdue University, 1964.

22. Jaworski, N., Lawton, G.W., and Rohlich, G.A., "Aerobic Sludge Digestion." Conference of Biological Waste Treatment, April 20-22, 1960.

23. Ahlberg, N.R. and Boyko, B.I., "Evaluation and Design of Aerobic Digesters." *Journal Water Pollution Control Federation*, 44, 634 (1972).

24. Personal communication with Mr. Pearson of BIF Purifax, Providence, Rhode Island.

25. Farrell, J.R., Smith, J.E., Jr., Hathaway, S.W., and Dean, R.B., "Lime Stabilization of Chemical-Primary Sludges at 1.15 mgd." 45th Annual Conference, Water Pollution Control Federation, Atlanta, Georgia, October, 1972.

LIST OF FIGURES AND TABLES – SECTION 4

Table 4-1	Design Data for Chicago Digesters
Table 4-2	Summary of Operating Results – Southwest
Table 4-3	Summary of Operating Results – Calumet
Table 4-4	Properties of Digester Supernatant (Municipal Wastewater Sludge)
Table 4-5	Analysis of Supernatant from Several Plants
Table 4-6	Processes for the Removal of Constituents of Anaerobic Supernatant
Table 4-7	Information Taken from References on the Aerobic Stabilization of Sludge
Table 4-8	Physical Plant Data
Table 4-9	Aerobic Digestion Process
Table 4-10	Characteristics of Digester Feed Sludges (mg/l)
Table 4-11	Characteristics of Digester Sludges (mg/l)
Table 4-12	Characteristics of Digester Supernatants (mg/l)
Table 4-13	Preliminary Comparison of Lime Costs for Raw, Alum and Iron Sludges
Table 4-14	Bacteriological Studies of Sludge Produced in Plant-Scale Tests
Table 4-15	Average Cost of Lime Addition: Plant-Scale Tests
Table 4-16	Effect of Lime on Filtrability of Al^{+++} and Fe^{+++} Sludges

TABLE 4-1

DESIGN DATA FOR CHICAGO DIGESTERS[1]

Solids to digesters, tons/day	100
Sludge to digesters, % solids	3.3
Sludge to digesters, % volatile	67
Digester displacement, days	14
Volatile solids digested, %	40 to 45
Gas per pound volatile solids digested, cu ft	16 to 18
Heat per cubic foot of gas, BTU	600 to 650
Temperature of digesters, ° F.	90 to 95
Sludge to digesters:	
Activated sludge solids, %	80 to 100
Primary sludge solids, %	20 to 0

Note: Tons X 0.907 = metric tons
Cu ft/lb X 0.0617 = cu m/kg
BTU/cu ft X 9 = kg-cal/cu m
° C. = 0.555 (° F. - 32)

[1] See Reference 5.

TABLE 4-2

SUMMARY OF OPERATING RESULTS – SOUTHWEST[1]

		Feed									
		Dry Solids (percent)					Dry Solids (tons/day)				
	Date	Total	Volatile	pH	Alkalinity (mg/l)	gpd x 1,000	Total	Volatile	Volatile Solids (lb/day/cu ft)	Detention (days)	Temperature (° F.)
1964	July[2]	3.1	60.1	6.5	493	354	47.1	28.3	0.042	23.0	95
	Aug.[2]	2.7	63.3	6.5	591	591	65.8	41.5	0.062	21.8	95
	Sept.[2]	2.5	64.2	6.5	575	649	69.0	44.3	0.066	15.5	95
	Oct.[2]	2.7	63.5	6.6	493	714	80.4	51.1	0.076	14.0	94
	Nov.[2]	2.5	65.3	6.5	458	762	79.2	51.9	0.077	13.2	94
	Dec.[2]	2.6	68.2	6.4	549	671	72.8	49.6	0.074	14.9	90
1965	Jan.[3]	3.0	70.0	6.4	791	742	92.7	64.8	0.096	13.5	87
	Feb.[3]	3.1	70.8	6.4	898	755	98.7	69.5	0.103	13.2	89
	Mar.[3]	3.0	67.5	6.5	800	735	93.0	62.9	0.093	13.6	90
	Apr.[3]	4.0	65.2	6.5	790	631	104.1	68.0	0.101	15.8	92
	May[3]	3.4	64.0	6.5	802	628	86.6	55.4	0.082	15.9	95
	June[3]	4.2	61.4	6.5	815	605	105.9	65.0	0.097	16.5	95
Average		3.1	65.3	6.5	671	653	82.9	54.4	0.081	15.95	93

[1] See Reference 6
[2] 100 percent activated sludge used as feed
[3] Mixture of activated and preliminary sludges

TABLE 4-2 (Continued)

SUMMARY OF OPERATING RESULTS – SOUTHWEST[1]

Date		Drawoff						Volatile Solids		Gas Produced	
		Dry Solids (percent)									
		Total	Volatile	pH	Alkalinity mg/l	Dry Solids (total tons/day)	Total Solids (reduced tons/day)	Reduction (percent)	Reduction tons/day	Total (1,000 cu ft/day)	cu ft/lb Volatile Destroyed
1964	July	3.8	49.8	7.0	1,245	44.7	2.4	32.2	9.1	340.9	18.7
	Aug.	2.4	53.4	7.0	1,745	58.8	10.0	33.7	14.0	643.8	23.0
	Sept.	2.1	54.8	7.0	1,933	56.0	13.0	32.4	14.3	620.5	21.8
	Oct.	2.2	54.2	7.1	1,629	65.7	14.7	31.9	16.3	665.8	20.4
	Nov.	2.1	57.3	7.1	1,612	66.1	13.1	28.3	14.7	642.6	21.8
	Dec.	2.0	57.5	7.0	2,140	56.0	16.8	37.0	18.3	658.3	18.4
1965	Jan.	2.1	59.6	7.0	2,437	65.6	27.1	36.9	23.9	943.8	19.7
	Feb.	2.3	58.0	7.1	2,554	72.6	26.1	42.6	29.6	1,128.9	19.0
	Mar.	2.1	55.4	7.1	2,520	64.8	28.2	40.2	25.2	1,089.7	21.5
	Apr.	2.6	53.1	7.1	2,495	67.3	36.8	39.4	26.8	1,056.5	19.7
	May	2.6	52.5	7.1	2,885	68.0	18.6	37.7	20.5	783.1	19.1
	June	3.0	50.5	7.1	2,748	75.6	30.3	36.0	23.4	821.8	17.5
Average		2.4	54.7	7.1	2,162	63.4	19.8	35.7	19.7	783.0	20.0

[1] See Reference 6

Note: Gal x 3.785 = 1; tons x 0.907 = metric tons; lb/cu ft x 16.214 = kg/cu m; 0.5 (° F. – 32) = ° C.; cu ft x 0.028 = cu m; cu ft/lb x 0.0617 = cu m/kg.

TABLE 4-3

SUMMARY OF OPERATING RESULTS – CALUMET[1]

	Feed Sludge									
	Dry Solids (percent)					Dry Solids (tons/day)				
1965	Total	Volatile	pH	Alkalinity (mg/l)	gpd x 1,000	Total	Volatile	Volatile Solids (lb/day/cu ft)	Detention (days)	Temperature (° F.)
Jan.	3.65	61.5	6.6	408	169.2	25.9	15.9	–	–	95
Feb.	3.79	61.4	6.6	464	358.5	55.7	34.2	0.082	18	95
Mar.	3.61	61.2	6.6	434	494.8	74.5	45.6	0.088	16	95
Apr.	4.23	58.8	6.6	636	418.7	73.8	43.5	0.084	19	95
May	4.00	58.8	6.6	863	552.3	91.7	53.9	0.105	15	95
June	3.14	60.1	6.6	632	637.2	82.5	49.6	0.075	13	95
July	3.63	57.9	6.6	855	443.4	66.3	38.4	0.058	25	95
Aug.	4.02	56.5	6.6	798	515.1	85.2	48.1	0.950	15	95
Average	3.76	59.5	6.6	636	448.7	69.4	41.2	0.084	17	95

[1] See Reference 7

TABLE 4-3 (Continued)

SUMMARY OF OPERATING RESULTS – CALUMET[1]

	Drawoff Sludge						Volatile Solids		Gas Produced	
	Dry Solids (percent)									
1965	Total	Volatile	pH	Alkalinity (mg/l)	Dry Solids Total (tons/day)	Total Solids Reduced (tons/day)	Reduction (percent)	Reduced (tons/day)	Total (1,000 day)	cu ft/lb Volatile Destroyed
Jan.	2.95	45.8	6.9	1,472	11.9	14.0	–	–	238.6	–
Feb.	2.70	46.0	7.1	2,142	36.9	18.8	46.0	15.7	512.4	16.3
Mar.	2.57	46.8	7.2	2,711	48.5	26.0	44.2	20.2	678.6	16.8
Apr.	2.97	46.6	7.2	3,080	48.2	25.6	38.6	17.3	679.8	19.6
May	3.38	46.0	7.2	3,050	72.9	18.8	36.9	20.8	615.4	14.9
June	2.75	48.2	7.2	2,452	71.0	11.5	37.9	19.9	614.6	15.5
July	2.82	47.7	7.2	2,457	51.9	14.4	34.3	13.2	559.9	21.2
Aug.	3.11	48.2	7.2	2,405	65.2	20.0	29.5	14.5	567.0	19.5
Average	2.91	46.9	7.2	2,471	50.8	18.6	38.2	17.4	558.3	17.7

[1] See Reference 7

Note· Gal x 3.785 = 1; tons x 0.907 = metric tons; lb/cu ft x 16.214 = kg/cu m; 0.555 (° F.-32) = ° C.; cu ft x 0.028 = cu m; cu ft/lb x 0.0617 = cu m/kg.

TABLE 4-4

PROPERTIES OF DIGESTER SUPERNATANT

(MUNICIPAL WASTEWATER SLUDGE)[1]

Item	Standard Rate	High Rate
Temperature, °F.	85 – 90	110 – 125
Total susp. solids (mg/l)	4,000 – 5,000	10,000 – 14,000
Total solids (mg/l)	2,000 – 3,000	4,000 – 6,000
BOD (mg/l)	2,000 – 3,500	6,000 – 9,000
Volatile solids (mg/l)	650 – 3,000	2,400 – 3,800
Alkalinity (MO) (mg/l)	1,000 – 2,400	1,900 – 2,700
Color (Co-Pt) (mg/l)	3,000 – 4,000	4,900 – 6,700
H_2S (mg/l)	70 – 90	190 – 440
HN_3 - Nitrogen (mg/l)	240 – 560	560 – 620
pH	7.0 – 7.6	6.4 – 7.2
Odor	Slightly offensive	Offensive
Digester Loading	0.15 lb/BOD/cu ft/day	0.4 lb/BOD/cu ft/day

[1] See Reference 8

TABLE 4-5

ANALYSIS OF SUPERNATANT FROM SEVERAL PLANTS[1]

Item	Geneva Ill. 1944	Military Installation 1944	Downers Grove, Ill. 1963	Aurora, Colo. 1963	Fort Worth, Tex. 1963	Hogsmill Valley, England 1966
BOD–Range	542–2,852	173–1,825	540–4,300			
Average	1,328	398	2,460	2,300		
COD–Range			2,300–20,000			
Average			11,560			
IOD–Range			80–250			
Average			145			
Total–Range Solids		1,320–14,460				1,000–4,000
Average		3,108		14,673	12,100	3,300
Suspended Solids–Range	1,228–15,484	404–4,032	2,700–28,980			
Average	5,300	1,451	5,300	11,100		
Alkalinity–Range						500–3,100
Average					2,630	1,900
Nitrogen						
NH_3–Range					510	320
organic					465	60

[1] See Reference 9

TABLE 4-6

PROCESSES FOR THE REMOVAL OF CONSTITUENTS OF ANAEROBIC SUPERNATANT[1]

Constituent	Means of Removal
Suspended material	Coagulation, filtration, microstraining
Phosphorus	Removal with suspended material, chemical precipitation, ion exchange
Nitrogen	Removal with suspended material, stripping, ion exchange
CO_2	Lime addition, stripping, ion exchange
BOD	Removal with suspended material, stripping of volatile acids, biological treatment, adsorption on activated carbon

[1] See Reference 10

TABLE 4-7

INFORMATION TAKEN FROM REFERENCES ON THE AEROBIC STABILIZATION OF SLUDGE

Reference Information Taken From	Type of Sludge Stabilized	Loading (lb Volatile Suspended Solids per lb reactor solids/day)	Days that Sludge was Stabilized	Volatile Suspended Solids Reduction (percent)	Nitrate Level Achieved (mg/l)	Total Kjeldahl Nitrogen (mg/l)	Supernatant BOD level (mg/l)	Other
Barnhart[1]	Mixed Primary + Activated	–	–	Total Poss. = 60	–	–	–	–
Grich[2]	Waste Activated	–	–	–	50 – 100	–	Greatly Reduced	–
Lawton[3] + Norman	Mixed Primary + Activated	0.22	15	43	$\leq$900 w/ 60 Days Air	–	–	–
Dreier[4]	Waste Activated	0.145	10	43	50	–	$<$100	NH_3-N Near 0
Lawton[5] + Norman	Waste Activated	0.112	15	50	–	–	–	–
Loehr[6]	Waste Activated	0.1 – 0.44	–	Limited to 40 – 60	–	–	–	–
Irgens[7]	Waste Activated	0.1 – 0.4	–	–	High	Low	Low $<$10	–
Havan[8]	Raw Sludge	–	15	38	–	43	Low	Alkalinity 88
Malina[9] + Burton	Waste Activated	0.14	15	43	–	–	COD Reduction of 46%	–
Jaworski[10]	Waste Activated	–	–	43	High	–	–	NH_3-N Low

In general, a sludge age of 15 to 20 days is recommended.

[1-10]See References 1 through 10 respectively.

TABLE 4-8

PHYSICAL PLANT DATA

Plant	Plant Type	Plant Flow Design (mgd)[1]	Plant Flow Present (mg/l)[1]	Digester Type	Digester Capacity (cu ft)	Tank Configuration
A	Contact stabilization	0.33	0.40	Two-stage	#1–8,860 #2–4,430	Annular segment Annular segment
B	Conventional	0.50	0.25	Single-stage	15,700	Circular
C	Contact stabilization	1.85	1.40	Two-stage	#1–57,250 #2–10,800	Circular Rectangular
D	Conventional	0.33	0.37	Single-stage	9,720	Circular
E	Conventional	0.40	0.03	Two-stage	#1–11,540 #2–6,060	Circular segment Circular segment
F	Contact stabilization	0.54	0.90	Two-stage	#1–10,450 #2–13,500	Circular Circular
G	Extended aeration	0.05	0.03	Single-stage	1,370	Rectangular

[1] Imperial gallons

Note: mgd x 4,545.9 = cu m/day; cu ft x 0.0283 = cu m

TABLE 4-9

AEROBIC DIGESTION PROCESS

Plant and Digester	Hydraulic Retention (days)	Sludge Age (days)	Loading Design (lb VS/cu ft/day)	Loading Actual (lb VS/cu ft/day)	Air Supply Design (cfm/1,000 cu ft)	Air Supply Actual (cfm/1,000 cu ft)
A No. 1 Digester	14	30	0.08	0.024	20	–
No. 2 Digester	–	–	(overall)	–	20	–
B Single-stage	30	29	0.0256	0.025	25	19
C No. 1 Digester[1]	–	–	0.024	–	23	23[2]
No. 2 Digester	20	30	(overall)	0.025	8.4	8.4
D Single-stage	60	45	0.05	0.027	25	46
E No. 1 Digester	360	320	0.0166	0.0035	30	–
No. 2 Digester	–	–	(overall)	–	(both)	–
F No. 1 Digester	65[2]	45[2]	0.0326	0.012[2]	19	–
No. 2 Digester	–	–	(overall)	–	(both)	–
G Single-stage	60	100	0.024	0.020	29	29

[1] Occasionally used as a second-stage digester

[2] Estimated

Note. lb/cu ft/day x 16.0 = kg/cu m/day, cfm/1,000 cu ft = cu m/min/1,000 cu m

TABLE 4-10

CHARACTERISTICS OF DIGESTER FEED SLUDGES (mg/l)

Parameter	Overall Average	Range of Plant Averages	Range of Results
pH	6.7	6.3–7.0	5.5–7.4
COD	19,000	7,900–63,000	1,600–92,700
TS	20,200	8,550–41,600	1,960–86,600
TVS	11,500	5,210–29,200	870–63,000
Kjeldahl N	960	400–3,540	27–18,000
Total P	370	144–990	23–1,340

TABLE 4-11

CHARACTERISTICS OF DIGESTER SLUDGES (mg/l)

Parameter	Overall Average	Range of Plant Averages	Range of Results
pH	6.8	6.2–6.7	5.4–8.4
COD	20,800	14,100–33,200	1,900–51,000
TS	27,600	13,600–39,400	4,040–59,800
TVS	14,400	9,500–21,500	1,940–36,000
Kjeldahl N	1,050	640–1,460	25–4,100
Total P	510	325–900	10–1,500
Soluble P	35	1.3–70	0.6–113

TABLE 4-12

CHARACTERISTICS OF
DIGESTER SUPERNATANTS (mg/l)

Parameter	Overall Average	Range of Plant Averages	Range of Results
pH	7.0	5.9–7.7	5.7–8.0
BOD	500	9–1,700	5–6,350
Filtered BOD	51	4–183	3–280
COD	2,600	228–8,140	24–25,500
SS	3,400	46–11,500	9–41,800
Kjeldahl N	170	10–400	2.9–1,350
Total P	98	19–241	2.1–930
Soluble P	26	2.5–64	0.4–120

TABLE 4-13

PRELIMINARY COMPARISON OF LIME COSTS

FOR RAW, ALUM, AND IRON SLUDGES

Sludge Type	Raw	Alum	$FeCl_3$
Chemical Dose to Primary (mg/l)	0	27.3 Al	20.7 Fe
Sludge Suspended Solids (g/l)	89.1	32.1	20.1
Sludge Volatile Solids (% of SS)	64.0	55.9	45.7
pH before lime	5.2	6.2	6.2
pH after lime	11.0	11.0	11.0
$Ca(OH)_2$ added, (g/l sludge)	8.7	12.9	5.5
(g/g dry solids)	0.098	0.40	0.27
Cost of lime ($/ton dry solids)*	1.96	8.00	5.40

* Based on $Ca(OH)_2$ cost of $20/ton. Multiply by 1.10 for $/metric ton.

TABLE 4-14

BACTERIOLOGICAL STUDIES OF SLUDGE
PRODUCED IN PLANT–SCALE TESTS

	Bacterial Count (organisms/liter of sludge)		
Sludge	Salmonella Species	Pseudomonas aeruginosa	Total Aerobic Count x 10^{-8}
Alum-primary	110	1,300	41
Limed alum-primary	None detected	None detected	5.0
Ferric-primary	> 24,000	610	190
Limed ferric-primary	None detected	None detected	0.29

TABLE 4-15

AVERAGE COST OF LIME ADDITION: PLANT–SCALE TESTS

	Sludge		$Ca(OH)_2$ Dose		Cost[1]
Chemical	Dose (mg/l)	Solids (g/l)	(g/l)	(g/g)	(dollars/ton)
Al^{+++}	31.8	24.0	6.0	0.25	5.0
	22.7	28.5	6.3	0.22	4.4
	13.6	20.6	4.4	0.21	4.2
Fe^{+++}	31.0	20.2	2.2	0.11	2.2
	15.5	17.9	2.2	0.12	2.4

[1] $Ca(OH)_2$ at $20.00/ton.

TABLE 4-16

EFFECT OF LIME ON FILTRABILITY OF Al^{+++} AND Fe^{+++} SLUDGES

Sludge Property	Lime Addition	Al^{+++} Dose (mg/l)			Fe^{+++} Dose (mg/l)	
		31.8	22.7	13.6	31.0	15.5
Buchner Funnel Tests						
Specific Resistance at 20" Hg (cm/g x 10^{-11})	Before	19.0	28.0	29.0	14.9	21.6
	After	3.8	4.5	3.8	7.0	5.5
Compressibility	Before	0.50	0.46	0.59	0.53	0.60
	After	0.70	0.91	0.80	0.43	0.76
Filter Leaf Tests						
Yield (lb/hr/ft^2)[1]	Before	0.98	0.94	0.95	1.06	1.57
	After	1.97	2.10	2.58	1.57	2.40
Cake Moisture (lb w/lb d.s.)	Before	4.31	4.35	4.37	4.10	3.75
	After	3.87	3.92	3.83	4.28	3.75

[1] Multiply by 4.86 to get kg/hr/m^2

SECTION 5A – CASE STUDIES – PLANT RESULTS – CHEMICAL CONDITIONING – CONVENTIONAL ACTIVATED SLUDGE

CASE STUDY – WASHINGTON, D.C.

1. **Extensive History, Plant Process Engineering Studies**

   – Reference 2, Dahl, Zelinski and Taylor (WPCF award 1972).

   – Important regarding efficiency of various methods of handling organic sludges.

2. **Plant Process**
   (Figure 5A-1)

   – Currently modified high rate activated sludge.

   – Expanded to activated sludge in 1959 - Original rationale - same solids handling system as for primary sludge.

     Gravity thickening of excess activated with raw primary.

     Anaerobic high rate digestion, clutriation, vacuum filtration.

   – Problems

     Dirty thickener overflow and very polluted elutriate.

     Results - Fines build up in system, upset and high cost solid - liquid separation steps.

   – Temporary solution

     Vent elutriate (15–30 tons/day).

     Accept poor primary capture.

   – Current solution
     (Figure 5A-2)

     Flocculation in clutriation basins.

     Careful operation of basins to promote sludge compaction and thickening and good solids capture.

3. Sludge Removal Practices and Costs
(Table 5A-1)

- Initial results, even with venting of elutriate, costs were high and 3 lb/hr/ft^2 filter yields experienced.

- During initial months of treating elutriation basins and providing good solids removal rate, higher than normal rates were maintained to clean out plant system. (Prior to this work, another long term attempt had been made to recycle the elutriate - this loaded up the plant).
(Figure 5A-3 showing vacuum filters)

- After prolonged efficient thickening, solids capture and removal rates being attained, costs and required steady state rates became lower as a new plant equilibrium established (4 lb/hr/ft^2 yield).

4. Current Operations

- New belt type filters installed.
(Figure 5A-4)

- Interim use of alum/ferric in final clarifiers for increased BOD and solids removals.

- Some problems with release of cake from belt filters. Requires $3.80/ton more ferric chloride than older drum filters.

- Cloth use data comparison shows favorable results for drum type filters.

- Drum cloth life = 2,000 hours: preliminary indications are belts go same time before maintenance or changes required.

CASE STUDY – METRO TORONTO MAIN PLANT

1. Definitive, Thorough Plant Process Studies By Plant Personnel

   – Plant expanded over 1967–71 period to provide full scale secondary treatment.

   – Sludge processing problems encountered.

   – No separate activated sludge thickening, once again recirculation of same to head of plant. Digestion of mixed sludges.

   – Plant personnel responded to the challenge.

2. Process Description
   (Figure 5A-5)

   – Step aeration, two-stage anaerobic digestion, elutriation, vacuum filtration, incineration.

   – Slide does not completely reflect all available options on recycle stream directions.

   – Loadings and degree of treatment gradually increased 1967–71.

3. Effects of Increased Proportion of Activated Sludge
   (Figure 5A-6)

   – Gradual decrease in solids content of elutriated sludge to filters.

   – By 1970, below 4 percent, that critical level as far as efficient dewatering is concerned. By August, "to hell in a handbasket," below 3 percent regularly.

   – Concurrently (Figure 5A-7), the solids content of the raw sludge from the primaries was decreasing. The effect of recirculation of activated sludge to the head of the plant.

4. Sludge Removal Needs
   (Table 5A-2)

   – Due to loadings increase and full secondary treatment, solids removal rates as shown were essential.

   – But processing problems cited made attainment with normal mode of operation questionable.

- As recirculating solids occurred in plant, odor problems arose.

- Work commenced to improve the elutriation/filtration process.

5. **Elutriation/Filtration Studies**
   (Table 5A-3)

   - Over two month period, small polymer add in feed to elutriation, ferric chloride in decreasing amounts, plus polymer at vacuum filters.

   - Elutriated sludge solids up to 4 percent with corresponding increase in filter production rate.

   - After 2–3 months of operation (Table 5A-4), results improved even further as some of the fines were cleaned out of the plant.

   - The elutriation/filtration (Figure 5A-8) process improved in uniformity and ease of operation. Note excellent cake discharge and thickness of filter cake.

CASE STUDY – RICHMOND, CALIFORNIA

1. **On-Going, Plant Process Studies on Solids Handling**

   – During 1967-69 (Figure 5A-9) expanded plant to secondary treatment via activated sludge process (surface aeration).

   – Design included provision for separate thickening of activated sludge via D.A.F.

   – Combined sludges then to two stage anaerobic digestion, elutriation and vacuum filters. Filter cake to incinerator or landfill (40 mgd hydraulic capacity, average flow = 9 mgd).

2. Process Considerations

   – While D.A.F. thickening of E.A.S., was a positive step, there was some speculation about mixing the sludges early in the process.

   – Shortly after the advent of activated sludge operation, the same problems arose as in Toronto and Washington. Recirculation of loaded digester supernatant elutriate caused solids build-up within plant.

3. Remedial Action

   – Plant personnel carried out process studies on elutriation/filtration process (Table 5A-5).

   – Note that with primary sludge, before secondary treatment, things were rosy.

   – During the period when solids recirculation was occurring, note in column 2 the high costs - low yields and low cake solids obtained.

   – After realizing good compaction and solids capture in elutriation via flocculant use, note dramatic improvement in filtration performance.

4. Current Results

   – After protracted operation with effective elutriation (Table 5A-6) the results were as shown.

   – Total conditioning costs in elutriation and on filters (ferric chloride/lime) were about $11.00/ton.

- Richmond has belt filters which do not have particularly good cake release capabilities. This necessitates a higher than normal ferric/lime dosage. How many times have you seen a filter cake with all those drying cracks?

- More important, if the thickened activated sludge could be mixed with primary sludge just before filtration, results would improve and costs would decrease.

REFERENCES – SECTION 5A

1. Goodman, B.L., and Whitcher, C.P., "Polymer Aided Sludge Elutriation and Filtration." *Journal WPCF*, 37, 12, 1643 (1965).

2. Dahl, B.W., Zelinski, J.W., and Taylor, O W., "Polymer Aids Dewatering and Eliminates Solids Loss in Elutriation," presented at the 43rd Annual WPCF Conference, Boston, Massachusetts, October 6, 1970.

3. Ashman, P.S., "Operating Experiences of Vacuum Filtration at St. Helens." *Water Pollution Control*, 20-39 (1969).

4. Ashman, P.S., and Roberts, P.F., "Operating Experiences with Vacuum Filtration at St. Helens. A Solution to the Problem." *Water Pollution Control*, 638-648 (1970).

5. Stanbridge, H.H., "Operation and Performance of the Hogsmill Valley Sewage Treatment Works of the Greater London Council, 1958–1966." *Water Pollution Control*, 67, 21 (1968).

6. Private communications with: David A. Clough, Director of Metro Water Pollution Control; Earl Baldock, Assistant Director of Water Pollution Control, Wadid Salib, Plant Engineer – Main Plant.

7. Private communications with: E.L. MacDonald, Jr., Superintendent, and William Kennedy, Plant Supervisor, City of Richmond, California.

LIST OF FIGURES AND TABLES – SECTION 5A

Figure 5A-1	Plant Flow Diagram – District of Columbia
Figure 5A-2	Elutriation/Filtration System – District of Columbia
Table 5A-1	Sludge Removal Practices and Costs – District of Columbia
Figure 5A-3	Vacuum Filter Operation – District of Columbia
Figure 5A-4	New Filter Installation with Individual Conditioning Boxes – District of Columbia
Figure 5A-5	Plant Flow Diagram – Metro Toronto
Figure 5A-6	Percent Solids in Elutriated Sludge – Metro Toronto
Figure 5A-7	Percent Solids in Raw Sludge – Metro Toronto
Table 5A-2	Sludge Removal Needs – Metro Toronto
Table 5A-3	Elutriation/Filtration Results October-November – Metro Toronto
Table 5A-4	Elutriation/Filtration Results 1971 – Metro Toronto
Figure 5A-8	A View of Filters – Metro Toronto
Figure 5A-9	Plant Flow Diagram – Richmond, California
Table 5A-5	Filtration Results – Richmond, California
Table 5A-6	Elutriation/Filtration Operations – Richmond, California

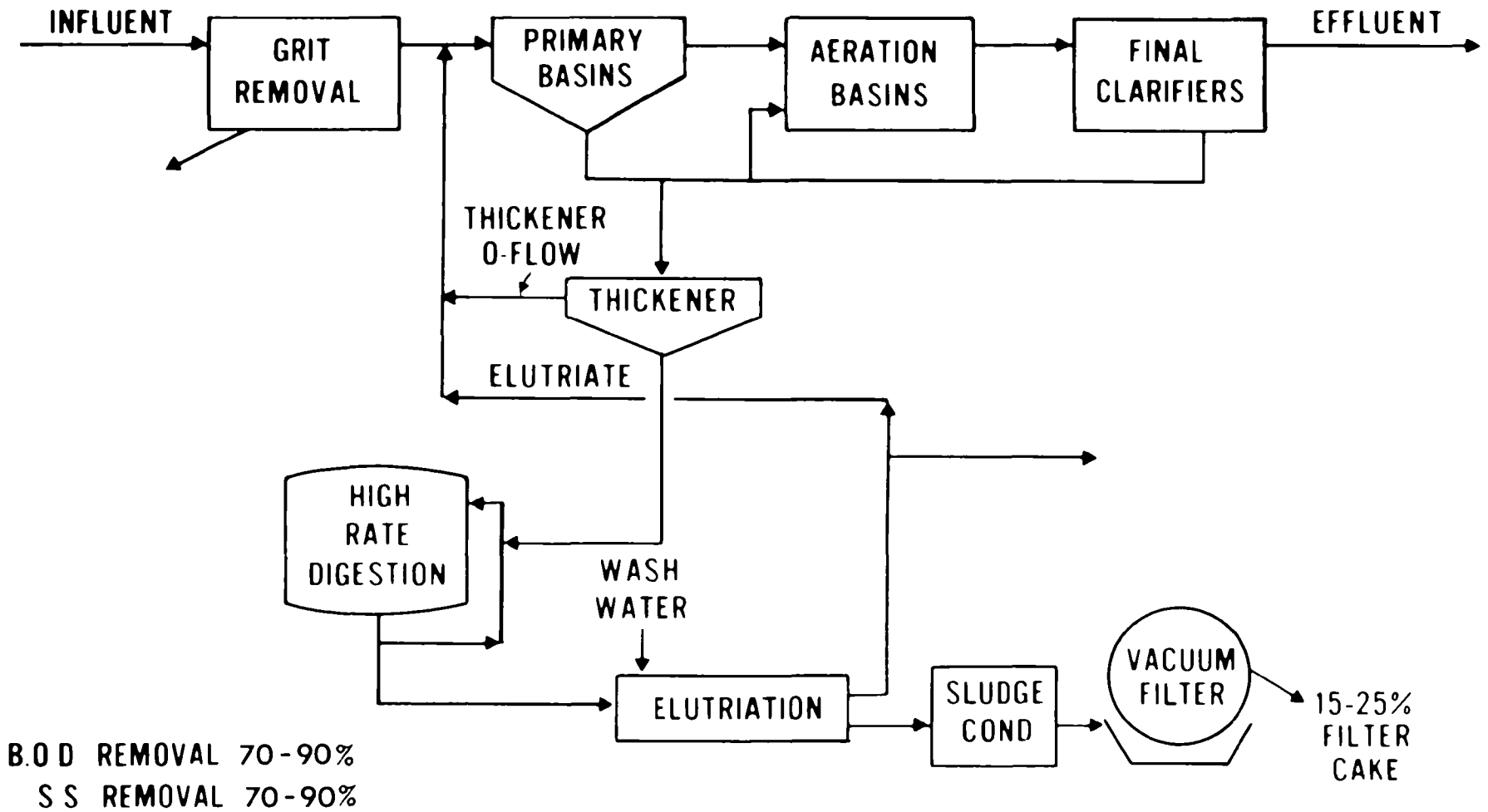
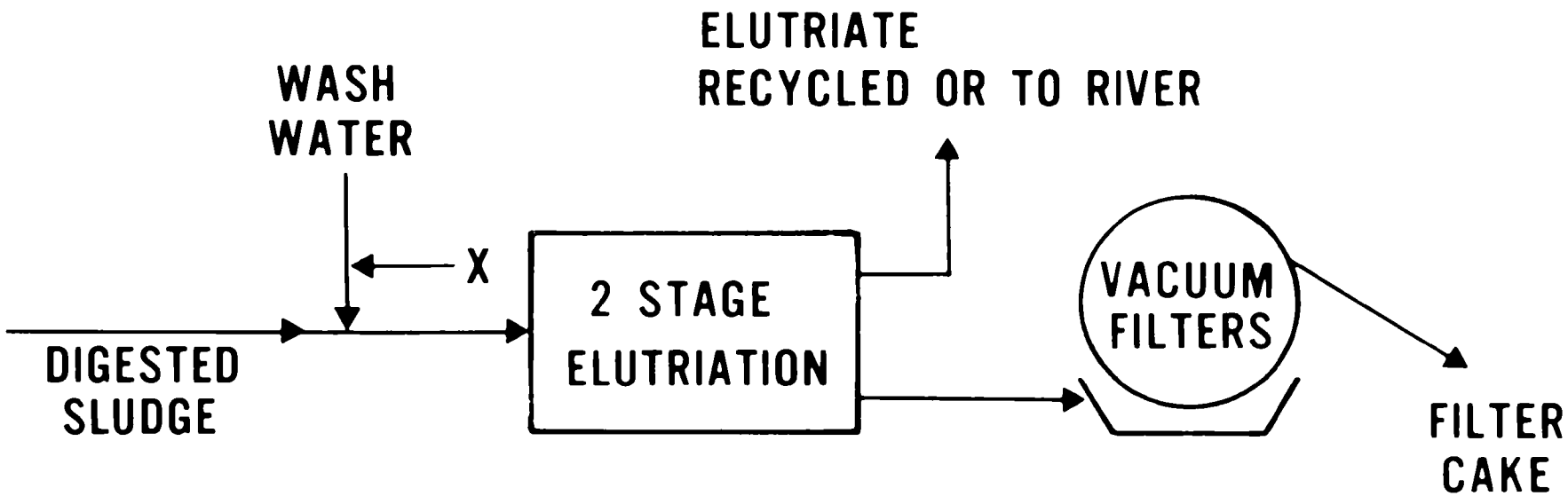


FIGURE 5A-1 PLANT FLOW DIAGRAM – DISTRICT OF COLUMBIA



X = CATIONIC POLYELECTROLYTE APPLICATION POINT

FIGURE 5A-2 ELUTRIATION/FILTRATION SYSTEM – DISTRICT OF COLUMBIA

	TONS/DAY REMOVED	CHEMICAL COST ($/TON)	
		ELUTRIATION	FILTRATION
ELUTRIATE TO RIVER	45	—	13.50
POST ELUTRIATE RECYCLE PERIOD (POLYMER IN ELUTRIATION)	80	4.68	7.42
AFTER PROLONGED POLYMER USE IN ELUTRIATION	70	TOTAL = 9.75	

TABLE 5A-1 SLUDGE REMOVAL PRACTICES AND COSTS – DISTRICT OF COLUMBIA

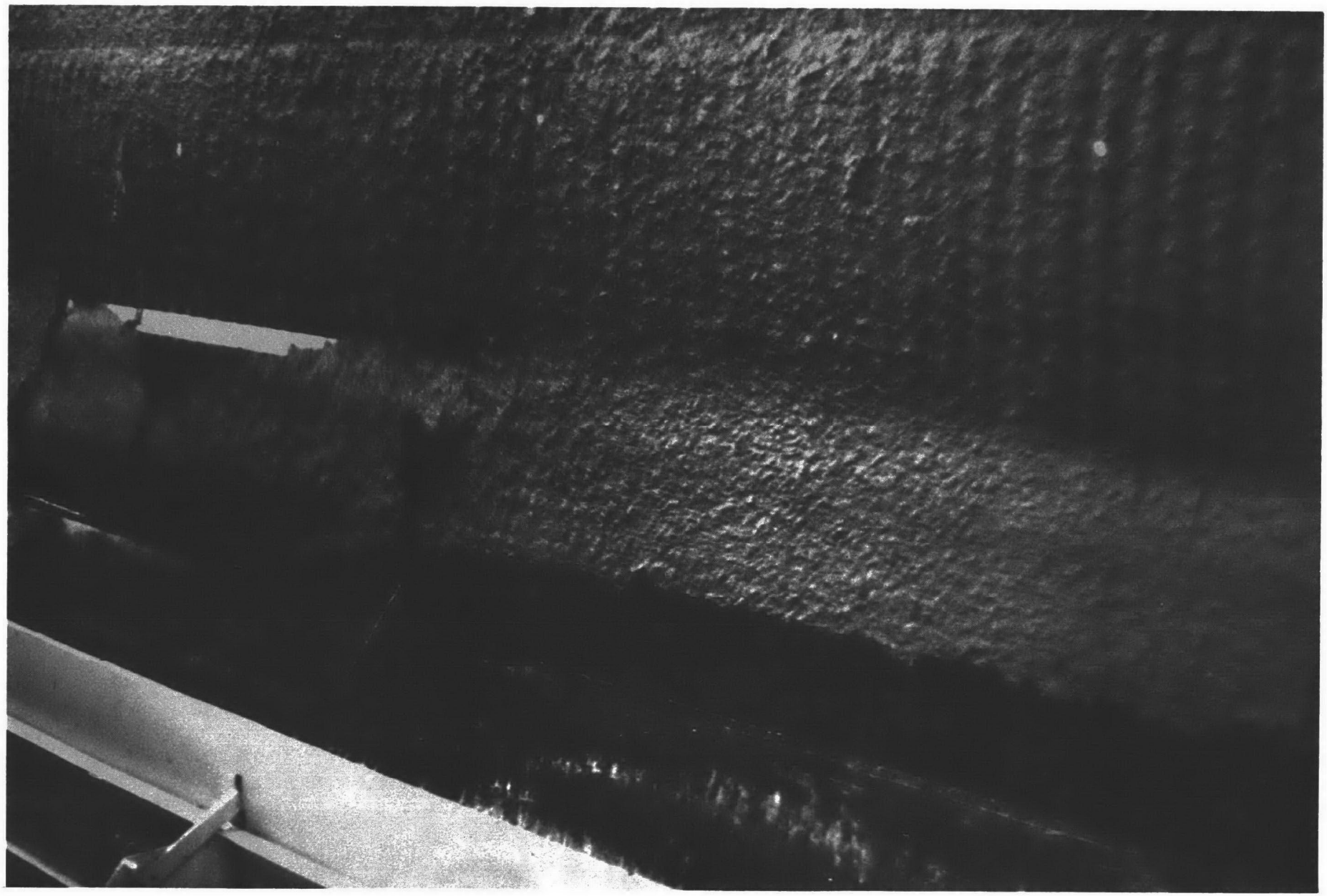


FIGURE 5A-3 VACUUM FILTER OPERATION – DISTRICT OF COLUMBIA

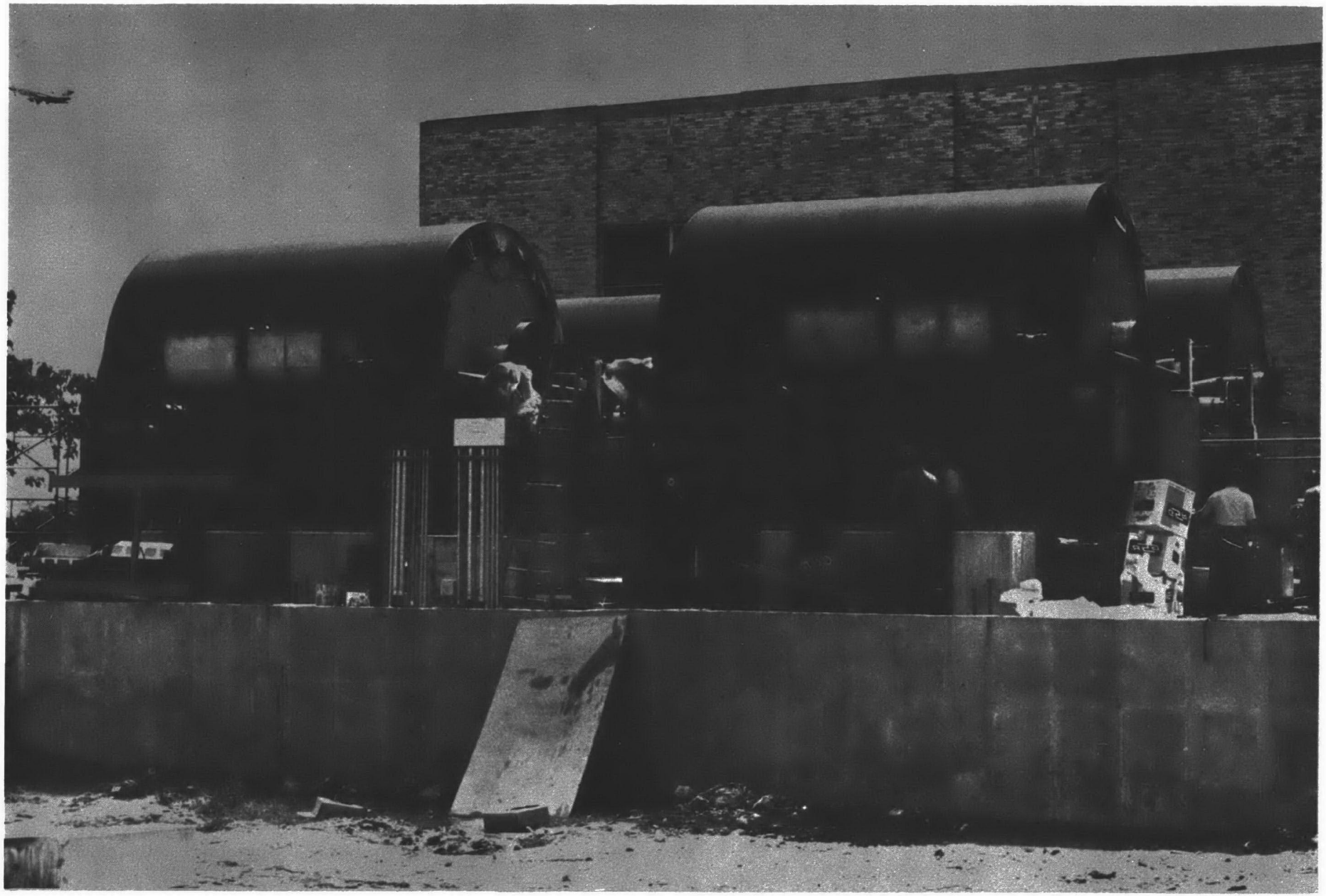


FIGURE 5A-4 NEW FILTER INSTALLATION WITH INDIVIDUAL CONDITIONING BOXES – DISTRICT OF COLUMBIA

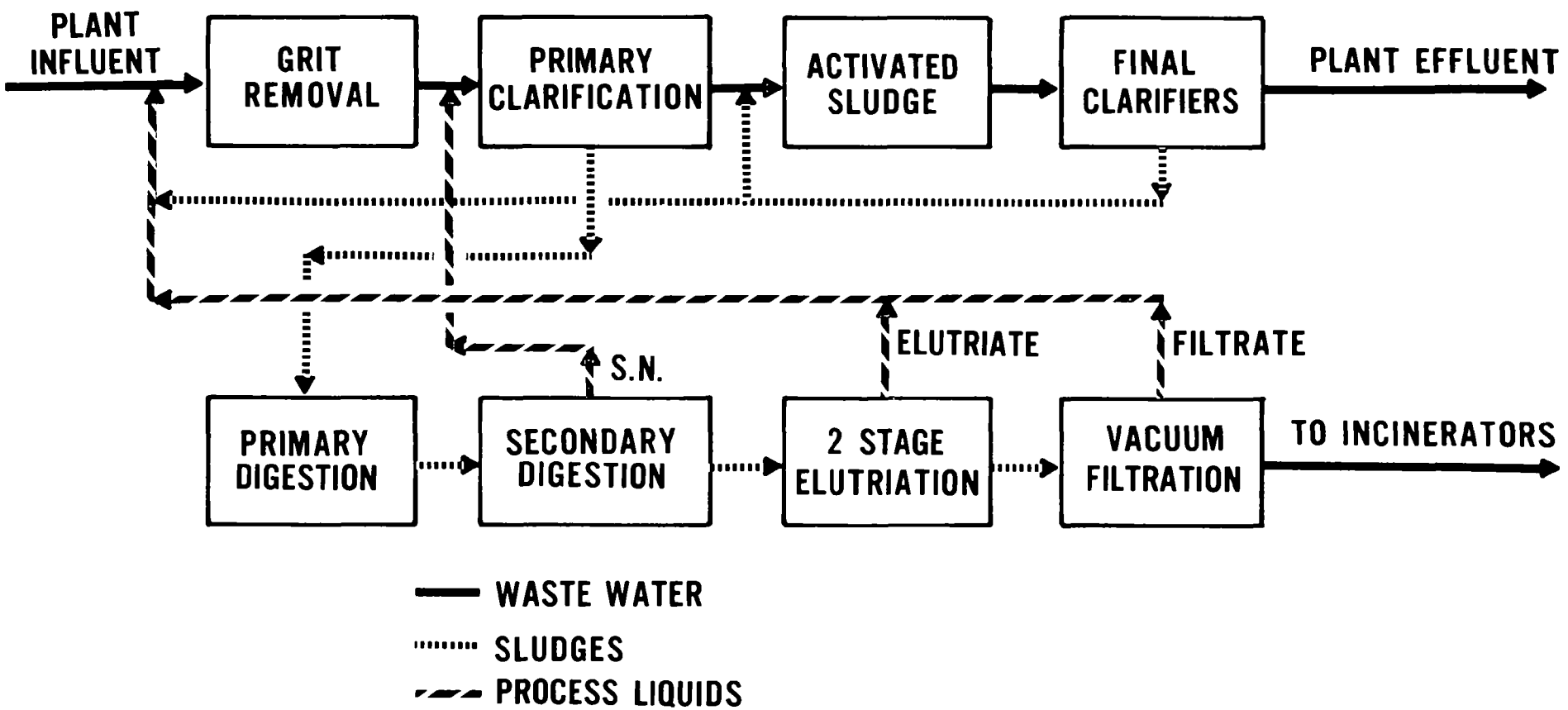


FIGURE 5A-5 PLANT FLOW DIAGRAM – METRO TORONTO

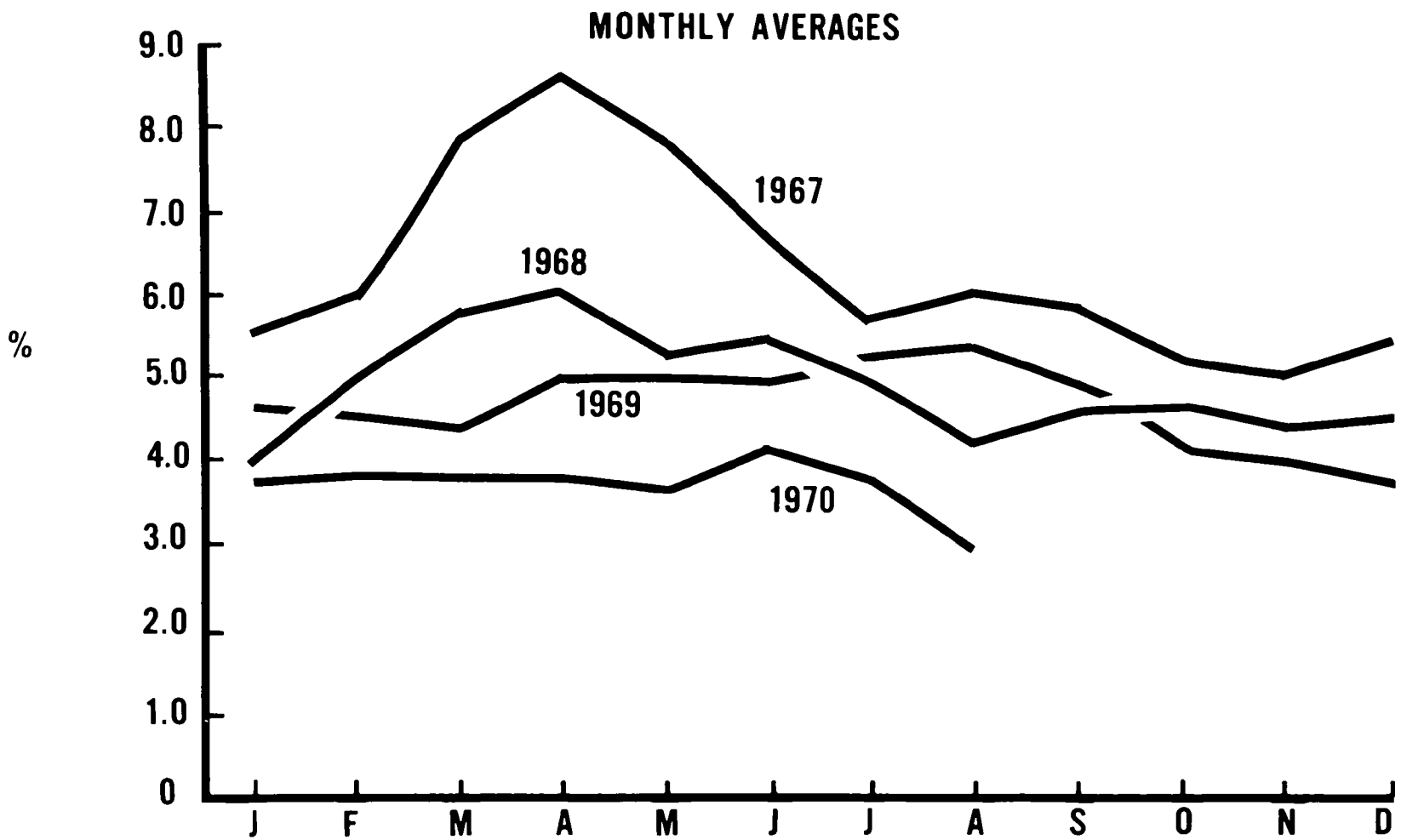


FIGURE 5A-6 PERCENT SOLIDS IN ELUTRIATED SLUDGE – METRO TORONTO

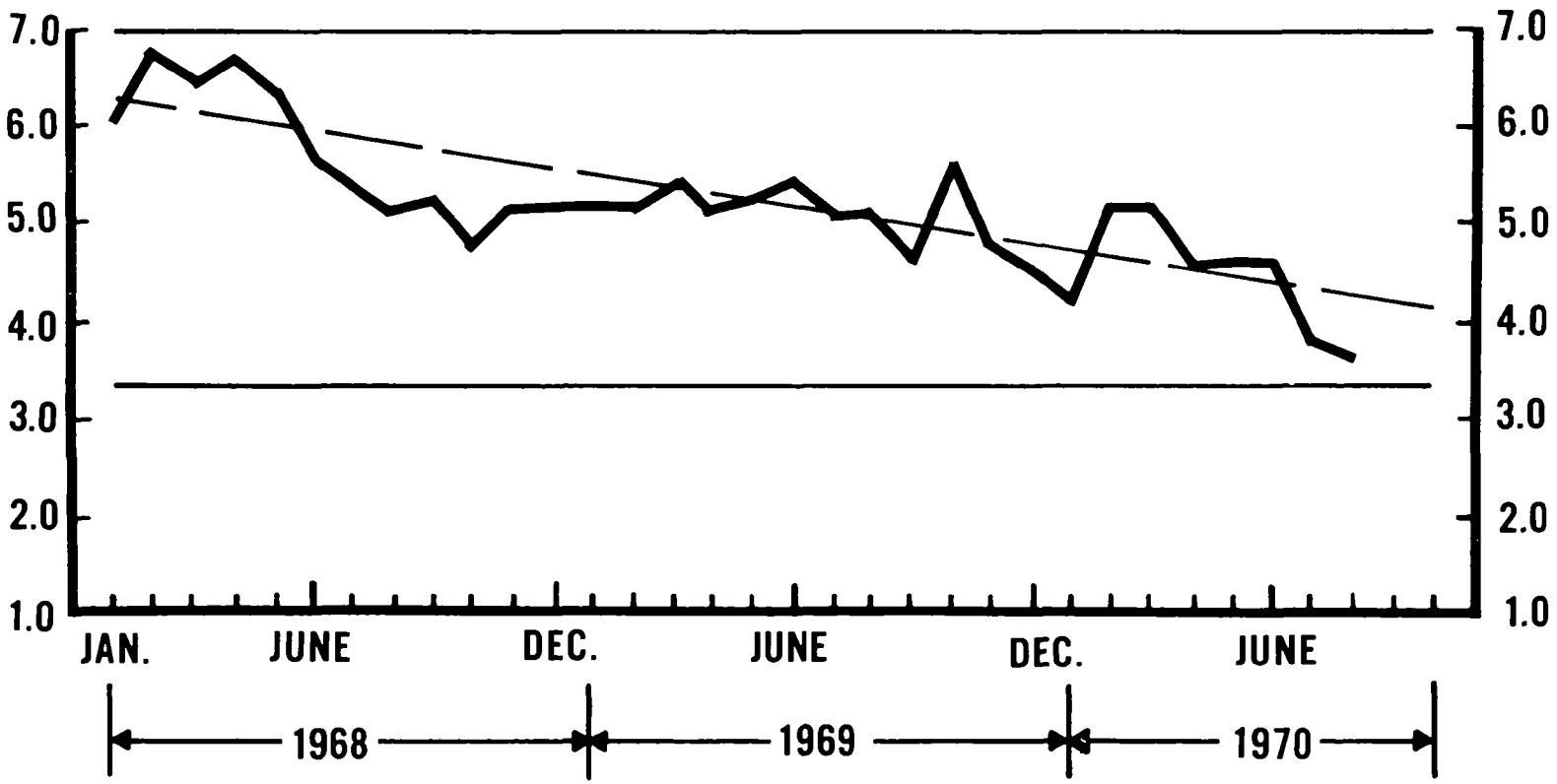


FIGURE 5A-7 PERCENT SOLIDS IN RAW SLUDGE
METRO TORONTO

	OPERABLE 1970	PREFERRED 1970	REQUIRED 1971
DRY TONS/MO.	2000	2500	3000
#/HR./FT.^{2}	3.0	3.7	4.4

TABLE 5A-2 SLUDGE REMOVAL NEEDS – METRO TORONTO

1970 PERIOD	POLYMER USED (#/TON)		SLUDGE SOLIDS (%)	#/HR./FT.^{2}	CAKE SOLIDS (%)
	ELUT.	FILT.			
OCTOBER	1.26	7.77	3.6	4.7	16
NOVEMBER	1.75	8.20	4.1	4.3	16

TABLE 5A-3 ELUTRIATION/FILTRATION RESULTS OCTOBER-NOVEMBER – METRO TORONTO

ELUT. FLOW (MGPD)		POLYMER (#/TON)		ELUTRIATE S.S. (PPM)		SLUDGE SOLIDS (%)	#/HR./FT.^{2}	CAKE SOLIDS (%)
WASH WATER	DIGEST. SLUDGE	ELUT.	FILT.	1ST	2ND			
1.0	0.6	1.94	10.96	120	18	6.1	4.7	16.0
3.5	1.4	0.62	9.34	6250	208	3.5	5.8	15.4

TABLE 5A-4 ELUTRIATION/FILTRATION RESULTS 1971 – METRO TORONTO

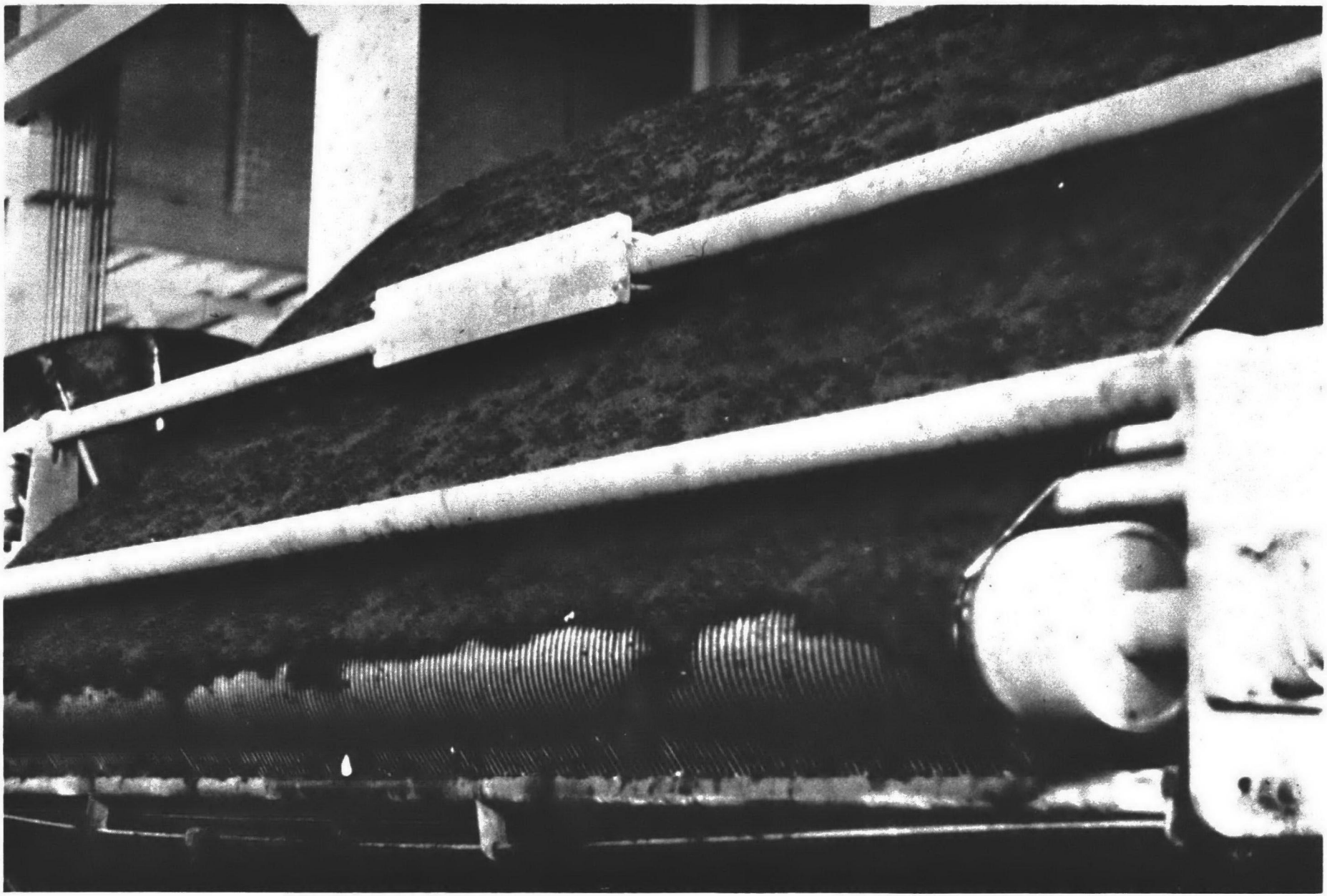


FIGURE 5A-8 A VIEW OF FILTERS – METRO TORONTO

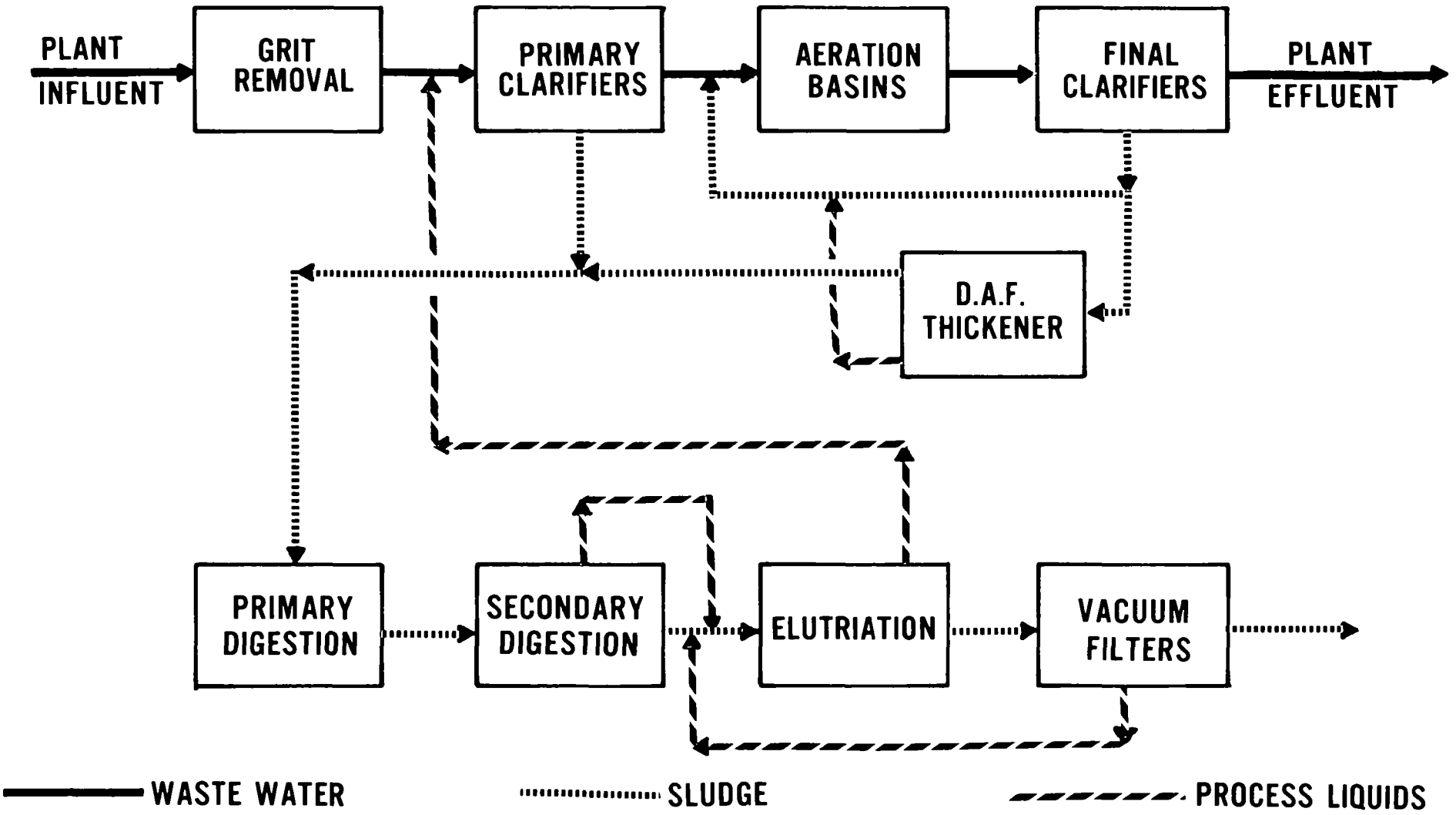


FIGURE 5A-9 PLANT FLOW DIAGRAM – RICHMOND, CALIFORNIA

	PRIMARY SLUDGE	MIXED SLUDGES	
		NO POLYMER	POLYMER IN ELUTRIATION
YIELD (LB./HR./FT.^{2})	7-9	1-2	5-7
CONDITIONER COST ($/TON)	$3.80/$4.00	$25/$30	$11/$14
CAKE SOLIDS (%)	29-31	16-18	20-22

TABLE 5A-5 FILTRATION RESULTS – RICHMOND, CALIFORNIA

	DIGEST SLUDGE % SOLIDS	ELUTRIATE SLUDGE % SOLIDS	POLYMER #/TON	ELUTRIATE SOLIDS PPM
ELUTRIATION	3.85	7.8	2.12	450

	$FeCl_3$ $/TON	LIME $/TON	FILTER CAKE % SOLIDS
FILTRATION	3.00	4.85	20.8

TABLE 5A-6 ELUTRIATION/FILTRATION OPERATIONS – RICHMOND, CALIFORNIA

SECTION 5B – CASE STUDIES – PLANT RESULTS – CHEMICAL CONDITIONING – PRIMARY PLANTS WITH CHEMICAL ADDITION

CASE STUDY – DETROIT

1. Primary plant since 1939 with sludge filtration and incineration

   – One of the early users of polymer for sludge conditioning.

2. Under expansion for secondary treatment

   – Replaced the 12 drum filters with belt filters and individual sludge conditioning tanks for each filter prior to 1970.

   – Started interim chemical treatment to remove 56 percent of the phosphorus in February, 1972.

3. Table 5B-1 shows plant results without and with chemical treatment for P removal.

4. Table 5B-2 shows sludge filtration data without and with chemical treatment for P removal.

CASE STUDY – WAYNE COUNTY, MICHIGAN

1. Primary plant since 1939 with sludge filtration and incineration

2. Under expansion for secondary treatment

   – Plant overloaded.

   – Interim chemical treatment to upgrade treatment and remove phosphorus.

3. Table 5B-3 shows plant removals BOD–SS–P.

4. Table 5B-4 shows sludge filtration data.

CASE STUDY – CLEVELAND WESTERLY

1. Primary plant for over 35 years

   – Primary tanks are Imhoff tanks.

   – Separate sludge digestion.

   – Sludge filtration and incineration.

2. Full plant long-term trial to upgrade treatment and remove phosphorus

   – In preparation for expansion to generate some data.

3. Presently using chemical treatment for interim upgrading of treatment and removing phosphorus

4. Table 5B-5 shows plant removals – BOD–SS–P.

5. Table 5B-6 shows sludge filtration data.

CASE STUDY – EAST LANSING, MICHIGAN

1. Primary treatment with contact stabilization

   – Plant overloaded.

   – Must improve to meet phosphorus removal requirement.

2. Full plant trial to upgrade treatment and remove phosphorus

3. Presently using chemical treatment as proved in plant trial to meet effluent requirements.

4. Table 5B-7 shows plant removals – BOD–SS–P.

5. Table 5B-8 shows sludge filtration data.

CASE STUDY – GRAND RAPIDS, MICHIGAN

1. **Primary treatment with high rate activated sludge**

   - Some plant improvement needed.

   - Must increase phosphorus removal to meet effluent requirement.

2. **Full-scale plant trial to upgrade treatment and remove phosphorus**

   - Many interruptions due to floods, construction, digester failure, and lack of sludge disposal capability.

3. **Longer term study resumed at present.**

4. **Table 5B-9 shows plant removals – BOD–SS–P.**

5. **Table 5B-10 shows sludge filtration data.**

CASE STUDY – TONAWANDA, NEW YORK

1. **Primary plant with sludge filtration and incineration**

   - Overloaded.

   - Need to upgrade to meet phosphorus removal requirement.

2. **Full-scale plant trial to upgrade and remove phosphorus**

3. **Table 5B-11 shows sludge filtration data.**

CASE STUDY – AMHERST, NEW YORK

1. **Primary plant with sludge digestion and sludge filtration**

   – Grossly overloaded.

   – Operations improvement needed to handle overload.

2. **Full-scale trial with chemical treatment**

3. **Interim chemical treatment implemented.**

4. **Table 5B-12 shows sludge filtration data.**

LIST OF FIGURES AND TABLES – SECTION 5B

Table 5B-1	Detroit, Michigan – Primary Treatment with Chemical Addition Plant Results
Table 5B-2	Detroit, Michigan – Primary Treatment with Chemical Addition Raw Sludge Filtration Data
Table 5B-3	Wayne County, Michigan – Primary Treatment with Chemical Addition Plant Results
Table 5B-4	Wayne County, Michigan – Primary Treatment with Chemical Addition Sludge Filtration Data
Table 5B-5	Cleveland Westerly – Primary Treatment with Chemical Addition Plant Results
Table 5B-6	Cleveland Westerly – Primary Treatment with Chemical Addition Sludge Filtration Data
Table 5B-7	East Lansing, Michigan – Primary Treatment with Chemical Addition and Contact Stabilization – Plant Results
Table 5B-8	East Lansing, Michigan – Primary Treatment with Contact Stabilization
Table 5B-9	Grand Rapids, Michigan – Primary Treatment + High Rate Activated Sludge Chemical Addition to Primary – Plant Results
Table 5B-10	Grand Rapids, Michigan – Primary Treatment + High Rate Activated Sludge Chemical Addition to Primary Treatment – Sludge Filtration Data
Table 5B-11	Tonawanda, New York – Primary Plant with Chemical Addition Raw Sludge Filtration Data
Table 5B-12	Amherst, New York – Primary Plant with Chemical Addition Digest Sludge Filtration Data

DETROIT, MICHIGAN

PRIMARY TREATMENT WITH CHEMICAL ADDITION

PLANT RESULTS

CHEMICAL TREATMENT	% REMOVAL		
	BOD	SS	P
NONE	35	55-60	19
10 ppm Fe^{2+} 0.25 ppm Anion Polymer	55-60	70-75	56

TABLE 5B-1

DETROIT, MICHIGAN

PRIMARY TREATMENT WITH CHEMICAL ADDITION

RAW SLUDGE FILTRATION DATA

Chemical Treatment	Filter Yield $lb/ft^2/hour$	Sludge Conditioning	
		Chemical	$/Ton
None	8 - 10	Cation Polymer	1.67
5 ppm Fe^{2+}	8 - 14	Anion Polymer	1.39
10 ppm Fe^{2+} 0.25 ppm Anion Polymer	7 - 10	Anion Polymer	0.90

TABLE 5B-2

WAYNE COUNTY, MICHIGAN

PRIMARY TREATMENT WITH CHEMICAL ADDITION

PLANT RESULTS

CHEMICAL TREATMENT	% REMOVAL		
	BOD	SS	P
None	43	60	19
10 ppm Fe^{2+} 30 ppm NaOH 0.5 ppm Anion Polymer	75	78	71

TABLE 5B-3

WAYNE COUNTY, MICHIGAN

PRIMARY TREATMENT WITH CHEMICAL ADDITION

SLUDGE FILTRATION DATA

TREATMENT	CHEMICAL	$/TON
NONE	CATION POLYMER	< 1.0
20 PPM Fe^{2+} 30 PPM NaOH 0.5 PPM ANION POLYMER	CATION POLYMER	3.0
17 PPM Fe^{3+} 0.7 PPM ANION POLYMER	ANION POLYMER	1.35

TABLE 5B-4

CLEVELAND WESTERLY

PRIMARY TREATMENT WITH CHEMICAL ADDITION

PLANT RESULTS

CHEMICAL TREATMENT	% REMOVAL		
	BOD	SS	P
None	34	33	21
20 ppm Fe^{3+} 0.5 ppm Anion Polymer	53	68	75

TABLE 5B-5

CLEVELAND WESTERLY

PRIMARY TREATMENT WITH CHEMICAL ADDITION

SLUDGE FILTRATION DATA

Chemical Treatment	Raw Sludge % Solids	Chemicals and Dose lb/Ton	Filter Yield $lb/ft^2/hour$
None	4.4	$FeCl_3/CaO$	1.0
20 ppm Fe^{3+} 0.5 ppm Anion Polymer	6.4	1# Anion Polymer + 35# Cation Polymer	6-10

TABLE 5B-6

EAST LANSING, MICHIGAN

PRIMARY TREATMENT WITH CHEMICAL ADDITION
AND CONTACT STABILIZATION

PLANT RESULTS

CHEMICAL TREATMENT	% REMOVAL		
	BOD	SS	P
None	59	45	18
20-25 ppm Fe^{3+} 0.3-0.4 ppm Anion Polymer	78	87	84

TABLE 5B-7

EAST LANSING, MICHIGAN

PRIMARY TREATMENT WITH CONTACT STABILIZATION

Chemical Treatment	Slude Conditioning	
	Chemical	$/Ton
None	Cation Polymer	2.5
25 ppm Fe^{3+} 0.4 ppm Anion Polymer	Cation Polymer	7-11
25 ppm Fe^{3+} 0.4 ppm Anion Polymer	Cation Polymer	4.0

TABLE 5B-8

GRAND RAPIDS, MICHIGAN
PRIMARY TREATMENT + HIGH RATE ACTIVATED SLUDGE
CHEMICAL ADDITION TO PRIMARY

PLANT RESULTS

	% REMOVAL					
	PRIMARY			TOTAL PLANT		
TREATMENT	BOD	SS	P	BOD	SS	P
NONE	20	26	13	74	71	39
17-20 PPM Fe^{3+} 0.3-0.4 PPM ANION POLYMER	47	55	61	79	75	72

TABLE 5B-9

GRAND RAPIDS, MICHIGAN

PRIMARY TREATMENT + HIGH RATE ACTIVATED SLUDGE

CHEMICAL ADDITION TO PRIMARY TREATMENT

SLUDGE FILTRATION DATA

Chemical Treatment	Raw Sludge % Solids	Filter Yield $lb/ft^2/hour$	Sludge Conditioning Chemicals	Sludge Conditioning $/Ton
None	9.0-5.9	9.7-3.9	$FeCl_3/CaO$	4.75 - 8.09
17-20 ppm Fe^{3+} 0.3-0.4 ppm Anion Polymer	10.1-6.2	9.2-3.0	$FeCl_3/CaO$	2.15 - 7.69

TABLE 5B-10

TONAWANDA, NEW YORK

PRIMARY PLANT WITH CHEMICAL ADDITION

RAW SLUDGE FILTRATION DATA

Chemical Treatment	Filter Yield $lb/ft^2/hour$	Sludge Conditioning	
		Chemicals	$/Ton
None	2.5	Nonionic Polymer	0 - 2
25 ppm Fe^{3+} 0.5 ppm Anion Polymer	2.5	Anion + Cation Polymer	3 - 4
25 ppm Fe^{3+} 0.5 ppm Anion Polymer	3.5	Cation Polymer	5 - 6

TABLE 5B-11

AMHERST, NEW YORK

PRIMARY PLANT WITH CHEMICAL ADDITION

DIGEST SLUDGE FILTRATION DATA

Chemical Treatment	Filter Yield $lb/ft^2/hour$	Sludge Conditioning Chemicals	Sludge Conditioning $/Ton
15 ppm Fe^{3+} 0.5 ppm Anion Polymer	~2.0	$FeCl_3/CaO$	10 - 15
15 ppm Fe^{3+} 0.5 ppm Anion Polymer	4.0	Cation Polymer	9

TABLE 5B-12

SECTION 5C –
REMOVAL OF PHOSPHORUS FROM WASTEWATER BY CHEMICAL ADDITION

1. Introduction

- In wastewater treatment the principal new source of sludge solids to be handled is from chemical precipitation processes.

- Need information on the production rates, dewatering characteristics, dewatering methodologies and the costs of treating sludges produced by the addition of chemicals to primary, secondary, and tertiary systems for the removal of phosphorus.

2. Expected Sludge Masses and Volumes with Phosphorus Removal

- Available data is very limited. It is mostly from laboratory and pilot studies.

- A recent review of 13 case histories provided sludge production information on primary, secondary and tertiary phosphorus removal schemes (Reference 1).

  Table 5C-1 shows the additional sludge to be handled when chemicals are added to the primary to remove phosphorus.

  Table 5C-2 shows the additional sludge to be handled when chemicals are added to the secondary to remove phosphorus.

  Table 5C-3 shows the additional sludge to be handled when chemicals are added to the secondary effluent for removing phosphorus.

  Table 5C-4 gives a way of interpreting this data and relating it back to the chemical dose.

- From Table 5C-4

  The greatest increase in sludge mass occurred when aluminum was added to secondary effluent.

  The minimum increase occurred when lime was added at a level of from 800–1,600 mg/l to raw sewage.

  The maximum amount of additional sludge volume to be handled was with iron addition to secondary effluent.

The minimum additional volume was with lime addition to raw sewage.

3. Difficulty in Dewatering these Physical-Chemical Sludges

- Recent work performed at Salt Lake City studied the removal of phosphorus from raw wastewater by adding aluminum, iron or lime (Reference 2). Their data is given in Table 5C-5.

- Dow Chemical Company reports (see References 3, 4, 5, and 6) indicate little change in filtering primary and digested primary sludges containing iron salts, although one case of vacuum filter blinding was reported (Reference 7).

- Some investigators have found a filter yield of 1.0 $lb/ft^2/hr$ for an iron sludge (Reference 8).

- Work done recently at the Chapel Hill, North Carolina 4 mgd primary and high rate trickling filter system (shown in Figure 5C-1) is reported on in Table 5C-6 (Reference 9).

  Alum is added to the trickling filter stream just prior to the final clarifier in the amount of 180 ppm based on liquid alum.

  Thickening tests revealed that sludge with alum thickened at a rate less than 2/3 that of the sludge with no alum.

- Washington, D.C. (alum added to secondary) (Reference 10).

  The Blue Plains Plant in Washington, D.C. will utilize the three-sludge system for wastewater treatment. The plant will comprise primary treatment, high rate activated sludge, nitrification, and denitrification. Aluminum will be added to the high rate activated sludge process for phosphate removal. The Blue Plains Plant has recently started to add alum to their activated sludge plant to start lowering phosphate levels in their effluent. Results from the full-scale plant are not well established at this point. Design information has been collected in experimental runs at the Blue Plains Pilot Plant, operated by Fred Bishop for the District of Columbia and EPA. The data reported below were obtained at the pilot facility.*

---

*Information below has been supplied by Steve Bennett, Blue Plains Pilot Plant.

Thickening

On 1 ft^2 Komline-Sanderson air flotation thickener, alum-activated sludge thickened without polymers to 4.0–6.1 percent solids (inlet solids =circa 1.3 percent solids, solids loading = circa 2 lb/ft^2-hr). Underflow concentration < 500 mg/l. Large scale units might need polymers.

Gravity thickening of alum-activated sludge produced 5–7 percent solids. Prediction from thickening data indicate 4.5 percent underflow concentration at a solids loading of 7 lb/ft^2/day.

Primary + alum-activated sludge settled to 16-18 percent solids over a 24-hour period. Thickening curves indicated that at a solids loading of 57 lb/ft^2-day, underflow concentration of 10 percent would result.

Dewatering

Results were obtained on a pilot rotary vacuum filter (Eimco 3 ft diam. x 1 ft face, belt-type), a Sharples 6-inch diameter solids bowl centrifuge (Model P600), and a pressure filter with 1 ft x 1 ft plates (Nichols).

Solids concentrations and chemical costs are shown in Table 5C-7, and production rates are shown in Table 5C-8. Alum-activated and primary + alum-activated sludge show filter yields very similar to activated and primary + activated sludges. The moisture content of the primary + alum-activated seems lower than would be expected for a primary + activated sludge. The ratio of alum secondary to primary sludge was 1.5 to 1 (dry weight basis) for these tests.

Full-Scale Plant

The full-scale plant has been introducing alum into the secondary by steps. Level is now at 80 mg/l. Filter yields on mixed digested sludge have not changed. However, solids content has dropped from circa 24 percent to circa 19 percent. Costs of conditioning chemicals for elutriation have increased.

4. Contra Costa* – Case Study (Reference 11)

   – The Contra Costa County Sanitary District has an agreement to supply renovated water to the CCC Water District for industrial uses. A 30 mgd plant will be constructed.

---

* Information was supplied by Dr. Denny Parker of Brown and Caldwell.

- The CCCSD will treat the wastewater by the ATTF system (Advanced Treatment Test Facility). It comprises lime coagulation-sedimentation, nitrification, and denitrification. The ATTF system is shown in Figure 5C-2. As noted in the diagram, biological sludges are returned to the primary and are removed with the primary sludge. The use of lime in the primary removes much of the organic carbon load from the oxidation-nitrification stage, thus allowing stable oxidation of ammonia to nitrate. In addition to removal of organic matter, the lime enhances the removal of phosphates, heavy metals, and pathogenic bacteria.

- The system performed satisfactorily at pH's of 10.2, 11.0 and 11.5. Most of the effort was concentrated on pH 11.0. At this pH, a supplemental dose of ferric chloride was needed to bring the P-level in the primary effluent to below 1.0 mg/l.

- Interpretation of data is complicated somewhat by the seasonal impact of food processing wastes from a cannery. Sludge solids concentrations from the primary clarifier are summarized as follows:

pH	10.2	11.0
Solids Content (Wt. %)	$\leqslant$ 4.5 With polymer (ICI Atlasep 3A3), 6.0	5.0 (up to 9.0, but handling problems at 7.0 in pilot plant) Cannery operating, $\leqslant$4.5

- CCCSD has received a State Water Resources Control Board and EPA R,D,&D grant to document results of tests on their solids processing system. A report will probably be available in a few months.

- The solids processing system being designed and tested is shown in Figure 5C-3. A two-stage centrifuge system is used to classify sludge into a fraction (cake) containing most of the lime, and a fraction (centrate) containing most of the organics, magnesium, and phosphate. The system is nearly the same as utilized at Lake Tahoe, but the feed is a primary-lime sludge, whereas at Tahoe, the sludge is a tertiary-lime sludge. The following summarizes conditions and results:

  First centrifuge:

  Machine operates at low g (circa 1,600), high throughput, and no polymer. Cake contains 80 percent of the $CaCO_3$, 30–40 percent of the organics, 10–20 percent of the phosphate, and 40 percent of the magnesium. Cake solids 50 percent.

Second centrifuge:

Machine operates at high g (circa 2,000). Little wear because there is no grit. Polymer is needed. Cake is wet, circa 13–19 percent solids.

- Lime is regenerated by incineration and calcination of first centrifuge cake. This lime, along with makeup, is used as the lime charge to the primary clarifier. Of the solids appearing in the underflow from the primary clarifier, approximately 22 percent is estimated to be recycled inerts.

- For more information, refer to "Full-Scale Testing of a Water Reclamation System," by G.A. Horstkotte (CCCSD), D.G. Niles (CCCSD), D.S. Parker (Brown and Caldwell), and D.H. Caldwell (Brown and Caldwell), presented at the 45th Annual Conference, WPCF, Atlanta, October, 1972.

REFERENCES – SECTION 5C

1. Adrian, D.D., and Smith, J.E., Jr., "Dewatering Physical-Chemical Sludges." Conference on Application of New Concepts of Physical-Chemical Wastewater Treatment, Vanderbilt University, September 18-22, 1972.

2. Burns, D.E., and Shell, G.L., "Physical Chemical Treatment of a Municipal Wastewater Using Powdered Carbon." Water Pollution Control Research Series 17020 EFB, Government Printing Office, Washington, D.C., 57 (1972).

3. Avon, "Application of Chemical Precipitation, Phosphorus Removal at the Cleveland Westerly Wastewater Treatment Plant." Dow Chemical Company, Midland, Michigan, April,1970.

4. Cherry, A.L., and Schuessler, R.G., "Private Company Improves Municipal Waste Facility." *Water and Wastes Engineering*, 8, 32 (1971).

5. Avon, "Phosphorus Removal Trial, Ford du Lac, Wisconsin." Dow Chemical Company, Michigan, July,1971.

6. Hennessey, J., Jelinski, R., Beeghly, J.H., and Pawlak, T.J., "Phosphorus Removal at Pontiac, Michigan." Presented at the Michigan State Water Pollution Control Association Meeting, Bryne Mountain, Michigan, June, 1970.

7. Stonebrook, W.J., Dykhuzen, V., Beeghly, J.H., and Pawlak, T.J., "Phosphorus Removal at a Trickling Filter Plant, Wyoming, Michigan." Dow Chemical Company, Midland, Michigan, 1971.

8. Farrell, J.B., Smith, J.E., Jr., Hathaway, S.W., and Dean, R.B., "Lime Stabilization of Chemical-Primary Sludges at 1.15 mgd." 45th Annual Conference, Water Pollution Control Federation, Atlanta, Georgia, October, 1972.

9. Hathaway, S.W., Personal communication, October,1972.

10. Bennett, S., Personal communication, Blue Plains Pilot Plant, Washington, D.C., October, 1972.

11. Horstkotte, G.A., Niles, D.G., Parker, D.S., and Caldwell, D.H., "Full-Scale Testing of a Water Reclamation System." Presented at 45th Annual Conference, Water Pollution Control Federation, Atlanta, Georgia, October,1972.

LIST OF FIGURES AND TABLES – SECTION 5C

Table 5C-1	Additional Sludge to be Handled with Chemical Treatment Systems Primary Treatment for Removal of Phosphorus
Table 5C-2	Additional Sludge to be Handled with Chemical Treatment Systems: Phosphorus Removal by Mineral Addition to Aerator
Table 5C-3	Additional Sludge to be Handled with Chemical Treatment Systems: Phosphorus Removal by Mineral Addition to Secondary Effluent
Table 5C-4	Additional Sludge to be Handled with Chemical Treatment Systems. Primary Treatment for Removal of Phosphorus
Table 5C-5	Vacuum Filtration Leaf Tests for Salt Lake City Raw Wastewater
Figure 5C-1	Schematic Representation of Chapel Hill Plant
Table 5C-6	Field Test Results at Chapel Hill
Table 5C-7	Cake Solids and Chemical Cost
Table 5C-8	Loadings
Figure 5C-2	ATTF System
Figure 5C-3	ATTF Solids Processing System

TABLE 5C-1

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS: PRIMARY TREATMENT FOR REMOVAL OF PHOSPHORUS

Sludge Production Parameter		Conventional Primary	Lime Addition to Primary Influent	Lime Addition to Primary Influent	Aluminum Addition to Primary Influent	Iron Addition to Primary Influent
Level of Chemical Addition (mg/l)		0	350–500	800–1,600	13–22.7	25.80
Percent Sludge Solids	Mean	5.25	11.1	4.4	1.2	2.25
	Range	5.0–5.5	3.0–19.5	2.1–5.5	0.4–2.0	1.0–4.5
lb/mg	Mean	788	5,630	9,567	1,323	2,775
	Range	600–950	2,500–8,000	4,700–15,000	1,200–1,545	1,400–4,500
gal/mg	Mean	4,465	8,924	28,254	23,000	21,922
	Range	3,600–5,000	4,663–18,000	16,787–38,000	10,000–36,000	9,000–38,000

TABLE 5C-2

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS: PHOSPHORUS REMOVAL BY MINERAL ADDITION TO AERATOR

Sludge Production Parameter		Al^{+++} Addition to Aerator		Fe^{+++} Addition to Aerator	
		Conventional Secondary	With Al^{+++} Addition	Conventional Secondary	With Fe^{+++} Addition
Level of Chemical Addition (mg/l)		0	9.4–23	0	10–30
Percent Sludge Solids	Mean	0.91	1.12	1.2	1.3
	Range	0.58–1.4	0.75–2.0	1.0–1.4	1.0–2.2
lb/mg	Mean	672	1,180	1,059	1,705
	Range	384-820	744–1,462	918–1,200	1,100–2,035
gal/mg	Mean	9,100	13,477	10,650	18,650
	Range	7,250–12,300	7,360–20,000	10,300–11,000	6,000–24,000

TABLE 5C-3

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS: PHOSPHORUS REMOVAL BY MINERAL ADDITION TO SECONDARY EFFLUENT

Sludge Production Parameters		Lime Addition	Alum Addition	Iron Addition
Level of Chemical Addition (mg/l)		268–450	16	10–30
Percent Sludge Solids	Mean	1.1	2.0	0.29
	Range	0.6–1.72	–	–
lb/mg	Mean	4,650	2,000	507
	Range	3,100–6,800	–	175–781
gal/mg	Mean	53,400	12,000	22,066
	Range	50,000–63,000	–	6,000–36,000

TABLE 5C-4

ADDITIONAL SLUDGE TO BE HANDLED WITH CHEMICAL TREATMENT SYSTEMS

Chemical Added	Level of Addition (mg/l)	Lb. Additional Sludge Solids/lb Chemical	Gal. Additional Sludge/lb Chemical
	Primary Treatment for Removal of Phosphorus		
Lime	350–500	1.4	1.3
Lime	800–1,600	0.9	2.4
Aluminum – Al^{+++}	13–22.7	3.6	125
Iron–Fe^{+++}	25–80	4.5	40
	Phosphorus Removal by Mineral Addition to Aerator		
Al	9.4–23	3.8	32
Fe	10–30	3.9	48
	Phosphorus Removal by Mineral Addition to Secondary Effluent		
Lime	268–450	1.6	18
Al	16	15	90
Fe	10–30	3.0	132

TABLE 5C-5

VACUUM FILTRATION LEAF TESTS FOR
SALT LAKE CITY RAW WASTEWATER

Chemical Treatment	Test	Feed Solids (percent)	Cycle Time min.	Filter Yield lb/hr-ft^2	Cake Solids (percent)
$FeCl_3$ + Polymer	A1	2.5	16	0.37	15
$FeCl_3$ + Polymer	A2	3.3	20	0.32	17
$FeCl_3$ + Polymer	A3	1.6	25	0.27	20
$FeCl_3$ + Polymer + 24% $Ca(OH)_2$	A4	1.6	5	1.0	18
$FeCl_3$ + Polymer + 47% $Ca(OH)_2$	A5	1.6	5.3	1.0	17
$Al(SO_4)_3 \cdot 14H_2O$ + .43% Anionic polymer	B1	0.70	8	0.38	15
$Al_2(SO_4)_3 \cdot 14H_2O$ + 0.70% Cationic polymer	B2	0.36	23	0.14	23
$Ca(OH)_2$	C1	17.9	1.8	12.8	33
$Ca(OH)_2$	C2	9.4	3.0	4.5	28

[1] Series A tests were for ferric chloride doses of 95-145 mg/l and 0-1.5 mg/l polymer. Series B tests were for alum doses of 143 mg/l. All filter yields were for 33 percent submergence, a 3/16 inch cake, a 20 in Hg vacuum and a 0.8 scale-up factor.

SCHEMATIC REPRESENTATION OF CHAPEL HILL PLANT

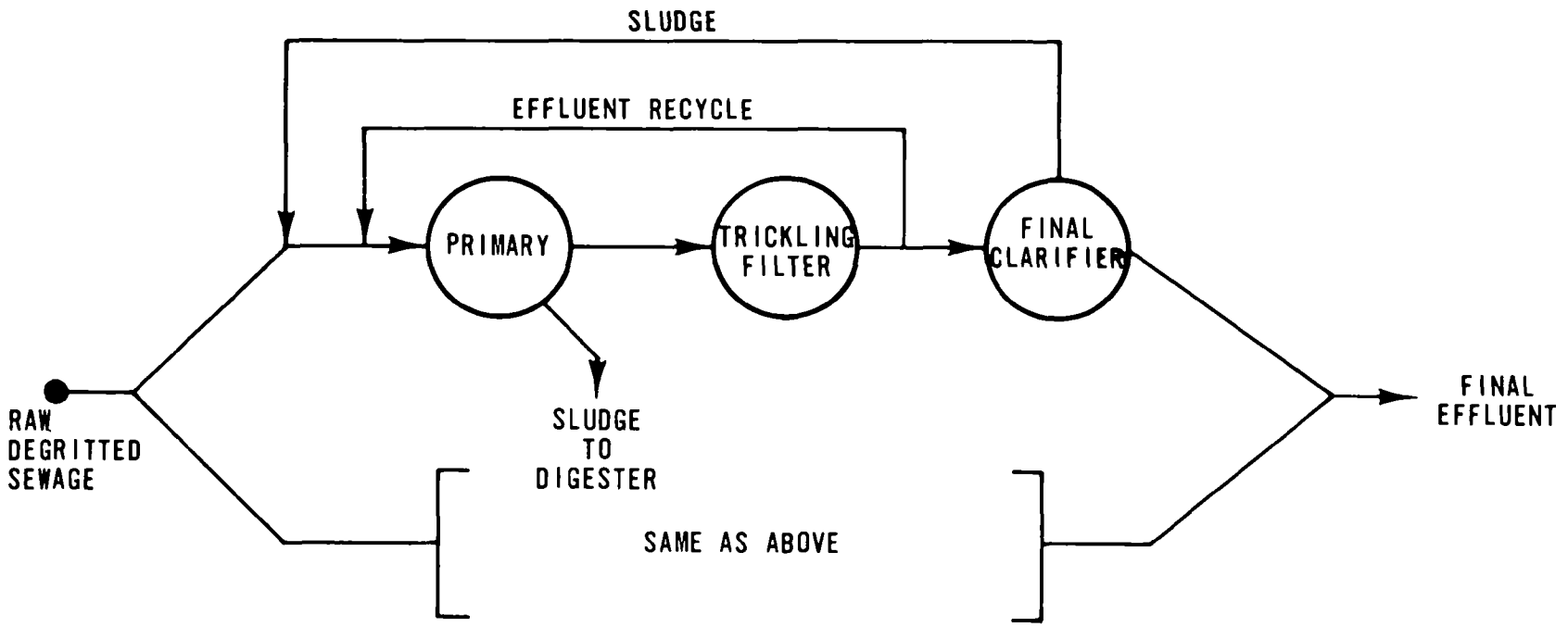


FIGURE 5C - 1

TABLE 5C-6

FIELD TEST RESULTS AT CHAPEL HILL[1]

Type of Sludge	Solids Content (g/l)	r′ x 10" (at 15 Hg) (cm/g)	Filter Yield (lb/hr/ft^2)	Cycle Time Min.	Polymer	
					Type	Dose (lb/ton)
TF	20.6	1.58	2.1	2	WT-2660	19
TF-A	7.7	47.0	Not Filterable	–	837A	–
P-TF	39.0	8.38	2.9	4	WT-2660	10
P-TF-A	30.0	2.55	3.6	2	WT-2660	10

[1] Personal communication with S. Hathaway

TABLE 5C-7

CAKE SOLIDS AND CHEMICAL COST

	Vacuum Filter		Leaf Test		Centrifuge		Filter Press	
	Cake Solids (percent)	Chemical Cost (dollars/ton d.s.)	Cake Solids (percent)	Chemical Cost (dollars/ton d.s.)	Cake Solids (percent)	Chemical Cost (dollars/ton d.s.)	Cake Solids (percent)	Chemical Cost (dollars/ton d.s.)
Alum	14–15	10–11	11–14	9	9–12	0.50–1.25	30–31	8–10
Alum–Primary	20–23	7–14	20–22	9–13	16–18	3–6	33–34	8–9
IPC Low Lime	28–29	none	27–31	none	23–29	1.0–4.5	45–47	none
Ferric–Primary	21–23	5–11	20–22	–	–	–	–	–

TABLE 5C-8

LOADINGS

	Vacuum Filter Yield, psf/day	Leaf Test Yield	Centrifuge tons/day	Filter Press 16 d.s./ft^3 –day[1]
Alum	4–6[2] (3.6–4.7)[4]	2.5–3.0[3]	.38–.57	150–175
Alum–Primary	4–6	3–4	20–30	150–170
Ferric–Primary	2–6	3.6	–	–
IPC Low Lime	1.8–3.0	1.6–2.5	85–115	210–310

[1] Chemical weight included
[2] Includes weight of chemicals
[3] Four minute cycle time, 25 percent submergence
[4] Estimate value after subtracting weight of flocculants

ATTF SYSTEM

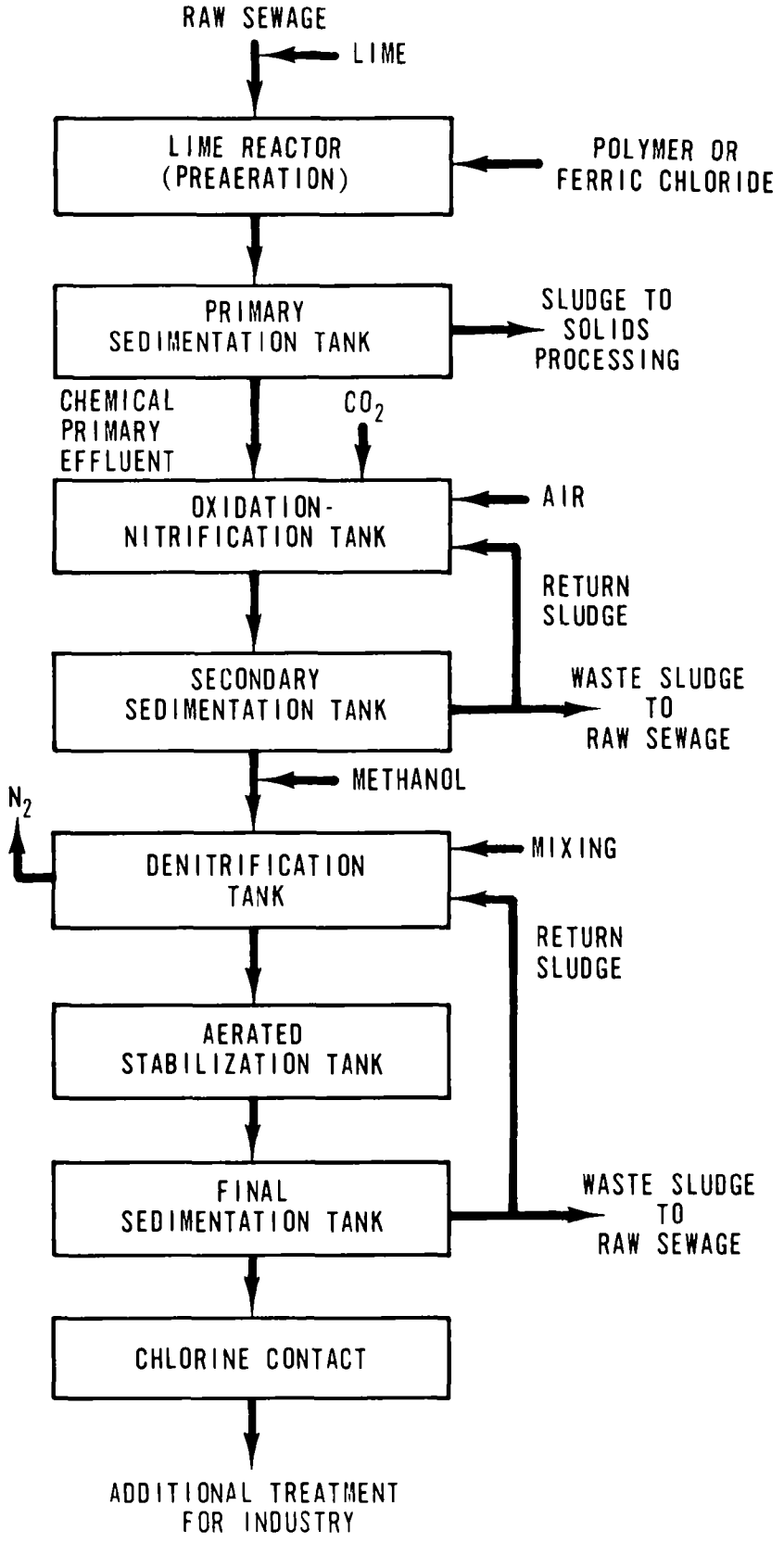


FIGURE 5C - 2

ATTF SOLIDS PROCESSING SYSTEM

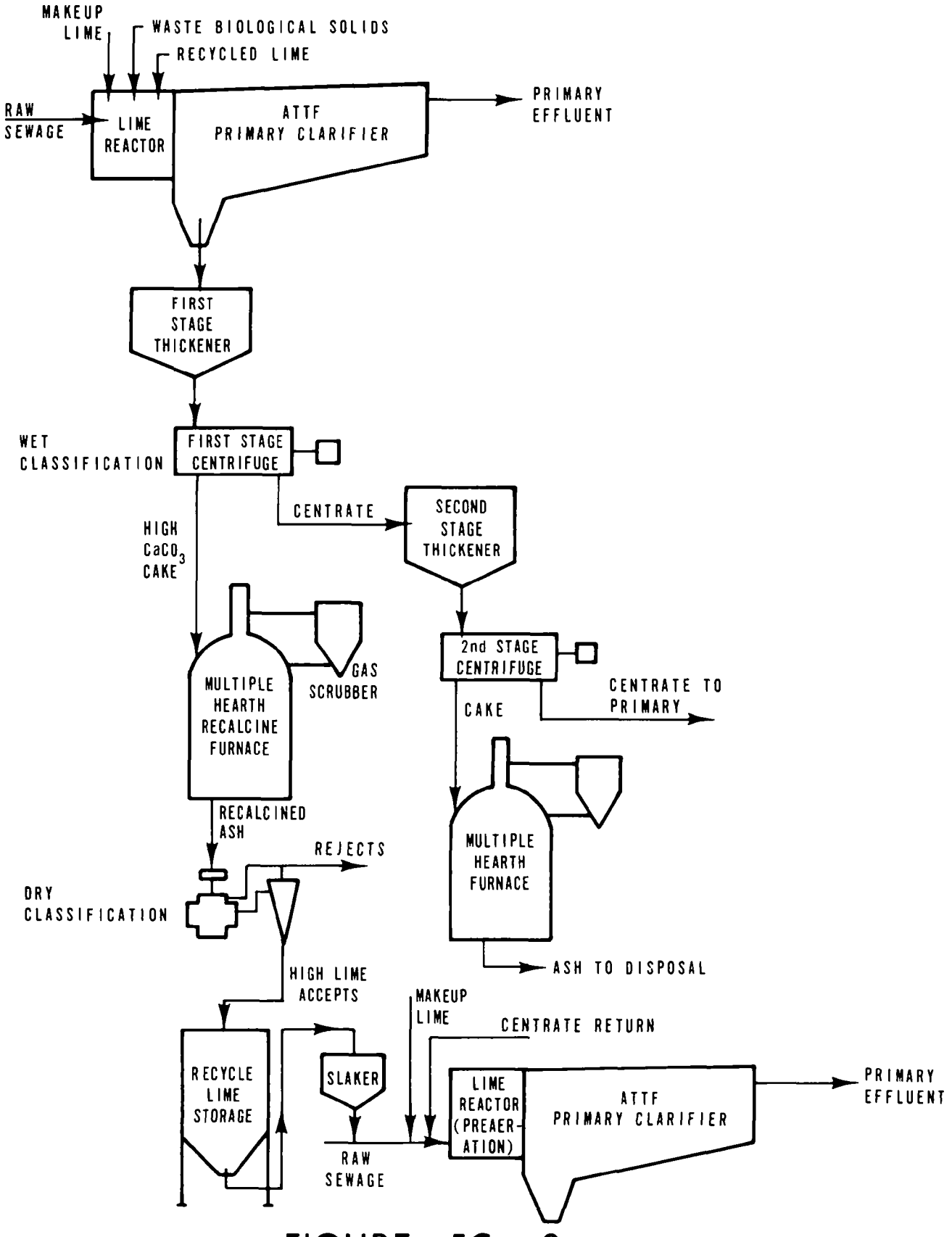


FIGURE 5C - 3

SECTION 6A – OXYGEN ACTIVATED SLUDGE PROCESS

1. Significant Process Development

   – Engineering innovations

     Production and cost of oxygen.
     Application of oxygen within system.

   – Two major suppliers

     Union Carbide - Unox system.
     Air Products and Chemicals - Oases system.

   – Many pilot plants and several full scale plants

   – Overriding Importance

     Improvement in sludge handling and disposal processes and costs.

   – Through documentation, both suppliers and TTP. Note reference list - only broad generalities here.

2. Basic Process Nature
   (Figure 6A-1)

   – Utilization of pure oxygen in place of air in activated sludge basins

   – Higher oxygen transfer driving force (more totally aerobic conditions)

   – Higher mixed liquor solids inventory

   – Lower production of excess activated sludge

3. Oxygen Activated Sludge Aeration Basins

   – (Figure 6A-2) – Sparger type oxygen injection system (low pressure) Note gas recirculation compressors 90 percent oxygen efficiency.

   – (Figure 6A-3) – Surface aerator type oxygen system - Power requirements for dissolution = 1/5 – 1/6 of that for air systems.

4. Oxygen Availability

   - Generation = 2 systems
     Cryogenic
     Pressure Swing Adsorption

   - Liquid (for small plants)

5. Oxygen Process Characteristics
   (Figure 6A-4)

   - Concurrent gas flow

   - High D.O. levels - all stages

   - System pressure 2/4 inches

   - Resistance to shock loads

6. Reasons for Process Effectiveness
   (Figure 6A-5)

   - Oxygen utilization efficiency - $90^{+}\%$

   - Power requirements - low

   - Improved sludge characteristics

7. Comparison of Design Conditions
   (Figure 6A-6)

   - Most important for purposes of this seminar.

     Recycle sludge concentration - 2/4 percent vs. 0.5/1.5 percent Sludge Volume Index.

8. Summary Design Data – Oxygenation Tanks
   (Figure 6A-7)

   - Comparison of design figures for Carbide and results of Metcalf and Eddy study and design - Middlesex City.
     (References 5 and 7)

   - Seem to be comparable - tank sizing a little low in Middlesex County.

9. Middlesex County Costs Forecast
(Figure 6A-8)

- Large municipal/industrial plant.

- Most speculative portion = sludge processing and disposal costs. Wonder what detailed design shows.

- In any event, impressive.

10. Detroit Costs Forecast
(Figure 6A-9)

- Billion gallon/day plant with several modules.

- Side by side oxygen and air aeration modules.

- Impressive forecast.

11. Plants Constructed, Under Construction or Publicly Announced Design Phase
(Figure 6A-10)

- An impressive total (35).

- Many more in consideration or bidding phase.

12. Estimated New Plant Total Treatment Costs, Air Aeration and Oxygen Activated Sludge
(Figure 6A-11)

- From Reference 17, an excellent summation by Stamberg of EPA.

- Once again, how much is due to solids handling savings?

13. Typical Plant Installation
(Figure 6A-12)

- Compact, relatively simple plant.

- Full scale operations with regular plant personnel have been demonstrated.

LIST OF FIGURES AND TABLES – SECTION 6A

Figure 6A-1	Oxygen Process Flow Sheet
Figure 6A-2	Schematic Diagram of Oxygen System with Rotating Sparger
Figure 6A-3	Schematic Diagram of Oxygen System with Surface Aerator
Figure 6A-4	Oxygen Process Characteristics
Figure 6A-5	Reasons for "Cost Effectiveness" of the Oxygen System
Figure 6A-6	Comparison of Process Design and Performance Parameters
Figure 6A-7	Design Data – Oxygenation Tanks
Figure 6A-8	Middlesex County Costs
Figure 6A-9	Detroit Costs
Figure 6A-10	Oxygen Activated Sludge
Figure 6A-11	Estimated Costs Comparison – Air Aeration and Oxygen Aeration
Figure 6A-12	Typical Plant Photograph

OXYGEN PROCESS FLOW SHEET

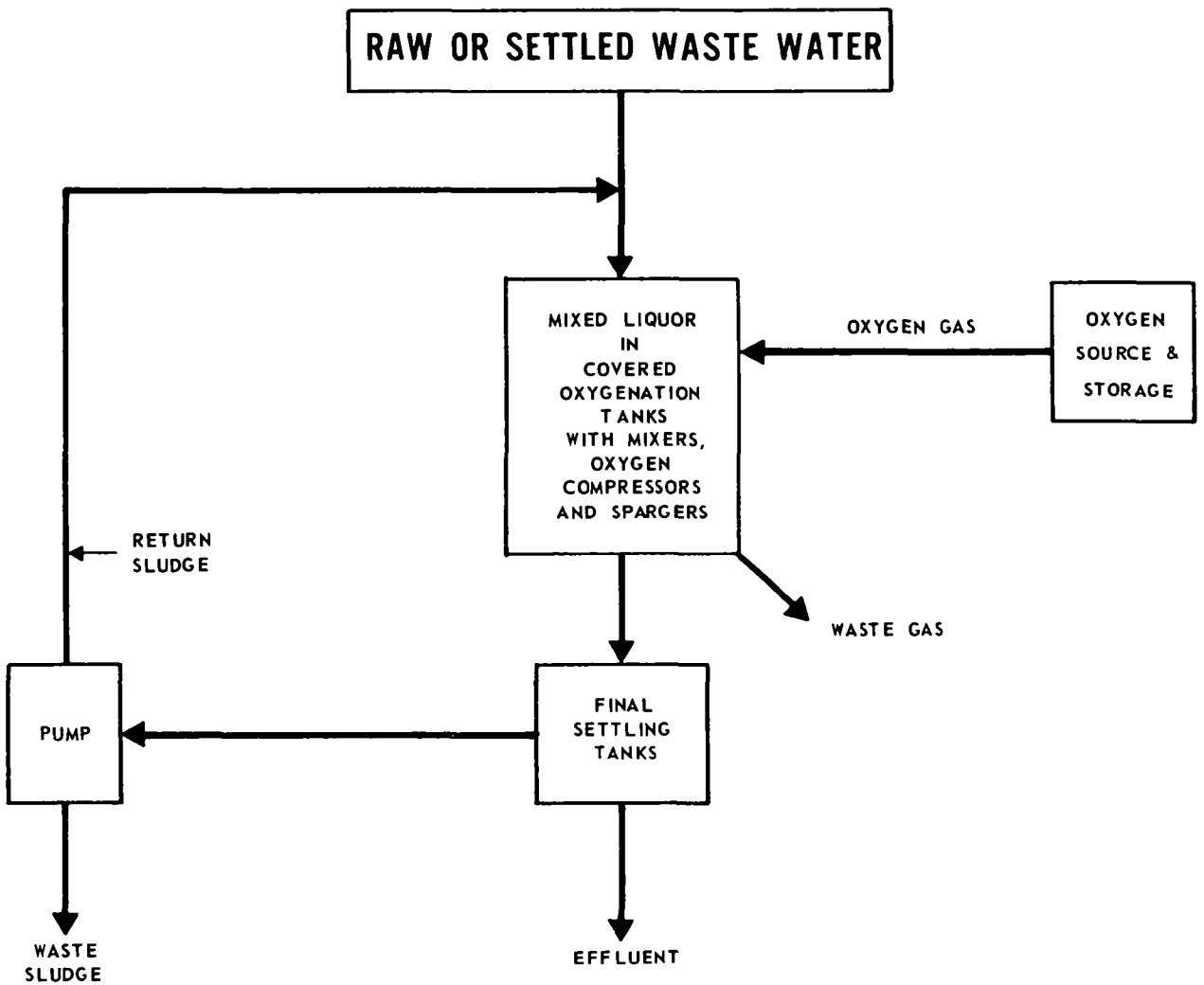


FIGURE 6A-1

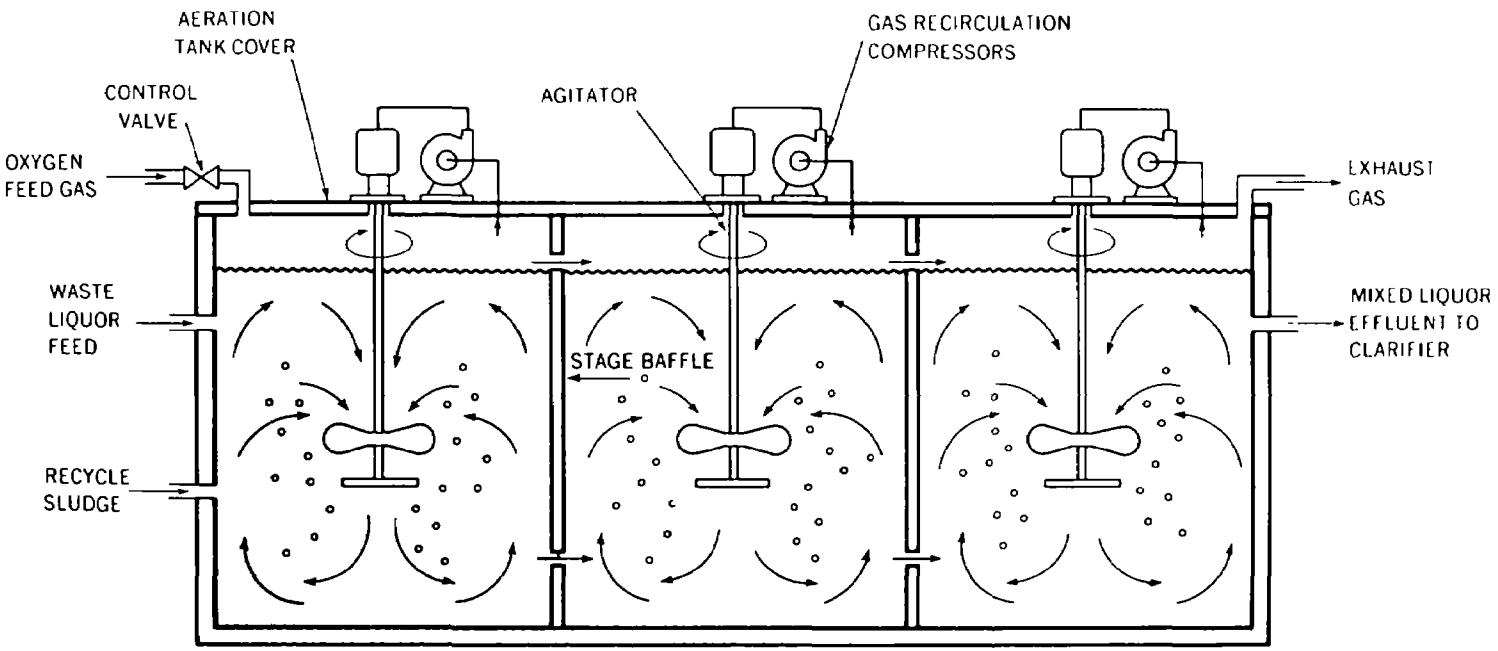


FIGURE 6A-2 SCHEMATIC DIAGRAM OF OXYGEN SYSTEM WITH ROTATING SPARGER

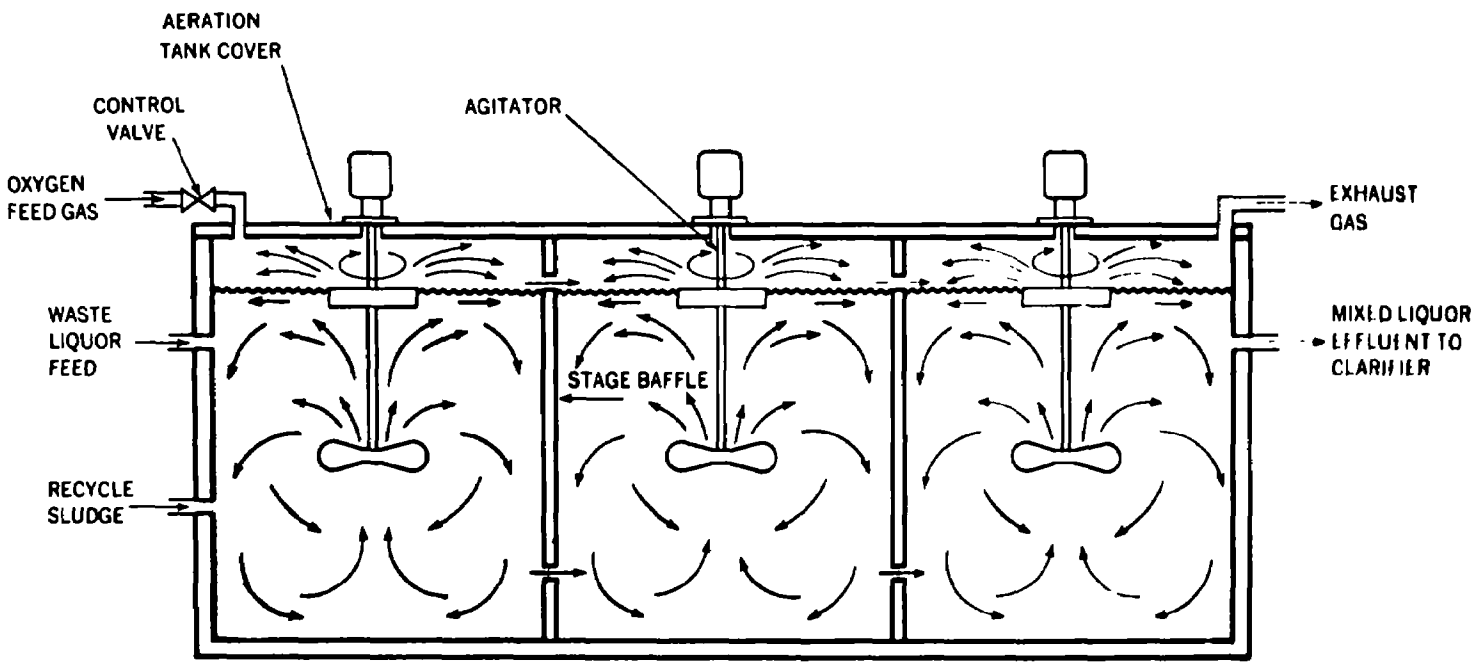


FIGURE 6A-3 SCHEMATIC DIAGRAM OF OXYGEN SYSTEM WITH SURFACE AERATOR

OXYGEN PROCESS CHARACTERISTICS

COCURRENT GAS-LIQUID FLOW

HIGH D.O. LEVELS IN ALL STAGES

LOW SYSTEM PRESSURE (2-4 INCH W.G.)

LOW WASTE GAS VOLUME

HIGHLY AEROBIC WASTE GAS

OXYGEN DISSOLUTION DRIVING FORCE AND STAGE UPTAKE DEMAND ARE MATCHED

HIGH MLVSS - SHORT DETENTION

AUTOMATIC OXYGEN FEED CONTROL

RESISTANCE TO SHOCK LOADS

FIGURE 6A-4

REASONS FOR "COST EFFECTIVENESS" OF THE OXYGEN SYSTEM

HIGH PURITY OXYGEN IS GENERATED ON-SITE ECONOMICALLY IN ALL PLANT SIZES

OXYGEN UTILIZATION GREATER THAN 90 % IS TYPICAL

POWER REQUIREMENTS FOR OXYGEN DISSOLUTION ARE EXTREMELY LOW

MIXING POWER INPUT CAN BE OPTIMIZED

REDUCED WASTE ACTIVATED SLUDGE PRODUCTION IS EXPERIENCED

DEWATERING AND HANDLING CHARACTERISTICS OF WASTE SLUDGE ARE UNIQUE

HIGH RATE TREATMENT IS EASILY ACHIEVED

FIGURE 6A-5

COMPARISON OF PROCESS DESIGN AND PERFORMANCE PARAMETERS

	"UNOX" SYSTEM	CONVENTIONAL AIR SYSTEMS
1. D.O. LEVEL (mg/l)	6-10	1-2
2. DETENTION TIME (hrs)	1-2	3-6
3. MLSS CONC. (mg/l)	6,000-10,000	1,500-4000
4. VOLUMETRIC ORGANIC LOADING (lbs BOD/DAY/1,000 ft^3)	150-250	30-60
5 F/m RATIO (lbs BOD/DAY/lb MLVSS)	0.4-0.8	0.3-0.6
6. RECYCLE SLUDGE RATIO	0.2-0.5	0.3-1.0
7. RECYCLE SLUDGE CONC. (ms/l)	20,000-40,000	5,000-15,000
8. SLUDGE PRODUCTION (lbs VSS/lb BOD REMOVED)	0.3-0.45	0.5-0.75
9. SVI	30-50	100-150

FIGURE 6A-6

DESIGN DATA-OXYGENATION TANKS

	MIDDLESEX CTY.	SUMMARY
MIXED LIQUOR D.O.	3–9 MG/L	8–10 MG/L
MIXED LIQUOR SUSP. SOLIDS	5500 MG/L	6–10,000 MG/L
MIXED LIQUOR V.S.S.	5000 MG/L	4–6500 MG/L
FOOD BIOMASS RATIO	0.51	0.4–0.8
TANK SIZING–(# BOD/K Cu. Ft.)	160	215 +

FIGURE 6A-7

MIDDLESEX COUNTY COSTS

	OXYGEN PROCESS	AIR AERATION
CAPITAL	83,580,000	104,020,000
OPERATING/YEAR	7,390,000	8,290,000

FIGURE 6A-8

DETROIT COSTS

	OXYGEN PROCESS	AIR AERATION
CAPITAL	39,500,000	51,700,000
OPERATING YEAR	1,599,000	1,911,000

FIGURE 6A-9

OXYGEN ACTIVATED SLUDGE

STATES	NO. OF PLANTS	FLOW TOTAL - MGD
FLORIDA	4	171
PENNSYLVANIA	3	370
N. YORK/N. JERSEY	3	144
MICHIGAN/OHIO	3	422
OTHERS	22	779
TOTAL	35	1886

FIGURE 6A-10

ESTIMATED COSTS COMPARISON— AIR AERATION AND OXYGEN AERATION

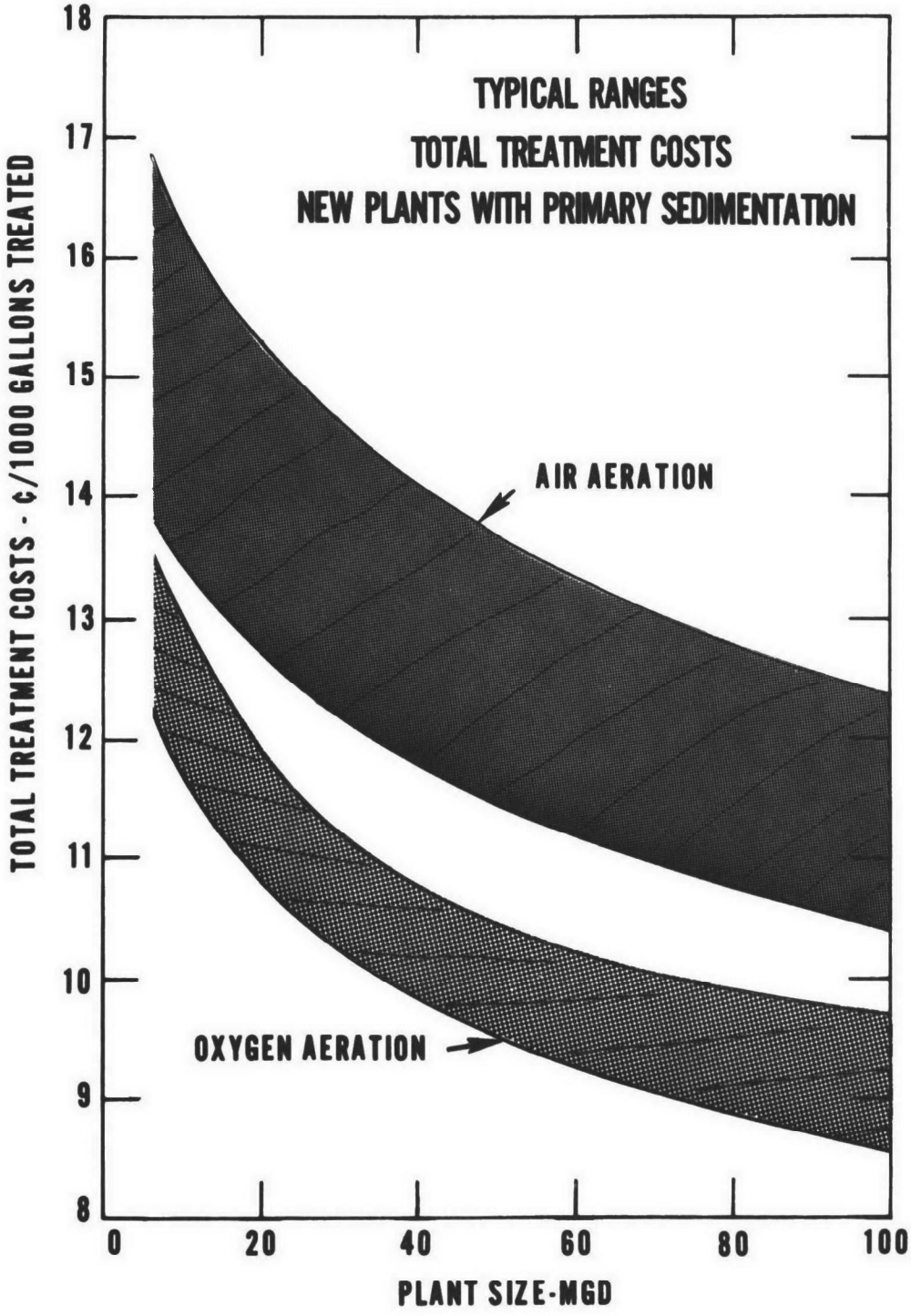


FIGURE 6A-11

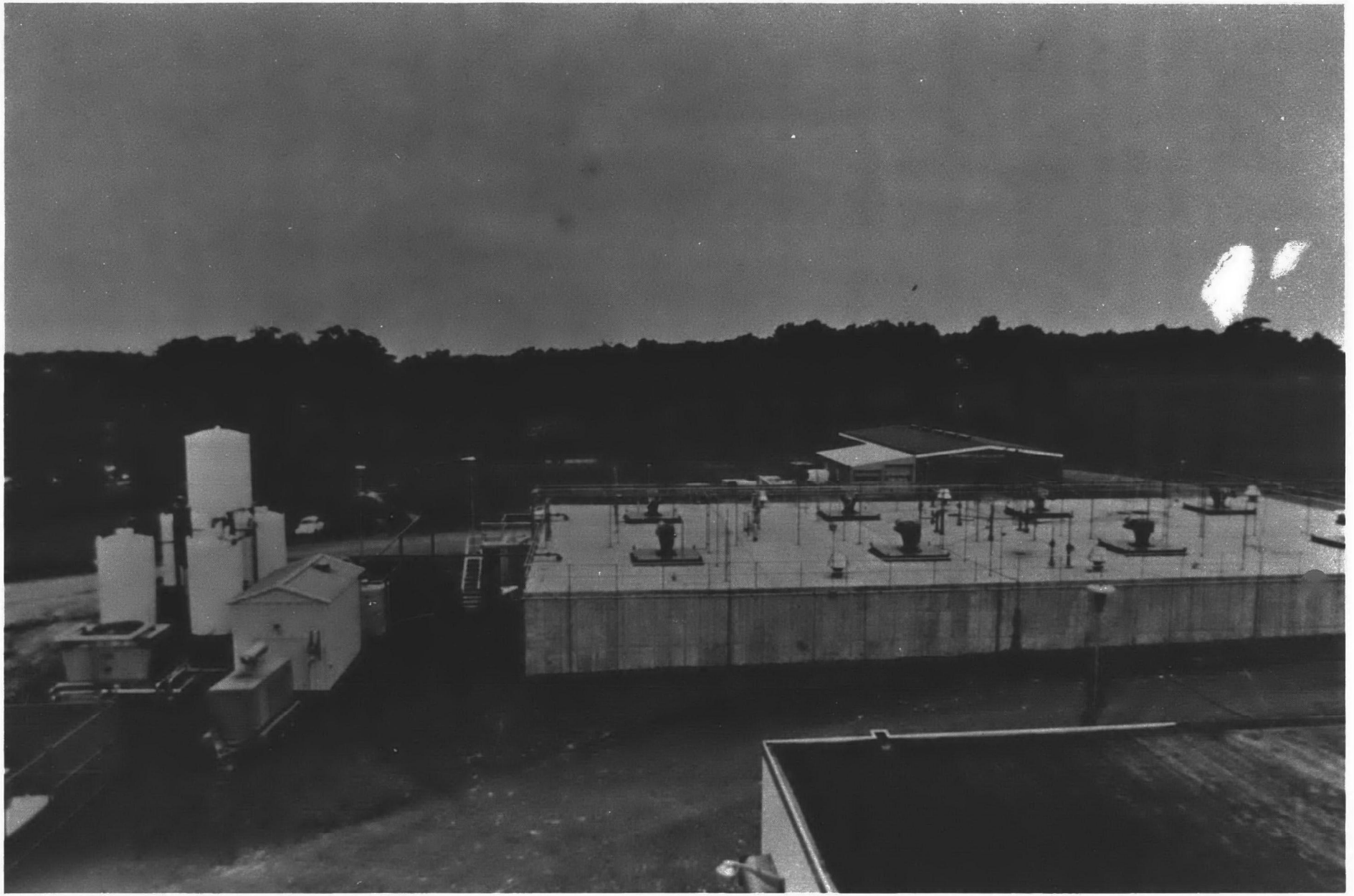


FIGURE 6A-12 TYPICAL PLANT PHOTOGRAPH

SECTION 6B – OXYGEN ACTIVATED SLUDGE

CASE STUDY – FAIRFAX – WESTGATE

1. **Detailed Study - (Reference 13)**

   – Robson, Block, Nickerson, Klinger

   – A landmark paper

   – Conversion of an overloaded intermediate treatment level plant into a 90 percent BOD removal plant

   – Dispatch and efficiency (180 day conversion)

2. **Most Important Facet**

   – Sludge handling data generated

3. **Original Plant**

   – (Figure 6B-1) = Process Flow

   Comminution - Sedimentation/Aeration/Clarification

   Chlorination (digesters not used)
   Vacuum filtration (landfill)

   – (Figure 6B-2) = Longitudinal Section - Sedimentation Tank

   Original use building moratorium problems

   – Westgate Plant Functions - (Figure 6B-3)

   Original plant design
   Overload by 1970
   Interim chemical treatment 1971
   Oxygen activated sludge October 1971

4. Current Westgate Process Flow
(Figure 6B-4)

- Converted 3 phase tank to do two jobs
  (Oxygen activated sludge use)

- Installed 2 - 120' diameter x 11' S.W. depth clarifiers

- Installed 2 - 250 ft^2 D.A.F. units

- Installed 2 - 5 hp mixers on sludge decant tanks

- LOX because of temporary nature

5. Results Liquid Treatment
(Figure 6B-5)

- Liquid treatment has been highly successful.

  Exceeded removal goals
  93 percent instead of 80 which was goal
  Equivalent to conventional aeration with 3 times tank volume
  T.S.S. removal efficiencies of 90 percent
  Stable operation with routinely qualified personnel
  Oxygen cost = lower than predicted

6. Solids Settling Results

- Excellent Settling Characteristics

  Note good SVI
  Reasonable zone settling velocity

- Significantly less excess activated sludge produced - due to endogenous respiration.

7. Thickening and Dewatering Results
(Figure 6B-6)

- D.A.F. units worked but ingenuity and benefits of oxygen activated sludge prevailed.

- Mixture of O.A.S. and primary sludge proved very amenable to gravity thickening.

- Small dose of flocculant = clear supernatant and rapid thickening to 6–8 percent solids.

- Key point = mixers provided on sludge decant or blend tanks
  So many plants not provided.

- Efficient thickening and good drainability characteristics of Primary/O.A.S. blend = efficient, economical dewatering
  (Figure 6B-7 - Sludge Filters).

- Production rate = 5 $lb/hr/ft^2$
  (Good for 90^+% removal plant.

- Cake solids = 22–28 percent also good.

- Filtrate = 0.05 percent T.S. (very low recycle rate).

- Sludge conditioning = can and have used both polymers and $FeCl_3$/lime combinations.

  Routinely use $FeCl_3$ lime because of odor control problem in haulage.

  Normal optimized conditioning cost based on proper conditioning for vacuum filtration = 5 to 6 dollars/ton.

  For purposes of odor control and adding excess lime for landfill and haulage purposes, use about $8.00/ton of ferric and lime.

  If plant were not going - phase out other odor control and lower costs.

  (Figure 6B-8) – Photograph of plant.

  Note proximity to residential areas.

LIST OF FIGURES AND TABLES – SECTION 6B

Figure 6B-1	Westgate – Original Process Flow
Figure 6B-2	Westgate Sedimentation Tank Longitudinal Section
Figure 6B-3	Westgate Plant Functions
Figure 6B-4	Current Westgate Process Flow
Figure 6B-5	Results – Westgate Oxygen Process
Figure 6B-6	Thickening and Vacuum Filtration – Westgate Oxygen Process Sludge
Figure 6B-7	Photograph of Sludge Off Filters
Figure 6B-8	Photograph of Plant

WESTGATE- ORIGINAL PROCESS FLOW

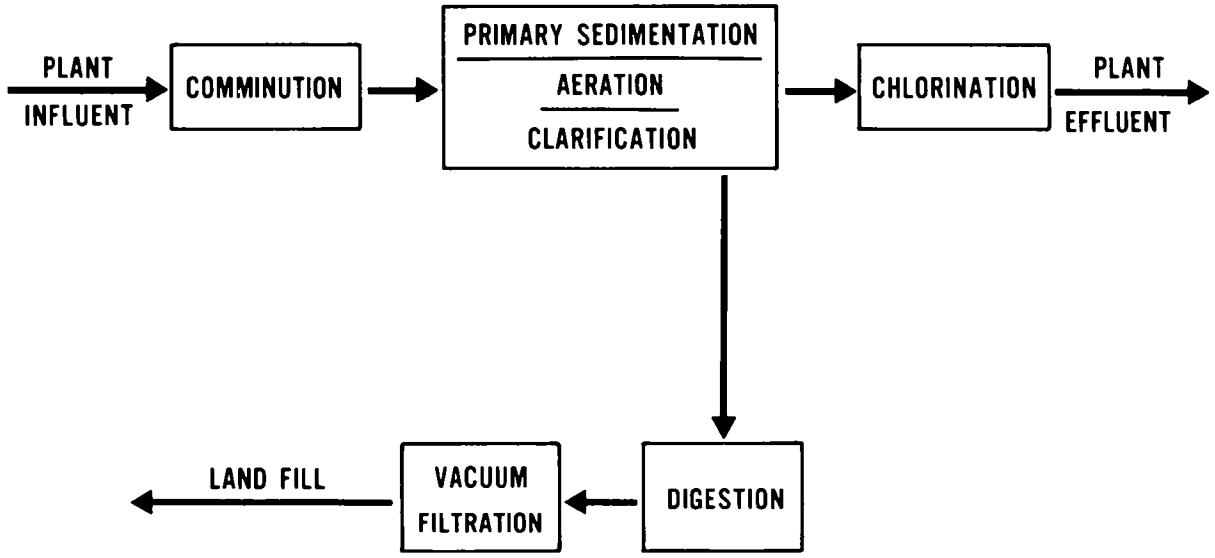


FIGURE 6B-1

WESTGATE SEDIMENTATION TANK
LONGITUDINAL SECTION

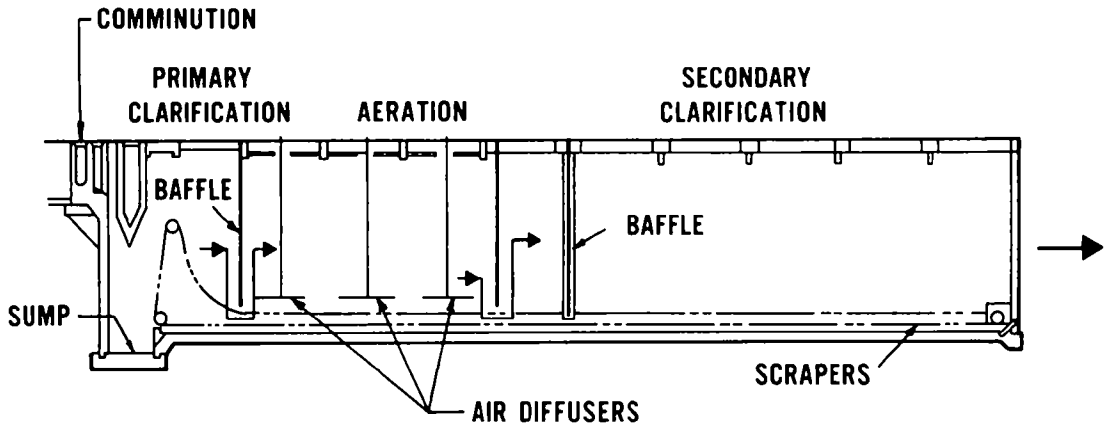


FIGURE 6B-2

WESTGATE PLANT FUNCTIONS

PERIOD	DESIGN FLOW (MGD)	% REMOVAL BOD 5	PLANT PROCESS
1954	8	50 +	ORIGINAL
1970	12	35–40	ORIGINAL
1971	12	75 +	CHEMICAL Ppt.
1971–72	12	80–90	OXYGEN ACTIVATED SLUDGE

FIGURE 6B-3

CURRENT WESTGATE PROCESS FLOW

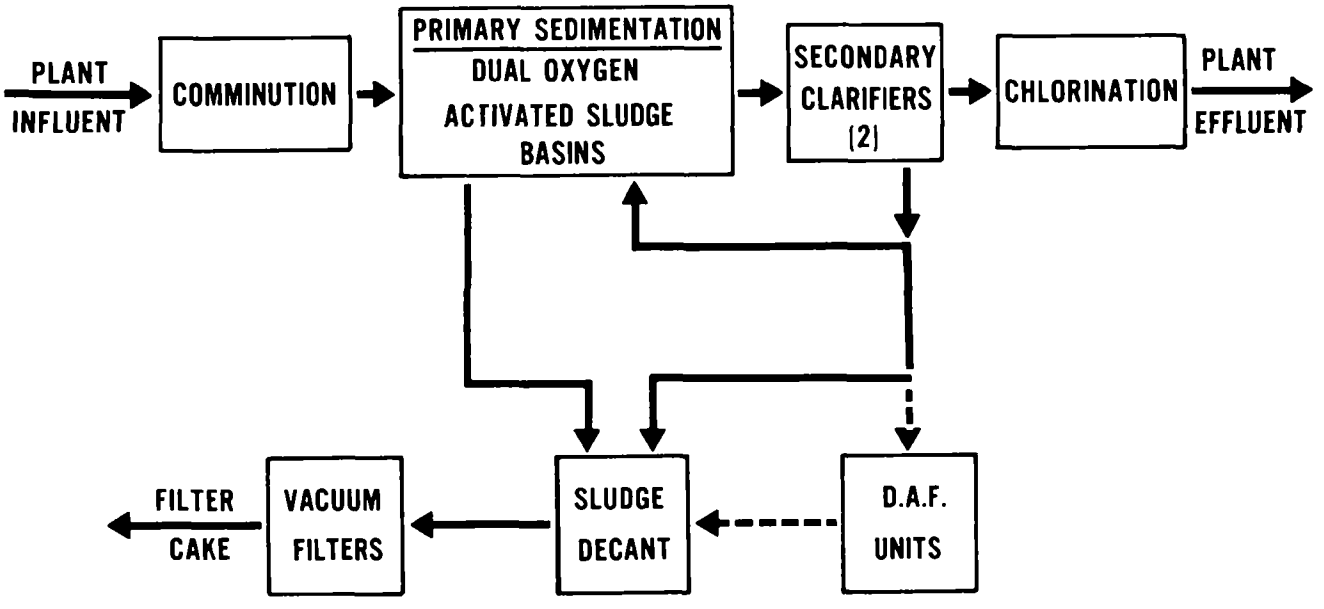


FIGURE 6B-4

RESULTS
WESTGATE OXYGEN PROCESS

% REMOVAL			W.A.S.	ZONE
BOD 5	T.S.S.	S.V.I.	lb V.S.S. / lb BOD REMOVED	SETT. VEL. (Ft./HR)
93 +	90 +	35-56	0.33	6.0

FIGURE 6B-5

THICKENING AND VACUUM FILTRATION
WESTGATE OXYGEN PROCESS SLUDGE

THICKENING			VACUUM FILTRATION	
METHOD	POLYMER lb./TON	% SOLIDS THICK. SLUDGE	lb/HR/Ft^2	% CAKE SOLIDS
GRAVITY	3	6-8	4.0-5.0	22-28

FIGURE 6B-6

FIGURE 6B-7 PHOTOGRAPH OF SLUDGE OFF FILTERS

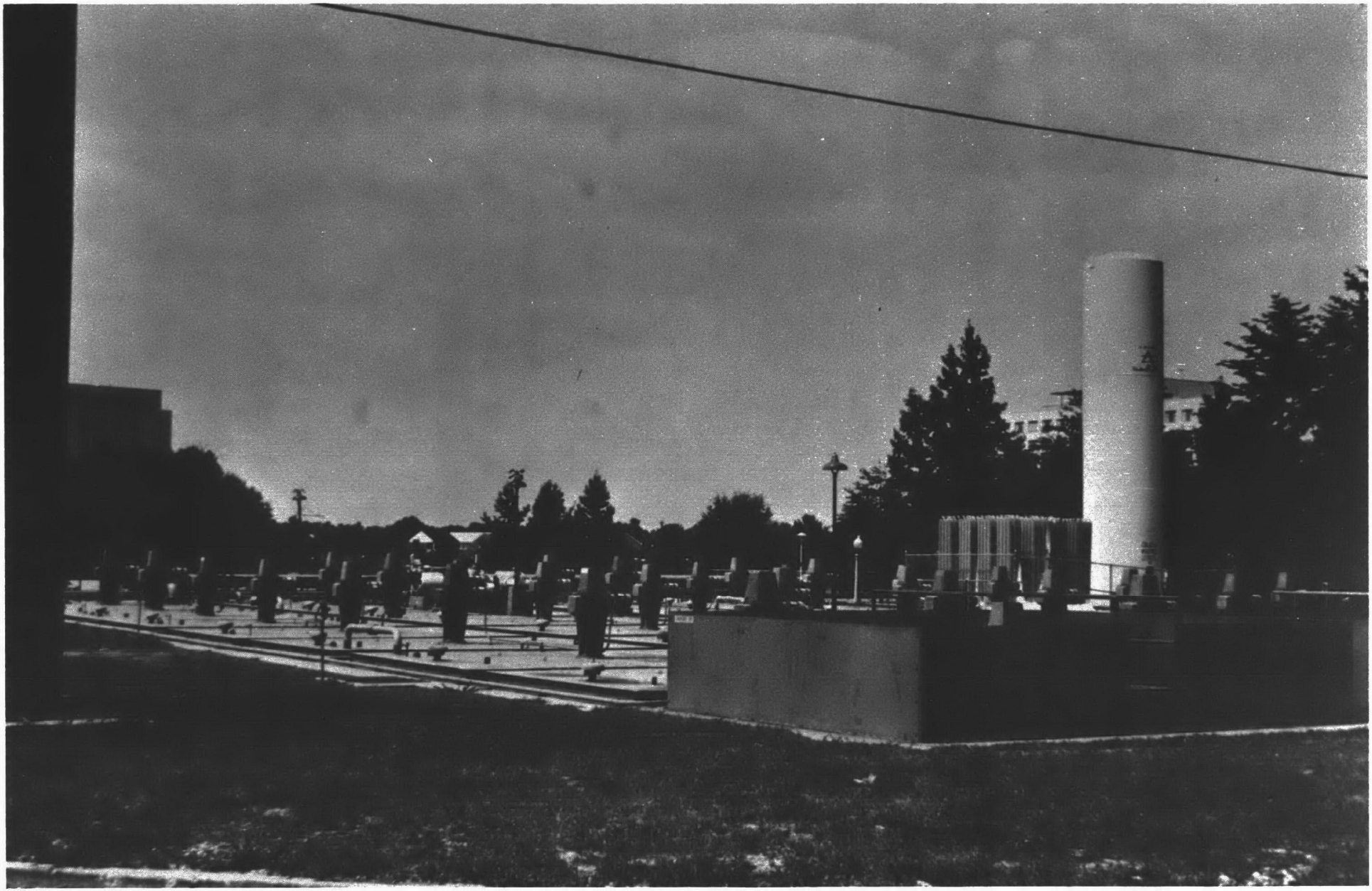


FIGURE 6B-8 PHOTOGRAPH OF PLANT

SECTION 6C – OXYGEN ACTIVATED SLUDGE

CASE STUDY – NEW ORLEANS, LOUISIANA

1. Reference 8

   - Grader and Dedke of Union Carbide
     Powell and Wiebelt of New Orleans
     Sewerage and Water Board

   - "Pilot plant results using pure oxygen for treating New Orleans Wastewater" - A.E.CH.E. Meeting.

   - Consultant – Waldemar S. Nelson and Co., Inc.

   - Design Criteria – 141 mgd East Bank Plant

2. Characteristics of New Orleans Sewage
   (Figure 6C-1)

   - Primarily domestic
     Brewery, food processing (chicken/shrimp)

   - BOD = 200 mg/l
     COD/BOD = 1.5 (high fraction organic biodegradables)

   - Flow Variation → Sunday - 160 mg/l BOD
     Wednesday - 266 mg/l BOD

3. Proposed Plant Process Flow
   (Figure 6C-2)

   - Screening - grit removal - oxygenation tanks - clarifiers - chlorination

   - Solids handling - to be determined

4. Unox Pilot Plant Used

   - Biological Reactor

     Liquid Depth = 5' x 2"
     Stage Volume = 400 gallons
     Total Liquid Volume = 1,600 gallons

- Clarifier

  Two different ones used
  Details later

5. Process Results
   (Figure 6C-3)

   - Phased Study

     Steady state design flows
     Diurnal flow feed pattern
     Steady state with centrate recycle (all gave 93-95 percent BOD removal and 88-90 percent S.S. removal)

6. Excess Sludge Production

   (Figure 6C-4) (Biomass Loading vs. Excess Sludge Production)

   - Staged process = high degree of endogenous respiration

   - High D.O. levels = lower excess sludge production

   - Slide shows higher loading = more net excess activated sludge

   - Claimed ≈ 30–50 percent less excess sludge than air system

7. Settling and Compacting of Excess Sludge in Clarifier

   - 2.5 to 3.2 percent solids in clarifier
     Underflow (at least double what could be expected in air systems)

   - Mass loadings = 50 lb/SS/ft^2 /day at 699–900 gpd/ft^2

8. Centrifugation Tests
   (Figure 6C-5)

   - Evaluation carried out – solid bowl scroll type centrifuge

   - Purpose

     Dewatering performance of oxygen E.A.S.

- Provision

  Recycle solids laden centrate

- Evaluate

  Effect on oxygenation system and centrifuge performance

- Results
  (Figure 6C-6)

  As expected - without polymers - centrifuge fractionates sludge.

  Heavy solids captured
  Light solids in centrate

- Postulation made

  Operation of centrifuges on excess oxygen A.S. without sludge conditioning (solids capture of 35–60 percent) is feasible in that polluted recycle stream can be handled in oxygen system (Figure 6C-7).

- Observations

  No data presented on feed rates. Centrate solids data skimpy. An incomplete picture.

9. Intrenchment Creek Work
   (Figure 6C-8)

   - Two stage trickling filter plant

     90 percent removal - 20 mgd design
     90 percent removal - 14 mgd design

   - Interesting Centrifugation Works
     (Figure 6C-9)

     Relatively economical and efficient dewatering
     Question = production rate data
     Optimized centrate recycle load
     (Plant at $\frac{14}{20}$ = 70 percent design capacity

LIST OF FIGURES AND TABLES – SECTION 6C

Figure 6C-1	New Orleans, Louisiana Feed Wastewater Characteristics
Figure 6C-2	New Orleans, Louisiana Process Flow
Figure 6C-3	Oxygen System – New Orleans, Louisiana
Figure 6C-4	"Unox" System New Orleans, Louisiana, Effect of Biomass Loading on Solids Wasting Rate
Figure 6C-5	"Unox" System New Orleans, Louisiana, Flow Diagram with Centrate Recycle
Figure 6C-6	"Unox" System New Orleans, Louisiana, Centrifuge Performance
Figure 6C-7	Centrifugation – New Orleans, Louisiana Oxygen Activated Sludge
Figure 6C-8	Intrenchment Creek Flow
Figure 6C-9	Centrifugation – Atlanta Mixed Sludge – Primary and T.F.

REFERENCES – SECTIONS 6A, 6B, AND 6C

1. Union Carbide Corporation Unox System – Status of Unox Sludge Pretreatment and Dewatering.

2. Robson, C.M., Nickerson, G.L., Clinger, R.C., and Burke, Donald, "Pure Oxygen Activated Sludge Operation in Fairfax County, Virginia," WPCF Meeting, Roanoke, Virginia, 1972.

3. EPA Technology Transfer Program, New York City, February, 29, 1972, "Operating Experience and Design Criteria for Unox Wastewater Treatment Systems," by Union Carbide Corporation, Linde Division, Tonawanda, New York.

4. EPA 17050 DNW 02/72, "Activated Sludge Processing," February, 1972, by Union Carbide Corporation, Linde Division, Tonawanda, New York.

5. McWhirter, J.R., Union Carbide, "Oxygenation Challenges Air Aeration." *Water and Wastes Engineering,* 53 (September, 1971).

6. McWhirter, J.R., Union Carbide, "New Era for an Old Idea." *C. & E. News,* 31 (April 26, 1971).

7. EPA Technology Transfer Program, Pittsburgh, Pennsylvania, August 29, 1972, Unox Design Information for Contract Documents, by Metcalf and Eddy, Inc., Engineers.

8. Grader, R.J., Dedeke, W.C., Union Carbide, and Powell, C.J., Wiebelt, A.H., of New Orleans, Louisiana, "Pilot Plant Results Using Pure Oxygen for Treating New Orleans Wastewater," 71st National Meeting of A.I.Ch.E., Dallas, Texas, February 21, 1972.

9. Stamberg, John B., Bishop, D.F., Hais, A.B., and Bennett, S.M., "System Alternatives in Oxygen Activated Sludge," EPA, paper presented at WPCF Atlanta Meeting, October, 1972.

10. Speece, R.E., and Humenick, M.J., University of Texas, "Solids Thickening Limitation and Remedy in Commercial Oxygen Activated Sludge," presented at WPCF Atlanta Meeting, October 9, 1972.

11. Dick, R.I., and Young, K.W., "Analysis of Thickening Performance of Final Settling Tanks," Purdue Industrial Waste Conference, May 2-4, 1972.

REFERENCES (Continued)

12. Eckenfelder, W.W., Jr., "Boost Plant Efficiency." *W. & W. Engineering,* E-1 (September, 1972).

13. Robson, C.M., Block, C.S., Nickerson, G.L., and Klinger, R.C., "Operational Experience of a Commercial Oxygen Activated Sludge Plant," presented at WPCF Atlanta Meeting, October, 1972.

14. Wastewater Treatment, Unox System, Union Carbide, 82-0258.

15. Newtown Creek project, personal communication, William Pressman, Project Engineer, New York City Department of Water Resources.

16. Vandiver, E.C., and Noble, James A., "Centrifuge Improves Intrenchment Creek Water Pollution Control Plant." *Water and Sewage Works,* (September, 1972).

17. EPA Research and Development Activities with Oxygen Aeration, Technology Transfer Design Seminar, Pittsburgh, Pennsylvania, August, 29, 1972.

NEW ORLEANS, LA.
FEED WASTE WATER CHARACTERISTICS

PARAMETER	DEGRITTED RAW WASTE AVERAGE
CHEMICAL OXYGEN DEMAND, mg/l	
TOTAL	316
SOLUBLE	183
BIOCHEMICAL OXYGEN DEMAND,mg/l	
TOTAL	210
SOLUBLE	98
SUSPENDED SOLIDS,mg/l	
TOTAL	183
VOLATILE	133
pH	7.4(6.6–8.8)
TEMPERATURE, °F	71(65–83)

FIGURE 6C-1

NEW ORLEANS PROCESS FLOW

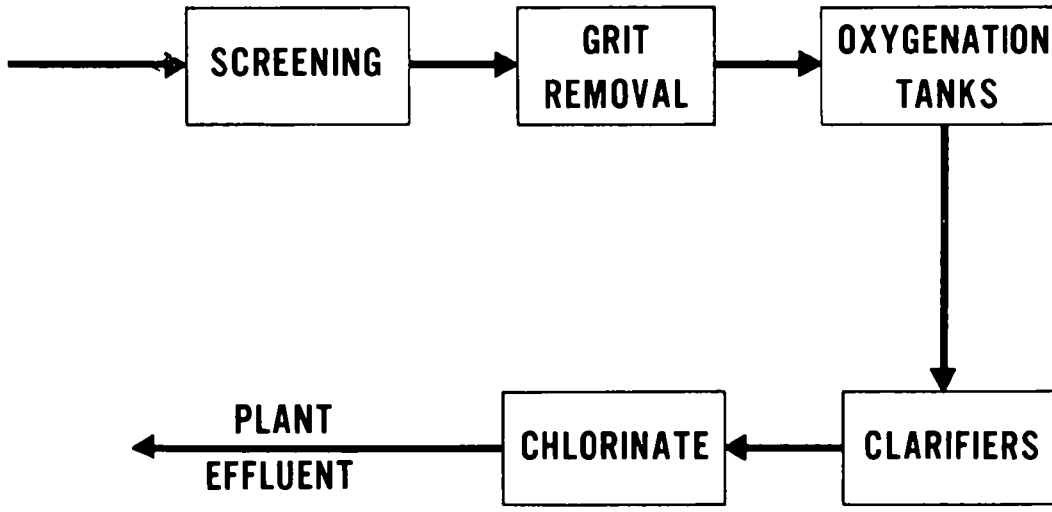


FIGURE 6C-2

OXYGEN SYSTEM-NEW ORLEANS

	STEADY STATE DESIGN	DIURNAL FLOW PATTERN	CENTRATE RECYCLE
RETENTION (HRS.)	1.8	1.4	1.8
MLSS (mg/l)	5560	5770	7350
lb. BOD/KFt^3-DAY	181	246	193
OVERFLOW(GAL/Ft^2/DAY)	655	855	655
SLUDGE VOL. INDEX	79	64	48

FIGURE 6C-3

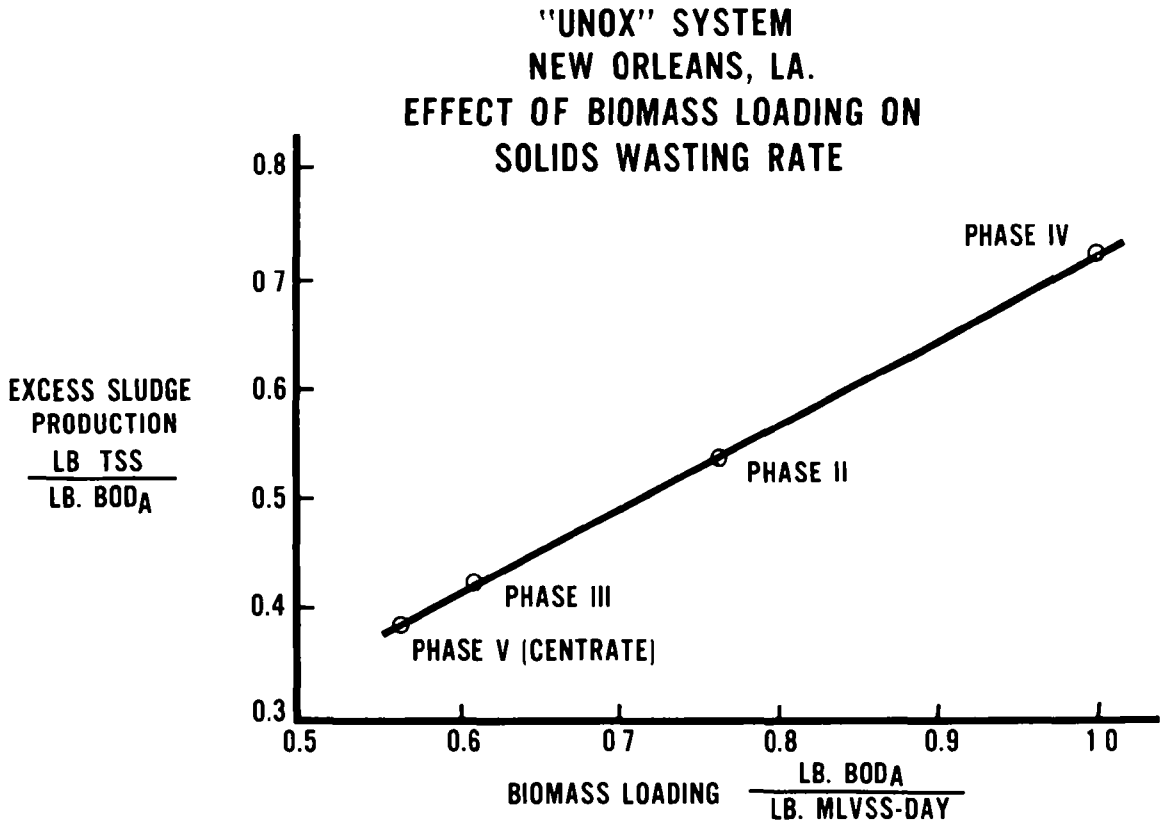


FIGURE 6C-4

"UNOX" SYSTEM
NEW ORLEANS, LA.
FLOW DIAGRAM WITH CENTRATE RECYCLE

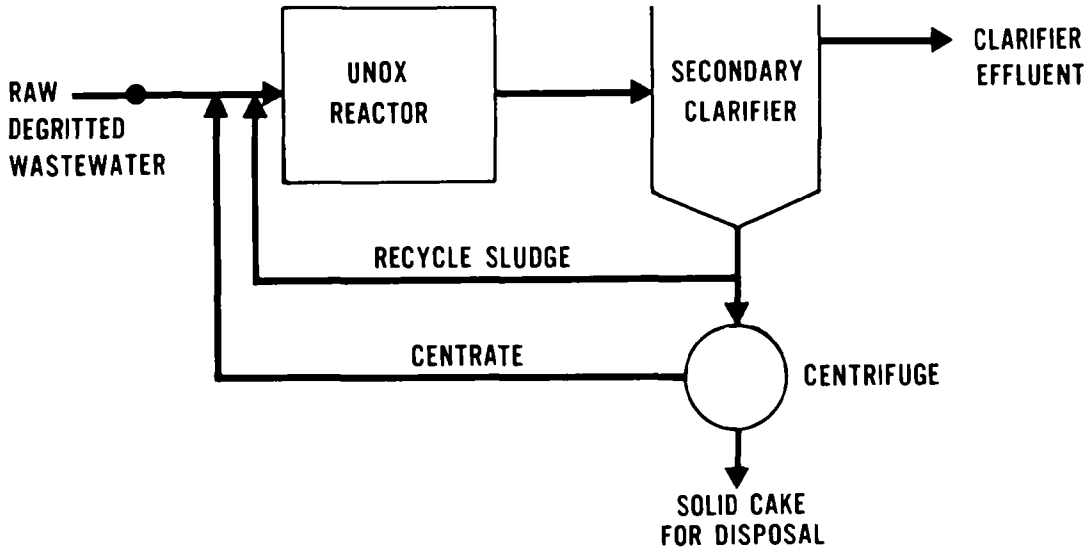


FIGURE 6C-5

"UNOX" SYSTEM
NEW ORLEANS, LA.
CENTRIFUGE PERFORMANCE

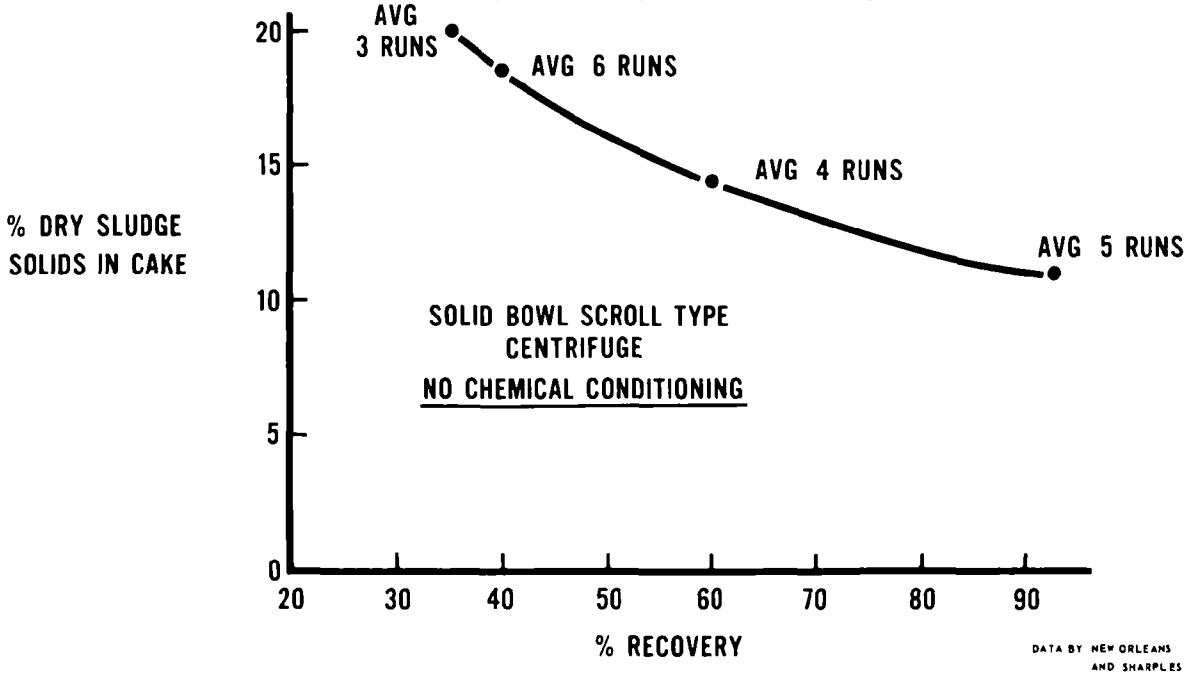


FIGURE 6C-6

CENTRIFUGATION-NEW ORLEANS
OXYGEN ACTIVATED SLUDGE

FEED COND. % SOLIDS	FEED COND. GPM	% SOLIDS CAPTURE	% CAKE SOLIDS	CENTRATE SOLIDS (%)
?	?	60	15	2.1
?	?	35	20	

FIGURE 6C-7

INTRENCHMENT CREEK FLOW

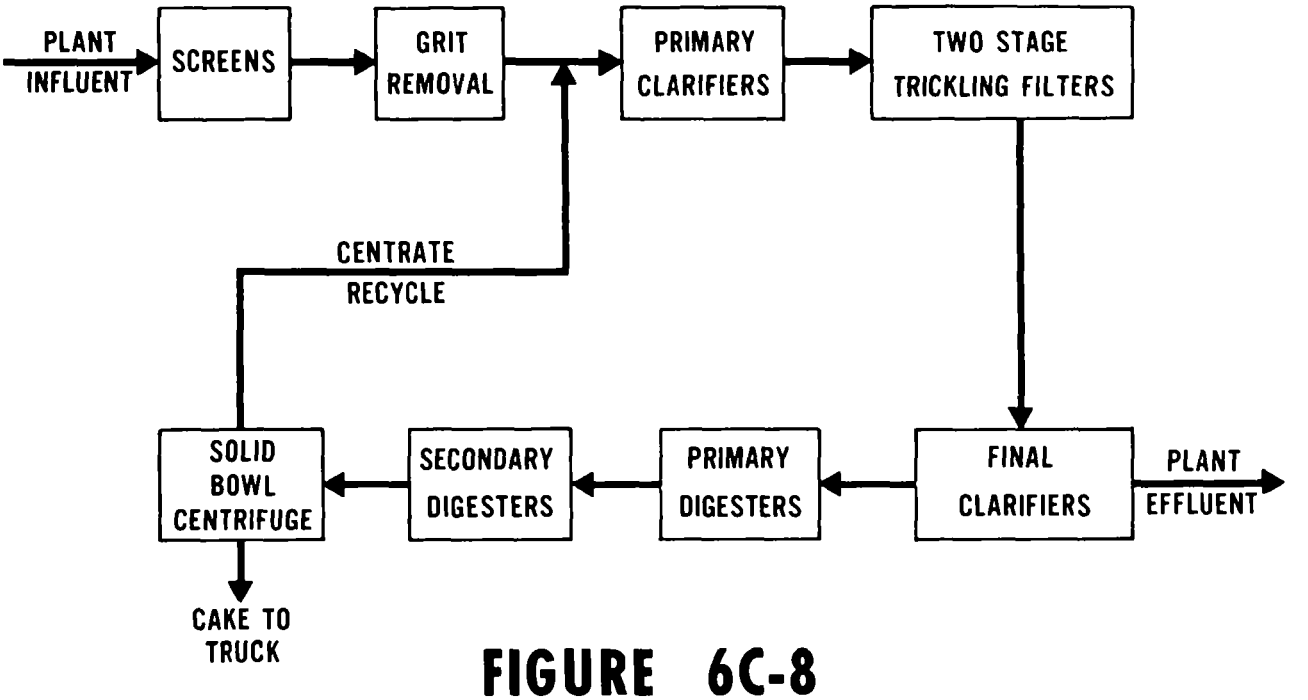


FIGURE 6C-8

CENTRIFUGATION-ATLANTA

MIXED SLUDGE-PRIMARY & T. F.

FEED COND.		% SOLIDS CAPTURE	% CAKE SOLIDS	POLYMER $/TON
% SOLIDS	GPM			
4-6	—	90	21	5.74
4-6	—	80	24	4.05

FIGURE 6C-9

SECTION 7 – THERMAL PROCESSING OF SLUDGE

1. High Temperature and High Pressure Sludge Treatment

   – Two basic types - European origin (wet air oxidation and thermal conditioning).

   – Old processes - few installations - 1930's (not widely adopted in Europe).

   – Thermal conditioning - August - 1970, "Wastewater Treatment in Great Britain" - "A few years ago much interest and promise were shown with heat treatment and sludge pressing, but lately there is less enthusiasm for this type of plant."

   – Wet air oxidation - relatively few U.S. plants in operation, some have closed down. Still, a few more are being built.

WET AIR OXIDATION

2. Process Description
   (Figure 7-1)

   – Flameless combustion, burning of sludge at 450°- 550° F. and high pressures (1,200 psig) with air injection.

   – Equipment - sludge grinder, heating tank, heat exchangers, high pressure reactors, separators, expansion engine and auxiliaries.

   – End products - ash and sludge liquor.

   – Insoluble organics converted to soluble organics CO_2, H_2O, ammonia, sulfates, acetates.

   – At 250° C. and 83.4 percent COD reduction of sludge the oxidized liquor shows a COD of 10,000 mg/l + BOD is only 54 percent of COD.

   – The pH of the oxidized liquor is 4.8.

   – Summation, W.A.O. does reduce sludge volumes and produce a stable solid residue, but the nature of the oxidized acidic liquor and the costs of the process are of some concern.

3. Installations and Operating Experiences

- Chicago - South West, Wheeling - West Virginia, Rye - New York, South Milwaukee - Wisconsin, Wausau - Wisconsin (have been in operation for a number of years).

- Few additional installations underway.

4. Wheeling, West Virginia Installation
(Figure 7-2)

- Plant = thickened raw primary sludge 25 mgd design/8 mgd flow 5.6 tons/day dry solids.

- W.A.O. process - 500° and 1,200 psig.

- Maintenance = alternate caustic and muriatic acid washing of exchangers.

- Capital cost = $284,000 in 1963–65.

- Design and Operating Conditions (Table 7-1)
90 percent removal of insoluble organic matter.

- But?? Quantity and quality of oxidized liquor?

- Sludge Disposal Costs (Table 7-2).

  $20/ton for raw primary sludge operating and maintenance
  (No amortization)
  (Not particularly low contrasted to plants employing conventional methods)

5. Chicago, South West, Wet Air Oxidation

- Commenced operation 1962 (500° F. - 1,500 psi)
$17,900,000 for 300 tons/day design capacity.

- Modifications = $4,000,000
Total = $20/annual ton (design)
Capacity achieved = 125–188 tons/day
Actual = $32/annual ton performance - maximum

- Safety improvments - $1,000,000.

- Two serious accidents - 4 fatalities.

- Over years much intensive R&D to improve performance.
- W.A.O. costs = $50/ton (including high rate digestion).
- Ceased operation about September 1, 1972.

6. Summation

- Very few new installations.
- Cost Analysis (Kansas City - Reference 21) (Primary Sludge).

	Plant Cost	Annual Operation Cost
Dewatering and Incineration	1.0	1.0
Wet Air Oxidation	1.97	1.54

THERMAL SLUDGE CONDITIONING

7. Two Similar Processes

- Porteous (Figure 7-3) steam injection, batch process.
- Sludge storage - grinding - pre/heater - high pressure and temperature (365° F. and 250 psi) - decanter/thickener - dewatering - auxiliary liquor treatment - off gas deodorizer - steam boiler.
- Zimpro LPO (Figure 7-4) same as Porteous except adds air via compressors.
- Farrer (Figure 7-5) same as Zimpro but claims continuous operation mode.

8. Installations

- Porteous - U.S. 1 operating and 2/3 planned (10 in U.K.).
- Zimpro - 14 built and 12 under construction.
- Farrer - No U.S. installations, to my knowledge.

9. Porteous Type Process

Coors/Golden (5.0 mgd plant)

- Activated sludge plant - 5.0 mgd.
- Domestic and brewery wastes.
- 1970 - Porteous type plant installed.
- Vacuum filters - still required 3.8 percent ferric chloride (Table 7-3).
- Cooking liquor - sometimes as high as 20,000 ppm solids content.
- Discontinued after about one year's operation.

10. Colorado Springs

- Only domestic Porteous installation.
- Currently 66 percent BOD removal trickling filter plant - 25 mgd.
- Porteous unit - built 1968/69 - 2,000 lb/hr 370° F. and 250 psi.
- Results reported (to some extent).
- Reference 4 - Good vacuum filtration results (12 lb/hr/ft^2 - 37 percent). (Cake Solids)
- No chemical conditioning required (used to be $18–20/ton).
- State's filtrate and decant streams easily handled with no additional aeration requirement.
- Does not provide even cursory material balance data on process.
- Periodic visits to plant reveal many problems encountered with the recycle load from heat treatment and with odor.
- Recycle load is much greater than expected even though this is a primary and trickling filter sludge (not activated sludge).
- Lengthy plant process work trying to reduce recycle load. Including massive lime chemical precipitation of liquors.

- State's cost of operation for Porteous process and dewatering = $2/ton.

- Reference 9 - State's chemical conditioning costs used to run $20–$40/ton. State's operating costs for Porteous run $15/ton (fuel, power, labor and water).

- Current plans - convert to activated sludge. Porteous = 400° F. and 300 psi (this will surely increase recycle load).

11. United Kingdom Experiences

- Very little published definitive data.

- Most informative = Reference 13, 14 and 16.
  (Brooks - Fisher/Swanwick)

- Lab and subsequent plant scale analyses/cooking liquors (Table 7-4).

- Brooks - Based on solids percent solids in sludge - this data assumes 4 percent sludge (typical).

- Fisher/Swanwick - Both W.A.O. and thermal conditioning at various temperatures and pressures (Figure 7-6).

  Up to 66 percent suspended solids dissolved and recycled - thermal conditioning.

  Up to 79 percent during W.A.O.

  Effect most marked for activated sludge.

  About 33 percent of cooking liquor not amenable to biological treatment.

12. Borough of Pudsey – United Kingdom – Farrer
    (Reference 23)

- The only paper seen which attempts to present thorough definitive data on plant performance.

- Farrer process - 1969/70 - sludges about 82 percent content trickling filter and 18 percent activated sludge.

- One and one half years operation.

- Many qualifying statements reflect severe operation and maintenance problems encountered.

- "Teething troubles were perhaps to be expected - unfortunately these expectations have been realized and substantial periods of nonoperation of the plant have been due to the necessity of carrying out modifications."

- "The operator requires to be of a higher skill than the grade of labor normally associated with natural sludge dewatering "

- Cost Data - "Here again the authors found themselves in some difficulty since the operation so far makes running costs appear disproportionate due to the modifications, maintenance and supervision required during the first year. Sufficient experience has, however, been gained to make it possible to estimate costs, these excluding cake disposal and liquor treatment" (Figure 7-7).

- Total heat treating and dewatering costs are estimated to be $37.20/ton dry solids, assuming problems mentioned are easily overcome.

- Cost of treating recycle liquors from heat treatment (50 percent BOD reduction via plastic trickling filter) are estimated to be $5/ton.

- Thus exclusive of press cake disposal, total costs, on an optimistic basis are $42.20/ton of dry solids.

13. Kalamazoo

- Reference papers 17 and 24 describe installation and operation of Zimpro LPO unit at Kalamazoo.

- Activated sludge, 1965, 34 mgd.
  Influent = domestic + paper mills + pharmaceutical wastes.

- Sludge volatile/inert = 1:1 originally (supposed to settle in lagoons).

- Sludge 1.5:1 volatile/inert because of change in influent characteristics (77 percent waste activated/23 percent raw primary now).

- Quote - "Our sludge is unusual, what with large proportion of paper mill wastes and pharmaceutical wastes loads, and requires very high chemical dosages in order to dewater either by vacuum filtering or centrifuging."

- Installation Costs (Figure 7-8)

  Zimpro - $1,908,557 (97.5 tons/day)

  Incinerator - $658,511

Electrical - $154,950

General Contract - $1,212,534

- Treating lagooned sludge initially

- Operating temperatures = 358° F.
  (Figure 7-9) Pressure = 400+ psi

- Performance (Figure 7-10) thickening and dewatering

  Good gravity thickening - no data on decantate
  Cake solids good, but only 4.9 lb/hr/ft^2 rate

- Cost Data - Not clear = $20/ton processing costs, but does not include operating and maintenance labor, must be amortization ($10/ton) plus fuel, power, etc.

- No significant data on

  Recycle liquor loads
  Effect of same on plant
  Total cost of systems

REFERENCES – SECTION 7

1. Lumb, C., "Heat Treatment as an Aid to Sludge Dewatering - Ten Years Full-scale Operation." *Water and Sanitary Engineer,* (March, 1951).

2. Mulhall, K.G., and Nicks, B.D., "The Heat Treatment of Sewage Sludge," a paper presented for discussion by the East Anglian Branch of the Institute of Water Pollution Control.

3. Personal communication with R.J. Sherwood, Director of Marketing, Municipal Equipment Division, Envirotech Corporation.

4. Sherwood, R., and Phillips, James, "Heat Treatment Process Improves Economics of Sludge Handling and Disposal." *Water and Wastes Engineering,* 42 (November, 1970).

5. McKinley, J.B., "Wet Air Oxidation Process, Wheeling, West Virginia." *Water Works and Wastes Engineering,* (September, 1965).

6. Bjorkman, A., "Heat Processing of Sewage Sludge," 4th International Congress of the I.R.G.R., Basle, June 2-5, 1969.

7. Koenig, L., for U.S.P.H., AWTR - 3, "Ultimate Disposal of Advanced Treatment Waste," (October, 1963).

8. Martin, Louis V., "Wet Air Oxidation for Sludge Treatment." *WPCF Deeds and Data,* (March, 1972).

9. Kochera, B., "Operation of a Thermal Treatment System for Sludge," WPCF Meeting, Atlanta, Georgia, 1972.

10. Harrison, J. and Bungay, H.R., "Heat Syneresis of Sewage Sludges." *Water and Sewage Works,"* (May, 1968).

11. Sebastian, F.P., and Cardinal, P.J., "Solid Waste Disposal." *Chemical Engineering,* (October, 1968).

12. Bennett, E.R., and Rein, D.A., "Vacuum Filtration – Media and Conditioning Effects."

13. Brooks, R B., "Heat Treatment of Sewage Sludge." *Water Pollution Control,* 92 (1970)

REFERENCES (Continued)

14. Everett, J.G., and Brooks, R.B., "Dewatering of Sewage Sludges by Heat Treatment." *Water Pollution Control,* 458 (1970).

15. Bouthilet, R.J., and Dean, R.B., "Hydrolysis of Activated Sludge," 5th International W.P.R. Conference, July - August, 1970.

16. Fisher, W.J., and Swanwick, J.D., "High Temperature Treatment of Sewage Sludges." *Water Pollution Control,* London, 70, 355-373 (1971).

17. Swets, D.H., Pratt, L, and Metcalf, C., "Combined Industrial – Municipal Thermal Sludge Conditioning and Multiple Hearth Incineration," WPCF Annual Meeting, Atlanta, Georgia, 1972.

18. Bacon, V.W., and Dalton, F.E., "Professionalism and Water Pollution Control in Greater Chicago." *Journal WPCF,* 40, No 9, 1586.

19. "Stickney Sludge Site Closed Temporarily," *Chicago Tribune,* October 1, 1972.

20. Hurwitz, E., Teletzke, G.H., and Gitchel, W.B., "Wet Air Oxidation of Sewage Sludge." *Water and Sewage Works,* 298 (1965).

21. Weller, L., and Condon, W., "Problems in Designing Systems for Sludge Incineration," 16th University of Kansas Sanitary Engineering Conference, 1966.

22. Grant, R.J., "Wastewater Treatment in Great Britain." *Water and Sewage Works,"* 266-270 (August, 1970).

23. Hirst, G., Mulhall, K.G., and Hemming, M.L., "The Sludge Heat Treatment Plant at Pudsey," Northeastern Branch of the Institute of Water Pollution Control, March 25, 1971.

24. Swets, D.H., "Trials, Tribulations, and Now Triumph." *Public Works,* (August, 1971)

LIST OF FIGURES AND TABLES – SECTION 7

Figure 7-1	Wheeling, West Virginia Flow Diagram
Figure 7-2	Wet Air Oxidation System – Wheeling, West Virginia
Table 7-1	Design and Operating Conditions – Wheeling, West Virginia
Table 7-2	Sludge Disposal – Operating Costs Wheeling, West Virginia
Figure 7-3	Flow Diagram of the Porteous Process
Figure 7-4	Thermal Sludge Conditioning and Dewatering
Figure 7-5	Flow Sheet for the Dorr-Oliver Farrer System
Table 7-3	Total Solids PPM – Heat Treatment Liquors
Table 7-4	Percent Solids Solubilized – Heat Treatment and Wet Air Oxidation at Various Temperatures
Figure 7-6	Cost Data – Pudsey Plant
Figure 7-7	Sludge Disposal Facilities
Figure 7-8	Operating Temperature Balance
Figure 7-9	Kalamazoo – Thickening and Dewatering
Figure 7-10	Cooking Liquor Treatment

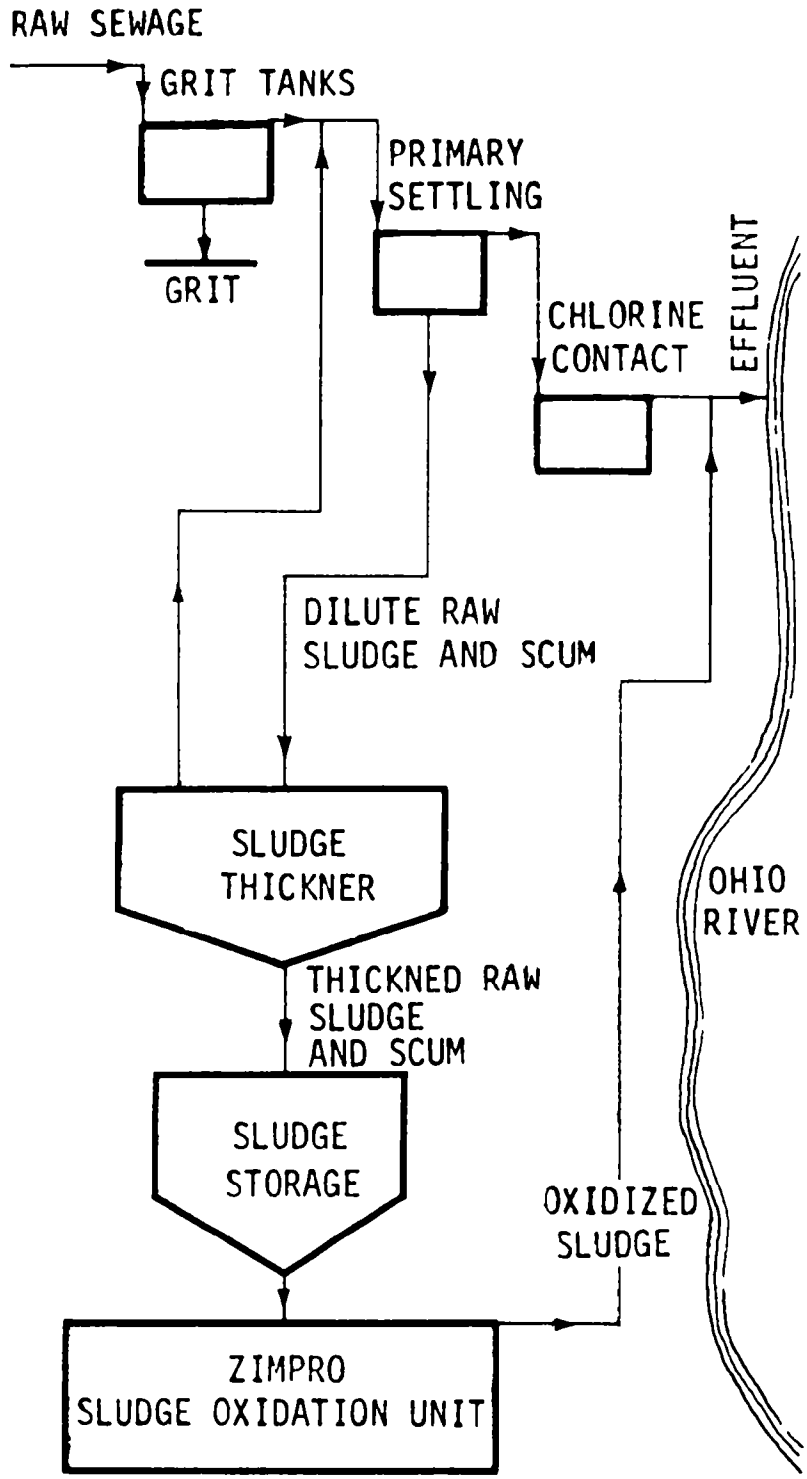


FIGURE 7-1 WHEELING, WEST VIRGINIA FLOW DIAGRAM

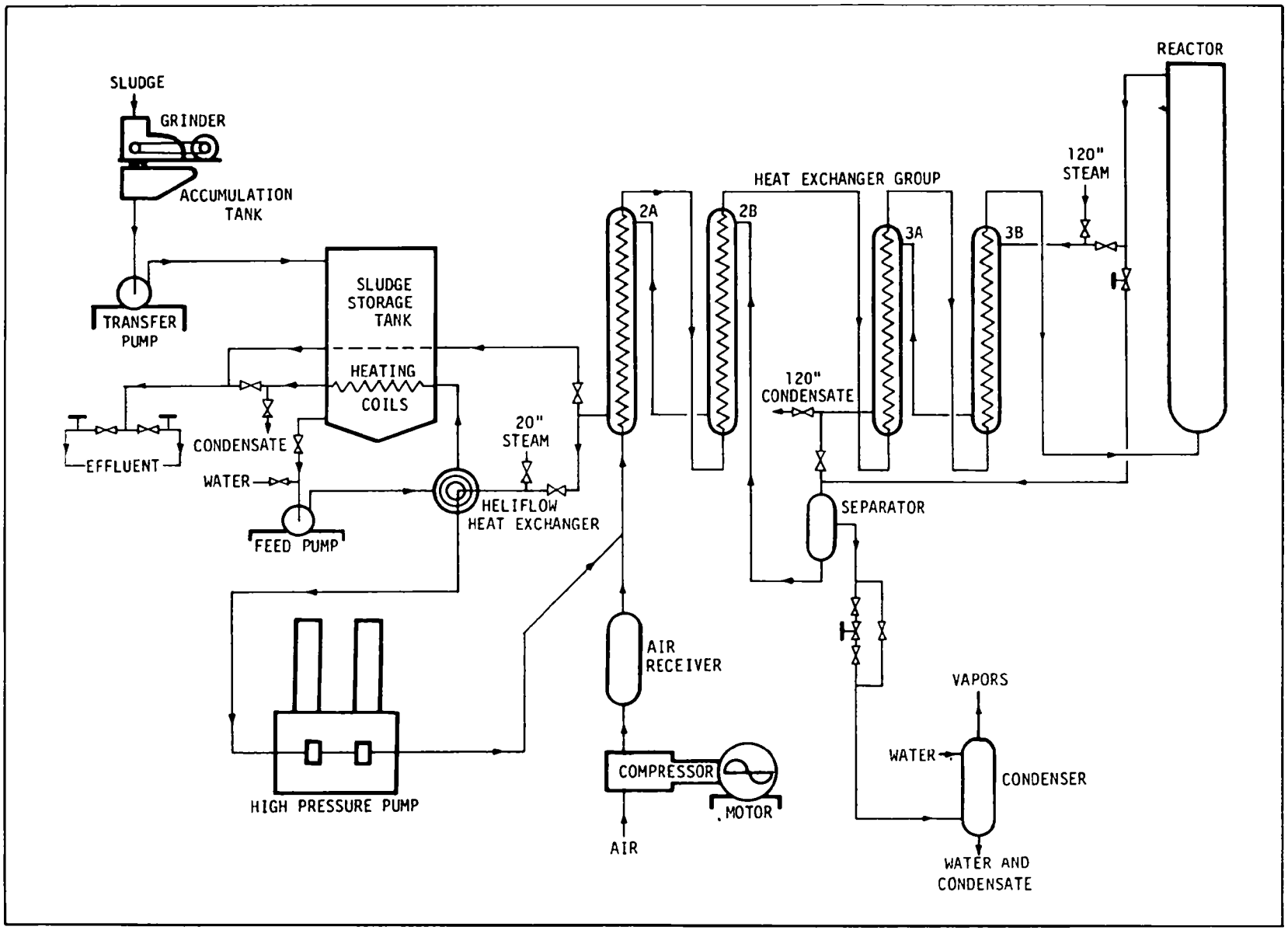


FIGURE 7-2 WET AIR OXIDATION SYSTEM – WHEELING, WEST VIRGINIA

TABLE 7-1 DESIGN AND OPERATING CONDITIONS – WHEELING, WEST VIRGINIA

	Design	Ave.	Conditions — Max. & Min. Processing Rates	
			Max.	Min.
Processing Rate tons per day dry solids	5.6	7.35	12.2	4.1
Flow—gpm	15.5	17.35	21.0	16.7
Total Solids—%	6	7.14	9.7	4.0
Chemical Oxygen Demand—g/l	90	70	95	43.0
Insoluble Organic matter removed—%	90	90	82.6	90.2

Maximum Insoluble Organic Removal = 93.2%

TABLE 7-2 SLUDGE DISPOSAL – OPERATING COSTS
WHEELING, WEST VIRGINIA

	Cost/Ton Solids Processed To January 1, 1965
Electricity	$ 6.11
Chemicals	4.13
Start-up Fuel	1.65
Maintenance	1.17
	$13.06
Labor—1 man during Zimpro Unit Operation	6.91
Total Operating Cost—$/ton	$19.97

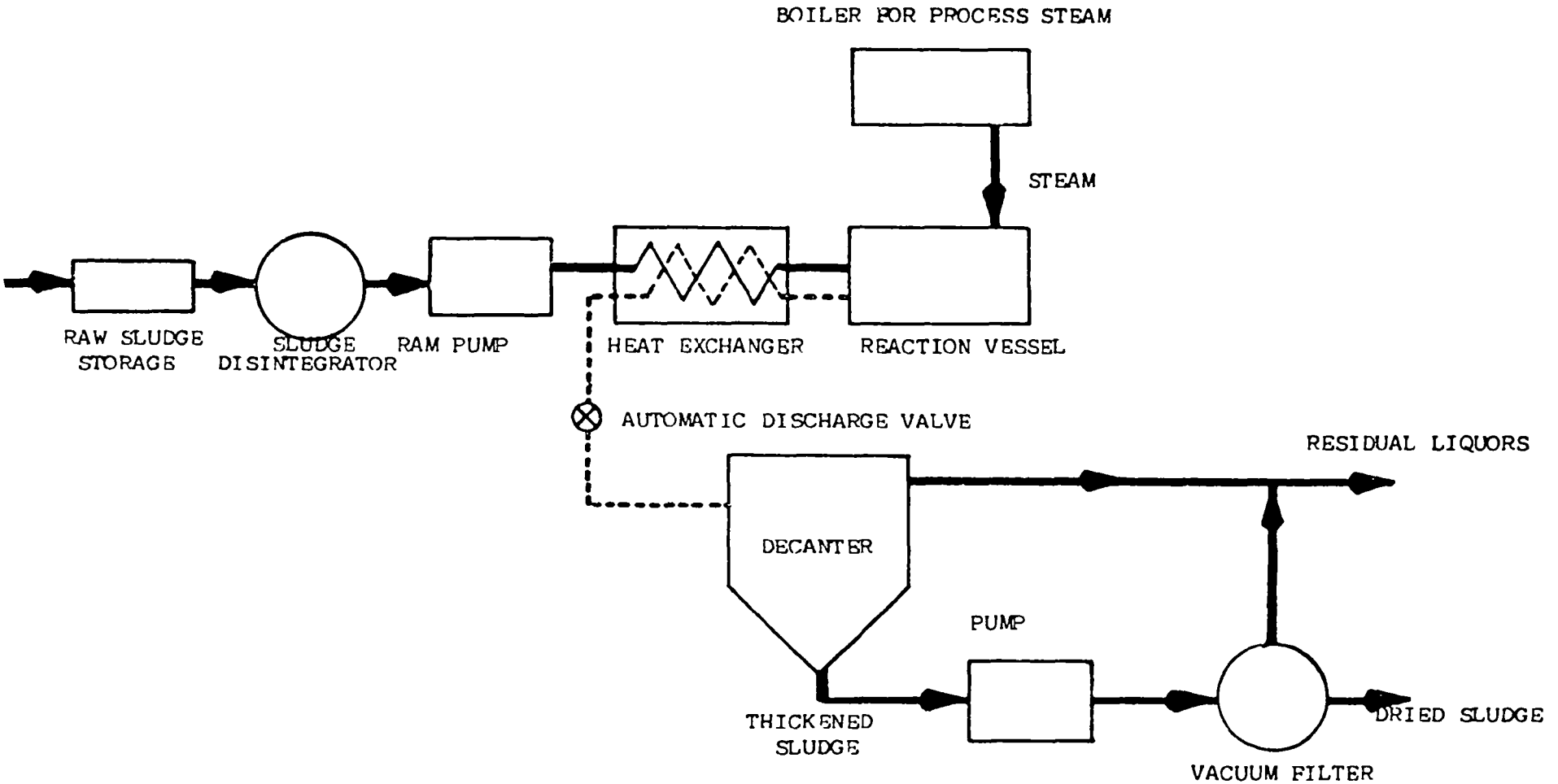


FIGURE 7-3 FLOW DIAGRAM OF THE PORTEOUS PROCESS

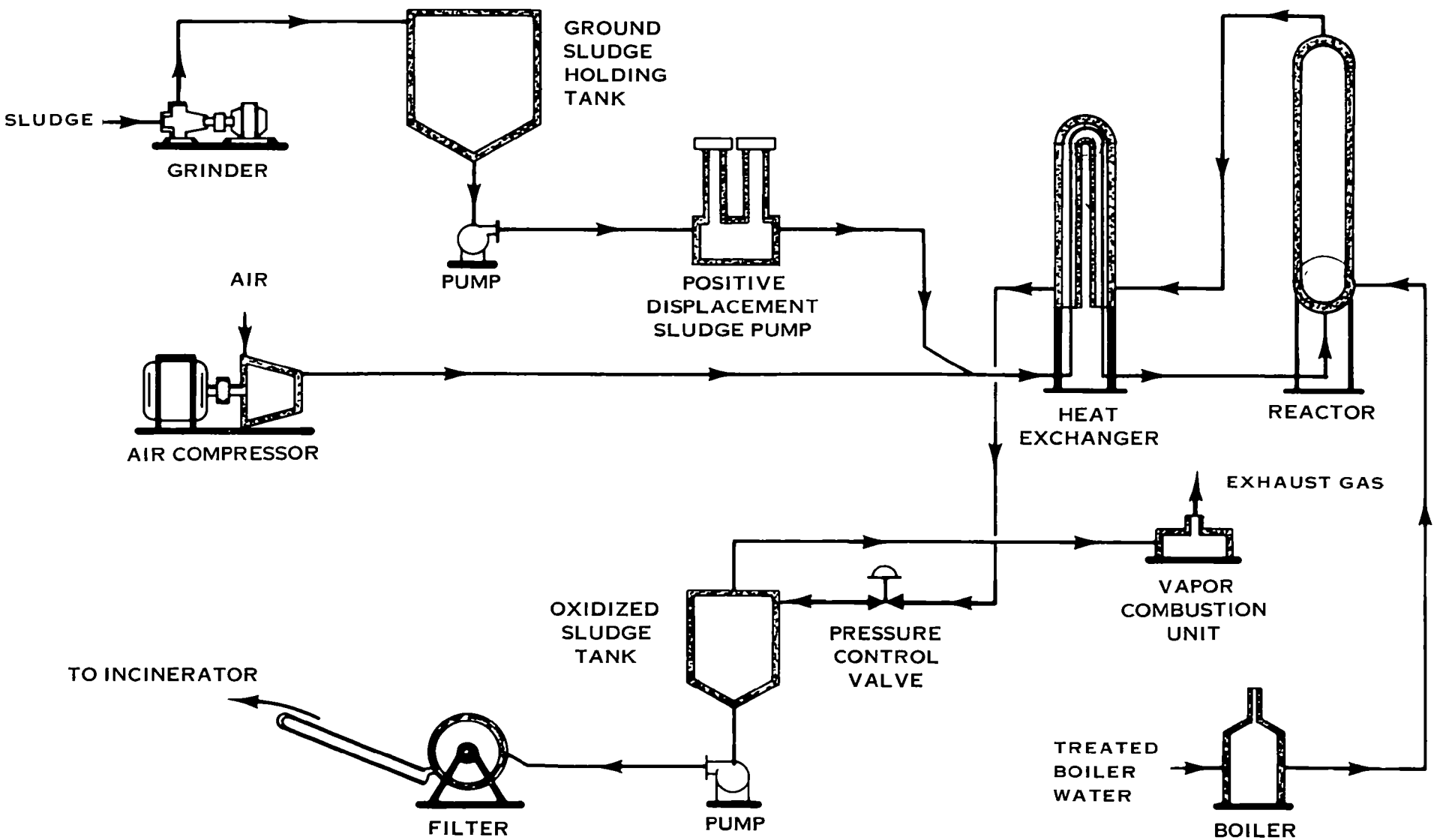


FIGURE 7-4 THERMAL SLUDGE CONDITIONING AND DEWATERING

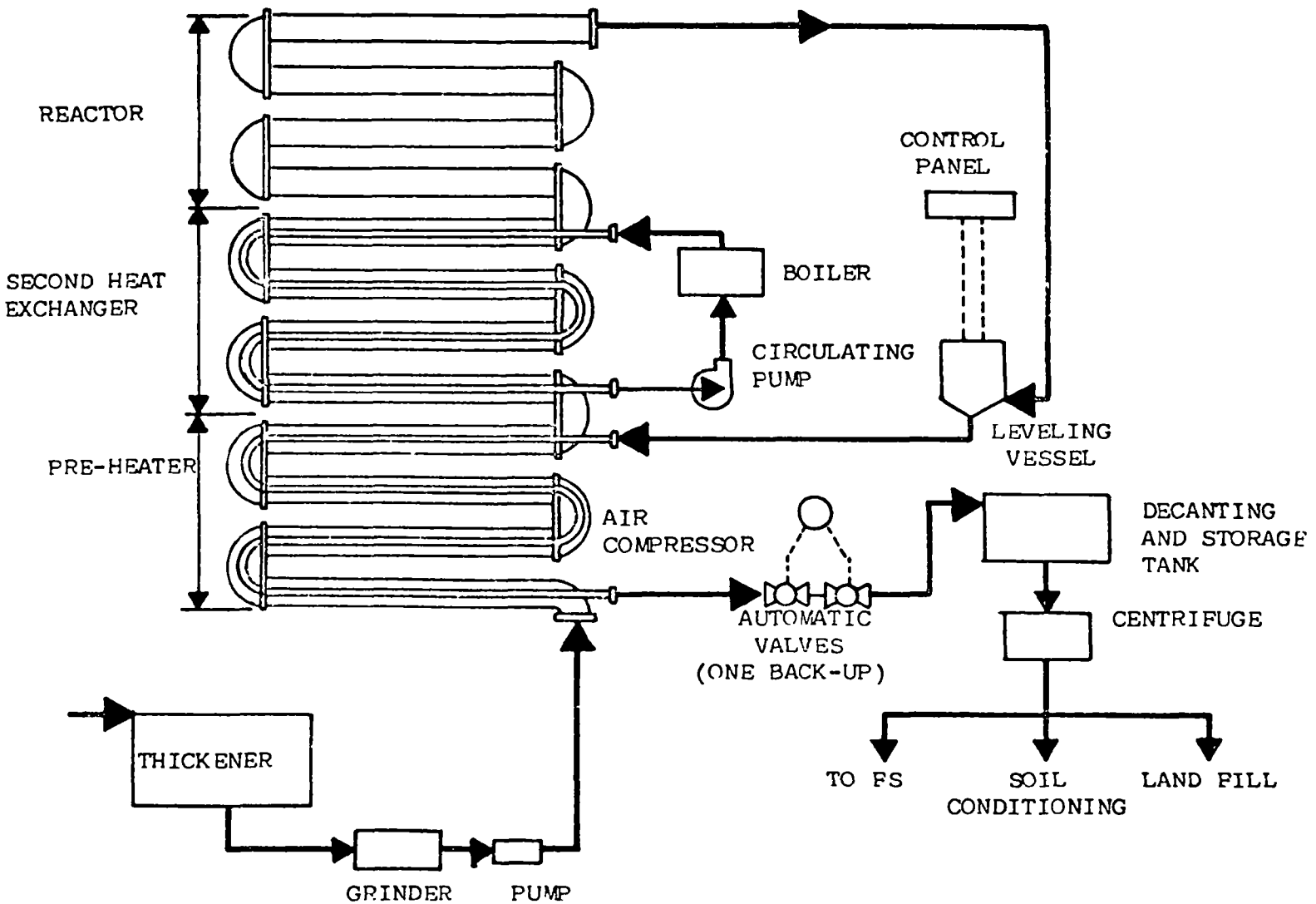


FIGURE 7-5 FLOW SHEET FOR THE DORR-OLIVER FARRER SYSTEM

	LABORATORY	PLANT SCALE
WOKINGHAM	35,880	35,940
FARNSBOROUGH	29,800	29,800

TABLE 7-3 TOTAL SOLIDS PPM – HEAT TREATMENT LIQUORS

	TEMPERATURES (°C.)	% SUSPENDED SOLIDS SOLUBILIZED
H.T. (HEAT TREATMENT)	170:200:230	66
W.O. (WET AIR OXIDATION)	170:200:230	79

TABLE 7-4 PERCENT SOLIDS SOLUBILIZED – HEAT TREATMENT AND WET AIR OXIDATION AT VARIOUS TEMPERATURES

COST DATA-PUDSEY

($/TON OF SLUDGE-EX CAKE DISPOSAL)

O/M	CAPITAL	TOTAL	LIQUOR TREAT
22.32	14.88	37.20	5.00

FIGURE 7-6

SLUDGE DISPOSAL FACILITIES

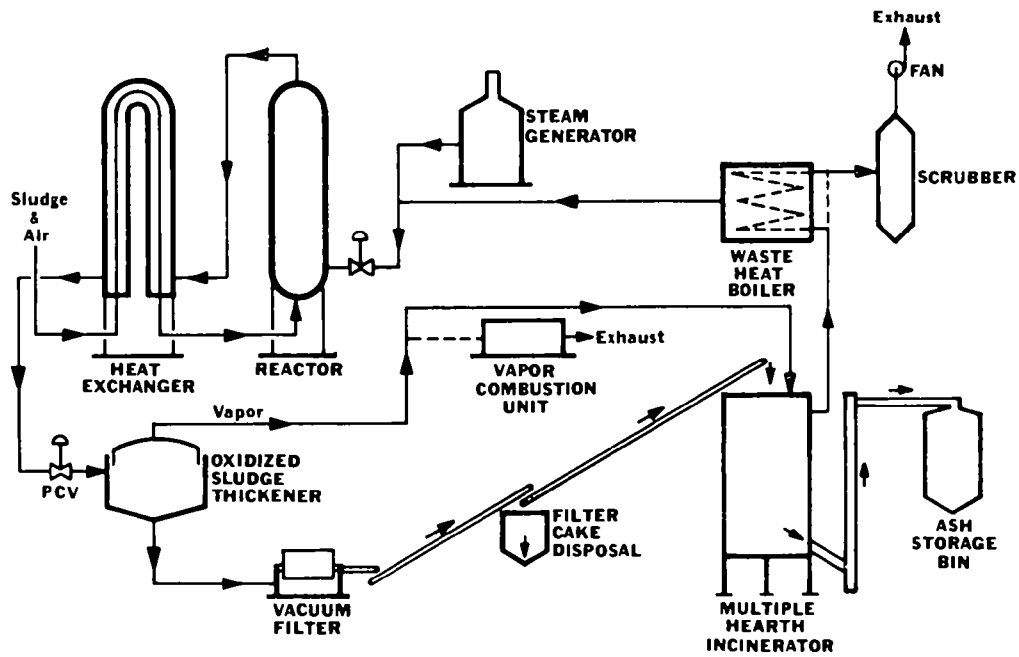


FIGURE 7-7

OPERATING TEMPERATURE BALANCE

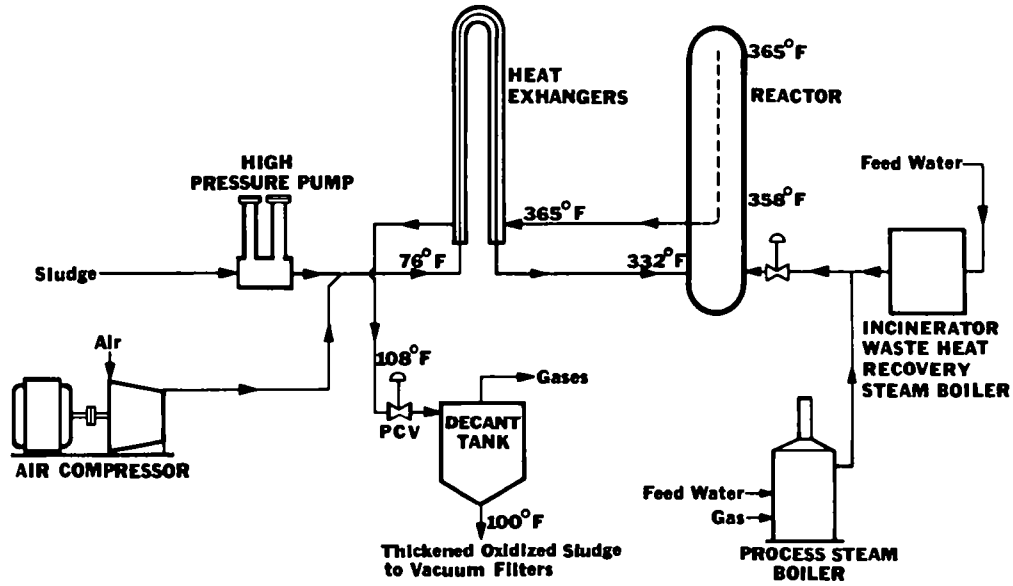


FIGURE 7-8

KALAMAZOO
-THICKENING AND DEWATERING

% SOLIDS				
THICKENER FEED	THICKENED SLUDGE	lb/HR/Ft.^{2}	% CAKE SOLIDS	COST $/TON
5.0	9.7	4.9	45	20

FIGURE 7-9

COOKING LIQUOR TREATMENT

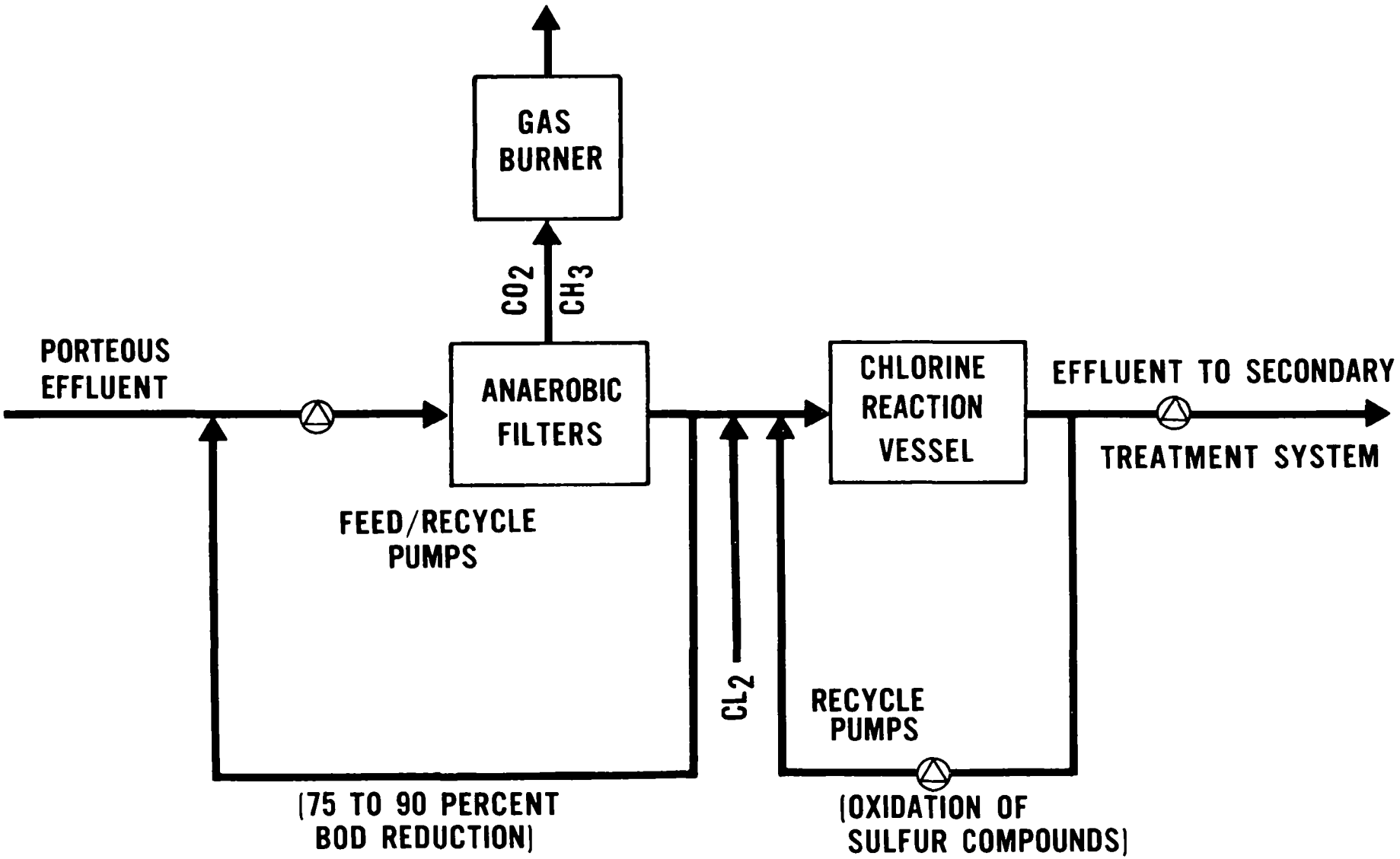


FIGURE 7-10

SECTION 8 – FINAL DISPOSAL PROCESSES AND CASE STUDIES

1. Ultimate Disposal

- Criteria to follow in selection of method.

  Should be in accordance with interstate, state, and Federal Quality Office requirements.

  Should not result in any significant degradation of surface or groundwater, air, or land surfaces.

  No sludge residues, grit, ash, or other solids should be discharged into the receiving waters or plant effluent.

  Sludge disposal to ocean waters is not recommended if toxic materials may be transmitted to the aquatic food chain. Present indications are that ocean disposal will be banned.

  Stabilization of sludge should be considered prior to spreading on land.

- Ultimate disposal is the final treatment process. This transforms the sludge in some instances and places it at its final site.

- Incineration

  Sludge is burned and reduced to combustion gases or ash.

  Multiple hearth furnaces range in capacity from 200 to 8,000 lb/hr of dried sludge and operate at 1,700° F.

  a. Furnace consists of refractory lined circular steel shell with refractory hearths, which lie one above the other.

  b. Sludge enters through flopgate and proceeds with the help of rabble arms to move down from hearth to hearth until ash discharges at bottom.

  c. Reported total annual cost for incineration varies between $10 and about $30/ton dry solids depending on the need for supplemental fuel, pollution control, etc. (Reference 1).

d. Typical section of multiple hearth incinerator is shown in Figure 8-1.

e. Examples – continuous operation at Minneapolis, St. Paul intermittent operation, town X.

In a fluidized bed furnace, the dewatered sludge is fed into a fluidized sand-bed that is supported by air at 3.5 to 5.0 psi.

a. The sludge solids are normally first degritted.

b. Fluid bed reactor is a single chamber unit where moisture evaporates and combustion of organics occurs at 1,400 to 1,500° F.

c. Reported total operating costs vary between about $26 to $35/ton dry solids depending on the supplemental fuel requirement (Reference 1).

d. Typical section of a fluid bed reactor is shown in Figure 8-2.

e. Special cases – Air pollution measurements, Waldrich, New Jersey
Intermittent operation, East Cliff - Capitola, California

– Use of Sludge in Agriculture

Stabilized, either biologically or by some other mode, sludge may be used as a fertilizer or soil supplement. Raw sludge presents health and nuisance problems.

Transportation costs must be considered.

Fertilizer value is normally measured by the nitrogen, phosphorus, and potash content.

<u>Fertilizer Value of Undigested Biological Sludge</u>

Nitrogen	1 – 5%
Phosphate	1 – 3%
Potash	0.1 – 0.3%

The nitrogen and phosphorus contents are generally reduced 40–50 percent by digestion.

Transportation costs can make this mode of disposal uneconomical.

Advantages of land spreading are·

a. economy.

b. it is the final treatment process.

c. it utilizes the water, nutrients, and organic material.

d. it is nuisance-free if done right.

Disadvantages are.

a. creation of health hazards and nuisance conditions when done wrong.

b. possible accumulation of toxic metals.

c. possible nitrate contamination of groundwater.

Quantity of sludge to be spread is determined by

a. soil characteristics.

b. climate.

c. land use or intended crop.

d. type and solids content of the sludge.

Typical application rates

a. for a corn field – 10 - 30 tons of solids/acre/yr.

b. for a strip mine – 1,000 tons of solids/acre/yr.

– Composting

Received attention because of its applicability to organic, industrial, agricultural as well as domestic sludges.

Degree of interest in this country as well as abroad is dwindling for economic reasons.

Difficulty exists in finding a market for the product.

- Lagooning and Landfill

  Lagoons may be used for

  a. anaerobic digesters but aesthetics may rule this out.

  b. as evaporation ponds.

  c. as permanent lagoons or landfills – if dewatering is incomplete a full permanent lagoon remains as a permanent liability.

  Area requirement and management are important.

- Drying of Sludge Filter Cake

  Sell as soil conditioner.

  Sell for manufacture of commercial fertilizer.

  Reported to be safe hygienically.

  Process is used in Houston, Milwaukee, and Chicago.

  Reported cost is approximately $45/ton dry solids, net for Chicago (Reference 2).

  Figure 8-3 shows equipment used in flash drying.

2. **Case Histories of Land Reclamation with Sludge**

- Objectives

  To improve soil quality.

  To grow crops.

  To provide an economically attractive solution for the disposal of wastewater treatment plant sludges.

  To encourage good public relations by not causing unsightliness, obnoxious odors and health hazards.

- Site No. 1, Saint Marys, Pennsylvania (Reference 3)

  Has 1.30 mgd activated sludge plant treating domestic and industrial waste. Sludge is digested and the product contains about 5 percent solids.

  Chose to dispose of their 900,000 gal/yr of wet digested sludge on fields and have done so for last six years.

  Requires about 10 minutes to load 1,500 gallon tank truck and about 5 minutes to empty in a 5 foot wide path. The average round trip is 5 to 8 miles.

  Sludge is spread on hay, pasture, oats stubble, corn stubble, poor lawn, brush, orchard and athletic fields.

  The average application rates for two fields is shown below.

Field	% Solids	gal/acre/yr	tons dry solids/acre/yr
Hay	4.25	19,600	3.54
Pasture	3.7	17,450	2.60

  No complaints have been heard from liquid sludge spreading, rather there has been a tremendous demand from farmers.

  The cost of disposal has averaged $19.92 per ton of dry solids.

- Site No. 2, Hanover Park, Chicago, Illinois (Reference 4)

  Has a 1.5 mgd treatment plant with primary, activated sludge, effluent filtration, anaerobic digestion and sludge lagoon processes.

  Chose to dispose of their liquid digested sludge after a short lagoon retention on land. The soils of the area are classed as medium textured.

  The land area is approximately 1-1/8 acre in area and is divided into six plots. Furrow irrigation is used.

  Corn is planted on ridges and all the fields drain into a central sand drain bed.

The sludge contains about 4 percent solids and for study purposes has been applied at levels of 0, 1/4, and 1/2 inch. The respective application rates are shown below.

inches/acre	gallons/acre	tons dry solids/acre/yr
0	0	0
1/2	13,578	2.28
1/4	6,789	1.14

Response to land spreading

a. Very favorable response of corn.

b. Good public acceptance, area is situated right in housing development and there have been no complaints.

– Site No. 3, Houston, Texas (Reference 5)

Sole purpose is disposal of oily sludges.

Land areas are capable of assimilating petroleum wastes and oily sludges efficiently under proper spreading and treatment procedures, although vegetation will not survive if subjected to repeated applications of oily and concentrated sludges. However, it will be able to again survive if applications are suspended for a period of time.

Shell Oil Refinery in Houston has applied all of the petroleum sludges and stable emulsion from tank bottoms, oil water separators, sewer boxes, and ship ballast water to land since 1961.

Land area consists of 7 acres divided into 4 sections.

Sludge is spread to a depth of 6 inches over an entire section. This is then mixed with about 6 inches of soil.

Consumption requires 3 to 9 months and is a function of temperature, soil moisture and the type of hydrocarbon. This means that from 0.217 to 0.65 million gallons of sludge can be applied per acre per year.

Early work showed that decomposition of the oily wastes varied from 5 to 60 pounds of oil per cubic foot of soil per month.

REFERENCES – SECTION 8

1. Balakrishnan, S., Williamson, D.E., and Okey, R.W., "State of the Art Review on Sludge Incineration Practice," Water Pollution Control Research Series, 17070DIV, FWQA, USDI, April,1970.

2. Dalton, F.E., Stein, J.E., and Lynam, B.T., "Land Reclamation – A Complete Solution of the Solid Disposal Problem." *Journal Water Pollution Control Federation*, 40, (5), 789 (May, 1968).

3. Wolfel, R.M., "Liquid Digested Sludge to Land Surfaces – Experiences at St. Marys and Other Municipalities in Pennsylvania." Presented at the 39th Annual Conference, Water Pollution Control Association of Pennsylvania, August 11, 1967.

4. Rose, B.A., "Sanitary District puts Sludge to Work in Land Reclamation." *Water and Sewage Works*, (September, 1968).

5. Dotson, C.K., Dean, R.B., Kenner, B.A., and Cooke, W.B., "Land Spreading a Conserving and Non-Polluting Method of Disposing of Oily Wastes." Presented at the Fifth International Water Pollution Research Conference and Exhibition, San Francisco, California, July 26–August 1, 1970.

LIST OF FIGURES AND TABLES – SECTION 8

Figure 8-1 Typical Section of Multiple Hearth Incinerator

Figure 8-2 Typical Section of a Fluid Bed Reactor (Dorr-Oliver, Inc.)

Figure 8-3 Flash Drying

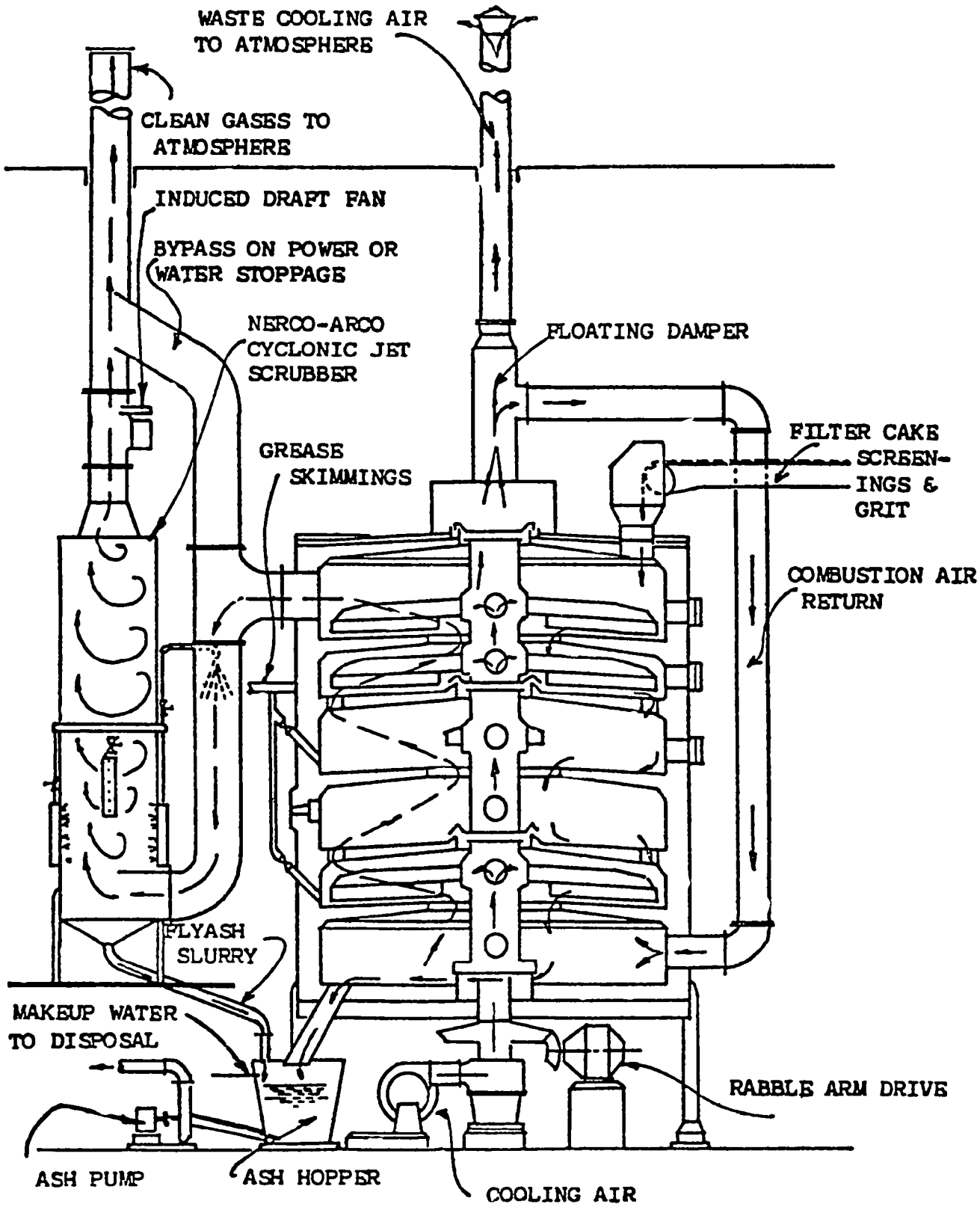


FIGURE 8-1 TYPICAL SECTION OF MULTIPLE HEARTH INCINERATOR

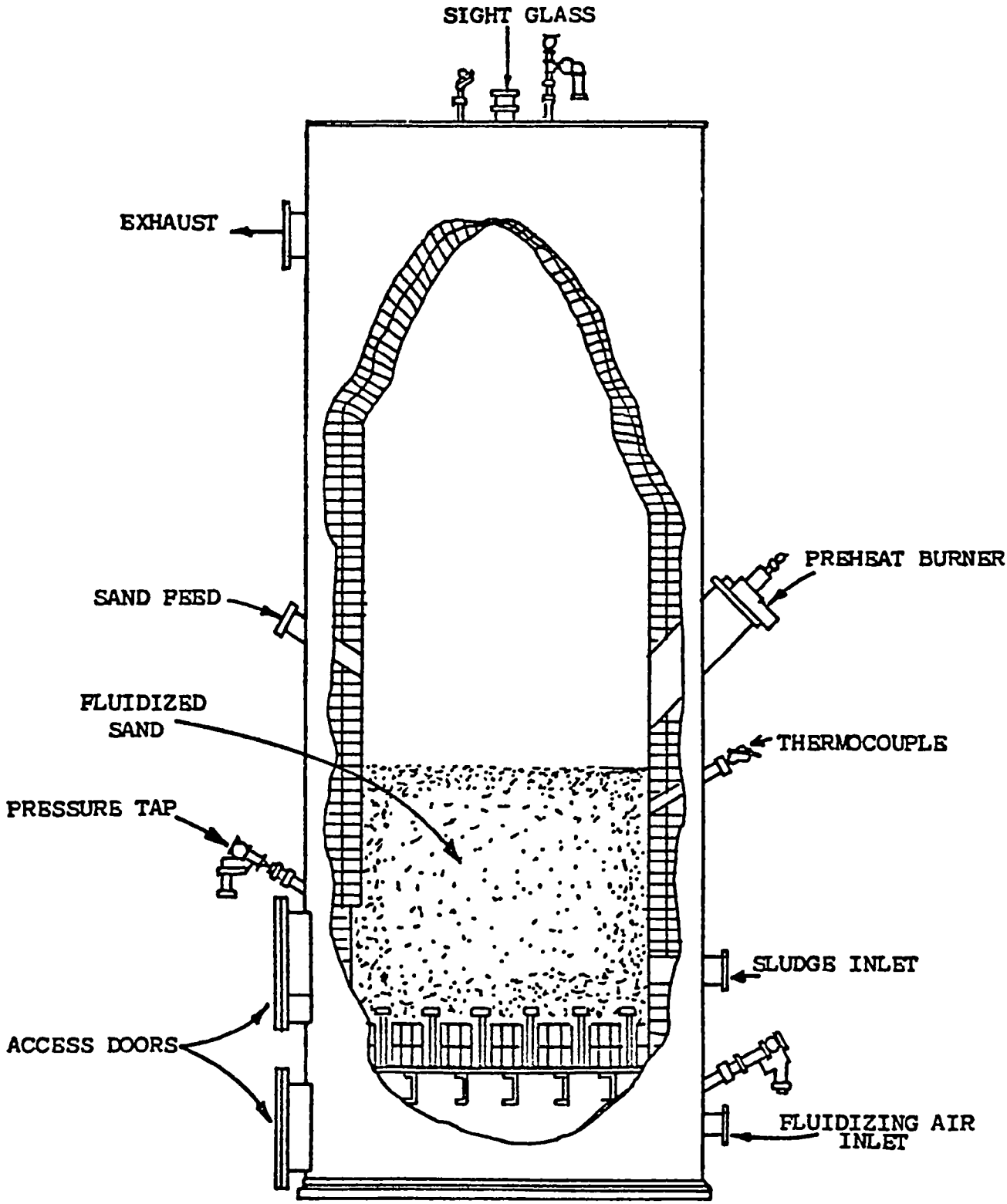


FIGURE 8-2 TYPICAL SECTION OF A FLUID BED REACTOR (DORR-OLIVER, INC.)

FLASH DRYING

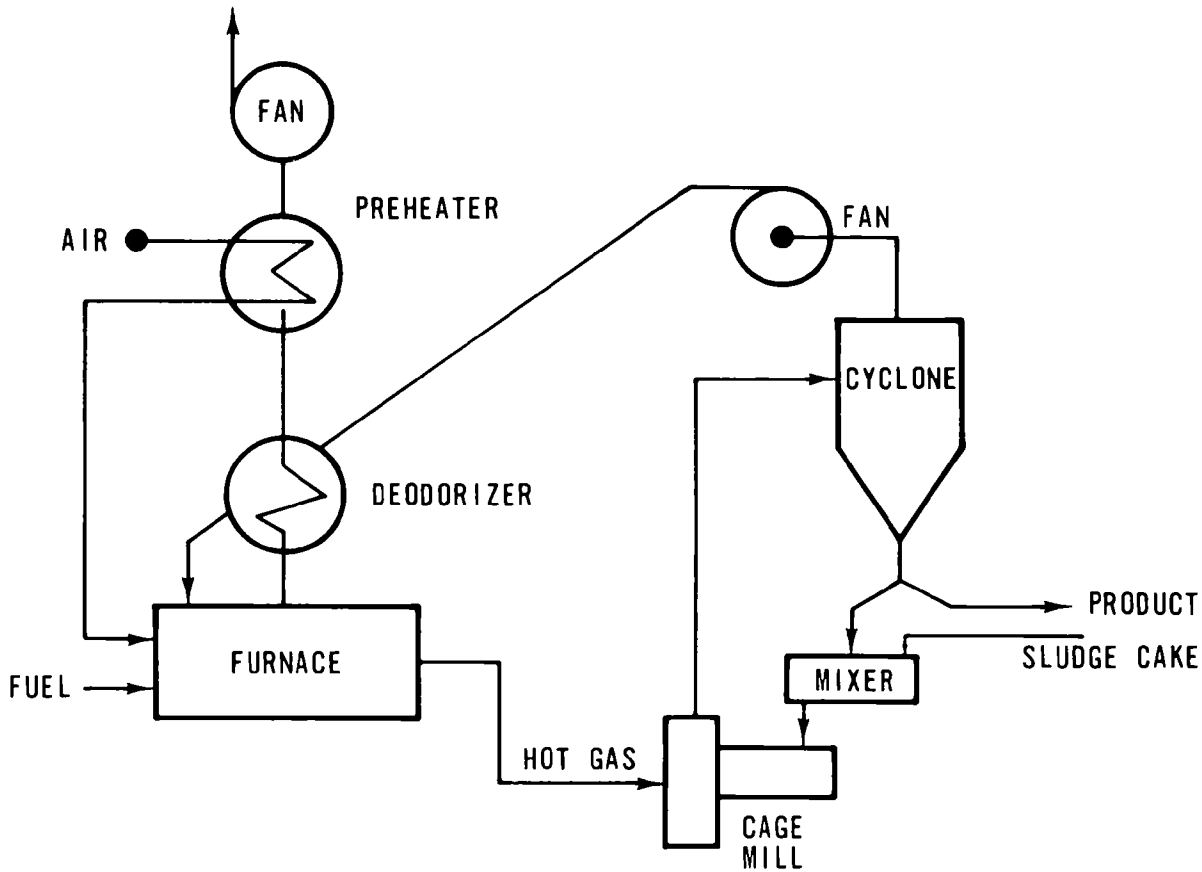


FIGURE 8 - 3

SECTION 9 – SLUDGE THICKENING AND BLENDING

1. Sludge Particles

- Heterogeneous mixture of various materials ranging from the size of colloids to the size of flocculated particles as shown in Table 9-1.

- Type of matter can be animal, vegetable or mineral and can be fibrous, granular or amorphous in shape.

- Particles can be hydrophobic (non-water loving) or hydrophilic (water loving). Hydrophilic particles, due to presence of polar groups such as hydroxyl, carboxyl, or amino, have a strong affinity for the water solvent and retain a sheath of water around the particles which tend to resist compaction.

- Surface charge of most particles such as paper fibers, bacterial cells, clays, sands, hydrated metal oxides, and the usual material found in wastewater is negative as shown in Figure 9-1.

- Behavior of the particles is dependent on their size, surface charge, solvation, and the temperature, pH, and ionic type and concentration of the water. But particles can have capability of adsorbing positive or negative charge as is also shown in Figure 9-1.

2. Sludge Blending

- Varieties of sludges are numerous primary, conventional activated, high rate activated, oxygen activated, trickling filter humus, with or without chemical addition in any of the above, then any of the foregoing may be raw, anaerobically digested, aerobically digested, chlorinated or heat treated. Just from the kinds above mentioned results in so many possible combinations as to boggle even a sanitary engineer's mind.

- Purpose of blending is to mix any two or three sludges that result from the various kinds of wastewater treatment to eliminate or minimize variation, eliminate duplication of facilities, and produce a decreased volume of sludge with a higher solids concentration.

- Important considerations
  All of the factors previously discussed under sludge particles are obviously important in sludge blending and thickening.

It is possible that blending will result in compaction as a result of particles interacting with each other just like particles and chemicals as shown in Figure 9-2.

On the other hand, it is possible that blending will result in only a minimum of compaction such as the case of the plant that blended primary sludge, waste activated final effluent, and centrate from the heat treated sludge. The resultant sludge thickened to a concentration of only 1 percent.

The question appears to be whether sludges should be blended to result in thickening, or thickened and then blended for further processing. The latter is called for in the design of the expansion at Washington, D.C., where activated sludge will be thickened separately by flotation and primary sludge will be thickened in gravity thickeners, and the two sludges will be blended enroute to vacuum filtration.

3. Gravity Thickening (Sedimentation)

- Gravity thickening has produced results that range from good to fair to mediocre. Table 9-2 shows sludge concentrations obtained in primary settling tanks with and without polymer used for raw sewage flocculation. Although polymer improved the efficiency of suspended solids removal in all five plants, the polymer increased sludge concentration in only four of the five plants.

- Table 9-3 shows gravity thickening data for three types of sludges. Note the effect of "picket-type" thickener and the difference in the thickened sludge solids for the two primary + activated sludges.

- Table 9-4 shows gravity thickening data for waste activated sludges. Note again the effect of "picket-type" thickener and the effect of SVI on the thickened sludge concentration. The oxygen sludge indicates better thickening, but also shows a wide range in the solids loading parameter indicating the variability of the sludges even from an oxygen activated sludge process.

- Gravity thickening was formerly accomplished in anaerobic digesters which produced thickened solids from the bottom and relatively low suspended solids in the straw-colored supernatant. However, the present mode of operation blends sludges in the digester not only physically but mechanically. This produces sludge that does not settle completely in the secondary digester and thus produces a supernatant that is usually a sludge of only slightly lower solids concentration than the digester underflow.

- An alternate or additional problem resulting from the digested sludges is the decreased efficiency of solids capture in elutriation. But with the advent of new polymer chemicals, solids capture and thickening are again being accomplished with these sludges in elutriation as shown in Table 9-5.

- Satisfactory supernatant production was accomplished in at least two cases by dosing the sludge being transferred to the secondary stage digester with cationic polymer.

4. **Flotation Thickening**

- Flotation is the opposite of gravity thickening – the solids are caused to float due to attachment and entrapment of fine air bubbles. Usually one volume of water saturated with air at 40 psig will provide sufficient air bubbles to float the solids in an equal volume of sludge containing suspended solids at a concentration of 5,000 mg/l.

- Table 9-6 shows one compilation of data on flotation thickening of activated sludge without chemical conditioning.

- Table 9-7 shows a compilation of data on flotation thickening of a combination of primary and activated sludge without chemical conditioning.

- Table 9-8 depicts data on flotation thickening of activated and contact stabilization sludges with chemical conditioning. Note that solids capture with chemical is usually 99 percent in contrast to 83–99 percent range without chemicals. The chemical costs appear to be a fair representation, although one plant has a chemical cost as low as $2.50/ton while another plant has a cost as high as $12/ton.

- It should be noted that flotation with chemicals effects only marginal increase in thickened sludge concentration, but use of chemicals does permit a 100 pe[illegible] to 300 percent increase in solids loading and about a 10 percent in[illegible]ntal increase in solids capture. The latter may be or may not be an imp[illegible]ant consideration in a given plant regarding recycle of solids.

- It should also be noted that the usual chemical used in flotation was a cationic polymer. However, anionic polymer is also sometimes effective and should not be overlooked. This was recently demonstrated at one plant when a metal salt addition to the activated sludge was implemented for operation improvement purposes. This changed the sludge characteristics which required use of an anionic polymer to condition the sludge for flotation, but it appears that there was also a decrease from 8 percent to 6 percent in the floated sludge concentration. In another plant the sludge responded equally to either cationic or anionic polymer conditioning, so that choice could depend in such cases on the relative costs of the two chemicals.

5. Centrifugal Thickening

- Centrifugal thickening is accomplished by utilizing centrifugal force which can be developed in a centrifuge to exert the equivalent of 2,000 times the force of gravity that was utilized in gravity thickening previously discussed.

- Table 9-9 shows operational data of two types of centrifuges on activated sludge.

- Although the data in previous Table 9-8 indicate 50 percent operating efficiency for the disc-nozzle type centrifuge, it is still being used and there is at least one industrial application of the same type machine where activated sludge is thickened to 4.0 percent solids concentration.

6. Considerations in Design for Thickening

- Provide variable speed sludge pumps so that blending and thickening can be continuous.

- Provide for possible use of chemicals. Install chemical injection taps into pipelines at points where sludges meet, or water and sludge meet, and also into dilution water line upstream of where water meets the sludge. Install tap for chemical injection immediately downstream of the pressure reducing valve or the water line in the case of dissolved air flotation. Piping design should provide for good mixing of water, sludge and polymer, and then minimum of turbulence and shear to prevent deflocculation.

LIST OF FIGURES AND TABLES – SECTION 9

Table 9-1	Relative Sizes of Suspended Particles
Figure 9-1	Charged Particle
Figure 9-2	Polymer and Particle Interactions
Table 9-2	Polymer Effect on Primary Sludge Solids Concentration
Table 9-3	Gravity Thickening Data
Table 9-4	Gravity Thickening Data
Table 9-5	Elutriation
Table 9-6	Flotation Thickening – Activated Sludge (No Chemical)
Table 9-7	Flotation Thickening – Primary and Activated Sludge (No Chemical)
Table 9-8	Flotation Thickening – Activated Sludge
Table 9-9	Centrifugal Thickening – Activated Sludge

RELATIVE SIZES OF SUSPENDED PARTICLES

Class	Diameter, mm
Colloidal	0.000001 - 0.001
Dispersed	.001 - .1
Coagulated	.1 - 1.
Flocculated	1. - 10.

TABLE 9-1

CHARGED PARTICLE

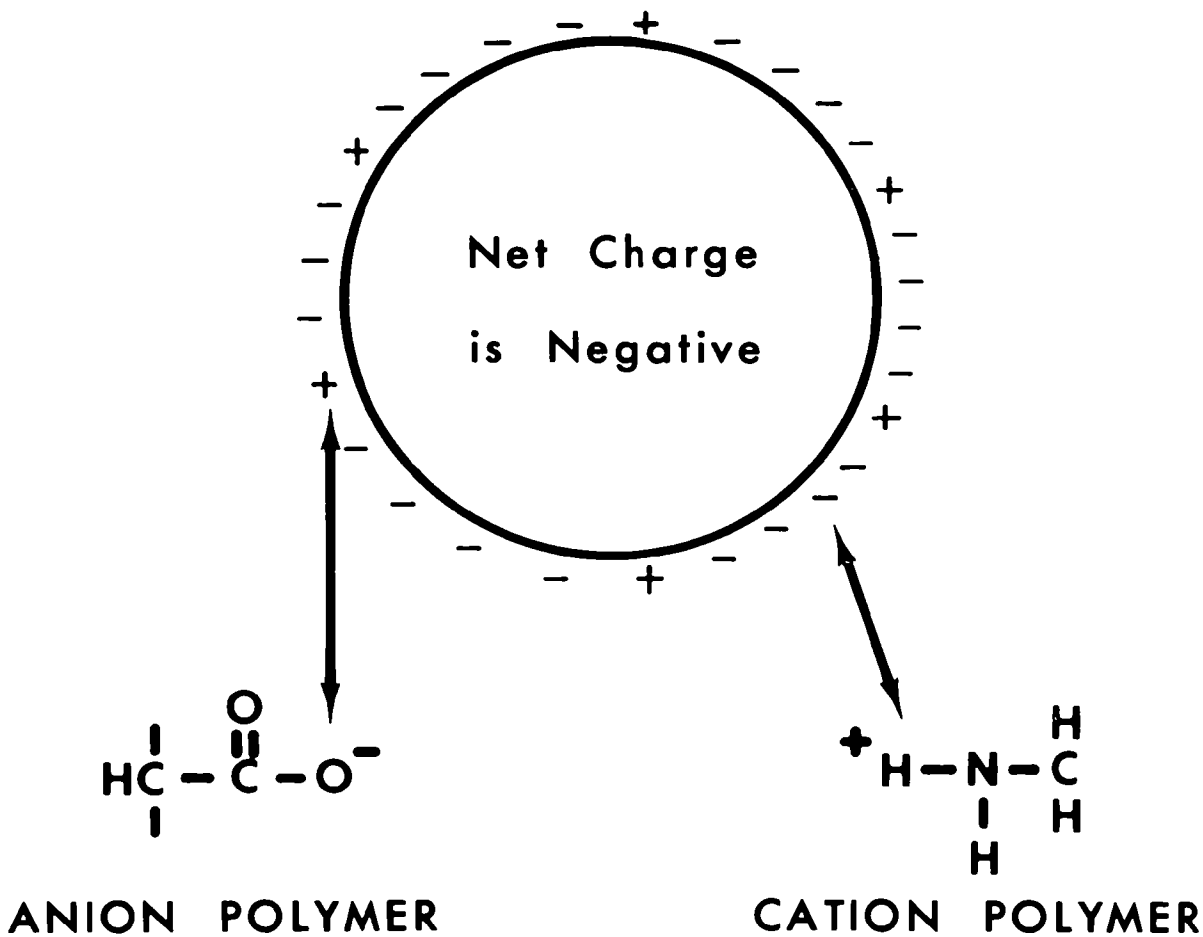


FIGURE 9-1

POLYMER AND PARTICLE INTERACTIONS

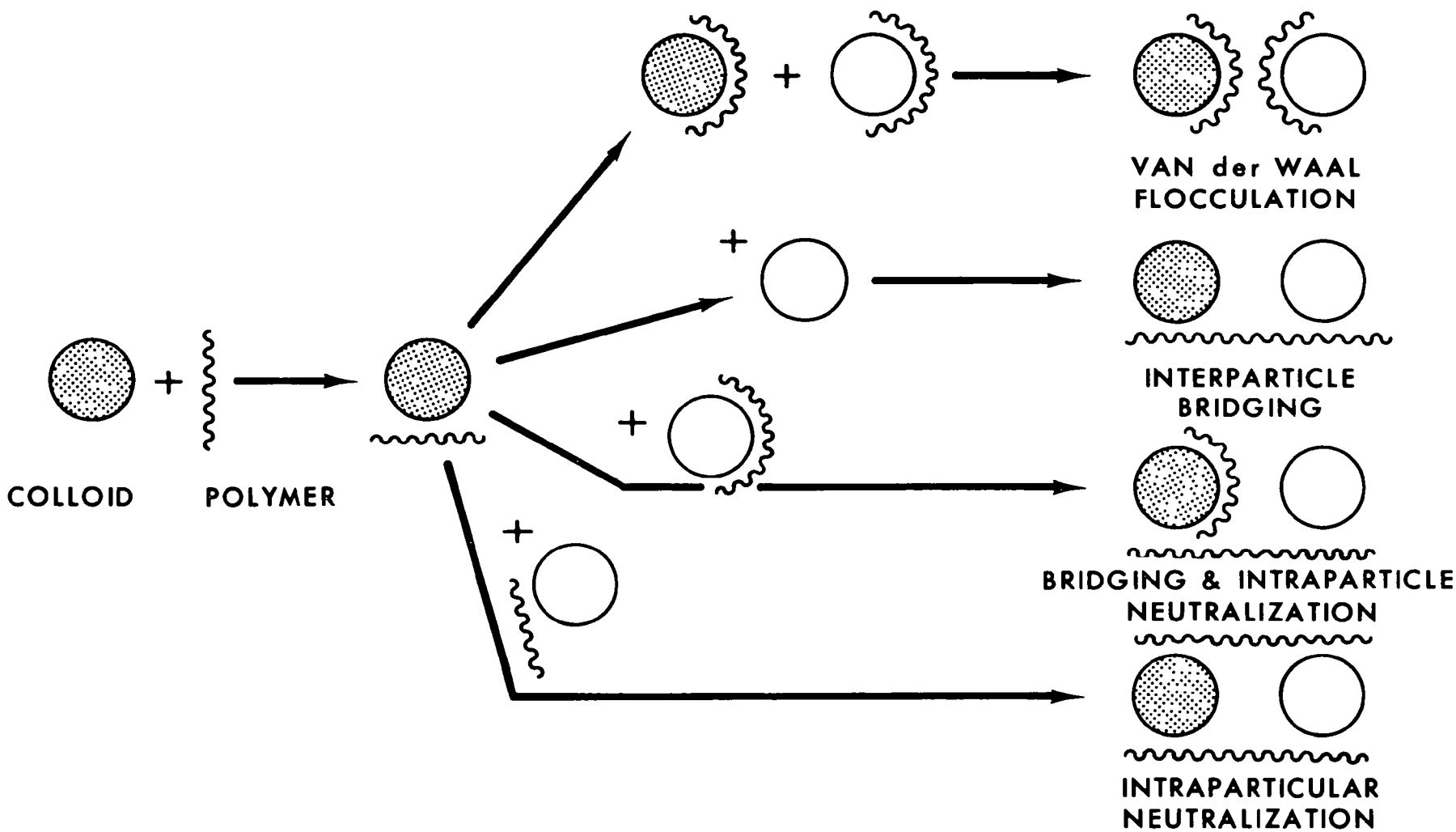


FIGURE 9-2

POLYMER EFFECT ON PRIMARY SLUDGE
SOLIDS CONCENTRATION

Plant No.	% Total Solids in Primary Sludge		% Increase
	Without RSF	With RSF	
1	3.4	4.7	38
2	4.6	7.5	63
3	6.6	6.6	-
4	7.9	9.0	14
5	6.0	8.2	36

TABLE 9-2

GRAVITY THICKENING DATA

FEED SLUDGE		SOLIDS LOADING	THICKENED SLUDGE
TYPE	% SOLIDS	LB/FT^2/DAY	% SOLIDS
PRIMARY	0.2 - 0.6	13 - 31	4 - 5
PRIMARY + ACTIVATED	0.2 - 1.2	3 - 38	4 - 8
PRIMARY + ACTIVATED	1.1	20	3.3 (4.4)*
TRICKLING FILTER	-	8 - 10	7 - 9

*RESULTS IN () OBTAINED WITH "PICKET-TYPE" THICKENER

TABLE 9-3

GRAVITY THICKENING DATA

FEED SLUDGE		SOLIDS LOADING	THICKENED SLUDGE
TYPE	% SOLIDS	LB/FT^2/DAY	% SOLIDS
WASTE ACTIVATED	0.8	-	3.5
WASTE ACTIVATED (SVI = 74)	1.05	21	1.8 (3.0)*
WASTE ACTIVATED (SVI = 97)	0.87	20	1.4 (2.8)*
WASTE ACTIVATED	0.5 - 0.8	-	1.2 - 1.7
OXYGEN ACTIVATED	1.5 - 3.5	7 - 34	4.0 - 8.0

*RESULTS IN () OBTAINED WITH "PICKET-TYPE" THICKENER

TABLE 9-4

ELUTRIATION

Chemical Treatment	% Elutriated Sludge Suspended Solids	Elutriate (ppm) Suspended Solids	% Solids Capture
None	3.5	3,835	65.1
Anion Polymer 1.6 lb/ton	4.3	365	95.3

TABLE 9-5

FLOTATION THICKENING

ACTIVATED SLUDGE (NO CHEMICAL)

Feed Sludge % Solids	Thickened Sludge % Solids	Solids Capture %
0.81	3.3	85.0
0.77	3.7	99.0
0.45	4.6	83.0
0.77	4.1	90.0
0.80	6.5	93.0
0.46	4.0	88.0

TABLE 9-6

FLOTATION THICKENING

PRIMARY AND ACTIVATED SLUDGE (NO CHEMICAL)

Feed Sludge % Solids	Thickened Sludge % Solids	Solids Capture %
2.30	7.1	94.0
1.77	5.3	88.0
0.64	8.6	91.0

TABLE 9-7

FLOTATION THICKENING
ACTIVATED SLUDGE

Sludge Feed		Solids Loading	Thickened Sludge	Solids Capture	Chemical	
Type	% Solids	$lb/ft^2/day$	% Solids	%	Type	$/T
Activated	1.19	3.9	5.0	99.7	Cat. Pol.	4.50
Activated	0.8 - 0.9	2.5	3.5 - 6.5	99.0	Cat. Pol.	4 - 5
Activated	0.5 - 0.7	2.8 - 4.2	4.1 - 5.5	99.0	Cat. Pol.	6 - 8
Cont. Stab.	1.2	3.3	6.6	97.8	Cat. Pol.	6.00
Cont. Stab.	1.3	3.2	6.4	99.6	Cat. Pol.	4.50

TABLE 9-8

CENTRIFUGAL THICKENING
ACTIVATED SLUDGE

Type	Feed GPM	Feed Solids	Cake % Solids	Centrate % Solids	Capture %	Chemical	Cost $/Ton
Solid Bowl	50	0.7	5 - 7	0.1 - 0.2	79 - 84	5 Cation Polymers	10 - 18
DISC	50	0.7	5	0.1 - 0.2	85	None	*

*Daily disassembly required to unplug nozzles

TABLE 9-9

SECTION 10 – SLUDGE DEWATERING

1. Definition

   – Sludge dewatering in this discussion means further dewatering of slurries to change the physical form of the sludge from a slurry or liquid to a cake which should be a solid. However, some sludge filter cakes are not quite solid enough to keep from splashing when the cakes drop from the filter media onto a conveyor belt.

2. Purpose

   – Reduce volume occupied by the solids in case of disposal of sludge cake.

   – Reduce water associated with the solids in case of disposal by incineration.

   – Change the physical form from liquid to solid for handling purposes.

3. Chemical Sludge Conditioning

   – Very few wastewater sludges will dewater without any treatment.

   – Inorganic chemicals have been used for many years. The most notable have been iron chloride, calcium oxide, iron sulfate, alum, aluminum chloride. These chemicals are effective in most cases, but history tells us that there have been many failures in the past and we even see them performing poorly in certain plants today.

   – The need for something better than the inorganic chemicals led to the development of water soluble polymers for sludge conditioning. Polymers are water soluble, high molecular weight organic chemicals that are available in nonionic (no formal electrical charge), anionic (negatively charged), or cationic (positively charged). These polymers can be made in a variety of charge densities and a variety of molecular weights.

   – Other additives that are sometimes used in sludge filtration are fly ash, furnace ash, and diatomaceous earth. Even rice hulls have been used as a sludge filtration aid as well as paper pulp.

   – Considerations for design of sludge conditioning process and equipment should include laboratory and pilot plant studies, provide flexibility in the equipment so that a variety of conditioning materials could be used, provide variable speed

agitators and conditioning tanks where plug flow can be observed and conditioning agents can be added easily in a variety of points along with the conditioning tank for observation, provide for gentle open trough handling of conditioned sludges rather than through pipelines; avoid high shear of conditioned sludge, provide ratio control of conditioning chemical to sludge and also ratio control of water to sludge where polymers may be used.

4. Dewatering Equipment and Results

- Vacuum Filters.

  Coil filter, drum filter, and belt filter are three basic types. Coil filter and belt filter have continuous washing of the media, but usually not found on a drum filter. Drum and belt filters offer opportunity to change type of media but this is not easily done with a coil filter. Drum filters have air blow-back feature to aid in cake release and coil filter has tines to aid in cake release and cake discharge. Drum filter also has "doctor" blade for cake discharge. Belt filters have had successful and also some troublesome cake discharge problems even with "doctor" blades and "filppers" or beaters. The coil filter may produce a dirtier filtrate than a drum or belt filter since the media cannot be changed.

  All three types have been used with sludges conditioned with polymers as well as inorganic chemicals.

  Tables 10-1 through 10-7 show sludge filtration data obtained with various types of filters on various types of sludges with comparative performance on polymer conditioned sludge and sludge conditioned with $FeCl_3$ and CaO.

  Considerations in design for vacuum filtration should take into account the following the conditioned sludge to the filter pan should be distributed in more than one or two points – this is especially important with regard to low solids concentration sludges, the under-filter agitator should have a variable speed drive – How can a designer possibly know in advance the optimum speed? – make it variable and give the operator some leeway for adjustments and compensations, the eccentric which determines the length of the swing of the under-filter agitator should have provision for variability. Some filters provide no variability, others provide limited variability, proper level control of sludge in the filter pan should be provided so as to maintain continuous sludge conditioning and filtration, filtrate pumps should be of adequate capacity to accommodate as much as a 40 percent dilution factor when water is used with polymers, vacuum pump capacity should be adequate enough to maintain good vacuum even with more porous cakes which can result with some sludges with polymer or inorganic chemical conditioning, filter valve bridge blocks should be provided for adjustment as necessary in the field.

- Centrifuges There are three basic types – horizontal solid bowl with scroll, disc type with nozzles, and basket type.

  The horizontal solid bowl is the most widely used in wastewater sludge dewatering. This type of centrifuge can be put on the line and left to operate with only occasional attention. The efficiency of this type of centrifuge can be greatly increased by use of polymers. Internal feed of polymer has been found to reduce polymer dose and appears to be very beneficial.

  Figures 10-1 through 10-7 show performance data with horizontal solid bowl centrifuge on several sludges and the effect of various polymers.

  The disc type centrifuge is like the old farm cream separator. It is used for thickening of activated sludge but has the disadvantage of nozzles which seem to get plugged easily. Screening of the sludge has been tried with some success and at lease one installation uses a disc type for thickening to 4 percent solids in series with a horizontal bowl type which dewaters to about 20 percent solids. No polymers are used with the disc type. Table 10-7 shows comparative data of a disc centrifuge and solid bowl type.

  The basket type has recently been evaluated and reported to be in contention. Polymers may or may not be used with this type machine which can be automated even though it operates on a batch cycle.

- Sandbeds have been used for sludge dewatering for many years. The more sophisticated type sludges of today, no doubt, have not been dewatering as well as the digested sludges of yesteryears. But that is because present day digested sludges are not very dewaterable without conditioning.

  Figures 10-4 through 10-6 show effects of polymer conditioning on digested sludge and digester supernatant.

- Press filters, moving bed filters, rotating cylindrical screens and capillary type dewatering devices are marketed in this country, but no large installations are in operation as yet.

5. Polymer Preparation Equipment

- Since polymers are useful and sometimes necessary for sludge conditioning, perhaps a discussion of polymer preparation equipment is in order.

  Polymers are available as dry flakes or powders and also as liquids.

  Preparation of liquid polymers presents no problem because they mix with water very readily.

Preparation of dry polymers is not difficult but care must be taken when contacting the dry polymers with water. Unless each polymer particle is quickly and thoroughly wetted, the particles stick together to form aggregates of particles from the size and appearance of fish eyes to slubs as large as golf balls or even larger.

To provide means for preparing solutions of dry polymers, polymer manufacturers have developed manual devices and automatic equipment. Also chemical feed equipment manufacturers have developed their own lines of automatic equipment to meet the needs of the field.

Figures 10-7 through 10-11 depict schematics of manual and automatic dry polymer dispersing systems and a liquid polymer preparation and feed system.

Several manufacturers of automatic equipment for handling and preparing solutions of dry polymers are listed below.

Acrison, Inc., Carlstadt, New Jersey
BIF Corporation, Providence, Rhode Island
Chemix Corporation, Troy, Michigan
Wallace & Tiernan, Belleville, New Jersey

Several polymer manufacturers also market automatic equipment for preparing solutions of dry polymers and these are listed below

Calgon Corporation, Pittsburgh, Pennsylvania
The Dow Chemical Company, Midland, Michigan
Hercules Inc., Wilmington, Delaware

6. Physical Sludge Conditioning

- Freezing is an effective technique for conditioning sludge for dewatering but no practical economical method has yet been worked out, although the literature cites a new method that is being investigated.

- Heat treatment is another effective method of conditioning sludge for dewatering. Midland, Michigan has a new heat treatment unit and heat treated sludge is filtered at the same yield as polymer conditioned sludge, but filter cake is drier.

This subject will be covered in more detail by other speakers.

LIST OF FIGURES AND TABLES – SECTION 10

Table 10-1	Vacuum Filtration Raw Primary Sludge Eimco Drum Filter, Open Synthetic Fiber Media
Table 10-2	Vacuum Filtration Elutriated Digested Primary Sludge Eimco Drum Filter, Napped Dacron Media
Table 10-3	Vacuum Filtration Elutriated Digested Primary and Secondary Sludge Dorr-Oliver Drum Filter, Napped Dacron Media
Table 10-4	Vacuum Filtration Raw Primary Sludge Komline-Sanderson Coilfilter
Table 10-5	Vacuum Filtration Elutriated Digested Primary Sludge Dorr-Oliver Drum Filter, Napped Dacron Media
Table 10-6	Vacuum Filtration Digested Primary Sludge Drum Filter 44 X 44 Saran Media
Table 10-7	Centrifuge Dewatering – Digested Primary and Secondary Sludge
Figure 10-1	Centrifugation of Primary Sludge
Figure 10-2	Centrifugation of Activated Sludge
Figure 10-3	Centrifugation of Primary-Activated Sludge Mixture
Figure 10-4	Digested Sludge Dewatered on Sand Drying Beds at Various Chemical Dosages
Figure 10-5	Sand Bed Dewatering – Digested Sludge (4%) + Cationic Polymer
Figure 10-6	Supernatant Dewatering on Sand Bed with Cationic Polymer
Table 10-8	Toronto Digested Sludge Centrifugation
Figure 10-7	Flocculant Feed System Utilizing Manual Dispersing Equipment and Separate Feed Tank

LIST OF FIGURES AND TABLES – SECTION 10

(Continued)

Figure 10-8	Disperser for Purifloc Flocculants (Cross-section)
Figure 10-9	Flocculant Feed System Utilizing Automatic Dispersing Equipment
Figure 10-10	Automatic Flocculant Disperser
Figure 10-11	Liquid Flocculant Feed System

VACUUM FILTRATION RAW PRIMARY SLUDGE
EIMCO DRUM FILTER, OPEN SYNTHETIC FIBER MEDIA

% SLUDGE SOLIDS	% CHEMICAL USED	% CAKE SOLIDS	FILTER YIELD (Lb./sq.ft./hr.)	CHEMICAL COST (Dollars/ton)
15	4.0 $FeCl_3$ 14.0 LIME	40	5.0	12.50
12	0.9 CATION POLYMER	30	7.0	8.00

TABLE 10-1

VACUUM FILTRATION ELUTRIATED DIGESTED PRIMARY SLUDGE EIMCO DRUM FILTER, NAPPED DACRON MEDIA

% SLUDGE SOLIDS	% CHEMICAL USED	% CAKE SOLIDS	FILTER YIELD Lbs/Ft^2/Hr	CHEMICAL COST $/TON
10.9	5.4 $Fe_2(SO_4)_3$	34	2.8	4.00
11.1	0.45 CATION POLYMER	35	5.5	3.70

TABLE 10-2

VACUUM FILTRATION ELUTRIATED DIGESTED PRIMARY & SECONDARY* SLUDGE DORR-OLIVER DRUM FILTER, NAPPED DACRON MEDIA

% SLUDGE SOLIDS	% CHEMICAL USED	% CAKE SOLIDS	FILTER YIELD Lbs/Ft^2/Hr	CHEMICAL COST $/TON
8.0	18 $Fe_2(SO_4)_3$ 6 LIME	28.0	5.1	9.00
9.0	1.1 CATION POLYMER	25.0	7.25	8.00

* ACTIVATED & TRICKLING FILTER

TABLE 10-3

VACUUM FILTRATION RAW PRIMARY SLUDGE
KOMLINE-SANDERSON COILFILTER

% SLUDGE SOLIDS	% CHEMICAL USED	% CAKE SOLIDS	FILTER YIELD (Lb./sq.ft./hr.)	CHEMICAL COST (Dollars / ton)
7.57	8.12 $FeCl_3$ 8.34 LIME	20.1	6.91	9.89
7.00	0.7 CATION POLYMER	20.0	7.53	6.50

TABLE 10-4

VACUUM FILTRATION ELUTRIATED DIGESTED PRIMARY SLUDGE DORR-OLIVER DRUM FILTER, NAPPED DACRON MEDIA

% SLUDGE SOLIDS		% CHEMICAL USED	% CAKE SOLIDS		FILTER YIELD Lbs/Ft^2/Hr	CHEMICAL COST $/TON
TOTAL	VOLATILE		TOTAL	VOLATILE		
10.4	39.8	5.0 $FeCl_3$	32.7	32.3	3.88	4.50
10.1	39.3	0.4 CATION POLYMER	38.6	38.2	5.94	3.20

TABLE 10-5

VACUUM FILTRATION DIGESTED PRIMARY SLUDGE

DRUM FILTER, 44 x 44 SARAN MEDIA

% SLUDGE SOLIDS	% CHEMICAL USED	% CAKE SOLIDS	FILTER YIELD LBS/FT^2/HR.	CHEMICAL COST $/TON
15	3.3 $FeCl_3$ 10.3 LIME	43	9.2	9.66
15	.85 CATIONIC POLYMER	32	25.0	7.60

TABLE 10-6

CENTRIFUGE DEWATERING
DIGESTED PRIMARY & SECONDARY SLUDGE

FEED SOLIDS %	MACHINE		CENTRATE SOLIDS %	CAKE SOLIDS %	REMOVAL EFFICIENCY %	CATION POLYMER LBS/TON
	RPM	LOADING GPM				
7.1	1500	10	3.8	14.6	46.5	—
7.3	1500	25	4.3	21.8	41.1	—
7.8	1500	10	0.2	15.8	97.5	10
7.7	1500	25	0.1	17.2	98.8	11.5

TABLE 10-7

CENTRIFUGATION OF PRIMARY SLUDGE

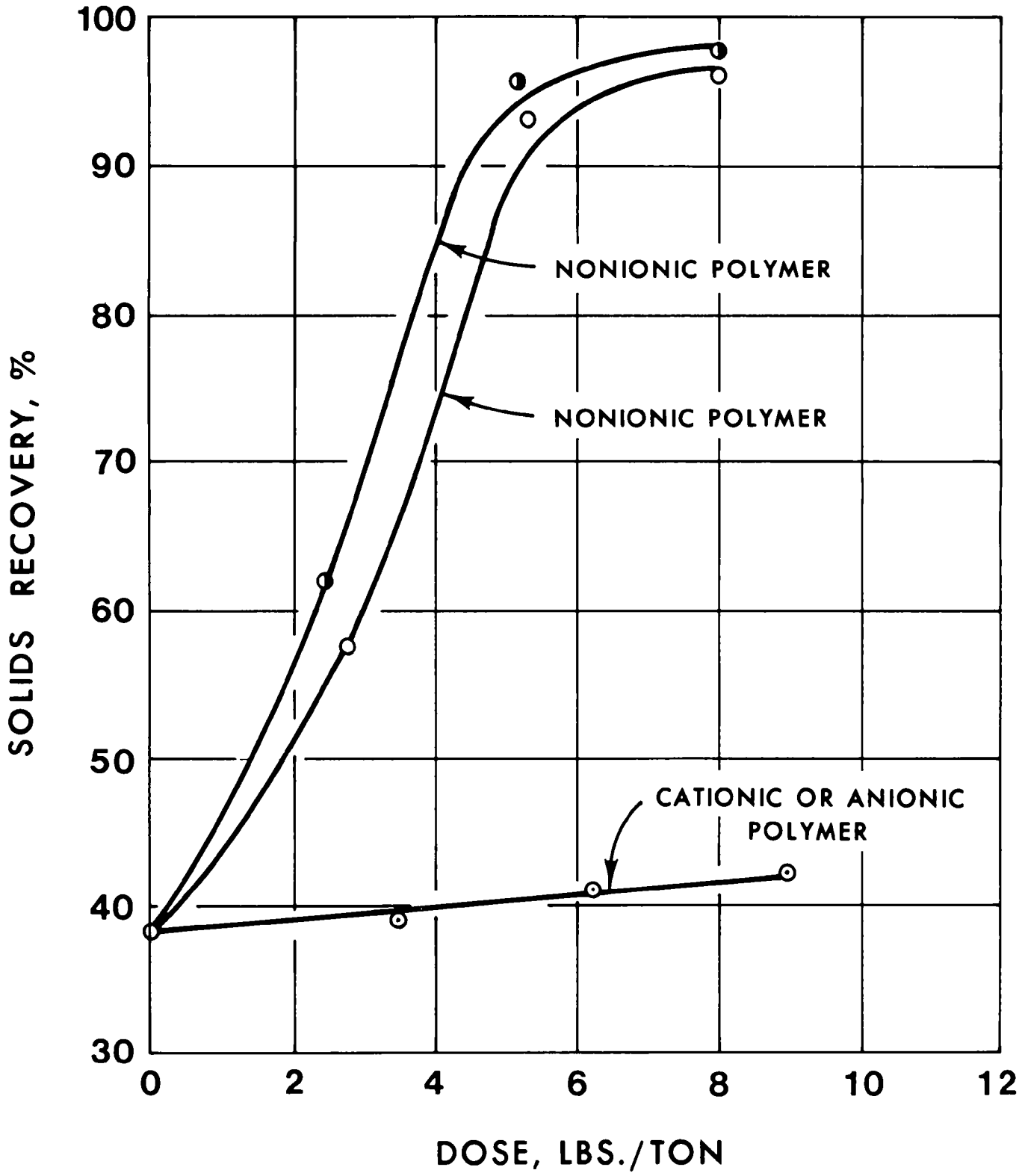


FIGURE 10-1

CENTRIFUGATION OF ACTIVATED SLUDGE

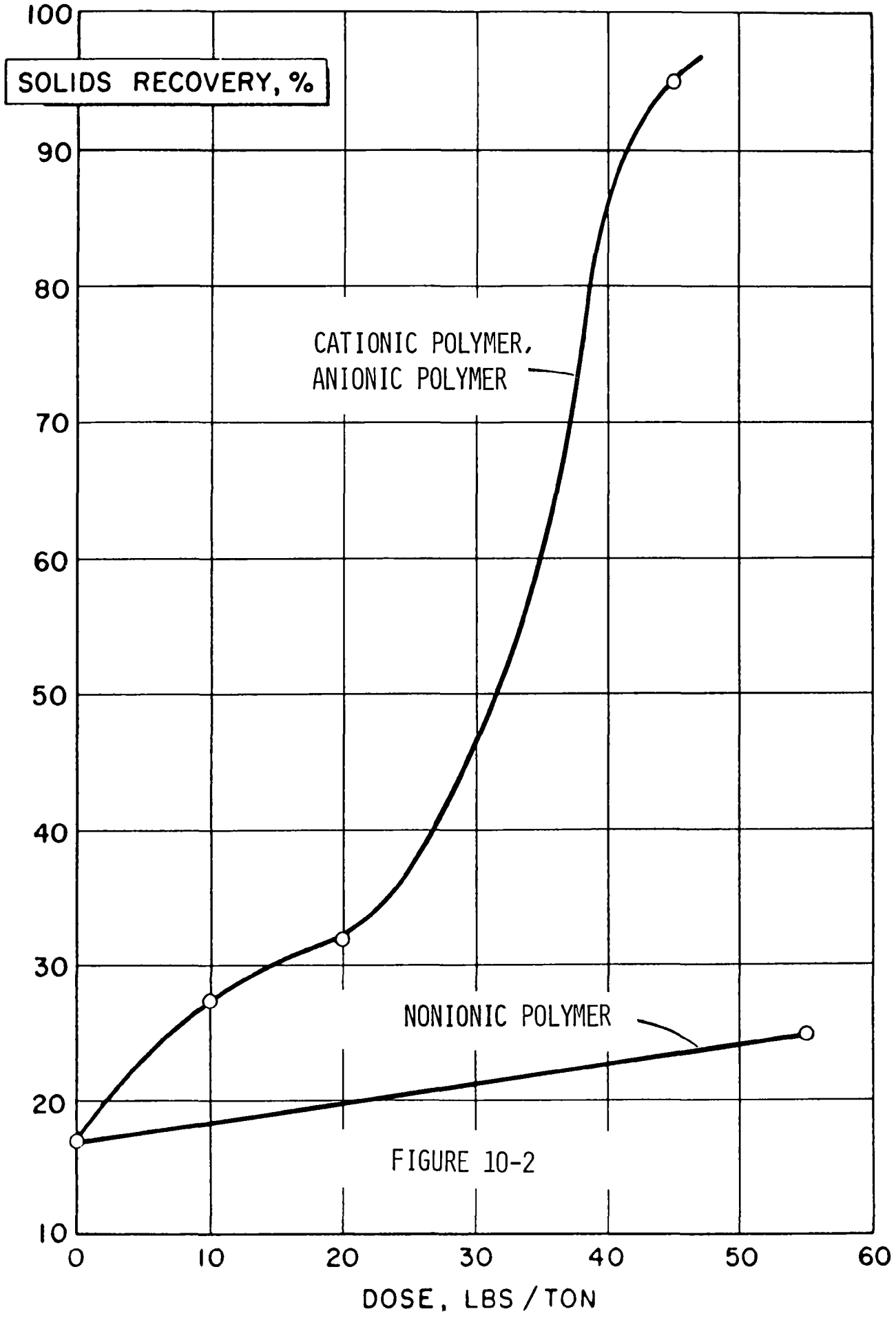


FIGURE 10-2

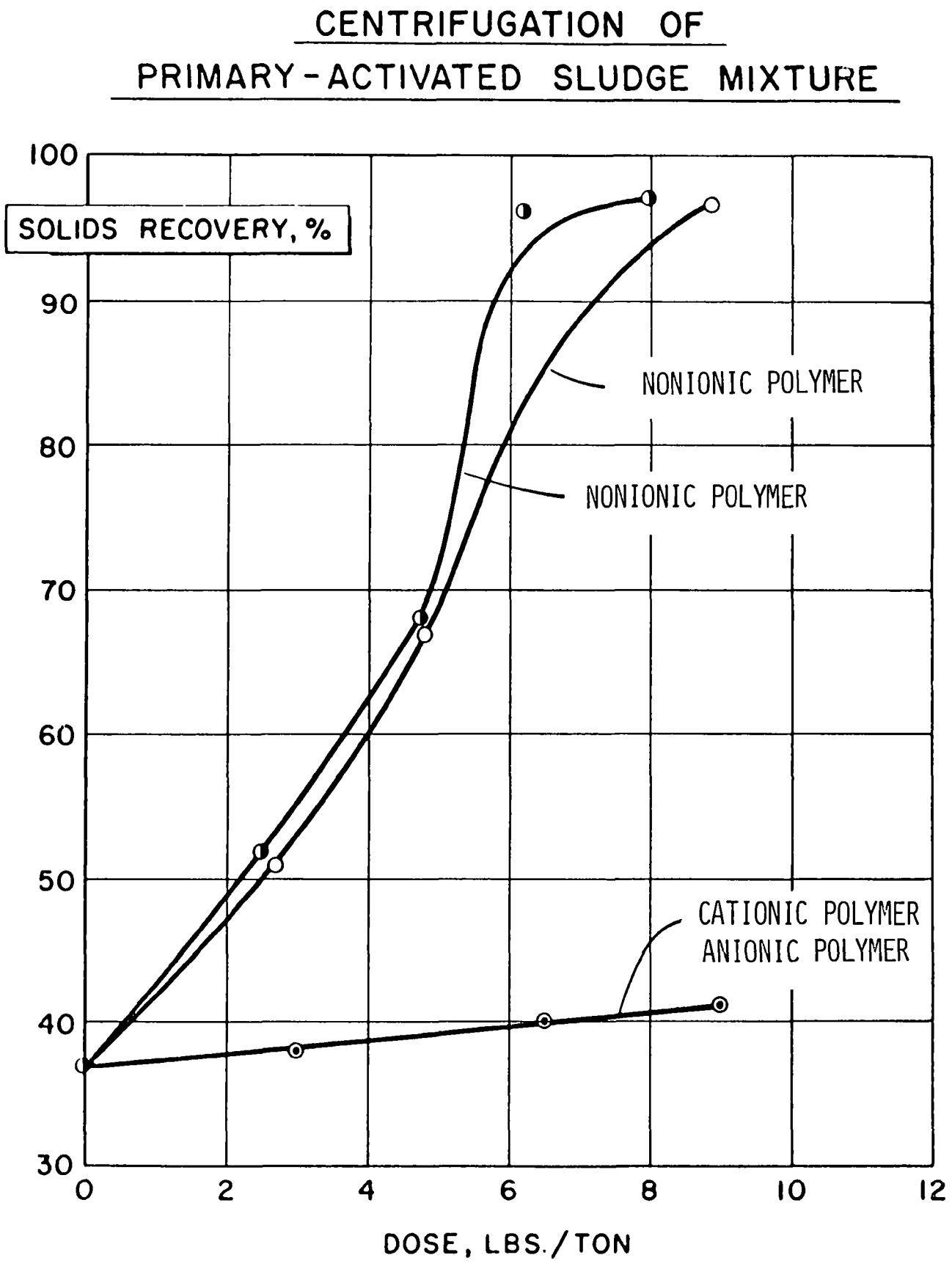

CENTRIFUGATION OF
PRIMARY-ACTIVATED SLUDGE MIXTURE
SOLIDS RECOVERY, %
100
90
80
70
60
50
40
30
0
2
4
6
8
10
12
NONIONIC POLYMER
NONIONIC POLYMER
CATIONIC POLYMER
ANIONIC POLYMER
DOSE, LBS./TON

FIGURE 10-3

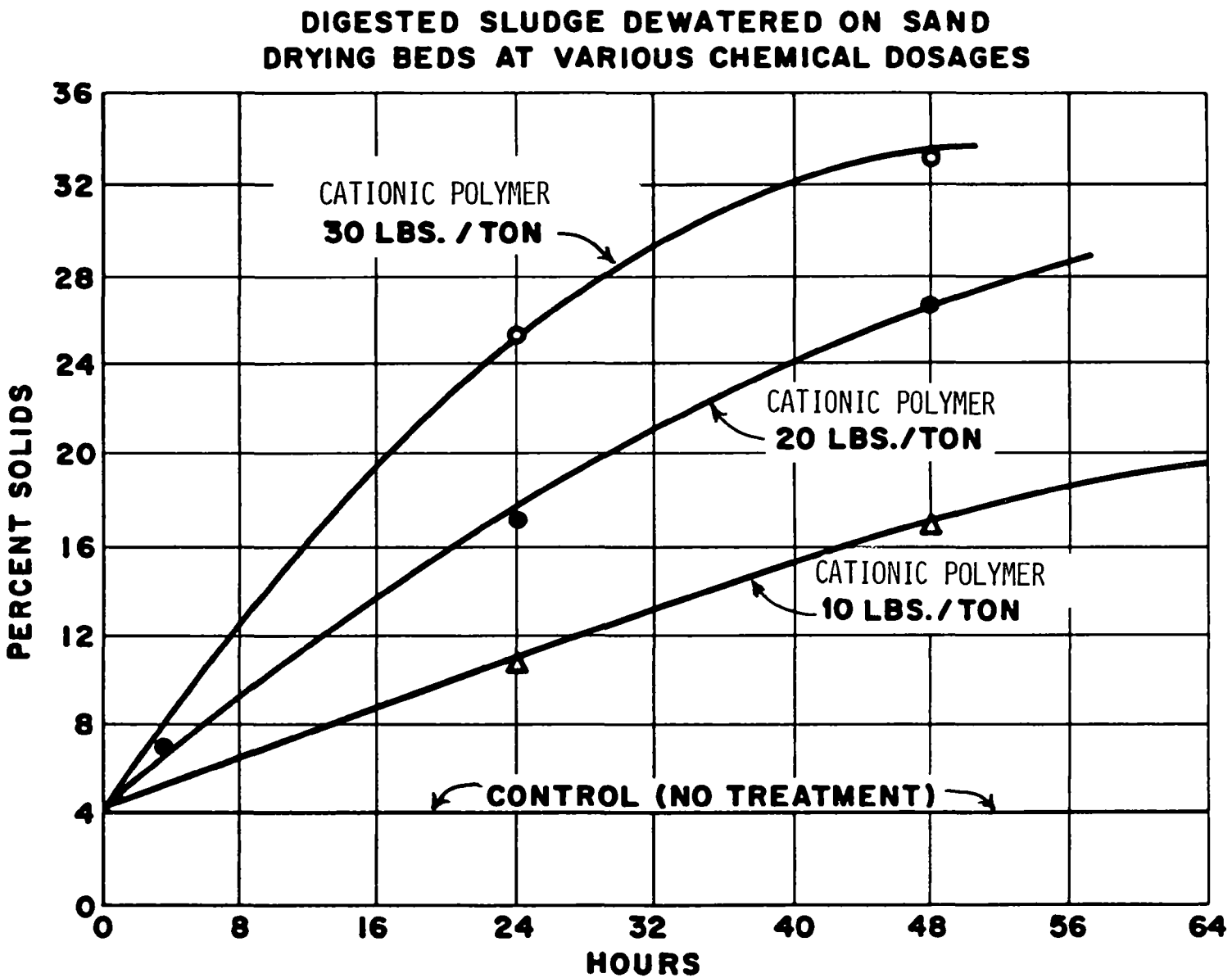

DIGESTED SLUDGE DEWATERED ON SAND
DRYING BEDS AT VARIOUS CHEMICAL DOSAGES
CATIONIC POLYMER
30 LBS. / TON
CATIONIC POLYMER
20 LBS./TON
CATIONIC POLYMER
10 LBS./TON
CONTROL (NO TREATMENT)
PERCENT SOLIDS
0
4
8
12
16
20
24
28
32
36
0
8
16
24
32
40
48
56
64
HOURS

FIGURE 10-4

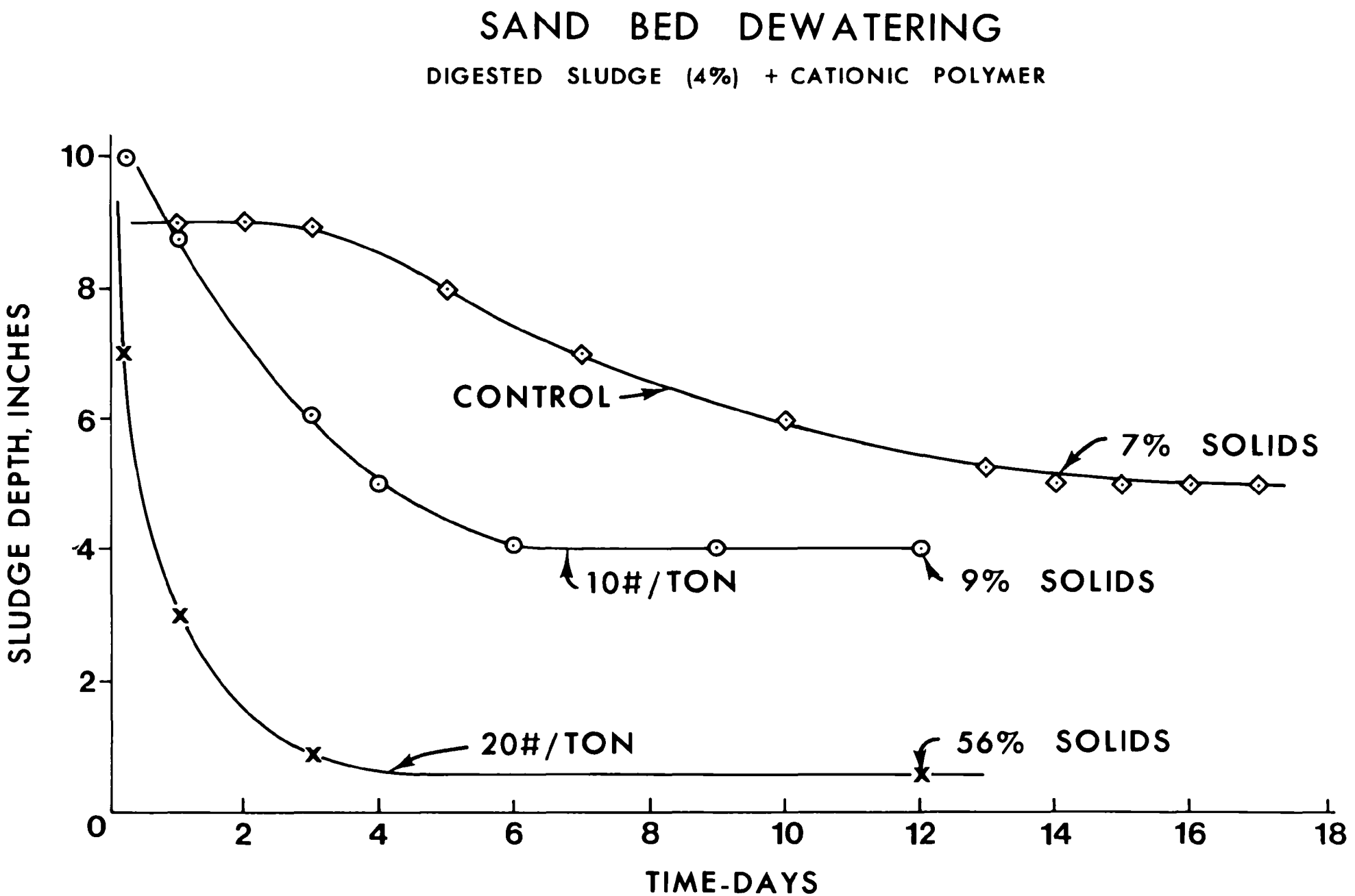

SAND BED DEWATERING
DIGESTED SLUDGE (4%) + CATIONIC POLYMER
SLUDGE DEPTH, INCHES
10
8
6
4
2
0
2
4
6
8
10
12
14
16
18
TIME-DAYS
CONTROL
7% SOLIDS
10#/TON
9% SOLIDS
20#/TON
56% SOLIDS

FIGURE 10-5

SUPERNATANT DEWATERING ON SAND BED WITH CATIONIC POLYMER

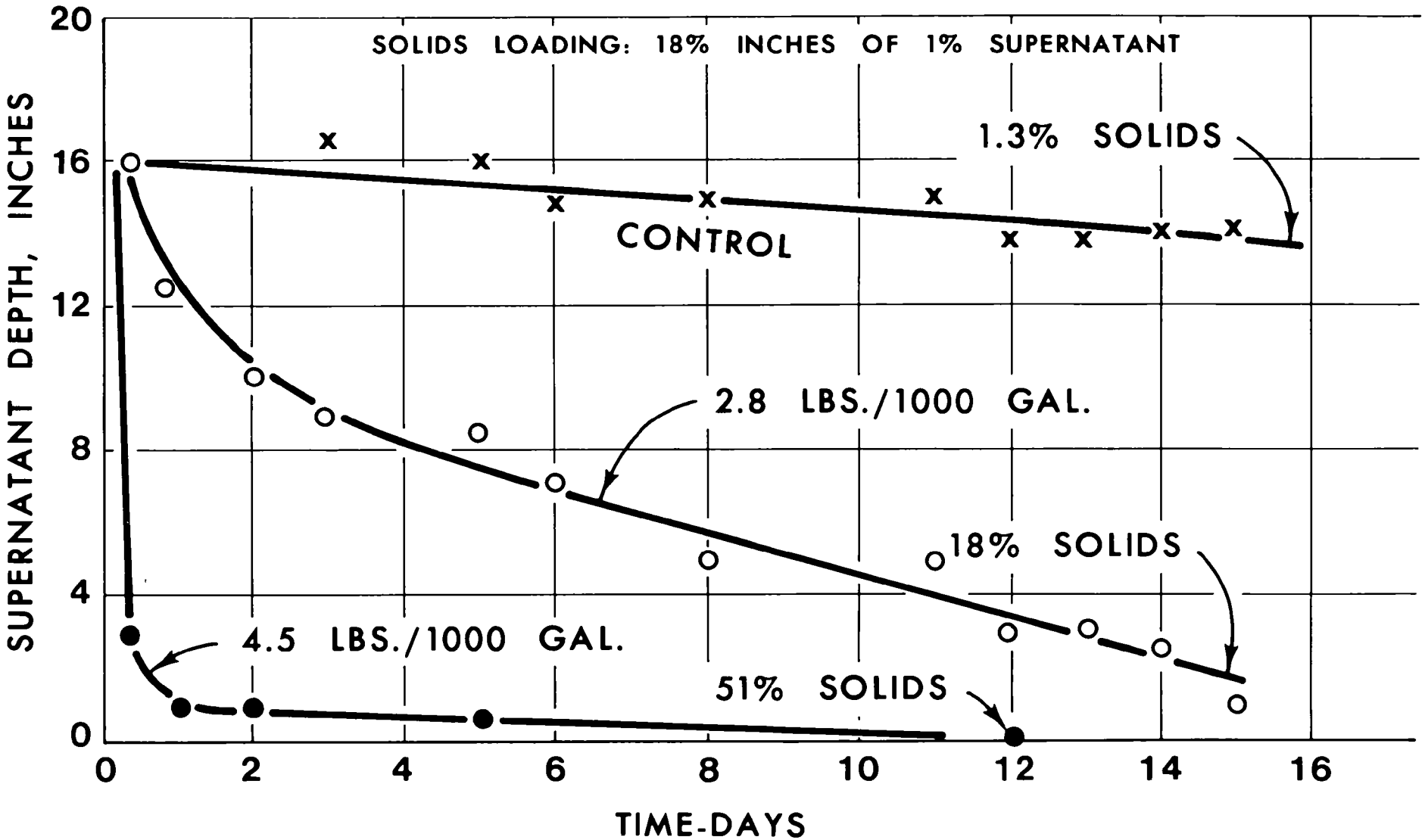


FIGURE 10-6

TORONTO

DIGESTED SLUDGE CENTRIFUGATION

SLUDGE FEED		CHEMICAL	CAKE	CENTRATE	COST
GPM	% SOLIDS	CONDITIONER	% SOLIDS	% SOLIDS	$/TON
40	4.0	CATIONIC POLYMER	15-17	0.2-0.8	18.00

TABLE 10-8

FLOCCULANT FEED SYSTEM UTILIZING MANUAL DISPERSING EQUIPMENT & SEPARATE FEED TANK

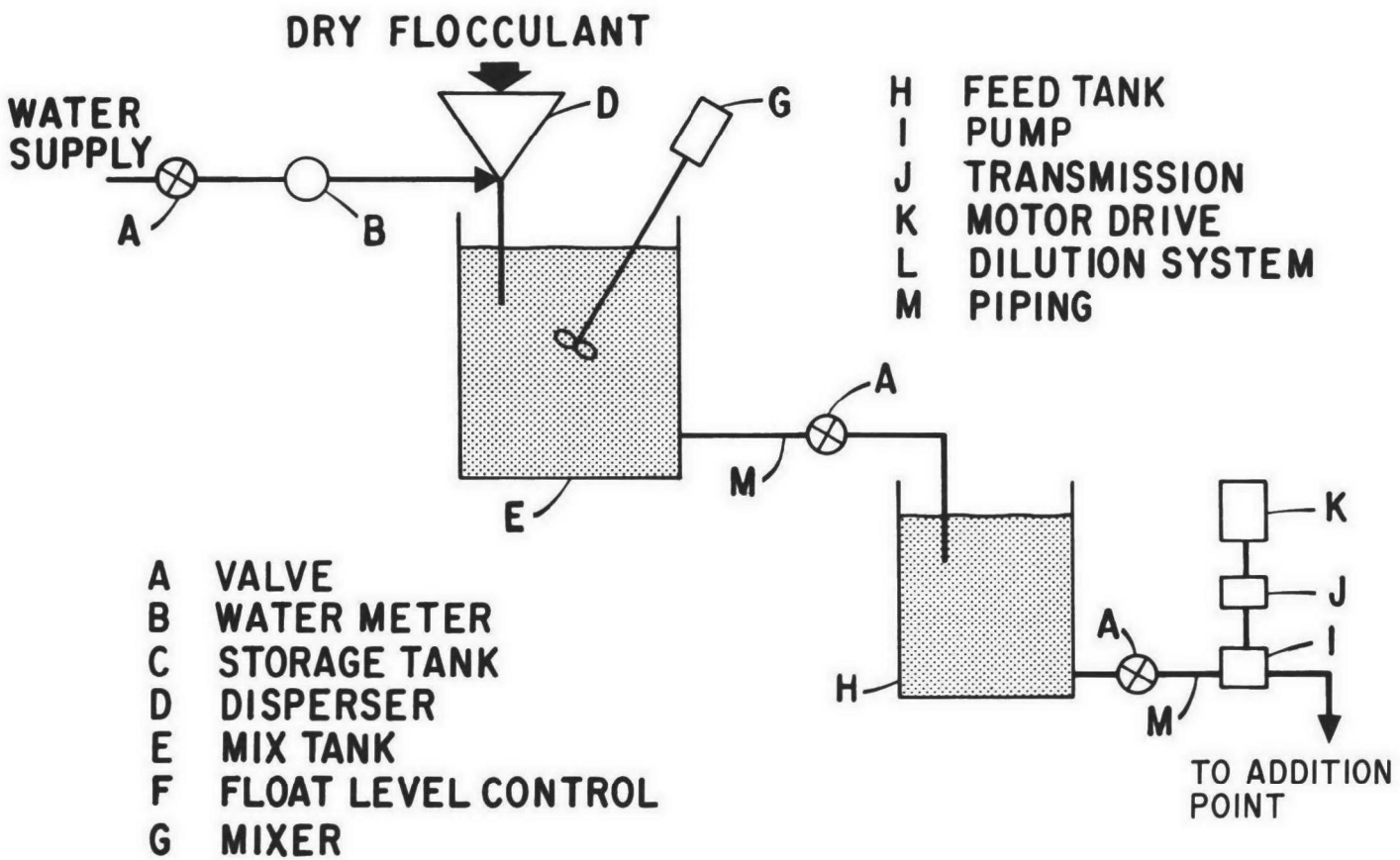
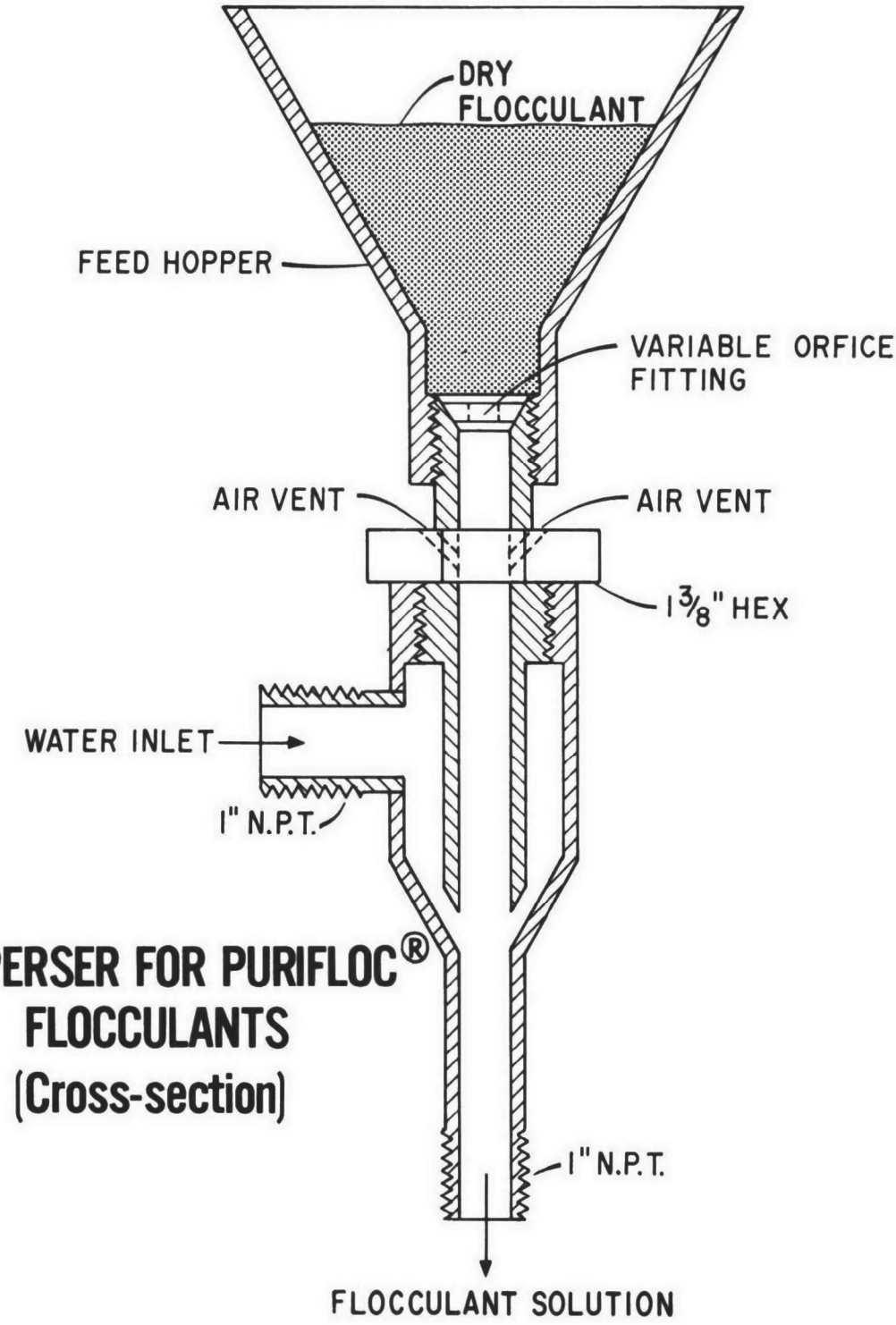


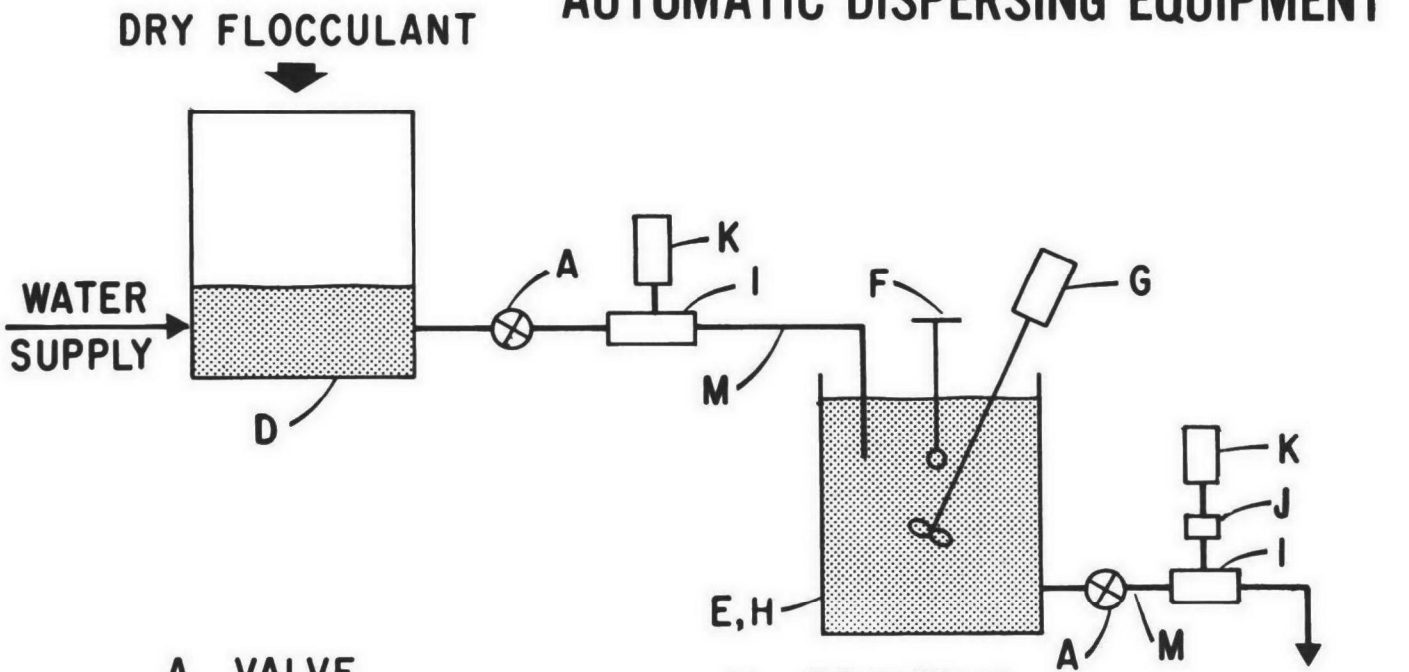
FIGURE 10-7



DISPERSER FOR PURIFLOC® FLOCCULANTS (Cross-section)

FIGURE 10-8

FLOCCULANT FEED SYSTEM UTILIZING AUTOMATIC DISPERSING EQUIPMENT



A	VALVE
B	WATER METER
C	STORAGE TANK
D	DISPERSER
E	MIX TANK
F	FLOAT LEVEL CONTROL
G	MIXER
H	FEED TANK
I	PUMP
J	TRANSMISSION
K	MOTOR DRIVE
L	DILUTION SYSTEM
M	PIPING

FIGURE 10-9

AUTOMATIC FLOCCULANT DISPERSER

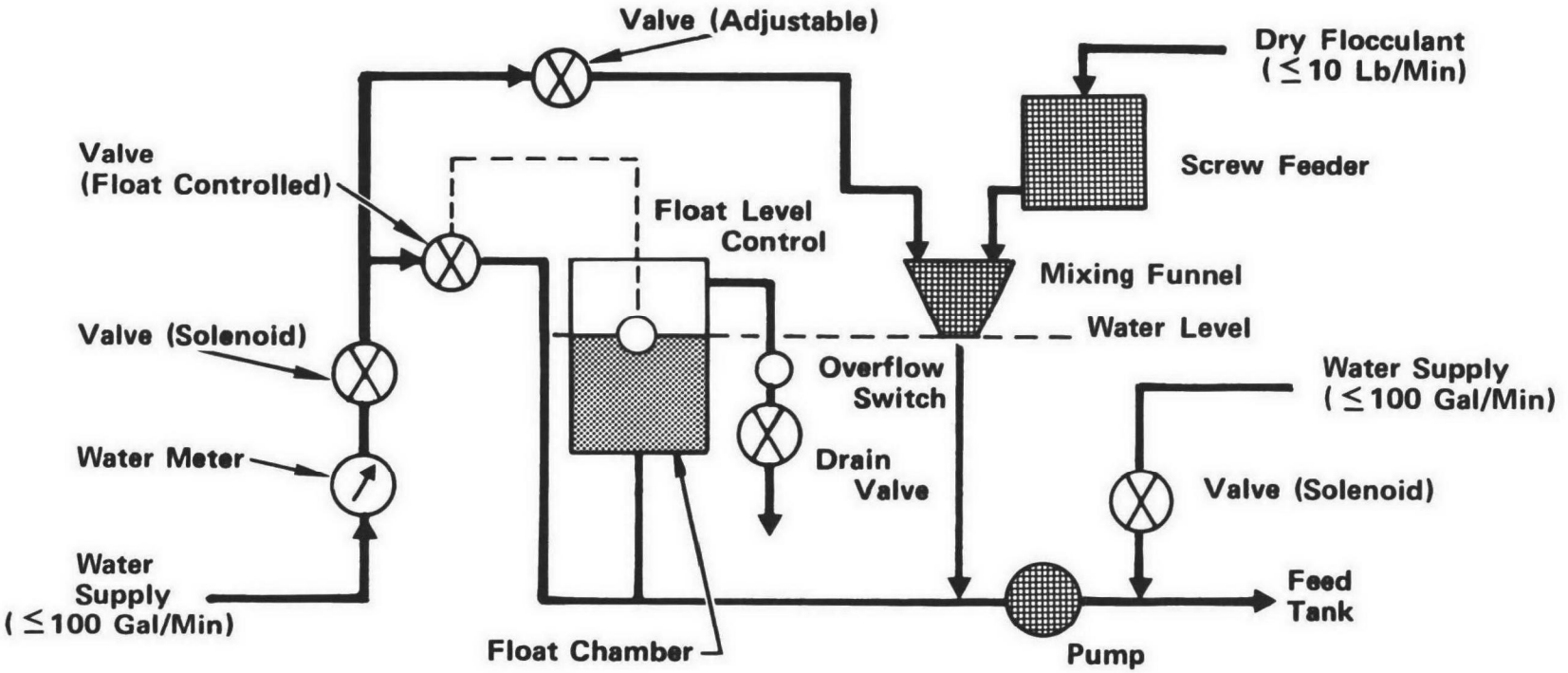


FIGURE 10 - 10

LIQUID FLOCCULANT FEED SYSTEM

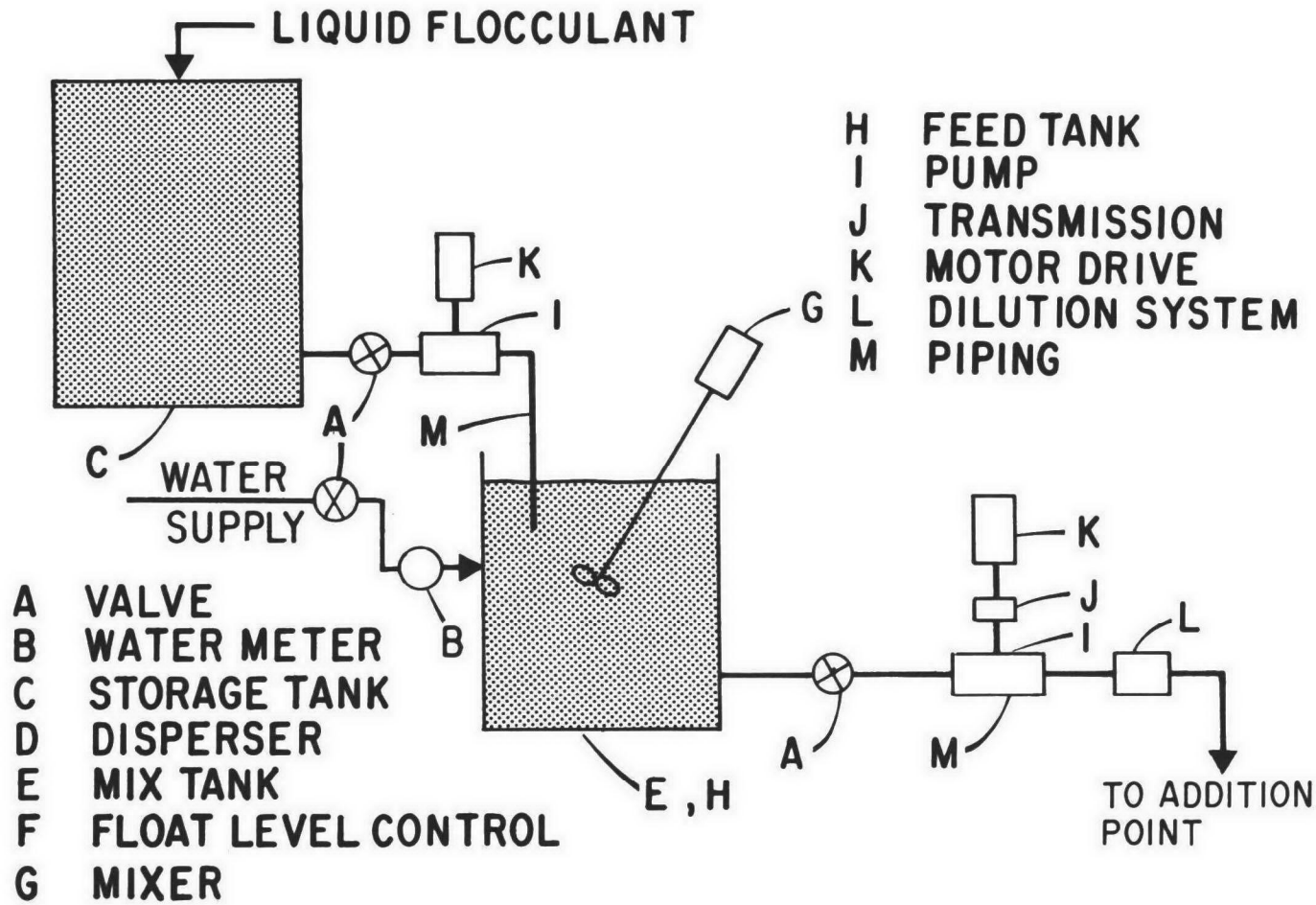


FIGURE 10-11