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. Joseph P. Farrell
National Environmental Research Center
Environmental Protection Agency
Cincinnati, Ohio

November 13–14, 1972
Royal Inn of Anaheim
Anaheim, California

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

TABLE OF CONTENTS

SECTION 1 – IMPORTANCE OF SLUDGE PROCESSING AND DISPOSAL

1. Amounts and Types of Sludges Produced

- Sludges: Liquid to semi-solid residues from wastewater processing. Solid contents: 1 to 10 percent.

- Masses of sludges produced in conventional wastewater processing (see Table 1-1, Reference 1).

- The use of anaerobic digestion to reduce mass and volume (see Table 1-1 and Figure 1-1, Reference 2).

- 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 1-2, from Reference 3).

- 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 1-3). Measured quantities were about 20 percent higher than calculated values.

2. 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 (see Figure 1-2, calculated from Eilers and Smith, Reference 4).

TABLE 1-1

SLUDGES PRODUCED IN CONVENTIONAL TREATMENT*

	Primary Treatment	Primary + TF	Primary + AS
Overall SS Removal (%)	60	85	95
Total raw sludge (lb d.s./mg)	1020	1310	1615
% solids (from clarifier)	6	5	4
% solids (after 2 days thickening)	8	6.5	5.3
Digested sludge (lb d.s./mg)	555	710	1035
% solids	8.8	6.9	5.5
% reduction in sludge mass	45.5	45.5	36
% reduction in volatile solids	65	65	52
Drying bed loadings (lb d.s./ft^2 - yr)	35	30	25

* From Fischer, A. J., *Sewage Works Journal.*

TABLE 1-2

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 Chemical Sludge/lb Cation: 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 1-3

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.

REFERENCES – SECTION 1

1. Fischer, A.J., *Sewage Works Journal,* 248 (1936).

2. Fair, G.M., Geyer, J.C., and Okum, D.A., "Water Purification and Wastewater Treatment and Disposal." *Water and Wastewater Engineering,* 2, 36-6 – 36-8 (1968).

3. 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 .

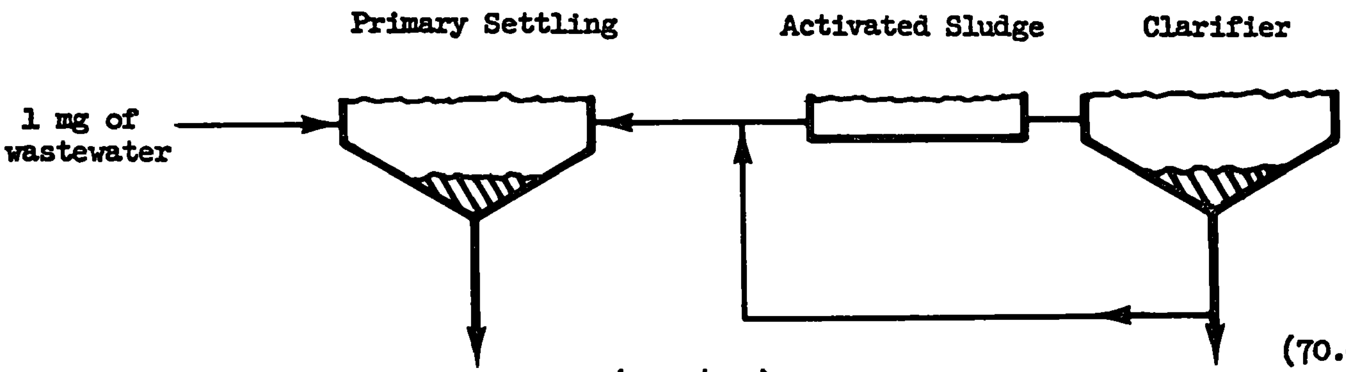
4. Eilers, R.G., and Smith, R., "Wastewater Treatment Plant Cost Estimating Program," AWTRL of EPA, April 1971, Internal Report (Computer Deck available).

LIST OF FIGURES AND TABLES – SECTION 1

FIGURE 1-1 SLUDGE QUANTITIES*

Basis: 1 million gallons of domestic wastewater

<u>Quantities Before Digestion</u>

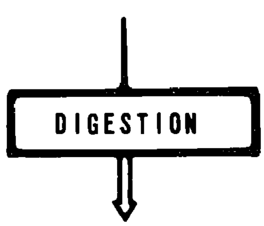


Primary Sludge (72.2% VS)
1190 lb. solids.
If 5% solids, 2830 gal.

Waste Activated Sludge
660 lb. solids.
If 1.5% solids, 5260 gal.

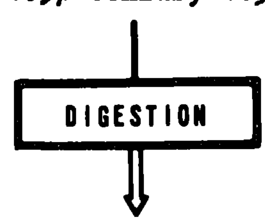
<u>Quantities After Anaerobic Digestion</u>

If primary only
is digested, (46.4% VS)



576 lb.
If 13% solids, 673 gal.

If primary and W.A.S. are combined,
1850 lb. solids.
If 4.5% solids, 4890 gal.



890 lb. (45.5% VS)
If 7% solids, 1980 gal.

* These quantities were taken from an example in Fair, G. M., Geyer, J. C. and Okum, D. A., "Water and Wastewater Engineering, Vol. 2: Water Purification and Wastewater Treatment and Disposal," pp. 36-6 to 36-8, J. Wiley and Sons, N. Y. (1968).

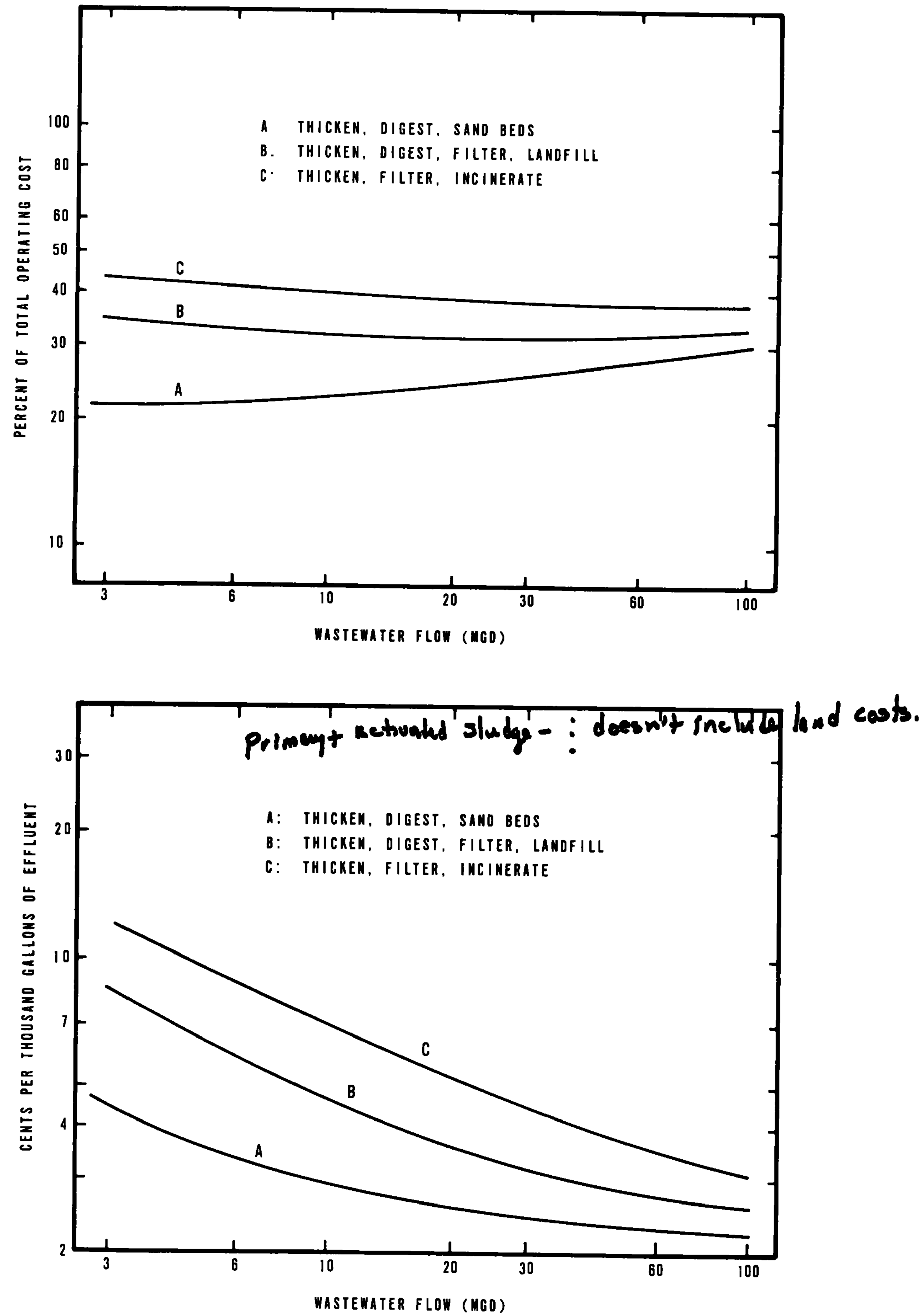


FIGURE 1-2 COSTS OF SLUDGE PROCESSING AND DISPOSAL - INCLUDING AMORTIZATION

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

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

FIGURE 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

Post paper discussion - helpful. watch for self serving

- ADEQUACY OF AVAILABLE LITERATURE
- SUPPLIERS RECOMMENDATIONS
- PLANT DATA - FACT VS. FOLKLORE * most important O&M - ?

→ mistakes die hard

PROCESS ENGINEERING

FIGURE 2-4

THE TOTAL VERSUS THE FRACTIONAL APPROACH

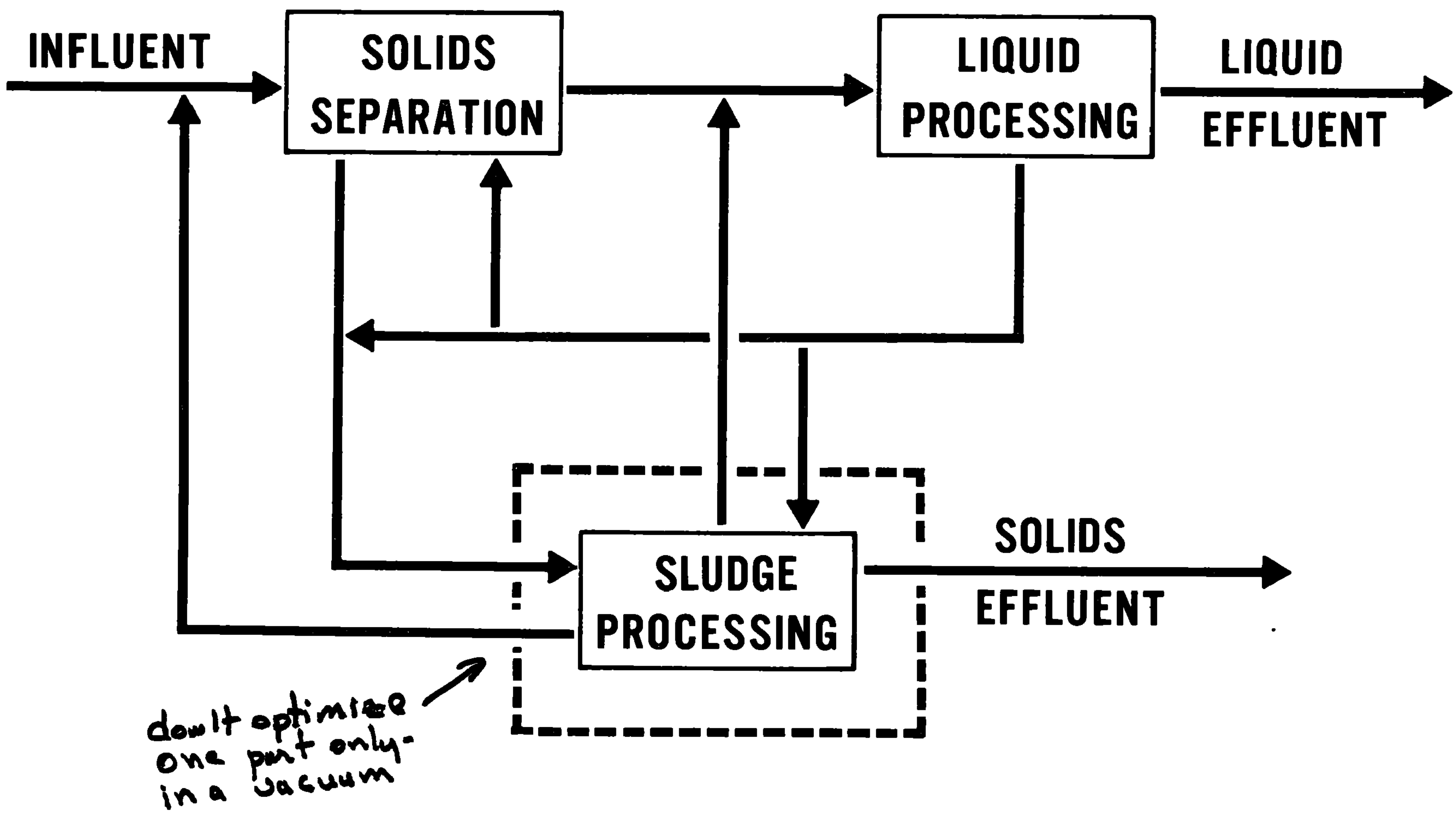


FIGURE 2-5

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

LIST OF FIGURES AND TABLES – SECTION 3

(Continued)

MAXIM

" ALL GENERALITIES
ARE INHERENTLY FALSE
INCLUDING THIS ONE."

FIGURE 3-1

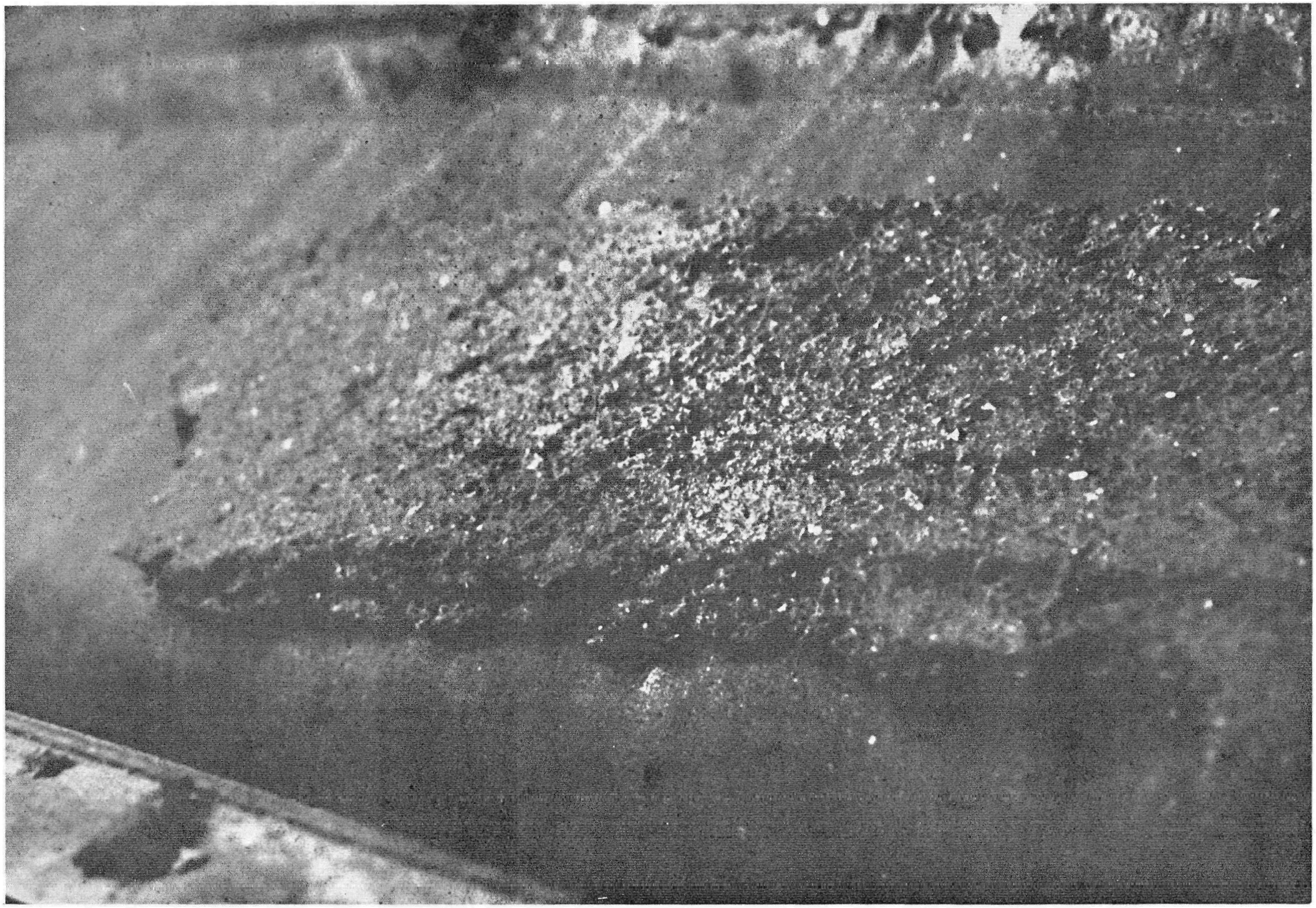


FIGURE 3-2 CLOSE–UP RAW PRIMARY SLUDGE FILTER CAKE

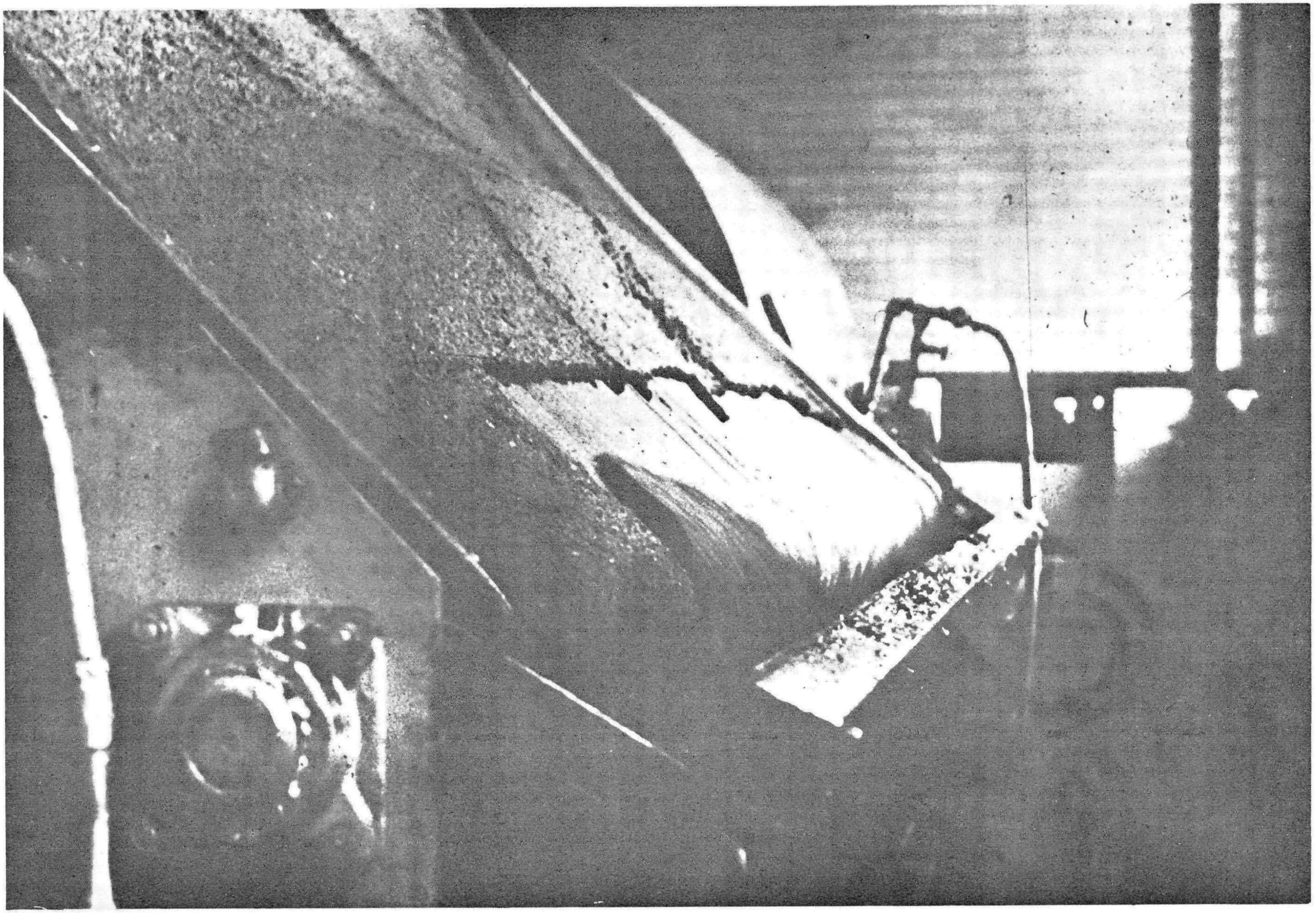


FIGURE 3-3 RELEASE CHARACTERISTICS – RAW PRIMARY SLUDGE FILTERS

% 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 water	5.0	12	flocculation (out)
LOOSELY HELD water	2.5	9	filtration (out)

FIGURE 3-4

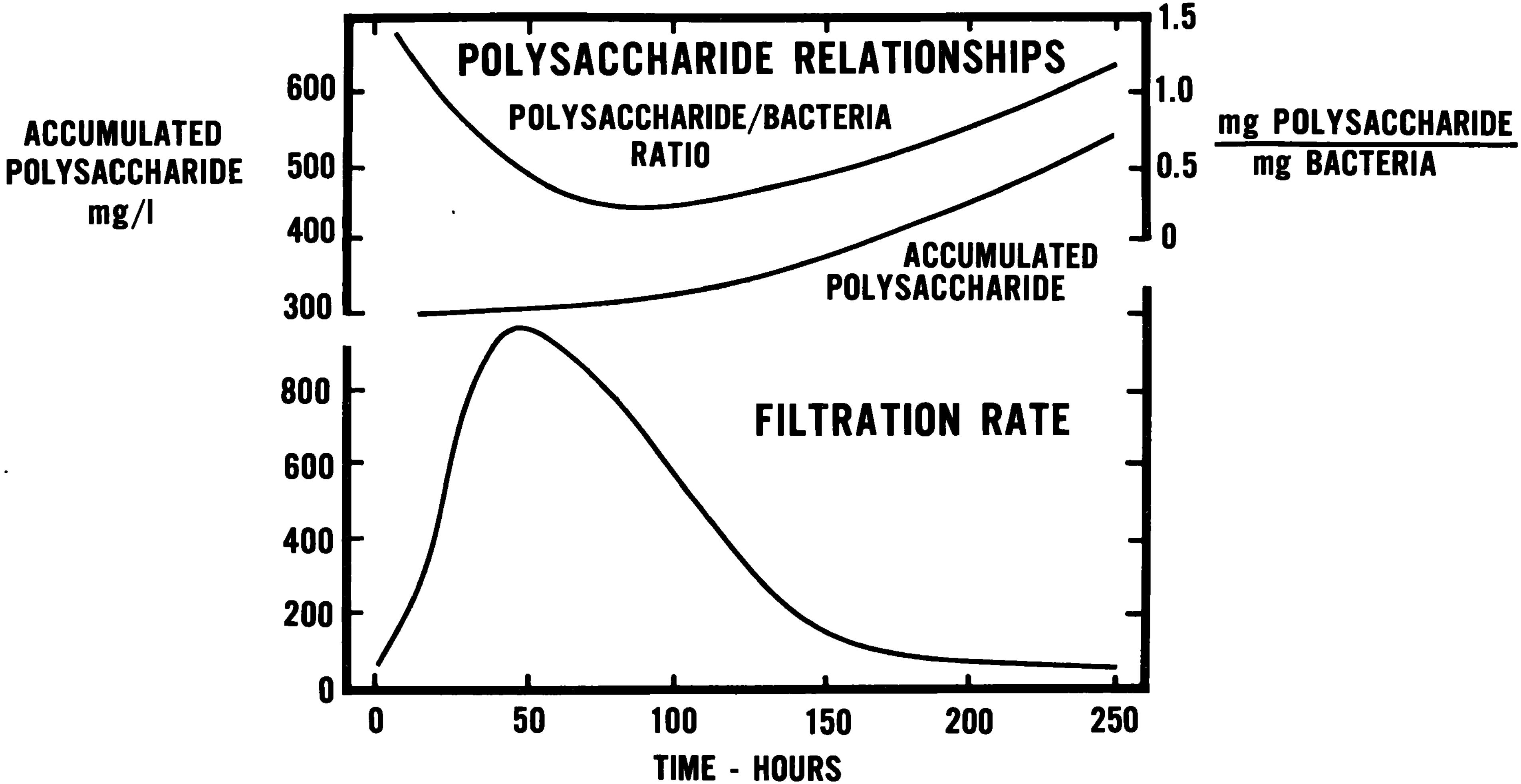


FIGURE 3-5 EFFECT OF AERATION TIME ON BIOPOLYMER PRODUCTION AND DEWATERABILITY

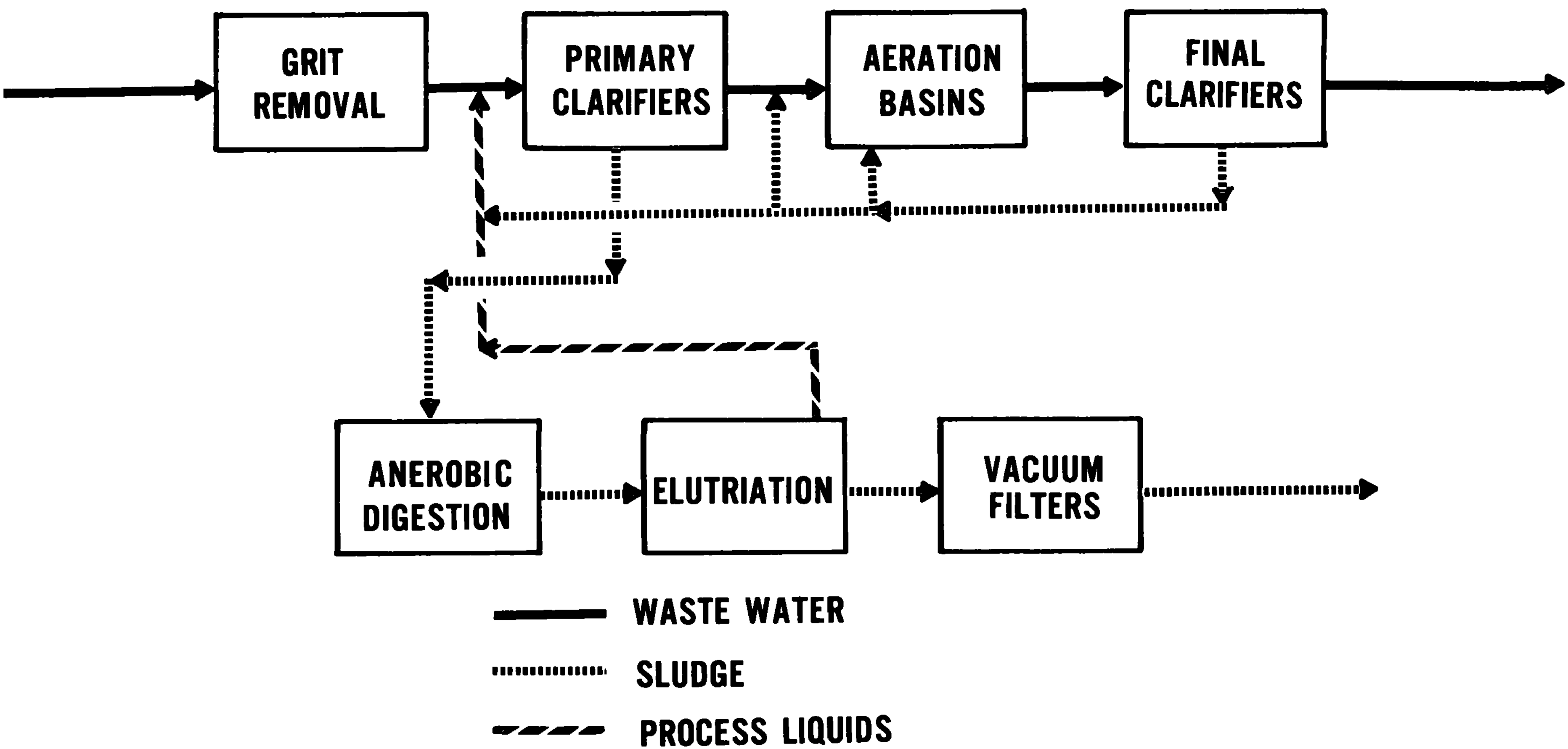


FIGURE 3-6 SECONDARY PLANT WITH SURPLUS ACTIVATED SLUDGE TO HEAD OF WORKS

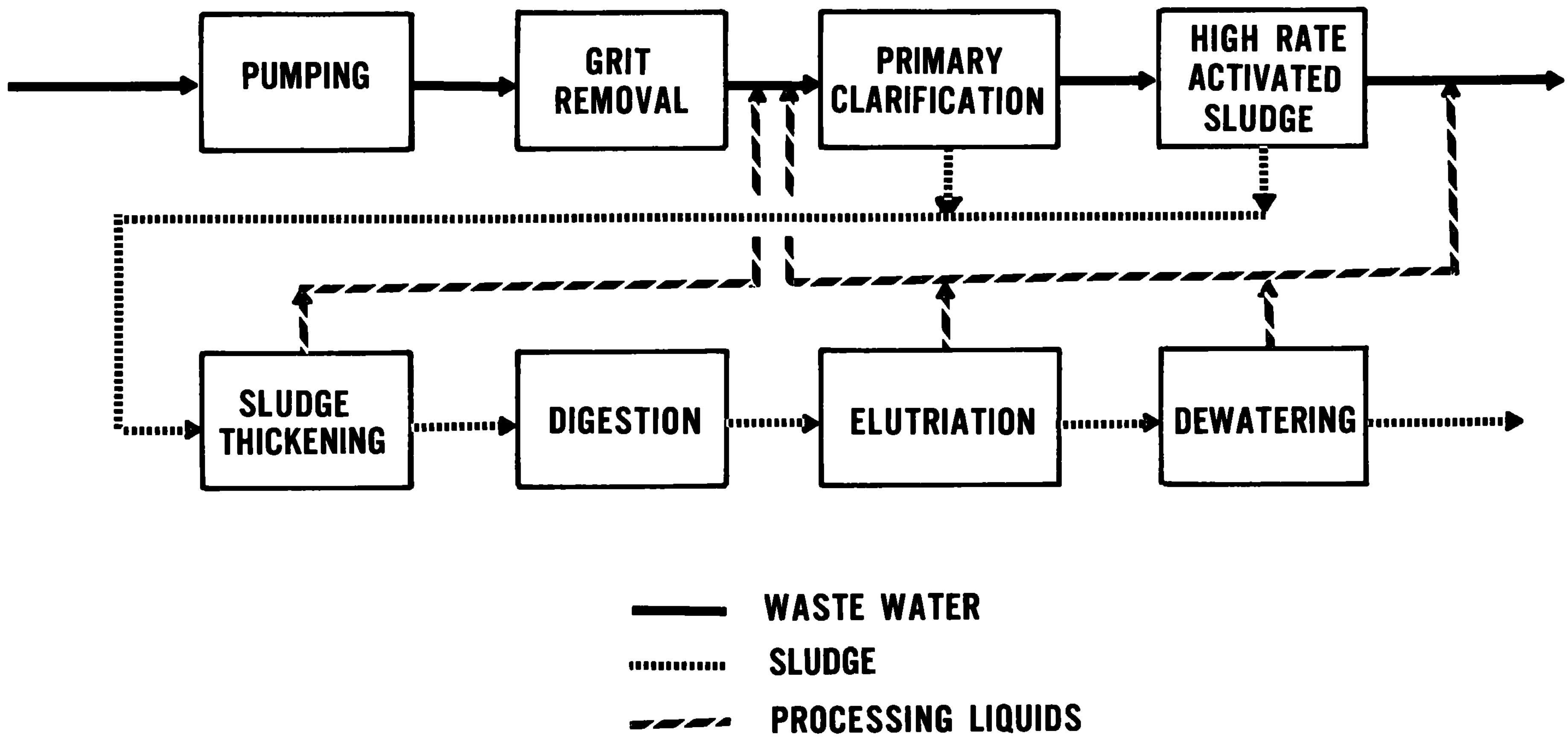


FIGURE 3-7 SECONDARY PLANT WITH SURPLUS ACTIVATED SLUDGE MIXED WITH PRIMARY SLUDGE PRIOR TO THICKENING AND DIGESTION

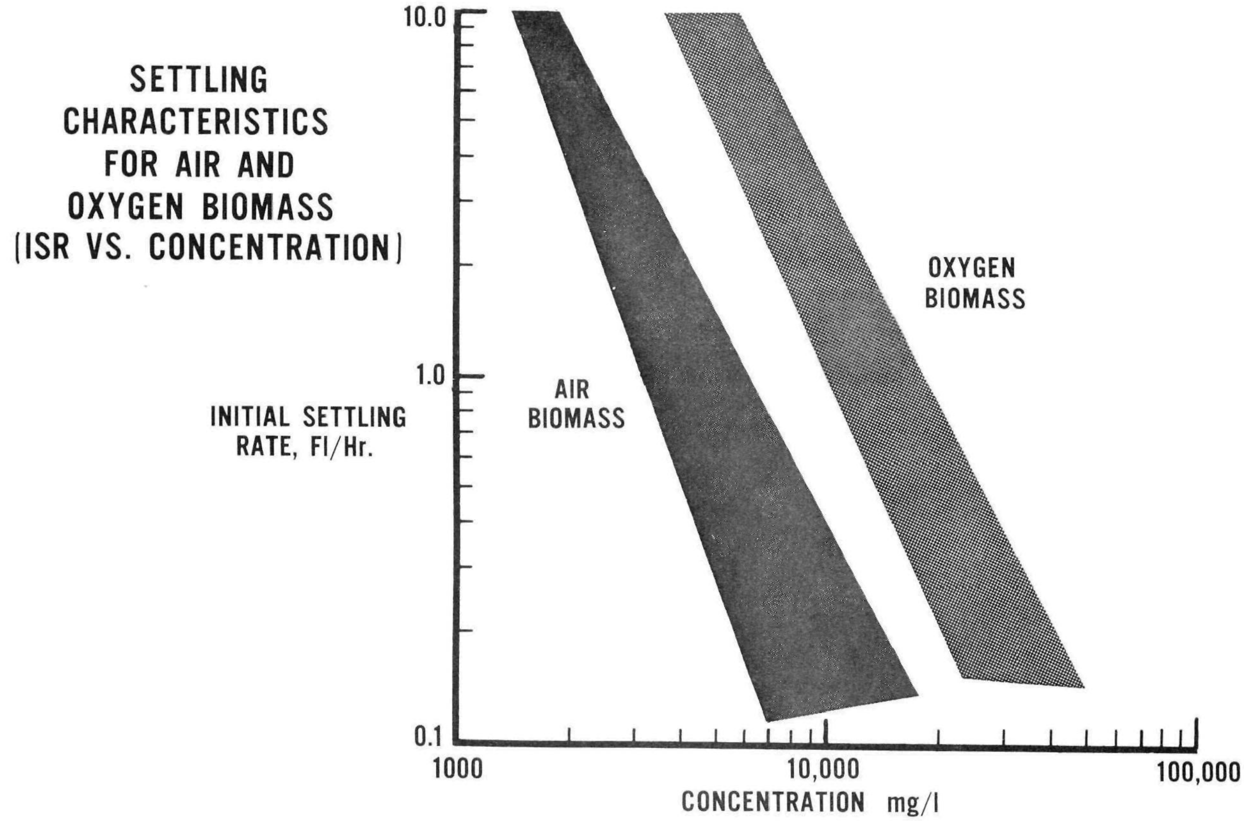


FIGURE 3-8

TYPICAL CLARIFIER PERFORMANCE FOR AIR AND OXYGEN SLUDGES
(AT 30 % RECYCLE)

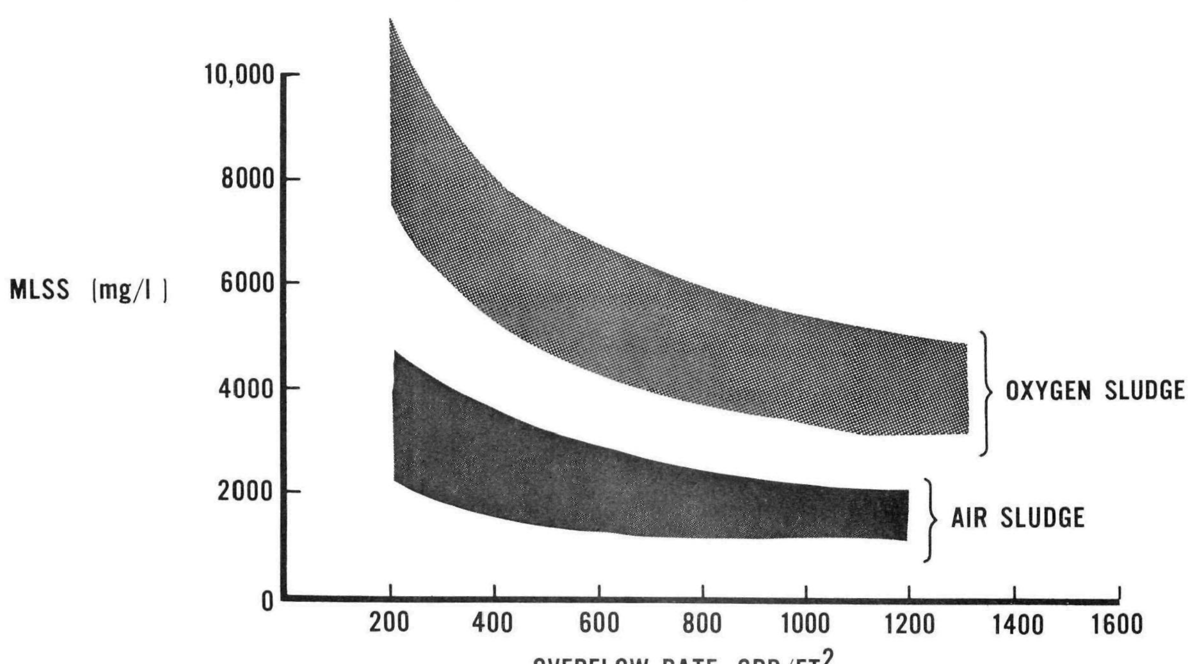


FIGURE 3-9

TYPICAL CLARIFIER PERFORMANCE FOR AIR AND OXYGEN SLUDGES

(AT 30 % RECYCLE)

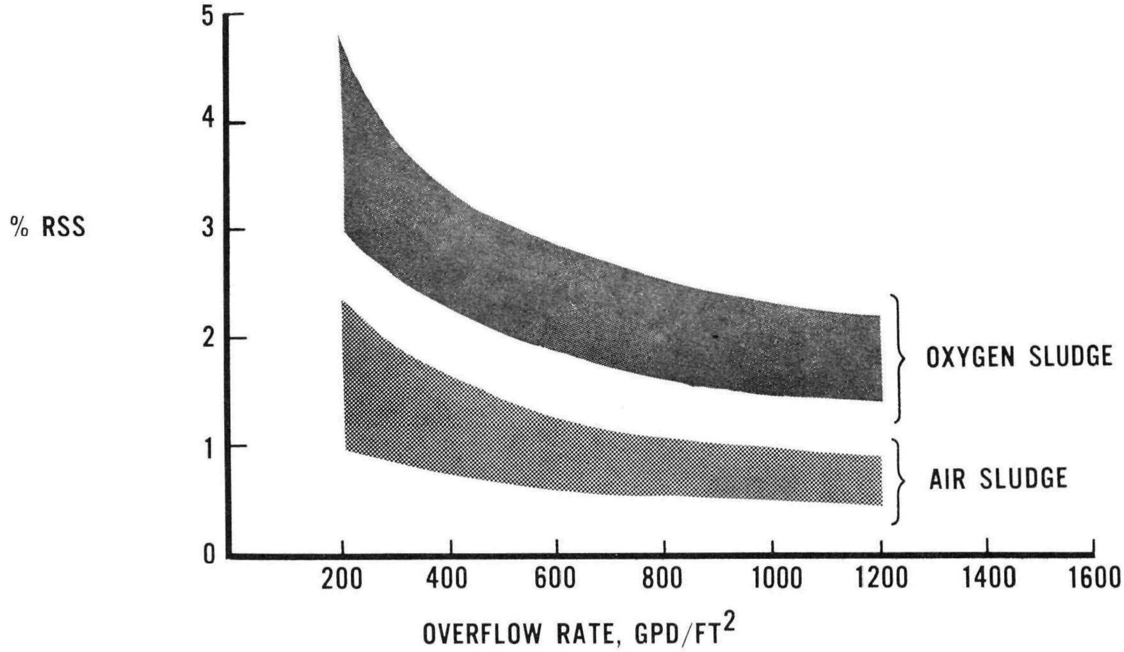


FIGURE 3-10

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

	FEED SLUDGE		CONDITIONER #/TON D.S.		YIELD	CAKE
LOCATION	TYPE	% SOLIDS	FeCl3	LIME	#/Ft.2/HR.	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	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	SOLIDS		$
METAL SALT	DOSE MG/L	POLYMER MG/L	SLUDGE % 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

phosphate removal.

Chemical to Sludge

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

seems high

easier to dewater

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

phosphorus removal

FIGURE 3-19

LAKE TAHOE SOLIDS HANDLING

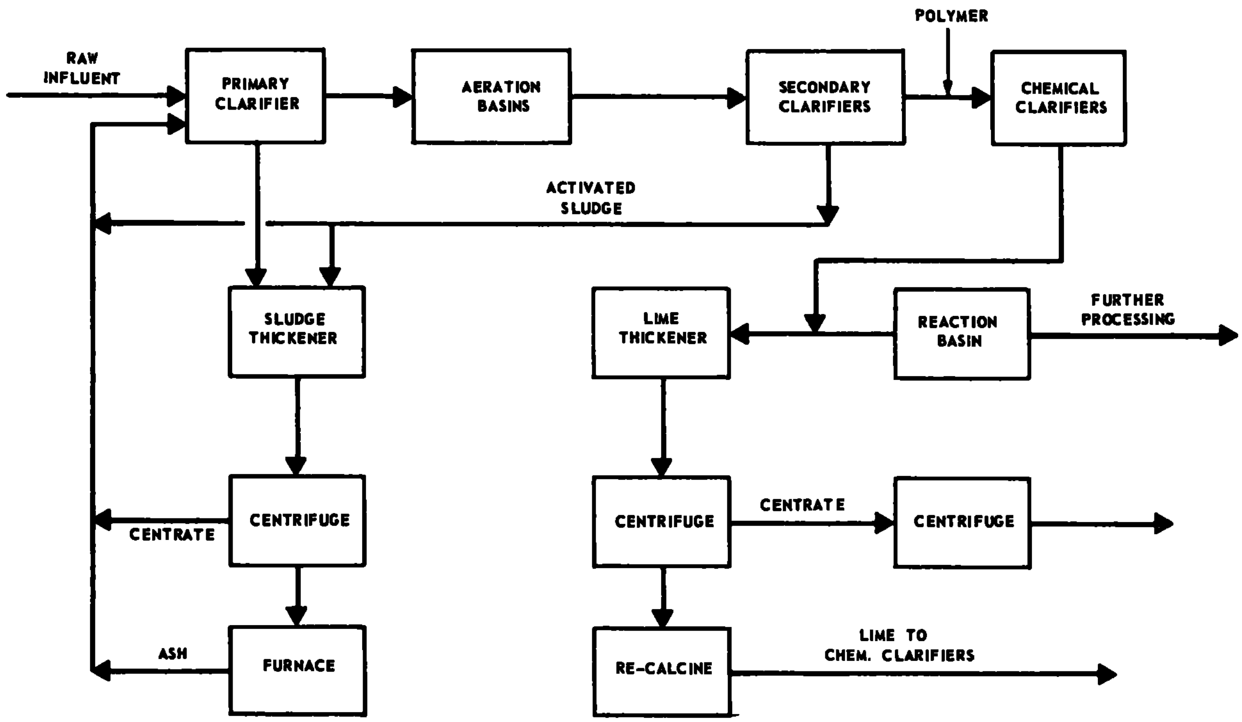


FIGURE 3-20

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	MG O
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"

reduces mass & volume

1. **Anaerobic Digestion**

   – 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).

   – 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 (Table 4-1 from Reference 2). If sludge density is increased (e.g., by two-stage high rate digestion), yield can be increased.

   – Schepman and Cornell (Reference 3) conclude that raw sludges may vary from very good to very poor yields, whereas digested sludges from different sources are more uniform (Table 4-2).

   – Anaerobic digestion solubilizes much sludge, releases nutrients back to treatment plant. High dissolved solids can interfere with chemical conditioning. Table 4-3 shows some supernatant compositions reported recently (Reference 4).

2. **Aerobic Stabilization**

   – Aerobic stabilization is often 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.

   – Aerobically stabilized sludge has poor dewatering characteristics on vacuum filters although a recent publication claims otherwise (Reference 6). Ordinarily, this sludge is dewatered on sand beds or applied in liquid form to cropland.

3. **Chlorine Oxidation**

   – The Purifax process oxidizes sludge with heavy doses of chlorine (circa 2,000 mg/l). Sludge dewaters well on sand beds. 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 7).

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

4. Lime Treatment

- Lime treatment of sludge stabilizes the sludge as long as the pH stays high. Kill of pathogenic bacteria is excellent (Reference 8). 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.

TABLE 4-1

TYPICAL AVERAGE SEWAGE SLUDGE FILTRATION RATES

Type of Sludge	Feed Solids[2] (percent)	Filtration Rate Dry lb/hr - ft^2	Average Cake Moisture (percent)	Average Chemicals (percent)	
				$FeCl_3$	CaO
Primary Sludge					
Raw	8	10.0	66	1.5	7.0
Digested	8	8.0	70	3.0	8.5
Digested – Elutriated	8	6.5	71	2.5	(4.0)[1]
Primary – Trickling Filter					
Raw	7	9.0	68	1.5	8.0
Digested	8	7.0	71	3.0	8.5
Digested – Elutriated	8	6.5	72	2.5	(4.0)[1]
Primary – Activated Sludge					
Raw	5	4.5	79	4.0	4.0
Digested	6	4.5	76	4.0	9.0
Digested – Elutriated	6	4.5	78	5.0	(5.0)[1]
Activated Sludge – Concentrated	3	2.0	84	5.5	0

[1] Lime is frequently added to elutriated sludges to give higher filtration rates and lower cake moistures.

[2] If feed sludge concentration differs from value listed, the expected filtration rate will differ directly in proportion to the change in feed solids concentration. Example: If 9% solids raw primary sludge is filtered an average filtration rate of $\frac{9}{8} \times 10 = 11.25$ lb/hr/ft^2 may be expected.

TABLE 4-2

FILTRATION RATES AND CAKE MOISTURE

FOR DIFFERENT TYPES OF SLUDGES

Plant	Sludge Conc. (%)	Chemicals (%) CaO	Chemicals (%) $FeCl_3$	Filter Rate[1]	Cake Moisture (%)
PRIMARY SLUDGES					
Saginaw, Mich.	16	9.9	0	8.5	54.0
Providence, R.I.	5.5	6	2.2	13.0	73.0
Wyandotte, Mich.[2]	8.0	15	5	8.0	70.0
DIGESTED - PRIMARY SLUDGES					
Rockford, Ill.	9.5	7.1	5.4	11.5	71.5
Schenectady, N.Y.	8.5	6.0	4.0	11.5	77.0
Long Beach, N.Y.[3]	3.8	17.0	3.5	14.0	73.0
Greenwich, Conn.	5.6	6.0	3.0	11.0	74.0
Dallas, Texas	7.5	5.5	2.5	14.5	72.5
ELUTRIATED - DIGESTED - PRIMARY SLUDGES					
Cincinnati, Ohio	8.5	0	4.5	3.1	64.0
Toronto, Ont.	7.7	0	4.0	8.0	70.0
East Providence, R.I.	9.0	0	1.5	20.0	72.5
Dallas, Texas	8.0	0	0.8	15.5	70.5
DIGESTED - PRIMARY - ACTIVATED SLUDGE					
Nassau County, N.Y.	4.5	12.0	8.0	3.0	79.0
ELUTRIATED - DIGESTED - PRIMARY - ACTIVATED SLUDGES					
Cranston, R.I.	2.4	0	7.0	3.4	85.0
Houston, Texas	2.7	0	5.5	5.5	84.2
Ann Arbor, Mich.	5.0	15.0	3.0	5.0	72.5
Cleveland, Ohio	5.5	9.0	2.5	6.3	71.5
Hyperion, (L.A.) Calif.[4]	5.1	0	1.9	5.8	76.5

[1] Filter rate or yield, $lb/(hr)(ft^2)$

[2] Sludge hauled to plant from other collecting points in county; therefore, it is somewhat septic, depending on temperature and elapsed time.

[3] Testing conditions prevented optimum operation.

[4] Separan also added at approximately 0.02 percent.

TABLE 4-3

AVERAGED RESULTS OF ANALYSES OF DIGESTER SUPERNATANTS (MG/L)

	Irvington	Milpitas	Massolli*
pH	7.3	7.0	7.3
Suspended Solids	2,200	383	
Total Solids	4,540	1,470	3,260
Total Volatile Solids	2,930	814	1,540
Total PO_4 (as P)	143	63	56
Soluble-Ortho-PO_4 (as P)	66	45	
NH_3-N	850	253	402
Organic-N	290	53	
Alkalinity	3,780	1,350	1,675
COD	4,560	1,380	
Hardness	264	322	890

* Reference 5

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. Schepman, B.A., and Cornell, C.F., "Fundamental Operating Variables in Sewage Sludge Filtration." *Sew. and Industrial Wastes,* 28, No. 12, 1443-1460 (1956).

4. Bennett, G.E., "Development of a Pilot Plant to Demonstrate Removal of Carbonaceous, Nitrogenous, and Phosphorus Materials from Anaerobic Digester Supernatant and Related Process Streams," U.S. EPA, Report ORD-17010 FKA 05/70, May, 1970.

5. Masselli, Joseph W., et al., "The Effect of Industrial Wastes on Sewage Treatment," New England Water Pollution Control Commission, Boston, Massachusetts, 1965 .

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

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

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.

LIST OF FIGURES AND TABLES – SECTION 4

SECTION 5 – 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 5-1)

   – 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, elutriation, 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 5-2)

     Flocculation in elutriation basins.

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

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

- 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 5-3 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 5-4)

- 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 5-5)

   - 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 5-6)

   - 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 5-7), 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 5-2)

   - 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 5-3)

   - 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 5-4), results improved even further as some of the fines were cleaned out of the plant.

   - The elutriation/filtration (Figure 5-8) 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 5-9) 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 5-5).

   – 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 clutriation (Table 5-6) the results were as shown.

   – Total conditioning costs in elutriation and on filters (ferric chloridc/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.

LIST OF FIGURES AND TABLES – SECTION 5

REFERENCES – SECTION 5

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.

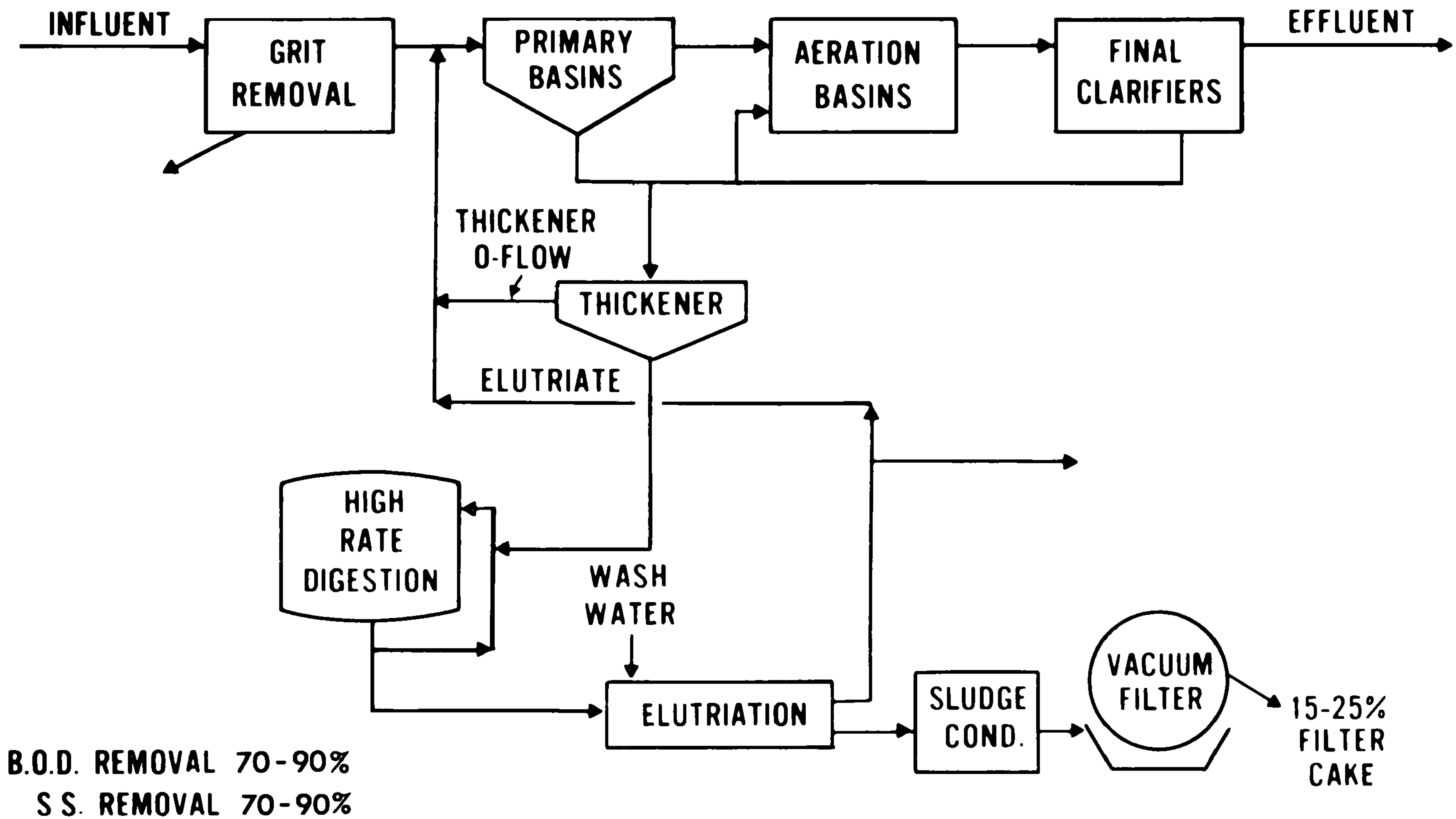
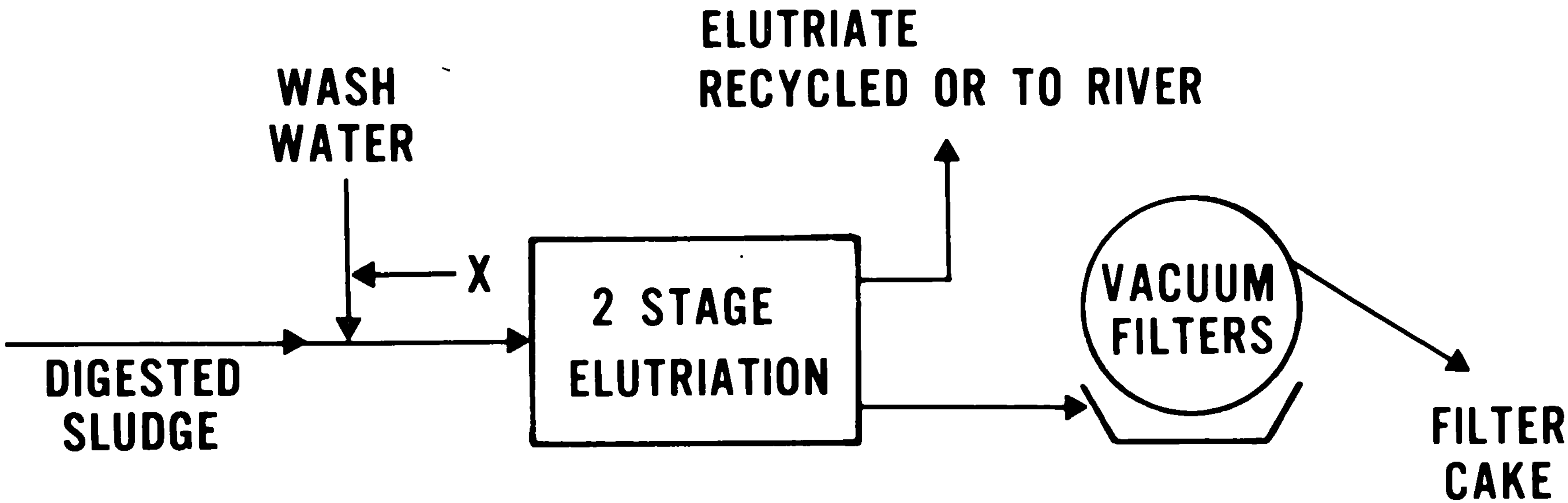


FIGURE 5-1 PLANT FLOW DIAGRAM — DISTRICT OF COLUMBIA



X = CATIONIC POLYELECTROLYTE APPLICATION POINT

FIGURE 5-2 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 5-1 SLUDGE REMOVAL PRACTICES AND COSTS – DISTRICT OF COLUMBIA

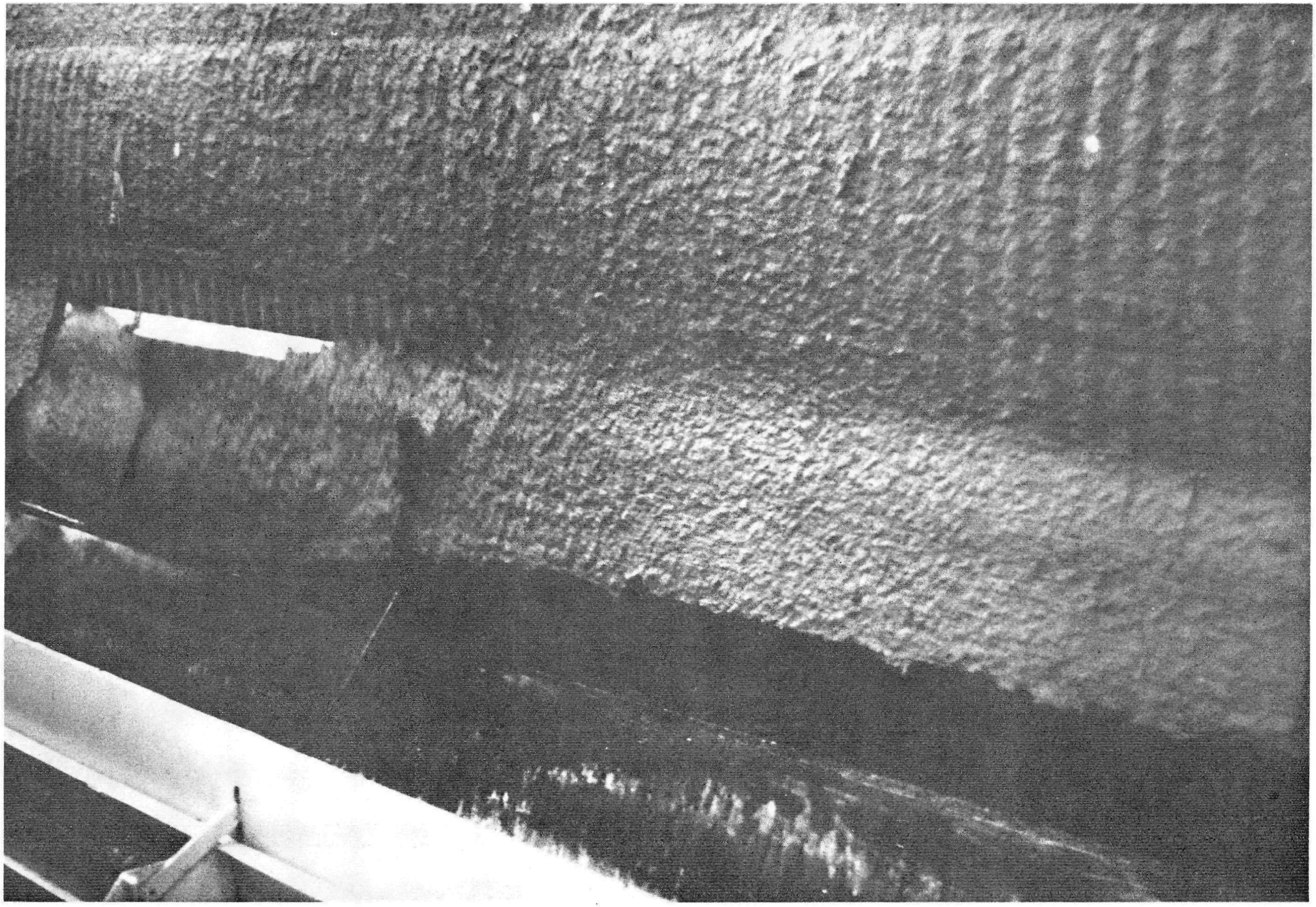


FIGURE 5-3 VACUUM FILTER OPERATION – DISTRICT OF COLUMBIA

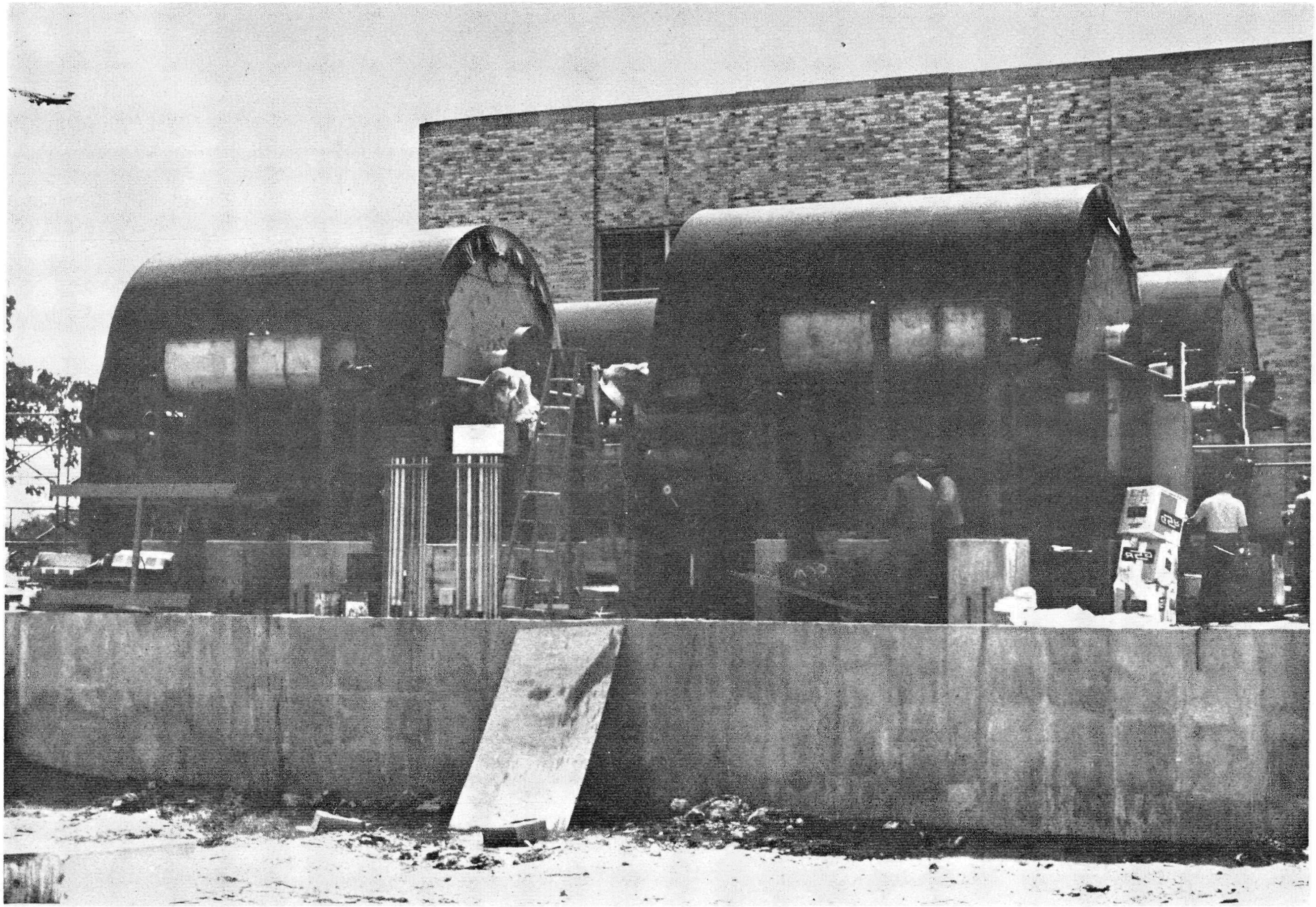


FIGURE 5-4 NEW FILTER INSTALLATION WITH INDIVIDUAL CONDITIONING BOXES – DISTRICT OF COLUMBIA

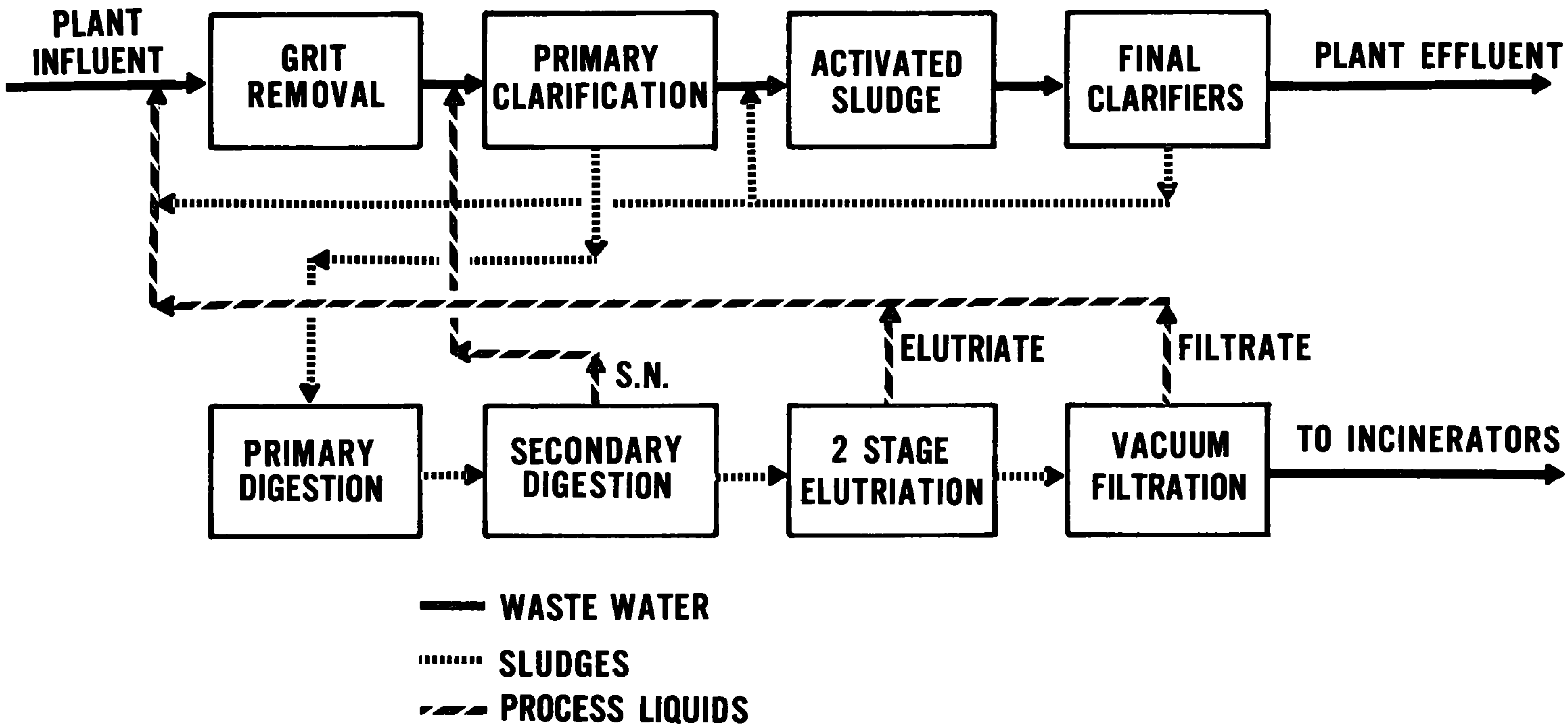


FIGURE 5-5 PLANT FLOW DIAGRAM – METRO TORONTO

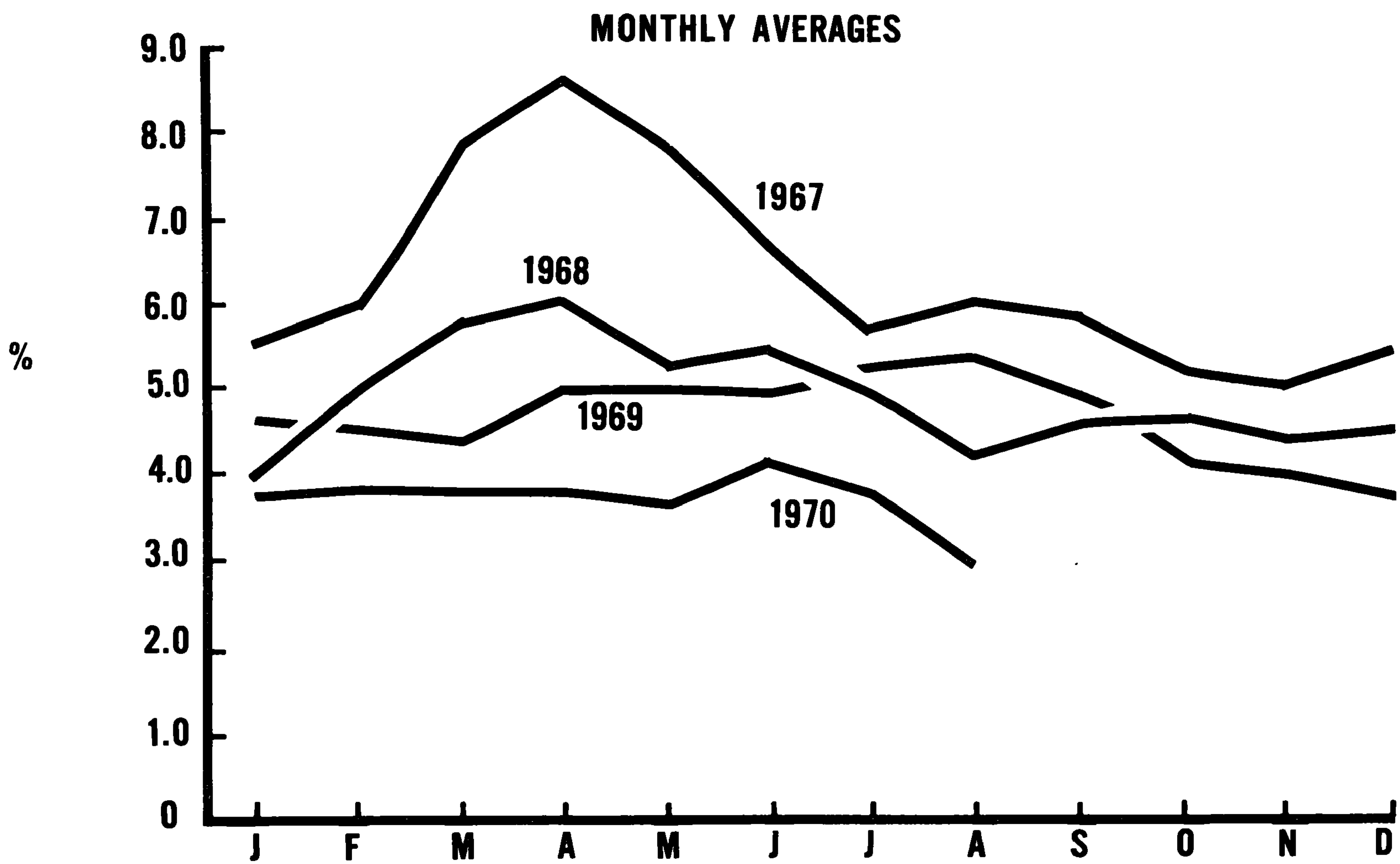


FIGURE 5-6 PERCENT SOLIDS IN ELUTRIATED SLUDGE – METRO TORONTO

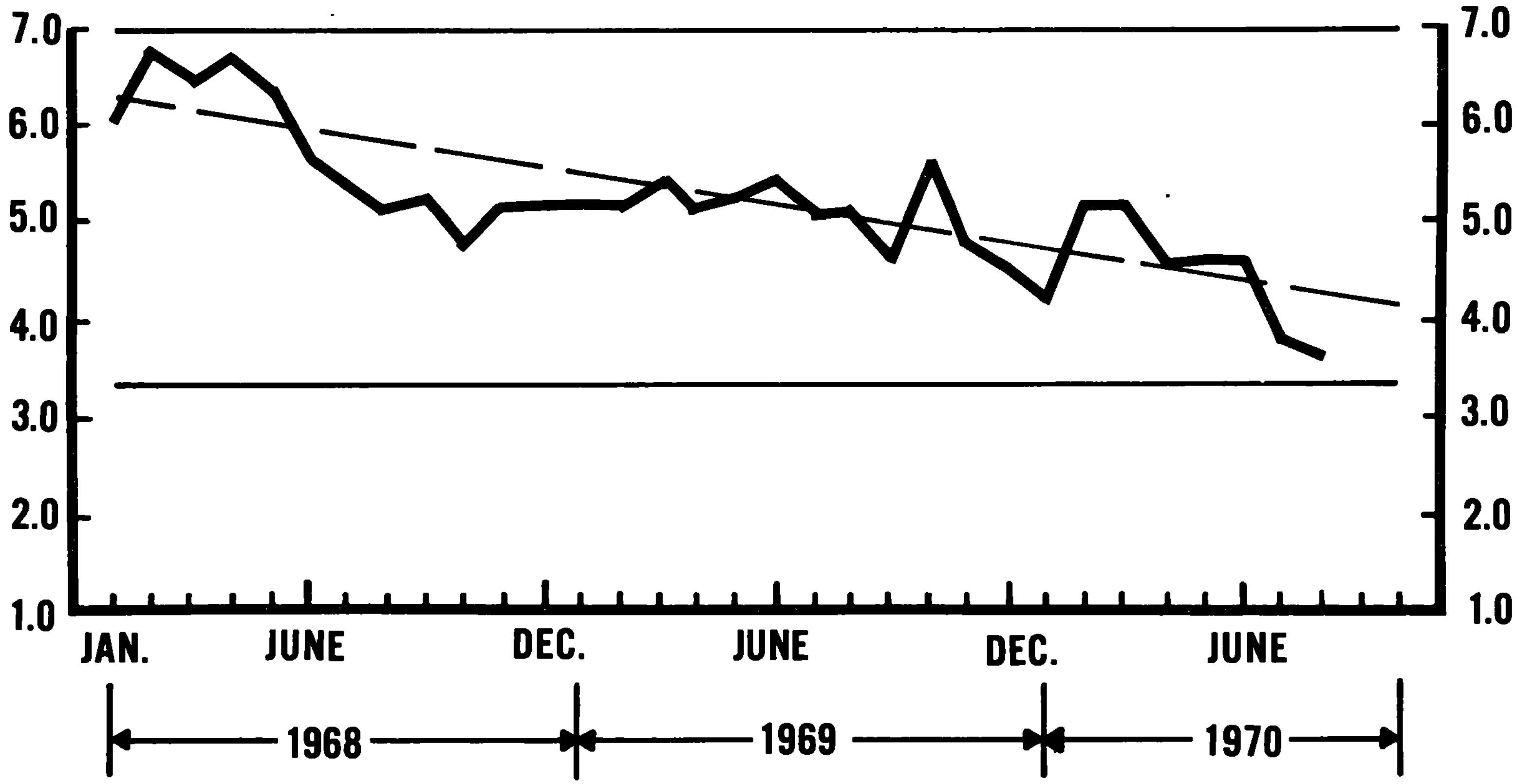


FIGURE 5-7 PERCENT SOLIDS IN RAW SLUDGE
METRO TORONTO

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

TABLE 5-2 SLUDGE REMOVAL NEEDS – METRO TORONTO

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

TABLE 5-3 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 5-4 ELUTRIATION/FILTRATION RESULTS 1971 – METRO TORONTO

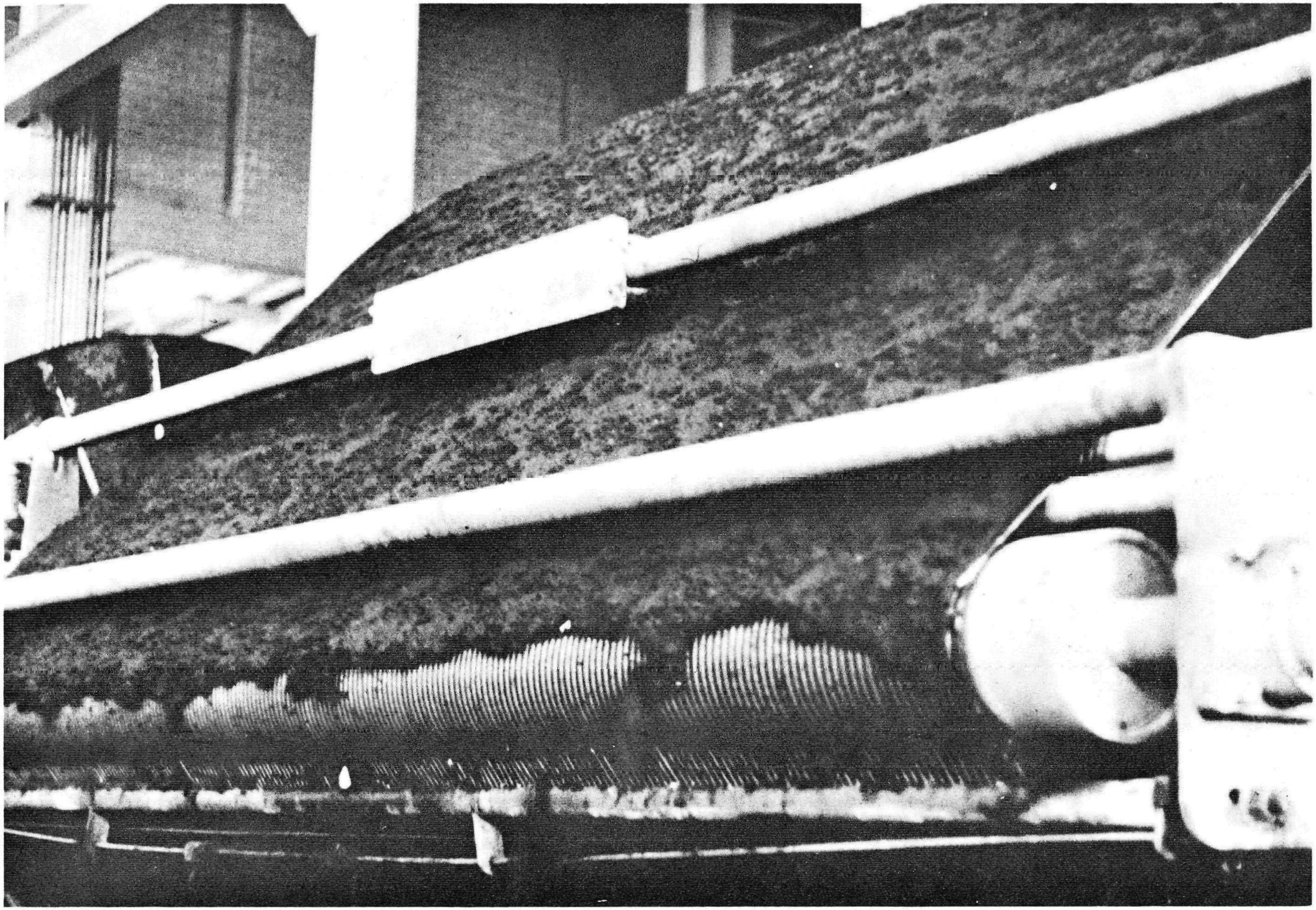


FIGURE 5-8 A VIEW OF FILTERS – METRO TORONTO

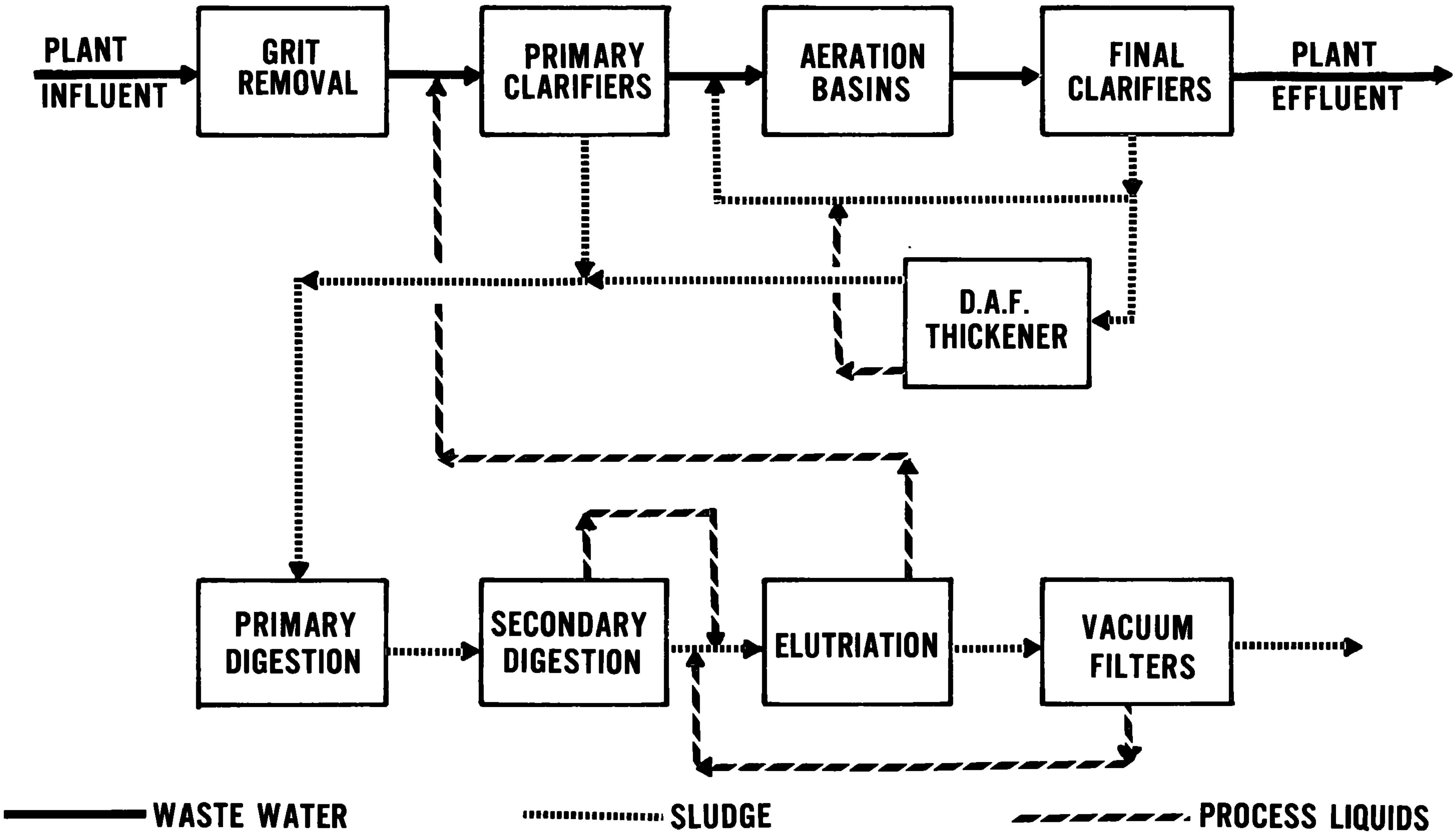


FIGURE 5-9 PLANT FLOW DIAGRAM – RICHMOND, CALIFORNIA

	PRIMARY SLUDGE	MIXED SLUDGES: NO POLYMER	MIXED SLUDGES: 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 5-5 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 5-6 ELUTRIATION/FILTRATION OPERATIONS — RICHMOND, CALIFORNIA

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

OXYGEN PROCESS FLOW SHEET

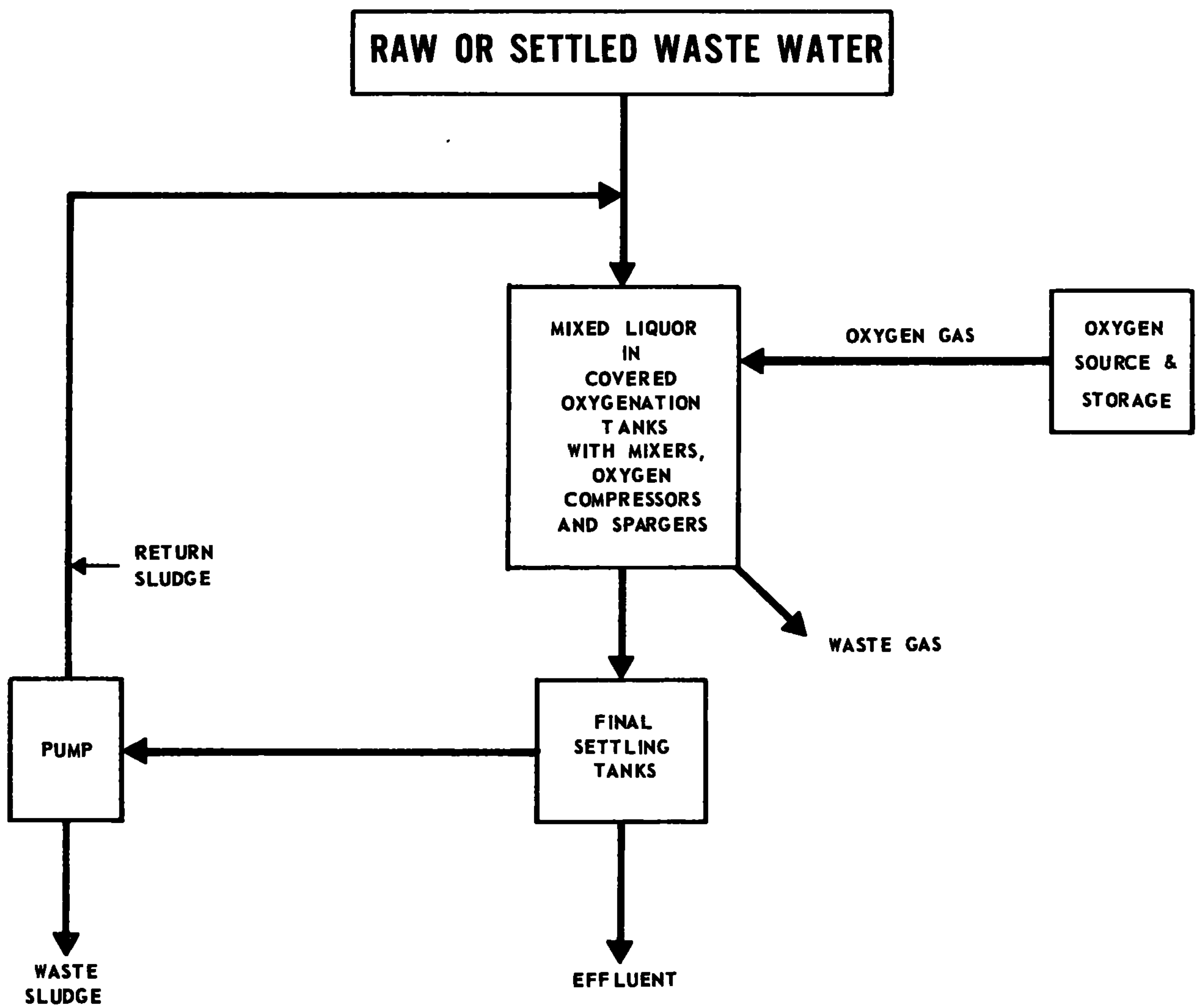


FIGURE 6A-1

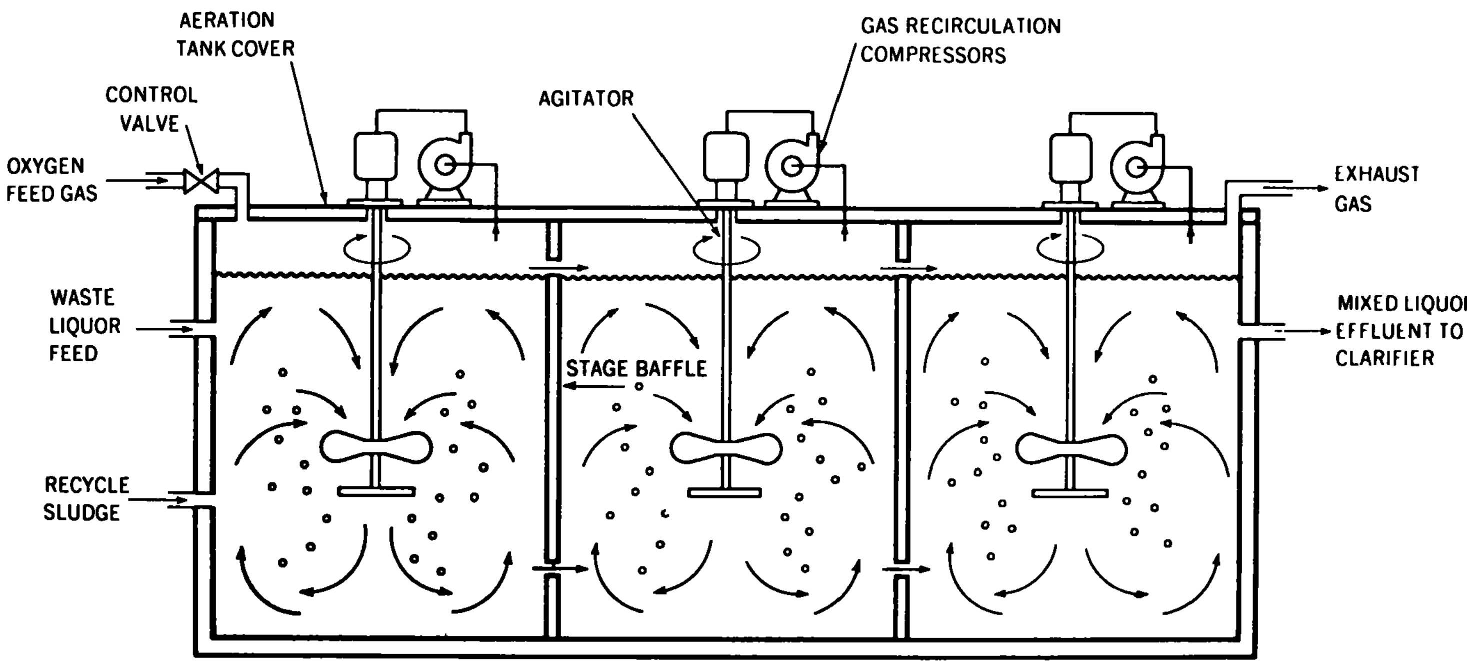


FIGURE 6A-2 SCHEMATIC DIAGRAM OF OXYGEN SYSTEM WITH ROTATING SPARGER

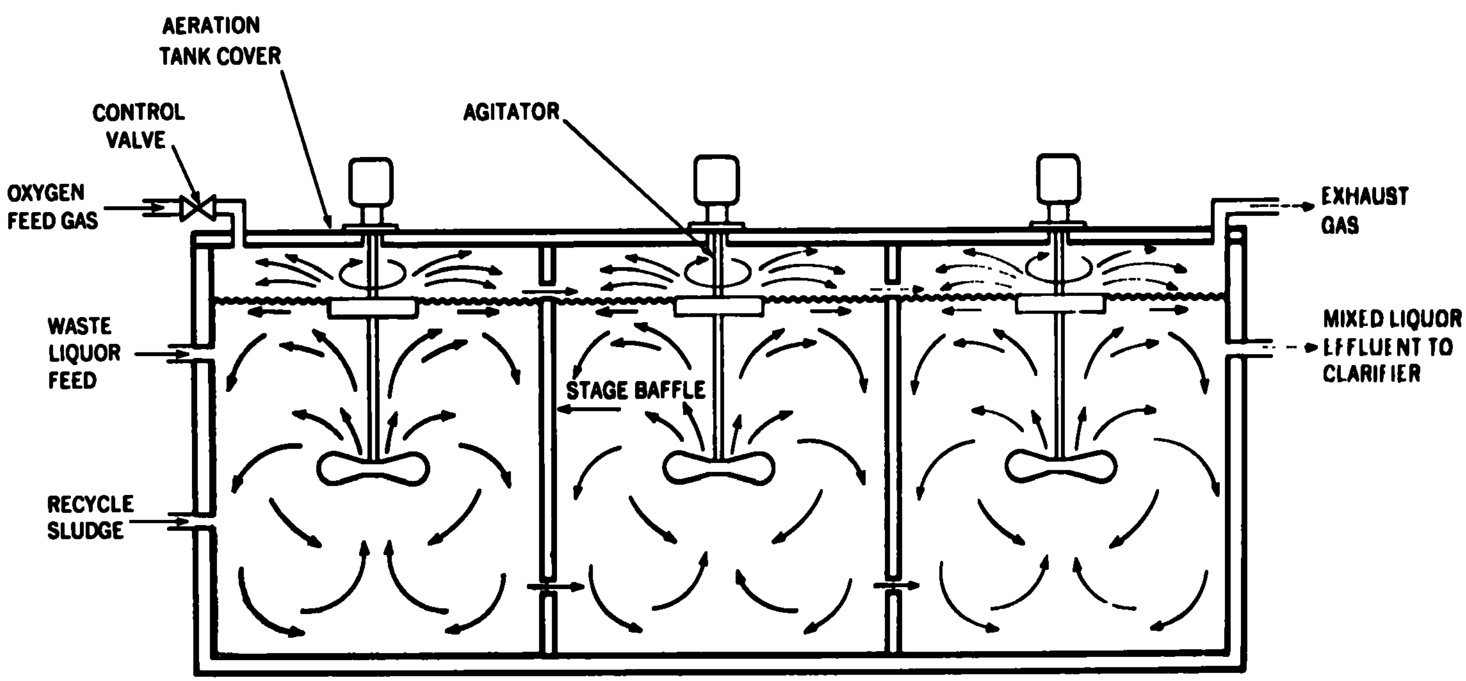


FIGURE 6A-3 SCHEMATIC DIAGRAM OF OXYGEN SYSTEM WITH SURFACE AERATOR

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

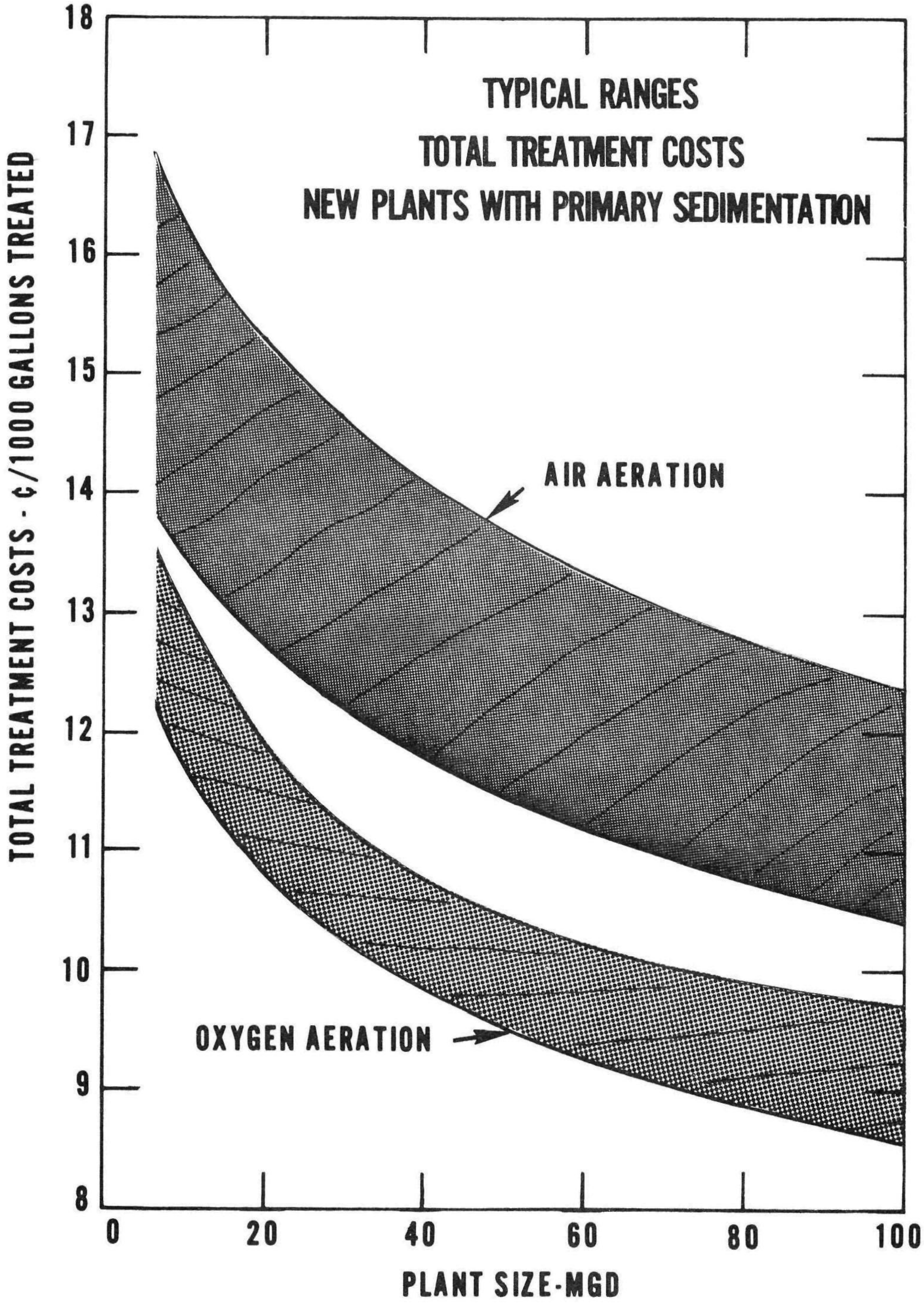


FIGURE 6A-11

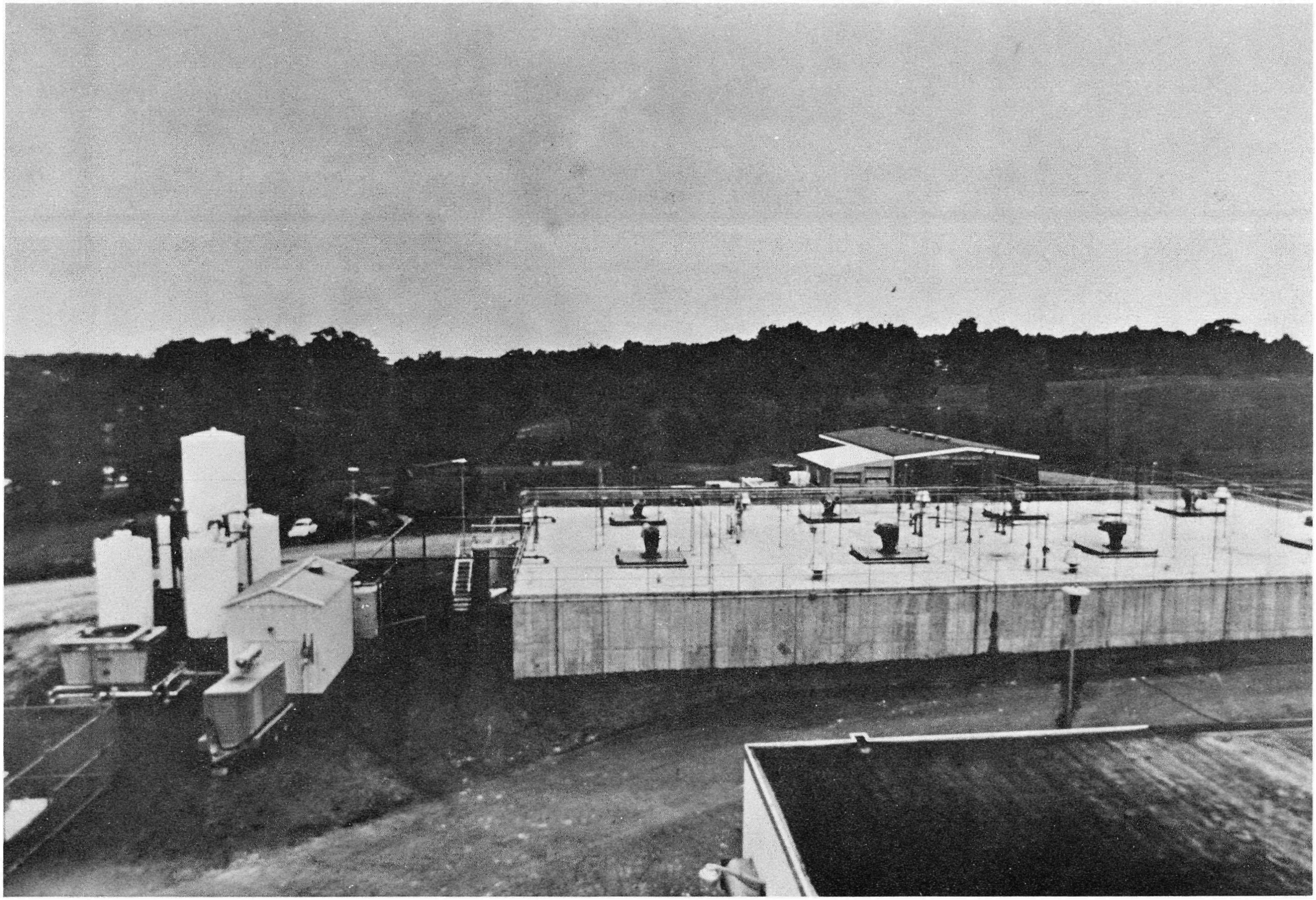


FIGURE 6A-12 TYPICAL PLANT PHOTOGRAPH

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

WESTGATE- ORIGINAL PROCESS FLOW

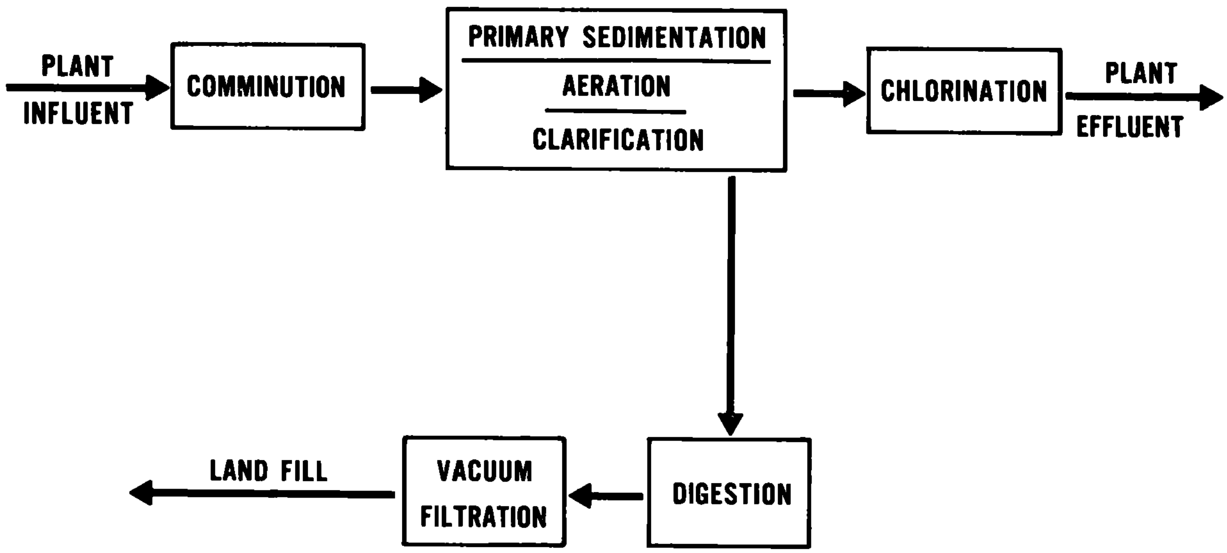


FIGURE 6B-1

WESTGATE SEDIMENTATION TANK
LONGITUDINAL SECTION

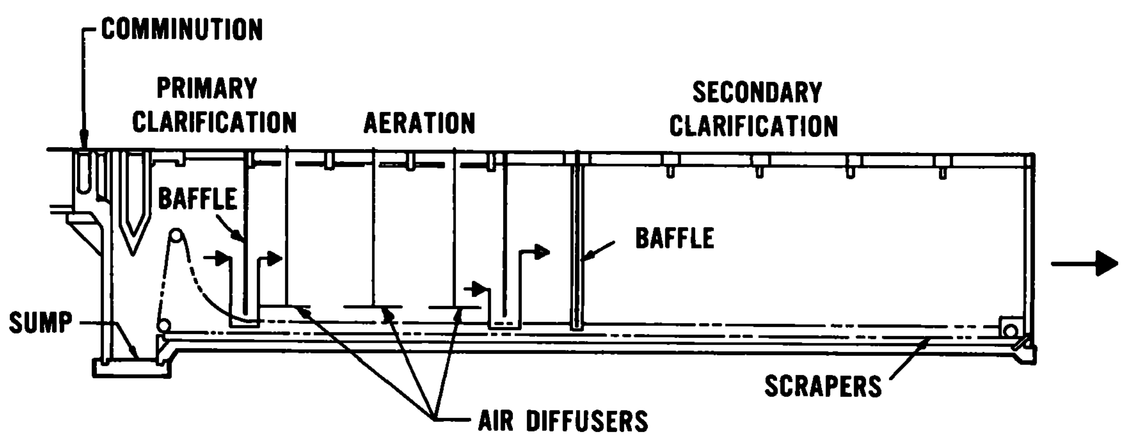


FIGURE 6B-2

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

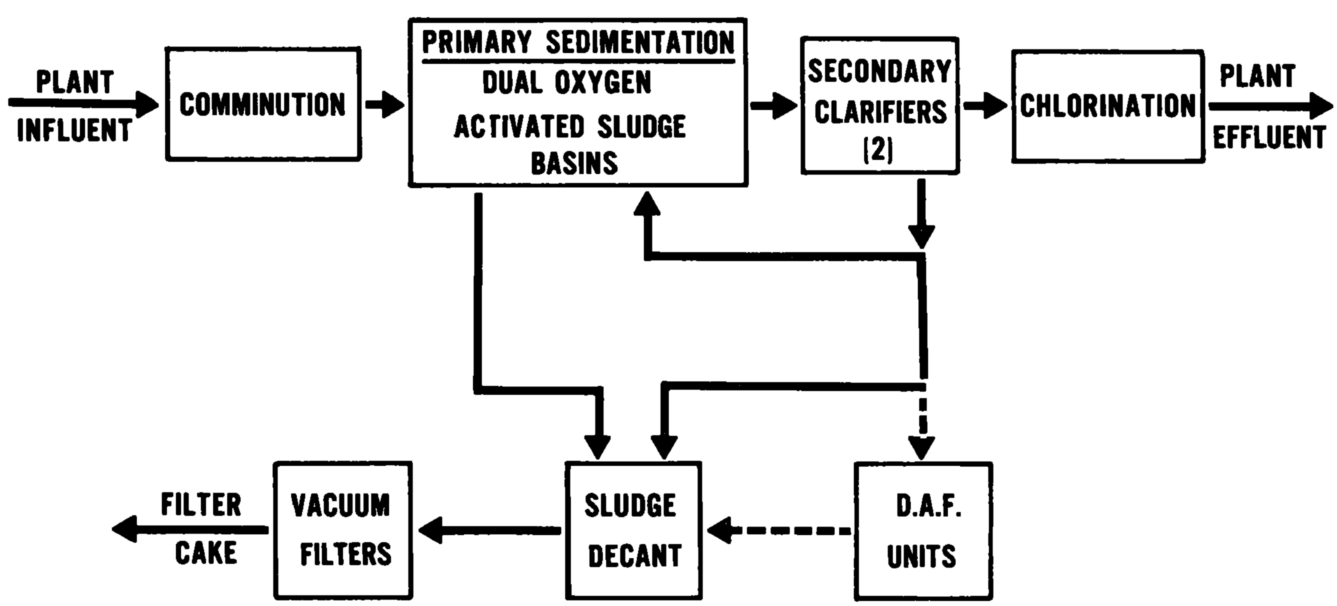


FIGURE 6B-4

RESULTS
WESTGATE OXYGEN PROCESS

% REMOVAL BOD 5	% REMOVAL T.S.S.	S.V.I.	W.A.S. lb V.S.S. / lb BOD REMOVED	ZONE 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

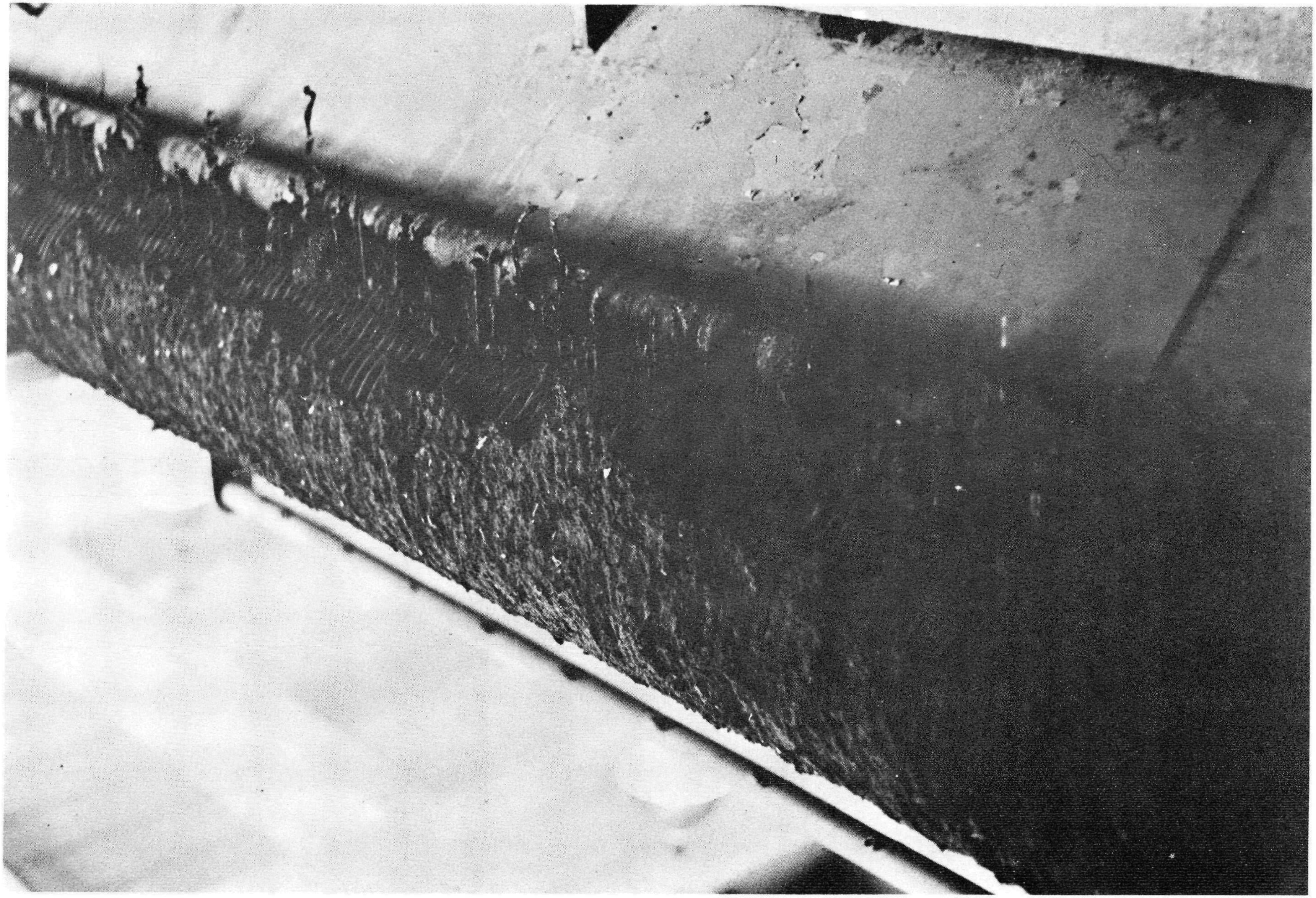


FIGURE 6B-7 PHOTOGRAPH OF SLUDGE OFF FILTERS

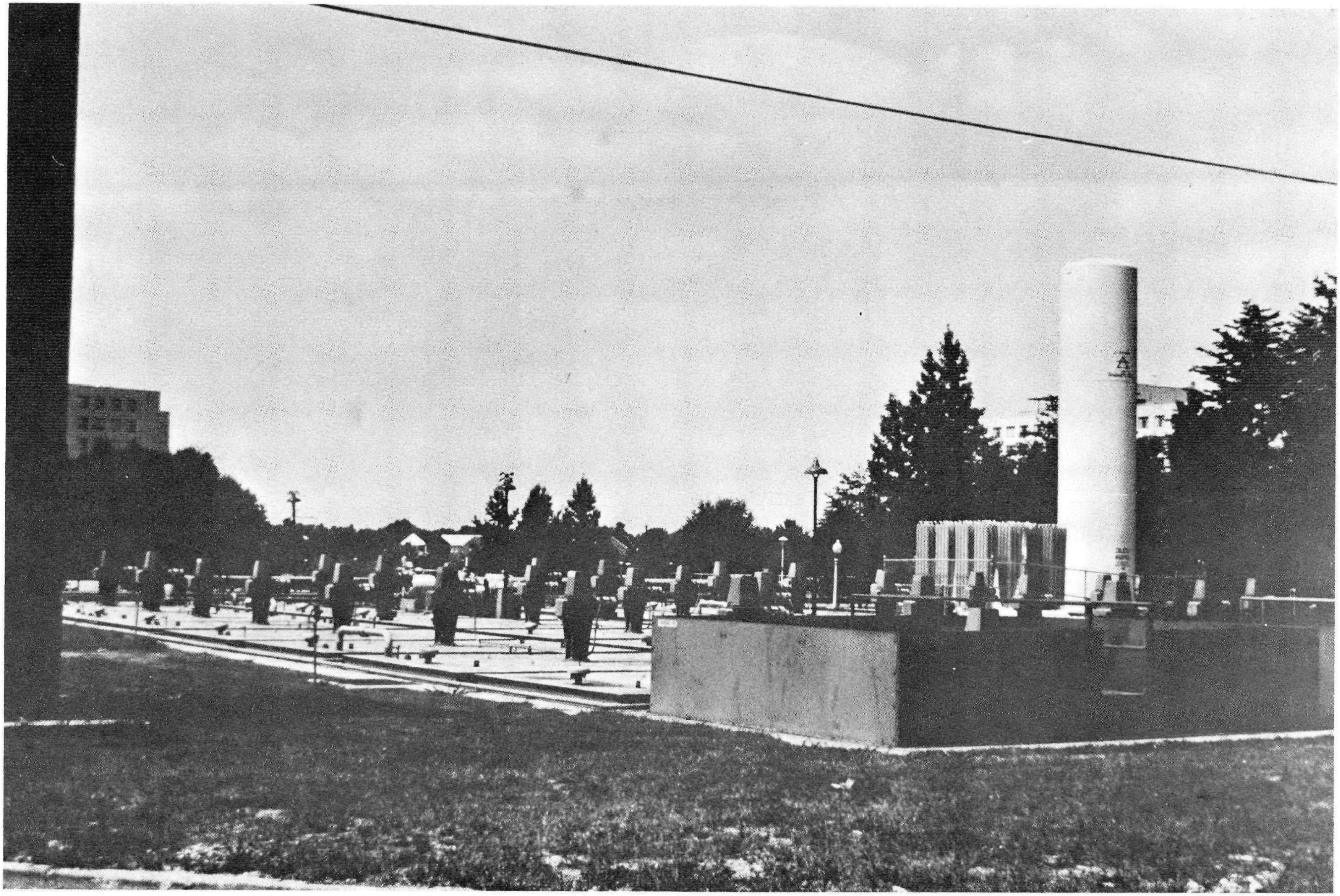


FIGURE 6B-8 PHOTOGRAPH OF PLANT

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

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

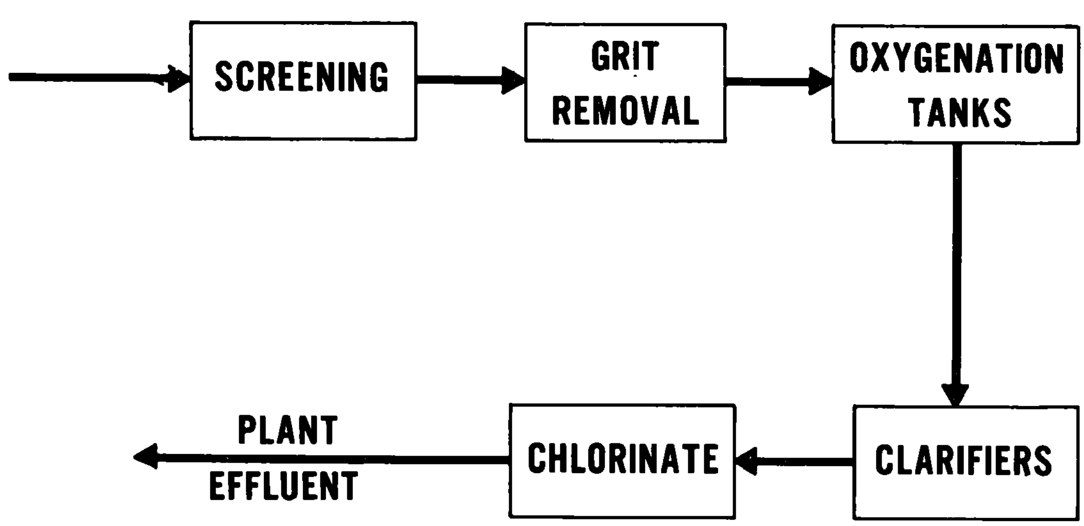


FIGURE 6C-2

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

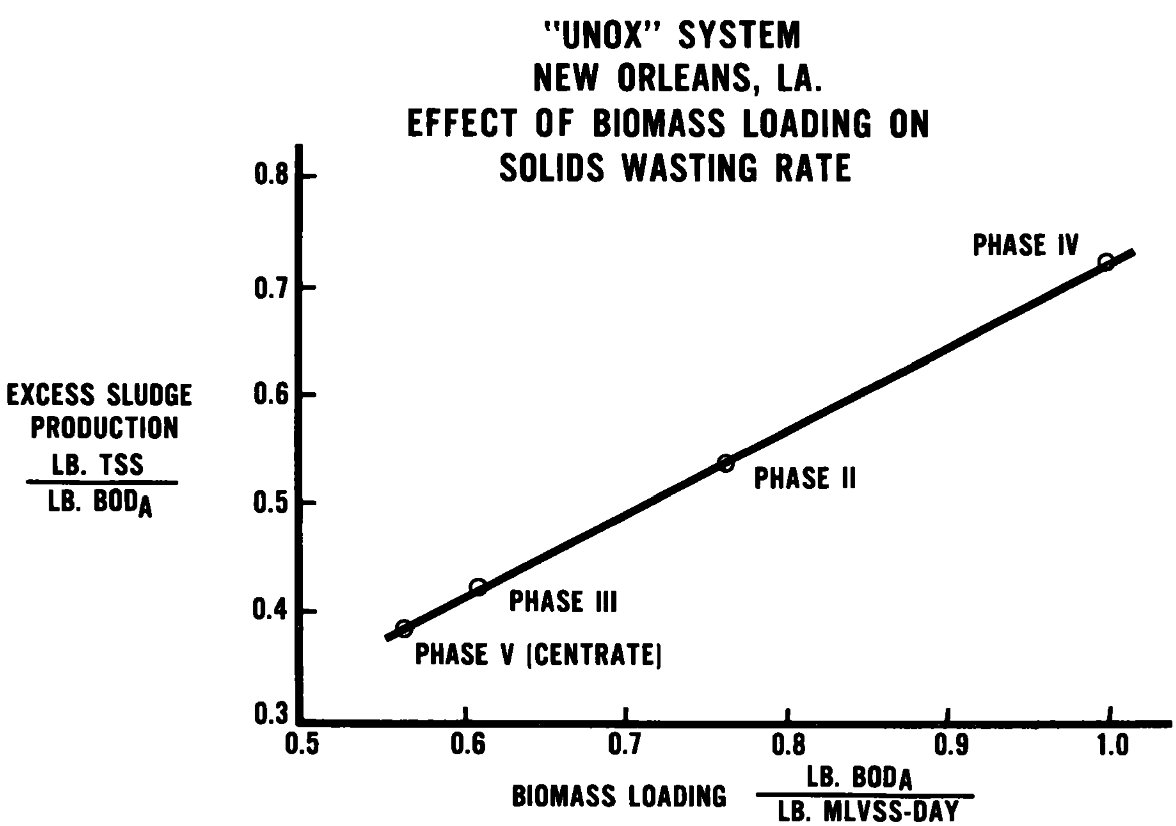


FIGURE 6C-4

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

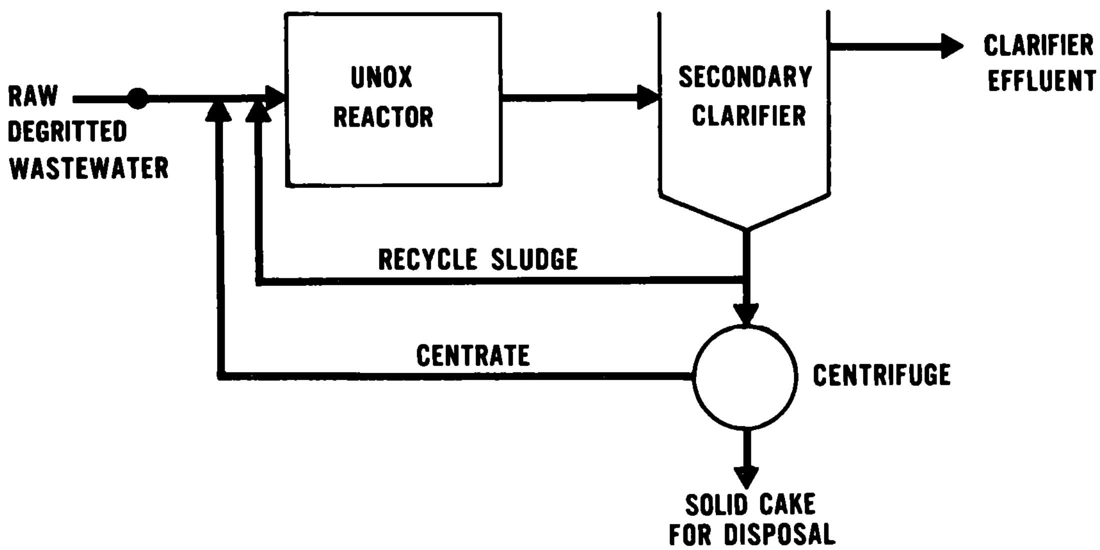


FIGURE 6C-5

"UNOX" SYSTEM
NEW ORLEANS, LA.
CENTRIFUGE PERFORMANCE

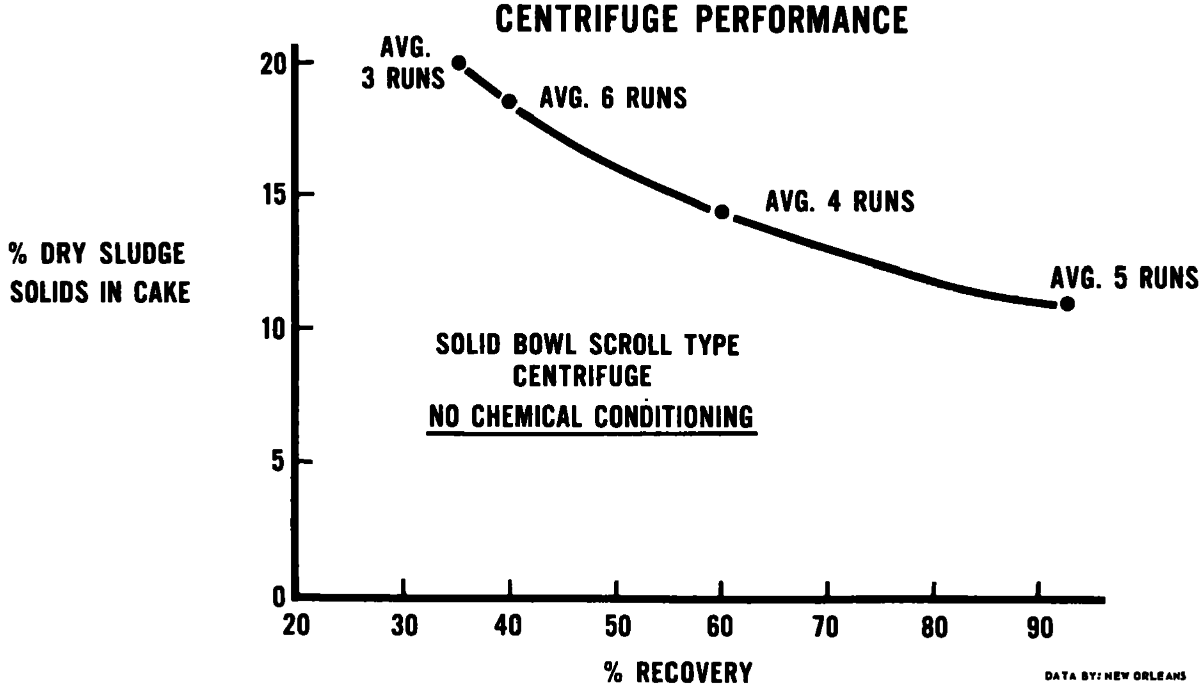


FIGURE 6C-6

CENTRIFUGATION-NEW ORLEANS OXYGEN ACTIVATED SLUDGE

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

FIGURE 6C-7

INTRENCHMENT CREEK FLOW

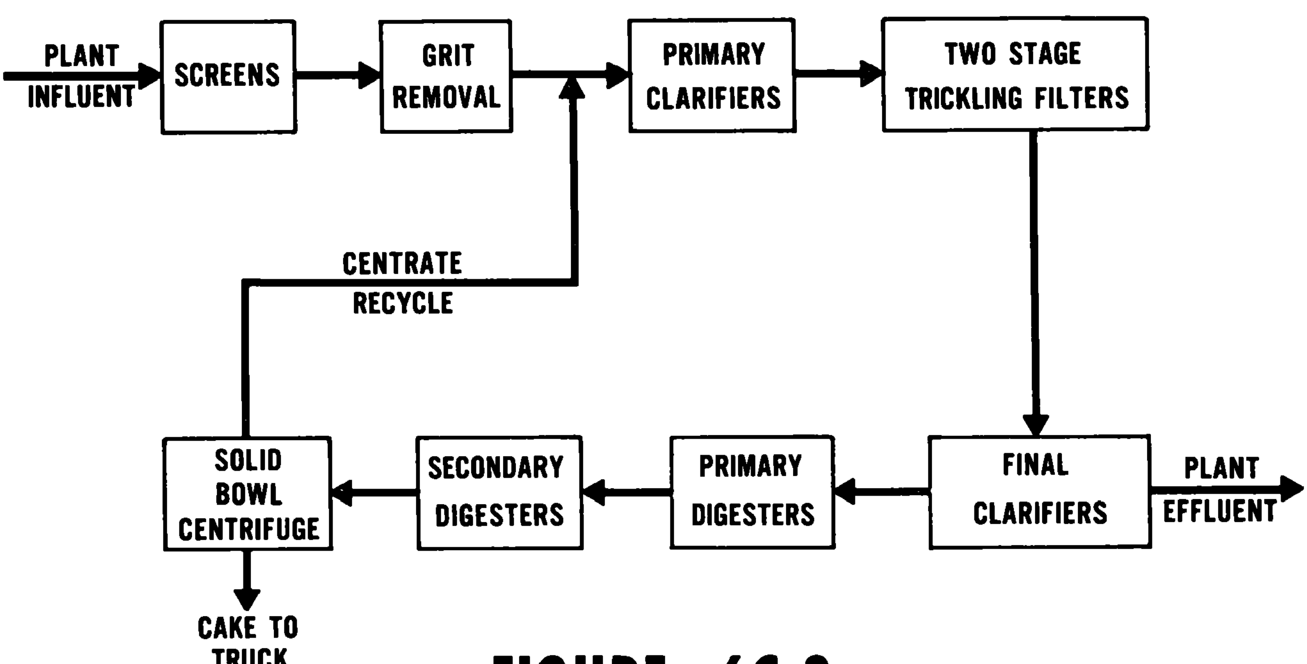


FIGURE 6C-8

CENTRIFUGATION-ATLANTA
MIXED SLUDGE-PRIMARY & T. F.

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

FIGURE 6C-9

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.

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 year's 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 $51.40/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 $56.40/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).

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

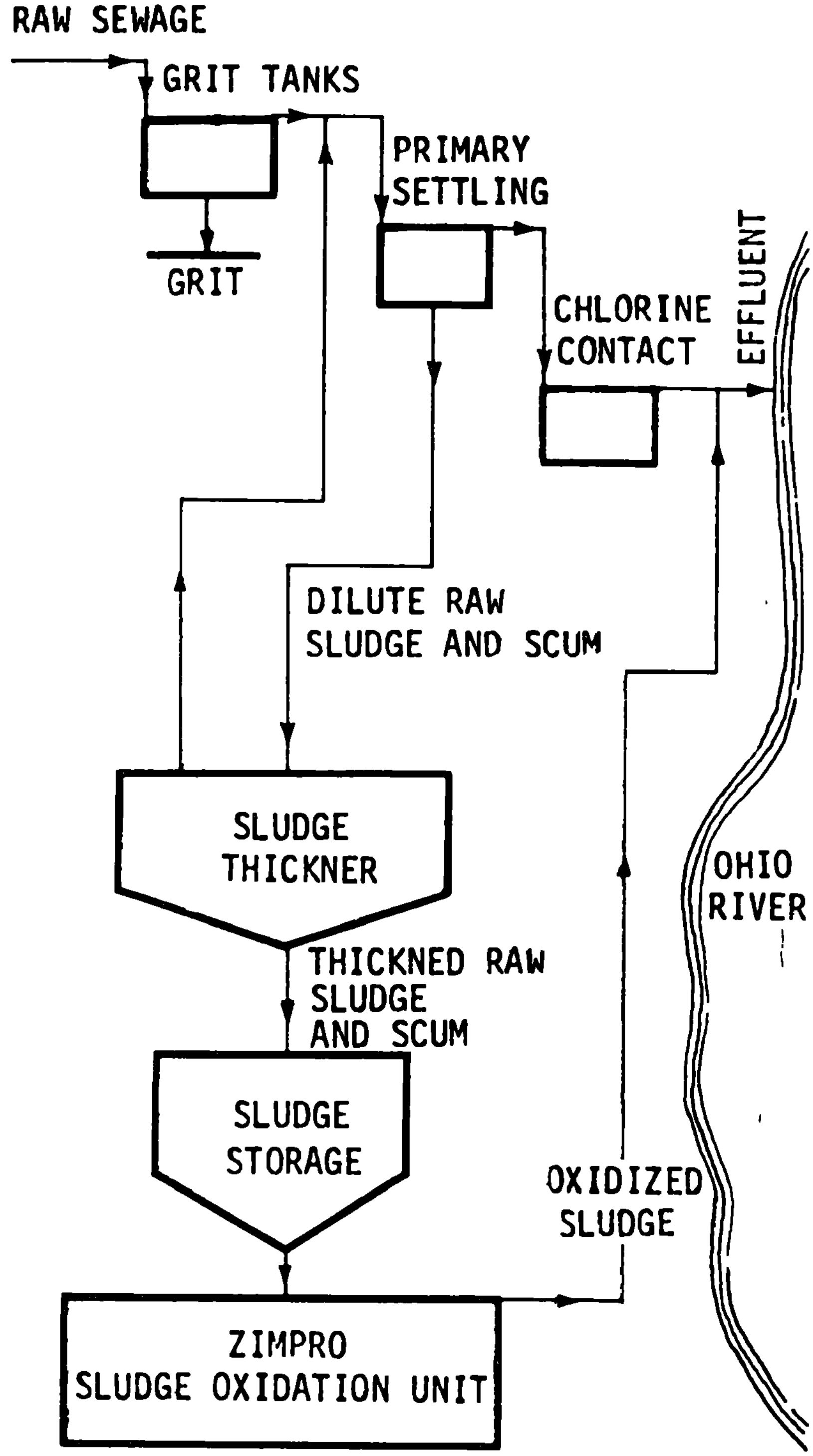


FIGURE 7-1 WHEELING, WEST VIRGINIA FLOW DIAGRAM

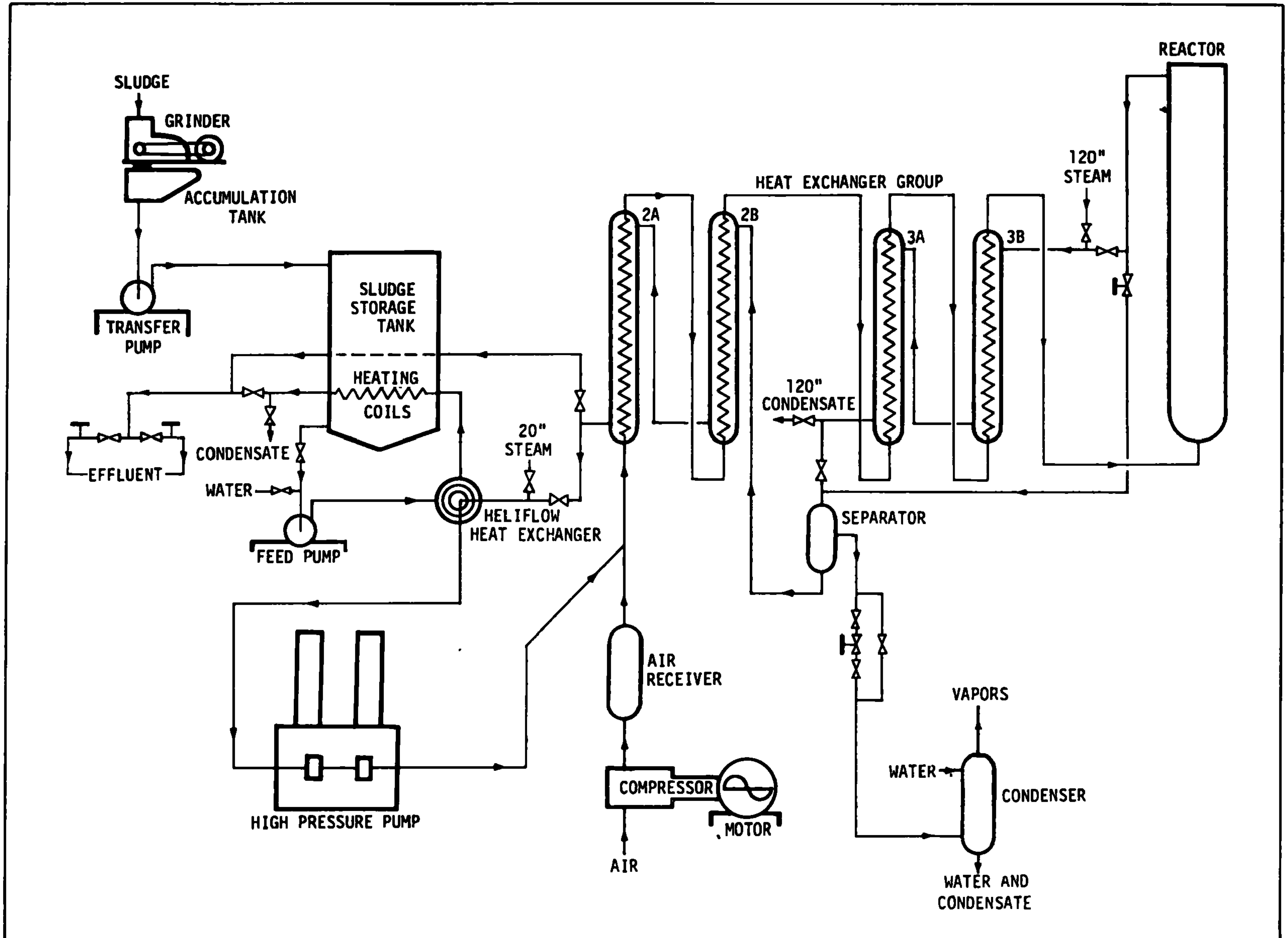


FIGURE 7-2 WET AIR OXIDATION SYSTEM – WHEELING, WEST VIRGINIA

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

	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

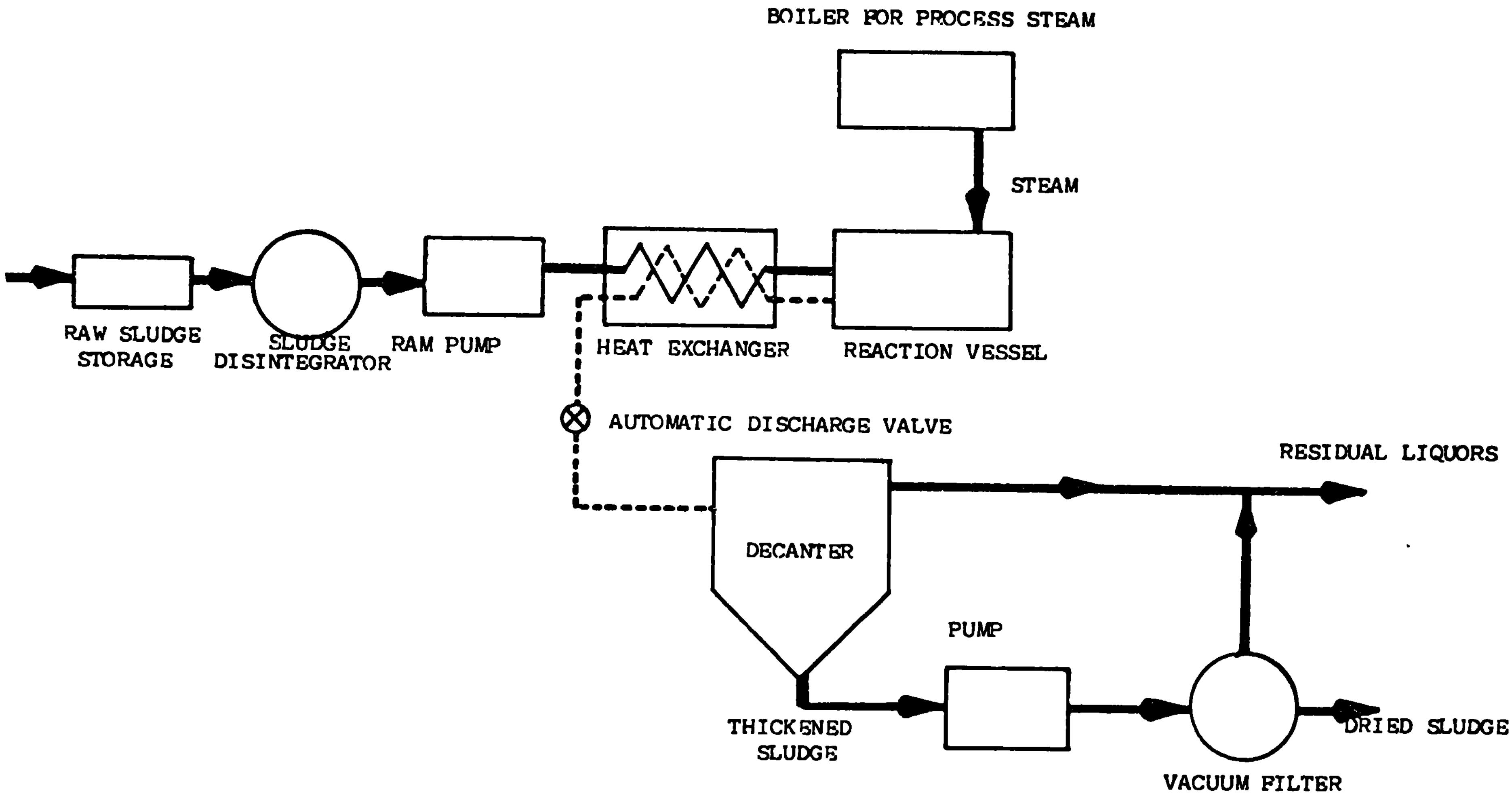


FIGURE 7-3 FLOW DIAGRAM OF THE PORTEOUS PROCESS

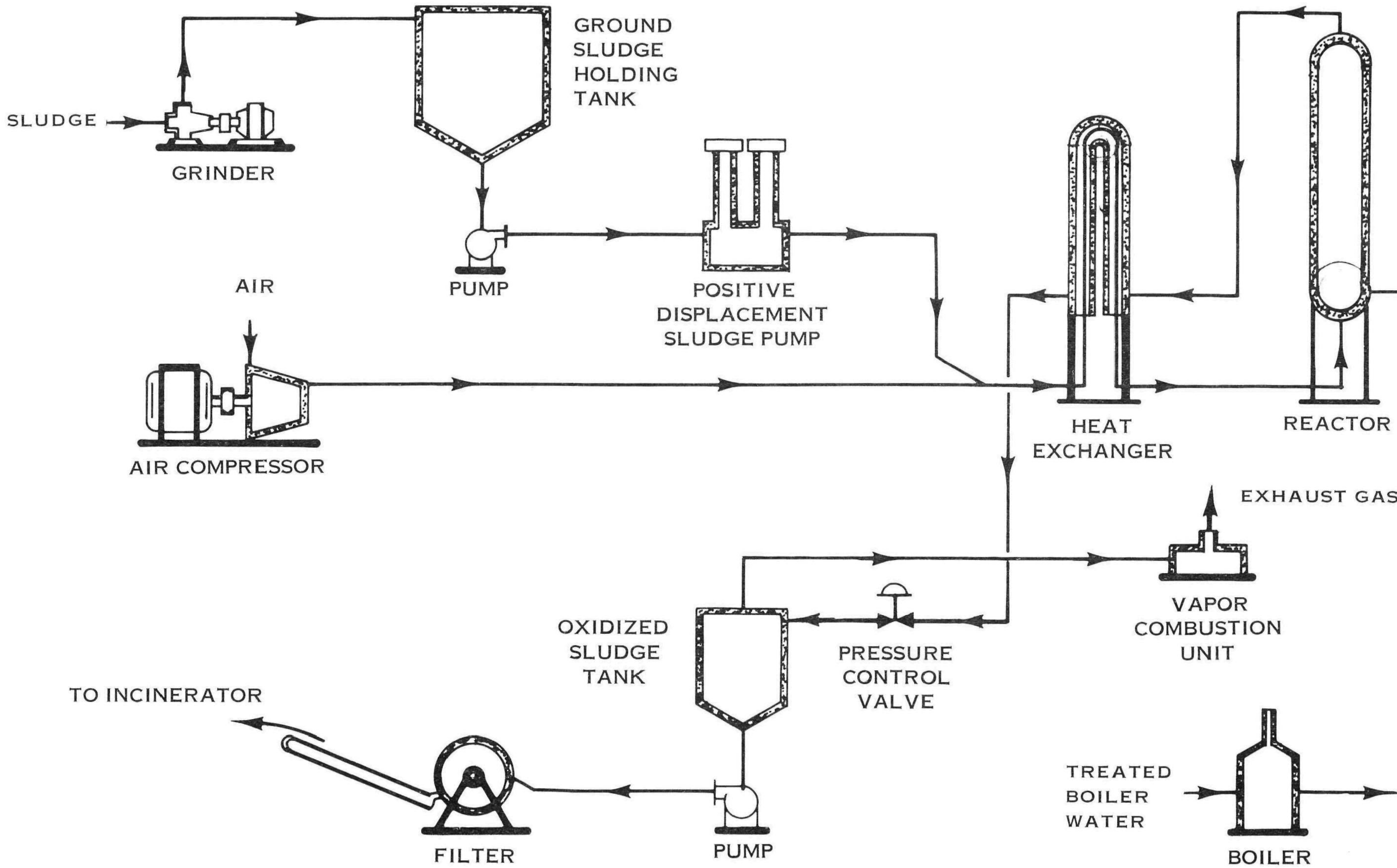


FIGURE 7-4 THERMAL SLUDGE CONDITIONING AND DEWATERING

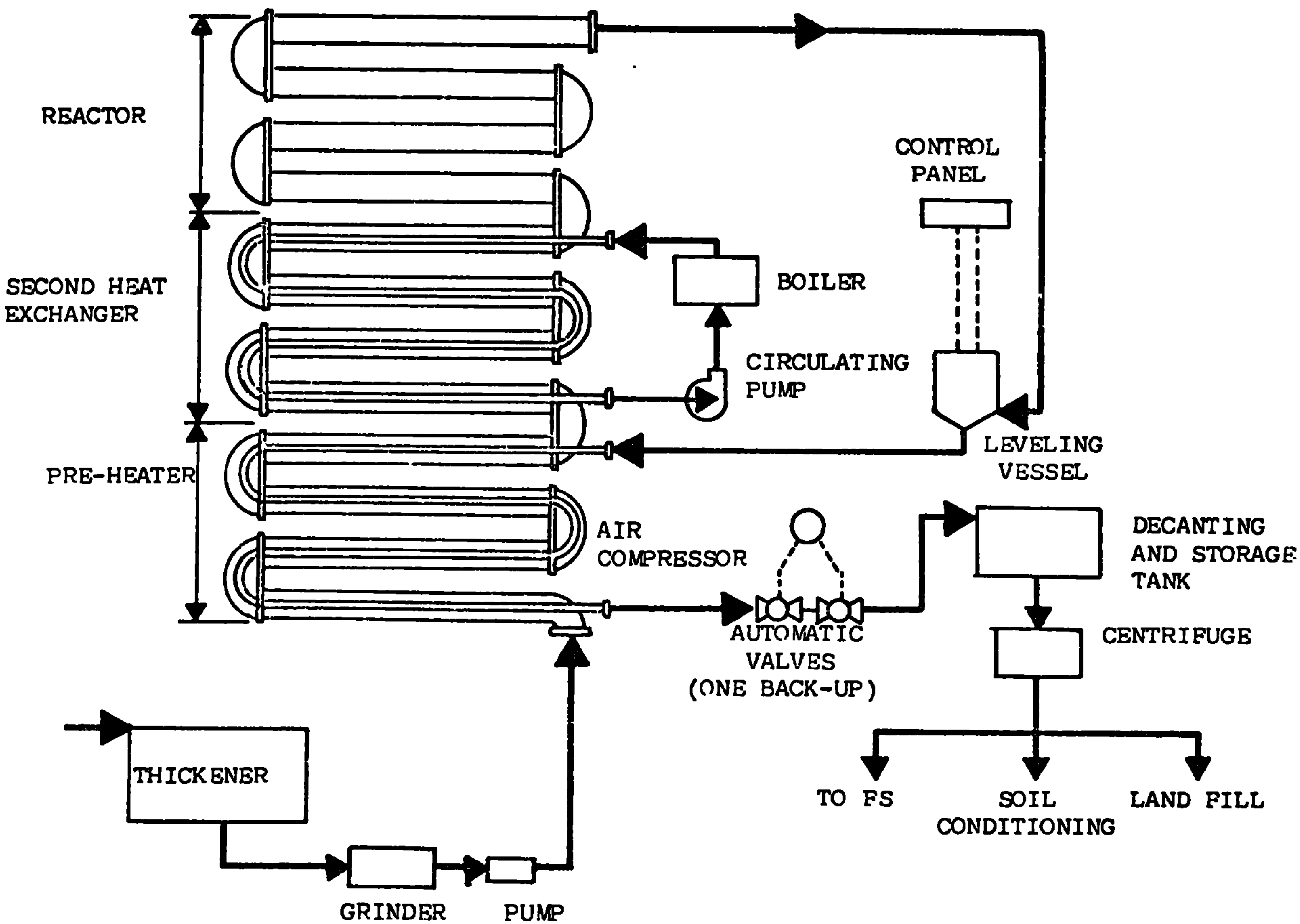


FIGURE 7-5 FLOW SHEET FOR THE DORR-OLIVER FARRER SYSTEM

	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.
19.20	32.20	51.40	5.00

FIGURE 7-6

SLUDGE DISPOSAL FACILITIES

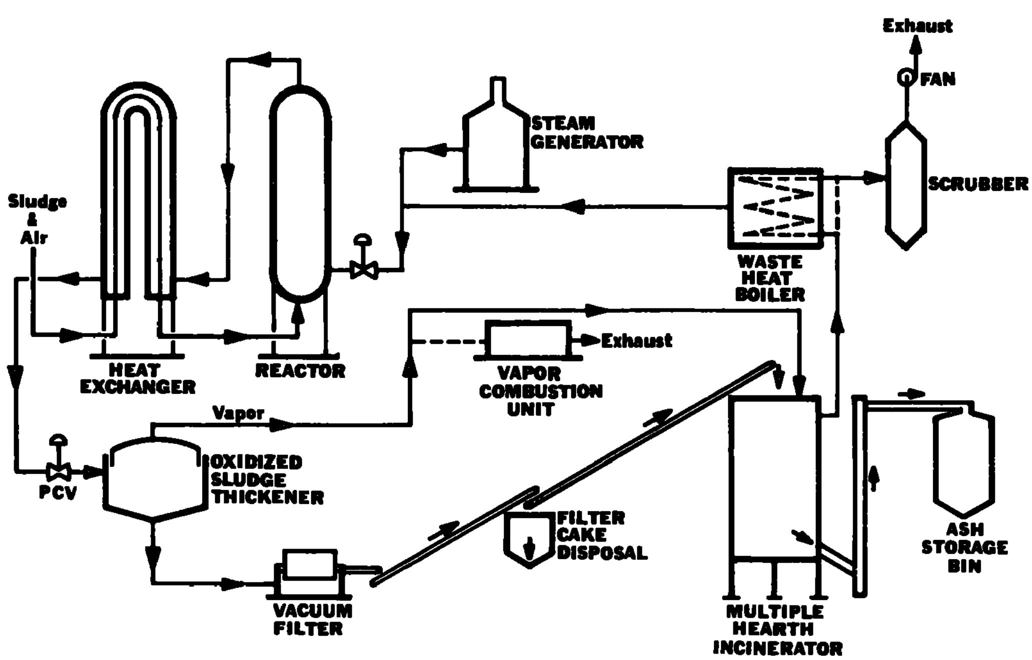


FIGURE 7-7

OPERATING TEMPERATURE BALANCE

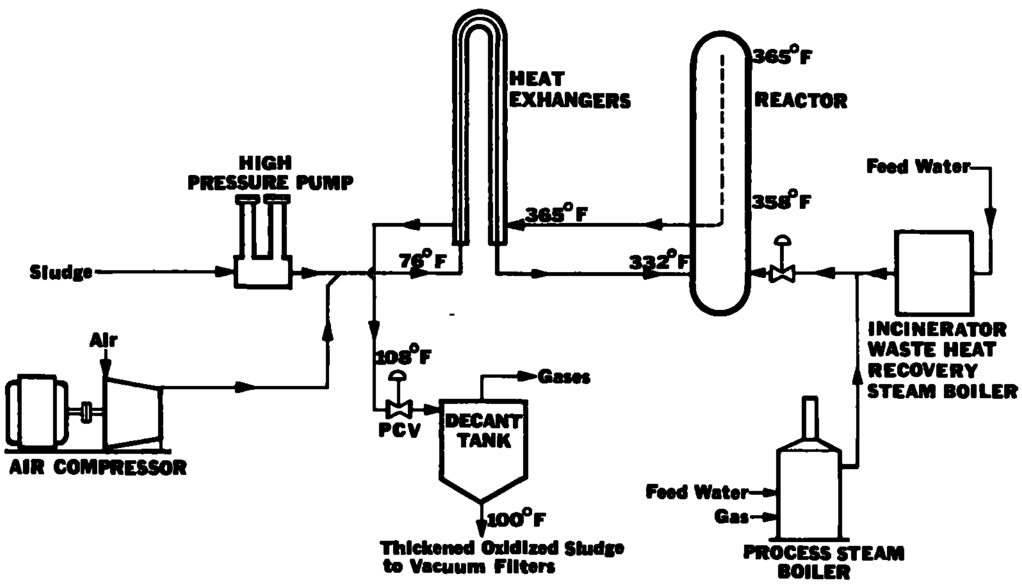


FIGURE 7-8

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

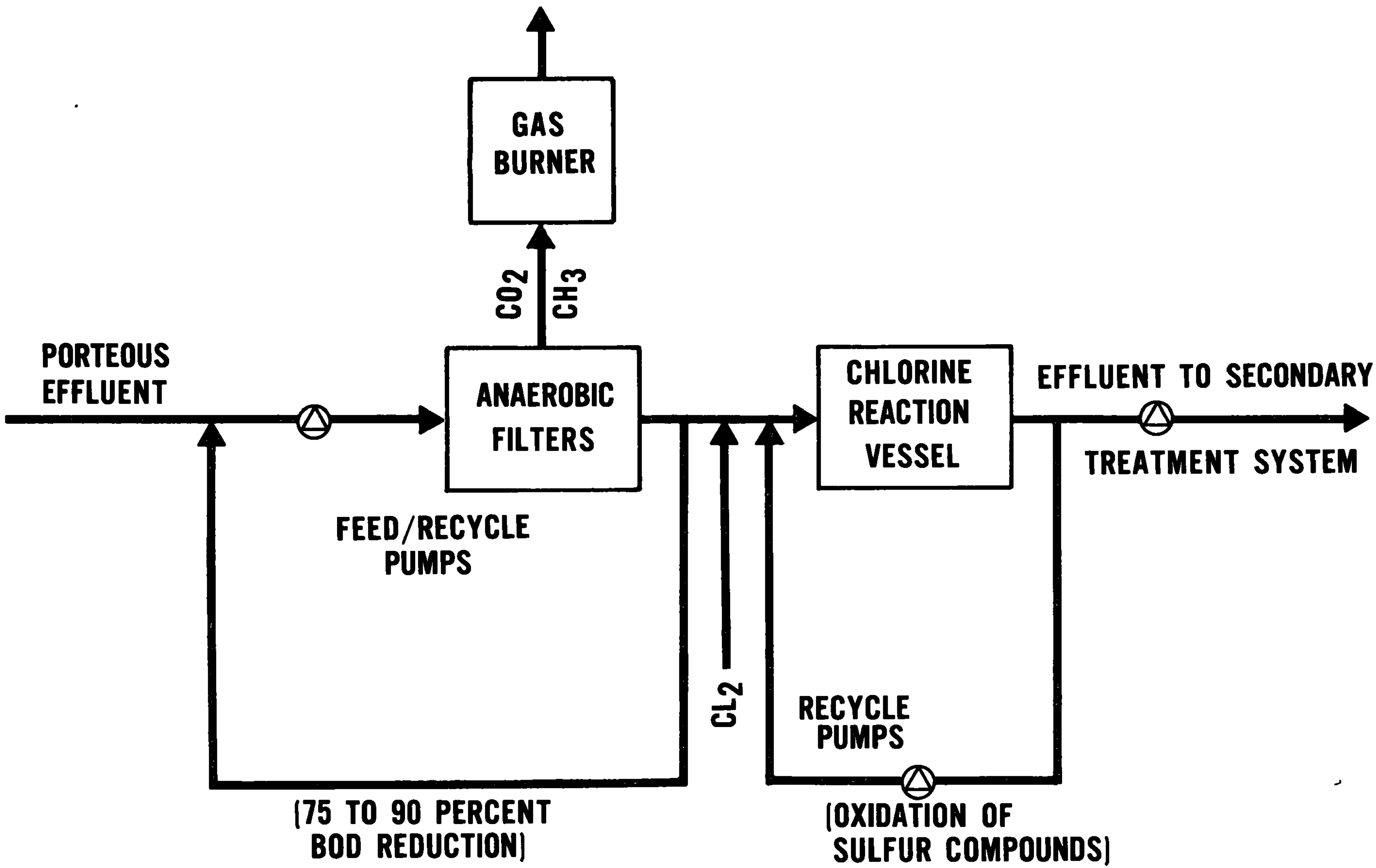


FIGURE 7-10

SECTION 8 – FINAL DISPOSAL PROCESSES AND CASE STUDIES

1. **Incineration**

   - Introduction
   - Incinerator types
   - Heat recovery by countercurrent action by heat recovery boilers
   - Air pollution requirements, devices for controlling air pollution
   - Multiple hearth incinerator

     Continuous operation, Minneapolis, St. Paul

     Intermittent operation, town X

   - Fluidized bed incinerator

     Air pollution measurements, Waldwich, New Jersey

     Intermittent operation, East Cliff - Capitola, California

   - Flash drying/incineration

2. **Landfill**

   - Bad practice
   - Good practice

3. **Land Spreading**

   a. Background

   - Landspreading is popular with wastewater plants treating less than 10 mgd, and in a few large cities. Its use is widespread in Europe. U.S. practice is being critically assessed in an EPA study.

- Potential problems are contamination of the soil with metals, and contamination of the groundwater with nutrients. Both can be handled by proper design. Chance of bacterial contamination can be reduced to a negligible degree by proper procedures or, if indicated, by pasteurization.

- Sludge has been transported by truck, barge, or pipeline. The choice depends on scale of operation and the circumstances.

- Deep, well drained, permeable, level soils are usually preferred. A careful survey of the soils, geology, and hydrology is important for proper design of a land disposal system. Lands that are used for tilled crops, pastures, forests, and recreation have been used for sludge spreading.

b. Procedures

- Methods for discharging sludge to the land

- Rates of application

- Means for controlling pathogens

- Assessment of the hazard of metal contamination

c. Land Spreading at Chicago

- Chicago is transporting sludge 200 miles by barge, and disposing it to the land for a total cost, including digestion, of $72/dry ton. Barging costs are inflated because dock and 20-mile pipeline had to be amortized over 3 years. When a pipeline is built, costs will fall to $35/dry ton.

REFERENCES – SECTION 8

1. Dalton, F.E., and Murphy, R.R., "Land Reclamation," presented at the 45th Annual Conference of the Water Pollution Control Federation, Atlanta, Georgia, 1972.

2. Lynam, B.T., Sosewitz, B., and Hinesly, T.D., "Liquid Fertilizer to Reclaim Land and Produce Crops." *Water Research*, 6, 545-549 (1972).

3. Dotson, G.K., Dean, R.B., and Stern, G., "The Cost of Dewatering Digested Sludge on Land," to be presented at the 65th Annual Meeting A.I.CH.E., New York, New York, November, 1972.

4. White, R.K., and Hamdy, M.Y., "Sludge Disposal on Agricultural Soils," presented at the 27th Annual Purdue Industrial Waste Conference, 1972.

5. Graham, R.E., and Dodson, R.E., "Digestion Sludge Disposal at San Diego's Aquatic Park," presented at the 41st Annual Conference of the Water Pollution Control Federation, Chicago, Illinois, September 22-27, 1968.

LIST OF FIGURES AND TABLES – SECTION 8

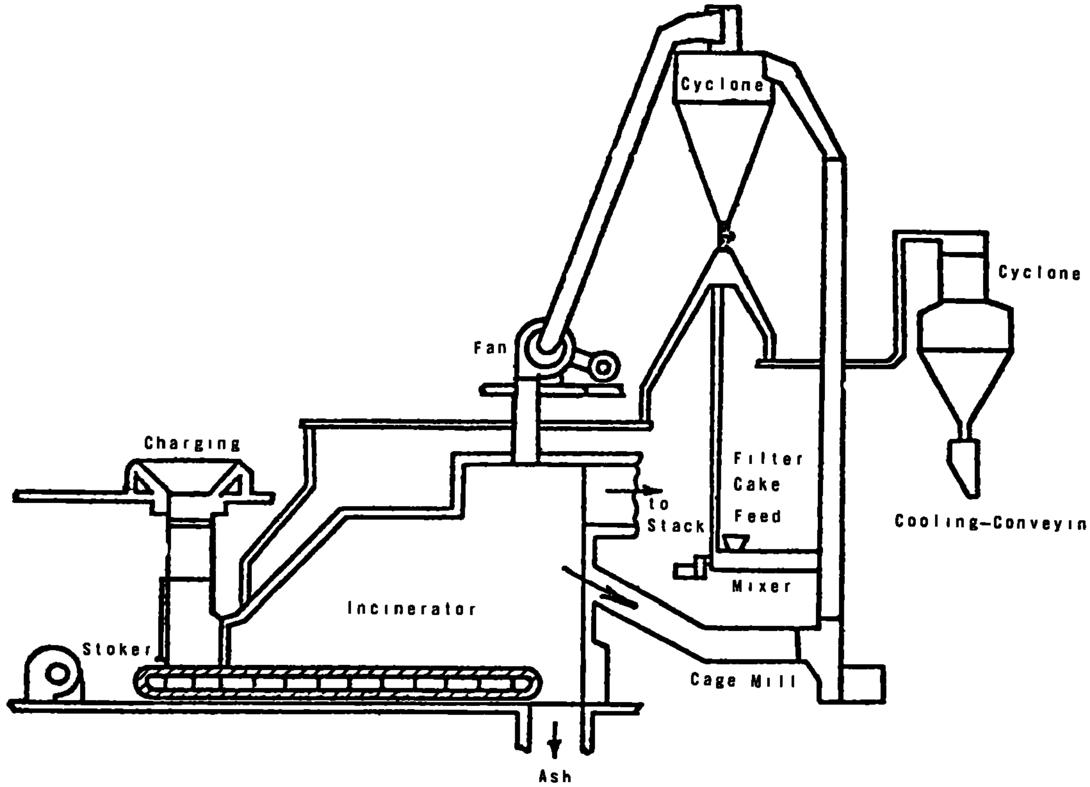


FIGURE 8-1 FLASH-DRYING SYSTEM WITH MIXED-REFUSE INCINERATOR

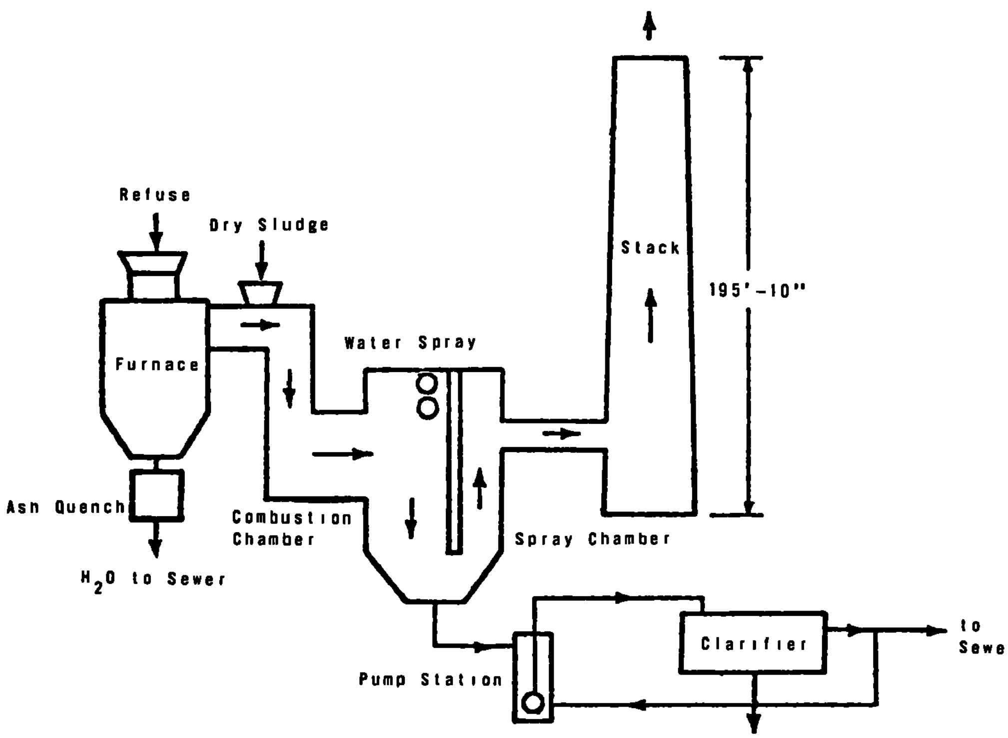


FIGURE 8-2 FLOW DIAGRAM OF WASTE-DISPOSAL SYSTEM

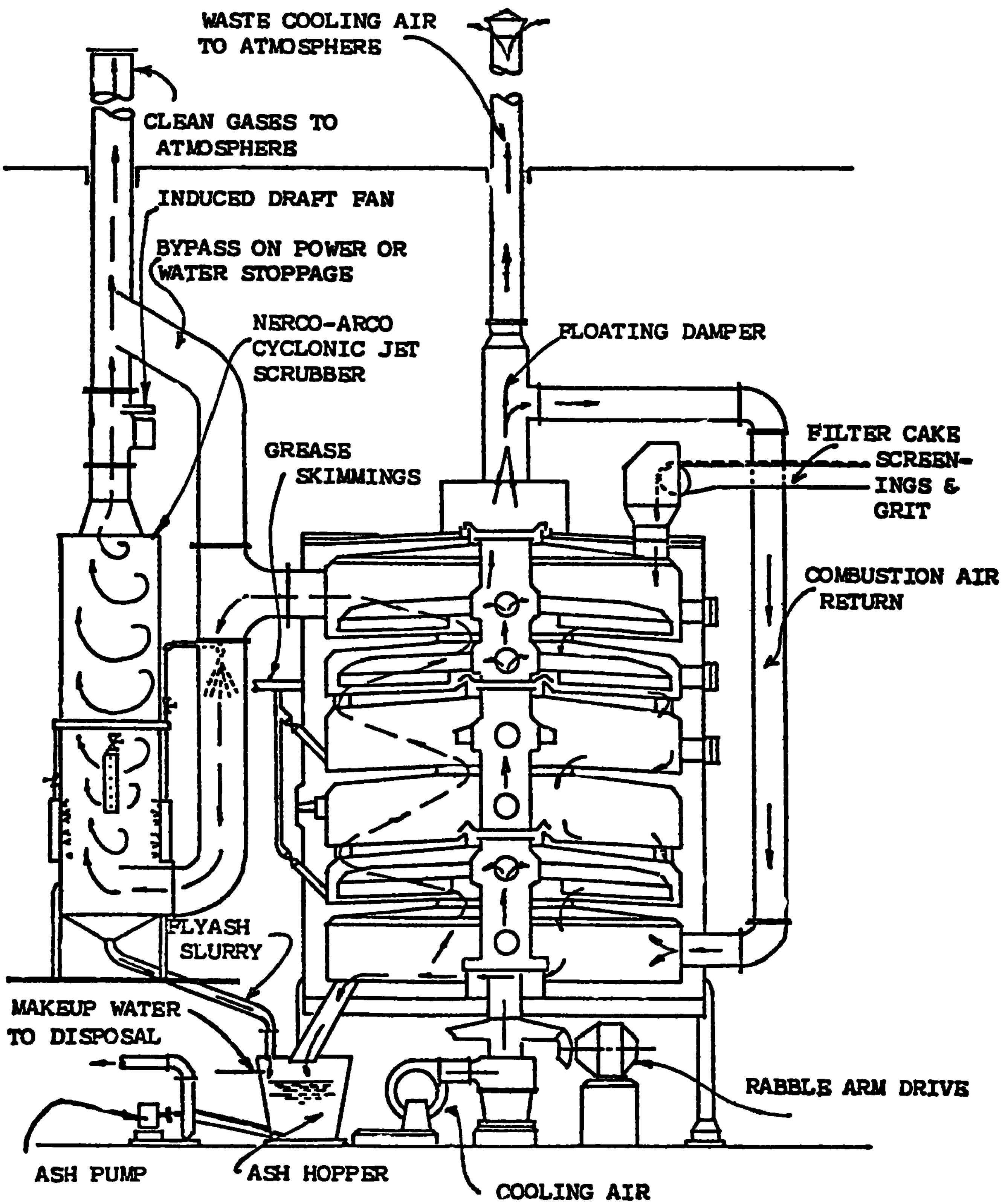


FIGURE 8-3 TYPICAL SECTION OF MULTIPLE HEARTH INCINERATOR

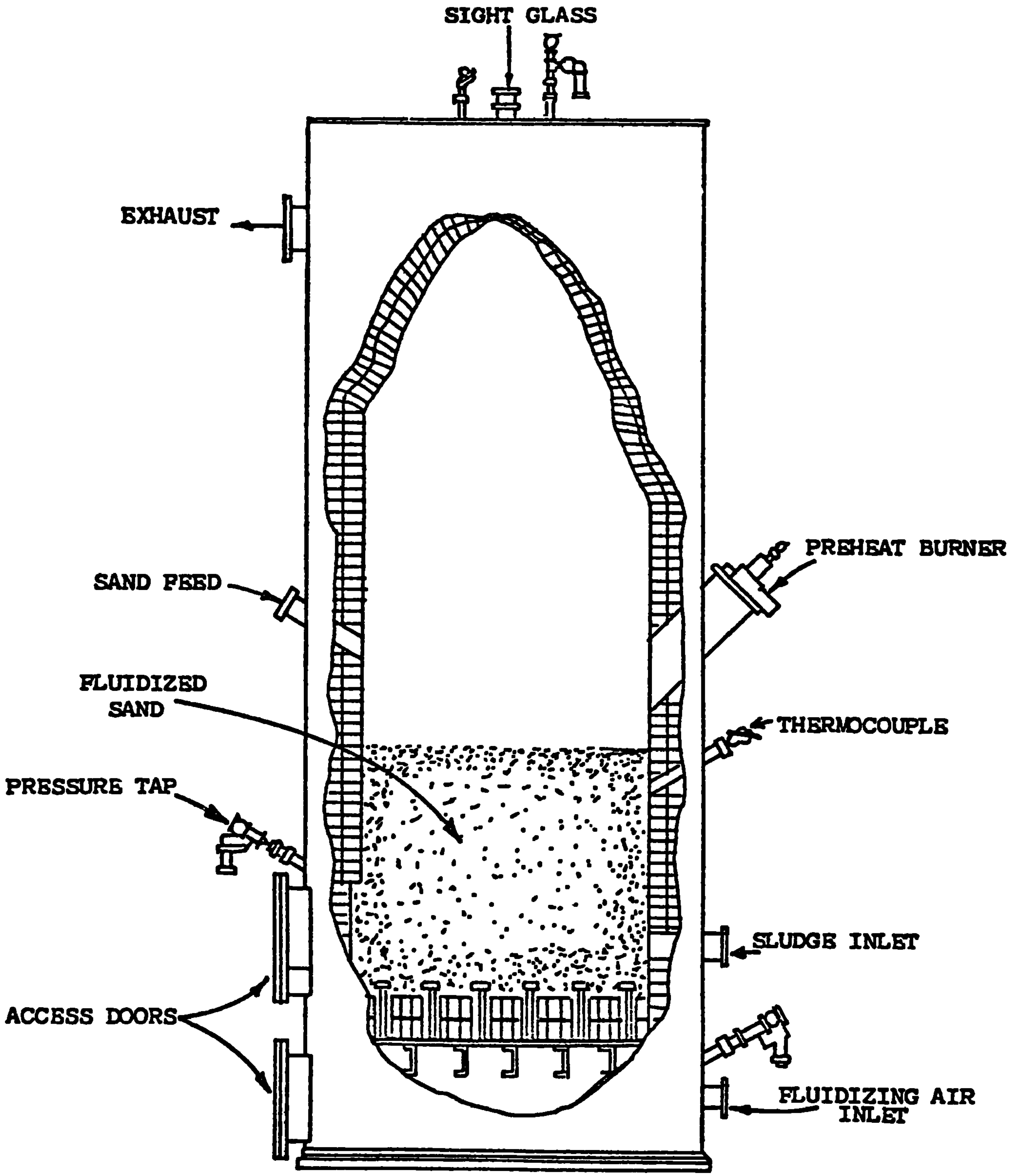


FIGURE 8-4 TYPICAL SECTION OF A FLUID BED REACTOR (DORR-OLIVER, INC.)