United States
Environmental Protection
Agency

Municipal Environmental
Research Laboratory
Cincinnati OH 45268

Technology Transfer

Design Manual

Dewatering Municipal Wastewater Sludges

EPA-625/1-82-014

PROCESS DESIGN MANUAL
FOR
DEWATERING MUNICIPAL WASTEWATER SLUDGES

U.S. ENVIRONMENTAL PROTECTION AGENCY

Office of Research and Development
Municipal Environmental Research Laboratory

October 1982

Published By
U.S. ENVIRONMENTAL PROTECTION AGENCY
Center For Environmental Research Information
Cincinnati, Ohio 45268

NOTICE

ABSTRACT

This manual presents a critical review of municipal wastewater sludge dewatering process technology. Particular emphasis is given to the development of a procedure for the selection and design of a dewatering process.

Included in the manual are discussions of sludge characteristics, dewatering processes, their performance capabilities and operational variables, chemical conditioning, cost and energy considerations, and case-study information.

Dewatering processes discussed are basket centrifuge, low G and high G solid bowl centrifuges, belt filter press, vacuum filter, fixed volume and variable volume recessed plate filter presses, drying bed, sludge lagoon, and gravity/low pressure devices.

ACKNOWLEGEMENTS

There were four groups of participants involved in the preparation of this manual: (1) the contractor, (2) the authors, (3) the technical directors, and (4) the technical reviewers. The contractor for this project was SCS Engineers of Long Beach, California. The manual was written by personnel from Culp/Wesner/Culp of Santa Ana, California. Technical direction was provided by U. S. Environmental Protection Agency (EPA) personnel from the Office of Research and Development in Cincinnati, Ohio. The technical reviewers were experts in wastewater treatment plant sludge dewatering and included university professors, wastewater equipment manufacturers, consultants, and government officials. Each reviewer provided an invaluable constructive critique of the manual. The membership of each group is listed below.

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Chapter 1

INTRODUCTION

1.1 Purpose and Scope

This manual has been prepared to present up-to-date information on dewatering processes applicable to municipal wastewater sludge, as well as to present a strategy to be used in the selection of these processes. The manual both complements and supplements those chapters in the EPA - Process Design Manual for Sludge Treatment and Disposal that discuss conditioning and dewatering (1). Significant advances have been made in dewatering technology since preparation of the latter manual.

Information is presented on design parameters, performance capabilities, design deficiencies, and cost and energy requirements for all dewatering processes. The manual specifically discusses those processes where the most extensive progress has been made including centrifugation, belt press filtration, and pressure filtration.

The manual is current as of the summer of 1982 and includes detailed discussions of and presentation of case history information on the newer process equipment, including solid bowl centrifuges with backdrive capability and optimized bowl design, third generation belt filter presses, and diaphragm filter presses. Provided also are the capabilities of these and other dewatering processes by presenting data from full-scale field testing and operating installations. Information presented is restricted to sludges produced during primary and secondary wastewater treatment. Chemical sludges produced during advanced wastewater treatment are not considered.

In general, the manual has been prepared for use by experienced engineers involved in the design and selection/specification of dewatering equipment. Federal, state, and local decision-making officials, however, will also find useful information here. Little background information is presented on solids handling processes other than dewatering, although the strategy approach presented for the selection of a dewatering process is strongly dependent on analysis of the entire sludge handling and disposal operation. For more information on sludge handling processes, refer to the references at the end of each chapter and to the Bibliography.

The major types of dewatering processes discussed in this manual include:

- Centrifugation
  - Basket Centrifuges
  - Solid Bowl Centrifuges - high G and low G

- Belt Press Filtration
- Vacuum Filtration
- Pressure Filtration
  - Fixed Volume
  - Variable Volume
- Drying Beds
- Sludge Lagoons
- Gravity/Low Pressure Dewatering

All of these are in common usage today, although processes such as the basket centrifuge and the vacuum filter are rarely seen in new installations. The manual does not discuss processes which have been installed at one or two plants or processes which do not have a proven background of performance.

1.2 Objectives of Dewatering

The general objectives of dewatering are to remove water and thereby reduce the sludge volume, to produce a sludge which behaves as a solid and not a liquid, and to reduce the cost of subsequent treatment and disposal processes. No generally accepted lower limit exists for the percent solids content of a dewatered sludge. In many cases, the lower limit is set by the requirements for subsequent treatment and disposal. However, the lower limit is always significantly higher than the percent solids content of a thickened sludge. This manual considers the use of low pressure first generation type belt presses which dewater sludge to a 10-12% solids concentration, as well as drying beds which produce a 60-70% solids content cake.

1.3 Location of the Dewatering Process

The type and order of processes used for solids treatment, dewatering, transport, and disposal vary widely from plant to plant. Generally however, the dewatering process is preceded by a stabilization process, such as anaerobic or aerobic digestion, thickening by either gravity, centrifugation or air flotation, and chemical or heat treatment conditioning. In some cases, raw sludge, particularly raw primary sludge, may be dewatered directly, although the method of ultimate disposal would have to be considered in such a decision. After the dewatering operation, further stabilization may be provided by composting, volume and organic reduction may be accomplished by incineration, or the dewatered sludge may be ultimately disposed of by transport to a landfill or a site for landspreading.

1.4 Guide To Intended Use

This manual is organized to allow users to locate particular information and to concentrate on specific areas of interest as easily as possible. The following brief chapter and appendix descriptions are provided as an introduction to the organization of the manual.

Chapter 2 - Sludge Characteristics Affecting Dewatering

Seven sludge characteristics which significantly affect dewatering capabilities and conditioning requirements are discussed along with the interrelationships between these characteristics.

Chapter 3 - Dewatering Process Descriptions

Descriptions are presented for dewatering processes in common usage. Included in these descriptions are operational principles, key advantages and disadvantages, and common design shortcomings.

Chapter 4 - Capabilities of Dewatering Processes

Performance capabilities of dewatering processes are discussed for a variety of different types of sludge and sludge mixtures. Graphic presentations are included to illustrate the capabilities of dewatering processes. The impact of process operational variables on dewatering results and the influence of dewatering on sludge volume are also discussed.

Chapter 5 - Chemicals Used in Dewatering

Major conditioning chemicals used in dewatering, their applications and typical conditioning requirements are discussed. Important considerations which the designer should recognize in addition to performance and cost are included.

Chapter 6 - Strategy for Dewatering Process Selection

A strategy applicable to selection of a dewatering process for new or existing facilities is described. Five stages of analysis comprise this strategy, which is a progressive selection procedure. Processes are given increasing scrutiny as more detailed cost, operational, and design data are collected.

Chapter 7 - Comparative Cost Analyses of Sludge Treatment and Disposal Systems

Comparative cost analyses are presented for three sizes of sludge handling systems: 910, 4,540 and 45,400 kg/day of dry sludge solids. Design criteria and flow diagrams are presented for each system evaluated, and a ranking of systems based upon total annual cost is presented.

Chapter 8 - Energy Considerations in Dewatering Process Selection

Direct energy requirements for dewatering and indirect energy requirements associated with production of conditioning chemicals are described and quantified. Graphic and tabular comparisons are included for each dewatering process.

Chapter 9 - Summary of Recent Side-By-Side Comparisons of Dewatering Processes at Ten Treatment Plants

Evaluations conducted by ten large utilities in various parts of the U.S. are described. The utilities' findings, conclusions, and progress made to date relative to installation of additional dewatering equipment are presented.

Appendix A - Manufacturers of Dewatering Equipment

An up-to-date listing of manufacturers of centrifuges, belt filter presses, vacuum filters, filter presses, and drying bed systems is presented.

Appendix B - Example Calculations Showing Sludge Volumes Produced By Different Dewatering Processes

Example calculations are presented for major dewatering processes. The calculations are self descriptive and are the basis for several figures in Chapter 4.

Appendix C - Cost of Dewatering Equipment

Construction and operation and maintenance cost curves are presented for nine dewatering processes. These construction cost estimates are for installed equipment, and include all concrete structures, housing, pipes and valves, electrical and instrumentation equipment and installation labor. Operation and maintenance requirements are presented individually for labor, building electrical, process electrical, diesel fuel, and maintenance materials. A complete description of the design assumptions used for the development of the cost data is presented.

1.5 References

1. "Process Design Manual For Sludge Treatment and Disposal," USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-625/1-79/011, September 1979.

Chapter 2

SLUDGE CHARACTERISTICS AFFECTING DEWATERING

2.1 Introduction

Many factors influence the dewaterability of a sludge. They include the source of the sludge and prior treatment or storage which can change the sludge characteristics prior to dewatering. A number of characteristics can be used to define the ability of a sludge to be dewatered. Some of these characteristics are readily measured with equipment available at most plants, while others are difficult or impossible for the plant operator to measure in day-to-day operation, and can only be measured with sophisticated analytical techniques and equipment.

2.2 Characteristics Affecting Dewatering

2.2.1 General Considerations

In general, all characteristics relate to the difficulty of forcing sludge solids closer together, or to the difficulty of water movement through the voids between the sludge solids. The purpose of sludge conditioning is to counteract adverse characteristics which decrease the rate or degree of water removal.

The sludge characteristics which most significantly affect dewatering and conditioning requirements are:

- Particle surface charge and hydration
- Particle size
- Compressibility
- Sludge temperature
- Ratio of volatile solids to fixed solids
- Sludge pH
- Septicity

These characteristics and their interrelationships are discussed in the following sections.

2.2.2 Particle Surface Charge and Hydration

Sludge particles have a negative surface charge and repel each other as they are forced together. This repulsive force increases exponentially as the sludge particles are forced closer together. Additionally, sludge particles weakly attract water molecules to their surface either by adsorption or by capillary action between particles. Although the water is only weakly held at the particle surface, it does interfere with dewatering.

Conditioning chemicals are used to overcome the effects of surface charge and surface hydration. Typically used chemicals are organic polymers, lime, and ferric chloride. Generally they act by reducing or eliminating the repulsive force, thus permitting the particles to come together or flocculate. Water can be more readily removed at a higher rate during the subsequent mechanical dewatering.

2.2.3 Particle Size

Particle size is generally recognized as the most important factor influencing dewaterability. As average particle size decreases, the surface area for a given sludge mass increases. The effects of increasing the surface area include:

- Greater electrical repulsion between sludge particles due to a larger area of negatively charged surface.
- Greater frictional resistance to the movement of water.
- Greater attraction of water to the particle surface due to more adsorption sites.

Particle size is influenced by both the sludge source and prior treatment. Generally, primary sludge has a larger average particle size than secondary sludge. This is because fine and colloidal solids tend to pass through the primary clarifier. Some of these same particles are then removed in the secondary clarifier along with the less dense, flocculated cellular material that is created during biological treatment. Sludge treatment prior to dewatering, particularly by aerobic or anaerobic digestion, also decreases the average particle size. This is the principal reason that digested sludge is more difficult to dewater than raw sludge. Other conditions which can result in decreased particle size are mixing, storage, and sludge transport. Therefore, to maximize the dewaterability of a sludge, use of these conditions should be minimized.

2.2.4 Compressibility

If sludge particles were idealized incompressible solids, the solids would not deform, and the void area between particles would remain constant during mechanical dewatering. In such an ideal situation, resistance to filtration would be proportional to sludge depth, and there would be no increase in resistance to filtration as dewatering progresses. Unfortunately, sludge particles are compressible to a degree, which results in particle deformation and a reduction in the void area between particles. This reduction in void volume inhibits the movement of water through the compressed portion of the sludge cake, and reduces the rate of dewaterability.

Proper conditioning improves dewaterability primarily by producing a flocculant matrix of solids in relatively clear water prior to initiation of filtration. When this matrix is deposited on a filtering medium, the bulk cake retains a substantial porosity. However, if an excess pressure drop occurs across the sludge floc, the conditioned sludge cake may collapse, resulting in a decrease in filtration rate. The net result of conditioning is more rapid removal of water, principally due to the higher rate of water removal at the start of the filtration cycle.

2.2.5 Sludge Temperature

As sludge temperature increases, the viscosity of the water present in the sludge mass decreases. Viscosity is particularly important in centrifuges, since sedimentation is a key component of the centrifugation process. According to Stokes Law, the terminal settling velocity during centrifugal acceleration varies according to an inverse linear relationship with viscosity of the water. For example, if viscosity is decreased by 50%, the rate of centrifugal acceleration is increased by 100%. To illustrate the relationship beween water temperature and viscosity of water, Table 2-1 is presented:

TABLE 2-1

VISCOSITY OF WATER AS A FUNCTION OF TEMPERATURE

Temperature - °C	Viscosity-Centipoises
10	1.308
15	1.140
20	1.005
25	0.894
30	0.800
35	0.723

---

1 centipoise = 0.001 pascal seconds

A complete discussion of the influence of centrifugal acceleration on centrifuge operation is included in Reference 1.

Dewatering processes which utilize filtration principles would not be expected from theory to be affected by sludge temperature as greatly as centrifuges. Information available from manufacturers of vacuum filters, belt filter presses, and filter presses confirms this expectation.

2.2.6 Ratio of Volatile Solids to Fixed Solids

Sludges tend to dewater better as the percentage of fixed solids increases, assuming all other factors are equivalent. One high G centrifuge manufacturer utilizes the percentage of fixed solids as a key parameter in sizing of equipment (2). (See Section 3.2.2.1 for a description of low G and high G centrifuges). According to this manufacturer, the cake from centrifugal dewatering of an anaerobically digested mixture of primary and waste activated sludge shows a 5% increase in its solids concentration when the percentage of volatile solids in it decreases from 70% to 50% (2).

2.2.7 Sludge pH

Sludge pH affects the surface charge on sludge particles, as well as influences the type of polymer to be used for conditioning. Generally, anionic polymers are most useful when the sludge is lime conditioned and has a high pH, while cationic polymers are most suitable at pH slightly above or below neutral.

2.2.8 Septicity

Septic sludge is more difficult to dewater and requires higher dosages of chemical conditioners than fresh sludge, assuming other conditions are equal. This phenomenon has been experienced at many locations, and is most likely due to a reduction in the size of sludge particles and to generation of gases that remain entrained in the sludge.

2.3 References

1. Vesilind, P.A., "Treatment and Disposal of Wastewater Sludges," Revised Edition, Ann Arbor Science Publishers, Ann Arbor, Michigan, 1980.

2. Personal communication, Richard T. Moll, Manager of Process Engineering, Sharples-Stokes Division, Pennwalt Corporation, Warminster, Pennsylvania, June 1982.

CHAPTER 3

DEWATERING PROCESS DESCRIPTIONS

3.1 Introduction

A wide variety of mechanical dewatering processes are available, in addition to evaporation/percolation processes such as sand drying beds and sludge lagoons. This chapter briefly discusses for each process its operational principles, key advantages and disadvantages, and design shortcomings. Detailed performance information for each process is presented in Chapter 4. Chemical conditioning requirements for the different dewatering processes are presented in Chapter 5. The processes which are described and the order in which they are presented are as follows:

- Centrifugation
    - Basket centrifuge
    - Solid bowl centrifuge
- Belt press filtration
- Vacuum filtration
- Pressure filtration - fixed volume and variable volume
- Drying bed
    - Sand drying bed
    - Paved drying bed
    - Wedgewater drying bed
    - Vacuum-assisted drying bed
- Sludge lagoon
- Gravity/low pressure dewatering
    - Rotating cylindrical gravity dewatering device
    - Low pressure belt press

At present, belt filter presses and solid bowl centrifuges are the mechanical devices most commonly selected for dewatering municipal wastewater sludges. Vacuum filters, although commonly installed up to the mid-1970's, are rarely selected today. Basket centrifuges have never been a common selection for municipal sludge dewatering. Filter presses have seldom been selected due to their high capital and operating costs, yet for certain cases where a very dry cake is required, a filter press can be cost-effective. The gravity/low pressure dewatering devices are still occasionally selected for small plants where a lower cake solid concentration is desired or acceptable. Drying beds and lagoons have commonly been used at small plants which have land available and in larger plants which have both high evaporation and available land.

A list of manufacturers of currently available dewatering equipment is contained in Appendix A. Although the list is intended to be up-to-date and complete, it is possible that some manufacturers are excluded. Due to the dynamic nature of the equipment manufacturing business, it is probable that some companies on the list may in the future discontinue the manufacture of the equipment for which they are listed. References such as the Journal Water Pollution Control Federation, Pollution Equipment News, and Water & Wastes Digest should be consulted for additional suppliers.

3.2 Centrifugation

Centrifugal dewatering of sludge is a process which uses the force developed by fast rotation of a cylindrical drum or bowl to separate the sludge solids and liquid. In the basic process, when a sludge slurry is introduced to the centrifuge, it is forced against the bowl's interior walls, forming a pool of liquid. Density differences cause the sludge solids and the liquid to separate into two distinct layers. The sludge solids "cake" and the liquid "centrate" are then separately discharged from the unit. The two types of centrifuges used for municipal sludge dewatering, basket and solid bowl, both operate on these basic principles. They are differentiated by the method of sludge feed, magnitude of applied centrifugal force, method of solids and liquid discharge, cost, and performance. A third centrifuge type, the disc-nozzle centrifuge, has been used for thickening waste activated sludge (WAS), but does not produce a dewatered material. It will not be discussed in this manual.

3.2.1 Basket Centrifuge

The imperforate basket centrifuge is a semi-continuous feeding and solids discharging unit that rotates about a vertical axis. A schematic diagram of a basket centrifuge in the sludge feed and sludge plowing cycles is shown in Figure 3-1. Sludge is fed into the bottom of the basket and sludge solids form a cake on the bowl walls as the unit rotates. The liquid (centrate) is displaced over a baffle or weir at the top of the unit. Sludge feed is either continued for a preset time or until the suspended solids in the centrate reach a preset concentration.

After sludge feeding is stopped, the centrifuge begins to decelerate, and a special skimmer nozzle moves into position to skim the relatively soft and low solids concentration sludge on the inner periphery of the sludge mass. These skimmings are typically returned to the plant headworks or the digesters. After the skimming operation, the centrifuge slows further to about 70 rpm, and a plowing knife moves into position to cut the sludge away from the walls; the sludge cake then drops through the open bottom of the basket. After plowing terminates, the centrifuge begins to accelerate and feed sludge is again introduced. At no time does the centrifuge actually stop rotating.

The cake solids concentration produced by the basket machine is typically not as dry as that achieved by the solid bowl centrifuge. However, the basket centrifuge is especially suitable for dewatering biological or fine solids

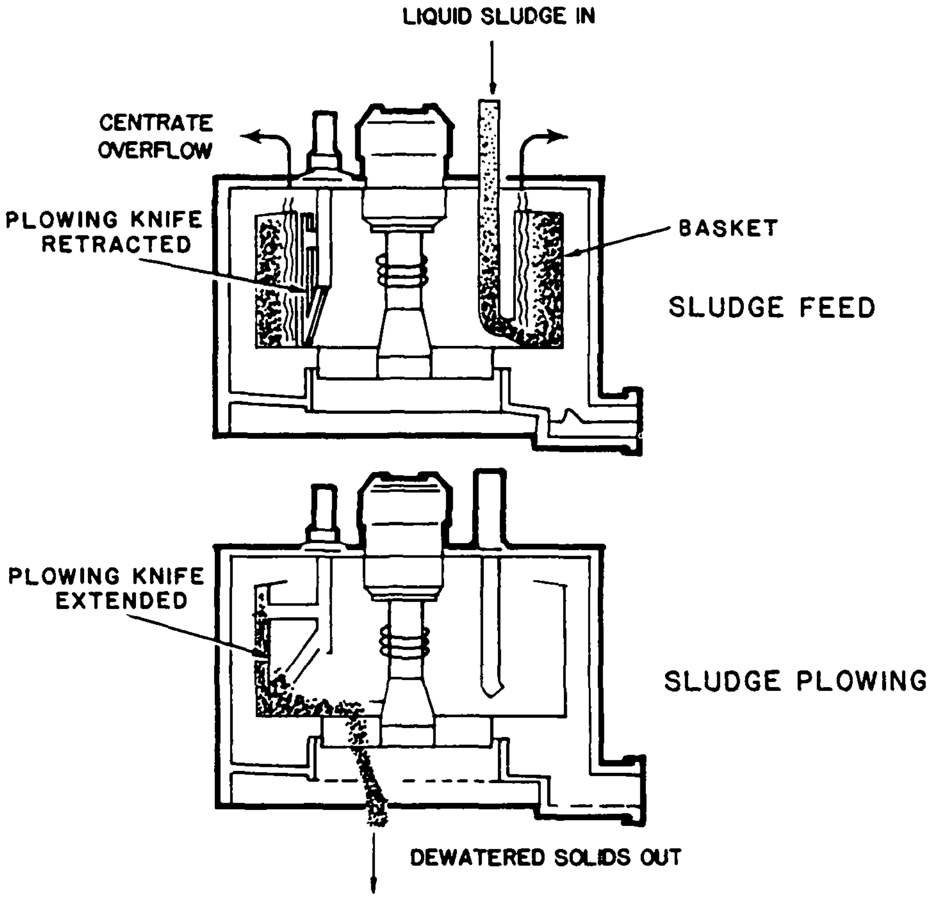


FIGURE 3-1

BASKET CENTRIFUGE IN SLUDGE FEED AND SLUDGE PLOWING CYCLES

sludges that are difficult to dewater, for dewatering sludges where the nature of the solids varies widely, and for sludges containing significant grit. The basket centrifuge is most commonly used for thickening WAS. Advantages and disadvantages of an imperforate basket centrifuge compared to other dewatering processes are presented in Table 3-1. Common design shortcomings experienced in basket centrifuge installations are presented in Table 3-2.

Performance of a basket centrifuge is measured by the cake solids content, the solids capture, the required polymer dosage, and the average feed rate or solids throughput. Cake solids concentration must be considered as average solids content, since the solids content is maximum at the bowl wall and decreases toward the center. The polymer requirement for a basket centrifuge is generally lower than that required by other mechanical dewatering equipment. The average feed rate includes the period of time during a cycle when sludge is not being pumped to the basket (acceleration, deceleration,

TABLE 3-1

ADVANTAGES AND DISADVANTAGES OF BASKET CENTRIFUGES

Advantages	Disadvantages
Same machine can be used for both thickening and dewatering	Unit is not continuous feed and discharge
Is very flexible in meeting process requirements	Requires special structural support, much more than a solid bowl centrifuge
Is not affected by grit	Has a high ratio of capital cost to capacity
Little operator attention is required; full automation is possible	Discharge of wet sludge can occur if there is a machine malfunction or if the sludge is improperly conditioned.
Compared to belt filter press and vacuum filter installations, is clean looking and has little to no odor problems	Provision should be made for noise control.
Is excellent for dewatering hard-to-handle sludges, although sludge cake solids are only 10-15% for digested primary + WAS	Continuous automatic operation requires complex controls.
Flexibility in producing different cake solids concentrations because of skimming ability	

discharge). Therefore, dividing total gallons pumped per cycle by total cycle time gives the average feed rate. Solids throughput can be determined using the average feed rate, the percent feed solids, and the solids capture.

A basket centrifuge can be a good application in small plants with capacities in the range of 0.04 to 0.09 cu m/s (1 to 2 mgd); where thickening is required before or after stabilization, or where dewatering to 10 to 12 percent solids is adequate. The basket centrifuge is sometimes used in larger plants. For example, at the Los Angeles County Sanitation Districts' Joint Water Pollution Control Plant at Carson, California, 44 basket centrifuges are used to dewater anaerobically digested primary sludge from a 15.3 cu m/s (350 mgd) advanced primary treatment plant. Typical results achieved are 21% cake solids, at a polymer consumption of 1.5 g/kg (3 lb/ton) and a solids capture of 95 percent, from a feed solids concentration of about 3 percent.

The ability to be used either for thickening or dewatering is an advantage of the basket centrifuge. A basket centrifuge will typically dewater a 50:50 blend of anaerobically digested primary and waste activated sludge to

TABLE 3-2

COMMON DESIGN SHORTCOMINGS OF BASKET CENTRIFUGE INSTALLATIONS

Shortcomings	Resultant Problems	Solution
Rigid piping connections to centrifuge	Cracked or leaking pipes	Use flexible connectors
Inadequate structural support	Cracks in supports	Redesign and reconstruct
Inadequate solids capture due to insufficient machine capacity or no provision for polymer feed	High solids content in centrate	Add more machines or properly condition sludge
Electrical control panels located in same room with centrifuges, conveyor belts, etc.	Corrosive atmosphere deteriorates controls	Redesign and relocate controls in separate room away from corrosive atmosphere
No provision for centrate sampling	Process control is hampered	Install sample tap in the centrate line
No flow meters on sludge feed lines	Process control is hampered	Install flow meters

10-15% solids. Detailed performance data for basket centrifuges are presented in Chapter 4.

3.2.2 Solid Bowl Centrifuge

Solid bowl centrifuge technology has greatly advanced in the past five to six years, as both the conveyor life and machine performance have been improved. At many treatment plants in the U.S., older solid bowl centrifuge installations have required very high maintenance expense due to rapid wear of the conveyor and reduced performance. Recently the use of replaceable ceramic tiles in low-G centrifuges (less than 1,100 G's) and sintered tungsten carbide tiles in high-G centrifuges (greater than 1,100 G's) have greatly increased the operating life prior to overhaul. In addition, several centrifuge manufacturers also offer stainless steel construction, in contrast to carbon-steel construction, and claim use of this material results in less wear and vibration caused by corrosion. Revised bowl configurations and the use of new automatic backdrives and eddy current brakes have resulted in improved reliability and process control, with a resultant improvement in dewatering performance. In addition, in recent years several centrifuge manufacturers have reduced the recommended throughput of their machines in direct response to competition from the belt filter press. This has allowed for an increase in solids residence time in the centrifuge and subsequent improvement in cake dryness.

As opposed to the semi-continuous feed/discharge cycles of the imperforate basket centrifuge, the solid bowl centrifuge, also called decanter or scroll centrifuge, is a continuously operating unit. This centrifuge, shown in Figure 3-2, consists of a rotating horizontal cylindrical bowl containing a screw type conveyor or scroll which rotates also, but at a slightly lower or higher speed than the bowl. The differential speed represents the difference in revolutions per minute (rpm) between the bowl and the conveyor. The conveying of solids requires that the screw conveyor rotate at a different speed than the bowl. The rotating bowl, or shell, is supported between two sets of bearings and at one end necks down to a conical section that acts as a dewatering beach or drainage deck for the screw type conveyor. Sludge enters the rotating bowl through a stationary feed pipe extending into the hollow shaft of the rotating conveyor and is distributed through ports in this hollow shaft into a pool within the rotating bowl.

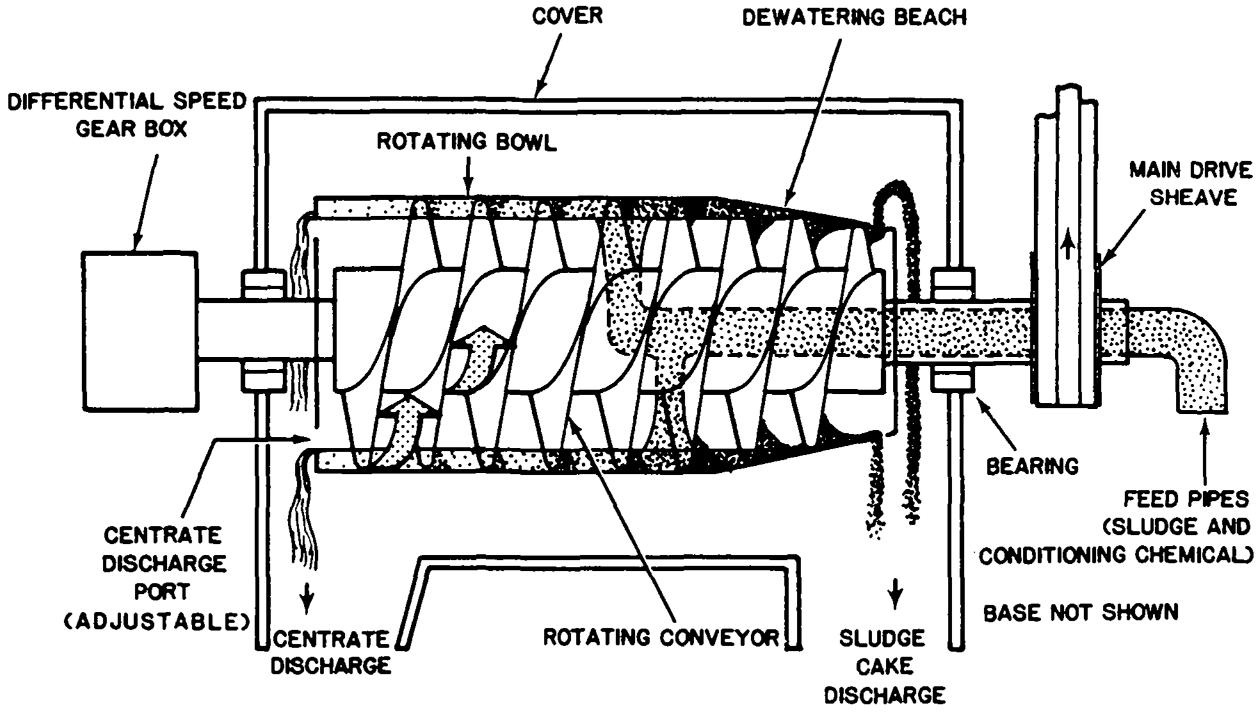


FIGURE 3-2

CONTINUOUS COUNTERCURRENT SOLID BOWL CENTRIFUGE

The centrifuge illustrated in Figure 3-2 operates in the countercurrent mode. Influent sludge is added through the feed pipe; under the influence of centrifugal force, sludge solids settle through the liquid to the bowl wall because their density is greater than that of the liquid. The solids are then moved gradually by the rotating conveyor from left to right across the bowl, up the dewatering beach to outlet ports and from there drop downward into a sludge cake discharge hopper. As the settled sludge solids move from left to right through the bowl toward the sludge cake outlet, progressively finer solids are settled centrifugally to the rotating bowl wall. The water or centrate drains from the solids on the dewatering beach and back into the pool. Centrate is actually moved from the end of the feed pipe to the left, and is discharged from the bowl through ports in the left end, which is the opposite end of the centrifuge from the dewatering beach. The location of the centrate removal ports is adjustable, and their location establishes the depth of the pool in the bowl.

A second variation of the solid bowl centrifuge is the concurrent model shown in Figure 3-3. In this unit, liquid sludge is introduced at the far end of the bowl from the dewatering beach, and sludge solids and liquid flow in the same direction. General construction is similar to the countercurrent design except that the centrate does not flow in a different direction than the sludge solids. Instead, the centrate is withdrawn by a skimming device or return tube located near the junction of the bowl and the beach. Clarified centrate then flows into channels inside the scroll hub and returns to the feed end of the machine where it is discharged over adjustable weir plates through discharge ports built into the bowl head.

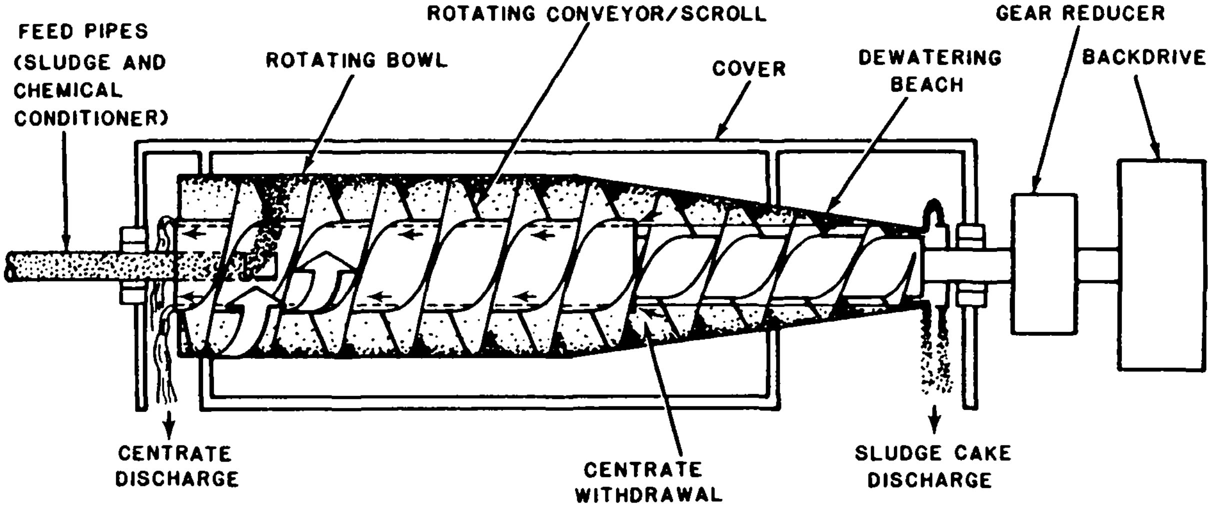


FIGURE 3-3

CONTINUOUS CONCURRENT SOLID BOWL CENTRIFUGE

A relatively new development in solid bowl decanter centrifuges is the use of a backdrive to control the speed differential between the scroll and the bowl. The objective of the backdrive is to control the differential to give the optimum solids residence time in the centrifuge and thereby produce the optimum cake solids content. A backdrive of some type is considered essential when dewatering secondary sludges because of the fine particles present. The backdrive function can be accomplished with a hydraulic pump system, an eddy current brake, D.C. variable speed motor, or a Reeves type variable speed motor. The two most common backdrive systems are the hydraulic backdrive and the eddy current brake.

Cake solids content increases of 4% or more relative to machines without a backdrive are achievable, although it must be recognized that the effective capacity of the machine is decreased by utilizing a backdrive to produce a higher solids content cake. A backdrive unit will generally not reduce the quantity of polymer required, but it will increase overall stability of centrifuge performance when the feed solids characteristics vary.

The eddy current brake backdrive is commonly provided by one high G centrifuge manufacturer. The eddy current brake is attached to the pinion shaft of the gearbox and consists of a stationary field coil and a brake rotor on the shaft. When a D.C. voltage is applied to the stationary field coil, magnetic flux lines are created in the brake rotor. The amount of flux in the rotor is a function of the speed differential between the rotor and the field coil as well as the D.C. current applied to the field coil. This flux produces eddy currents which create a resistance to turning, or a braking action. Thus, varying the D.C. voltage applied to the stationary field coil results in a change in the speed differential between the bowl and the scroll.

An automatically-controlled variable speed hydraulic backdrive is commonly provided by several low G centrifuge manufacturers to control the speed differential between the scroll and the bowl. The differential is controlled to maintain a constant torque on the scroll shaft, with the resulting production of a high solids content sludge cake. A hydraulic pump and a hydraulic backdrive motor are the two principal components of the hydraulic backdrive unit. The hydraulic backdrive is a noise producing operation, whereas the eddy current brake is silent.

Most centrifuge installations have the centrifuge mounted a few feet above the floor, and use a belt conveyor to move dewatered cake away. Other methods of installing a solid bowl centrifuge are to put the centrifuge on the second floor of a two story building and drop the dewatered cake into either trucks or a storage hopper on the first level; to mount the centrifuge about a foot off the floor and to drop cake into a screw conveyor built into the floor; or to let the centrifuge cake drop into an open throated progressive cavity type pump for transfer of the cake to a truck, incinerator, or storage.

Centrifuge performance is measured by the percent solids of the sludge cake, the percent solids capture, the overall quality of the centrate, the solids loading rate, and the polymer requirement. The performance of a particular centrifuge unit will vary with the sludge feed rate and the characteristics of the feed sludge, including percent solids, sludge temperature and ash content.

Centrifuge performance is also affected by polymer selection and the dosage utilized as well as its point of introduction. Centrifuge performance on a particular sludge will also vary with bowl and conveyor design, bowl speed, differential speed, and pool volume. Bowl and conveyor design are not variable after installation. Although pool depth is variable on solid bowl units, up to several hours of labor may be required to change the pool depth. Increasing the pool depth will normally result in a wetter sludge cake but better solids recovery, however, this is not necessarily true on newer machines equipped with an automatic backdrive.

Bowl speed is not normally varied on most centrifuge models once a centrifuge is installed. An increase in bowl speed normally results in a drier sludge cake and better solids recovery, although in some cases it may result in shearing of the sludge floc and a reduction in solids capture. With the addition of polymer internally into the bowl of the centrifuge, a capability available from several manufacturers, no shearing occurs since both the polymer and the solids are up to bowl speed when the formation of the floc occurs. Conveyor differential speed normally can be varied, yet it may require some disassembly of the machine. On centrifuges equipped with an automatic backdrive, the differential speed can be easily varied. Increasing the differential between the bowl speed and the scroll speed normally results in a wetter sludge cake, poorer solids recovery, and higher machine throughput. On the other hand, reducing the differential speed produces a dryer cake, increases solids capture, and decreases machine throughput. Operating at too low a differential speed can cause the pile of solids formed in front of the scroll conveyor blade to increase in overall height such that it infringes on the clarified liquid area. This may result in the skimming of some fine solids from the top of the cake pile to the centrate, lowering solids capture. Too low of a differential speed, unless adequately controlled, can also result in plugging the centrifuge, if solids are removed at a slower rate than they are fed to the machine.

Some of the advantages and disadvantages of a solid bowl decanter centrifuge compared with other dewatering processes are presented in Table 3-3, and Table 3-4 lists common design shortcomings associated with solid bowl centrifuges.

The ability to be used either for thickening or dewatering provides flexibility and is a major advantage for solid bowl centrifuges. For example, a centrifuge can be used to thicken ahead of a filter press, reducing chemical usage and increasing solids throughput. During periods of downtime of the filter press, the solid bowl centrifuge can serve as an alternate dewatering device. Another advantage of the solid bowl centrifuge for larger plants is the availability of equipment with the largest sludge throughput capability for single units of any type of dewatering equipment. The larger centrifuges are capable of handling 19 to 44 l/s (300 to 700 gpm) per unit depending on the sludge's characteristics. The centrifuge also has the ability to handle higher than design loadings, such as a temporary increase in hydraulic loading or solids concentration, and the percent solids recovery can usually be maintained with the addition of more polymer; while the cake solids concentration will drop slightly, the centrifuge will stay on line.

TABLE 3-3

ADVANTAGES AND DISADVANTAGES OF SOLID BOWL DECANTER CENTRIFUGES

Advantages	Disadvantages
Clean appearance, little to no odor problems, and fast start-up and shutdown capabilities	Scroll wear can be a high maintenance item. Hardsurfacing and abrasion protection materials are extremely important in reducing wear
Easy to install and requires a relatively small area	Prescreening or a grinder in the feed stream is recommended
Does not require continuous operator attention	Requires skilled maintenance personnel in large plants where scroll maintenance is performed
Can operate with a highly variable feed solids concentration on many sludge types	Noise is very noticeable, especially for high G centrifuges and hydraulic backdrive units
Can be operated either for thickening or dewatering	Vibration must be accounted for in designing electronic controls and structural components
High rates of feed per unit, thus reducing the number of units required	High power consumption for a high G centrifuge
Use of low polymer dosages when compared to other devices, except the basket centrifuge	A condition such as poor centrate quality can be easily overlooked since the process is fully contained
Can handle higher than design loadings with increased polymer dosage, although cake solids content may be reduced	Requires extensive pretesting to select correct machine settings before placement in normal service

Solid bowl centrifuges are typically capable of dewatering a 50:50 mixture of anaerobically digested primary and secondary sludges to a 15-21% solids concentration. More detailed performance data are presented in Chapter 4.

3.2.2.1 Low G vs High G Solid Bowl Centrifuge Controversy

Solid bowl centrifuges are currently available as both low G and high G machines. A low G machine operates at bowl speeds causing centrifugal forces of 1,100 times the force of gravity or less. In the Process Design Manual for

TABLE 3-4

COMMON DESIGN SHORTCOMINGS OF SOLID BOWL DECANTER CENTRIFUGE INSTALLATIONS

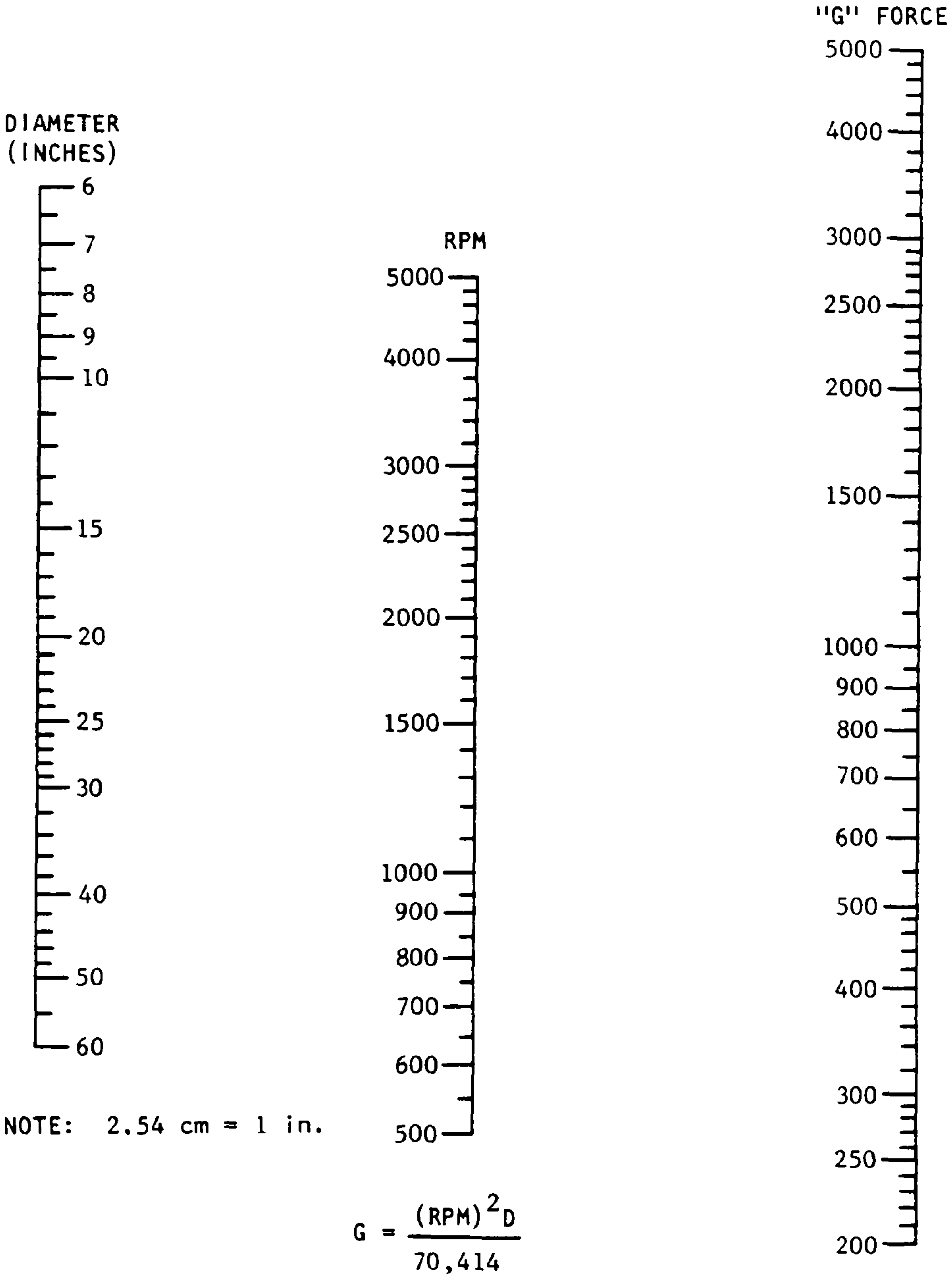
Shortcomings	Resultant Problems	Solution
Improper materials used for scroll tips	Excessive wear	Replace with harder, more abrasion-resistant tips
Inability to remove bowl assembly during maintenance	Bowl is bulky and heavy and can not be removed without using lifting equipment.	Install overhead crane
Rigid piping used to connect feed pipe to centrifuge	Cracked or leaking pipes or pipe connections	Replace with flexible connections
Grit present in sludge	Excessive centrifuge wear	Install a degritting system on the sludge or on the wastewater prior to sludge removal
Electronic controls, structural components, and fasteners not designed for vibration	Electrical connections become loose; structural components and fasteners fail	Isolate sensitive electronic controls from vibration; redesign and construct structural components and fasteners to resist vibration
Electrical control panels located in same room with centrifuges, conveyor belts, etc.	Corrosive atmosphere deteriorates controls	Redesign and relocate controls in separate room away from corrosive atmosphere

Sludge Treatment and Disposal (1), the low G and high G centrifuges are described as "low speed" and "high speed" centrifuges. "Low speed" centrifuges are defined as those operating at a bowl speed of 1,400 rpm or less (1). Note that the gravity force level (G) increases with the bowl diameter, as shown in the nomograph and equation on Figure 3-4. It can be seen that a 61 cm (24 in) diameter centrifuge operating at 1,400 rpm would develop 668 G's, while a 144 cm (56.5 in) diameter centrifuge also operating at 1,400 rpm would develop centrifugal force of 1573 G's. For a small diameter centrifuge, even the low G machines would typically be operating above 1,400 rpm in order to achieve a higher G force. Therefore, G force is a better method of describing solid bowl centrifuges than bowl speed alone, since G force takes into account both bowl speed and bowl diameter. However, because of the common usage, both "G" and "speed" will be used in this manual to describe solid bowl scroll centrifuges.

There has been considerable controversy over the benefits of low G and high G centrifuges. Low G decanter centrifuge manufacturers claim that their machines consume less energy, have a lower noise level, and require less maintenance than comparable high G machines. On the other hand, high G decanter centrifuge manufacturers claim that their machines require less polymer and achieve a higher throughput because of the higher G forces utilized. Resolution of whether or not low G centrifuges have a lower total annual cost than high G centrifuges can only be determined after side-by-side tests are conducted with a particular sludge and the design parameters are known for each machine.

There have been few cases where simultaneous side-by-side testing with exactly the same sludge between low G and high G solid bowl centrifuges has been conducted. One recent side-by-side dewatering test between Sharples' high G centrifuge and KHD Humboldt Wedag's low G centrifuge occurred in June 1982 at the Littleton-Englewood, Colorado wastewater treatment plant. A report summarizing the comparison was expected to be completed by the end of 1982. An additional side-by-side dewatering test was initiated during the summer of 1982 by the City of San Francisco.

The materials used in constructing a solid bowl centrifuge are also a source of controversy between low G and high G centrifuge manufacturers. Abrasive wear on scroll conveyor blades or flights has traditionally been the item of greatest maintenance, both in terms of time and expense. Several factors tend to influence the rate of abrasive wear including the abrasiveness of the sludge, the centrifugal force at the bowl wall, the differential speed, and the abrasion resistance of the material used to form scroll blade tips. Manufacturers of low G, concurrent flow centrifuges maintain that their machines are much less prone to scroll tip wear than high G countercurrent flow machines, because the low G machines operate at lower centrifugal forces and lower differential speeds. Manufacturers of high G machines maintain that their problems with high abrasive wear rates can be overcome by the use of the proper abrasion resistant materials. A method of measuring wear rates and volume loss on abrasion resistant materials is the ASTM G65-80 (Procedure A) test.



NOTE: 2.54 cm = 1 in.

$$G = \frac{(RPM)^2 D}{70,414}$$

FIGURE 3-4
NOMOGRAPH AND EQUATION USED TO CALCULATE G-FORCE FOR SOLID BOWL CENTRIFUGE

Various types of hardfacing have been used to reduce wear on scroll tips. These include many different welder applied metallic hardfacings (such as Colmonoy #6, Eutalloy, and Stellite) as well as tungsten carbide and ceramic tiles. Field replaceable ceramic tiles have recently been recommended by several low G manufacturers because of their long life, relatively low replacement cost and ease of replacement. However, they are more fragile than metallic hardfacings, tending to chip easily. They also may occupy more space in the bowl and not form as smooth a surface on the conveyor blades as do metallic hard facings. Ceramic tiles can be glued on to the flights although in some cases they are both glued and bolted to the flights. Tungsten carbide tiles have an extremely long life hardfacing, but one study found them to be 5-10 times as expensive as ceramic tiles (3). One high-G centrifuge manufacturer claims that sintered tungsten carbide tiles are no more than 2 times as expensive as ceramic tiles (4). Sintered tungsten carbide tiles are generally welded to the flights and are usually required for only the portion of the conveyor blade near the dewatering beach (4).

One manufacturer of low G centrifuges using ceramic tile hardsurfacing material will routinely guarantee scroll conveyor life for 15,000-20,000 hours between rebuilds (5). One high G centrifuge manufacturer will routinely guarantee scroll conveyor life for 30,000 hours using highly abrasion resistant sintered tungsten carbide tiles (4). Experience with low G concurrent flow centrifuges at the Los Angeles County Sanitation Districts' Carson Plant has indicated that conventional welder applied hardfacing has an operating life of about 5,000 hours (3).

3.3 Belt Press Filtration

Belt filter presses employ single or double moving belts to continuously dewater sludges through one or more stages of dewatering. In the past few years, belt filter presses and solid bowl centrifuges have become the most frequently selected dewatering devices. At least 14 equipment suppliers can furnish a type of belt press, as listed in Appendix A.

All belt press filtration processes include three basic operational stages: chemical conditioning of the feed sludge, gravity drainage to a nonfluid consistency, shear and compression dewatering of the drained sludge.

Figure 3-5 depicts a simple belt press and shows the location of the three stages. Although present-day presses are usually more complex, they follow the same principle indicated in Figure 3-5. The dewatering process is made effective by the use of two endless belts of synthetic fiber. The belts pass around a system of rollers at constant speed and perform the function of conveying, draining, and compressing. Many belt presses also use an initial belt for gravity drainage, in addition to the two belts in the pressure zone.

Good chemical conditioning is very important for successful and consistent performance of the belt filter press. A flocculant (usually an organic polymer) is added to the sludge prior to its being fed to the belt press. Free water drains from the conditioned sludge in the gravity drainage stage of the press.

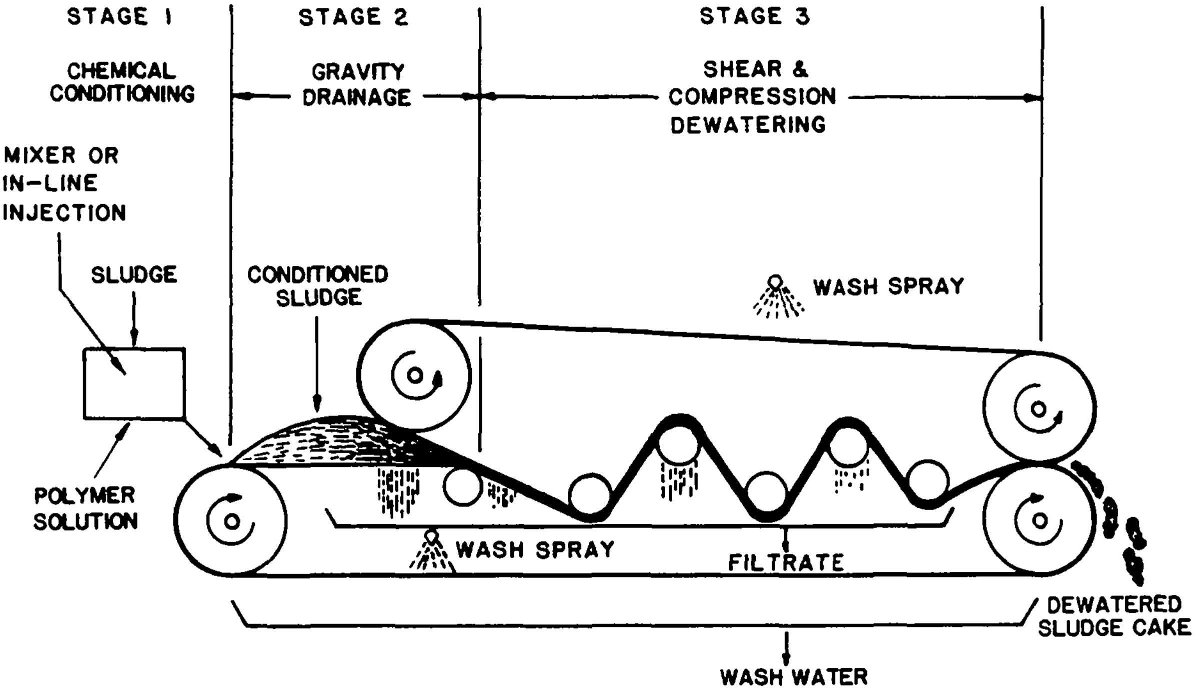


FIGURE 3-5
THE THREE BASIC STAGES OF A BELT FILTER PRESS

The sludge then enters a two-belt contact zone, where a second upper belt is gently set on the forming sludge cake. The belts with the captured cake between them pass through rollers of generally decreasing diameter. This stage subjects the sludge to continuously increasing pressures and shear forces. Pressure can vary widely by design, with the sludge in most presses moving from a low pressure section to a medium pressure section. Some presses include a high pressure section which provides additional dewatering. Progressively, more and more water is expelled throughout the roller section to the end where the cake is discharged. A scraper blade is often employed for each belt at the discharge point to remove the cake from the belts.

Two spray-wash belt cleaning stations are generally provided to keep the belts clean. Typically, secondary effluent can be used as the water source for the spray-wash. High pressure jets can be equipped with a self-cleaning device used to continuously remove any solids which may tend to plug the spray nozzles.

Belt press performance is measured by the percent solids of the sludge cake, the percent solids capture, the solids and hydraulic loading rates, and the required polymer dosage. Several machine variables including belt speed, belt tension, and belt type influence belt press performance (6).

Belt speed is an important operational parameter which affects cake solids, polymer dosage, solids recovery, and hydraulic capacity. Low belt speeds result in drier sludge cakes. At a given belt speed, increased polymer dosages result in higher cake solids. With an adequate polymer dose, solids recoveries are improved by lowering belt speeds. Hydraulic capacity increases at higher belt speeds; however, the solids capture drops. Depending on desired performance, the belt speed setting can be used to produce a variety of different results.

Belt tension has an effect on cake solids, maximum solids loading, and solids capture. In general, a higher belt tension produces a drier cake but causes a lower solids capture, at a fixed flow rate and polymer dose. A possible drawback of using higher tension is increased belt wear. For sludges with a large quantity of WAS, the belt tension must be reduced to contain the sludge between the belts. The maximum tension which will not cause sludge losses from the sides of the belts should be used. The high pressure zones on belt presses may cause problems with some WAS blends and may be unusable or require the lowest pressure setting possible.

Belt type is important in improving overall performance. Most belts are woven of polyester filaments. Belts are available with weaves of different coarseness and different strengths. A belt with a coarser and stronger weave may require higher polymer dosages to obtain adequate solids capture.

Failure of the chemical conditioning process to adjust to changing sludge characteristics can cause operational problems. If sludge is underconditioned, improper drainage occurs in the gravity drainage section, and either extrusion of inadequately drained solids from the compression section or uncontrolled overflow of sludge from the drainage section may occur. Most manufacturers' belt presses can be equipped with sensing devices which can be set to automatically shut off the sludge feed flow in case of underconditioning. Both underconditioned and overconditioned sludges can blind the filter media. In addition, overconditioned sludge drains so rapidly that solids cannot distribute across the belt. Vanes and distribution weirs included in the gravity drainage section help alleviate the problem of distribution of overconditioned sludge across the belt. Inclusion of a sludge blending tank before the belt press can also reduce this problem. Scraper units and filtrate trays are sites where solids build up. A belt press installation should be designed for daily washdown by hosing; therefore, drainage and safe walking areas around the press are important.

The flow rate required for belt washing is usually 50 to 100 percent of the flow rate of sludge to the machine and the pressure is typically 690 kPa (100 psi) or more. The combined filtrate and belt washwater flow is normally about one and one-half times the incoming sludge flow. Some belt presses recirculate washwater from the filtrate collection system, but normally, secondary effluent or potable water is used. This combined flow of washwater and filtrate contains between 500 and 2,000 mg/l of suspended solids and is typically returned either to the primary or secondary treatment system.

Belt presses have numerous moving parts, that include up to 25 to 30 rollers and 50-75 bearings. Spare parts should be kept available to prevent prolonged unit down-time. Belts, bearings, and rollers can deteriorate quickly, if maintenance is inadequate. However, most parts are small and easily accessible, so that even small facilities should have little difficulty in maintaining these replacement parts.

Table 3-5 lists some of the advantages and disadvantages of the belt filter press compared to other dewatering processes. Common design shortcomings associated with belt filter press installations are listed in Table 3-6. When dewatering a 50:50 mixture of anaerobically digested primary and waste activated sludge, a belt filter press will typically produce a cake solids concentration in the 18-23% range. More complete performance data are presented in Chapter 4.

TABLE 3-5

ADVANTAGES AND DISADVANTAGES OF BELT FILTER PRESSES

Advantages	Disadvantages
High pressure machines are capable of producing drier cake than any machine except a filter press	Very sensitive to incoming feed characteristics and chemical conditioning
Low power requirements	Machines hydraulically limited in throughput
Low noise and vibration	Short media life as compared with other devices using cloth media
Operation easy to understand for inexperienced operator because all parts are visible and results of operational changes are quickly and readily apparent	Wash water requirement for belt spraying can be significant
Continuous operation	Frequent washdown of area around press required
Media life can be extended when applying the low belt tension typically required for municipal sludges	Require prescreeening or grinding of sludge to remove large objects and fibrous material
	Can, like any filtration device, emit noticeable odors if the sludge is poorly stabilized
	Require greater operator attention than centrifuge
	Condition and adjustment of scraper blades is a critical feature that should be checked frequently
	Typically require greater polymer dosage than a centrifuge

TABLE 3-6

COMMON DESIGN SHORTCOMINGS OF BELT FILTER PRESS INSTALLATIONS

Shortcomings	Resultant Problems	Solution
Improper tracking of filter belt	Belt creeps off rollers and dewatering operation must be stopped for repair	Repair or adjust automatic tracking device, if one exists. If not, attempt to add such a device
Inadequate wash water supply	Sludge buildup on belts and/or rollers	Increase spray water pressure or install new spray heads
Improper belt type	Frequent tearing or wrinkling or inadequate solids capture	Experiment with different belt types and install proper belt for actual conditions
Inadequate control of conditioning	Frequent underconditioning or overconditioning of sludge	Install a feedback control system which monitors sludge solids content and sets required polymer addition
Wash water not metered	Difficult to calculate solids capture	Install a water meter in wash water line
Spray wash unit poorly sealed	Fine mist escapes from spray wash unit increasing moisture/corrosion problems	Replace or modify spray wash unit to provide better seal around belt
Inadequate mixing time for polymer and feed sludge before belt press	Underconditioning of sludge	Move polymer injection point upstream toward feed pumps to increase mixing time or install polymer/sludge mixing before belt presses
No flow meters on sludge feed lines	Process control is hampered	Install flow meters

3.4 Vacuum Filtration

The most common means of mechanically dewatering municipal wastewater sludge up until the mid-1970's was vacuum filtration. A vacuum filter consists basically of a horizontal cylindrical drum which rotates partially submerged in a vat of sludge. The filter drum is divided into multiple compartments or sections by partitions (seal strips). Each compartment is connected to a rotary valve by a pipe. Bridge blocks in the valve divide the drum compartments into three zones which are referred to as the cake formation zone, the cake drying zone, and the cake discharge zone. The filter drum is submerged to about 25% of its depth (variable) in a vat of conditioned sludge, and this submerged zone is the cake formation zone. Vacuum applied to the submerged drum section causes filtrate to pass through the media and sludge cake to be retained on the media. As the drum rotates, each section is successively carried through the cake forming zone to the vacuum drying zone (See Figure 3-6). This zone begins when the filter drum emerges from the sludge vat. The cake drying zone represents from 40 to 60 percent of the drum surface and ends at the point where the internal vacuum is shut off. At this point, the sludge cake and drum section enter the cake discharge zone, where sludge cake is removed from the media.

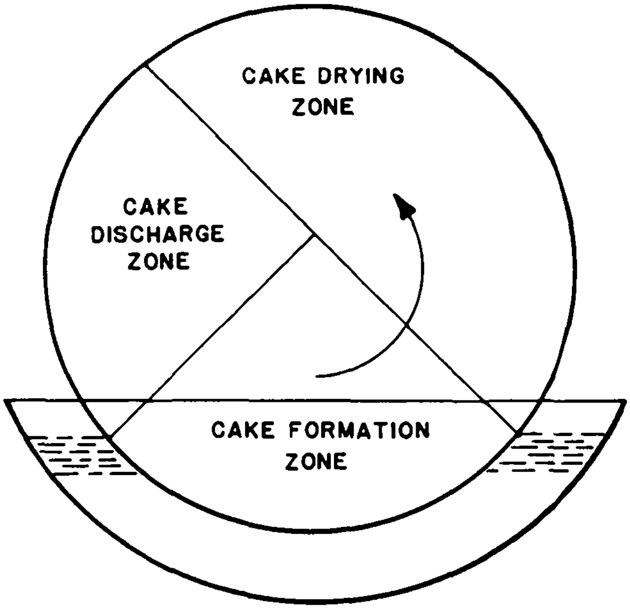


FIGURE 3-6
OPERATING ZONES OF A ROTARY VACUUM FILTER

The discharge cycle varies with the type of medium used. Up until the 1960's, the drum or scraper type rotary vacuum filter was predominant. Since then, the belt-type rotary filter has become dominant. There are two coverings that are most commonly used with belt-type units: coil springs and fiber cloth (woven cloth or metal belt). Belt-type filters differ from the drum or scraper-type units because the drum covering leaves the drum.

Figure 3-7 shows a cross sectional view of a coil spring, belt-type vacuum filter. This filter uses two layers of stainless steel coils arranged around the drum. After the dewatering cycle, the two layers of springs leave the drum and are separated from each other. In this way, the cake is lifted off the lower layer of springs and can be discharged from the upper layer. Cake release is usually not a problem if the sludge is properly conditioned. After cake discharge, the coils are spray washed and returned to the drum just before the drum enters the sludge vat.

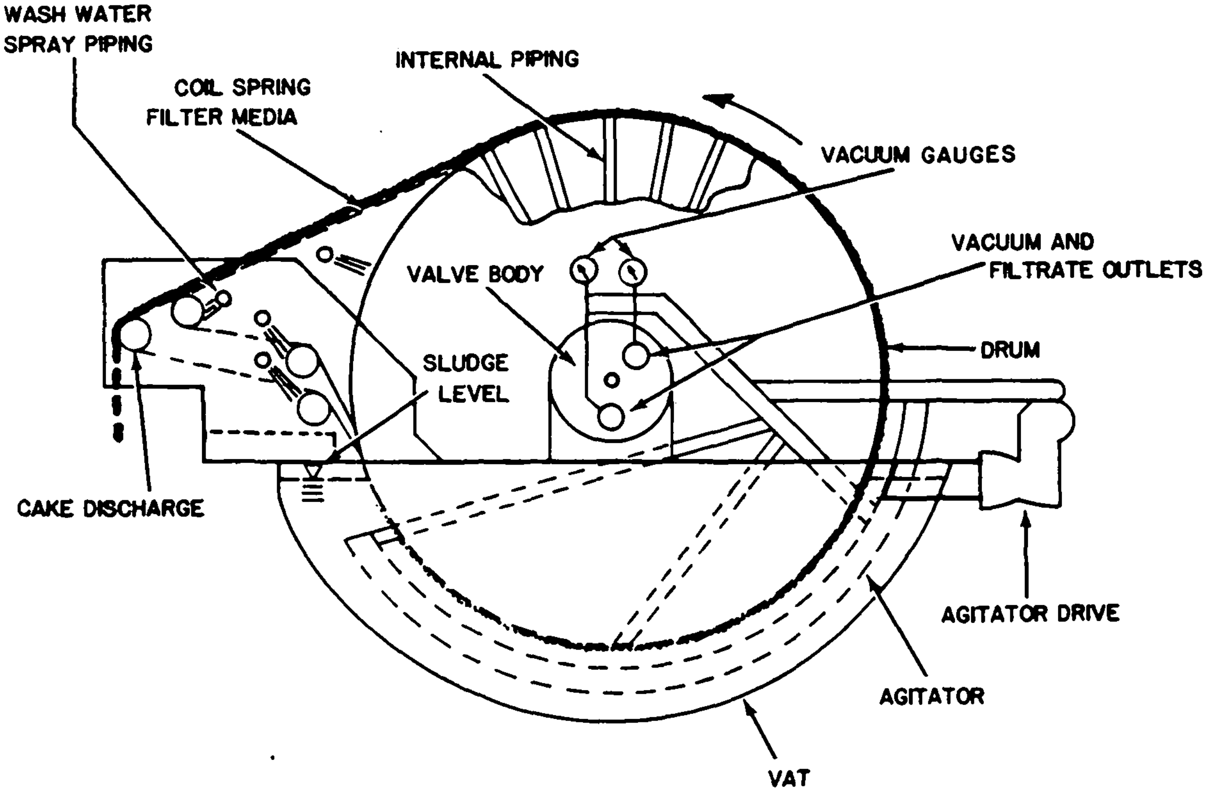


FIGURE 3-7

CROSS SECTIONAL VIEW OF A COIL SPRING, BELT-TYPE ROTARY VACUUM FILTER

The coil springs, which have 7 to 14 percent open area, act to support the initial solids deposit which in turn serves as the filtration media. Because of the open area of the springs, it is important that the feed solids concentration be high or that it contain sufficient fibrous material to control the loss of fine solids. Sludges with particles that are both extremely fine and resistant to flocculation dewater poorly on coil filters, and solids capture is low. Cloth media is required when filtering unthickened sludge that is predominantly secondary solids.

Figure 3-8 shows a schematic cross section of a fiber cloth, belt-type rotary vacuum filter. Media on this type unit leaves the drum surface at the end of the drying zone and passes over a small-diameter discharge roll to facilitate cake discharge. Washing of the media occurs after discharge and before it returns to the drum for another cycle. This type of filter normally has a small-diameter curved bar between the point where the belt leaves the drum and the discharge roll. This bar aids in maintaining belt dimensional stability. In practice, it is frequently used to ensure adequate cake discharge. Remedial measures, such as addition of scraper blades, use of excess chemical conditioner, or addition of fly ash, are sometimes required to obtain cake release from the cloth media. This is particularly true at wastewater treatment plants which produce sludges that are greasy, sticky, and/or contain a large quantity of waste activated sludge. In general, cloth media made from staple fiber produces cleaner filtrate but has lower throughput than cloth media made from monofilament fiber.

The performance of vacuum filters may be measured by several criteria including the yield, the efficiency of solids removal, and the cake characteristics. Yield, the most common measure of filter performance, is expressed in terms of kg dry solids in the cake discharged from the filter per sq m of effective filter area per hour (lb/sq ft/hr). A typical range of vacuum filter yields for anaerobically digested primary and waste activated sludge is about 17-29 kg/sq m/hr (3.5 - 6 lb/sq ft/hr).

The efficiency of solids removal, or percent solids recovery, is the actual percentage of feed solids recovered in the filter cake. Solids removals on vacuum filters with adequate chemical conditioning range from about 85 percent for coarse mesh media to 99 percent with close weave, long nap media. The recycled filtrate solids impose a load on the treatment plant and should normally be kept to a practical minimum. However, it may be necessary to reduce the percent recovery in order to deliver more filter output and thus keep up with sludge production. Cake solids concentration is another important parameter used in evaluating vacuum filter performance.

Table 3-7 lists some of the advantages and disadvantages of vacuum filtration relative to other dewatering processes, and Table 3-8 lists design shortcomings which have been noted at a number of vacuum filter installations. Typically, a vacuum filter will produce a cake with a solids concentration of between 15 and 20% (including conditioning chemicals) on a 50:50 blend of anaerobically digested primary and waste activated sludge. More detailed performance data for vacuum filters are presented in Chapter 4.

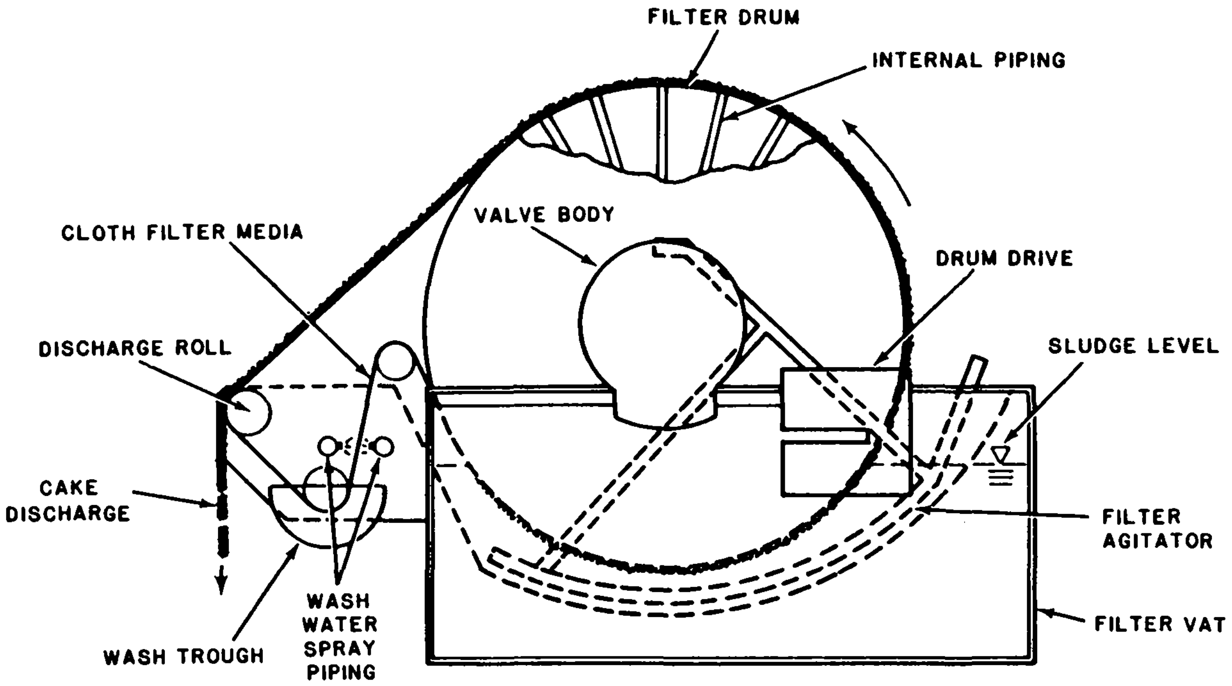


FIGURE 3-8

CROSS SECTIONAL VIEW OF A CLOTH, BELT-TYPE ROTARY VACUUM FILTER

In 1978, an evaluation was made of the feasibility of using a high pressure belt press following vacuum filtration to produce a drier cake and to increase vacuum filter throughput (7). At that time, three manufacturers were marketing such devices. At present, however, all three manufacturers have ceased marketing high pressure presses for this application. The manufacturers indicate that the principal reason for withdrawing from this application is the difficulty of transferring the vacuum filter cake to the belt press in a satisfactory manner (8) (9) (10).

3.5 Pressure Filtration

The two types of filter presses which are commonly available to dewater municipal wastewater sludges are the fixed volume recessed plate filter press and the variable volume recessed plate filter press, also referred to as the diaphragm filter press. The recessed plate filter press is often confused with the plate and frame filter press, which is not commonly marketed to dewater

TABLE 3-7

ADVANTAGES AND DISADVANTAGES OF VACUUM FILTRATION

Advantages	Disadvantages
Operation is easy to understand because formation and discharge of sludge cake are easily visible	Consumes a large amount of energy per unit of sludge dewatered
Continuous operation	Vacuum pumps are noisy
Will continue to operate even if the chemical conditioning dosage is not optimized	Can emit strong odors if the sludge is poorly stabilized
Coil spring media has very long life compared to any cloth filter media	Lime and ferric chloride conditioning can cause considerable maintenance-cleaning problems
Has low maintenance requirements for a continuously operating piece of equipment except in certain cases with lime conditioning	The use of lime for conditioning can produce strong ammonia odors with digested sludge
	Requires at least 3 percent feed solids to achieve adequate cake formation and discharge

TABLE 3-8

COMMON DESIGN SHORTCOMINGS OF VACUUM FILTER INSTALLATIONS

Shortcomings	Resultant Problem	Solution
Improper filter media	Filter blinds, provides inadequate solids capture, and/or poor cake release	Replace media after testing for optimum media
Improper chemical conditioning used	Poor solids capture, low solids loading rate, and low cake solids concentration	Change to correct chemical conditioners
Inadequate water pressure for spray nozzles	Improperly cleaned media	Provide booster pumping to maintain 345 kPa (50 psig) minimum pressure

municipal wastewater sludges, although several installations do exist. The recessed plate filter press is also referred to as a chamber filter press. In the fixed volume recessed plate filter press, liquid sludge is pumped by high pressure pumps into a volume between two filter cloths, held in place by a rigid framework. As a result of the high pressure that the sludge is under, a substantial portion of the water in the feed sludge passes through the filter cloth and drains from the press. Sludge solids and the remaining water eventually fill the void volume between the filter cloths, and continued pumping of solids to the press is no longer productive. At this point, pumping is stopped and the press is opened to release the dewatered sludge cake prior to initiation of a new cycle. In a variable volume recessed plate or diaphragm filter press, sludge is pumped into the press at a low pressure until the volume of the press has been filled with a loosely compacted cake, then sludge pumping is stopped and the diaphragm is inflated for a preset time. For the diaphragm press, although most of the water removal occurs when sludge is being pumped into the press, a significant quantity of water is also removed after the diaphragm is inflated.

In the fixed volume recessed plate press, filter media is used on both sides of the filtering volume. As shown in Figure 3-9, sludge is pumped into the volume between the cloth media, and water is expelled through the media. Sludge pumping is at relatively high pressures, up to 1,550 kPa (225 psi), and the driving force for movement of water through the cloth is this high pressure. Low pressure recessed plate presses are also available which operate at about 690 kPa (100 psi). When little or no additional filtrate is being produced, the pumping is stopped, the press is opened, and sludge cake falls from the press. Periodic washing of the filter cloth is required as the high pressure tends to cause blinding of the cloth. Since lime conditioning is normally required, periodic acid washing is also required to remove lime scale.

The diaphragm press is a relatively new innovation, which uses a diaphragm to further compress the sludge solids after low pressure, about 690 kPa (100 psi), sludge pumping into the press is ineffective in promoting further dewatering. The diaphragm is expanded by pumping either air or water into the diaphragm at pressures up to between 1,480 kPa (215 psi) and 1,965 kPa (285 psi), depending upon the manufacturer. After a pre-set time has elapsed, the diaphragm is deflated and the press opens, allowing the cake to drop out the bottom. Periodically the filter cloth is washed, by permanent spray nozzles. Figure 3-10 shows the basic configuration of one cell of Ingersoll Rand's Lasta diaphragm press and the four separate stages of operation. Figure 3-11 shows the operational cycle of the Envirex-NGK diaphragm press.

The diaphragm press has several advantages over the fixed volume recessed plate press. First, a dryer cake with a relatively uniform moisture content is produced. This uniformity generally does not occur in the fixed volume press, because low solids content feed sludge which produces the filtering pressure is being continually added; thus, the inner part of the cake in each cell is generally of low solids content. The second key advantage of the diaphragm press is an overall shorter cycle time and therefore a higher production thoughput. The primary reason for this shorter cycle is that the diaphragm creates a more effective and uniform pressure on the sludge cake

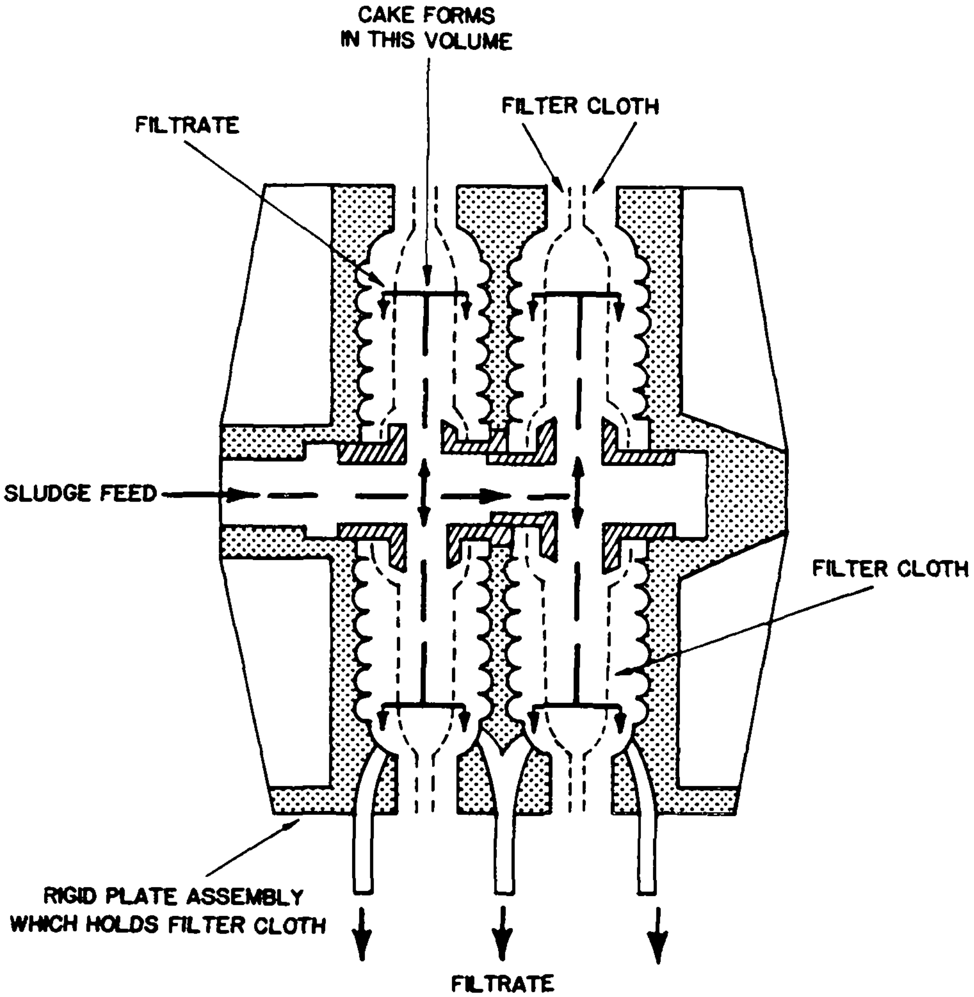
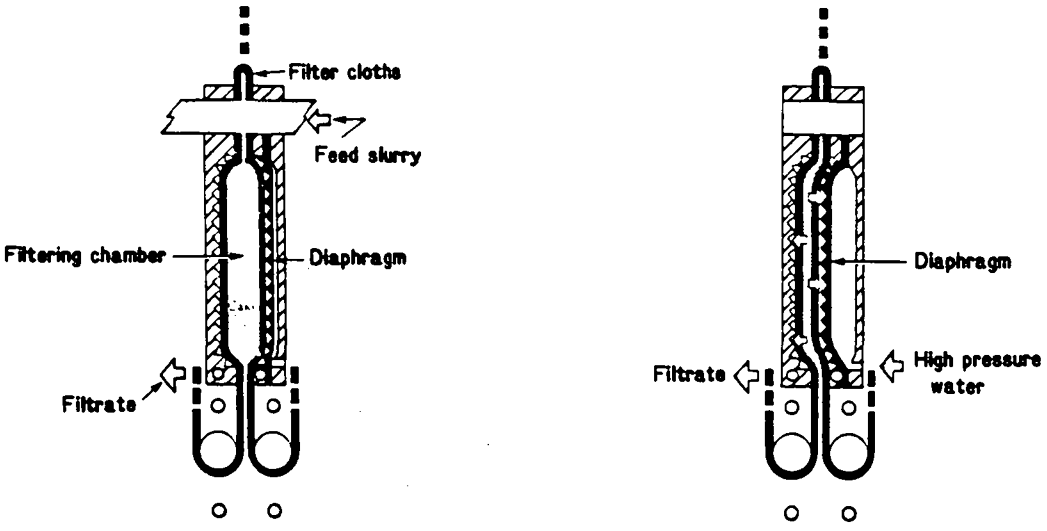


FIGURE 3-9

CROSS SECTION OF A FIXED VOLUME RECESSED PLATE FILTER PRESS ASSEMBLY

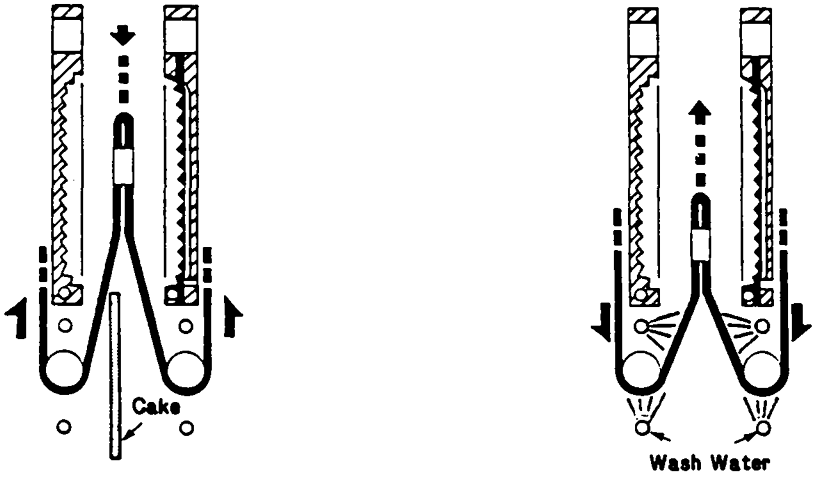
than occurs when liquid sludge is pumped into the chamber. Two other advantages of the diaphragm press are the lower operation and maintenance requirements for the sludge feed pumps, and the ability to dewater a marginally conditioned sludge to a high solids content. Generally, a fixed volume recessed plate press can not dewater a marginally conditioned sludge to a satisfactory cake concentration. Another advantage of the diaphragm press is that it does not require a precoat while a precoat is frequently required with a fixed volume press.

The principal disadvantage of the diaphragm press is its higher initial cost, which can be two to three times the cost of a fixed volume recessed plate



STEP 1–LOW PRESSURE FILTRATION

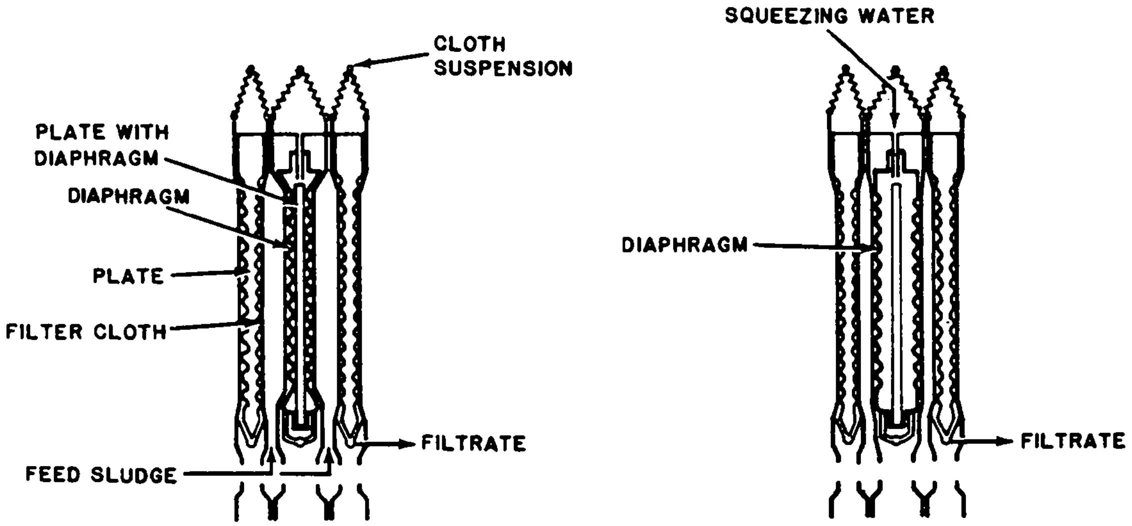
STEP 2–COMPRESSION OF SLUDGE BY THE DIAPHRAGM



STEP 3–CAKE DISCHARGE

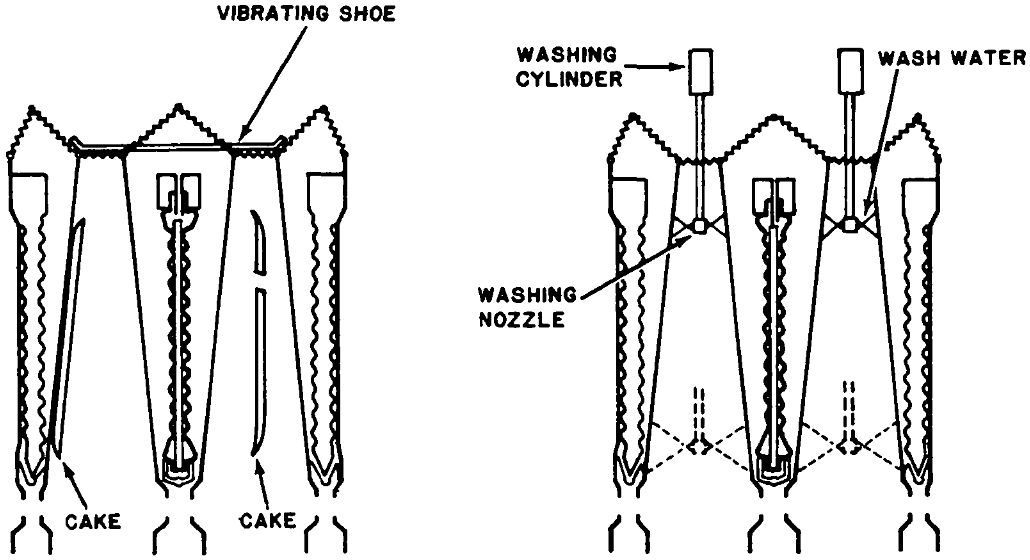
STEP 4–FILTER CLOTH WASHING

FIGURE 3–10
OPERATIONAL CYCLE FOR A LASTA DIAPHRAGM FILTER PRESS
(Courtesy of Ingersoll–Rand)



STEP 1 - FILTRATION

STEP 2 - SQUEEZING



STEP 3 - CAKE DISCHARGE

STEP 4 - CLOTH WASHING

FIGURE 3-11

OPERATIONAL CYCLE FOR AN ENVIREX-NGK DIAPHRAGM FILTER PRESS
(COURTESY OF REXNORD)

press with the same daily throughput. Another disadvantage is that although the diaphragm press has a lower cycle time, the capacity of the largest diaphragm filter press is generally less than that of the largest fixed volume recessed plate filter press.

Filter press performance is measured by the solids content in the feed sludge, required chemical conditioning dosages, cake solids content, total cycle time, solids capture, and the yield, in kg/sq m/hr (lb/sq ft/hr). These performance parameters are all interrelated; for example, as the feed solids content increases, the required chemical dosages and total cycle time usually decrease, while the filter yield, or throughput, usually increases. As the chemical conditioning dosage is increased up to the optimum level, the cake solids content, solids capture, and yield all increase, while the cycle time decreases. It should be noted that increasing chemical conditioning beyond the optimum level can increase the overall volume and reduce the heat value of the filter cake because of the addition of large quantities of inorganic chemicals.

Control of filter presses may be manual, semi-automatic, or fully automatic. Labor requirements for operation will vary dramatically depending on the degree of instrumentation utilized for control. In spite of automation, operator attention is often needed during the dump cycle to insure complete separation of the solids from the media of the filter press. Process yields can typically be increased 10 to 30 percent by carefully controlling the optimum cycle times with a micro-controller. This is important since the capital costs for filter presses are very high.

Table 3-9 presents the principal advantages and disadvantages of filter presses compared to other dewatering processes. Common design shortcomings associated with filter press installations are listed in Table 3-10, along with solutions for these shortcomings. The fixed volume recessed plate filter press will typically dewater a 50:50 blend of digested primary and waste activated sludge to between 35-42% solids, while a diaphragm press will produce a 38-47% solids cake on the same sludge. These cake solids concentrations include large amounts of inorganic conditioning chemicals. Chapter 4 of this manual presents more complete performance data for each type of press.

3.6 Drying Bed

Although the expression "drying bed" originally referred to a sand drying bed, three other types of beds are also available: paved drying beds, wedgewater filter beds, and vacuum assisted drying beds. Drying beds generally work best in areas with little rainfall; however, they are extensively used in small plants even in localities where rainfall averages up to 102 cm (40 in) per year. It is important that sludge be well stabilized before being applied to drying beds. If poorly stabilized or raw sludge is applied to sand beds, dewatering will occur very slowly and substantial problems will result. Two major problems are odor production and the occurrence of flies resulting from further biological stabilization on the bed.

TABLE 3-9

ADVANTAGES AND DISADVANTAGES OF FILTER PRESSES

Advantages	Disadvantages
High solids content cake	Large quantities of inorganic conditioning chemicals are commonly used for filter presses
Can dewater hard-to-dewater sludges, although very high chemical conditioning dosages or thermal conditioning may be required	Polymer alone is generally not used for conditioning due to problems with cake release and blinding of filter media. Experimental work on polymer conditioning is continuing.
Very high solids capture	High capital cost especially for diaphragm filter presses
Only mechanical device capable of producing a cake dry enough to meet landfill requirements in some locations	Labor cost may be high if sludge is poorly conditioned and if press is not automatic
	Replacement of the media is both expensive and time consuming
	Noise levels caused by feed pumps can be very high
	Requires grinder or prescreening equipment on the feed
	Acid washing requirements to remove calcified deposits caused by lime conditioning can be frequent and time consuming
	Batch discharge after each cycle requires detailed consideration to ways of receiving and storing cake, or of converting it to a continuous stream for delivery to an incinerator

TABLE 3-10

COMMON DESIGN SHORTCOMINGS OF FILTER PRESS INSTALLATIONS

Shortcomings	Resultant Problems	Solution
Improper conditioning chemicals utilized	Blinding of filter cloth and poor cake release	Switch conditioning chemicals or dosages
Insufficient filter cloth washing	Blinding of filter cloth, poor cake release, longer cycle time required, wetter cake	Increase frequency of washing
Inability to transport dewatered cake from dewatering building	Cake buildup and spillage onto the floor	Install cake breakers; redesign angle of screw conveyors or belt conveyors to 15° maximum angle. Alternatively, use a heavy duty flight conveyor.
Improper filter cloth media specified	Poor cake discharge; Difficult to clean	Change media
Inadequate facilities when dewatering a digested sludge with a very fine floc.	Poor cake release	(1) Try two-stage compression cycle with first stage at low pressure to build up thickened sludge "media" before increasing pressure (2) If this fails, install precoat storage and feed facilities
Feed sludge is too dilute for efficient filter press operation	Long cycle time and reduced capacity	Thicken sludge before feeding to filter press
Sludge feed at only one end of large filter press	Unequal sludge distribution within the press	Use equalizing tank or centrifugal pump to feed at opposite end of press

3.6.1 Sand Drying Beds

The operative dewatering principles involved in sand drying bed installations are evaporation and percolation. Percolation may be either to the groundwater, or to underdrain tiles located underneath the sand drying bed, and it generally occurs quickly after sludge application. Evaporation is then responsible for any further water removal. In some locations, environmental constraints due to leaching of nitrogen compounds and other constituents have resulted in the requirement to seal the bottom of the drying bed with an impermeable liner. In this case, an underdrain system would be mandatory for proper dewatering. To enhance the capabilities of sand drying beds in climates with high precipitation rates, the use of covered drying beds has occasionally been practiced. A key to the proper operation of covered beds is to provide good ventilation.

Sludge conditioning is possible prior to application of sludge to the drying beds. Such conditioning is generally not economically justified unless it is a short term remedy until additional bed area can be constructed, or if adverse weather has decreased the effectiveness of the beds. Long term operation with polymer conditioning may also be practical if there is insufficient area for drying bed expansion. Use of lime and ferric chloride for conditioning could in certain cases result in chemical blinding of the sand layer.

In cases where underdrains are used, the gravel layer is typically 30 to 46 cm (12 to 18 in) deep, the sand is 15 to 30 cm (6 to 12 in) deep, and the drainage pipes are located 3 to 6 m (10 to 20) apart. Sludge is applied in a layer between 20 to 30 cm (8 to 12 in) across the entire bed and allowed to drain and dry until the sludge is caked and cracked. At this point the dried sludge is removed either manually or mechanically. Caking and cracking will generally occur when the solids content reaches 35 to 40%, and this is the content at which most sludge is removed. Sludge may, however, be removed at higher or lower solids contents, depending upon the operator's ability to remove it from the bed, and upon the disposal method for the dried sludge. Drying time varies in a nonlinear manner with the depth of the applied sludge. For example, a 20 cm (8 in) layer of sludge may dry in one-half the time required for a 30 cm (12 in) layer of sludge. The optimum sludge application depth must be determined on a sludge by sludge basis, and will be a function of the total bed area, the number of beds, the digester capacity, the climate, and the desired cake solids content for removal of dried sludge from the beds.

Advantages and disadvantages of sand drying beds are listed in Table 3-11, and common design shortcomings are listed in Table 3-12.

Sludge removal from drying beds may be either manually or with a front-end loader. Depending upon bed thickness, use of mechanical equipment can cause problems because of its weight. Additionally, a portion of sand is lost as the sludge is removed, and periodic sand replenishment is necessary.

TABLE 3-11

ADVANTAGES AND DISADVANTAGES OF SAND DRYING BEDS

Advantages	Disadvantages
Low capital cost--excluding land	Weather conditions such as rainfall and freezing weather have an impact on usefulness
Low operational labor/skill requirement	Requires large land areas
Low energy	High labor requirement for sludge removal
Low maintenance material cost	May be aesthetically unpleasing, depending on location
Little or no chemicals required	Potential odor problem with poorly stabilized sludge
High cake solids content possible	

TABLE 3-12

COMMON DESIGN SHORTCOMINGS OF SAND DRYING BED INSTALLATIONS

Shortcomings	Resultant Problem	Solution
Inadequate Bed Area	Sludge must be removed before it is dry enough; conditioning chemicals may be required	Construct additional beds or use conditioning chemicals
Inadequate access for removal of dried sludge	Dried sludge must be moved considerable distance to reach hauling truck	Construct roadway between beds; cast concrete treadways in beds for vehicle access; use planks on bed to support vehicles
Inadequate drainage system	Longer than necessary drying time	Add additional drainage pipes
Poor sludge distribution on the beds	Inadequate use of bed area	Partition large beds into smaller beds; level sand in beds
Improper sand gradation	Slow drainage	Remove and replace sand

3.6.2 Paved Drying Bed

To alleviate the problem of mechanical sludge removal equipment damaging the underdrain pipes, paved drying beds were developed. In this concept, the beds are paved with asphalt or concrete, and have approximately a 1.5 to 2% slope toward the center. A perforated drainage pipe is located in the center beneath a sand drainage strip, at an elevation below the paved bed. The key advantage of this type of bed is the ability to use mechanical equipment for sludge removal without causing damage to underdrain pipes or loss of sand. The main disadvantages are high capital cost and a larger land area requirement than for sand beds.

3.6.3 Wedgewater Drying Beds

This type drying bed uses a wedgewater panel media placed in an open concrete basin. The concrete basin may be either a new structure, or an existing sand drying bed retrofitted by removing the sand and pouring a concrete bottom. The Wedgewater panel media acts as a false bottom, and the volume beneath is used for collection and removal of water which percolates through the media. Two types of Wedgewater panel media are available. One is constructed of stainless steel and the other is constructed of polyurethane. The stainless steel media requires supports to be placed on the concrete floor of the basin, while the newer polyurethane media has integrally molded supports and is self-supporting. The polyurethane media is manufactured in one square foot pieces, each two inches high, which lock together using an integrally molded locking arrangement. Both types of media can support a small front-end loader, when properly installed.

Prior to introducing sludge, the valve controlling removal of drainage water is closed, and the beds are filled with water to slightly above the media surface. The sludge is then introduced, and the initial drainage rate from the sludge is controlled by controlling the rate of water removed from the volume beneath the media. Controlled drainage for a period of 15 minutes to 2 hours is recommended by the manufacturer to maintain sludge porosity and reduce compression of the sludge matrix. After the controlled drainage phase, the sludge is allowed to further dewater by natural drainage for up to 24 hours. It can then be removed.

According to the manufacturer, aerobically digested sludges can be dewatered on a wedgewater drying bed to 8 to 12% solids within 24 hours and anaerobically digested sludges can be dewatered to 16 to 20% in 24 hours. The manufacturer indicates that the Wedgewater drying bed is most practical for the smaller treatment plant which has an average daily flow of 0.13 cu m/s (3 mgd) or less (11). As of July 1982, approximately 35 installations were operating, with 8 new projects under construction.

3.6.4 Vacuum-Assisted Drying Bed

Vacuum assisted drying beds use a porous media filter plate set above an aggregate filled support plenum, which drains to a sump. A relatively small vacuum pump is connected to draw vacuum from the sump. When polymer conditioned sludge is added to the bed surface, dewatering begins by gravity drainage. When the maximum sludge level in the bed is reached, 30 to 46 cm (12 to 18 in), flow of conditioned sludge is stopped, and the vacuum pump operation begins at 2.5 to 25 cm (1 to 10 in) of mercury. At the point when the cake cracks, the vacuum pump is shut off, and the sludge can be mechanically removed using a front-end loader.

The porous media filter plate is a specially fabricated material consisting of a thin carborundum plate overlying a layer of sized aggregate which is held together with epoxy. The media filter plates are supplied in sheets, which are caulked together after they are placed on the aggregate filled plenum. Caulking is also used around the periphery of the bed in order to provide a vacuum seal. A typical size for one bed is 6 by 12 meters (20 by 40 ft), with a 1 hp (0.7 kW) vacuum pump required for this size.

The manufacturer claims that a polymer conditioned anaerobically digested sludge can be dewatered to 12-16% solids in less than 24 hours. Polymer cost in this application would be about $8-12 per ton of dry solids. Typical design loadings are about 10 kg/sq m (2 lb/sq ft) per application, or about 30-57 l/sq m (8-15 gal/sq ft) per application. There are six installations at municipal wastewater treatment plants in the U.S. which have been installed since 1979, and at least three more installations are currently under construction. Filtrate is low in suspended solids, generally less than 10 mg/l (12).

3.7 Sludge Lagoon

Sludge lagoons are not a commonly utilized dewatering process, and little definitive design criteria are available. Two types of sludge lagoons may be utilized: storage lagoons and drying lagoons. The objective of storage lagoons is to store sludge in relatively deep earthen or concrete basins for a multi-year period, until a method of disposal is available. On the other hand, drying lagoons are relatively shallow and are designed for in-place drying of the sludge. In either type of lagoon, it is usually necessary to periodically decant supernatant from the top of the lagoon and return it to the wastewater treatment facility.

Sludge storage lagoons are between 1.5 and 4.6 m (5 and 15 ft) deep. The duration of storage may be anywhere from 1 to 5 years, with the storage time established by the ultimate form of disposal and variable local factors. At some plants, storage lagoons have been used either because there was no method available for disposal, or because the disposal methods could not accept all of the sludge.

Sludge drying lagoons are relatively shallow, with sludge being applied to a depth generally between 15 and 38 cm (6 and 15 in). Water removal from lagoons is by evaporation, and decanting is also frequently practiced. After sludge has reached an air dried state, it is typically removed either by a front-end loader or other mechanical equipment.

Table 3-13 lists advantages and disadvantages of sludge lagoons. Because there are no defined guidelines for lagoon design, it is difficult to enumerate common design shortcomings. However, areas in which the most mistakes occur in lagoon design are: (1) too steep a bank slope, making bank maintenance difficult; (2) inability to easily decant supernatant from the lagoon surface; (3) an inadequate number of lagoons, even though overall volume of lagoons is sufficient; (4) surface water is not diverted away from the lagoon; (5) no ramps into the lagoon to allow entrance of sludge removal equipment; and (6) insufficient concern is given to visual aesthetics and/or odor potential.

3.8 Gravity/Low Pressure Dewatering

Several manufacturers market devices which concentrate sludge by gravity drainage or a combination of gravity drainage and low pressure pressing. For descriptive purposes, they are referred to in this section as rotating cylindrical gravity dewatering devices and low pressure belt presses. The most commonly used units are the Permutit Dual Cell Gravity Unit (DCG) sometimes in conjunction with a Multiple Roll Press (MRP), the Ralph B. Carter Company sludge Reactor-Thickener, and the Smith and Loveless Sludge Concentrator. These devices are typically capable of producing a dewatered sludge with a cake solids concentration in the range of 8 - 12%. The devices rely on large dosages of polymer to condition the sludge. As a result, they are typically considered for small plants where the annual cost of even large dosages of conditioning chemicals is small.

A characteristic of gravity/low pressure dewatering devices is their simplicity and relatively low cost compared to other dewatering devices. They are quite useful where a large sludge volume reduction is required, as long as the requirement for final sludge concentration does not exceed 12%. The large volume changes which are experienced in dewatering from 3 - 4% to 10 - 12% are illustrated in Figure 4-5. A sludge which is dewatered to only 8 percent solids is often desired when the ultimate disposal method is land application using a sludge truck designed for spreading or subsurface injection. Table 3-14 lists advantages and disadvantages of these types of dewatering device.

3.8.1 Rotating Cylindrical Gravity Dewatering Device

This type of equipment uses a cylindrical framework covered with a filter media on the interior. As the device rotates, the conditioned sludge is continuously exposed to clean filter media, which enhances gravity drainage. These devices are sized on the basis of hydraulic loading.

TABLE 3-13

ADVANTAGES AND DISADVANTAGES OF SLUDGE LAGOONS

Advantages	Disadvantages
Low energy, labor, maintenance material, and chemical requirements	Visually unattractive
Low capital cost - excluding land	Potential odor source
Relatively insensitive to operational upsets in the treatment system	Potential problems with flies and mosquitos
Some organic decomposition will take place	Requires more land than most other dewatering concepts

TABLE 3-14

ADVANTAGES AND DISADVANTAGES OF GRAVITY/LOW PRESSURE DEWATERING DEVICES

Advantages	Disadvantages
Low energy and maintenance requirements	Only suitable for smaller plants due to limited capacity per machine
Low capital costs	Can not produce a solids concentration much above 10 - 12% without excessive chemical use.
Requires little operator skill	Require relatively large conditioning chemical costs
Low space requirements	
Very little noise	
Very useful for dewatering sludge to 8 percent solids level often required for land application	

The Permutit DCG unit uses two cylindrical cells and a single piece of filter cloth, as shown in Figure 3-12. The purpose of the first cell is dewatering, while the second cell is used for additional dewatering and cake formation. A variable rim depth on the discharge end of the second cell is used to control sludge depth in this cell.

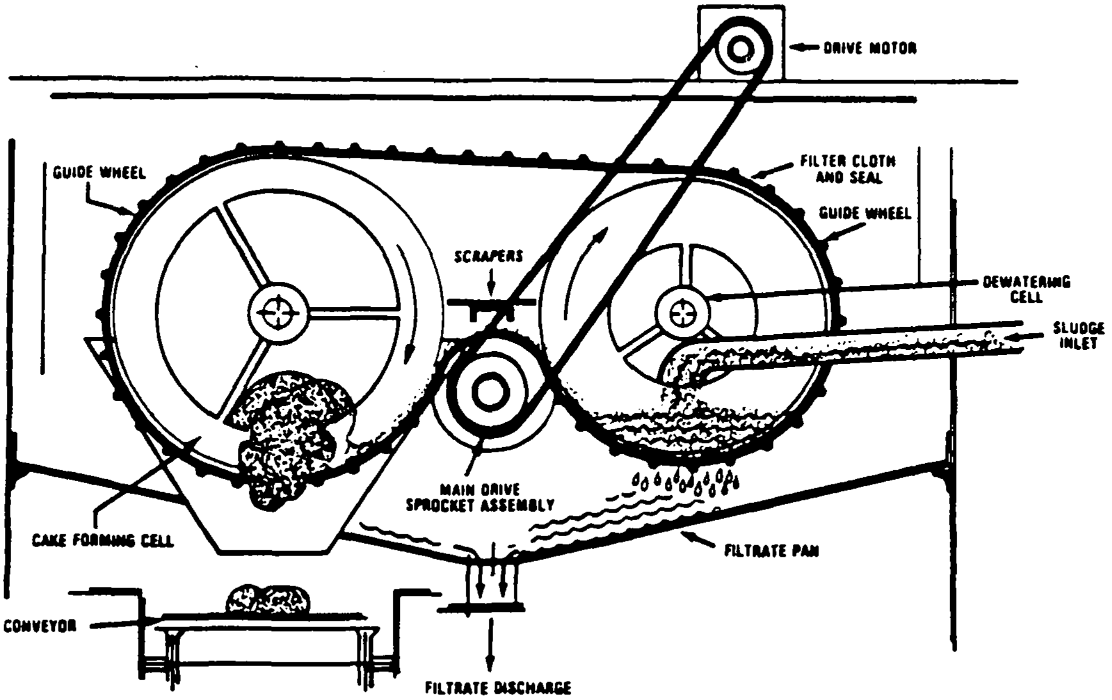


FIGURE 3-12

CROSS SECTION OF A DUAL CELL GRAVITY UNIT
(Courtesy of the Permutit Company)

The Ralph B. Carter Company sludge Reactor-Thickener operates on the same theory as the DCG unit, but only a single cylinder and combination screen made of stainless steel and polyester weave are utilized. The Carter Reactor Thickener system is also used on some Carter Belt Filter presses in place of a gravity drainage zone. The manufacturers claim this increases the hydraulic capacity of the belt press because the reactor thickener is more efficient than gravity drainage (13). Paduska and Stroupe found this to be true based on testing of an industrial waste activated sludge (14).

Performance data for the DCG indicate the capability of dewatering an aerobically digested mixture of primary and waste activated sludge from 2.5% to 9%, and an aerobically digested primary sludge from 2.5% to 8%. In general, both manufacturers indicate that their units are capable of dewatering most sludges to at least 8-10% solids. In 1980, Permutit reportedly had over 20 DCG installations on municipal applications (15). The Ralph B. Carter Company reports that four Reactor-Thickener Units (without belt presses) for municipal treatment plants have been installed since 1979 (13).

3.8.2 Low Pressure Belt Presses

Low pressure belt presses are the Smith and Loveless Sludge Concentrator and Permutit MRP. The Sludge Concentrator, shown in Figure 3-13, is skid mounted, and consists of a flashmix/flocculator, a gravity dewatering screen, and a dewatering screen which passes under a series of rollers, with each roller exerting higher pressure. Both belts are open mesh, and are variable speed. Smith & Loveless reports that they had over 140 U.S. installations in 1981 and that more than 15 Sludge Concentrators have been installed at municipal treatment plants since 1980 (16). The Permutit MRP is a single pass, low pressure spring loaded device, which presses sludge between two moving belts. This device was developed to provide further dewatering of output from a DCG unit.

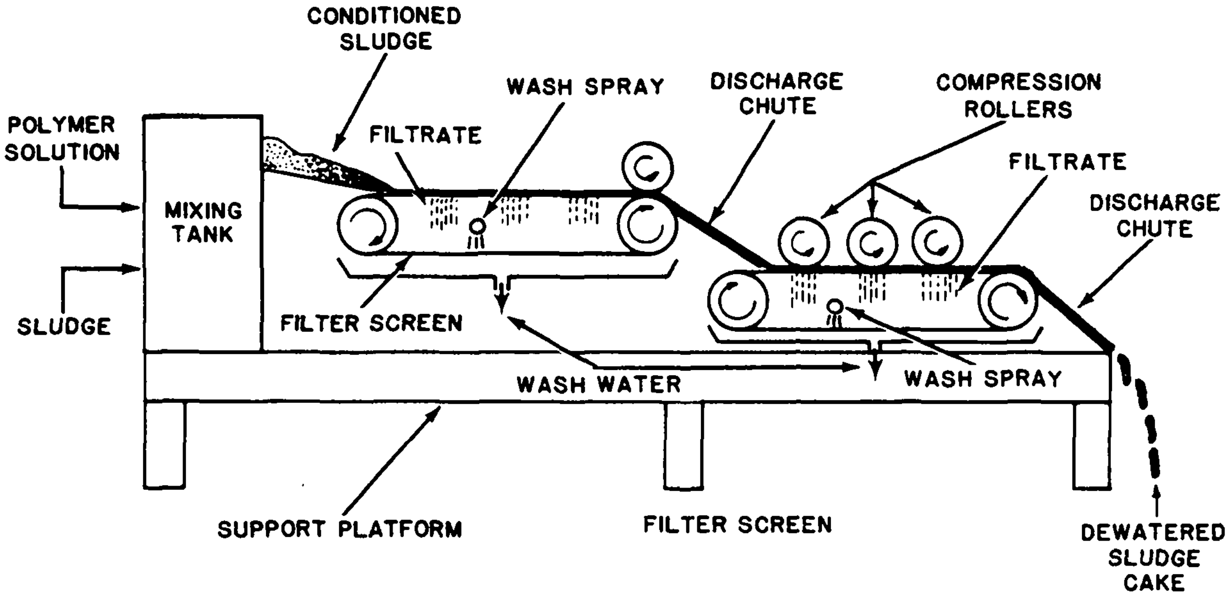


FIGURE 3-13

CROSS SECTION OF A SMITH & LOVELESS CONCENTRATOR

These devices are significantly less costly then the more complex, higher pressure belt presses, which produce a higher solids content cake. Typical sludge cakes produced by these low pressure presses are in the range of 8 to 12% with polymer dosages of 5 to 7.5 g/kg (10 to 15 lb/ton) depending on the sludge type. When the MRP is used after the DCG unit, sludge concentrations up to 15% have been claimed by the manufacturer.

3.9 References

1. "Process Design Manual For Sludge Treatment and Disposal," USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-625/1-79/011, September 1979.

2. "Innovative and Alternative Technology Assessment Manual," USEPA - Office of Water Program Operations, Washington, D.C., 20460, MCD-53, EPA-430/9-78-009, February 1980.

3. Bachtel, David R., "Operation and Maintenance of a Low Speed Scroll Centrifuge," County Sanitation District No. 2 of Los Angeles County, California, March 1982.

4. Personal communication with Richard T. Moll, Manager of Process Engineering, Sharples-Stokes Division, Pennwalt Corporation, Warminster, Pennsylvania, June 9, 1982.

5. Personal communication with Stephen H. Silverman, Sales Manager, Centrifuge Division, KHD Humboldt Wedag, Atlanta, Georgia, June 1982.

6. Trubiano, R., Bachtel, D., LeBrun T., and Horvath, R., "Parallel Evaluation of Low Speed Scroll Centrifuges and Belt Filter Presses for Dewatering Municipal Sewage Sludge," Draft EPA Report, Contract 68-03-2745, 1981. (Authors are with County Sanitation Districts of Los Angeles County, Whittier, California.)

7. Harrison, J.R., "Review of Developments in Dewatering Wastewater Sludges," Sludge Treatment and Disposal, Volume 1 - Sludge Treatment, USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-625/4-78-012, October 1978.

8. Personal communication, Don Cline, Fulco Sales, Garden Grove, California, Sales Representative for Envirotech, August 1981.

9. Personal communication, Don Herman, Herman-Phinney-Kodmur, Los Angeles, California, Sales Representative for Parkson Corporation, June 1981.

10. Personal communication, Eric Hammarstron, Komline Sanderson Engineering Corporation, Peapack, New Jersey, June 1981.

11. Personal communication, Vince Spalding, Hendrick Fluid Systems, Carbondale, Pennsylvania, July 1982.

12. Personal communication, Rob Ramsay, U. S. Environmental Products, Santa Ana, California, April 1982.

13. Personal communication, LeRoy A. Swenson, Ralph B. Carter Company, May 25, 1982.

14. Poduska, R.A. and Stroupe, R.C., "Belt-Filter Press Dewatering Studies, Implementation, and Operation at the Tennessee Eastman Company Industrial Activated Sludge Wastewater Treatment System," presented at the 35th Annual Purdue Industrial Waste Conference, May 1980.

15. Personal communication, Bob Nagle, Permutit Company, Inc., Paramus, New Jersey, June 1982.

16. Personal communication, Don Aholt, Smith & Loveless, Inc., Lenexa, Kansas, May 27, 1982.

CHAPTER 4

CAPABILITIES OF DEWATERING PROCESSES

4.1 Introduction

To define the capabilities of dewatering processes, a comprehensive and critical review was made of all available experience from full-scale operations. Engineering judgment was used in interpreting the data reviewed, and it is possible that others would reach different conclusions from the same information. Sources of information included the published literature, communication with manufacturers, literature from manufacturers, wastewater treatment plant contacts, communication with consultants, discussions with government officials, and the authors' own files. It is realized that there may exist information that differs from that presented here and which was not readily available to the writers of this manual.

Data were obtained from side-by-side comparisons of different dewatering processes as well as side-by-side comparisons of the same type of equipment supplied by different manufacturers. Similarly, data were obtained for equipment permanently installed at plant sites. Much of the information gathered included the newer advances in dewatering technology: the solid bowl centrifuge with backdrive capability, third generation belt filter press, and the diaphragm filter press.

The principal factors which influence the capabilities of dewatering processes, and which were considered in the writers' review, are:

- Source of Sludge - Domestic wastewater
    - Domestic wastewater with a varying percentage of industrial wastewaters

- Type of Sludge - Primary
    - Biological (WAS, TF, RBC, etc)
    - Combinations of primary and biological

- Sludge Solids Concentration

- Prior Handling of Sludge - Thickening
    - Stabilization
    - Storage
    - Transport

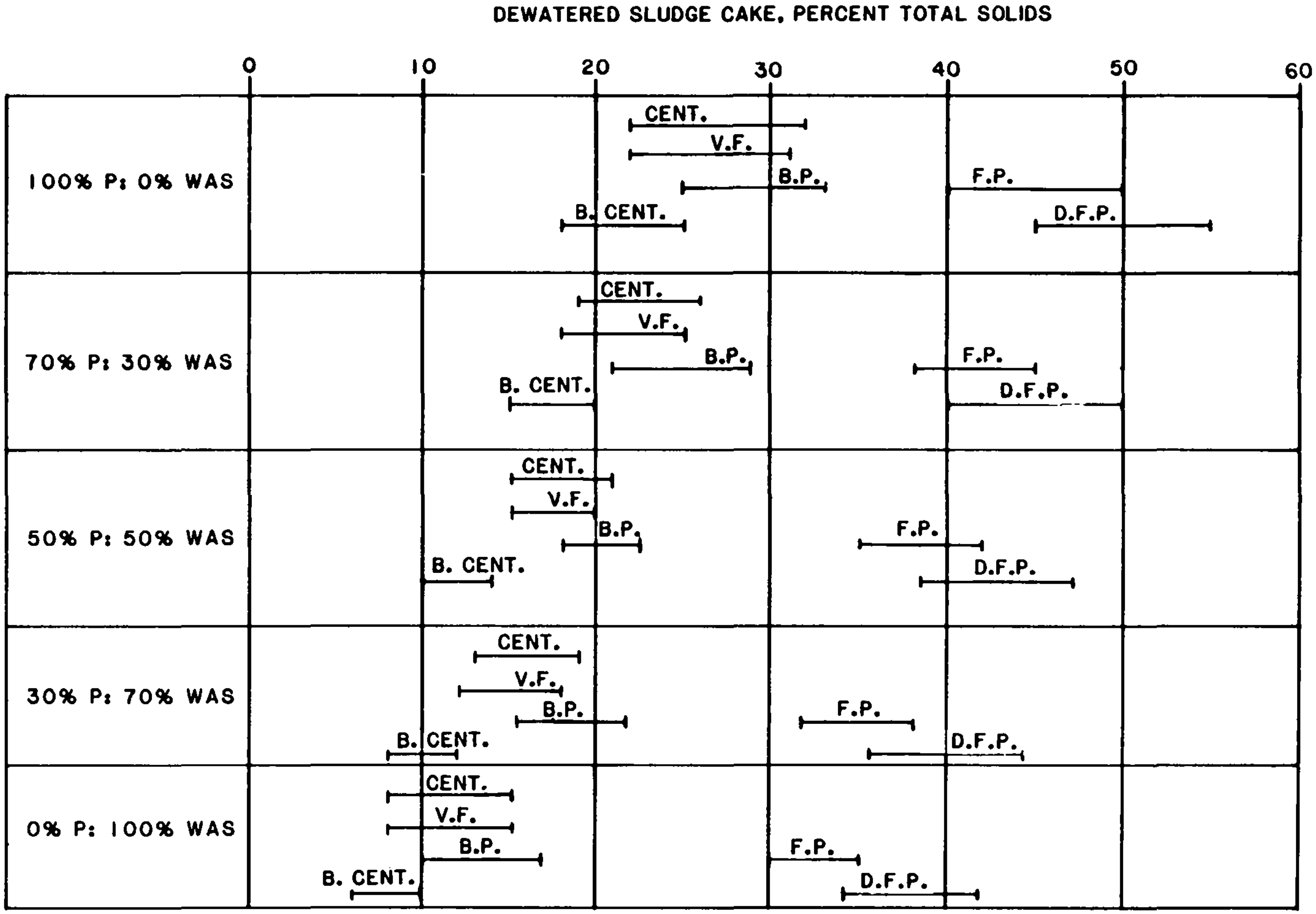
- Process Design - Conditioning provisions
    - Operational flexibility

4.2 Performance Capabilities of Mechanical Dewatering Processes

Based upon an evaluation of the performance information collected, a series of four figures was developed to illustrate the typical performance of mechanical dewatering processes with different types of sludges. Each figure presents a range for the sludge cake solids concentration expected from each dewatering process. The cake solids concentration varies for several reasons. First and most importantly, the cake solids concentration produced by any dewatering process can be influenced by the sludge feed rate and by changing the parameters that influence the process operation. Principal process operational variables will be described in Section 4.3 of this Chapter. Naturally, both overall economics and the degree of solids capture need to be considered in determining the optimum operation of the dewatering process. Secondly, choice and quantity of conditioning chemicals added can dramatically change the final sludge cake solids concentration; again, economics are a key factor to be considered in selecting the optimum chemical dosage. Third, no sludge consistently exhibits the same dewatering characteristics, and sludges from different plants exhibit wide variations in their ability to be dewatered. A number of factors are responsible for such variations, including the influence of industrial discharges on sludge composition, particularly its organic content, and the variability of preceding processes in the sludge treatment system such as thickening, storage or holding, transport, and stabilization operations.

Figures 4-1 to 4-4 are presented to illustrate the capabilities of mechanical dewatering processes on different types of sludge, and each of these figures is described in subsequent paragraphs. In utilizing the information in these figures, the reader is cautioned that the cake solids concentrations given do not correct for any inorganic conditioning chemicals, do not take into account the cost of chemical conditioning, and do not take into account the percent recovery obtained. The data are, however, based on reasonable levels of chemical conditioning and solids recoveries for the processes considered.

Figure 4-1 provides typical ranges for dewatered sludge cake solids concentrations produced by mechanical dewatering processes on digested primary and waste activated sludge (WAS) combinations. It is apparent from this figure that as the percentage of WAS increases, the achievable cake solids concentration decreases, and similarly, that 100% primary sludge is much easier to dewater than 100% WAS. Figure 4-1 also illustrates the differences in the capabilities of various mechanical dewatering processes. The diaphragm filter press will typically produce the driest, most highly dewatered sludge cake of any mechanical dewatering process, while the fixed volume recessed plate or conventional filter press (both high and low-pressure) will produce the next highest solids content cake. Belt filter presses, solid bowl centrifuges, and vacuum filters can all produce similarly dewatered cakes, although belt presses are generally capable of producing the driest cake of these three processes. Basket centrifuges generally produce a cake somewhat lower in solids concentration than the other dewatering processes. It should be noted that the cake solids contents for the diaphragm filter press, the conventional filter press, and the vacuum filter will usually include large amounts of inorganic conditioning chemicals. These additives reduce the actual sludge solids content.



LEGEND

CENT.	-SOLID BOWL CENTRIFUGE	B. CENT.	-BASKET CENTRIFUGE
V.F.	-VACUUM FILTER	F.P.	-FILTER PRESS
B.P.	-BELT PRESS	D.F.P.	-DIAPHRAGM FILTER PRESS

REFERENCES - 1,2,3,4,5,6,7,
8,9,10,11,12,
13,14,15,16,
17,18,19,20,
21,22,23,24

FIGURE 4-1

DEWATERED SLUDGE CAKE PERCENT SOLIDS FOR MIXTURES OF DIGESTED PRIMARY (P) AND DIGESTED WASTE ACTIVATED SLUDGE (WAS)

In Figure 4-2, typical dewatered sludge cake solids concentrations are shown for raw primary and raw WAS. From Figure 4-2, it can be seen how much more difficult it is to dewater the raw WAS than the raw primary sludge. Also, by comparing Figures 4-1 and 4-2, it is evident that most mechanical processes can dewater raw sludge to between 2 to 5% higher solids concentration than digested sludge. This difference partially occurs because anaerobic digestion produces a larger proportion of fine-sized particles than is typically found in raw sludge, and these smaller particles tend to hinder dewatering as discussed in Chapter 2. Anaerobic digestion also significantly reduces the quantity of sludge solids to be dewatered; however, the sludge solids concentration is also significantly reduced, which adversely affects dewatering.

Figure 4-3 shows typical dewatered sludge cake solids concentrations for raw primary plus raw WAS, raw trickling filter (TF) sludge, raw primary plus raw TF sludge, and raw primary plus raw rotating biological contactor (RBC) sludge. Data were not available for the performance of all mechanical dewatering processes with all types of sludges, and therefore for some of the sludge types only one or two dewatering processes are shown. This does not necessarily mean that only the processes shown are appropriate for dewatering that type of sludge, and the equipment manufacturer should be consulted for specific advice on particular applications. A comparison between raw primary plus WAS and raw primary plus TF sludge shows that TF sludge is generally easier to dewater than WAS. Raw primary plus RBC sludge is also easier to dewater than raw primary plus WAS. In general, these variations are the result of the denser nature of the attached growth TF and RBC sludges and the fact that suspended growth WAS contains more fine material.

Figure 4-4 presents typical data for the dewatering of digested TF sludge and digested primary plus TF sludge. These data, when compared with the data for raw primary plus TF sludge and raw TF sludge in Figure 4-3, again illustrate that digestion increases the difficulty in dewatering. Also shown in Figure 4-4 are data for thermal conditioned primary plus WAS and primary plus TF. Thermal conditioning will produce a sludge with excellent dewatering characteristics, because cellular solids have been broken down and the intercellular liquid contents are released. However, there are also a number of unfavorable aspects of thermal conditioning which must be considered.

The overall conclusions which can be reached after comparing the data presented in Figures 4-1 to 4-4 are:

- Solid bowl centrifuges and vacuum filters produce comparable cake solids concentrations.

- A third generation belt filter press can produce a cake with up to a several percent higher solids content than can a solid bowl centrifuge or vacuum filter.

- Diaphragm filter presses produce sludge cakes with a 2-6% higher solids concentration than a conventional fixed volume filter press.

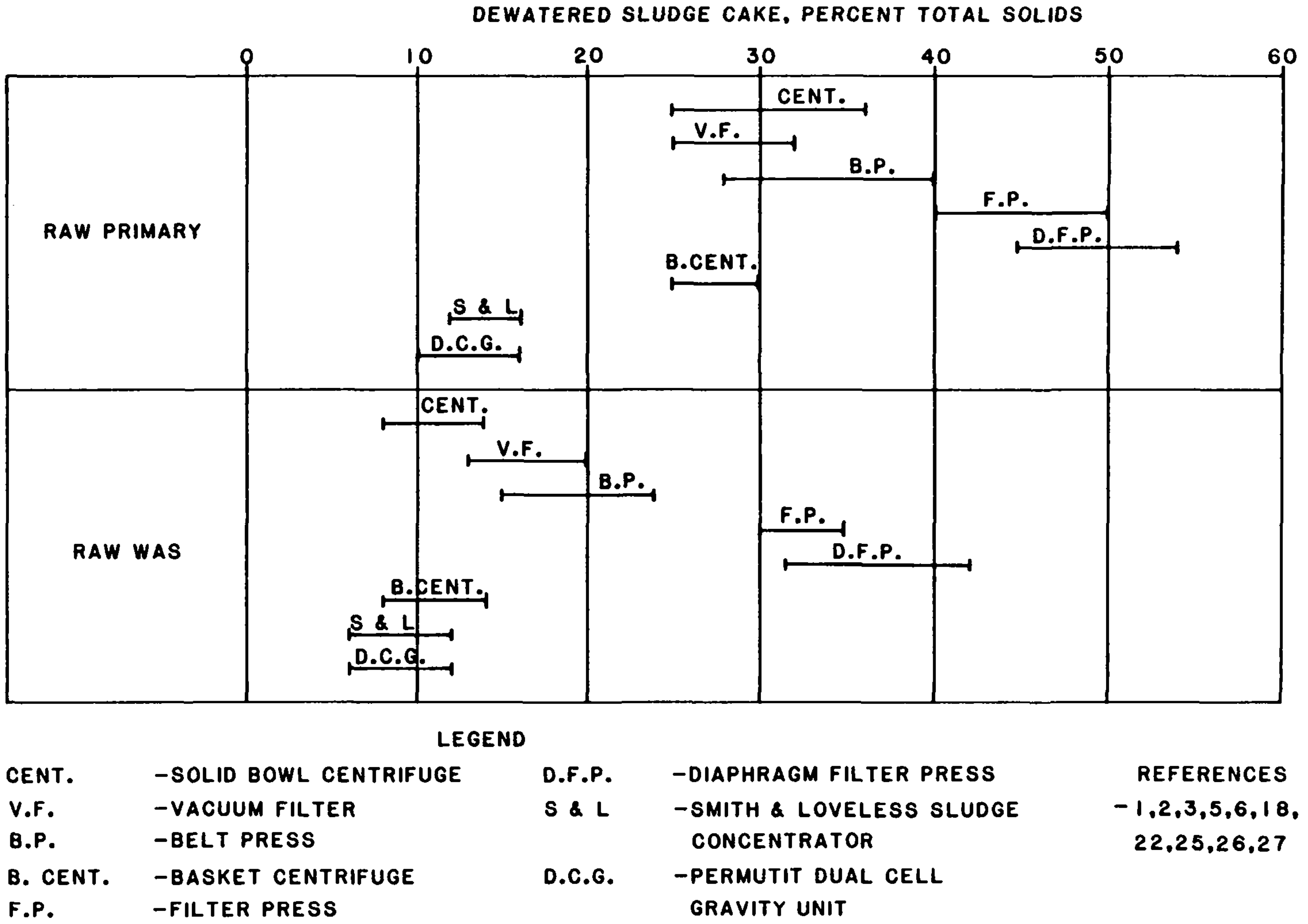
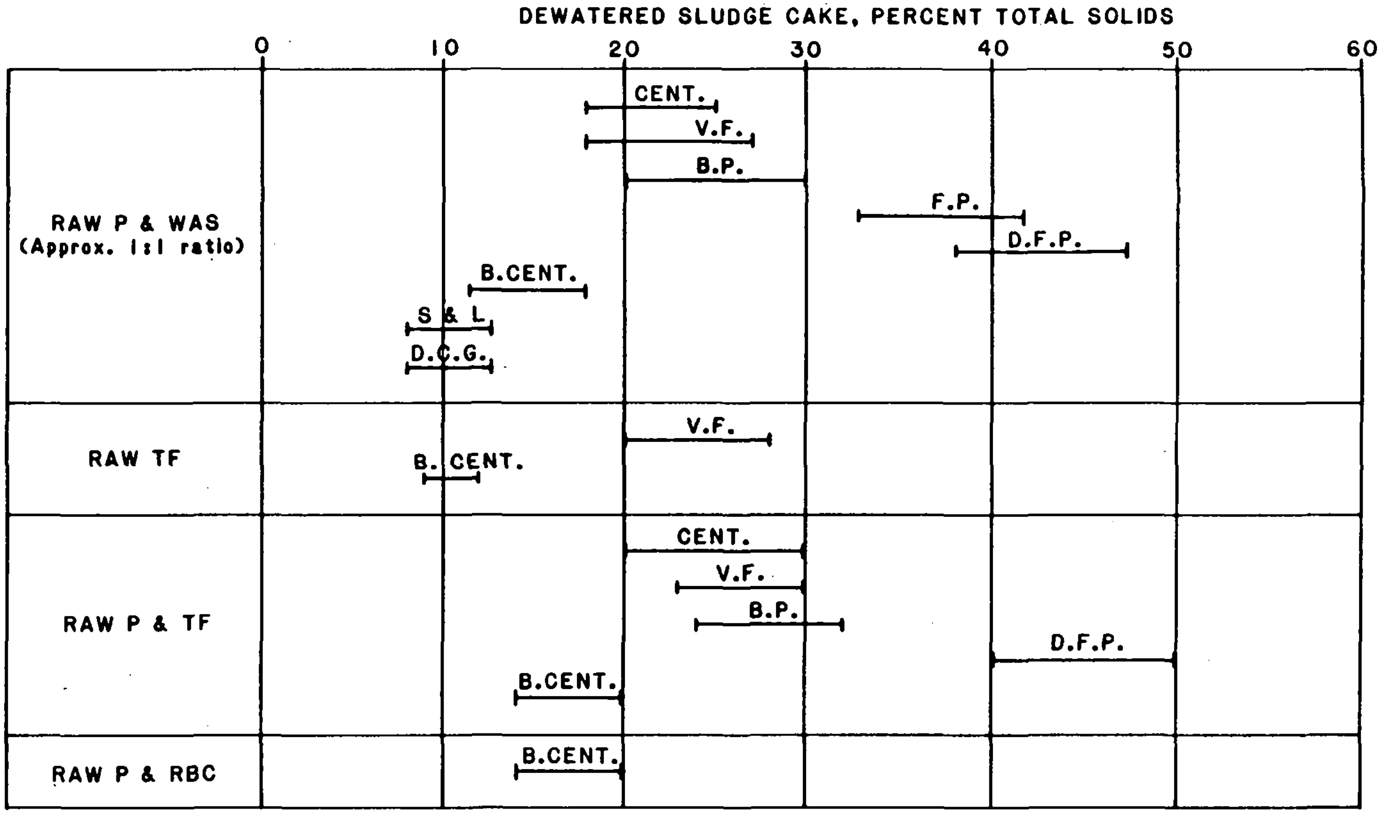


FIGURE 4-2
DEWATERED SLUDGE CAKE PERCENT SOLIDS
FOR RAW PRIMARY AND RAW WAS



LEGEND

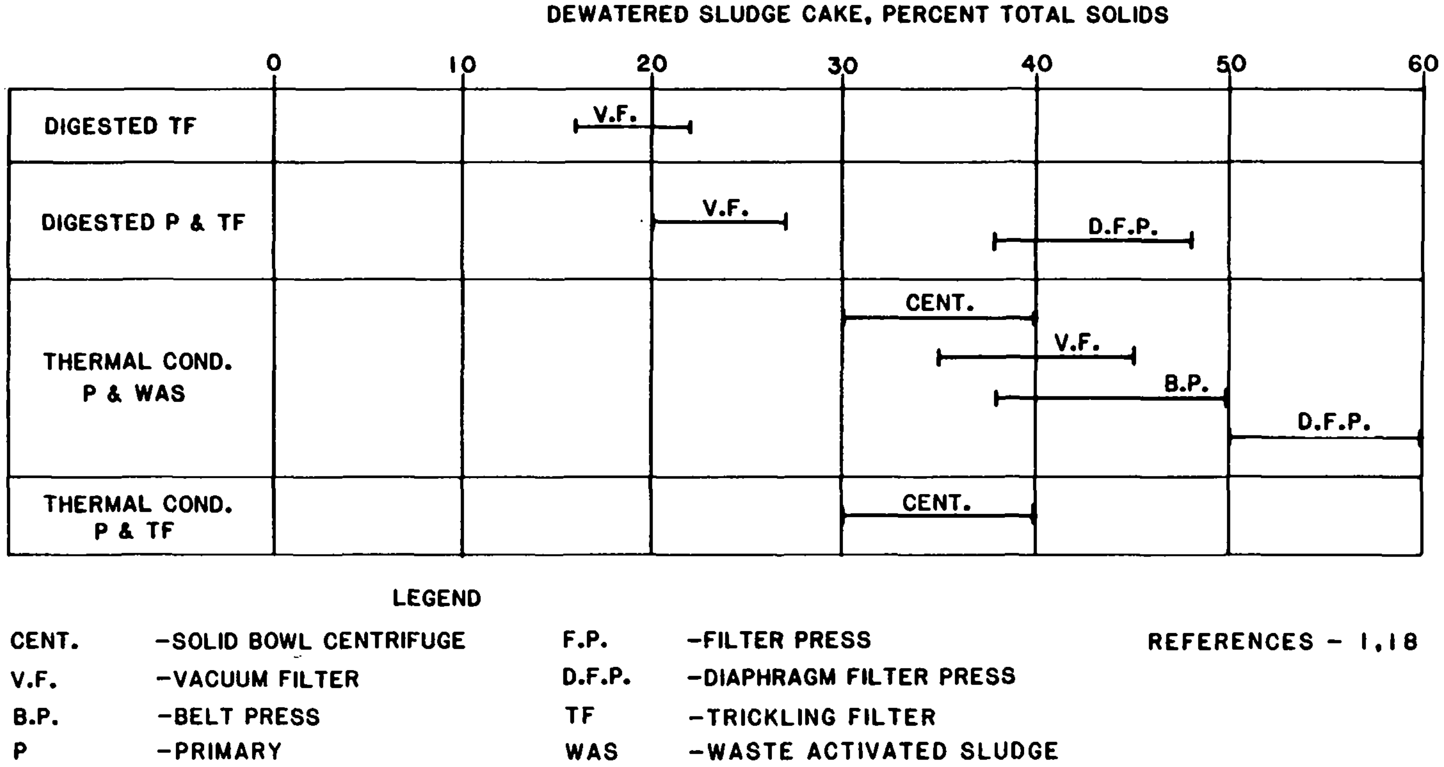
CENT. -SOLID BOWL CENTRIFUGE
V.F. -VACUUM FILTER
B.P. -BELT PRESS
B. CENT. -BASKET CENTRIFUGE
F.P. -FILTER PRESS
D.F.P. -DIAPHRAGM FILTER PRESS
S & L -SMITH & LOVELESS SLUDGE CONCENTRATOR

D.C.G. -PERMUTIT DUAL CELL GRAVITY UNIT
RBC -ROTATING BIOLOGICAL CONTACTOR
P -PRIMARY
WAS -WASTE ACTIVATED SLUDGE
TF -TRICKLING FILTER

REFERENCES
-1,2,4,7,15,18, 22,28,29,30

FIGURE 4-3

DEWATERED SLUDGE CAKE PERCENT SOLIDS FOR MIXTURES OF RAW PRIMARY AND SECONDARY SLUDGES



REFERENCES - 1,18

FIGURE 4-4

DEWATERED SLUDGE CAKE PERCENT SOLIDS FOR MIXTURES OF DIGESTED PRIMARY AND SECONDARY SLUDGE AND HEAT TREATED PRIMARY AND SECONDARY SLUDGE

- Digested primary sludge can be dewatered to a significantly higher solids content than digested WAS. The extent varies among the different dewatering processes.

- Raw sludge can typically be dewatered to a solids concentration that is 2 to 4% higher than that for the same sludge which has been digested.

- TF and RBC sludges, either raw or digested, dewater to a higher solids content than WAS.

- All processes exhibit a range of probable sludge cake solids concentrations, due to varying loading or feed rates, amount and type of conditioning utilized, equipment operational variables, and the variability of the sludge composition from location to location.

4.3 Process Operational Variables Which Affect Dewatering Results

As the prior section illustrates, a substantial range in dewatered sludge cake solids concentrations is evidenced for all mechanical dewatering processes. One reason is variable sludge composition from plant to plant, while an important second reason is the number of variables associated with operation of the dewatering process. All dewatering processes have several operational variables which influence process performance. The four key factors normally used to evaluate process performance are: cake solids concentration; percent solids capture; process throughput; and conditioning chemical requirements. It is not possible to vary process operation to simultaneously optimize all four process performance indicators. For example, a change in process operation to increase cake solids concentration without changing conditioning chemical dosage, would likely result in decreases in process throughput and solids capture. The process operator must determine which of the four process performance indicators are most important and change the operational variables to achieve the desired results.

For the dewatering processes included in this manual, Table 4-1 lists key operational variables, and these operational variables are discussed in the following sections.

4.3.1 Basket Centrifuge

Increasing the bowl speed and the time at full speed will increase cake solids content and usually solids capture, although increasing the time at full speed will reduce machine throughput. An increase in the depth of skimming will result in a drier cake, but it will return more solids back to the plant for subsequent retreatment. Polymer dosage increase will increase cake solids concentration and percent solids capture up to a point. An increase in sludge feed rate will increase the throughput, but may require more polymer and produce a lower cake solids concentration with a lower solids capture.

TABLE 4-1

OPERATIONAL VARIABLES FOR DEWATERING PROCESSES

1. BASKET CENTRIFUGE
    - A. Bowl speed
    - B. Time at full speed
    - C. Depth of skimming
    - D. Sludge feed rate
    - E. Polymer conditioner
        - Dosage utilized
        - Point of addition

2. SOLID BOWL CENTRIFUGE
    - A. Bowl/conveyor differential speed
    - B. Pool depth
    - C. Sludge feed rate
    - D. Polymer conditioner
        - Dosage utilized
        - Point of addition

3. BELT FILTER PRESS
    - A. Belt speed
    - B. Belt tension
    - C. Washwater flow and pressure
    - D. Belt type
    - E. Sludge feed rate
    - F. Polymer conditioner
        - Dosage utilized
        - Point of addition; contact time; mixing

4. VACUUM FILTER
    - A. Quantity of wash H_2O used
    - B. Drum Speed
    - C. Vacuum level
    - D. Conditioning chemicals - type & dosage
    - E. Drum submergence
    - F. Vat agitation
    - G. Filter media used

5. CONVENTIONAL FILTER PRESS
    - A. Pressure of feed sludge
    - B. Filtration time
    - C. Use of Precoat
    - D. Conditioning chemicals - type & dosage
    - E. Cloth washing frequency
    - F. Filter cloth used

6. DIAPHRAGM FILTER PRESS
    - A. Pressure of feed sludge
    - B. Filtration time
    - C. Diaphragm pressure
    - D. Diaphragm squeezing time
    - E. Conditioning chemicals
        - Type & Dosage
        - Point of addition
    - F. Filter cloth used
    - G. Frequency of cloth washing

7. DRYING BEDS
    - A. Depth of sludge application
    - B. Conditioning of sludge
    - C. Duration of drying time
    - D. Method of sludge cake removal

8. SLUDGE LAGOONS
    - A. Frequency of sludge addition
    - B. Method of sludge removal
    - C. Method of supernating

9. GRAVITY/LOW PRESSURE DEWATERING
    - A. Rate of sludge feed
    - B. Polymer concentration
    - C. Belt speed
    - D. Force applied by rollers
    - E. Depth of dewatered sludge in cylindrical devices

4.3.2 Solid Bowl Centrifuge

Increasing the bowl speed will in theory increase the cake dryness, because of higher gravitational force. However, in some cases the increased shear of the sludge floc which occurs when the sludge is fed will tend to offset the advantage of the higher bowl speed. Shearing of the sludge floc at increased G forces is usually not a problem in a centrifuge where the polymer is added internally and the floc is formed after both the polymer and feed have reached the speed of the centrifuge. In a solid bowl conveyor centrifuge, the scroll operates at a slightly slower or higher speed than the bowl. As the scroll speed approaches the bowl speed, the resultant differential speed is reduced and machine capacity decreases. As the bowl-conveyor differential speed increases, solids are removed from the machine quicker, thereby increasing machine capacity. Offsetting this, however, is the usual production of a wetter cake, when the solids are removed faster from the machine. Use of a backdrive to maintain either a constant torque or a constant differential speed between the scroll and the bowl will usually result in a drier sludge cake, but at the same time will decrease machine throughput. An increase in the pool depth will result in increased solids capture, but generally a wetter sludge cake is produced. Increasing the polymer dosage will generally increase both cake dryness and solids capture, although an increase in solids capture can cause the cake solids content to be reduced as more fine material is captured.

4.3.3 Belt Filter Press

Machine throughput can be increased by increasing belt speed, with the usual result being production of a lower solids content cake, because both gravity drainage time and press time are decreased. Increased belt tension will promote a drier cake, but solids capture will normally decrease, and belt wear will increase. An increase in washwater flow and/or pressure can increase cake solids concentration, if the washwater was not adequately cleaning the belt. Also, the more porous the belt, the drier the cake and lower the solids capture. An increase in sludge feed rate can increase machine throughput if the belt speed is high enough to move the sludge, and if the polymer dosage is high enough to maintain solids capture. As polymer dosage increases, both cake solids and solids capture increase, until an upper limit is reached. Point of polymer addition can be important to allow sufficient contact time before the conditioned sludge is applied to the belt press.

4.3.4 Vacuum Filter

In cases where insufficient cloth washing is used, increasing the amount of cloth wash water will increase the machine throughput and will help to somewhat increase cake dryness. A high drum speed will increase machine throughput but may decrease solids content of the cake. A high vacuum level will increase the cake solids content at the expense of increased energy consumption. An increased drum submergence will increase machine capacity but will decrease drying time and may decrease solids content of the cake. Vat agitation is necessary for proper cake formation, but over-agitation will result in breaking up the sludge floc and poor solids capture. The addition of scraper blades, use of excess chemical conditioner, or addition of fly ash, are sometimes required to obtain cake release from cloth media vacuum filters. This is especially true if the sludges are greasy, sticky, and/or contain a large quantity of waste activated sludge.

4.3.5 Fixed Volume Filter Press

Use of a higher feed pressure and a longer cycle time will increase cake solids concentration, although the latter will decrease machine throughput. Use of a precoat will improve solids capture, reduce filtration time, and preserve the media's efficiency. A precoat would normally be required only for a digested sludge which has very fine floc, or to obtain an adequate cake release. For a "sticky" sludge, use of a precoat actually saves time by significantly reducing the cloth washing frequency. Conditioning is particularly important. To achieve an adequate cake release and a reasonable filtration time, lime and ferric chloride are typically required for conditioning, although thermal conditioning can also be used and there has been some limited success using polymers. A correct conditioning chemical dosage will result in a dry cake, while an incorrect dosage will decrease machine throughput due to the use of excess chemicals, or will produce a wet sludge cake. Frequent filter cloth washing will increase machine throughput, cake dryness, and cloth life, while use of a suitable filter cloth will increase solids capture and probably the machine capacity.

4.3.6 Diaphragm Filter Press

Feed sludge pressure and pumping time only have a moderate effect on the product cake. More significant factors are the diaphragm pressure and the diaphragm squeezing time, both of which increase cake dryness when they are increased. Influence of other variables is similar to the fixed volume filter press. The type of filter cloth used is generally established by wear and abrasion resistance, ease of cake release, and quality of the filtrate (solids capture).

4.3.7 Drying Beds

Bed capacity is maximized by using shallow sludge applications and conditioning the sludge with polymer. Naturally, longer drying times will produce a greater cake solids content; however, if the cake is dry enough to be removed using mechanical equipment and if the bed capacity is required for the application of wet sludge, or if there is the potential for substantial rainfall, it may be necessary to remove the dried sludge prior to the achievement of optimum dryness. Sludge cake removal can be performed manually in very small plants, although typically it is removed with a front-end loader or grader.

4.3.8 Sludge Lagoons

Use of relatively infrequent sludge applications will result in better settling, a higher cake solids concentration and fewer solids in the recycle. If sludge is removed by a dragline and allowed to dry on the lagoon periphery, it will have a higher solids content than if a dredge is used for solids removal. Supernatant can be removed by fixed pipelines at several depths in the lagoon or by lowering a submersible pump or suction line to the desired depth in the lagoon.

4.3.9 Gravity/Low Pressure Dewatering

Both rotating cylindrical gravity dewatering devices and low pressure belt presses will produce a higher solids content cake at lower sludge feed rates and higher polymer dosages. These are the two most important operational factors. Other operational factors are the depth of sludge in the rotating cylindrical devices, and the belt speed and roller pressure in low pressure belt presses.

4.4 Effect of Dewatering on Sludge Volume

As cake solids content increases, dramatic reductions in sludge volume occur, as shown in Figure 4-5. However, as higher cake solids concentrations are achieved, the percentage volume reduction is not as great. For example, increasing dewatering from 10 to 15% solids reduces volume by 35%, while increasing dewatering from 20 to 25% solids only reduces volume by 21%. In other words, as the final dewatered cake concentration increases from a low level to a higher level, the incremental volume reduction becomes lower. This relationship is an important factor.

In certain situations, the relatively inexpensive dewatering processes that dewater from 3% solids to 8 to 12% cake solids may be economically justified even though hauling and disposal costs may be higher. This is because a volume reduction of 70 to 80% can be achieved with even the gravity/low pressure devices. Also, in situations involving further dewatering beyond 20%, volume and weight reductions may not be justified on an overall economic basis. While no economic decisions can be made based solely on Figure 4-5, the relationship presented is often useful in the initial screening stage of evaluating dewatering concepts, where dewatering requirements and possible ways of accomplishing them are being evaluated. This is discussed in detail in Chapter 6.

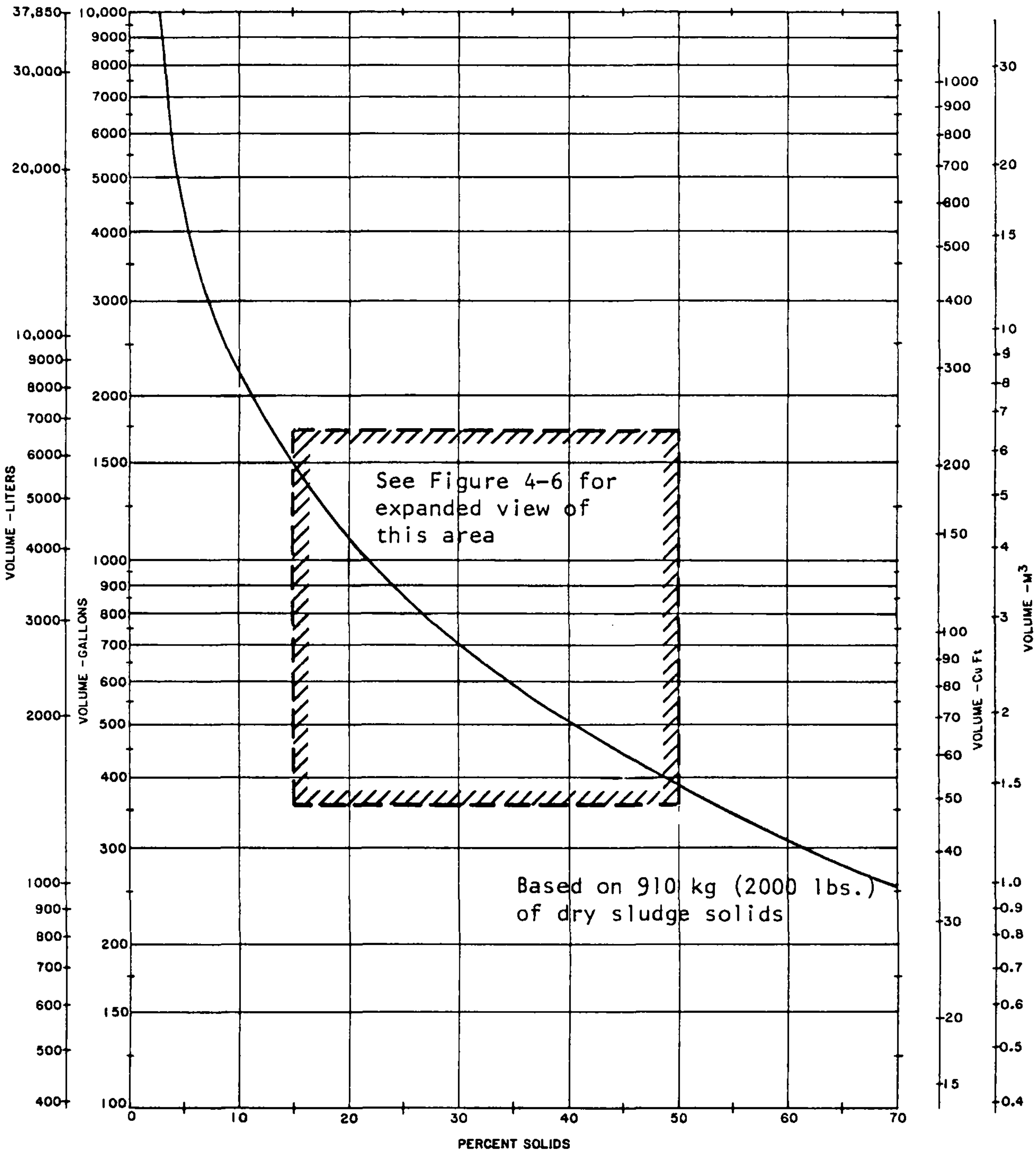


FIGURE 4-5

EFFECT OF PERCENT SLUDGE SOLIDS ON SLUDGE VOLUME

Another way of evaluating differing cake solids concentrations is to consider the moisture content in terms of mass of water per mass of solids. For example, filter press cake of 40 percent solids contains 1 1/2 lb of water/lb of solids, while a vacuum filter cake of 15-20 percent solids contains 4-5.7 lb of water/lb of solids. Therefore, if the sludge is to be reduced by incineration, 3 to 4 times as much water would have to be heated and vaporized from the vacuum filter cake compared to the filter press cake.

The use of an inorganic chemical conditioning chemical will increase the mass of sludge solids and may increase both the overall sludge mass and volume. This effect is shown in Figure 4-6 for conditioning chemical usages of 50, 100, 200 and 300 g/kg (100, 200, 400, and 600 lb/ton) of dry weight solids. This Figure indicates that, if conditioning chemicals are added equivalent to approximately 20% of the sludge weight with the sludge cake solids concentration fixed, the sludge volume is increased by 20%.

It is, however, possible to reduce the volume of the sludge cake produced by using inorganic conditioning chemicals. For example, if a vacuum filter produced a 15 percent cake on a primary sludge when conditioning with polymer, the volume from Figure 4-6 (based on 910 kg or 2,000 lb of solids) would be about 5.6 cu m (200 cu ft). If an inorganic conditioning chemical dosage of 100 g/kg (200 lb/ton) increased the cake solids concentration to 25 percent solids, the volume would be reduced to about 3.7 cu m (130 cu ft). This is a volume reduction of 35 percent. These important factors must be incorporated into the initial screening process and the initial cost evaluation, as described in Chapter 6.

Example calculations showing the computation of sludge volumes produced by different dewatering processes are shown in Appendix B. The cake volume comparison in Appendix B shows that the cake volumes (smallest volume to largest) per unit weight of solids dewatered including conditioning chemicals are: drying bed; diaphragm filter press; fixed volume filter press; sludge lagoons; belt press; solid bowl centrifuge; vacuum filter; basket centrifuge; and gravity/ low pressure dewatering devices. Some caution, however, must be applied to the use of cake volumes shown for drying beds and sludge lagoons since a very wide range of sludge cake solids can be produced. Sludge lagoons may produce a sludge with solids concentrations ranging from 5 to 40 percent, while drying beds may produce sludge cakes ranging from 15 to more than 70 percent solids. Given a sufficient drying time, a well designed and operated drying bed can produce a drier sludge (with a lower volume) than any mechanical device.

From the standpoint of trucking and subsequent handling, caution must be exercised in comparing filter press cake volumes with cake volumes of other mechanical devices which do not produce as dry a cake. For the filter press cake, the "bulk" volume of the sludge is the important factor, as it accounts for air spaces between the pieces of cake. For other types of sludge cake, the "true" volume is the important criterion, since the cake produced is generally moist enough to readily compact. The increase in volume for the filter press cake is not possible to quantify without actual testing.

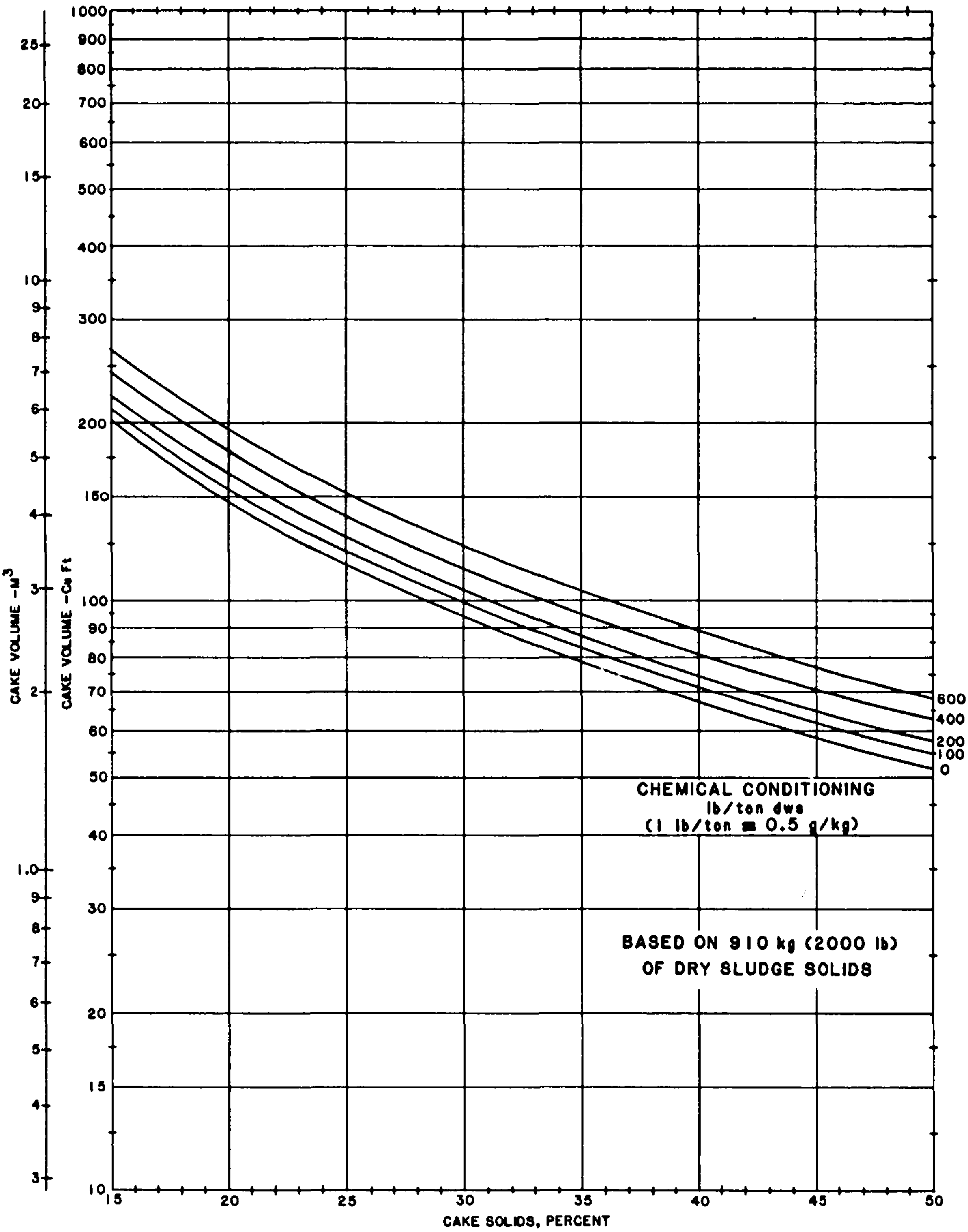


FIGURE 4-6

EFFECT OF INORGANIC CONDITIONING CHEMICAL DOSAGE ON DEWATERED SLUDGE VOLUME

4.5 References

1. "Process Design Manual For Sludge Treatment and Disposal," USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-625/1-79/011, September 1979.

2. Harrison, J. R., "Review of Developments in Dewatering Wastewater Sludges," Sludge Treatment and Disposal, Volume 1 - Sludge Treatment, USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-625/4-78-012, October 1978.

3. Trubiano, R., Bachtel, D., LeBrun, T., and Horvath, R., "Parallel Evaluation of Low Speed Scroll Centrifuges and Belt Filter Presses for Dewatering Municipal Sewage Sludge," Draft EPA Report, Contract 68-03-2745, 1981. (Authors are with County Sanitation Districts of Los Angeles County, Whittier, California)

4. Culp, Gordon L. and Hinrichs, Daniel J., "Municipal Wastewater Sludge Management Alternatives," prepared for the EPA Technology Transfer National Conference on 208 Planning and Implementation, 1977. (Authors are with Culp/Wesner/Culp, Cameron Park, California)

5. "Mechanical Dewatering Study - Los Angeles County Sanitation Districts," LA/OMA Project, Regional Wastewater Solids Management Program, Los Angeles-Orange County Metropolitan Area, September 1980. (County Sanitation Districts of Los Angeles County, Whittier, California)

6. "Mechanical Dewatering Study - Orange County Sanitation Districts," LA/OMA Project, Regional Wastewater Solids Management Program, Los Angeles-Orange County Metropolitan Area, September 1980. (County Sanitation Districts of Orange County, Fountain Valley, California)

7. Villiers, R. V. and Farrell, Joseph B., "A Look at Newer Methods for Dewatering Sewage Sludges," Civil Engineering - ASCE, December 1977.

8. CH_2M-Hill, "Michelson Water Reclamation Plant - Engineering Report for Dewatering Equipment Selection," Irvine Ranch Water District, Irvine California, June 1979.

9. Tavery, M. A., "Evaluation of Sludge Dewatering Equipment at the Metro Denver Sewage District," paper presented at the Colorado AWWA-WPCA Technical Activities Committee, May 3, 1979. (Author is with the Metropolitan Denver Sewage Disposal District No. 1, Denver, Colorado).

10. Parkson Corporation, "Summary of Test Results on Magnum Press at Metro Denver S.T.P., Denver, Colorado, October 30 - November 3, 1978." (Parkson Corporation, Fort Lauderdale, Florida)

11. Madden, J., "Tait-Andritz Sludge Dewatering Report to Metropolitan Denver Sewage Disposal District No. 1," January 10, 1979. (Author is with Pfister and Associates, Denver, Colorado)

12. Pennwalt Sharples, "Technical Department Report for Metro-Denver Sewage Disposal District No. 1," January 25, 1979. (Sharples-Stokes Division, Pennwalt Corporation, Warminster, Pennsylvania)

13. John Carollo Engineers, "Design Memorandum No. 5 - Dewatering Methods," County Sanitation Districts of Orange County, Fountain Valley, California, April 1979.

14. Consoer, Townsend & Associates Ltd., "Draft Project Report - Sludge Processing Facilities Plan For the Cities of San Jose and Santa Clara, California," May 1980.

15. Ettlich, William F., Hinrichs, Daniel J., and Lineck, Thomas S., "Operations Manual - Sludge Handling and Conditioning," USEPA - Office of Water Program Operations, Washington, D.C., 20402, EPA-430/9-78-002, February 1978.

16. Hansen, Blair E., Garrison, Walter E., and Smith, Donald L., "Start-up Problems of Sludge Dewatering Facility," Journal WPCF, October 1980.

17. Zenz, D. R., et al., "Evaluation of Unit Processes for Dewatering of Anaerobically Digested Sludge at Metro Chicago's Calumet Sewage Treatment Plant," The Metropolitan Sanitary District of Greater Chicago, October 1976.

18. Ingersoll-Rand, Unpublished data on filter press and centrifuge test results, 1977 - 1979. (Information from Wayne B. Gendron, Ingersoll-Rand, Nashua, New Hampshire)

19. Moser, J.H., et.al., "Milwaukee Water Pollution Abatement Program Solids Handling Study," Milwaukee Metropolitan Sewerage District, May 1981. (Author is with Milwaukee Metropolitan Sewerage District)

20. Sawyer, Bernard; Watkins, Robert; and Lue-Hing, Cecil, "Evaluation of Unit Processes for Mechanical Dewatering of Anaerobically Digested Sludge at Metro Chicago's West-Southwest Sewage Treatment Plant," Paper presented at the 31st Annual Purdue Industrial Waste Conference, May 1976. (Authors are with the Research and Development Department of The Metropolitan Sanitary District of Greater Chicago)

21. Greenhorne & O'Mara Engineers, "Nassau County Sludge Study Composting and Dewatering Demonstration Program--Final Report," July 1979. (Greenhorne & O'Mara Engineers are in Riverdale, Maryland)

22. Passavant Corporation, Unpublished data on filter press and belt filter press test results. (Information received from E. D. Simmons, Vice-President, Technical Services, Passavant, Birmingham, Alabama, May 1982)

23. East Bay Municipal Utility District, Unpublished Data on Low Speed Solid Bowl Centrifuge. (Information received from Daryl G. Deruiter, Associate Environmental Engineer, EBMUD, Oakland, California, June 1982)

24. Sharples, Stokes Division, Pennwalt Corporation, Unpublished Data on High-G Solid Bowl Centrifuge Test Results. (Information received from Richard T. Moll, Manager of Process Engineering, Sharples-Stokes, Warminster, Pennsylvania, June 1982)

25. Schillinger, George R., "Conversion of Sludge - Conditioning Chemicals," Deeds & Data, WPCF Highlights, April 1979.

26. Cassel, Alan F. and Johnson, Berinda P., "Evaluation of Dewatering Devices For Producing High-Solids Sludge Cake," USEPA - Municipal Environmental Research Laboratory, Cincinnati, Ohio 45268, EPA-600/2-79-123, August 1980.

27. Marx, C. J. and Keay, G. F. P., "Towards A Rational Sludge Disposal Policy For Johannesburg, "Presented at the Institute of Water Pollution Control Conference, Pretoria, South Africa, June 1980. (Author Keay is with City Engineer's Dept., Johannesburg, South Africa)

28. Ingersoll-Rand, "Lasta Filter Press Demonstration Detroit Metropolitan Wastewater Treatment Plant, July 16 - August 10, 1979 and August 20 - August 30, 1979, March 1980. (Information received from Wayne B. Gendron, Ingersoll-Rand, Nashua, New Hampshire)

29. Culp, G. L., "Handbook of Sludge Handling Processes - Cost and Performance," Garland STPM Press, New York, 1979.

30. Kupper Associates and Metcalf & Eddy, Inc., "Pilot Plant Dewatering Testing for the Recommended Land-Based Sludge Management Plan," Middlesex County Sewerage Authority, New Jersey, January 1979.

CHAPTER 5

CHEMICALS USED IN DEWATERING

5.1 Introduction

Inorganic chemicals, such as lime and ferric chloride, and organic polymers are typically used to condition a sludge prior to dewatering. These chemicals destabilize the surface charge on the sludge particles, and flocculate the sludge particles into a matrix which is more easily dewatered than the discrete particles, as discussed in Chapter 3. When comparing various conditioning chemicals, a number of factors must be evaluated in addition to performance and chemical costs. Among these factors are the volume/weight changes in the sludge, the difficulty of storing and handling the chemicals, chemical availability, and increased maintenance of the dewatering or subsequent sludge handling equipment due to the chemical(s) utilized.

This Chapter discusses, for the major conditioning chemicals, important considerations which the designer should recognize in addition to performance and cost. For additional information on chemical handling and feeding, references 1 and 2 should be consulted. Table 5-1 outlines the most common applications of conditioning chemicals for each dewatering process, and Table 5-2 presents typical dosages. For belt filter presses, vacuum filters and filter presses, the type of media used is also a factor which affects chemical dosages.

TABLE 5-1

CHEMICAL CONDITIONERS COMMONLY USED FOR
DIFFERENT DEWATERING PROCESSES

PROCESS	LIME*	FERRIC CHLORIDE*	POLYMER
Basket Centrifuge			C
Solid Bowl Centrifuge			C
Belt Filter Press			C
Vacuum Filter	C	C	C
Filter Press	C	C	P
Drying Beds			P
Sludge Lagoons		None Required	
Gravity/Low Pressure Devices			C

LEGEND:
C - Common Usage
P - Possible; Used in certain situations, but usage is not common
*Lime and ferric chloride are typically used together

TABLE 5-2

TYPICAL DOSAGES OF CHEMICAL CONDITIONERS FOR DIFFERENT DEWATERING PROCESSES[1]

Process/Chemical	Raw Primary g/kg (lb/ton)	Raw Primary & WAS g/kg (lb/ton)	Anaerobically Digested Primary & WAS g/kg (lb/ton)
Basket Centrifuge			
Polymer	0 - 2 (0-4)	0.5 - 2.5 (1-5)	1 - 3 (2-6)
Solid Bowl Centrifuge			
Polymer	1 - 2.5 (2-5)	2 - 5 (4-10)	3 - 5 (6-10)
Belt Filter Press			
Polymer	2 - 4 (4-8)	2 - 5 (4-10)	4 - 7.5 (8-15)
Vacuum filter			
Polymer[2]	2 - 5 (4-10)	3 - 6 (6-12)	--
Lime[3]	80 - 100 (160-200)	90 - 160 (180-320)	150 - 210 (300-420)
Ferric Chloride[3]	20 - 40 (40-80)	25 - 60 (50-120)	30 - 60 (60-120)
Filter Press			
Lime[3]	110 - 140 (220-280)	110 - 160 (220-320)	110 - 300 (220-600)
Ferric Chloride[3]	40 - 60 (80-120)	40 - 70 (80-140)	40 - 100 (80-200)

1. These typical dosages correspond to the typical recoveries shown in Table 6-3. Polymer requirements are for dry polymer and lime requirements are for lime as CaO.

2. Polymer can sometimes be substituted for lime and ferric chloride in conditioning raw sludges for vacuum filtration.

3. Lime and ferric chloride are typically used together at these dosages.

5.2 Ferric Chloride

Ferric chloride addition to sludge results in the formation of positively charged iron complexes which neutralize the negatively charged sludge particles. Reaction also occurs between alkalinity and ferric chloride, resulting in insoluble ferric hydroxide, which acts to flocculate the destabilized sludge particles.

Ferric chloride may be purchased as a liquid or solid, although most utilities purchase it in the liquid form. The liquid form is generally 20 to 45% ferric chloride and contains 12 to 17% iron by weight. Ferric chloride solutions are generally fed at the concentration received from the supplier, as dilution can lead to hydrolysis reactions and the precipitation of ferric hydroxide. An important consideration in the use of ferric chloride is its corrosive nature. Special materials must be utilized in handling, with the recommended materials being: epoxy, rubber, ceramic, Hypalon, PVC, vinyl, synthetic resins, and Penton. Contact with skin and eyes must be avoided. Rubber gloves, goggles or a face shield, and a rubber apron must be used when handling ferric chloride. Spillage should also be prevented, as staining of concrete and other surfaces will result. The corrosiveness and the staining capability make solution feed and measurement somewhat more difficult than with other chemicals, but specialized equipment constructed of acceptable materials is available.

Ferric chloride can be stored for long periods without deterioration. Customarily, it is stored in above ground tanks constructed of resistant plastic or in lined steel tanks. An important consideration is the potential for crystallization at low temperatures, which generally leads to locating tanks indoors, or using tank heaters and insulation. The crystallization temperature varies with the concentration of ferric chloride in the solution, as shown in Table 5-3.

TABLE 5-3

CRYSTALLIZATION TEMPERATURES FOR FERRIC CHLORIDE SOLUTIONS

Solution Strength % $FeCl_3$	Freezing Temperature of an Unagitated Solution	
	°F	°C
20	-5	-21
25	-25	-32
30	-50	-46
35	-40	-40
40	-10	-23
45	+30	-1

Interestingly, the lowest freezing points fall in the concentration range of 30 to 35% $FeCl_3$, and higher freezing points occur at both more dilute and more concentrated solutions.

Ferric chloride is most commonly used in conjunction with lime in vacuum filter and filter press installations.

5.3 Lime

Two types of dry lime are customarily used in sludge treatment: pebble lime (CaO), also called quicklime, and hydrated lime ($Ca(OH)_2$). Quicklime is less expensive to purchase and is generally used in larger facilities. It does require slaking (addition of water to produce calcium hydroxide) prior to use. Hydrated lime is the more costly form of lime, but is commonly used in smaller facilities due to its convenience.

Lime should have a minimum CaO content of 88 to 90% in order to be acceptable. Dolomitic limestone containing magnesium carbonate is often unacceptable, because it does not have this CaO content.

When lime as calcium hydroxide is added to sludge, the calcium hydroxide reacts with calcium bicarbonate to form calcium carbonate ($CaCO_3$), which is insoluble. The high pH conditions are conducive to release of ammonia from digested sludge. The use of lime as a conditioning agent for sludge can accomplish the following:

- Increase sludge porosity
- Decrease sludge matrix compressibility
- Dehydrate (to a degree) sludge solids
- Raise pH
- Help control odor formation
- Provide disinfection
- Flocculate fine solids

The extent that each of these is accomplished depends on the lime dose. Lime is most frequently utilized for conditioning prior to a vacuum filter or a filter press. Most commonly it is used in conjunction with ferric chloride.

Either form of lime can be purchased in bulk form or in bags. Typically, quicklime is purchased in bulk and hydrated lime is purchased in bags. If purchased in bags, a waterproof building should be used for storage, with the maximum storage time generally restricted to less than 60 days. If bags of quicklime are allowed to become wet, slaking will start within the bag, and the resultant heating and swelling may cause the bags to burst. If stored in bulk, the storage hoppers should be both water tight and air tight. Lime is not corrosive to steel or concrete, and either can be used as a storage bin. The bottom slope on the bin should be about 60° from horizontal, and bin agitators may be necessary for bulk hydrated lime storage.

5.4 Polymers

Polymers are popular for sludge conditioning because they are generally easy to handle, store, and feed, and create little additional volume of sludge solids. Polymers may be purchased in the dry form, as emulsions, or as liquids, with the latter being the most expensive (when comparing active ingredients) because significant quantities of water must be transported along with the polymer. If purchased in the dry form, polymers must be thoroughly mixed with water according to manufacturer's recommendations prior to use.

The most common form of polymer for sludge conditioning is the cationic polymer. These polymers react with the negatively charged sludge particles, destabilize them and agglomerate the particles by forming bridges among them.

Anionic and nonionic polymers are also useful in conditioning, but they are generally used in conjunction with inorganic conditioning agents. In this role, the polymer is responsible for agglomeration of sludge particles which have already been destabilized by the inorganic agent.

Polymers are most frequently utilized in belt filter press, centrifuge, and occasionally vacuum filter and drying bed applications. There continues to be research into the use of polymers in filter press applications. Key advantages of polymers is the low dosages required, compared to inorganic chemicals, and the insignificant amount of dry solids added by polymer conditioning.

5.5 Waste Pickle Liquor (Ferrous Chloride)

Waste pickle liquor, a by-product of steel processing operations, is available in some parts of the country which are near such operations. To oxidize the ferrous iron to ferric iron, chlorine must be added to the waste pickle liquor. The oxidized pickle liquor is then suitable as a replacement for ferric chloride in conditioning applications.

Waste pickle liquor contains 20 to 25% ferrous chloride, and generally weighs between 1.19 and 1.25 kg/l (9.9 and 10.4 lb/gal). As a result of its production, free acid is present at a concentration of about 2% by weight.

Continuous availability of waste pickle liquor is a factor which should be considered. Often, provisions are made for storage and feed of ferric chloride when waste pickle liquor is unavailable.

5.6 References

1. Heim, Nancy E., and Burris, Bruce E., "Chemical Aids Manual for Wastewater Treatment Facilities," USEPA - Office of Water Program Operations, Washington, D.C., 20460, MO-25, EPA-430/9-79-018, December 1979.

2. "Process Design Manual for Sludge Treatment and Disposal," USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-625/1-79/011, September 1979.

CHAPTER 6

STRATEGY FOR DEWATERING PROCESS SELECTION

6.1 Introduction

The most important factor which must be kept in mind when either evaluating or selecting a dewatering process is the inherent influence that both the prior treatment processes and subsequent disposal practices have. A dewatering process can not be evaluated independently without consideration of the other processes involved in the overall solids handling system. Selection of a dewatering process requires evaluation of the complete solids handling system. This can be a complex procedure because of the vast number of combinations of unit processes which are available for thickening, stabilization, conditioning, dewatering, and ultimate disposal. Figure 6-1 presents a general schematic of a typical solids handling system and the unit processes which are most commonly utilized to perform each of these functions.

The strategy involved in selection of a dewatering process at either new or existing plants involves five stages of analysis, as shown in Figure 6-2. The stages represent a screening procedure in which dewatering processes under consideration are given increasing scrutiny as more detailed cost, operational, and design data are collected. The components of each of these stages are:

Stage 1 - Initial Screening of Dewatering Processes

A large number of factors are reviewed to determine if any processes can be eliminated prior to the intial cost analysis. Factors to be considered in the initial screening include: compatibility with plant size and existing facilities, including type and quantities of sludge produced; compatibility with the planned or existing ultimate disposal technique; compatibility with labor availability, degree of conditioning required, and land availability; environmental considerations; and field experience with equipment or processes at other operating installations.

Stage 2 - Initial Cost Evaluation

Based on the best estimates of design and operational criteria for the potentially feasible dewatering processes, an initial cost evaluation should be conducted. In many cases, 10 to 20 complete solids handling alternatives, which may include four or five different dewatering processes, are evaluated in this initial stage. Generally, three to five of the lowest cost alternatives are selected for more detailed evaluation.

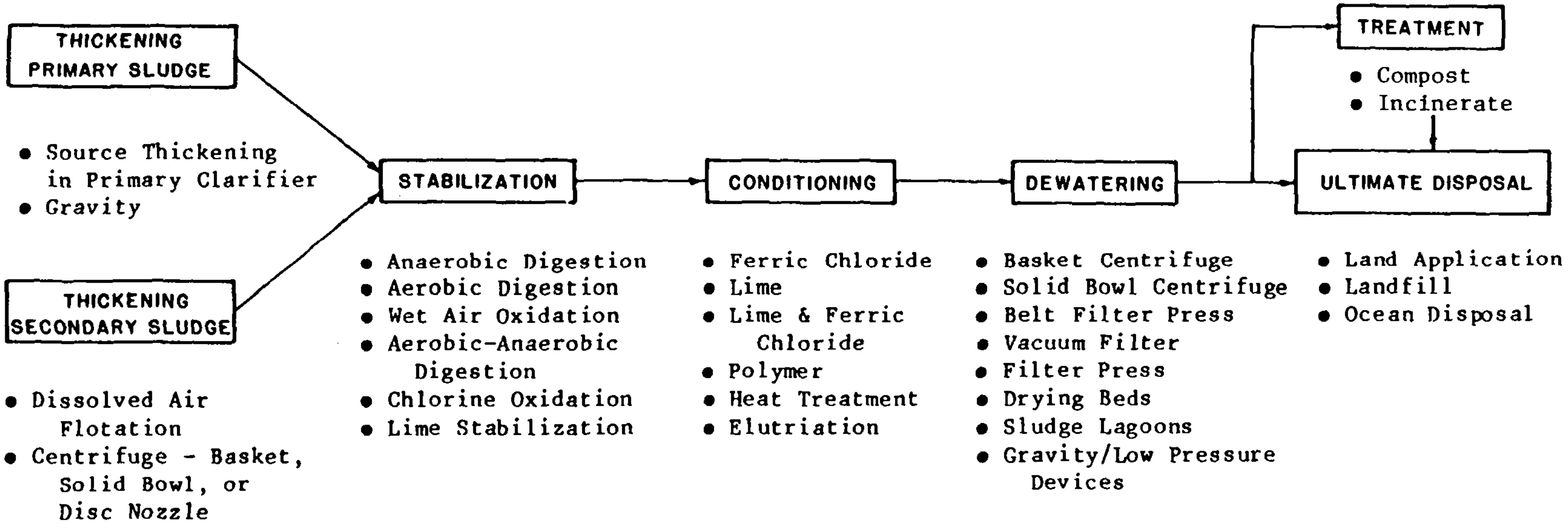


FIGURE 6-1

GENERAL SCHEMATIC FOR SOLIDS HANDLING SHOWING MOST COMMONLY USED METHODS OF TREATMENT AND DISPOSAL

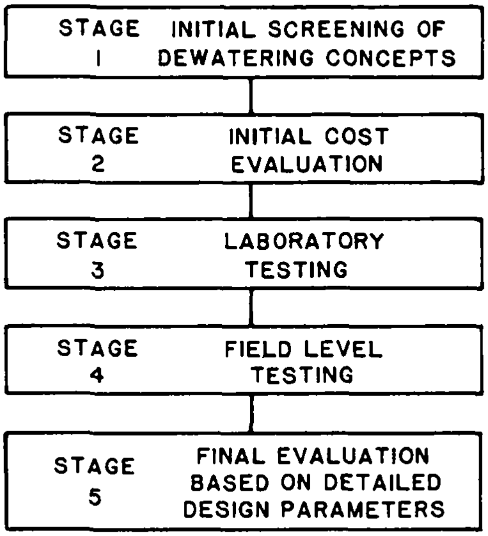


Figure 6-2. Five Stages of Analysis in Selection of a Dewatering Process

Stage 3 - Laboratory Testing

Laboratory testing should be conducted on the dewatering processes selected in Stage 2 to further define design criteria for the more favorable dewatering techniques. This laboratory testing may be conducted at the plant or by equipment manufacturers in their laboratories.

Stage 4 - Field Testing

After Stage 3, two or three dewatering techniques may remain. The objective of Stage 4 is to conduct on-site testing of the pilot-scale or full-scale equipment required for each process. This testing further defines equipment design parameters; chemical, labor and energy requirements; and potential O&M problem areas. Since there are a number of manufacturers who supply equipment for the same dewatering process, it may also be desirable to evaluate equipment from more than one equipment manufacturer in Stage 4. The need and justification for field testing depends in part upon the size of the treatment plant in question. At very small plants with a capacity of less than 0.04 cu m/s (1 mgd), it may not be cost-effective to conduct pilot-scale or full-scale testing. Instead laboratory or bench-scale testing by the manufacturer may be adequate.

Stage 5 - Final Evaluation Based on Detailed Design Parameters

After Stage 4 is completed, accurate scale-up and sizing of equipment is performed by the design engineer, with the aid of the equipment manufacturer; and more refined estimates can be made of the capital cost, labor, energy, chemical, and maintenance material requirements for the dewatering process under consideration. This information can also be supplemented with information from other plants using the same process. Additionally, judgements can be made by the operating utility based on performance and operational problems experienced in Stage 4. Based upon more accurate capital and operation and maintenance cost information, a final cost evaluation can be made in conjunction with an evaluation of other parameters. The net result of Stage 5 is the selection of a dewatering process to be used and in many cases the preferred manufacturer.

Throughout this five stage process, decisions based on trade-offs will continually be made. In many cases, the total annual cost of two or more solids treatment systems are nearly identical, and the decision must be made on some basis other than cost. Frequently such a decision is based upon capital cost vs. O&M cost considerations, ease of equipment operation, energy requirements, performance, or other factors. A significant point to keep in mind is that often the decision is not clear cut.

It is important to realize that the overall complexity of analysis will vary depending on the size of the plant and whether or not a new solids handling system is being designed or an old one upgraded. If the solids handling system is all new, there will probably be few constraints on processes to be evaluated, conditioning method to be used, and ultimate disposal techniques to be considered. In other situations, if the entire treatment facility is new, or if it is being upgraded from primary to secondary, sludge of the correct composition will not be available for conduct of field tests. Relative to plant size, Stage 4 is generally not conducted for most small capacity plants, those less than 0.04 cu m/s (1 mgd). For the small plant, it is usually more economical to design facilities based on laboratory or bench-scale testing, often performed by the manufacturer of the equipment, than it is to conduct the field-scale testing.

The following sections discuss in detail, the five stages required in the analysis:

6.2 Stage 1 - Initial Screening of Dewatering Processes

The purpose of the initial screening is to eliminate early in the analysis processes which are not acceptable for any of a variety of reasons. Factors to be considered in the initial screening include:

- Compatibility with existing facilities
- Compatibility with size of plant
- Compatibility with ultimate disposal technique(s)
- Influence of secondary treatment and prior sludge treatment
- Conditioning requirements
- Solids capture during dewatering
- Labor requirements
- Environmental considerations
- Long term utility
- Plant location
- Experience at other operating installations
- Bias by individuals or agencies

6.2.1 Compatibility With Existing Facilities

Existing facilities which must be considered in evaluating dewatering processes include:

- Type of dewatering equipment presently utilized, and its compatibility with future requirements
- Existing conditioning chemical storage and feed facilities
- Existing building used for dewatering and ancillary equipment
- Existing site constraints
- Existing sludge transport facilities

Considerations which relate to existing facility requirements are now discussed.

6.2.1.1 Existing Dewatering Equipment

Existing dewatering equipment customarily plays a major role in the selection of additional equipment, particularly if space is available and has been planned for expansion of the present dewatering facilities. If existing equipment is providing satisfactory performance (from both a cost and operational standpoint) for the plant staff, and if the product cake is suitable for the ultimate disposal technique which is being used, in all likelihood the same dewatering process would be desired in the expansion. This would be particularly true if the dewatering facilities had been designed to accomodate more equipment of the same type. In perhaps the majority of situations, existing equipment is providing unsatisfactory performance and requires more chemicals or energy than originally anticipated. In other cases the sludge characteristics have adversely changed since design, and the original equipment can not be operated at the original design capacity. In some cases existing equipment can not perform as well or as efficiently as some of the newer equipment available, or the cake produced by existing equipment is not suitable for the future ultimate disposal technique.

In a large percentage of the cases involving expansion of dewatering facilities, the plant staff is dissatisfied with the operation of the existing equipment. Typical situations are: (1) vacuum filter installations where lime coating of the filter media, filter drum, and filtrate piping presents an expensive and continuing maintenance problem; (2) filter press installations that often have chemical requirements substantially higher than originally expected; (3) older existing solid bowl centrifuge installations where a great deal of scroll maintenance is required due to abrasive wear and/or where the operating performance is poor; and (4) drying beds or lagoons where odors, the visual impacts, intensive labor requirements or difficulty with sludge removal make the process an operations problem for the plant staff. These situations and other possible situations not described here can cause headaches for the operation and maintenance staffs and can decrease effective dewatering capacity and increase operating costs when equipment must be taken out of service for repairs and/or cleaning.

Variation in sludge characteristics after design and installation of equipment, and therefore variation in the ability of the sludge to be dewatered, presents a particularly vexing problem. Invariably, this leads to higher conditioning and energy requirements than originally projected, and in some cases the inability to produce a dewatered cake suitable for ultimate disposal. In some instances, equipment may need to be operated at less than design capacity due to changed sludge characteristics. Evaluation should be conducted to determine the likelihood and severity of changes in sludge feed rate and characteristics. If significant variations are anticipated, equipment which is less sensitive to such changes should be selected.

6.2.1.2 Existing Conditioning Chemical Storage and Feed Facilities

Most plant staffs have a preference for the types of chemicals which they desire to handle, and a bias against ones which they dislike to handle. Assuming that conditioning chemicals presently utilized are acceptable to the plant staff, this would give an added preference to dewatering processes which utilize the same chemicals. Another factor is the cost and availability of storage and feed facilities. It is important to assess the unused capacity of both storage and feed facilities. If unused capacity is available, this must be considered in process selection, particularly in the Stage 2 cost analysis.

6.2.1.3 Existing Building Used for Dewatering Equipment

As discussed previously, often space has been planned and constructed for the same type of equipment as that presently used. This is an important factor to consider.

Also to be considered is the present building's structural capacity for modern heavyweight equipment, and whether the building has sufficient height for the equipment being considered. Dewatering equipment like solid bowl centrifuges, belt filter presses, and filter presses frequently discharge dewatered solids downward. This requires elevated mounting to allow for conveyor belts under the equipment and can be incompatible with low roof buildings.

Building structural capacity also must be analyzed. Heavy equipment such as a filter press may not be compatible with a building originally designed for a centrifuge installation, even though both have bottom discharge of cake solids. Basket centrifuges require greater structural support than solid bowl centrifuges. In the case where there is an existing overhead crane, heavy equipment may exceed the allowable capacity, and lighter equipment should perhaps be considered.

An important factor which the designer must continually keep in mind, even if a new method of dewatering is selected, is the usefulness of the existing facilities. In many cases, the new dewatering process will only be used to supplement existing facilities. In other situations, because of a change in the ultimate disposal technique or because of generally unsatisfactory operation, the new facilities will replace existing facilities. When this occurs, rather than removing existing facilities, strong consideration must be given to their use as standby or backup facilities to the new facilities. Often they can be used on a short-term basis in this role even if they do not produce a sufficiently dry cake for the disposal technique used.

Equipment previously used for dewatering is occasionally converted to sludge thickening prior to anaerobic digestion. This may be especially advantageous if anaerobic digester capacity is lacking and expansion of the digester capacity is being considered. Examples include use of centrifuges to thicken WAS prior to digestion, or use of any dewatering device to dewater a portion of the sludge and then blend the dewatered cake with the dilute feed sludge to produce a thickened sludge. An economic analysis should be conducted prior to such use, as chemical and energy requirements may be significantly greater than alternative techniques. Solids capture efficiency must also be considered in such conversions.

6.2.1.4 Existing Site Constraints

Drying beds and sludge lagoons both require considerable land area. Expanded use of these processes may not be practical if land is unavailable, or if environmental constraints make continued use unacceptable. However, often the existing beds or lagoons can be used in conjunction with a different dewatering process.

6.2.1.5 Existing Sludge Transport Facilities

This consideration would probably relate only to a decision of whether or not to dewater. For example, if a considerable investment had previously been made in trucks or a pipeline and pumping facilities for liquid sludge transport, the decision may be made not to dewater. Another possibility could be to dewater at a site remote from the treatment facility if liquid transport facilities are available. Although these decisions are generally made on the basis of cost, their recognition during the initial screening may save substantial time in the decision making process.

6.2.2 Compatibility With Size of Plant

Use of uncomplicated sludge handling systems increases the chances for successful operation in any size plant. Complex equipment is especially unsuited for small plants for several reasons. First, the amount of operator time available generally decreases as plant size decreases. Second, the overall skill of both operations and maintenance personnel is not as great at small plants. Third, less complex equipment is generally less expensive to purchase, and since little economy of scale occurs for small plants, this is of particular benefit.

The choice of the dewatering process to be used is customarily left up to the designer and owner. No specific rules exist for which processes should be used for a particular size of installation. However, certain guidelines do exist based on results experienced at plants across the U.S. These guidelines are summarized in Table 6-1, which presents a matrix showing compatibility of different dewatering techniques with various plant sizes.

Designers should only use the information presented in Table 6-1 as a guide. Every situation must be considered independently, as location specific considerations can have a large influence on the dewatering process. For example, drying beds and sludge lagoons may be cost-effective at a plant larger than 0.44 cu m/s (10 mgd) if weather is favorable and land is available at reasonable cost. Other variations may occur, when more than one type of dewatering is used at a plant, or where a plant is a regional solids handling center, and solids treatment capacity is in excess of liquid treatment capacity.

TABLE 6-1

COMPATIBILITY OF DEWATERING EQUIPMENT WITH PLANT SIZE

	<0.04 cu m/s (<1 MGD)	0.04-0.44 cu m/s (1 - 10 MGD)	>0.44 cu m/s (>10 MGD)
Basket Centrifuge		X	X
Solid Bowl Centrifuge		X	X
Belt Filter Press	X[1]	X	X
Vacuum Filter		X	X
Filter Press		X	X
Drying Beds	X	X	
Sludge Lagoons	X	X	

[1] Only low pressure press is commonly used in this range

6.2.3 Compatibility With Ultimate Disposal Technique

This is the most important factor in the screening process. Careful attention must be paid to the methods of ultimate disposal available, and the solids content required for disposal by them. A potentially costly situation which should be avoided is for the dewatering process to remove more water than necessary for the selected or available disposal technique.

Table 6-2 presents general guidelines for the compatibility of the principal ultimate disposal techniques with the seven principal methods of dewatering. Similar to the information presented in Table 6-1, the information in Table 6-2 must be evaluated on a case-by-case basis. There are undoubtedly exceptions to these general guidelines, and it is not intended that the designer completely eliminate from consideration any process which does not fit the guidelines.

TABLE 6-2

DEWATERING PROCESS COMPATIBILITY WITH SUBSEQUENT TREATMENT OR ULTIMATE DISPOSAL TECHNIQUES

Dewatering Process	Incineration[1]	Composting	Agricultural Land Application	Landfill[2]
Basket Centrifuge			X	X
Solid Bowl Centrifuge	X	X[3]	X	X
Belt Filter Press	X	X[3]	X	X
Vacuum Filter	X	X[3]	X[4]	X
Filter Press	X	X	X[4]	X
Drying Bed		X	X	X
Sludge Lagoon			X	X

1. Solids content required for self-sustaining combustion will vary depending upon the percent of solids that are organic and the calorific value of the organics.

2. Some states and municipalities have rigid requirements on the solids content of sludges placed in landfills. Local regulations should be checked by the designer.

3. Suitability of this method depends on organic content of sludge. Thermodynamics of composting must be evaluated. (For more information see references 1, 2, and 3.) Generally, sludges with 20% or greater solids content can be composted, depending on the degree of prior stabilization and weather conditions.

4. Soil characteristics are important. For some alkaline soils (i.e. some calcareous soils), land application may not be desirable because of lime in the dewatered sludge cake. For soils with a high sodium content, however, addition of calcium can beneficially increase the calcium/sodium ratio and result in improved tilth. There are very few soils where a problem would be anticipated due to application of sludge cake. Advice of agriculturists is recommended.

It should be recognized, however, that just because a dewatering process is compatible, it may not be the most cost-effective technique. For example, use of a filter press is compatible with landfilling, but a belt filter press would in most cases represent a more cost-effective method of dewatering prior to landfilling.

Designers should remember that the objective of dewatering is only to remove sufficient water to produce a sludge compatible with the selected disposal technique. Removal of additional water is not cost-effective and may require the unnecessary expenditure of energy and chemicals.

Table 6-2 indicates that only the filter press, solid bowl centrifuge, belt filter press, and vacuum filter are compatible with incineration. It is frequently concluded that only a filter press can produce a dewatered cake compatible with incineration. This conclusion is based upon the criteria that only an autogeneous or nearly autogenous sludge should be incinerated. However, in some instances where digestion is not used or where the sludge is thermally conditioned, nearly autogenous cakes can be produced by belt filter presses, solid bowl centrifuges, and vacuum filters. This is particularly true if only raw primary sludge is being dewatered.

6.2.4 Influence of Secondary Treatment and Prior Sludge Treatment

6.2.4.1 Secondary Treatment

The influence of the type of secondary treatment on the sludge produced and its dewaterability was reviewed in Chapter 4. The most important conclusion reached was that both trickling filter (TF) and rotating biological contactor (RBC) sludges dewater better than waste activated sludge (WAS). This is true whether sludges are raw or digested. The difference between the TF/RBC sludges and WAS is due to the nature of the biological growth. The TF and RBC sludges are from attached growth biological systems which produce dense, easily settleable sludge solids. The WAS is from a suspended growth system, in which the sludge is dispersed in nature, with large amounts of water contained between dispersed sludge particles. The nature of the WAS is also strongly dependent upon the process variation of the activated sludge process which is utilized. High rate systems using high food to microorganism ratios (F/M >0.4) produce quantities (by weight) of biomass which are greater than the conventional activated sludge process (F/M of 0.2 - 0.4), and this biomass is particularly difficult to dewater due to the large quantities of intercellular water. Problems have also been experienced at plants using the extended aeration modification of the activated sludge process (F/M < 0.15), because of the pin-point, discrete nature of the biological floc.

6.2.4.2 Prior Sludge Treatment

Prior sludge treatment by thickening, digestion or storage will affect the ease of dewaterability. Thickening, generally used before digestion to reduce digester capacity, produces beneficial results due to a higher solids content feed to the dewatering process. Conversely, both digestion and storage are usually detrimental to the ease of dewatering.

Vacuum filters generally have a requirement for the feed sludge total solids concentration to be at least 3.0 percent. If the feed sludge is more dilute than this, it becomes difficult to form a cake on the filter that is thick enough or dry enough for adequate discharge. For this reason the role of the preceding sludge handling processes is an especially important one.

The major benefit associated with feeding a thickened sludge to mechanical dewatering processes is the higher solids throughput obtainable. This can reduce the number of machines required and the overall space requirements. All dewatering devices are to some extent hydraulically limited because the hydraulic capacity is exceeded before the solids capacity. The belt filter presses offered by several manufacturers have a larger or separate gravity drainage zone which allows them to be loaded with either a wetter feed sludge or a higher solids loading rate. For these machines the gravity drainage zone actually thickens the sludge to at least 6 percent solids, and it is doubtful that prethickening would substantially reduce the number of machines required, unless the feed solids are below about 2 percent. For a filter press, a thicker feed sludge reduces the fill time and overall cycle time because there is less water to force through the cake and filter media, and therefore the total required filter area is reduced.

Another benefit of a thicker feed sludge is a reduction in the chemical requirements for conditioning. Although there may be an increase in solids loading rates and some reduction in chemical requirements, there generally will not be a major increase in cake solids achievable, especially for a centrifuge, a belt press, or a filter press. One mechanical dewatering device which may show a significant increase in cake solids content due to higher sludge feed concentrations is a vacuum filter.

Although it is not a common problem, it is possible to have a feed sludge for dewatering which is too thick to be easily handled. A suggested maximum feed solids concentration of 7 to 8% is recommended for dewatering equipment. Solids contents higher than 8% will tend to make the sludge difficult to transfer to the dewatering unit.

Anaerobic digestion generally degrades the dewaterability of raw sludge because of fines produced by the process. This fine material is hard to dewater due to its large surface area, its difficulty in being flocculated during conditioning, and its compressibility during dewatering. This overall difficulty often further results in poor capture of the fines during dewatering, and recycle of fine material to the plant liquid handling processes. The best solution for the problem of fine material produced during digestion is adequate conditioning prior to dewatering. Because the mass of solids is reduced by anaerobic digestion, the actual number of dewatering devices required may be less. In addition to the problem of fine material, anaerobic digestion also creates alkalinity during the breakdown of organic matter. This alkalinity reacts with ferric chloride, ferrous sulfate, and lime if they are used for conditioning, with a resultant increase in the quantity of conditioning chemical(s) required.

Storage of sludge prior to dewatering generally is detrimental to dewaterability. Storage may be necessary, however, to equalize the rate of sludge feed to the dewatering process.

6.2.5 Conditioning Requirements

Conditioning before dewatering can be by thermal treatment or by chemical addition. Chemical conditioning is much more common than thermal conditioning, but thermal treatment has the advantage of substantially improving the dewaterability of a sludge without requiring the addition of chemicals. At existing thermal conditioning facilities, plant operating personnel may be dissatisified due to problems with complexity, odor generation, and the high-strength recycle stream produced. Additionally, thermal treatment facilities installed before 1973, when fuel and electricity prices began to rapidly escalate, may not be justified on a cost-effective basis at current fuel prices. These costs should be reevaluated when expansion plans are formulated.

As discussed relative to existing facilities, preference by plant personnel for specific chemicals, as well as the availability of storage and feed facilities for certain chemicals, are important considerations. Other factors which need to be considered are availability and cost of chemicals. If the conditioning chemical(s) is readily available, on-site storage times can be reduced and a savings will result in storage facility costs. Chemical cost is also a factor and it will vary from location to location, depending upon its source. The impact of these costs will become evident during the cost comparison (Stage 2 of the evaluation procedure), but it is important that they be recognized during the initial screening phase also.

6.2.6 Solids Capture During Dewatering

Incomplete capture of solids during dewatering, with recycle of these solids to the plant headworks, will generally not create a problem if solids capture exceeds 90% and plant effluent suspended solids (SS) limits are 30 mg/l. When effluent SS limits are 20 mg/l or 10 mg/l, often times 95% solids capture may be necessary to allow the plant to meet effluent discharge limitations.

Solids loss during dewatering generally occurs by two mechanisms: (1) solids passage through the filtering media, or with centrifuges, solids lost in the centrate, and (2) incomplete separation of solids from the media and the need to spray wash the media prior to the next application of sludge.

The percentage of solids captured is highly variable and depends upon the type of sludge being dewatered (particularly the percentage of waste activated sludge), whether the sludge has been stabilized or not, the type and amount of conditioning chemicals utilized, the type of equipment used for dewatering, and the desired percent solids in the dewatered sludge. Table 6-3 lists typical ranges of solids capture exhibited by dewatering processes. The solids concentrations of liquid sidestreams from dewatering processes (such as centrate, filtrate, and percolated liquid) are inversely proportional to percent solids capture. For detailed information on the characteristics of these liquid sidestreams, see Reference 3.

TABLE 6-3

TYPICAL SOLIDS CAPTURE OF DEWATERING PROCESSES

Process	Typical Solids Capture %
Basket Centrifuge	80 - 98
Solid Bowl Centrifuge	90 - 98
Belt Filter Press	85 - 95
Vacuum Filter	88 - 95
Filter Press	>98
Drying Beds	>99
Sludge Lagoons	>99
Gravity/Low Pressure Devices	88 - 95

Note: Solids captures shown are for properly operated dewatering systems with well conditioned sludge. With improper operation, solids capture as low as 50% has been noted for some processes.

The centrifugation process relies on centrifugal settling of solids; because of this, centrifuges classify the solids, settling the heavier solids first. Other dewatering processes which rely on filtration in general achieve more even distribution of solids captured. Because of this difference in operation, it is possible for a buildup of fines to occur in treatment plants using centrifuges, if the centrifuge is operating improperly due to inadequate conditioning or due to a malfunction.

6.2.7 Labor Requirements

Two labor factors are important in evaluating dewatering processes: the amount of labor required and the skill of labor required. Both the amount and skill of labor required typically increase as the plant size increases. At small plants, operators generally have little time available for operation or maintenance of complex pieces of equipment. They also often have no desire to attempt proper operation of a complex mechanical dewatering device.

Generally drying beds, lagoons, or low pressure belt presses are best suited to small facilities. Little time or skill is required for drying beds or lagoons. Low pressure belt press/gravity drainage processes require rather large polymer dosages to achieve dewatering, but they are relatively easy to operate and maintain.

6.2.8 Environmental Considerations

Environmental factors should be considered in the initial screening process. The key considerations which relate specifically to the dewatering process include:

- Energy Requirements
- Noise
- Vibration
- Odor Potential
- Aesthetics (visual impact)
- Groundwater Contamination

An evaluation of each of these environmental considerations is presented in Table 6-4 for the principal dewatering processes, and they are further discussed in the following sections.

6.2.8.1 Energy Requirements

Energy requirements for mechanical dewatering equipment are moderate to high, with the exception of belt presses and other low pressure or gravity drainage type devices, which have relatively low energy requirements. Generally, the requirement for energy is proportional to the degree of dryness required in the cake. To some extent, energy utilization can be reduced by increasing the level of conditioning, but this would generally not be cost-effective. Conditioning chemical dosage adjustment would usually only be made to increase machine capacity, increase solids capture, or aid in cake removal from the dewatering equipment. Drying beds and sludge lagoons require energy only for pumping sludge to the beds or lagoons and for the equipment used to remove dewatered sludge from the beds or lagoons. Energy requirements for these solar processes are low in relation to that needed by mechanical dewatering equipment.

Energy requirements for the dewatering equipment can not be considered without also taking into account the energy and costs required for subsequent transportation and disposal of the dewatered sludge. Often dewatering to 20 to 25% cake solids and hauling at this solids content is more cost-effective and less energy consuming than the alternative of dewatering to 35 to 45% solids and incinerating. Naturally it is environmentally desirable to always utilize the overall lowest energy consuming processes for treatment, transportation and

TABLE 6-4

EVALUATION OF ENVIRONMENTAL CONSIDERATIONS OF DEWATERING PROCESSES

Process	ENVIRONMENTAL CONCERN					
	Energy Requirement	Noise	Vibration	Odor Potential*	Visual Impact	Potential For Groundwater Contamination
Basket Centrifuge	High	Moderate	High	Low	None	None
Solid Bowl Centrifuge	Moderate to High	Moderate to High	High	Low	None	None
Belt Filter Press	Low	Low	Low	Moderate	None	None
Vacuum Filter	Moderate to High	Moderate	Low	Moderate	None	None
Filter Press	Moderate to High	Moderate	Low	Moderate	None	None
Drying Beds	Low**	None***	None	High	High	High
Sludge Lagoons	Low**	None***	None	High	High	High

*Rating is based on dewatering a poorly stabilized sludge. If sludge is well stabilized, there should be no significant odor from any dewatering process.

**Energy required is electricity for sludge pumping and diesel fuel for equipment used to remove dewatered/dried sludge.

***Noise levels for drying beds and lagoons can be high during cleaning due to heavy equipment and "beep-type" signaling device required when operating in reverse.

ultimate disposal. Often, however, the alternative with the lowest overall cost for capital and operation and maintenance does not have the lowest energy consumption. In such a situation, different individuals or utilities reach different conclusions; some select the lower cost alternative while others select the higher cost alternative which uses less energy.

A further discussion of energy requirements is presented in Chapter 8 of this manual.

6.2.8.2 Noise

For equipment located indoors, noise is a consideration for plant operators, and for equipment located out of doors, noise is a consideration for both operators and neighbors to the treatment facility. The processes for which noise is a potential problem are basket centrifuges, solid bowl centrifuges, vacuum filters, and filter presses. High speed solid bowl centrifuges create more noise problems than the lower speed models. Noise resulting from vacuum filters and filter presses is primarily caused by vacuum pumps and high pressure hydraulic pumps, respectively. Often, vacuum pumps are located by the designer in another room away from vacuum filters, and this isolates vacuum filter noise problems.

6.2.8.3 Vibration

Only centrifuges create major vibration problems, and this is essentially a design consideration since with proper use of vibration isolators, the vibrations caused during normal centrifuge operation can be effectively dampened. Vibration can also be an indication of inadequate maintenance or the need for maintenance. These are factors which should be considered relative to the location of other equipment and operator's stations.

6.2.8.4 Odor Potential

Odor is a key concern relative to residential, commercial, and industrial neighbors of the treatment facility. It may also be of concern, depending on the design, for indoor installations which have poor ventilation. Another factor to consider is that operators may find the odor to be objectionable enough that they may prefer to stay away from the process, perhaps creating operation and/or maintenance problems. The kinds of odor which may present problems are hydrogen sulfide, mercaptans, indole, skatole, and ammonia. Ammonia is often released when the sludge pH is raised by the addition of lime for sludge conditioning.

Drying beds and sludge lagoons present the highest odor potential, but only if sludge has not been adequately stabilized before application to the beds or lagoons. If sludge is properly stabilized, only an earthy or musty odor will emanate from the beds or lagoons, and this odor is normally not offensive. During normal operation raw sludge or poorly stabilized sludge should not be placed on drying beds. On a temporary basis, raw sludge that has been raised to pH 12 by lime addition could be placed on drying beds.

For partially digested sludge, use of centrifuges will generally not create an odor problem, while use of vacuum filters, belt filter presses, and filter presses may create a moderate odor problem.

For lime conditioned sludges, a localized occasional odor problem may occur due to ammonia release. This is generally not a problem, although good ventilation should be provided to protect workers and to prevent corrosion of metal surfaces and electrical equipment.

6.2.8.5 Aesthetics (Visual Impact)

Depending on the plant location, lagoons and drying beds may create aesthetic problems. Landscaping around the plant perimeter as well as directly around the beds or lagoons will help, as will berms. Well chosen, isolated locations on the plant site, or perhaps locations in remote areas, may be most suitable for the beds or lagoons.

In mild climates, centrifuge installations may be outdoors. This should generally not create a visual problem, as centrifuges are visually compatible with other plant equipment.

6.2.8.6 Groundwater Contamination

Unlined lagoons or drying beds may allow downward percolation of water toward the groundwater. The quantity and quality of this percolate will depend upon how much the sludge has been previously thickened and the character of the soil. Clay and clay containing soils will allow passage of water at very low rates while filtering out solids. In general sand and gravel will allow downward passage at relatively high rates. Additionally, sludge lagoons often seal themselves to a certain extent, greatly reducing percolation. Drying bed underdrains also greatly reduce percolation, catching most of the percolating water so that it can be returned to the plant headworks for treatment. The quality of the percolating water will also change as it moves downward through the soil. The reactions which occur will depend on the type of soil, how long the soil has been used for this purpose, whether the soil is aerobic or anaerobic, and the depth to groundwater. Seasonal variations in groundwater levels may also create problems in certain areas and should be investigated prior to process selection.

Sealing of drying beds or the use of underdrains should be considered if tests indicate that groundwater contamination will be likely to occur. Drying bed bottoms are commonly sealed with concrete or asphalt, while lagoons are sealed most often with a compacted bentonite clay layer or an impermeable plastic membrane.

6.2.9 Long Term Utility

The appropriateness and cost-effectiveness of the dewatering process is closely linked with long-term consistency of sludge quality and the ultimate disposal method which is utilized. Evaluation of the long term utility of a dewatering process should involve consideration of these factors. For example, if the type of secondary treatment is changed from trickling filtration to activated sludge, the resultant sludge characteristics will change and this can affect the cost of dewatering and the overall appropriateness of the dewatering process being used. Another example would be the expansion of sand drying beds. Although such an expansion may be cost-effective at the present time, if the same land is required for future expansion of the liquid handling components of the treatment process, it may be preferable to select a different dewatering strategy rather than changing a few years later. Another example would be selection of a belt press, centrifuge, or vacuum filter for dewatering prior to landfill, when the landfill has only a few years of life remaining, and no other nearby landfill site is available; in such a case, it may be appropriate to consider a filter press, because of the probability of a long truck haul to a landfill or land application site. In addition, the lower volume of a filter press cake may help extend the life of the existing landfill. Considerations such as these are important in evaluation of the long term utility of a dewatering process.

6.2.10 Plant Location

Factors associated with plant location and the effect on dewatering process selection include:

- Land Availability
- Proximity To Ultimate Disposal Location
- Proximity To Developed Areas

6.2.10.1 Land Availability

Plant location can greatly influence land availability for plant expansion, for construction of land intensive dewatering processes such as drying beds and lagoons, and for providing a buffer zone around the plant. Land availability is a factor in expansion of an existing plant including its dewatering facilities. A plant in an isolated location is more likely to have room for expansion or for drying beds or lagoons than a plant located in a heavily populated area. Land availability can also be important to provide room for a buffer zone around a plant, to help control odor problems with close neighbors or to allow landscaping to visually shield the plant.

Available land does not have to be immediately adjacent to the plant in cases where a plant is located in a heavily populated area. Although not common, dewatering facilities can be located a distance from the main plant processes with liquid sludge transported by pipeline or truck to the location for dewatering.

6.2.10.2 Proximity To Ultimate Disposal Location

Dewatering options are closely tied to either an existing or a future ultimate disposal method. If a landfill or a site for composting or land application is located nearby, this can influence the selection of the dewatering process, since dewatering to a very dry cake such as that produced by a filter press may be unnecessary. However, if there is no ultimate disposal location nearby, dewatering by filter press for long distance hauling or for incineration may be cost-effective.

6.2.10.3 Proximity to Developed Areas

The proximity of the wastewater treatment plant to residential, commercial, or industrial development can limit the options available for dewatering. Sand drying beds and lagoons both have a potential for major odor problems. In addition, lagoons and drying beds can be visually unattractive and may require either landscaping around the perimeter or construction of berms.

6.2.11 Experience at Other Operating Installations

Experience at other operating installations with similar sludges is another important screening criterion. There are undoubtedly other wastewater treatment plants somewhere in the region which have had similar dewatering problems, and evaluation of their experiences can be invaluable. It is for this reason that Chapter 4 with the capabilities of dewatering processes and Chapter 9 with summaries of side-by-side comparisons were included in this manual. For drying beds or lagoons, nearby locations with similar weather are particularly good indicators of the type of performance which can be expected.

6.2.12 Bias by Individuals or Agencies

The plant owner, plant operators, and/or the enforcement agency may have preconceived biases for or against certain processes. The extent and rationale for such biases should be investigated by the designer. A decision should be made relative to the reasonableness of the bias and whether it should be used as a basis for eliminating a process from further consideration.

6.3 Stage 2 - Initial Cost Evaluation

The purpose of the initial cost evaluation is to develop budget level cost estimates for sludge treatment processes and techniques which remain after the initial screening process, and to eliminate techniques which are not remotely cost-effective. Importantly, this cost evaluation must include not only the dewatering process, but also the entire sludge handling system, which includes prior treatment processes and subsequent transport and ultimate disposal of the sludge cake. Because of the number of treatment, dewatering, transportation, and ultimate disposal processes available, up to 10 to 20 process combinations may be evaluated in the initial cost evaluation.

This initial cost evaluation uses budget level cost curves and cost data for development of total sludge treatment and disposal system costs. Generally, budget level cost estimates can be expected to be within ±15% of true cost, assuming appropriateness of the design parameters used to develop the costs. A number of references are available which present capital and O&M cost data for many sludge handling processes from which budget level costs can be developed (3-11). Construction cost and operation and maintenance cost curves for nine different dewatering processes are presented in Appendix C. The curves are based on April 1982 cost levels.

Equipment costs can also be obtained from equipment manufacturers and equipment suppliers. Often manufacturers do not have comprehensive data available on O&M requirements and can offer only general guidelines. Thus O&M requirements should be based on the above references, the Appendix C cost data, or the experience of the designer or manufacturer.

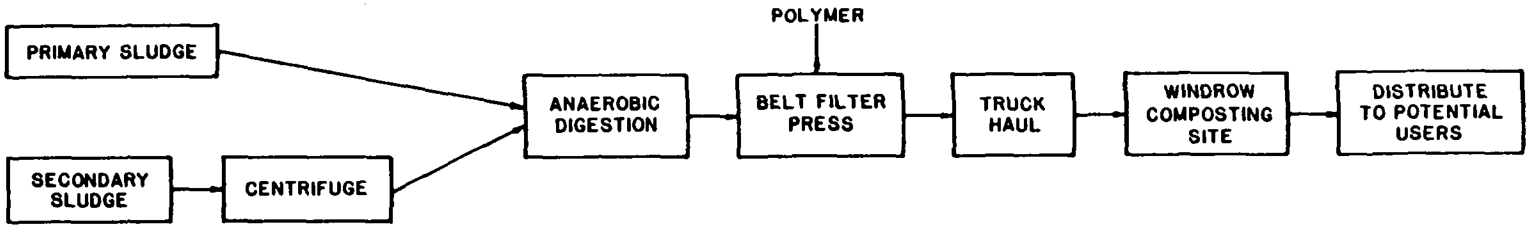
It is important that costs and O&M requirements presented in these or other references be updated to either the time of the subject cost analysis, or some future time, depending upon the requirements of the project. The simplest approach is to use a single composite index to update construction costs. The index most commonly used for this purpose is the Engineering News Record (ENR) Construction Cost Index (CCI). The ENR Construction Cost Index average for 20 cities was 348.64 in April 1982.

The initial cost evaluation should develop capital and O&M costs, and express the total cost in either total annual cost or present worth cost. The relative cost-effectiveness of alternatives is then evaluated by ranking the alternatives on the basis of either the total annual cost or the present worth cost.

An example cost evaluation, similar to one which should be conducted to develop budget level costs during the initial cost evaluation phase, has been prepared for one solids handling alternative for a 1.1 cu m/s (25 mgd) activated sludge plant operating at design capacity. A process flow diagram and design criteria for solids treatment and handling are shown on Figure 6-3.

For this example, a raw wastewater flow of 25 mgd has suspended solids and BOD_5 concentrations of 275 mg/l and 230 mg/l, respectively. Primary clarification removes 65% of the suspended solids and 35% of the BOD_5; the primary sludge has a 5% solids content with 65% of the solids being volatile. During

PROCESS FLOW DIAGRAM



DESIGN CRITERIA

Avg. Flow - 1.1 cu m/s (25 mgd)

Primary Sludge - 16,920 kg/d (37,300 lb/d)
338 cu m/d (89,400 gal/d) @ 5%

Secondary Sludge - 11,340 kg/d (25,000 lb/d)
1509 cu m/d (398,700 gal/d)
@ 0.75%

Centrifuge Output - 174 cu m/d (46,000 gal/d)
@ 6.5%

Anaerobic Digester - 20 day detention time
Single stage complete mix

Belt Filter Press
Feed = 18,200 kg/d (40,135 lb/d)
Feed Rate = 284 kg/hr/m (627 lb/hr/m)
Product @ 20% DWS = 119 cu yd/d
Polymer Usage = 6.5 g/kg (13 lb/ton) DWS

Truck Haul
Distance = 16.1 km (10 mi) - one way
Truck Capacity = 22.9 cu m (30 cu yd)

Compost Site
Windrow Technique
30 day active compost time
60 days on-site storage of composted material

FIGURE 6-3

PROCESS FLOW DIAGRAM AND DESIGN CRITERIA FOR A
SOLIDS HANDLING SYSTEM USING ANAEROBIC DIGESTION, BELT FILTER PRESS
DEWATERING, TRUCK HAUL AND COMPOSTING

biological treatment, the remaining 65% of BOD_5 is converted to cellular material: 0.8 pounds of cells are produced per pound of BOD_5 removed. WAS has a 0.75% solids content, and the solids are 80% volatile. It is thickened to a 6.5% solids content using a low-speed solid bowl centrifuge. During complete mix single-stage anaerobic digestion, 50% of the volatile solids are destroyed, resulting in a feed to the belt press of 18,200 kg/d (40,135 lb/d) at a rate of 284 kg/hr/m (627 lb/hr/m). Polymer is used to condition the sludge at a rate of 6.5 g/kg (13 lb/ton). The belt press cake of 20% solids is hauled in a 22.9 cu m (30 cu yd) truck to a remote composting location. Composting is by the windrow technique with frequent turning of the windrows, particularly in the early stages. Composting time is 30 days followed by 60 days on-site storage prior to stabilization. No income was included for sale of the compost product.

Installed, operating and standby equipment design capacities are shown in Table 6-5 for sludge handling processes. To develop construction costs and building energy requirements, installed capacity was used as the basis. Operating capacity was used as the basis for labor, energy, maintenance material and chemical requirements.

Capital and operation and maintenance costs for sludge handling operations in this example are shown in Table 6-5. Based upon the capital cost of $6,318,200, and an annual cost of $483,500/year, the total annual cost for sludge handling is $1,287,400/year. Development of construction cost and O&M requirements for the low-speed solid bowl centrifuge used for WAS thickening and the belt filter press used for digested sludge dewatering are based upon Appendix C, Figures C-4 to C-6 and C-10 to C-12, respectively. Other construction costs and O&M requirements were developed using references (3) through (11). Unit costs used for labor, electrical, digester gas, and diesel fuel are shown in Table 6-5.

Costs developed using this general approach will have an accuracy of ± 15% of the actual equipment cost, which is sufficient for this stage of the analysis. After determining costs for each of the different alternatives, about four or five of the lowest cost alternatives should be selected for more detailed scrutiny, and refinement of cost data by determining equipment loadings from laboratory and field scale testing. In many situations, more than one dewatering process would be included in the remaining four to five alternatives.

Naturally such cost estimates, although accurate to ±15%, must be based on conservative estimates of dewatering throughput rates at this stage of the analysis, since no laboratory or field testing on the actual sludge has yet been performed. It is possible that the facility may be overdesigned by as much as 50 to 100 percent in this initial cost evaluation. Designs tailored to the specific sludge require field and/or laboratory test data. This type of information is required before final cost estimates for the dewatering alternatives can be made.

TABLE 6-5
CAPITAL AND O&M COST ESTIMATES
SOLIDS HANDLING SYSTEM INCLUDING ANAEROBIC DIGESTION, BELT FILTER PRESS DEWATERING, TRUCK HAUL, AND COMPOSTING

PROCESS	EQUIPMENT DESIGN			CONSTRUCTION COST	LABOR	ELECTRICITY	NATURAL GAS	DIESEL FUEL	MAINTENANCE MATERIALS	CHEMICALS
	INSTALLED	OPERATING	STANDBY	$	hr/yr	kwh/yr	btu/yr	gal/yr	$/yr	$/yr
Centrifuge - Low G - gpm	420	280	140	705,000	2,600	770,000	--	--	15,000	--
Anaerobic Digestion - cu ft	362,000	362,000	--	2,062,000	4,000	1,150,000	(52,560X10^{6})*	--	9,000	--
Polymer Feed - lb/day	260	260	--	38,000	250	28,000	--	--	500	189,800**
Belt Filter Press - gpm	210	140	70	760,000	1,600	250,000	--	--	4,000	--
Truck Haul	1 Tractor 2 Trailers	1 Tractor 2 Trailers	-- --	110,000	2,900	--	--	19,500	8,800	
Compost Site & Required Equipment	--	--	--	838,000	2,000	--	--	17,500	12,000	--
TOTAL CONSTRUCTION COST				4,513,000	13,350	2,198,000	(52,560X10^{6})	37,000	49,300	189,800
Engineering, Contingencies, Contractors Overhead & Profit, Legal, Fiscal and Administrative, and Interest during Construction - 40%				1,805,200	$12/HR	$ 0.05/KWH	$\$1.30/10^{6}$BTU	$ 1.15/GAL	--	--
TOTAL CAPITAL COST				$6,318,200	$160,200/YR	$ 109,900/YR	($68,300/YR)	$42,600/YR	$49,300/YR	$189,800/YR

AMORTIZED CAPITAL COST = $ 803,900/YR***
TOTAL O&M COST = $ 483,500/YR

TOTAL ANNUAL COST = $1,287,400/YR

*This represents captured gas which is available after digester heating.
**Polymer cost is $2.00/lb.
***All facilities are amortized at 10% and 20 years except for trucks and compost site equipment, which are amortized at 10% and 8 years.

NOTE: Construction costs are based on installed capacity, while O&M and chemical requirements are based on operating capacity.
Costs for centrifuge are from Appendix C, Figure C-4 to C-6, and for the belt press, Figure C-10 to C-12.

Metric conversions: gpm x .0631 = l/s; cu ft x .0283 = cu m; lb x 0.454 = kg; btu x 1.055 = kJ; gal x 3.785 = l

6.4 Stage 3 - Laboratory Testing

A number of different tests can be performed in the laboratory to determine the dewaterability of sludge. These tests serve a number of purposes, including:

- Development of sizing criteria for full or pilot-scale installations
- Testing the influence of conditioning techniques
- Use as an operational control technique

The more commonly utilized laboratory testing procedures are described in the following discussion.

6.4.1 Filter Leaf Test

This test is utilized for performance evaluation, sizing, and operational control of vacuum filters. With the filter leaf test it is possible to vary the solids content of the feed sludge, sludge conditioning, filter media, cycle time, percent filter submergence, and vacuum level. Its intent is to duplicate as closely as possible the actual operation of a vacuum filter (12)(13). The equipment required to conduct the filter leaf test is shown in Figure 6-4.

The procedure for the filter leaf test is to place a portion of filter cloth identical to that used or planned for use with the vacuum filter on the test apparatus. Vacuum in the test apparatus is adjusted to be equivalent to the actual vacuum in the cake forming stage of filter operation, and this vacuum is maintained for a time equivalent to the time of cake formation. The filter cloth portion of the apparatus is then withdrawn from the agitated sludge and maintained at a vacuum equivalent to the vacuum used during the drying stage of vacuum filter operation. The cake solids content on the filter leaf and the suspended solids content of the filtrate can be analyzed to determine performance results. Generally, experiments are made with a variety of chemical conditioning agents and dosages so that an approximate optimum conditioning dosage and dewatering rate can be established.

The principal advantage of the filter leaf test is that it uses the same filtering media as the vacuum filter. However, in order for the results to be accurate, the sludge must be representative, the sample must be uniformly stirred, and vacuum and cycle times must be identical to those utilized for the full scale vacuum filter. Extrapolation of results to those which would be expected from a pilot scale or full-scale unit should be done with the help of an equipment manufacturer. Otherwise, the results are only an indication of potential performance.

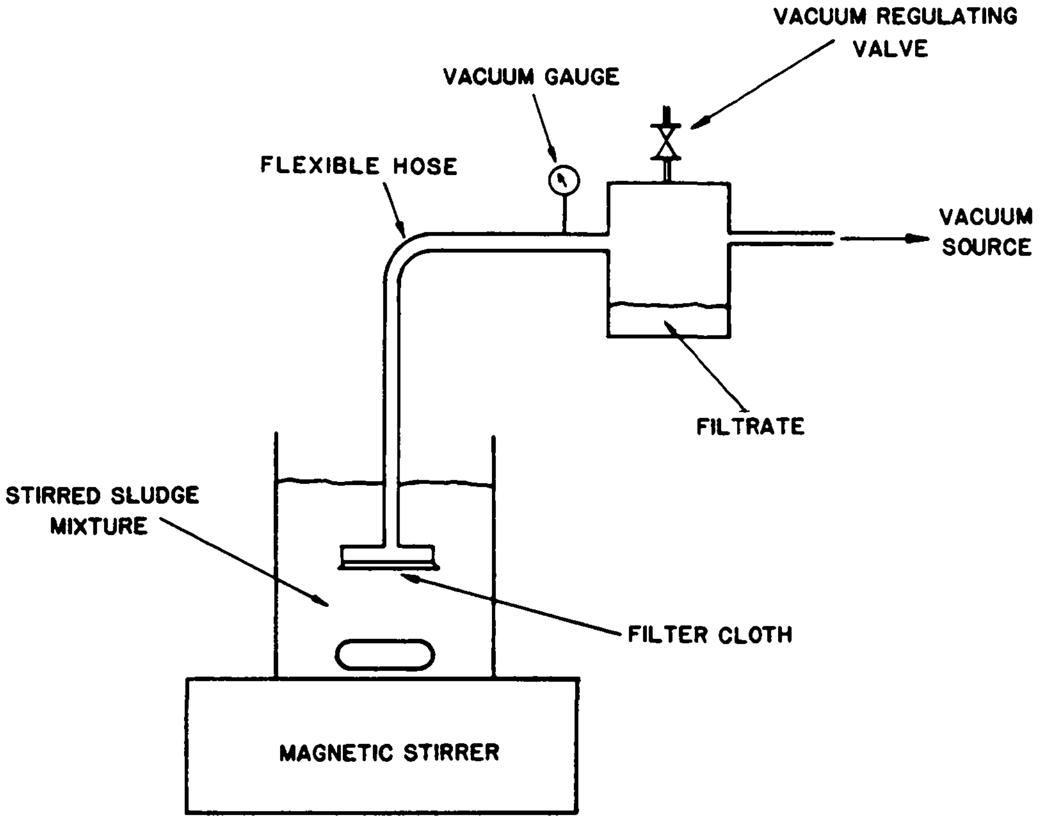


FIGURE 6-4

FILTER LEAF TEST APPARATUS

6.4.2 Specific Resistance Testing

The Specific Resistance Test, also known as the Buchner Funnel method, is used to determine the dewaterability of sludge (13)(14)(15). A Buchner funnel with a paper filter is mounted on top of a graduated cylinder, and a vacuum is applied to the graduated cylinder. As a mixed sample of sludge is added to the Buchner funnel, the volume of filtrate is recorded at preestablished time intervals, and a plot is made of time/filtrate volume vs filtrate volume, as shown in Figure 6-5.

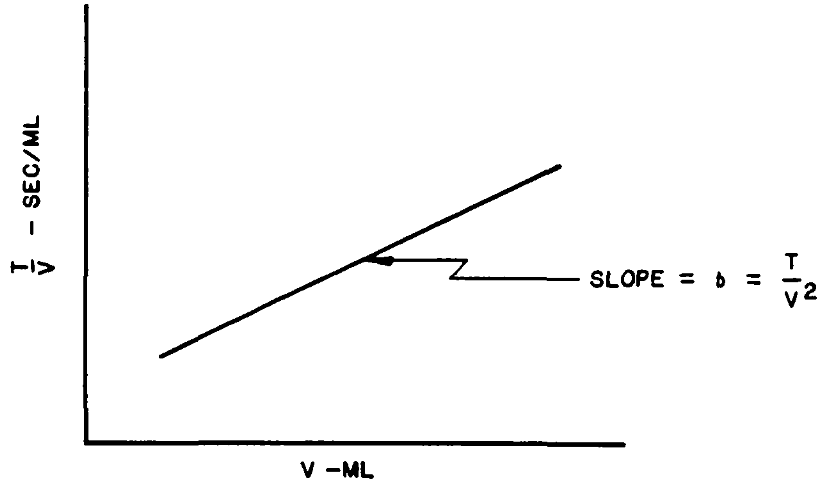


FIGURE 6-5
TIME/FILTRATE VOLUME VS. FILTRATE VOLUME PLOT
USED IN SPECIFIC RESISTANCE TESTING

Using the slope of this line, specific resistance (r) is calculated from the formula:

$$r = \frac{2\ PA^2b}{uw}$$

where:

r = specific resistance - m/kg
P = pressure of filtration - Pa
A = area of filter - sq m
b = slope of time/volume vs volume curve - s/m^6
u = viscosity of filtrate - Pa.s
w = weight of dry solids per volume of filtrate - kg/cu m

Although it is possible to utilize laboratory specific resistance data to calculate filter size and loadings, this procedure is not recommended because of dissimilarities between the specific resistance test and actual vacuum filter operation. Key dissimilarities are the use of top feed into the Buchner funnel in contrast to pickup of sludge from the feed tank in actual practice, and use of a paper filtering medium rather than the actual filtering medium used on the vacuum filter.

The best use of the specific resistance test is to indicate the influence of varying dosages of conditioning chemicals on sludge dewaterability. Figure 6-6 illustrates such a plot and its usefulness in determining optimum conditioning chemical dosage.

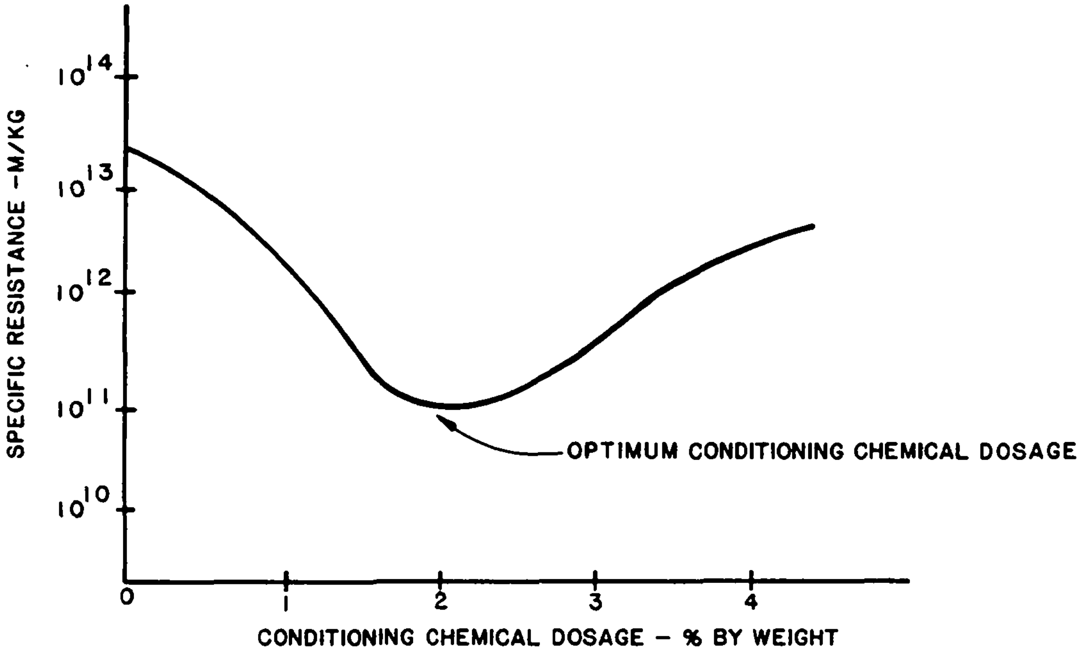


FIGURE 6-6
USE OF SPECIFIC RESISTANCE TO DETERMINE OPTIMUM CHEMICAL DOSAGE

6.4.3 Capillary Suction Time

The Capillary Suction Time (CST) is a simple and easy laboratory test to conduct (13)(16)(17). The test gives a quick indication of sludge dewaterability but the results are only meaningful when they are correlated with specific resistance or some other test of sludge dewaterability. After this correlation has been established, operation at the desired specific resistance can be accomplished by operating at the CST corresponding to this specific resistance.

The concept of the CST test is to measure the time required for the liquid portion of the sludge to travel one centimenter, or any other fixed distance, on a sheet of blotter paper. The device used to run the CST is shown in Figure 6-7. As illustrated, a timer is used to measure the time required for sludge movement between the two electrodes.

As an example of how to use the CST test, a typical CST time for an unconditioned sludge is 200 seconds. For a filter press, this sludge must be sufficiently conditioned to obtain a CST time of 10 seconds or less to produce a cake where positive discharge is assured (18)(19). The CST test is very useful in screening conditioning agents and evaluating the effect of conditioner dosage on sludge dewaterability.

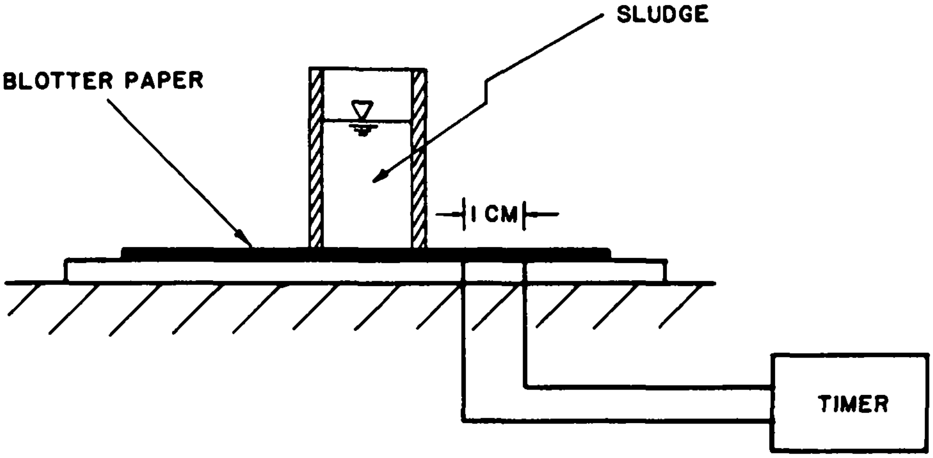


FIGURE 6-7
CAPILLARY SUCTION TIME (CST) TEST SET-UP

6.4.4 Filterbelt Press Simulator

An instrument designed to test specifically for sludge dewaterability on a belt filter press was devised in Sweden (20) (21). In this device, sludge is placed in a filtration cell and pressed by a stainless steel piston into a section of filter medium. The press is equipped with a pressure recording device and a filtrate recording device. Shearing action, similar to that which occurs as belts pass around rollers in a full-scale belt press, is simulated by using a piece of filter media on the end of the piston, and then rotating the piston.

Usefulness of the data generated is principally for operational control purposes, and insufficient information is available to determine how closely the results correlate with full-scale performance data. There are two different graphic techniques to analyze data. One approach shows the cake solids content versus pressing time, and this curve can be plotted for varying pressures, as shown in Figure 6-8. This figure is based on no gravity drainage prior to pressing. The second approach is to plot the cake solids content versus conditioning chemical dosage. A typical plot is shown in Figure 6-9. On either plot, filtrate suspended solids concentration can also be plotted if desired.

Halde feels this test is much more applicable to belt filter presses than any other dewatering test method, such as specific resistance or the Capillary Suction Time (20). In one series of tests, four samples of the same sludge were conditioned with four different chemicals. Although the specific

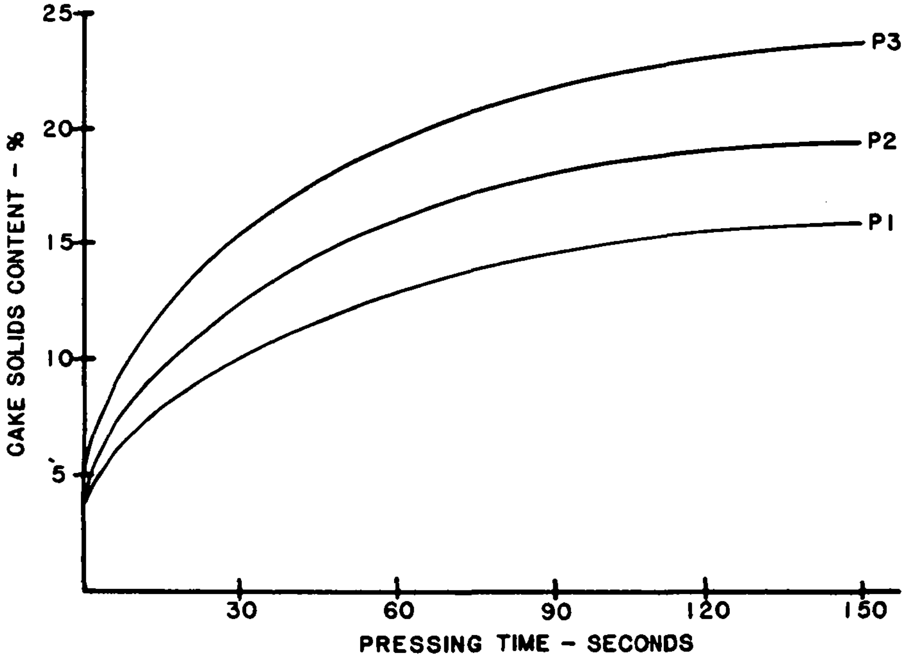


FIGURE 6-8
FILTERBELT PRESS SIMULATOR - EFFECT OF PRESSURE AND TIME ON CAKE SOLIDS CONCENTRATION

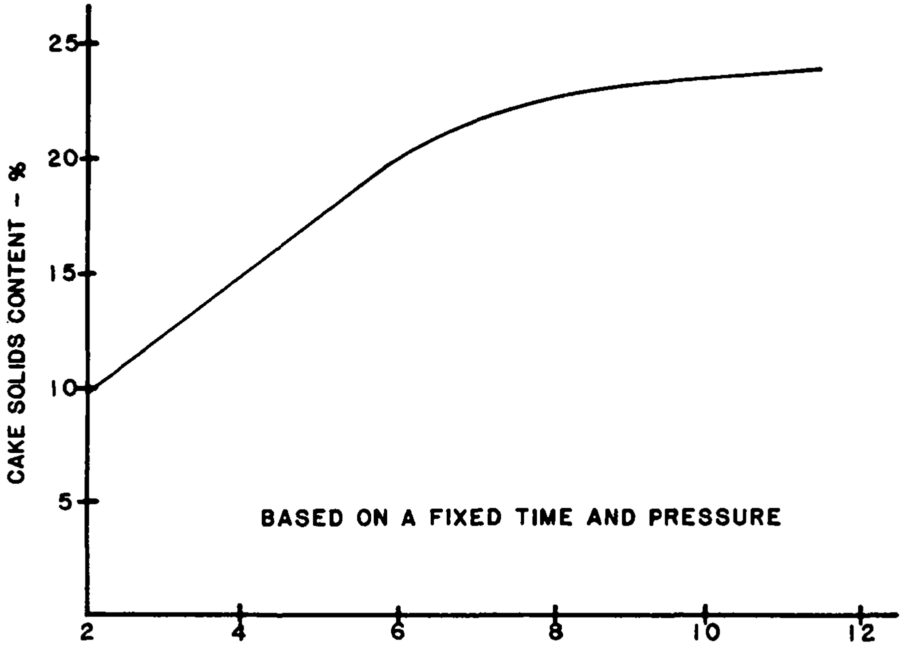


FIGURE 6-9
FILTERBELT PRESS SIMULATOR - EFFECT OF POLYMER DOSAGE ON CAKE SOLIDS CONCENTRATION

resistance was the same for each of the conditioned sludges, cake solids contents according to the filterbelt press simulator ranged from 8% to 23% (including conditioning chemical). This result appears to indicate that this test may be more applicable to belt presses than specific resistance testing.

6.4.5 Laboratory Scale Centrifuge Testing

Laboratory centrifuge techniques have been developed. These tests are useful for determination of the effect of centrifugal force on cake solids concentration, the influence of centrifuge retention time on cake concentration, and the influence of conditioning chemicals on cake solids concentrations. The first two, centrifugal force and retention time in the centrifuge are the factors with the greatest influence on effectiveness of the centrifuge.

The most frequently used laboratory test technique, sometimes called the bottle centrifuge method, is to spin a graduated centrifuge tube at different G forces or for different lengths of time. At the termination of testing, the centrate is decanted and the cake solids are measured. A typical plot of data which could be obtained by this technique is shown in Figure 6-10. Retention time in the centrifuge and conditioning chemical dosage will affect the shape of the curve and the cake solids concentration achievable. This test can also be used to evaluate the effect of various polymer dosages on sludge dewaterability. It does not take into account the agitation and drainage which will occur in a horizontal solid bowl centrifuge and thus the cake solids in the full-scale unit may be higher than that predicted by the bottle centrifuge test. Such tests are used by manufacturers to determine quickly on unknown applications whether or not a centrifuge is feasible. It provides an excellent tool for judging success, but is not effective for scale-up and sizing of equipment.

Vesilind has proposed a modification of this technique in which a strobe light is utilized to allow continuous observation of the sludge cake/centrate interface (13). This technique can be useful for predicting optimum detention time in the centrifuge.

6.5 Stage 4 - Field Testing

Following the initial screening, initial cost evaluation, and laboratory testing, often two or more dewatering alternatives have similar overall costs and it is often necessary to field test different dewatering processes. The need and justification for field level testing depends in part upon the size of the wastewater treatment plant. At very small plants with a capacity less than 0.04 cu m/s (1 mgd), it may not be cost-effective to conduct pilot-scale or full-scale testing. Instead laboratory or bench-scale testing by the manufacturer may be adequate.

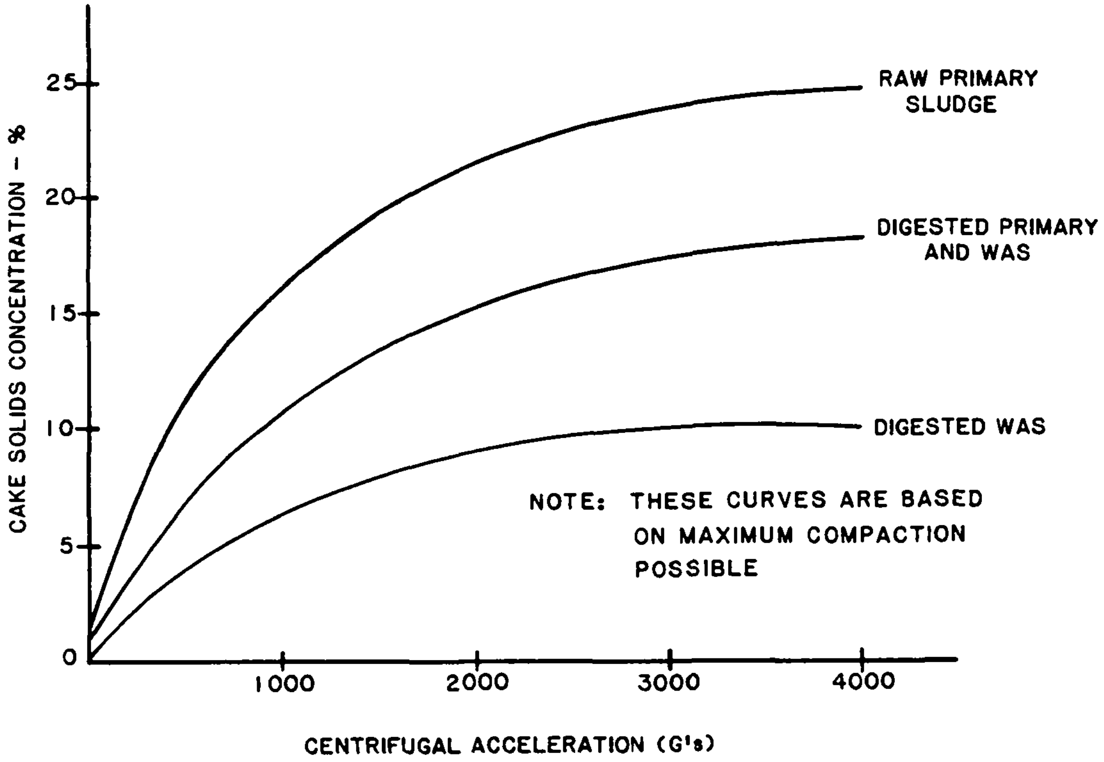


FIGURE 6-10
TYPICAL PLOT
VARIATION OF CAKE SOLIDS CONCENTRATION
WITH CENTRIFUGAL ACCELERATION

Although laboratory dewatering tests do give an indication of such parameters as chemical conditioning requirements and cake solids concentrations, actual solids loadings (or throughput) per unit of machine capacity and percent solids recovery can usually be determined only by field testing. In addition, actual verification of the design criteria and O&M requirements developed during the initial cost analysis and laboratory testing can only be accomplished by field testing. When considering field testing, it is important to contact the appropriate equipment manufacturers to verify the capabilities of their equipment for the particular application.

The determination of which devices to field test must be made, based in part, on which processes are remaining following the initial screening and initial cost evaluation. If two dewatering processes are judged to be the best processes in the intial cost analysis, then it may be desirable to compare the two processes under field test conditions. Two or more of the same type devices or machines supplied by different manufacturers can also be tested. In some instances the availability of field test units from manufacturers determines which manufacturer's units are tested, since fairly tight time constraints are often involved in evaluations of dewatering processes. A list of current manufacturers of dewatering equipment is presented in Appendix A.

Pilot-scale devices are usually the smallest production scale machines available. Although these are production machines, they are typically referred to as pilot-scale units, while the larger units are typically referred to as full-scale units. For example, a pilot-scale belt filter press would normally be only 0.5 m or 1.0 m wide, versus a 2 m wide full-scale unit. Pilot-scale solid-bowl centrifuges may have a capacity of only 0.95 to 2.2 l/s (15 to 35 gpm), while the largest centrifuges have capacities in excess of 25 l/s (400 gpm). Pilot-scale filter presses often have only four filtering chambers, while the largest presses have more than 40 chambers.

Scale-up from the small pilot-scale units to the larger full-scale units is generally predictable and can usually be estimated by the manufacturer based upon previous field test experience. Thus, often pilot-scale field testing is all that is required prior to the final economic evaluation and selection of a dewatering process. However, it is not always true that scale-up from pilot-scale to full-scale units is predictable. For example, at the Los Angeles County Sanitation Districts, both pilot- and full-scale testing of belt filter presses and low-speed centrifuges was conducted (22)(23). Of the two belt presses evaluated in detail, one manufacturer's belt press had a 50 percent lower sludge throughput capacity in the pilot-scale testing, but had a throughput capacity that was more than 30 percent higher than the other machine in the full-scale testing. It was also concluded that the performance of smaller belt presses was consistently better than that of larger units on all sludge blends tested. Some consideration should therefore be given by the designer to possible changes in performance when scaling-up the design and performance of pilot-scale belt filter presses for full-scale operation.

Field testing of dewatering processes can be on an intermittent or continuous basis, depending upon the ability to provide sludge feed and to provide for the removal of sludge cake. In addition, the chemical conditioning cost increases in proportion to the length of testing. Ten different test programs performed at various locations in the United States are summarized in Chapter 9. The total time required for field testing ranged from several weeks to over six months. Pilot- and full-scale units were not operated continuously over the entire testing period; in most cases, the units from different manufacturers were operated at different times and not concurrently. At least 15 separate runs covering three days or more each appears to be the minimum needed to evaluate the many variables associated with each dewatering unit.

Field testing of several dewatering processes provides specific design criteria which can be used to develop a more realistic cost comparison between units. If practical, simultaneous pilot- or full-scale testing of the different dewatering devices being evaluated is recommended to obtain directly comparable results. In summary, field testing should include the following:

- Field test as many machines as possible.
- Use actual sludge (or sludges) to be dewatered in final plant, if possible.
- Test various levels and types of conditioning.
- Field test machines using same sludge feed in simultaneous side-by-side comparisons, if possible.

- Field test machines which are as close in size to design machines as possible.
- Have at least one engineer or senior operator be involved in field testing program. Do not rely entirely on manufacturer's representative for evaluation and reporting of test results.
- Verify or modify design criteria established in initial cost evaluation.

6.6 Stage 5 - Final Evaluation Based on Detailed Design Parameters

After the results from the laboratory and/or field level testing are available, it will be possible to scale-up or size the actual equipment which would be used in the final detailed design. A final evaluation should then be made, with the objective being to determine the validity of the prior design criteria, assumptions and conclusions which were made. A final cost analysis should be performed on the lowest cost alternatives from Stage 2, using the same approach to the cost evaluation that was taken in Stage 2. Generally, the lowest cost alternative will be selected, assuming all other factors are comparable.

The most probable factors which may have changed based on results of field and/or laboratory testing are:

- Cake solids concentration
- Solids capture during dewatering
- Conditioning requirements
- Equipment throughput per unit of time
- Equipment cost based on manufacturer's quotations
- Operator acceptance and ease of equipment maintenance
- Maintenance cost and energy consumption
- Reliability of equipment
- Ability to handle variations in sludge quantity and quality

6.6.1 Cake Solids Concentration

Cake solids concentration will affect the cost of subsequent transportation and disposal. If cake solids are lower than original projections, transportation and disposal costs will increase, and in some instances, the method of ultimate disposal may become unsuitable. Situations where this may occur involve either incineration or composting of the dewatered cake, or landfill operations which require a minimum solids concentration for disposal. A related factor which may have changed from original assumptions for a filter press is the ease of cake release. To achieve an adequate cake release may require considerably more or less chemicals than originally planned.

6.6.2 Solids Capture During Dewatering

If solids capture is lower than originally expected, this will place a higher solids load on the liquid handling portion of the treatment plant. This increased solids recycle could adversely affect plant performance and result in poorer effluent quality. Low solids capture during laboratory or field testing may indicate the need for reevaluation of the selected dewatering process.

6.6.3 Conditioning Requirements

Conditioning chemical dosages are highly dependent on the character of the sludge being dewatered, as discussed in Chapter 5. In the initial cost evaluation, chemical dosages must be based upon "typical" dosages for similar sludges. After laboratory and/or field testing, more definitive information will be available on dosages, and this more accurate data should be used in the final cost evaluation.

6.6.4 Equipment Throughput Per Unit Time

A variation in throughput from the initial assumptions will affect the number of pieces of equipment required and therefore the capital cost, and perhaps, the O&M costs of the dewatering process. A large variation could change the conclusion of the cost evaluation, and this should be checked during this phase of the project.

6.6.5 Equipment Cost Based on Manufacturer's Quotations

At this point in the selection process, many contacts will have been made with manufacturers, and equipment from several manufacturers may have been tested. Based upon refined design criteria, equipment manufacturer's will be able to furnish more accurate equipment costs than the budget level estimates used in Stage 2 - Initial Cost Evaluation.

6.6.6 Operator Acceptance and Ease of Equipment Maintenance

The acceptance by plant operators of new equipment plays a large role in how efficiently the equipment operates and how well it is maintained. Generally, a piece of equipment which is difficult to operate and maintain will probably not operate at peak efficiency or be adequately maintained. In several of the studies evaluated in Chapter 9, the final decision between two types of equipment with comparable costs was made on the basis of overall operability. The operator's role is particularly important in selecting between belt filter presses and centrifuges, which have comparable overall costs.

6.6.7 Maintenance Cost and Energy Consumption

Full-scale testing can be helpful in gathering additional data on maintenance requirements and energy consumption. Variations from original estimates may occur in belt or filter media life, frequency of replacement of minor parts, wash water requirements for a filter press or a belt filter press, and overall energy consumption per unit weight of dry solids.

6.6.8 Reliability of Equipment

If equipment is prone to frequent breakdowns, maintenance costs will increase and throughput will decrease. Effort should be directed to selection of the most reliable equipment available when all other factors are comparable. Should equipment be selected that is prone to frequent breakdowns, the normal tendency is for plant operators to dislike both operating and maintaining the equipment. The end result is that the equipment operates at low efficiency, is poorly maintained, and will probably need replacement well before its anticipated useful life.

6.6.9 Ability to Handle Variations in Sludge Quantity and Quality

Variations in sludge quality occur frequently, and without appropriate changes in conditioning chemical dosages, the conditioned sludge will be difficult to dewater. Belt filter presses are particularly susceptible to having large changes in solids recovery due to changes in sludge quality or flow. Centrifuges and vacuum filters can handle variations in sludge feed fairly well, although cake solids and solids recovery may be reduced somewhat. Proper conditioning is important to all dewatering processes, however, and it is a necessary part of a process to be able to quickly and easily change chemical dosages in response to changes in sludge characteristics or flow.

6.7 References

1. Haug, R. T., "Compost Engineering - Principles and Practice," Ann Arbor Science Publishers, Inc., Ann Arbor, Michigan, 1980.

2. Wesner, G. M., "Sewage Sludge Composting," Sludge Treatment and Disposal, Volume 2 - Sludge Disposal, USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-625/4-78-012, October 1978.

3. "Process Design Manual For Sludge Treatment and Disposal," USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-625/1-79/011, September 1979.

4. Culp, G. L., "Handbook of Sludge Handling Processes - Cost and Performance," Garland STPM Press, New York, 1979.

5. "Innovative and Alternative Technology Assessment Manual," USEPA - Office of Water Program Operations, Washington, D.C., 20460, MCD-53, EPA-430/9-78-009, February 1980.

6. Culp, Gordon L. and Hinrichs, Daniel J., "Municipal Wastewater Sludge Management Alternatives," prepared for the EPA Technology Transfer National Conference on 208 Planning and Implementation, 1977. (Authors are with Culp/Wesner/Culp, Cameron Park, California)

7. Benjes, H. H., Jr., Faisst, J. A., and Lineck, T. S., "Capital and O&M Cost Estimates for Biological Wastewater Treatment Processes, "EPA Contract No. 68-03-2556, August 1979. (Lead author is with Culp/Wesner/Culp, Denver, Colorado)

8. "Cost and Performance Handbook - Sludge Handling Processes," Culp/Wesner/Culp, Wastewater Treatment and Reuse Seminar, South Lake Tahoe, California, October, 1977. (Culp/Wesner/Culp, Cameron Park, California)

9. Ettlich, W. E., "Transport of Sewage Sludge," USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-600/2-77-216, December 1977.

10. Culp, G. L., et al., "Costs of Chemical Clarification of Wastewater," U.S. EPA Task Order Contract 68-03-2186, 1976. (Lead author is with Culp/Wesner/Culp, Cameron Park, California)

11. Ewing, L. J., Jr., Almgren, H. H., and Culp, R. L., "Effects of Thermal Treatment of Sludge on Municipal Wastewater Treatment Costs," USEPA, Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-600/2-78-073, 1973.

12. "Sludge Dewatering," Manual of Practice No. 20, Water Pollution Control Federation, Washington, D. C., 1969.

13. Vesilind, P. A., "Treatment and Disposal of Wastewater Sludges," Revised Edition, Ann Arbor Science Publishers, Ann Arbor, 1980.

14. Rich, Linvil G., "Unit Operations of Sanitary Engineering," John Wiley and Sons, Inc., New York, 1961.

15. Coakley, P. & Jones, B. R. S., "Vacuum Sludge Filtration, I. Interpretation of Results by the Concept of Specific Resistance, Sewage & Industrial Wastes, Vol. 28, p. 963, 1956.

16. Baskerville, R.C., and Gale, R.S., "A Simple Automatic Instrument for Determining the Filterability of Sewage Sludges", Water Pollution Control (Br), Vol. 67, p.233, 1968.

17. Gale, R.S., and Baskerville, R.C., "Capillary Suction Method for Determination of the Filtration Properties of a Solid/Liquid Suspension," Chemistry and Industry, 1967.

18. Pietila, Kenneth A. and Joubert, Paul J., "Examination of Process Parameters Affecting Sludge Dewatering with a Diaphragm Filter Press," Journal Water Pollution Control Federation, Vol. 53, p. 1708, 1981.

19. Personal communication, Ken Pietila, Rexnord, Inc., Milwaukee, Wisconsin, February 1982.

20. Halde, Rolf E., "Filterbelt Pressing of Sludge - A Laboratory Simulation," Journal Water Pollution Control Federation, Vol. 52, p. 310, February 1980.

21. Baskerville, R.C., et al., "Laboratory Techniques for Predicting and Evaluating the Performance of a Filterbelt Press," Filtration and Separation, Vol. 15, p. 445, 1978.

22. "Mechanical Dewatering Study - Los Angeles County Sanitation Districts," LA/OMA Project, Regional Wastewater Solids Management Program, Los Angeles-Orange County Metropolitan Area, September 1980.

23. Trubiano, R., Bachtel, D., LeBrun, T., and Horvath, R., "Parallel Evaluation of Low Speed Scroll Centrigues and Belt Filter Presses for Dewatering Municipal Sewage Sludge," Draft EPA Report, Contract 68-03-2745, 1981. (Authors are with County Sanitation Districts of Los Angeles County, Whittier, California)

CHAPTER 7

COMPARATIVE COST ANALYSES OF SLUDGE TREATMENT AND DISPOSAL SYSTEMS

7.1 Introduction

In this chapter, capital and operation and maintenance costs are presented for complete sludge treatment and disposal systems utilizing many of the different dewatering processes described in this manual. Comparative cost analyses were made for three sizes of sludge handling systems: 910, 4,540 and 45,400 kg per day (1, 5, 50 tons per day) of dry sludge solids, which correspond approximately to 0.04, 0.2 and 2.2 cu m/s (1, 5 and 50 mgd) capacity wastewater treatment plants. These sludge quantities are for raw primary and secondary sludge prior to anaerobic digestion.

To develop capital and operation and maintenance costs, the same approach used in Figure 6-3 and Table 6-5 was followed. First, processes were sized using design criteria presented in this chapter. Construction costs for dewatering processes were obtained from the cost curves presented in Appendix C, which include equipment cost, excavation and site work, concrete structures, installation labor, electrical and instrumentation, piping, and housing. Construction costs for other sludge handling processes were based on references (1 - 6). All costs were updated to April 1982. As in Table 6-5, construction costs were increased by 40% to account for engineering, contingencies, contractors' overhead & profit, legal fiscal and adminstrative, and interest during construction. Land costs were included at \$4950/ha (\$2000/acre). Capital costs were amortized at 10% and 20 years, except for trucks, composting equipment, and front-end loaders, which were amortized at 10% and 8 years.

Operation and maintenance requirements were calculated as shown in Table 6-5. The O&M requirements were developed in terms of labor, electricity, natural gas, diesel fuel, maintenance material and chemicals. Unit cost factors used for each of these O&M categories are as follows:

Category	Unit Cost Factor
Labor	\$8 or 12/hr*
Electricity	\$0.05/kwh
Natural Gas	\$1.30/10^6 btu**
Diesel Fuel	\$1.15/gal
Maintenance Materials	\$/yr
Chemicals	\$2/lb polymer

*\$8/hr used for 910 kg/day (1 ton/day) systems and \$12/hr used for larger systems.

**Value of excess digester gas remaining after digester heating.

Users of this manual should recognize that the cost estimates presented in this chapter are based on a great number of assumptions relating to design and loading criteria. Since these loading criteria most certainly will vary from location to location, the costs developed and presented herein should be utilized for general purposes only.

7.2 Cost Comparison for One Ton Per Day Sludge Handling Systems

Four systems are compared for treatment of 910 kg/day (1 ton/day) of a primary/waste activated sludge (WAS) mixture. These systems are:

- belt press thickening of WAS, anaerobic digestion, lagoons
- belt press thickening of WAS, anaerobic digestion, sand drying beds
- belt press thickening of WAS, anaerobic digestion, low pressure belt press
- belt press thickening of WAS, anaerobic digestion, and vacuum assisted drying beds.

All systems used low pressure belt press thickening (such as Smith & Loveless Sludge Concentrator) of WAS and on-site disposal of dried sludge. Design criteria used for the sizing and loading of process equipment are listed in Table 7-1.

Capital and operation and maintenance costs for these alternatives, as shown in Table 7-2, indicate that the sludge lagoons are the lowest cost alternative, followed by sand drying beds, low pressure belt presses, and vacuum assisted drying beds. Although the latter two alternatives are more costly than lagoons or sand drying beds, they have potential application where land is unavailable for conventional sand drying beds or where lagoons are aesthetically or otherwise unacceptable.

7.3 Cost Comparison for Five Ton Per Day Sludge Handling Systems

Eight treatment and disposal systems were evaluated for 4,540 kg/day (5 ton/day) of raw primary and waste activated sludge. These sludge handling systems, as shown in Figure 7-1, consisted of low G solid bowl centrifuge thickening of WAS, anaerobic digestion, dewatering, 16 km (10 mile) one-way truck haul, and landfill of dewatered sludge. With the exception of the dewatering process, all other components of the system were the same. The dewatering processes evaluated were:

- Basket centrifuge
- Low G solid bowl centrifuge
- High G solid bowl centrifuge
- Belt filter press
- Vacuum filter
- Fixed volume filter press
- Sand drying beds
- Sludge lagoons

TABLE 7-1

DESIGN CRITERIA FOR 910 kg/Day (1 ton/day) SLUDGE HANDLING COST ANALYSES

A. SOLIDS PRODUCTION

Primary	0.14 kg/cu m (1150 lb/mil gal) - 60% volatile; 5% solids
Secondary Waste Activated Sludge	0.11 kg/cu m (950 lb/mil gal) - 80% volatile; 0.5% solids

B. SECONDARY SLUDGE THICKENING

Low pressure belt press
5% solids output
Polymer dosage - 6 g/kg (12 lb/ton)

C. ANAEROBIC DIGESTION

Single stage, completely mixed
15 day hydraulic detention time
Volatile solids loading - 2.6 kg V.S./cu m/dy (0.16 lb V.S./cf/d)
50 percent reduction of volatile solids
Flare digester gas remaining after digester heating

D. CHEMICAL CONDITIONING

Process	Conditioner	Dosage	
		g/kg	(lb/ton)
Lagoons	None	--	--
Sand drying beds	None	--	--
Low pressure belt press	Polymer	7.5	(15)
Vacuum assisted drying beds	Polymer	2.5	(50)

E. DEWATERING EQUIPMENT - CAKE SOLIDS AND LOADING RATE

Lagoons - Volume = 1110 cu m (39,600 cu ft)
No sludge removal
Sand drying beds - 50% cake solids
78 kg/sq m/yr (16 lb/sq ft/yr)
Vacuum assisted drying beds - 15% cake solids
9.8 kg/sq m/d (2 lb/sq ft/d)
One application/day
Low pressure belt press - 12% cake solids
50 kg/hr/m (75 lb/hr/ft)

TABLE 7-2

COST SUMMARY FOR 910 KG/DAY (1 TON/DAY) CAPACITY SLUDGE TREATMENT AND DISPOSAL SYSTEMS

Sludge Dewatering System	Capital Cost Thousand $	O&M Cost $1,000/YR	Total Annual Cost $1,000/YR	Percent Higher Than Lowest Cost
Sludge Lagoons	84	25.7	35.6	--
Sand Drying Beds	294	11.1	45.6	28%
Low Pressure Belt Press	154	38.3	56.4	58%
Vacuum Assisted Drying Bed	294	35.3	69.8	96%

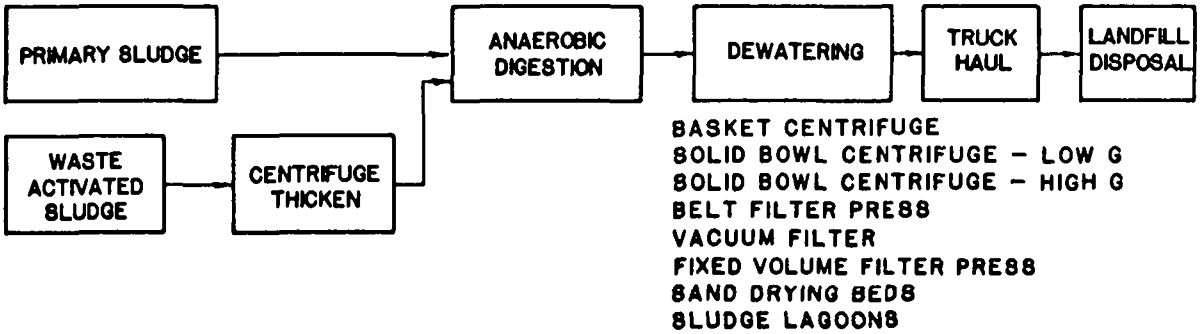


FIGURE 7-1

SLUDGE TREATMENT AND DISPOSAL SYSTEMS EVALUATED FOR 5 TON PER DAY COST ANALYSES

These dewatering techniques were selected on the basis of their applicability to systems of this general size. A flow diagram for the systems evaluated is shown in Figure 7-1 and design criteria used in the cost analyses are shown in Table 7-3.

Capital costs, operation and maintenance costs, and total annual costs are presented in Table 7-4. As shown in this table, the sludge treatment system using centrifuge thickening of WAS, anaerobic digestion of primary and WAS, dewatering by sludge lagoons and then a 16 km (10 mile) one-way truck haul to landfill disposal has the lowest total annual cost. The next lowest cost dewatering alternatives are high G solid bowl centrifuges, followed in order of increasing total annual cost by low G solid bowl centrifuges, belt filter presses, sand drying beds, basket centrifuges, and vacuum filters. The fixed volume filter press has the highest total annual cost (59 percent higher than sludge lagoons).

7.4 Cost Comparison For Fifty Ton Per Day Sludge Handling Systems

Nine treatment and disposal systems were evaluated for 45,400 kg/day (50 tons/day) of raw sludge. These systems were:

- Centrifuge thicken WAS, anaerobic digestion, low G solid bowl centrifuge, truck haul, landfill
- Centrifuge thicken WAS, anaerobic digestion, high G solid bowl centrifuge, truck haul, landfill
- Centrifuge thicken WAS, anaerobic digestion, belt filter press, truck haul, landfill
- Centrifuge thicken WAS, anaerobic digestion, vacuum filter, truck haul, landfill
- Centrifuge thicken WAS, anaerobic digestion, fixed volume filter press, truck haul, landfill
- Centrifuge thicken WAS, anaerobic digestion, diaphragm filter press, truck haul, landfill
- Centrifuge thicken WAS, fixed volume filter press, multiple hearth incineration, truck haul, landfill
- Centrifuge thicken WAS, heat treatment, vacuum filter, incinerate, truck haul, landfill
- Heat treatment, vacuum filter, incinerate, truck haul, landfill

For the first six of these systems, one-way haul distances of 16 km (10 miles) and 64 km (40 miles) were also evaluated, to determine the sensitivity of

TABLE 7-3

DESIGN CRITERIA FOR SLUDGE HANDLING COST ANALYSES
5 and 50 Ton Per Day Systems

A. SOLIDS PRODUCTION

Primary	0.14 kg/cu m (1150 lb/mil gal) - 60% volatile; 5% solids
Secondary Waste Activated Sludge	0.11 kg/cu m (950 lb/mil gal) - 80% volatile; 0.5% solids

B. SECONDARY SLUDGE THICKENING

Low G Solid Bowl Centrifuge - 6% solids output
No chemicals added

C. ANAEROBIC DIGESTION

Single stage, completely mixed
15 day hydraulic detention time
Volatile solids loading - 2.6 kg V.S./cu m/dy (0.16 lb V.S./cf/dy)
50 percent reduction of volatile solids
Sell digester gas remaining after digester heating

D. CHEMICAL CONDITIONING

	Conditioner	Raw Sludge		Digested Sludge	
		g/kg	(lb/ton)	g/kg	(lb/ton)
1. Basket Centrifuge*	Polymer	--		3	(6)
2. Solid Bowl Centrifuge***					
Low G	Polymer	--		4	(8)
High G	Polymer	--		4	(8)
3. Belt Filter Press***	Polymer	--		6	(12)
4. Vacuum Filter***	Lime	--		180	(360)
	Ferric Chloride	--		60	(120)
5. Fixed Volume Filter Press***	Lime	140	(280)	180	(360)
	Ferric Chloride	40	(80)	60	(120)
6. Diaphragm Filter Press**	Lime	--		180	(360)
	Ferric Chloride	--		60	(120)
7. Drying Beds*	Polymer	Not Applicable		2.5	(5)
8. Lagoons*	None	Not Applicable		--	

TABLE 7-3 (Continued)

E. HEAT TREATMENT (Thermal Conditioning)**

Option without WAS Thickening
Feed Solids Concentration = 1.8%
Loading Based on sludge flow of 29 l/s for 45,400 kg/day (461 gpm for 50 ton/day)

Option with WAS Thickening
Feed Solids Concentration = 5.4%
Loading Based on Sludge Flow of 9.5 l/s for 45,400 kg/day (151 gpm for 50 ton/day)

Recycled Liquor Treatment includes increased aeration capacity

Odor control using carbon adsorption

F. DEWATERING EQUIPMENT - CAKE SOLIDS AND LOADING RATES

	Raw Sludge	Digested Sludge	Heat Treated Sludge
Basket Centrifuge*			
Cake Solids - %	--	14	--
Loading - Based on hydraulic loading to the unit			
Solid Bowl Centrifuge***			
Cake Solids - %	--	18	--
Loading - Based on hydraulic loading to the unit			
Belt Filter Press***			
Cake Solids - %	--	22	--
Loading - l/s/m	--	3.2	--
Loading - gpm/m	--	50	--
Vacuum Filter***			
Cake Solids - %	--	18	35
Loading - kg/sq m/hr	--	20	34
Loading - lb/sq ft/hr	--	4	7
Fixed Volume Filter Press***			
Cake Solids - %	40	36	--
Cycle Time	2.5 hr	2.5 hr	--

TABLE 7-3 (Continued)

	Raw Sludge	Digested Sludge	Heat Treated Sludge
Diaphragm Filter Press**			
Cake Solids - %	--	45	--
Loading - kg/sq m/hr	--	4.9	--
Loading - lb/sq ft/hr	--	1.0	--
Drying Beds*			
Cake Solids - %	--	50	--
Loadings - kg/sq m/yr	--	78	--
lb/sq ft/yr	--	16	--
Lagoons*			
Cake Solids - %	--	30%	--
Loading - Assumes sludge added to lagoons intermittently for 18 months, then rested for 6 months before removal			

G. INCINERATION**

Multiple Hearth Furnace
Combustion is self-sustaining with 35% feed solids
Fuel is required for startup only
24 hr/day operation, 6 start-ups/year
Loading of 44 kg/sq m/hr (9 lb/sq ft/hr) for 45,400 kg/day (50 ton/day) plant

H. TRUCK HAUL

One way distance = 16 km (10 Mi)
Type of Trucks:
- 4,540 kg/day (5 ton/day) plant - 7.6 cu m (10 cu yd) gasoline
- 45 400 kg/day (50 ton/day) plant - 22.9 cu m (30 cu yd) diesel

Operational Criteria
- 4,540 kg/day (5 ton/day) plant - 10 hr/day maximum haul time
- 45,400 kg/day (50 ton/day) plant - 16 hr/day permissible haul time

Ash density of 800 kg/cu m (50 lb/cu ft)

I. LANDFILL DISPOSAL

$1.96 per cu m ($1.50 per cubic yard)

*5 ton/day systems only
**50 ton/day systems only
***Both 5 and 50 ton/day systems

TABLE 7-4

COST SUMMARY FOR 4,540 KG/DAY (5 TON/DAY) CAPACITY SLUDGE TREATMENT AND DISPOSAL SYSTEMS

Sludge Dewatering System	Capital Cost million $	O&M Cost $1,000/yr	Annual Cost $1,000/yr*	Higher Than Lowest Cost
Sludge Lagoons	1.87	85	313	---
Solid Bowl Centrifuge - High G	2.10	121	378	17%
Solid Bowl Centrifuge - Low G	2.14	123	386	23%
Belt Filter Press	2.19	121	387	24%
Sand Drying Beds	2.34	115	398	27%
Basket Centrifuge	2.54	102	411	31%
Vacuum Filter	2.38	160	450	44%
Fixed Volume Filter Press	2.74	168	498	59%

Note: Facilities include centrifuge thickening of WAS, anaerobic digestion, dewatering, truck haul, and landfill disposal

*Capital cost converted to annual cost using a CRF of 0.11746 (10%, 20 yr) for all facilities except trucks, for which a CRF of 0.18744 (10%, 8 yr) was used.

overall cost to distance hauled. Flow diagrams for the systems evaluated are shown in Figure 7-2, and design criteria used for process sizing are listed in Table 7-3.

Capital, O&M and total annual costs for the systems evaluated are shown in Table 7-5. For a 16 km (10 mile) haul distance, the lowest cost system is for centrifuge thickening, anaerobic digestion, and dewatering by low G or high G solid bowl centrifuge with cake hauling to a landfill. Costs for these two systems are virtually identical. The system using belt press dewatering is 7% more costly than the centrifuge dewatering systems. A fixed volume filter press is more cost-effective than either a vacuum filter or diaphragm filter press. As the dewatered sludge haul distance is increased from 16 km (10 miles) one-way to 64 km (40 miles), the processes which produce a drier cake solids become somewhat more cost-effective, although the general ranking of the alternative concepts is the same with the exception that the diaphragm filter press becomes more cost-effective than the vacuum filter.

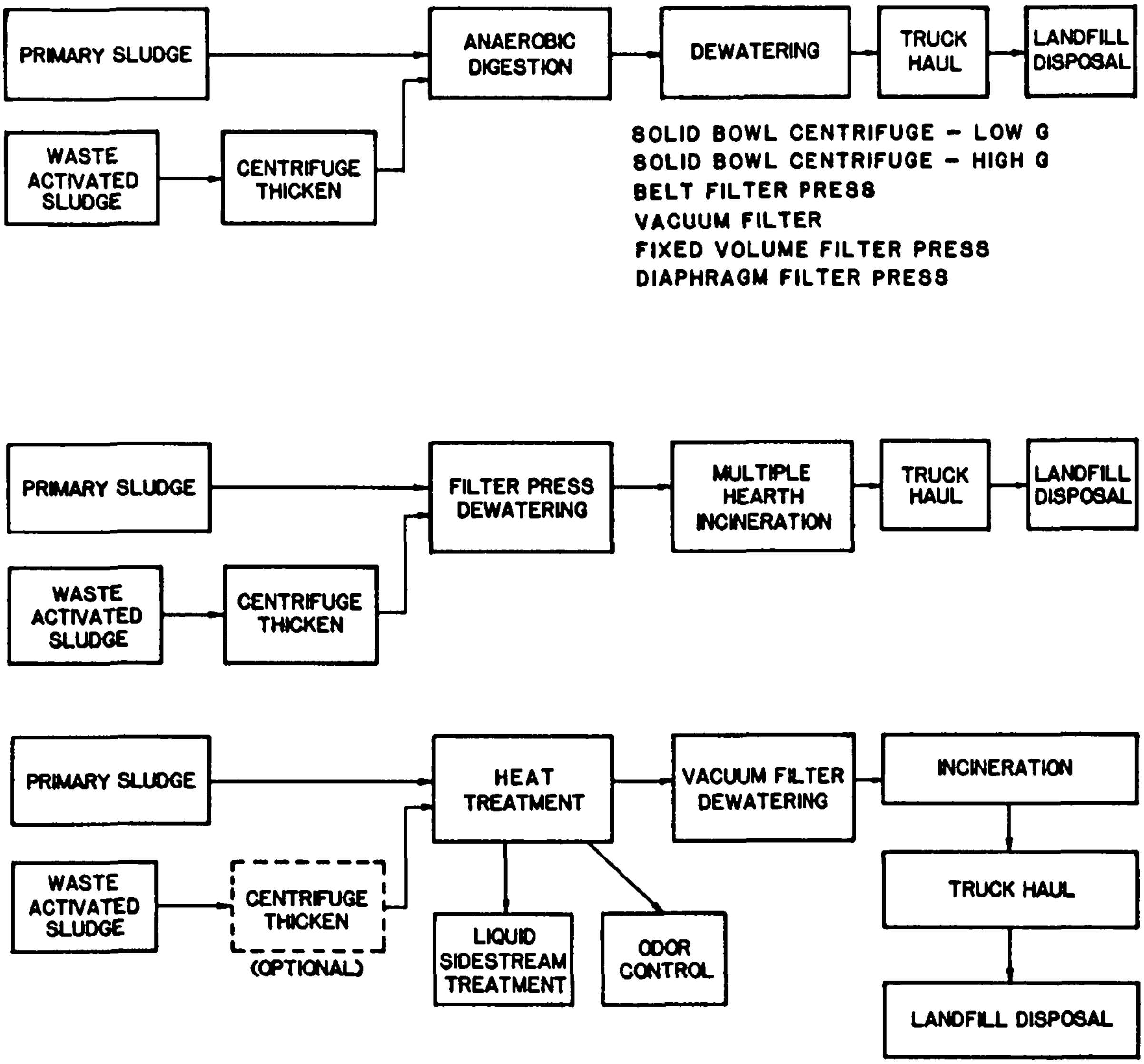


FIGURE 7-2

SLUDGE TREATMENT AND DISPOSAL SYSTEMS EVALUATED FOR 50 TON PER DAY COST ANALYSES

TABLE 7-5

COST SUMMARY FOR 45,400 KG/DAY (50 TON/DAY) CAPACITY SLUDGE TREATMENT AND DISPOSAL SYSTEMS

Sludge Dewatering System	Capital Cost million $	O&M Cost $1,000/yr	Total Annual Cost $1,000/yr*	Percent Higher Than Lowest Cost
• Centrifuge/Anaerobic Digestion/Dewater/Truck Haul/Landfill				
16 km (10 Mile) One-Way Haul				
Solid Bowl Centrifuge - Low G	6.61	648	1,446	--
Solid Bowl Centrifuge - High G	6.50	671	1,456	--
Belt Filter Press	7.03	694	1,540	7%
Fixed Volume Filter Press	8.43	726	1,733	20%
Vacuum Filter	7.54	930	1,840	27%
Diaphragm Filter Press	10.39	706	1,943	34%
64 km (40 Mile) One-Way Haul				
Solid Bowl Centrifuge - High G	6.61	803	1,588	--
Solid Bowl Centrifuge - Low G	6.50	807	1,605	1%
Belt Filter Press	7.07	820	1,674	5%
Fixed Volume Filter Press	8.44	817	1,828	15%
Diaphragm Filter Press	10.40	781	2,019	27%
Vacuum Filter	7.66	1,128	2,061	30%
• Centrifuge/Filter Press/Incinerate	13.51	945	2,544	76%**
• Centrifuge/Heat Treatment/Vacuum Filter/Incinerate	17.62	1,165	3,255	125%**
• Heat Treatment/Vacuum Filter/Incinerate	22.39	1,587	4,227	192%**

* Capital cost converted to annual cost using a CRF of 0.11746 (10%, 20 yr)

** Percent higher than cost of solid bowl centrifuge with 16 km (10 mile) haul

The cost estimates shown in Tables 7-2, 7-4, and 7-5 are only presented to illustrate the procedure of evaluating dewatering processes as a part of a complete sludge treatment system. These cost estimates are based upon the cost curves presented in Appendix C, several other references (1 to 6), and upon the specific design criteria assumed in this analysis. The costs presented are general in nature, and therefore, should only be used for general purposes until detailed, site-specific cost estimates can be prepared.

7.5 References

1. Culp, G. L., "Handbook of Sludge Handling Processes - Cost and Performance," Garland STPM Press, New York, 1979.
2. Benjes, H. H., Jr., Faisst, J. A., and Lineck, T. S., "Capital and O&M Cost Estimates for Biological Wastewater Treatment Processes, "EPA Contract No. 68-03-2556, August 1979. (Lead author is with Culp/Wesner/Culp, Denver, Colorado)
3. "Cost and Performance Handbook - Sludge Handling Processes," Culp/Wesner/Culp, Wastewater Treatment and Reuse Seminar, South Lake Tahoe, California, October 1977. (Culp/Wesner/Culp, Cameron Park, California)
4. Ettlich, W. E., "Transport of Sewage Sludge," USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-600/2-77-216, December 1977.
5. Culp, G. L., et al., "Costs of Chemical Clarification of Wastewater," U.S. EPA Task Order Contract 68-03-2186, 1976. (Lead author is with Culp/Wesner/Culp, Cameron Park, California)
6. Ewing, L. J., Jr., Almgren, H. H., and Culp, R. L., "Effects of Thermal Treatment of Sludge on Municipal Wastewater Treatment Costs," USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-600/2-78-073, 1973.

CHAPTER 8

ENERGY CONSIDERATIONS IN DEWATERING PROCESS SELECTION

8.1 Introduction

Energy required for sludge dewatering is important because energy costs can influence overall project cost as well as process selection. This chapter presents an analysis of both "direct" energy requirements, as well as the "indirect" energy requirements associated with production of the conditioning chemicals. Consideration of both the direct and indirect energy requirements is important in conducting an energy sensitivity analysis. Such an analysis should be conducted to determine the impact of energy cost escalations at rates greater than or less than the average inflation rate.

As is stressed in other portions of this manual, evaluation of the dewatering process can not be performed independently of other sludge treatment and disposal processes. This is true from an energy standpoint also. In many process flow concepts, dewatering energy requirements may be low, but the overall energy requirement for solids treatment, transportation, and disposal may be high. In other cases the converse is true.

8.2 Direct Energy Requirements for Dewatering

In order to compare direct energy requirements of the various dewatering options available, information was gathered from full scale equipment operating at wastewater treatment plants across the country, from dewatering equipment manufacturers, and from the EPA report "Energy Conservation in Municipal Wastewater Treatment--MCD-32" (1). A summary of this information is presented in Table 8-1. It is important to note that while all of the sludges shown in Table 8-1 are digested mixtures of primary and waste activated sludge (WAS), the percentage of difficult-to-dewater WAS in the mixture varies from 25 to 90 percent. Generally, as the ratio of primary to secondary sludge decreases, the energy required for dewatering increases.

Based upon the information in Table 8-1, ranges in electricity and fuel requirements for sludge dewatering were developed and are presented in Table 8-2. The ranges in total energy requirements presented for each dewatering process further illustrate the fact that sludges from different wastewater treatment plants vary greatly in their dewaterability. This variability emphasizes the need for full-scale testing of equipment comparable to the actual equipment which would be installed in order to define the actual throughput rates achievable. In addition to sludge quality, there are several

TABLE 8-1

DIRECT ENERGY REQUIREMENTS FOR SLUDGE DEWATERING - CASE STUDY RESULTS

Energy Requirement, kwh/ton dry solids

	INFORMATION SOURCES								
Dewatering Process	Metro Chicago Calumet Plant (2)	Metro Chicago West-S.W. Plant (3)	L.A. County (4)(5)	Irvine, Calif. (6)	Metro Denver(7)	Orange Co. San. Dist.(8)	San Jose Calif. (9)	Data From Manufacturers (10 - 13)	EPA Report(1)
(Sludge Type)[1]	(Approx. 40:60)	(10:90)	(75:25)	(Approx. 50:50)	(50:50)	(70:30)	(50:50)	(Approx. 50:50)	(65:35)
Drying Beds	--	--	--	--	--	--	--	--	3-4
Vacuum Filter	700[2]	247[2]	--	--	60	--	--	46-58	38-58
Basket Centrifuge	--	--	115[3]	--	--	--	--	--	89-107
Solid Bowl Centrifuge									
Low-Speed	53	213[2]	65	100	72-147	48	22-29	30,33,38	33
High-Speed	88	79	--	--	52-87	--	--	60-90	--
Belt Filter Press	25	35,37	20	58	8-12	7	--	10-15	--
Fixed Volume Filter Press	--	--	--	--	--	52	41-54	--	29-54
Diaphragm Filter Press	--	--	--	--	--	--	--	45-55	--

[1] All sludges are digested mixtures of primary and waste activated sludge, unless noted. Ratio shown is (Primary:WAS)

[2] These values seem high but are the values reported in the literature

[3] Digested primary sludge

Metric Conversion: 1 kwh/ton = 0.0011 kwh/kg

TABLE 8-2

GENERAL RANGES OF DIRECT ENERGY REQUIREMENTS FOR SLUDGE DEWATERING[1]

Process	Fuel		Electricity		Total Equivalent Electricity[2]	
	kJ/kg dry solids	(Btu/ton)	kwh/kg dry solids	(kwh/ton)	kwh/kg dry solids	(kwh/ton)
Basket Centrifuge	---	---	0.105-0.140	(90-120)	0.105-0.140	(90-120)
Solid Bowl Centrifuge						
Low-Speed	---	---	0.035-0.070	(30-60)	0.035-0.070	(30-60)
High-Speed	---	---	0.070-0.105	(60-90)	0.070-0.105	(60-90)
Belt Filter Press	---	---	0.011-0.029	(10-25)	0.011-0.029	(10-25)
Vacuum Filter	---	---	0.046-0.070	(40-60)	0.046-0.070	(40-60)
Fixed Volume Filter Press	---	---	0.046-0.070	(40-60)	0.046-0.070	(40-60)
Diaphragm Filter Press	---	---	0.041-0.064	(35-55)	0.041-0.064	(35-55)
Drying Beds	23	(20,000)	0.001-0.002	(1-2)	0.003-0.004	(3-4)
Sludge Lagoons	102 - 170	(88,000-146,000)	0.001-0.002	(1-2)	0.010-0.018	(9-16)

[1] For dewatering a digested 50:50 mixture of primary and WAS at 3 percent feed solids.

[2] Fuel converted to equivalent electricity using a factor of 11,080 kJ per kwh (10,500 BTU/kwh) and an electrical generation efficiency of 32.5%.

other variables which affect dewatering energy requirements: (1) solids concentration of sludge feed; (2) conditioning method selected; (3) number of machines - more energy is generally required to run two smaller machines than one large machine of equivalent capacity, although this is not generally true for solid bowl centrifuges if the same G force is used in both small and large centrifuges; (4) solids throughput achieved; and (5) differences in machines produced by different manufacturers.

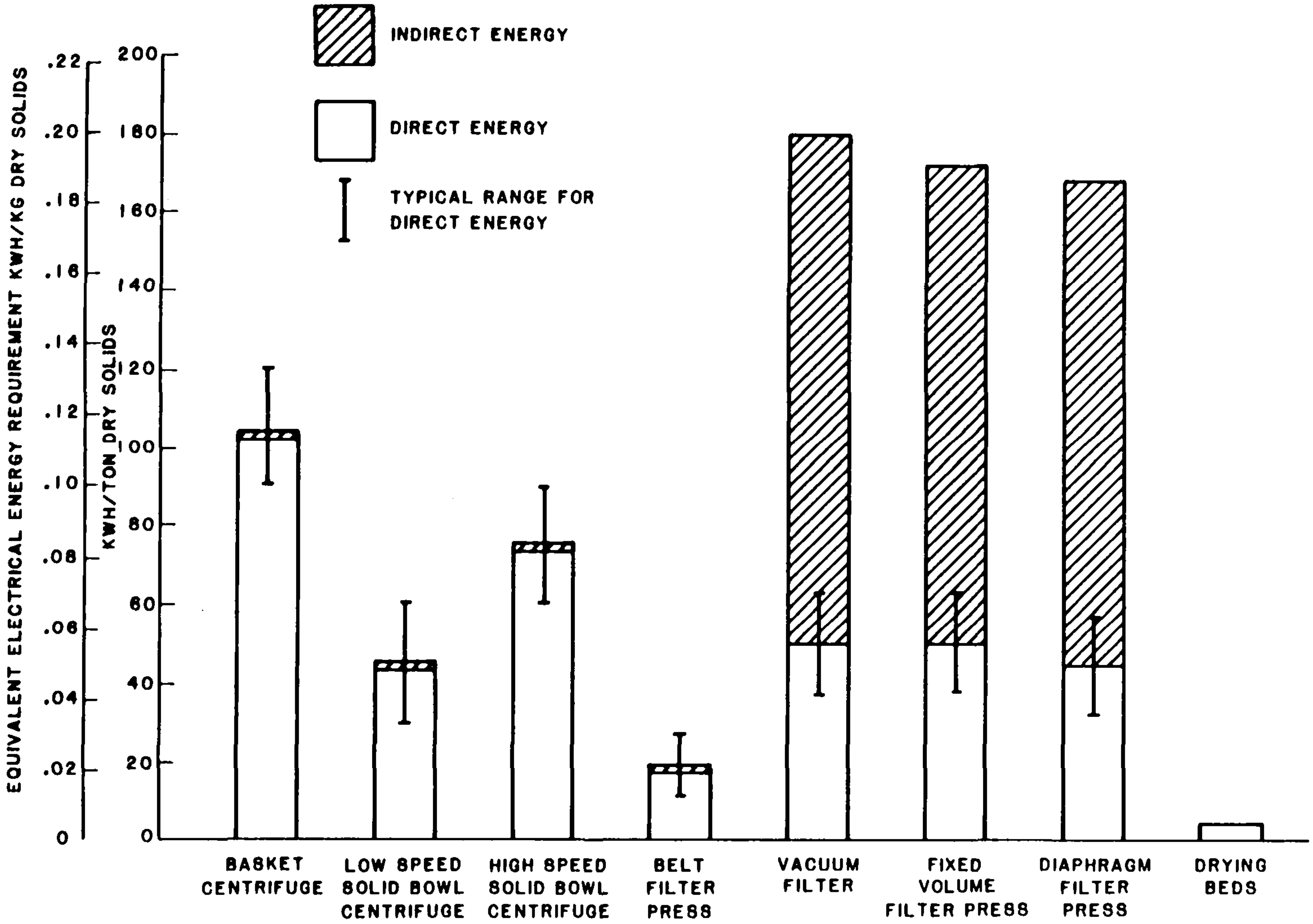
The energy requirements for drying beds shown in Table 8-2 include an electricity requirement for sludge pumping to the beds and a fuel requirement for operating a front-end loader used for sludge removal. The power required for pumping sludge to the drying beds is based on a TDH of 4.6 m (15 feet). This value could be low in some plants where long pumping distances are required, or high in a plant where there is gravity flow to the beds. Appropriate corrections need to be made for situations significantly different than 4.6 m (15 feet) of TDH. In smaller plants it is possible that manual labor is used for sludge removal and not a front-end loader.

The direct energy requirements presented in Table 8-2 are also shown in Figure 8-1. For the seven mechanical dewatering processes presented, the order of direct energy used, from lowest to highest, is:

Belt filter press
Low G solid bowl centrifuge
Diaphragm filter press
Fixed volume filter press
Vacuum filter
High G solid bowl centrifuge
Basket centrifuge

8.3 Indirect Energy Requirements for Dewatering

Most of the sludge dewatering processes operate more efficiently when the sludge is conditioned, typically with chemicals, prior to dewatering. Secondary energy is indirect energy required to produce consumables (chemicals) used in wastewater and sludge treatment processes. Consideration of these secondary energy requirements is supplemental to any cost-effectiveness analysis that may be performed in evaluating alternatives. However, the future cost of chemicals is directly affected by increases in the cost of energy, and this would be apparent in an energy sensitivity analysis which included secondary energy. A dewatering alternative having a relatively high secondary energy requirement has a greater dependence on energy than is indicated by the direct energy alone. Indirect energy requirements for sludge dewatering are shown in Table 8-3 and Figure 8-1. As shown, processes which utilize polymer conditioning (centrifuges and belt filter press) have low indirect energy requirements, while processes which utilize lime and ferric chloride conditioning (vacuum filter and filter presses) have high indirect energy requirements.



NOTE: Sludge type is digested primary and WAS, approximately 50:50 ratio.

FIGURE 8-1
DIRECT AND INDIRECT ENERGY REQUIREMENTS
FOR SLUDGE DEWATERING PROCESSES

TABLE 8-3

INDIRECT ENERGY REQUIREMENTS FOR SLUDGE DEWATERING*(1)

Dewatering Process	Conditioning Chemical	Chemical Dosage g/kg	(lb/ton)	Indirect Electrical Energy kwh/kg dry solids	kwh/ton dry solids
Basket Centrifuge	Polymer	3	(6)	0.0007	(0.6)
Solid Bowl Centrifuge	Polymer	4	(8)	0.0009	(0.8)
Belt Filter	Polymer	6	(12)	0.0013	(1.2)
Vacuum Filter	Lime	150	(300)	0.099	(90)
	$FeCl_3$	40	(80)	0.044	(40)
Filter Press	Lime	120	(240)	0.079	(72)
	$FeCl_3$	50	(100)	0.055	(50)

*Sludge type is digested primary + WAS.

Use of polymer conditioning has been tested at a number of filter press installations, but the results have been generally unsatisfactory, due to poor cake release, poor solids capture, and low cake solids concentrations. For vacuum filtration, the Process Design Manual for Sludge Treatment and Disposal reports that several facilities have realized cost savings using polymers for conditioning (14). However, more operator attention may be required to obtain good cake release, and the overall cake solids content may be somewhat lower while the volatile solids content of the dry cake will be higher. For some sludges, especially digested sludges and sludges containing large quantities of WAS, polymer conditioning may not be feasible.

8.4 Total Energy Requirements for Dewatering

Total energy requirements for sludge dewatering, including both direct and indirect energy, are summarized in Figure 8-1. As shown, processes which utilize polymer conditioning have the lowest total energy requirements.

When selecting a sludge dewatering system, it is important to evaluate not only the energy required for dewatering, but the overall energy requirements for sludge treatment and disposal. There are cases where the selected dewatering process consumes more energy than other alternatives, but the total sludge treatment and disposal energy requirements are lower. In some instances, the most cost-effective dewatering alternative may require more energy than other alternatives. In such cases an energy sensitivity analysis should be made to determine the effect of escalating energy costs. For example, if energy costs outpace inflation by 10 or 20 percent over the next 10 years, the cost-effective alternative at current energy prices may no longer be cost-effective at future energy prices.

8.5 References

1. Wesner G. M., et al., "Energy Conservation in Municipal Wastewater Treatment," USEPA - Office of Water Program Operations, Washington, D. C., 20460, MCD-32, EPA-430/9/77-011, March 1978.

2. Zenz, D. R., et al., "Evaluation of Unit Processes for Dewatering of Anaerobically Digested Sludge at Metro Chicago's Calumet Sewage Treatment Plant," The Metropolitan Sanitary District of Greater Chicago, October 1976.

3. Sawyer, Bernard; Watkins, Robert; and Lue-Hing, Cecil, "Evaluation of Unit Processes for Mechanical Dewatering of Anaerobically Digested Sludge at Metro Chicago's West-Southwest Sewage Treatment Plant," Paper presented at the 31st Annual Purdue Industrial Waste Conference, May 1976. (Authors are with the Research and Development Department of The Metropolitan Sanitary District of Greater Chicago)

4. Trubiano, R., Bachtel, D., LeBrun, T., and Horvath, R., "Parallel Evaluation of Low Speed Scroll Centrifuges and Belt Filter Presses for Dewatering Municipal Sewage Sludge," Draft EPA Report, Contract 68-03-2745, 1981. (Authors are with County Sanitation Districts of Los Angeles County, Whittier, California)

5. Personal Communication, Thomas J. LeBrun, Supervisor of Research Section, Joint Water Pollution Control Plant, County Sanitation Districts of Los Angeles County, Carson, California, June 1982.

6. CH_2M-Hill, "Michelson Water Reclamation Plant - Engineering Report for Dewatering Equipment Selection," Irvine Ranch Water District, Irvine California, June 1979.

7. Tavery, M. A., "Evaluation of Sludge Dewatering Equipment at the Metro Denver Sewage District," paper presented at the Colorado AWWA-WPCA Technical Activities Committee, May 3, 1979. (Author is with the Metropolitan Denver Sewage Disposal District No. 1, Denver, Colorado).

8. John Carollo Engineers, "Design Memorandum No. 5 - Dewatering Methods," County Sanitation Districts of Orange County, Fountain Valley, California, April 1979.

9. Consoer, Townsend & Associates Ltd., "Draft Project Report - Sludge Processing Facilities Plan For the Cities of San Jose and Santa Clara, California," May 1980.

10. Ingersoll-Rand, Unpublished data on filter press and centrifuge test results, 1977 - 1979. (Information received from Wayne B. Gendron, Ingersoll-Rand, Nashua, New Hampshire)

11. Personal communication, Brian Scholes, KHD Humboldt Wedag, Atlanta, Georgia, April 1981.

12. Personal communication, Gordon Wilson, Ingersoll-Rand sales representative, from Tom Ponton Industries, Santa Fe Springs, California, June 1979.

13. Personal communication, Dick Gray, Komline Sanderson Engineering Corporation, Peapack, New Jersey, July 1982.

14. "Process Design Manual For Sludge Treatment and Disposal," USEPA - Municipal Environmental Research Laboratory, Cincinnati, Ohio, 45268, EPA-625/1-79/011, September 1979.

Chapter 9

SUMMARY OF RECENT SIDE-BY-SIDE COMPARISONS OF DEWATERING PROCESSES AT TEN TREATMENT PLANTS

9.1 Introduction

In this chapter, the evaluation studies of dewatering alternatives conducted by ten large utilities in various parts of the U.S. are summarized. In each of the evaluations, pilot tests and full-scale field tests of at least two and sometimes three or four different types of mechanical dewatering processes were considered.

Of the ten evaluations, four recommended belt filter presses, four recommended solid bowl centrifuges, one recommended a fixed volume recessed plate filter press, and for one study no recommendation was made. A summary of these studies showing the equipment evaluated and the type of dewatering equipment recommended by the evaluation is shown in Table 9-1.

These ten studies are presented to show the manner in which different large utilities approached the selection of dewatering equipment. Although eight of the ten utilities selected centrifuges or belt presses, this does not necessarily imply that all utilities of comparable size should select one of these two types of dewatering devices. Each application is unique, and decisions on dewatering equipment selection should be made using the approach recommended in Chapter 6.

9.2 County Sanitation Districts of Los Angeles County (California)

During a two-year period from 1977 through 1979, several pilot-scale and some full-scale mechanical dewatering equipment including belt filter presses, centrifuges, and a diaphragm filter press were tested at the Joint Water Pollution Control Plant in Carson. At the time of the dewatering evaluations, no method of ultimate disposal had yet been selected.

Six different manufacturers sent pilot-scale belt filter presses to the Sanitation Districts for testing (1):

Ashbrook-Simon-Hartley Winklepress
Parkson Magnum Press
Tait-Andritz SDM
Carter Belt Filter Press
Komline-Sanderson Unimat
Envirotech Eimco High-Solids Press

TABLE 9-1

SUMMARY OF RESULTS FROM TEN EVALUATIONS OF MECHANICAL DEWATERING EQUIPMENT

Utility	Equipment Evaluated*	Recommended Dewatering Equipment
County Sanitation Districts of Los Angeles County - References 1, 3, and 4	BFP, C(LS), C(HS), DFP	Centrifuge--Low Speed with hydraulic back drive
County Sanitation Districts of Orange County (Ca.) - References 6, 7, and 8	BFP, C(LS), FP	Belt Filter Press
Irvine Ranch Water District (Ca.) - Reference 9	BFP, C(LS)	Belt Filter Press
Metropolitan Denver Sewage Disposal District No. 1 - References 10, 11, 12, 13, and 14	BFP, C(LS), C(HS), VF	Centrifuge
Metropolitan Sanitary District of Greater Chicago - References 15, 16, and 17	BFP, C(LS), C(HS), VF	Centrifuge--Either low speed or high speed
Middlesex County Sewerage Authority (N.J.) - References 18 and 19	BFP, DFP, FP	Belt Filter Press
Milwaukee Metropolitan Sewerage District - References 20 and 21	BFP, C(HS), FP	Fixed Volume Filter Press
Nassau County (N.Y.) - References 22, 23, and 24	BFP, DFP, FP	Belt Filter Press
San Jose--Santa Clara Water Pollution Control Plant - References 25 and 26	BFP, C(LS), C(HS), DFP, FP, VF	Centrifuge--Either low speed or high speed
District of Columbia Wastewater Treatment Plant at Blue Plains - References 27 and 28	BFP, DFP, FP, VF, VF Retrofit	Preliminary evaluation--no recommendation

*BFP = Belt Filter Press
C(HS) = High Speed Centrifuge
C(LS) = Low Speed Centrifuge
DFP = Diaphragm Filter Press
FP = Fixed Volume Filter Press
VF = Vacuum Filter

The Eimco High-Solids Press is not actually a belt filter press but rather a vacuum filter which advances sludge cake intermittently to a pneumatically operated press. Use of the unit was considered infeasible because of the requirement for large amounts of lime and ferric chloride for conditioning. The other five belt filter presses were tested on a number of blends of digested primary and waste activated sludge (WAS). With a blend of 30 percent primary and 70 percent WAS, cake solids concentrations of 20 percent and solids recoveries of 90 percent were obtained on the Winklepress and the Magnum Press. Cake solids concentrations on the Andritz SDM were 16 to 17 percent. Polymer requirements for the belt filter presses were 3 to 6 g/kg (6 to 12 lb/ton) dry solids. Descriptions, sketches, and differences in design and operation for many of the different manufacturers' belt filter presses are presented in an EPA Technology Transfer Seminar Publication (2).

Three different types of pilot-scale centrifuges were tested (1):

Sharples PM-35000 High-Speed Solid Bowl (Scroll) Centrifuge
Kruger 250 Low-Speed Solid Bowl (Scroll) Centrifuge
Robatel Basket Centrifuge (existing)

The Robatel basket centrifuge required only 2 to 2.5 g/kg (4 to 5 lb/ton) of polymer but could produce a cake solids concentration of only 15 to 20 percent on blends consisting of 30 to 50 percent WAS. Also, the basket centrifuges used a batch operation and required much operator and maintenance attention. Because of high cake disposal and O&M costs, the basket centrifuge was not considered further for dewatering blends of digested primary and WAS.

The Sharples centrifuge produced cake solids concentrations of 22 to 26 percent solids with 94 to 99 percent solids recoveries for the 100 percent digested primary sludges. The polymer doses ranged from 2 to 3 g/kg (4 to 6 lb/ton). For a 60 percent primary and 40 percent WAS mixture, cake solids concentrations were 16 to 20 percent, recoveries 94 to 97 percent, and polymer dosages 2.5 to 4.5 g/kg (5 to 9 lb/ton).

The Kruger centrifuge had problems with plugged centrate tubes after a few months and operation was judged to be unpredictable and unreliable. It was estimated that on 100 percent digested primary sludge a cake solids concentration of 24 to 27 percent and 90 percent solids recovery could be achieved using a polymer dosage of 3.5 to 4.0 g/kg (7 to 8 lb/ton). On a mixture of 70 percent primary and 30 percent WAS, polymer requirements were 7.5 g/kg (15 lb/ton) to achieve adequate solids recoveries.

The Ingersoll Rand Lasta automatic diaphragm filter press was evaluated in a four chamber pilot unit. The Lasta press produced sludge cakes ranging from 40 to 53 percent solids, however, lime and ferric chloride requirements were very high. On a 50:50 blend of digested primary and WAS, a cake solids concentration of 49 percent was produced, however 47 percent lime and 21 percent ferric chloride were required for conditioning, resulting in a corrected cake sludge solids of only 26 percent. Use of the Lasta diaphragm filter press was considered impractical because of the large amounts of conditioning chemicals required. Belt filter presses and scroll centrifuges proved to be the most effective dewatering devices.

Following the extensive pilot-scale testing study, two belt filter presses and two low speed scroll centrifuges were selected for full-scale parallel evaluation (3):

Ashbrook-Simon-Hartley Winklepress Model 3V - 2.2 m belt width
Parkson Magnum Press Model MP50 - 2.0 m belt width
Bird HB5900 Centrifuge - 0.9 m (36 in) bowl diameter
Kruger 280 MC Centrifuge - 0.8 m (32 in) bowl diameter

The Sanitation Districts did not evaluate full-scale high speed centrifuges such as are manufactured by Sharples. They chose to evaluate only low speed centrifuges because they felt low speed centrifuges had lower energy, polymer and maintenance time requirements for their operation (3).

The Magnum Press consistently produced about 4% drier cakes for all the sludge blends tested than did the Winklepress. However, polymer dosages for the Winklepress were consistently 1.5 to 2.0 g/kg (3 to 4 lb/ton) lower than for the Magnum Press. Solids recovery was also considerably better on the Winklepress. Because of superior performance of the Winklepress, it was used in comparisons with the centrifuge. Cake solids of 23 percent were achieved on the Winklepress for a 75/25 blend of digested primary to WAS with a polymer dose of 4.5 g/kg (9 lb/ton). On a 50/50 blend, the Winklepress produced a 22 percent cake with 89 percent solids recovery and a polymer dose of 7.3 g/kg (14.6 lb/ton).

The Bird centrifuge produced 19 percent cake solids and 95 percent recovery at a polymer dose of about 6 g/kg (12 lb/ton) on the 50/50 blend of digested primary and WAS. Although the operation of both the belt filter press and the centrifuge was judged to be unpredictable and fairly unstable on the 50/50 blend, it appeared on the average that the belt filter press could produce a drier cake but required more polymer than the centrifuge.

The results of the test work led to the following conclusions: 1) within the accuracy of the tests, there was no significant cost advantage for either the belt filter presses or the low speed scroll centrifuges equipped with automatically controlled hydraulic backdrives; the slightly drier cakes produced by belt filter presses and their lower power costs were offset by their increased polymer requirements; 2) low speed scroll centrifuge operation may be more difficult for the novice operator to understand because the process was not as visible as it was for the belt filter press; the centrifuges also produced more noise and vibration; 3) belt filter presses were found to require greater maintenance due primarily to a belt life of only three to six months; were susceptible to acute loss of solids recovery due to changes in sludge quality or flow; required greater operator attention and frequent washdown; emitted noticeable odors; and required prescreening of sludge to remove large objects and fibrous materials; and 4) low speed scroll centrifuges with hydraulic backdrives were judged to be preferable to belt filter presses for dewatering digested sewage sludge (3).

As a result of the side-by-side testing evaluation, the Districts advertised for bids for low-G scroll centrifuges in 1980. In August 1980, the bid was awarded to KHD Humboldt Wedag to provide 19 S-4-1 centrifuges to dewater an anaerobically digested 50:50 blend of primary and WAS. An 8.8 cu m/s (200 mgd) pure oxygen activated sludge plant to be completed in 1983 will generate WAS to be dewatered along with the existing primary sludge. The centrifuges, to be installed in two separate buildings with nine centrifuges in one building and ten in another, are expected to be on-line by late 1983 or early 1984 (4).

In October and November 1981 a Sharples PM 35000 high G solid bowl centrifuge and a KHD Humboldt Wedag S3-0 low G centrifuge were tested at the District 32 water reclamation plant in Valencia, California (4). The Sharples centrifuge was equipped with all of the Polymizer features and a manual version of the eddy current brake, and the Humboldt centrifuge was equipped with a hydraulic backdrive. The centrifuges were tested several weeks apart on an anaerobically digested 50:50 blend of primary and WAS. The feed sludge quality was somewhat different at the time the two machines were tested:

	Feed Solids	Volatile Solids
Sharples	2.7% TS	68%
Humboldt	3.0% TS	66%

At the start of the tests, the Districts' criteria for acceptable performance was a minimum cake solids of 15% and solids recovery of 95%. The Sharples machine never had a solids capture above 90%, and the cake solids content ranged up to 11.5 percent for solids captures of 80 to 90% and polymer dosages of 3.5 to 7 g/kg (7 to 14 lb/ton). The Humboldt machine was able to produce a cake solids concentration up to 16 percent with a 91 percent capture and a polymer dosage of 7 g/kg (14 lb/ton).

Based upon the test results, the Humboldt centrifuge was rated as a viable alternative for the dewatering facility and the Sharples centrifuge was rated as unacceptable. It should be noted that the centrifuge tests were not simultaneous side-by-side tests. A representative from Sharples described the difference in sludge quality (as noted by volatile solids content) as the major reason for the performance differences between the machines (5).

9.3 County Sanitation Districts of Orange County (California)

An evaluation of dewatering processes was undertaken by the Orange County Sanitation Districts during 1979 and 1980. The dewatering equipment processed an anaerobically digested mixture of primary and WAS consisting of about 70 percent primary and 30 percent WAS. The sludge was generated from a 6.0 cu m/s (138 mgd) primary treatment plant and a 2.0 cu m/s (46 mgd) activated sludge plant. At the time of the dewatering evaluation, ultimate sludge disposal alternatives had not yet been evaluated. A desktop cost evaluation of centrifuges, filter presses and belt filter presses was made in a prior design memorandum in 1979, and the results are shown in Table 9-2 (6).

Almost concurrently, pilot-scale field tests using one-meter presses were conducted on three different belt filter presses (7), to see if the actual belt press performance matched the design criteria in the earlier memorandum.

TABLE 9-2

DESIGN CRITERIA AND COST COMPARISON FOR DEWATERING AT COUNTY SANITATION DISTRICTS OF ORANGE COUNTY (CALIFORNIA)

	Centrifuge	Filter Press	Belt Filter Press
Unit Used	Bird Model HB 64000	Passavant Model 20	Ashbrook "Winklepress" Model 3V
No. Units Required	8	4	12
Rated Capacity	12.6 l/s (200 gpm)	56 m^3 (2,000 cu ft)	7.9 l/s (125 gpm)
Cake Solids	22%	38%	24%
Solids Capture	90%	95%	90%
Chemical Use	6 g polymer/kg dry solids	200 g lime/kg dry solids 80 g FeCl$_3$/kg dry solids	6 g polymer/kg dry solids
Power Usage	65 kw/unit	57.3 kwh/Mg solids	6 kw/unit
Construction Costs - Dewatering	$5,082,000	$8,805,000	$4,572,000
Construction Costs - Storage	860,000	725,000	820,000
Annual Operation and Maintenance Costs	1,057,000	1,230,000	1,100,000
Dewatering Cost[1] - $/Mg ($/ton)	43.55 (39.50)	63.16 (57.29)	42.76 (38.78)
Disposal Cost[1] - $/Mg ($/ton)	20.77 (18.84)	11.81 (10.71)	18.52 (16.80)
Total Sludge Handling Costs[1] - $/Mg ($/ton)	64.32 (58.34)	74.97 (68.00)	61.28 (55.58)

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[1] Present worth analysis using 6 7/8 % interest for a 10-year planning period.

The results of the field tests shown in Table 9-3, compared favorably with the previously established design criteria and belt filter presses were selected as the recommended dewatering method (7).

TABLE 9-3

RESULTS FROM FIELD TESTING OF BELT FILTER PRESSES AT COUNTY SANITATION DISTRICTS OF ORANGE COUNTY (CALIFORNIA)

Press	Feed Rate l/s	Feed Solids %	Polymer Average Dose g/kg	Average Capture %	Avg. Cake Solids %	Primary/ Secondary Sludge
EIMCO	3.22	2.13	4.4	96.6	19.34	69/31
Tait-Andritz	3.28	2.33	6.0	94.7	23.33	75/25
Winkle	3.30	2.33	5.9	95.6	21.50	75/25
Design	3.32	2.7	6.0	90.0	24.00	75/25

Four 2.2-m Winklepresses will be installed at Plant No. 1 by about December 1982 to dewater a digested blend of primary and air waste activated sludge. In addition, ten 2.2-m Winklepresses began operation in June 1982 at Plant No. 2 dewatering digested primary sludge. Preliminary results indicate that a 30% solids cake can be achieved at a polymer dosage of 3.5 to 4 g/kg (7 to 8 lb/ton) and that up to a 40% cake can be obtained at 6.5 g/kg (13 lb/ton) polymer. By late 1982 a new pure oxygen activated sludge plant will be operating, and the belt presses will be used to dewater a blend of digested primary and oxygen WAS. The belt presses at both plants will replace existing high G and low G solid bowl centrifuges. It is currently planned that the belt presses will be operated during the period from 10 pm to 12 noon four or five days per week as required, to keep the power costs as low as possible during the peak electrical demand period (8).

9.4 Irvine Ranch Water District (California)

During 1979 the Irvine Ranch Water District conducted a brief dewatering equipment evaluation for the Michelson Water Reclamation Plant (9). At the time of the evaluation, about 4,540 dry kg/d (5 tons/d) of aerobically digested, centrifuge-dewatered sludge were being transported to a sanitary landfill for disposal. The existing low speed Bird centrifuges were at that time producing a 11-13% solids cake, with 95% solids capture and a polymer cost of $44/dry Mg ($40/dry ton).

When the requirements for landfill disposal were raised to a minimum cake solids of 15 percent, an equipment evaluation was undertaken. The criteria for selecting new dewatering equipment were to produce a minimum of 15 percent cake solids at substantially lower operating costs than were possible with the existing centrifuges.

Four types of dewatering equipment were discussed as possible options for the Michelson Plant: existing centrifuges; belt filter presses; vacuum filters; and filter presses. Vacuum filters were not evaluated in detail because of their typical requirement for large quantities of lime and ferric chloride. Filter presses were eliminated early from consideration because of their high costs and requirements for lime and ferric chloride. This left belt filter presses to be compared with the existing centrifuges.

A pilot test of a 1-m Winklepress on site proved that a belt press could achieve a dewatered cake of 15 to 17 percent solids at a polymer cost of about $33/Mg ($30/ton) and a capture of 94 to 95 percent. An economic evaluation showed that leasing a 2-m belt press and operating an interim facility would reduce the annual cost of operation from about $480,000 to about $280,000. In addition, it was recommended that two belt filter presses be purchased if the leased unit operated satisfactorily for at least two months. Satisfactory operation of the belt filter press was obtained, and the existing centrifuge building was modified by the addition of two 2.2-m Winklepresses.

9.5 Metropolitan Denver Sewage Disposal District No. 1 (Colorado)

The Metro Denver Sewage District currently operates a 7.5 cu m/s (172 mgd) activated sludge plant. In 1979 the District completed an evaluation of three types of sludge dewatering equipment: belt filter presses, centrifuges and vacuum filters (10). The study was undertaken because the District could not process all the anaerobically digested sludge produced with six existing coil spring vacuum filters. At the time of the evaluation, the sludge disposal option chosen for the treatment plant was an agricultural reuse system. An alternate form of dewatering and disposal, however, was required on an interim basis. The staff recommended that pilot-scale production models of centrifuges and belt presses be brought to the District for on-site testing so the operational characteristics and costs could be evaluated and compared with the vacuum filters.

Two manufacturers of belt presses, the Parkson Corporation and the Tait-Andritz Company, and two firms which manufacture centrifuges, the Pennwalt-Sharples Corporation and Bird Machine Company, were invited to demonstrate their pilot units at the District. The above companies were selected primarily on their ability to provide equipment for evaluation prior to January 1979. The pilot equipment was operated by the associated companies under the supervision of the District's Operations Control Specialist. The average performance and costs of the belt press, centrifuge and vacuum filter are compared in Table 9-4 (10).

TABLE 9-4

RESULTS AND OPERATING COSTS FROM FIELD TESTING AT METROPOLITAN DENVER SEWAGE DISPOSAL DISTRICT NO. 1

	Belt Filter Press	Centrifuge	Vacuum Filter
Feed Sludge,			
% TS	3.1	3.0	3.1
% VS	62	64	62
Alkalinity, mg/l	5,200	4,820	5,180
Chemical Conditioning System	$FeCl_3$ & Anionic Polymer	Cationic Polymer	Cationic Polymer
Cake Solids, % TS	17.2	13.0	9.5
Solids Recovery, %	90-95	90-95	75-80
Chemicals, $/Mg ($/ton)	48.14 (43.66)	22.19 (20.13)	54.12 (49.09)
Labor, $/Mg ($/ton)	6.48 (5.88)	4.32 (3.92)	6.48 (5.88)
Power, $/Mg ($/ton)	0.28 (0.25)	3.09 (2.80)	1.59 (1.44)
Water, $/Mg ($/ton)	2.01 (1.82)	0.00 (.00)	0.36 (0.33)
Haul, $/Mg ($/ton)	26.79 (24.30)	29.91 (27.13)	40.68 (36.90)
TOTAL OPERATING COST, $/Mg ($/ton)	83.70 (75.91)	59.51 (53.98)	103.24 (93.64)

Based upon fairly limited data it appears that the Sharples high G centrifuge produced either a drier cake or used somewhat less polymer than the Bird low G centrifuge (11). The Sharples PM 35,000 centrifuge was able to produce cake solids contents of 10-11 percent with 8 lb/ton polymer, 11.5 - 12.5 percent with 9 lb/ton polymer and at a 50 percent lower flow rate, 14-14.5 percent solids with 12 lb/ton polymer. The Bird HB 2500 centrifuge was able to produce cake solids contents of 10-11 percent with 9-12 lb/ton polymer and, at a 50 percent lower flow rate, 12.5 - 13.5 percent with 11-12 lb/ton polymer.

The chief difference between the belt press, the centrifuge, and the existing vacuum filter was the chemical conditioning. The sludge fed to the centrifuge and vacuum filter was flocculated using a cationic polymer. In the belt press, the use of the cationic polymer produced large, fluffy flocs that squeezed out the sides of the belt in the low pressure zone and squeezed into the belt mesh in the high pressure area. This hydrophilic characteristic of the floc contributed to wet cakes and poor solids recoveries. The Parkson Corporation had tested successfully a ferric chloride-anionic polymer combination in their laboratory. When this dual chemical system was applied to the pilot belt press, there was a large improvement in cake solids (13 to 19%) and in solids recoveries (85 to 93%). It was also significant that the sludge loadings increased 50% after switching to the dual conditioning.

As indicated, the centrifuge had the lowest overall operating cost. The belt press, using the dual chemical system, had a high cost due to the use of ferric chloride, which accounted for 80% of the chemical cost. Vacuum filtration had the highest chemical cost. Based upon the field test results and final evaluation, solid bowl centrifuges were selected as the recommended method of dewatering. On August 18, 1981, Metro Denver received bids from two low G manufacturers and one high G manufacturer to provide one large solid bowl centrifuge to dewater an anaerobically digested blend (45 percent primary: 55 percent oxygen WAS). The contract was awarded to KHD Humboldt Wedag to provide one S-6 low G centrifuge to dewater 32 l/s (500 gpm) to 16 percent solids or to thicken 47 l/s (750 gpm) to 6 percent solids. The centrifuge has been installed and was operational by June 1982. Although the one centrifuge can handle the total sludge flow, consideration is being given to purchasing a second centrifuge for standby capacity and flexibility. Current plans are to dispose of digested thickened sludge by land application or to dewater sludge for possible composting when land is unavailable for application of liquid sludge (12).

Two manufacturers of diaphragm filter presses also conducted laboratory or bench-scale dewatering tests on the Metro Denver sludge, although at a later date than the field-testing of vacuum filters, belt presses and centrifuges. Ingersoll Rand conducted laboratory-scale tests on April 20-21, 1981 on a digested sludge which contained 3.0 percent total solids, 2.7 percent suspended solids, and 27.9 percent ash. The following results were obtained (13):

Conditioning Chemicals	Feed Time	Solids Loading Rate	Cake Solids	Solids Capture
30% Lime, 10% $FeCl_3$	5 min	1.68 kg/sq m/hr (0.34 lb/sq ft/hr)	37.9%	99.5%
30% Lime, 10% $FeCl_3$	7 min	1.85 kg/sq m/hr (0.38 lb/sq ft/hr)	33.4%	99.5%
30 lb/ton polymer,* Pfizer X-99	---	0.77 kg/sq m/hr (0.16 lb/sq ft/hr)	20.7%	---

*These results with polymer were considered unfavorable for pressure filtration by Ingersoll Rand.

Envirex also conducted bench-scale diaphragm filter press tests, with the following results obtained (14):

Conditioning Chemicals	Feed Solids	Cake Solids	Solids Capture
15% Lime, 5% $FeCl_3$	5.8%	34%	99.8%
30% Lime, 10% $FeCl_3$	3.0%	32%	99.8%

9.6 Metropolitan Sanitary District of Greater Chicago

During 1976 the District completed two evaluations of mechanical dewatering methods, one for the 9.6 cu m/s (220 mgd) Metro Chicago Calumet Sewage Treatment Plant (15) and one for the 52.6 cu m/s (1200 mgd) Metro Chicago West-Southwest Plant (16). Following dewatering the sludge was stored and dewatered on land to greater than 30 percent solids before distribution to the general public. Similar dewatering equipment was field-tested at both locations:

- Carter Belt Filter Press (Pilot Scale)
- Passavant Vac-U-Press (Full Scale)
- Komline Sanderson Vacuum Filter (Existing Full Scale)
- Sharples Centrifuge (Pilot Scale)
- Bird Centrifuge (Pilot Scale)

At the Calumet Plant the dewatering results shown in Table 9-5 were obtained with an anaerobically digested mixture of 30 to 45 percent primary sludge, and 55 to 70 percent WAS, and a sludge feed solids concentration of about 2 to 3 percent (15).

TABLE 9-5

RESULTS OF FIELD TESTING AT THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO CALUMET PLANT

	CAKE SOLIDS %	SOLIDS CAPTURE %	CHEMICAL COSTS $/dry Mg	SOLIDS LOADING	POWER USAGE kwh/dry Mg
Carter BFP	22.2	85.7	11.58	28.1 kg/sq m/hr	28
Passavant BFP	19.0	90.0	11.41	6.1 kg/sq m/hr	46
K.S. Vac. Fil. ($FeCl_3$)	16.6	89.0	15.44	10.3 kg/sq m/hr	1544
K.S. Vac. Fil. ($FeCl_3$ + CaO)	19.2	95.0	20.95	20.8 kg/sq m/hr	772
Sharples Cen.	20.1	93.2	7.72	87.2 kg/hr	97
Bird Cen.	19.9	98.8	16.32	177 kg/hr	58

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*1974 Prices

At the West-Southwest Plant the dewatering results shown in Table 9-6 were obtained with an anaerobically digested mixture of 10 percent primary and 90 percent WAS and a feed solids content of 3.5 to 4 percent (16).

TABLE 9-6

RESULTS OF FIELD TESTING AT THE METROPOLITAN SANITARY DISTRICT OF GREATER CHICAGO WEST - SOUTHWEST PLANT

	CAKE SOLIDS %	SOLIDS CAPTURE %	CHEMICAL COSTS* $/dry Mg	SOLIDS LOADING	POWER USAGE kwh/dry Mg
Carter BFP	12.1	82.0	17.64	20.5 kg/sq m/hr	39
Passavant BFP	14.2	90.0	13.89	6.8 kg/sq m/hr	41
K.S. Vac. Fil. ($FeCl_3$)	13.1	92.0	13.23	35.2 kg/sq m/hr	453
K.S. Vac. Fil. ($FeCl_3$ + CaO)	15.5	92.5	13.78	61.1 kg/sq m/hr	272
Sharples Cen.	15.3	96.4	13.67	85.4 kg/hr	87
Bird Cen.	17.1	97.6	13.56	95.3 kg/hr	235

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*1974 Prices

At the West-Southwest Plant, centrifuges produced the driest cake and achieved the highest solids capture at chemical conditioning costs approximately equal to the other unit processes tested. Based upon the test results, centrifuges were selected for the West-Southwest Plant.

At the Calumet Plant, centrifuges were selected because the percent solids recovery was higher than for the belt filter presses, and the cake solids concentration was nearly as high as that produced by the Carter belt press. Also, the Sharples centrifuge had the lowest chemical cost of the devices evaluated.

Eleven Sharples PC 81,000 high G centrifuges were installed at the West-Southwest Plant by January 1981 to dewater 159 dry Mg/d (175 tons/d) of digested sludge. The dewatering facility first achieved full production on a monthly basis in August 1981. Current operation of the facility consists of centrifuge dewatering of a portion of the digested sludge (10% primary:90% WAS) to a nominal 15 percent solids, then blending it with the remaining digested sludge at 4 percent solids to form a 7-8 percent sludge mixture. The sludge mixture is barged 322 km (200 mi) for land disposal on a 6,070 ha (15,000 ac) farm (17).

Five HS-805M high G centrifuges supplied by Ishikawajima-Harimic Heavy Industries Co. of Tokyo, Japan (IHI) through Marubeni America Corporation were installed at the Calumet Plant by January 1982 to dewater 91 dry Mg/d (100 tons/d) of digested sludge. The dewatering facility had not yet begun full-scale operation as of May 1982. Based upon test results and bid performance specifications it is expected that a dewatered cake solids concentration of about 20 percent will be produced on the digested sludge (30% primary:70% WAS). It is expected that the dewatered sludge will be further dewatered in lagoons to about 50% solids before disposal in landfills (17).

9.7 Middlesex County Sewerage Authority (New Jersey)

During 1978 the Middlesex County Sewerage Authority pilot tested four filter presses and four belt filter presses for sludge dewatering (18). The units tested were:

Passavant High-Pressure Fixed Volume Filter Press (Pilot Scale)
Nichols Low-Pressure Fixed Volume Filter Press (Bench Scale)
Ingersoll Rand Lasta Diaphragm Filter Press (Pilot Scale)
Rexnord Diaphragm Filter Press (Bench Scale)
Ashbrook-Simon-Hartley Belt Filter Press
Komline-Sanderson Belt Filter Press
Parkson Belt Filter Press
Tait-Andritz Belt Filter Press

During the testing period the feed sludge varied from 2.4 to 4.5 percent total solids concentration. A mixture of raw primary and WAS on about a 50:50 ratio was used for the testing. The test results shown in Table 9-7 were obtained during the field scale testing.

TABLE 9-7

TEST RESULTS AT
MIDDLESEX COUNTY SEWERAGE AUTHORITY

Unit	Cake Solids* %	Chemical Requirements
Filter Presses		
Recessed Plate Presses		
High-Pressure	36	18% Lime, 7% $FeCl_3$
Low-Pressure	30 - 34	18% Lime, 6% $FeCl_3$
Diaphragm Presses	40	20% Lime, 6% $FeCl_3$
Belt Filter Presses	20 - 30	Polymer, $13-18/Mg

*Note: Cake Solids Concentrations include conditioning chemicals.

Both belt filter presses and filter presses were considered to be capable of producing sludge cake suitable for landfilling, composting, starved air combustion, and co-disposal operations. A cost analysis indicated that belt press dewatering was the most economical system from among these disposal alternatives evaluated, and belt filter presses were selected. Although belt filter presses were selected for dewatering, as of July 1982 there are no plans for design and installation of belt presses. Current plans are to continue using barges for ocean disposal of liquid sludge (19).

9.8 Milwaukee Metropolitan Sewerage District (Wisconsin)

Field testing of pilot-scale and full-scale thickening and dewatering equipment was conducted by the Milwaukee Metropolitan Sewerage District at the Jones Island and South Shore Wastewater Treatment Plants during the period from June 1980 to January 1981 (20). The following dewatering units were tested on an anaerobically digested mixture of primary and WAS:

1. Centrifuge
   - Sharples PM-35,000 Polymizer horizontal solid bowl unit
2. Belt Filter Press
   - Passavant 2-m Vac-U-Press
   - Komline-Sanderson 0.5-m Kompress
   - Ralph B. Carter 0.8-m Model 32 unit
3. Fixed Volume Filter Press
   - Passsavant press (four round chambers, each with effective filtration area of 0.56 sq m [6.05 sq ft])
   - Edwards and Jones press (four square chambers, each with effective filtration area of 0.30 sq m [3.21 sq ft])
4. Diaphragm Filter Press (14)
   - Envirex press (six square chambers, each with a total filtration area of 0.97 sq m [10.4 sq ft])

Based on a feed solids concentration of 2.5 to 3.0 percent from the anaerobic digester, both the centrifuge and belt press could produce a cake solids concentration of 18 percent with a 95 percent solids recovery. However, the belt press typically required 50 percent more polymer than the centrifuge - 6 versus 4 g/kg (12 versus 8 lb/ton). The centrifuge option was shown to be 12 percent less costly than a belt press on a present worth basis.

For the filter press tests, with a feed solids concentration of 2.4 percent solids, typically a 41 percent cake solids was achieved using a lime dose of 35% (as CaO) and a ferric chloride dose of 5.5%. Centrifuge thickening the sludge before the filter press reduced the required chemical dosages to

17 to 24 percent lime and to 3.2 to 4.4 percent ferric chloride and produced a cake solids of about 38 percent. Prethickening also increased the machine throughput anywhere from 64 to 125 percent (20). Diaphragm filter press tests produced cake solids concentrations of 35 to 55 percent total solids with solids recoveries greater than 99.5 percent (14).

Fixed volume filter presses were selected as the recommended dewatering process for both the Jones Island Plant and the South Shore Plant in the Milwaukee Solids Handling Studies as of May 1981 (20). At the Jones Island Plant, filter cake would be landfilled in a sludge-only landfill. At the South Shore Plant, sludge storage in a building would be required during winter months. The ability to stack filter press cake in a ten-foot pile with a front-end loader with minimal drainage favored the filter press cake over the centrifuge or belt press cake. There was some concern over applying a filter press cake containing substantial quantities of lime to the alkaline soils available for land application. Thickening ahead of the filter press was recommended, in part because this greatly reduced the quantity of lime required for conditioning.

In May 1982 the District's plans were somewhat different than those described above. For the Jones Island Plant, the current plan is to use filter presses for dewatering primary sludge from primary clarifiers which are not yet constructed. Waste activated sludge will be thickened by solid bowl centrifuges and dewatered on existing vacuum filters for continued production of Milorganite. For the South Shore Plant, the current plan is to use existing flotation thickening of waste activated sludge and centrifugal dewatering of a digested blend of primary and waste activated sludge (21).

9.9 Nassau County (New York)

During 1978 and 1979, a sludge handling demonstration project was conducted as part of the Nassau County Sludge Management Plan to evaluate dewatering and composting of sewage sludge (22). The Cedar Creek Water Pollution Control Plant processes 72.6 Mg (80 tons) of sludge solids per day. Dewatering machines evaluated from the various manufacturers included:

- Komline-Sanderson Belt Filter Press (Unimat) - 0.5 m
- Ashbrook-Simon-Hartley Belt Filter Press (Klam press) - 0.5 m
- Passavant Recessed Plate Filter Press (Pilot Scale)
- Shriver Diaphragm Filter Press (Pilot Scale)
- Envirex Diaphragm Filter Press (Bench Scale)
- Nichols Engineering Diaphragm Filter Press (Full Scale)

Anaerobically digested sludge solids concentrations ranged from 1 to 5 percent and averaged about 2.3 percent. Both the fixed volume recessed plate and diaphragm filter presses were able to dewater the sludge to a solids content of 35 percent or greater (including chemicals). Chemical requirements for all filter presses tested were significantly higher than reported by equipment manufacturers for similar sludge types. The fixed volume recessed plate press required 45 to 67 percent lime and 15 to 27 percent ferric chloride. The

Envirex diaphragm press required 27 to 53 percent lime and 8 to 14 percent ferric chloride. The Nichols diaphragm filter press was able to produce a cake solids content of 31 percent when conditioning with polymer at a dosage of 18.5 g/kg (37 lb/ton). The polymer, however, was an experimental polymer not commercially available. The Nichols Engineering report also recommended the use of a precoat when conditioning the sludge with polymer.

The Komline-Sanderson belt filter press produced a sludge cake of about 20 percent solids, operating on a sludge solids feed of 2.5 percent and an average polymer dosage of 11 g/kg (22 lb/ton) dry solids, for a polymer cost of $43.65/Mg ($39.60/ton). The Ashbrook-Simon-Hartley belt filter press was able to produce a sludge cake of 30 percent solids, but required an average polymer dosage of 23 g/kg (46 lb/ton) dry solids, for a polymer cost of $90/Mg ($82/ton). Thus, by increasing polymer dosage, cake solids as high as 30 percent were achieved with a belt filter press. Advantages of the belt filter press cake were that it had relatively few inert chemical solids and it was easily broken up, which are desirable cake characteristics for disposal either by composting or by incineration.

Based upon the results of the dewatering demonstration and an economic evalution of each treatment alternative, the belt filter press system was selected as the most cost-effective and most compatible with the disposal options considered feasible for implementation (composting or incineration).

A dewatering building housing eight 2.5-m Belt Press Dewatering belt filter presses has been constructed (23), yet the facility was not being operated as of May 1982. There was tremendous public opposition to the plans for dewatering, composting, and landfill disposal, due to the possibility of contaminating the major water aquifer on Long Island. Because of this, the digested sludge is currently barged at 2.5 percent solids 19 km (12 mi) off the coast for ocean disposal. Current plans are for a continuation of this method of sludge disposal (24).

9.10 San Jose-Santa Clara Water Pollution Control Plant (California)

In 1977, a facilities planning study for the handling and disposal of wastewater sludge solids at the 6.26 cu m/s (143 mgd) activated sludge plant was started (25). In a preliminary screening the following devices or methods to achieve the required unit processes were reviewed for the purpose of developing system alternatives.

Unit Process	Method
1. Stabilization	1. Chlorine Oxidation
	2. Lime Treatment
	3. Heat Treatment
	4. Composting Raw Sludge
	5. Aerobic Digestion
	6. Anaerobic Digestion
	7. Aerobic-Anaerobic Digestion

Unit Process	Method
2. Primary Sludge Thickening	1. Centrifuge
	2. Gravity Thickening
	3. Dissolved Air Flotation
3. Conditioning	1. Polymer
	2. Elutriation
	3. Heat Treatment
	4. Ferric Chloride and Lime
4. Sludge Dewatering	1. Rotary Vacuum Filter
	2. Centrifuge
	3. Filter Press
	4. Belt Filter
	5. Sandbed Drying
	6. Asphalt Drying
	7. Drying of Lagoon Sludge
5. Final Disposal	1. Compost and Market Product
	2. Landfill On-Site
	3. Landfill - Off-Site

Primary sludge thickening was considered because during the canning season (July through August), large quantities of primary solids are removed. Primary sludge thickening would reduce the volume of sludge for digestion and was considered as an alternative to increasing digester capacity.

All stabilization alternatives were excluded except anaerobic digestion and lime stabilization primarily because of high costs and incompatibility with existing anaerobic digestion facilities. Elutriation for digested sludge conditioning was eliminated because of incompatibility with existing secondary treatment facilities.

All other methods were retained at this stage of analysis. Several pilot plant and laboratory studies were conducted to obtain information needed for the development and comparison of project alternatives, including anaerobic digestion, heat treatment of digested sludge, mechanical dewatering, primary sludge thickening, lime stabilization, and large scale solar dewatering.

The following types of mechanical dewatering devices were field tested on bench-scale and pilot-scale units during canning and noncanning seasons on an anaerobically digested mixture of primary and waste activated sludge:

1. Centrifuge (high and low speed)
2. Belt Filter Press
3. Filter Press (high pressure fixed volume and diaphragm)
4. Vacuum Filter

The San Jose sludge was found to be difficult to dewater on all types of mechanical dewatering devices. Higher than expected chemical dosages and lower cake solids were experienced. Design criteria developed from these tests are shown in Table 9-8 (25).

TABLE 9-8

DESIGN CRITERIA DEVELOPED FROM LABORATORY AND PILOT-SCALE TESTS AT SAN JOSE - SANTA CLARA WATER POLLUTION CONTROL PLANT

1. Centrifuge (Pilot Scale Tests)	
Cake Solids	15%
Recovery	90%
Polymer Demand	7 g/kg (14 lb/ton) canning season 5 g/kg (10 lb/ton) noncanning season
2. Belt Press (Pilot Scale Tests)	
Cake Solids	20%
Recovery	90%
Polymer Demand	11.5 g/kg (23 lb/ton) canning season 10 g/kg (20 lb/ton) noncanning season
3. Vacuum Filter (Filter Leaf Tests)	
Cake Solids	20%
Recovery	90%
Chemical Demand	10% $FeCl_3$ 30% Lime
4. Filter Press (Bench Scale and Pilot Scale Tests)	
Cake Solids	35%
Recovery	99%
Chemical Demand	27% Lime, 12% $FeCl_3$ canning season 20% Lime, 10% $FeCl_3$ noncanning season

Based on review of available solids handling unit processes and on the results of the pilot studies, fifteen project alternatives were developed. Alternatives were compared on the basis of cost, environmental impact, land use, energy use, reliability and flexibility. In this comparison stage, belt filter presses were considered to have equivalent overall costs as centrifuges but were eliminated from consideration because there was less belt filter operating experience available. Based on this comparison, five alternatives were selected for more detailed analysis:

1) Lagoon Drying, On Site Landfill for all sludge
2) Centrifuge Dewatering, Composting for portion of sludge, Sandbed Dewatering and On Site Landfill for remainder

3) Centrifuge Dewatering to Compost for portion of sludge, Lagoon Drying and On Site Landfill for remainder
4) Filter Press Dewatering, Composting for portion of sludge, Sandbed Drying and On Site Landfill for remainder
5) Filter Press Dewatering, Composting for portion of sludge, Lagoon Drying and On Site Landfill for remainder

These alternatives were more closely compared by determining factors for comparison, assigning a relative weight to each factor and assigning a value for each alternative. The factors used in the final evaluation were:

annual cost
environmental effects
dewatering experience
weather dependency
market constraint
energy
land use
dewatering flexibility
disposal flexibility
chemical use
resource recovery

Alternative 2, consisting of anaerobic digestion for stabilization, a combination of centrifuging, sandbed drying, and lagoon drying for dewatering, and compost/market and landfill for disposal, had the highest total score and was selected as the apparent best alternative system. No preference was made for either high-speed or low-speed centrifuges.

As of May 1982, no design or construction of the recommended dewatering facilities had begun. There were plans to construct additional anaerobic digesters, and this would precede any construction of new dewatering facilities. Current practice is to dispose of digested sludge in on-site sludge lagoons (26).

9.11 Blue Plains Wastewater Treatment Plant (District of Columbia)

In 1976 and 1977, a study was conducted of pilot-scale dewatering devices capable of producing high-solids sludge cakes (27). This study was funded by EPA Region III and EPA's Municipal Environmental Research Laboratory in Cincinnati.

The pilot-scale dewatering processes investigated were:

Vacuum filter
Vacuum filter retrofit (add-on) units - three manufacturers
Belt Press - two manufacturers
Fixed volume filter press - two manufacturers, one high pressure and one low pressure
Diaphragm filter press - three manufacturers

The ultimate plan at the time of this study was to dewater and incinerate the sludge. While the plant had vacuum filters, incinerators had not been obtained. Recent fuel cost increases appeared to have changed the cost-effectiveness of incineration of vacuum filtered sludge cake, and the study was conducted to evaluate several dewatering processes capable of producing cakes with significantly higher solids contents than vacuum filters.

Feed solids to the units averaged 5% total solids with a range of 2.4 to 10%. Several different ratios of raw primary sludge to raw WAS were tested, with emphasis on a 33:67 ratio. Conditioning chemicals investigated were lime, ferric chloride and polymer.

Conclusions of the study (27) were:

Chemical Conditioning

- The lime and ferric chloride dosages required to produce a filterable sludge varied with the percentage of WAS. Fibrous primary sludge filtered quite readily; WAS required greater quantities of conditioners and was more difficult to dewater. Generally, a 3/1 ratio of lime-to-ferric chloride was optimum for conditioning the raw Blue Plains sludge. Bench-scale filterability tests were found to be useful when optimizing and controlling the lime and ferric chloride dosages.

- Polymer conditioning of the raw 33:67 mixture of primary-to-WAS sludge was generally ineffectual. No single polymer was found which could adjust to the daily variations in the quality of sludge received from the primary and secondary treatment processes.

Filter Press-General

- Each of the filter presses was capable of dewatering all sludge ratios and total feed solids in the range of 2.4 to 10% to at least a 30% solids cake. The diaphragm press, however, was the only unit capable of dewatering the marginally conditioned sludges to the 35% solids required for an autocombustible cake.

- Once a minimum chemical conditioning requirement of lime and ferric chloride for adequate dewatering was established, increases in filtration yields (up to 20%) were obtained by slight increases in chemical dosages.

- In all the presses, suspended solids recovery in the filter cake was greater than 99%. The quantity of suspended solids in the filtrate was affected primarily by the type of filter cloth used and the degree of chemical conditioning.

- The filter presses did not satisfactorily dewater polymer conditioned sludges.

- The average specific resistance-to-filtration parameter was correlated directly with filter press yield.

Filter Press - Diaphragm Unit

- Average results for conditioning with 19.6% lime and 6.5% $FeCl_3$, and dewatering a 33:67 mixture of raw primary and WAS were a 38.7% solids cake with a yield between 2.39 and 2.93 kg/sq m/hr (0.49 to 0.6 lb/sq ft/hr). The pumping pressure required to feed the press was always less than 690 kPa (100 psig). The pumping cycle time averaged 17 minutes and was controlled by monitoring the total solids feed rate. A squeezing pressure of 1,470 kPa (213 psig) was generally used. The squeezing cycle time (18 minutes) was controlled by filtering to a specified filtrate flow rate.

- Different filter cloths were tested on both presses. All gave acceptable filtrate quality, but cloth life, resistance to abrasion, etc., were not evaluated.

Filter Press - Fixed Volume Unit

- The high-pressure press (225 psig) had an averge filtration yield of 1.51 kg/sq m/hr (.31 lb/sq ft/hr) and required 62.3% more filtration area than the diaphragm presses to produce equivalent results. The low-pressure press (100 psig) had an average full-scale yield of 1.07 kg/sq m/hr (.22 lb/sq ft/hr) and needed 126.8% more filter area than the diaphragm presses to produce equivalent results.

- Cycle time on the presses averaged 2-3 hours and was determined by filtering to a specified filtrate flow rate.

- The cakes from the fixed volume presses always contained a dry outer section and a wetter inner core. This resulted in a substantial variation in the solids content across the cake.

Belt Press

- Because of the highly variable sludge at Blue Plains, no polymer was found that could adjust to these variations and adequately condition the sludge at all times. The operation of the belt press, therefore, was not consistent.

- With thickened sludge feeds, the press capacity, final cake solids, and polymer consumption were all affected by the percentage of waste-activated sludge. The unit performed best when dewatering high percentages of fibrous, primary sludge.

- Suspended solids recovery in the filter cake averaged only 95%. This was felt to be insufficient due to plant discharge requirements.

Vacuum Filter Retrofit Unit

- The only vacuum filter retrofit device which showed promise was the high-pressure section of the continuous belt press when used to further dewater the vacuum filter cake. Cake solids of 35% were

- achieved in bench-scale work; however, demonstration of the system in a full-scale test was not successful because of problems with feeding the vacuum filtered cake to the press.

Economic Comparison

- The belt press at $35.63/Mg ($32.39/ton) and the vacuum filter at $43.01/Mg ($39.10/ton) provided the lowest cost for dewatering.
- Dewatering costs for each of the filter presses were nearly equal with unit costs of approximately $60.50/Mg ($55.00/ton).

As of July 1982, the Blue Plains plant is vacuum filtering two sludge types: anaerobically digested sludge and raw sludge, which have been conditioned with lime and ferric chloride. Dewatered sludge is composted. Future plans are indefinite, but should incineration become a viable alternative, it is likely the District would elect to dewater by pressure filtration. This choice is because of the desire to produce an autogenous sludge cake (28).

9.12 References

1. "Mechanical Dewatering Study - Los Angeles County Sanitation Districts," LA/OMA Project, Regional Wastewater Solids Management Program, Los Angeles-Orange County Metropolitan Area, September 1980.
2. Harrison, J. R., "Review of Developments in Dewatering Wastewater Sludges," Sludge Treatment and Disposal, Volume 1 - Sludge Treatment, USEPA - Center for Environmental Research Information, Cincinnati, Ohio, 45268, EPA-625/4-78-012, October 1978.
3. Trubiano, R., Bachtel, D., LeBrun, T., and Horvath, R., "Parallel Evaluation of Low Speed Scroll Centrifuges and Belt Filter Presses for Dewatering Municipal Sewage Sludge," Draft EPA Report, Contract 68-03-2745, 1981. (Authors are with County Sanitation Districts of Los Angeles County, Whittier, California)
4. Personal communication, Thomas J. LeBrun, Supervisor of Research Section, Joint Water Pollution Control Plant, County Sanitation Districts of Los Angeles County, Carson, California, June 1982.
5. Personal communication, Richard T. Moll, Manager of Process Engineering, Sharples-Stokes Division, Pennwalt Corporation, Warminster, Pennsylvania, June 9, 1982.
6. John Carollo Engineers, "Design Memorandum No. 5 - Dewatering Methods," County Sanitation Districts of Orange County, Fountain Valley, California, April 1979.

7. "Mechanical Dewatering Study - Orange County Sanitation Districts," LA/OMA Project, Regional Wastewater Solids Management Program, Los Angeles-Orange County Metropolitan Area, September 1980.

8. Personal communication, Blake P. Anderson, Chief of Operations, County Sanitation Districts of Orange County, Fountain Valley, California, June 1982.

9. CH_2M-Hill, "Michelson Water Reclamation Plant - Engineering Report for Dewatering Equipment Selection," Irvine Ranch Water District, Irvine, California, June 1979.

10. Tavery, M. A., "Evaluation of Sludge Dewatering Equipment at the Metro Denver Sewage District," paper presented at the Colorado AWWA-WPCA Technical Activities Committee, May 3, 1979. (Author is with the Metropolitan Denver Sewage Disposal District No. 1, Denver, Colorado).

11. Personal communication, Mary Ann Tavery, Metropolitan Denver Sewage Disposal District No. 1, Denver, Colorado, March 1981.

12. Personal communication, Colin McKenna, Facilities Engineer, Metropolitan Denver Sewage Disposal District No. 1, Denver, Colorado, June 1982.

13. Ingersoll-Rand, "Laboratory Test Report - Denver Metro - Anaerobically Digested Sludge," Ingersoll-Rand Company, Nashua, New Hampshire, April 20-21, 1981.

14. Personal communication, Kenneth A. Pietila, "Detailed Review of Draft Process Design Manual for Dewatering Municipal Wastewater Sludge," February 26, 1982. (Author is with Rexnord in Milwaukee, Wisconsin)

15. Zenz, D. R., et al., "Evaluation of Unit Processes for Dewatering of Anaerobically Digested Sludge at Metro Chicago's Calumet Sewage Treatment Plant," The Metropolitan Sanitary District of Greater Chicago, October 1976.

16. Sawyer, Bernard; Watkins, Robert; and Lue-Hing, Cecil, "Evaluation of Unit Processes for Mechanical Dewatering of Anaerobically Digested Sludge at Metro Chicago's West-Southwest Sewage Treatment Plant," Paper presented at the 31st Annual Purdue Industrial Waste Conference, May 1976. (Authors are with the Research and Development Department of The Metropolitan Sanitary District of Greater Chicago)

17. Personal communication, David R. Zenz, Coordinator of Research, Metropolitan Sanitary District of Greater Chicago, May-June, 1982.

18. Kupper Associates and Metcalf & Eddy, Inc., "Pilot Plant Dewatering Testing For The Recommended Land-Based Sludge Management Plan," Middlesex County Sewerage Authority, New Jersey, January 1979.

19. Personal communication, Allan Jacobs, Vice President, Metcalf & Eddy, Somerville, New Jersey, July 1982.

20. Moser, J.H., et.al., "Milwaukee Water Pollution Abatement Program Solids Handling Study," Milwaukee Metropolitan Sewerage District, May 1981. (Author is with Milwaukee Metropolitan Sewerage District)

21. Personal communication, John H. Moser, Milwaukee Metropolitan Sewerage District, Milwaukee, Wisconsin, May 1982.

22. Greenhorne & O'Mara Engineers," Nassau County Sludge Study Composting and Dewatering Demonstration Program--Final Report," July 1979. (Greenhorne & O'Mara Engineers are in Riverdale, Maryland)

23. Personal communication, Ray Advendt, Greenhorne & O'Mara Engineers, Riverdale, Maryland, May 1982.

24. Personal communication, John J. Pascucci, Department of Public Works, Nassau County, New York, May 1982.

25. Consoer, Townsend & Associates Ltd., "Draft Project Report - Sludge Processing Facilities Plan For the Cities of San Jose and Santa Clara, California," May 1980.

26. Personal communication, Douglas C. Humphrey, Sanitary Engineer, San Jose/Santa Clara Water Pollution Control Plant, San Jose, California, May 1982.

27. Cassel, Alan F. and Johnson, Berinda, P., "Evaluation of Dewatering Devices for Producing High-Solids Sludge Cake," USEPA - Municipal Environmental Research Laboratory, Cincinnati, Ohio, 45268, EPA-600/2-79-123, August 1979.

28. Personal communication, Russ Thomas, Superintendent of District of Columbia's Wastewater Treatment Plant at Blue Plains, Washington, D. C., July 30, 1982.

APPENDIX A

MANUFACTURERS OF DEWATERING EQUIPMENT

During the last several years, a number of well known manufacturers have withdrawn from the production of dewatering equipment, while others have entered the field with new products. Table A-1 presents a listing of suppliers of different dewatering equipment which is intended to be up-to-date and complete, although it is possible that some manufacturers are excluded. Due to the dynamic nature of the equipment manufacturing business, it is probable in the future that some on the list may discontinue making the equipment. References such as the Journal Water Pollution Control Federation, Pollution Equipment News, and Water & Wastes Digest should be consulted for additional suppliers.

This listing is presented as an aid to individuals involved in the selection of equipment, and does not represent an endorsement of any particular manufacturer or piece of equipment by either the EPA or Culp/Wesner/Culp. Suppliers are listed alphabetically, and the order of presentation does not constitute an order of preference.

TABLE A-1

MANUFACTURERS OF DEWATERING EQUIPMENT

CENTRIFUGES

Basket (Imperforate Bowl)

- Ametek
- Robitel
- Sharples
- Western States

Solid Bowl (Decanter or Scroll)

- Alfa Laval
- Bird
- Dorr-Oliver
- Ingersoll Rand (Kruger)
- KHD Humboldt Wedag
- Marubeni America Corporation (IHI)
- Sharples (Polymizer)
- Westfalia

BELT FILTER PRESSES

Low Pressure

- Permutit (DCG/MRP)
- Smith & Loveless (Sludge Concentrator)

High Pressure

- Arus-Andritz (SDM-SM Press)
- Ashbrook-Simon-Hartley (Winklepress & Klampress)
- Belt Dewatering
- Clow (Hydropress)*
- Envirex
- Envirotech (EVT Belt Press)
- Euramia
- Infilco - Degremont (Flocpress)
- Komline - Sanderson (Kompress)
- Koppers (Enelco Von Roll Rollpress)
- Parkson (Magnum Press)
- Passavant (Vac-U-Press)**
- Performance Systems, Inc.
- Ralph B. Carter

VACUUM FILTERS

- Ametek (Industrial only)
- Dorr-Oliver (Industrial only)
- Envirex
- Envirotech
- Ingersoll Rand
- Komline-Sanderson

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*Only a 0.5 meter wide press is available

**Combination press and vacuum type process, available with or without vacuum

TABLE A-1
(Continued)

FILTER PRESS

Fixed Volume Type

- Clow
- Edwards and Jones
- Envirotech (Shriver Press)
- Hoesch
- Koppers - Environmental Development Corporation
- Netzsch
- Passavant
- Performance System, Inc.
- D. R. Sperry and Company
- William R. Perrin Incorporated

Diaphragm Type

- Edwards and Jones
- Envirex (NGK)
- Ingersoll Rand (Lasta)
- Johnson Progress
- Performance Systems, Inc.

DRYING BED SYSTEMS

- U.S. Environmental Products (Rapid Sludge Dewatering System)
- Hendrick Fluid Systems (Wedgewater Filter Bed)
- International Sludge Reduction Company (Vacuum Drying Beds)
- Infilco-Degremont (Vacuum Drying Beds)

APPENDIX B

EXAMPLE CALCULATIONS SHOWING SLUDGE VOLUMES PRODUCED BY DIFFERENT DEWATERING TECHNIQUES

This appendix presents example calculations that (1) show how to use information in the manual; (2) illustrate how to determine sludge cake volumes; and (3) compare the sludge cake volumes produced by different dewatering processes. See Chapter 4, Section 4.4 of the manual for a detailed discussion of the comparisons presented here.

Sludge type: Digested (Primary + WAS), 50:50 Blend
Assume 2,000 lb dry solids

Dewatering Technique	Cake Solids	Chemicals Required
Basket Centrifuge	10-15, Use 13%	6 lb/ton polymer
Solid Bowl Centrifuge	15-21, Use 18%	8 lb/ton polymer
Belt Filter Press	18-23, Use 20%	12 lb/ton polymer
Vacuum Filter	15-20, Use 18%	15% Lime, 4% $FeCl_3$
Fixed Volume Filter Press	35-42, Use 38%	20% Lime, 10% $FeCl_3$
Diaphragm Filter Press	38-47, Use 43%	20% Lime, 10% $FeCl_3$
Drying Beds	15-70, Use 50%	None
Sludge Lagoons	5-40, Use 25%	None
Gravity/Low Pressure Devices	8-12, Use 10%	15 lb/ton polymer

NOTE: The specific gravities used in the following calculations are based upon the addition of lime and ferric chloride with the resultant production of calcium carbonate and ferric hydroxide. The following specific gravities were used to develop the specific gravity of the sludge cake mixture: volatile solids, 1.0; fixed solids, 2.5; ferric hydroxide, 3.4; and calcium carbonate, 2.8. The calculations are based upon the assumption that reaction products are equivalent in weight to the lime and ferric chloride added.

Basket Centrifuge

$$\text{Sludge Cake Volume} = \frac{\overset{\text{Includes chemicals}}{2{,}006\text{ lb dry solids}}}{\underset{\%\text{ solids}}{(0.13)}\ (8.34\text{ lb/gal})\ \underset{\text{Specific gravity of digested sludge cake}}{(1.05)}\ (7.48\text{ gal/cu ft})}$$

$$= 236\text{ cu ft}$$

Solid Bowl Centrifuge

$$\text{Cake Volume} = \frac{2{,}008\text{ lb}}{(0.18)\ (8.34)\ (1.07)\ (7.48)} = 167\text{ cu ft}$$

Belt Filter Press

$$\text{Cake Volume} = \frac{2{,}012\text{ lb}}{(0.20)\ (8.34)\ (1.08)\ (7.48)} = 149\text{ cu ft}$$

Vacuum Filter

$$\text{Cake Volume} = \frac{2{,}380\text{ lb}}{(0.18)\ (8.34)\ (1.07)\ (7.48)} = 198\text{ cu ft}$$

Fixed Volume Filter Press

$$\text{Cake Volume} = \frac{2{,}600\text{ lb}}{(0.38)\ (8.34)\ (1.17)\ (7.48)} = 94\text{ cu ft}$$

Diaphragm Filter Press

$$\text{Cake Volume} = \frac{2{,}600\text{ lb}}{(0.43)\ (8.34)\ (1.19)\ (7.48)} = 81\text{ cu ft}$$

Drying Beds

$$\text{Cake Volume} = \frac{2{,}000\text{ lb}}{(0.50)\ (8.34)\ (1.23)\ (7.48)} = 52\text{ cu ft}$$

Sludge Lagoons

$$\text{Cake Volume} = \frac{2{,}000 \text{ lb}}{(0.25)\ (8.34)\ (1.10)\ (7.48)} = 117 \text{ cu ft}$$

Gravity/Low Pressure Devices

$$\text{Cake Volume} = \frac{2{,}015 \text{ lb}}{(0.10)\ (8.34)\ (1.04)\ (7.48)} = 311 \text{ cu ft}$$

A comparison of the sludge cake volumes produced by the various dewatering processes is tabulated below. The largest cake volume, produced by the gravity/low pressure devices, is used as a basis for comparing the cake volumes. For example, drying beds produce a cake volume which is only 17 percent of the volume produced by the gravity/low pressure devices.

Cake Volume Comparison

	Volume cu ft	Percentage of Gravity/Low Pressure Devices
Basket Centrifuge	235	76%
Solid Bowl Centrifuge	167	54
Belt Filter Press	149	48
Vacuum Filter	198	64
Fixed Volume Filter Press	94	30
Diaphragm Filter Press	81	26
Drying Beds	52	17
Sludge Lagoons	117	38
Gravity/Low Pressure Devices	311	100

APPENDIX C

COST OF DEWATERING EQUIPMENT

C.1 Introduction

This section presents costs for the construction and operation of nine different dewatering processes. These processes in the order that they are presented are:

Basket Centrifuge
Solid Bowl Centrifuge - Low G
Solid Bowl Centrifuge - High G
Belt Filter Press
Vacuum Filter
Filter Press - Fixed Volume
Filter Press - Diaphragm
Sand Drying Beds
Sludge Dewatering Lagoons

For each of these processes, curves are presented for construction cost, process and building energy, diesel fuel, maintenance material costs, labor, and total O&M cost.

C.1.1 Construction Cost

The construction cost curves were developed from data supplied by equipment manufacturers, from actual bid prices, as well as from unit cost take-offs from both actual and conceptual designs. In developing the aggregate construction cost, separate cost estimates were made for eight principal components: (1) excavation and site work; (2) manufactured equipment; (3) concrete; (4) steel; (5) labor; (6) pipe and valves; (7) electrical equipment and process instrumentation; and (8) housing. This approach was used to enhance the accuracy of the cost data. Following development of the construction costs, 15% was added for contingencies which might be expected to be encountered during construction. The construction cost for each unit process is presented as a function of the most applicable design parameter for the process. For example, solid bowl centrifuge and belt press costs are presented in terms of gpm of machine capacity, vacuum filter costs are presented versus square feet of filter surface area, and plate and frame press costs are presented versus cubic feet of machine capacity. This approach of selecting a most applicable design parameter was utilized in both developing and presenting costs, as it allows the costs to be utilized with the greatest degree of flexibility.

The construction cost curves were developed using specific conceptual designs for equipment sizing and layout. In these conceptual designs, single units of equipment were used up to the maximum feasible size, and in larger installations multiple pieces of equipment were used. When preliminary cost analyses are being conducted for smaller installations, however, often multiple units are desired for operational flexibility or standby purposes. In these cases, it is recommended that the cost curve be entered with the desired size, then multiply the cost by the number of units, and finally reduce this cost by a factor of 25-35% for economy of scale.

Construction cost curves are based upon costs experienced in April 1982. It should be recognized that the curve for construction cost is not capital cost. The curve does not include costs for special site work, general contractor overhead and profit, engineering, land, legal, fiscal, and administrative work and interest during construction. These cost items are all more directly related to the total cost of a project rather than the cost of any one of the individual unit processes. These costs are therefore most appropriately added following cost summation of the individual unit processes, if more than one unit process is required. Typically, these costs add 35 to 45%, depending on project size and complexity, to the actual construction costs which are shown in the curves.

C.1.2 Operation and Maintenance Cost

Operation and maintenance requirements were developed from information collected at existing wastewater treatment facilities. For newer types of equipment for which actual full-scale operating data are limited or not available, such as the diaphragm filter press, O&M requirements which are presented are based upon the manufacturers' estimates and the experience of the authors.

Electrical energy requirements are presented for both building-related energy and process energy. Building energy includes heating, cooling, lighting and ventilation, and was based upon the required building size and an annual requirement of 904 kwh/sq m/yr (84 kwh/sq ft/yr). This number represents an average for 21 cities across the U.S., but it is highly variable and depends on heating and cooling requirements. It is suggested that this number be adjusted either upward or downward depending upon locally experienced requirements. Process energy requirements are for motors required to drive and otherwise operate the dewatering mechanism and appurtenant equipment. Process energy requirements will be constant from location to location. Electrical energy costs are expressed in terms of kwh/yr, and, in calculating annual O&M costs, the electrical cost component can be calculated using the local electrical cost in $/kwh. Certain processes such as sand drying beds and sludge dewatering lagoons require use of equipment which utilizes diesel fuel. Curves which are presented for diesel fuel requirements are presented in terms of gallons of fuel required per year.

Maintenance material cost includes the cost of periodic replacement of component parts necessary to keep the process operable and functioning.

Examples of maintenance material items which are required are valves, motors, instrumentation, and other process items of similar nature. Maintenance material cost shown in the curves are based upon April 1982 costs. The maintenance material requirements do not include the cost of chemicals required for process operation since chemical requirements will vary widely from sludge to sludge.

The labor requirement curve includes both operation and maintenance labor and is presented in terms of hours per year. Labor requirements were based upon 24 hour per day operation, including any required clean-up time.

A curve is also presented for total annual O&M costs. This curve was developed using an electrical energy cost of $0.05/kwh, a diesel fuel cost of $0.30/l ($1.15/gal) and a labor cost of $12/hour. If significantly different labor, electrical or diesel fuel costs are experienced, the total annual O&M cost should be adjusted as appropriate.

C.2 Basket Centrifuge

C.2.1 Construction Cost

Basket style centrifuges, because of design and operating features, are ideally suited to dewatering of light and hard-to-handle sludges such as waste activated sludge. Construction costs are for single units at smaller capacities and multiple units at larger capacities. Centrifuge costs are for automatic machines operating on a preprogrammed cycle, an approach which requires only minimal operator attention.

In addition to the basic machines, the costs include equipment for polymer preparation, storage, and application. If other conditioning chemicals are used, the costs would have to be adjusted accordingly. The costs do not include sludge and centrate pumping, sludge conveying, and sludge storage. It was assumed that centrifuges are located in two story concrete block buildings with bottom discharge to trucks or storage bins. Housing requirements were developed from equipment manufacturers' recommended layouts.

Figure C-1 presents construction costs for basket centrifuge installations with total installed machine capacities between 0.15 and 30.7 l/s (3500 and 700,000 gpd).

C.2.2 Operation and Maintenance Cost

Electrical energy requirements were computed from connected and operating horsepower information provided by equipment manufacturers. Basket centrifuge operating horsepower, computed on the basis of a complete cycle involving machine acceleration, sludge feeding, skimming, decelerating, and sludge plowing, averages 40 to 60 percent of the connected horsepower. Electrical power for polymer preparation and feeding is included, but energy for sludge pumps, centrate pumping and sludge conveying equipment is not included.

Maintenance costs were obtained from equipment manufacturers and from operating installations and represent an industrywide average of annual expenditures for maintenance, replacement parts, lubrication, and other consumable items associated with basket centrifuge operation. Maintenance material costs do not include the cost of polymers.

Labor requirements for O&M assume 24 hours per day of operation, with occasional downtime for maintenance as required. The major portion of the operating labor is devoted to machine start-up and adjustment, polymer preparation, and required maintenance.

Electrical requirements and maintenance material costs are shown in Figure C-2, while labor and annual O&M costs are shown in Figure C-3. Annual O&M costs are based upon $0.05/kwh for electricity and $12/hr for labor. Polymer costs are not included in the annual O&M costs. It should be recognized that operation and maintenance costs will vary widely depending on sludge dewatering characteristics and specific operating conditions related to the installation, and appropriate adjustment should be made if conditions vary significantly from those stated above.

C.3 Solid Bowl Centrifuge - Low G

C.3.1 Construction Cost

Costs for low-G solid bowl centrifuges, also commonly called low speed decanter or low speed scroll centrifuges, are shown in Figure C-4. According to the definition used in the cost development, low G refers to centrifuges operating at G forces generally less than 1,100. The costs are based on centrifuges with capacities between 0.63 and 126.4 l/s (10 and 2000 gpm). At capacities greater than 31.6 l/s (500 gpm) multiple units are utilized. Centrifuges were assumed to be equipped with automatically controlled backdrive units. In addition to the cost of the centrifuge, costs are included for polymer storage, preparation, and feed equipment. Although housing is not necessary in moderate climates, housing costs are included. Costs do not include sludge or centrate pumping, or conveyance of the sludge cake from the dewatering building.

C.3.2 Operation and Maintenance

Process energy usage was computed from manufacturers' information on connected and operating horsepower for main drive and back drive units and for polymer preparation and feed equipment. If back drive is not utilized, power costs would decrease by 5 to 20%, depending on the centrifuge manufacturer and the method of controlling the backdrive. The process energy does not include energy related to feed sludge pumping and handling of dewatered sludge.

Maintenance material costs were developed from data furnished by equipment manufacturers. These maintenance material costs are lower than experienced at most operating installations, since the new ceramic tile conveyor tips were assumed to be utilized in this installation.

Labor requirements for operation and maintenance were computed based on 24 hr/day of continuous operation. The major portion of the operating labor is devoted to polymer preparation, machine start-up and adjustment, and occasional maintenance involving machine and motor lubrication. Periodically, extensive maintenance will be required for replacement of the ceramic tile conveyor tips and bearing replacement, although the ceramic tiles should not require replacement more than every 15-20,000 hours of operation.

It is important to realize that the cost curves do not include the cost for purchase of polymer. Polymer usage is highly variable between machines produced by different manufacturers and between different sludge types. Polymer costs must be added separately. Figure C-5 presents process and building electrical requirements as well as maintenance material costs. Figure C-6 presents labor requirements and total O&M costs. Total O&M costs were calculated using $0.05/kwh for electrical energy and $12/hr for labor.

C.4 Solid Bowl Centrifuge - High G

C.4.1 Construction Cost

High G solid bowl centrifuges operate at G forces greater than 1,100. These high G forces are developed by high speed operation up to 3300 rpm. Machine throughput is significantly affected by the polymer dosage, and therefore the construction cost for a given feed rate varies with the polymer dose, as shown in Figure C-7. In this figure, single machines were assumed to be used for feed rates up to 31.5 l/s (500 gpm), with multiple units being used for higher feed rates. All machines are equipped with automatically controlled eddy current backdrive and have sintered tungsten carbide conveyor tips. Polymer storage preparation, and feed equipment is included in the costs, but costs for sludge feed pumping and centrate pumping are not included.

C.4.2 Operation and Maintenance Cost

Process energy was calculated from information supplied by a manufacturer of high G centrifuges and assumes use of an eddy current backdrive. Energy requirements could be reduced between 5 to 20% if the backdrive is not utilized. Included in the process energy requirements are the main drive motor, the eddy current backdrive, and equipment required for polymer preparation and feed. Energy required for feed sludge pumping and handling of the dewatered sludge is not included.

Maintenance material costs are relatively low due to the use of the long lasting sintered tungsten carbide conveyor tips. Maintenance material requirements include replacement of the conveyor tips every 30,000 hours of operation, as well as replacement of other necessary components of the centrifuge and the electrical controls.

Operation and maintenance labor requirements are based upon 24 hours per day of continuous operation. Most operational labor is devoted to polymer preparation and machine start-up and adjustment. Occasional maintenance is required for lubrication, with more extensive maintenance required approximately every 30,000 hours for replacement of the sintered tungsten carbide conveyor tips.

The cost curves presented do not include the cost of polymer. The polymer dosage is highly dependent on the characteristics of the sludge being dewatered, and polymer dosage will also have a great influence on the throughput of the centrifuge, as shown in Figure C-7. Figure C-8 presents process and building electrical requirements as well as maintenance material costs. Figure C-9 presents labor requirements and total O&M costs. Total O&M costs were calculated using $0.05/kwh for electrical energy and $12/hr for labor.

C.5 Belt Filter Press

C.5.1 Construction Cost

The new third generation belt filter presses are becoming increasingly popular for dewatering a wide range of different types of sludges. As contrasted to earlier generations of belt filter presses, which used short contact time and low pressures, the newer presses rely on longer pressing times and multiple passes over a series of rollers. Such passing over rollers creates shear between the sludge particles, exposing new surfaces and enhancing water removal.

Construction costs are for belt filter press dewatering systems that include the belt press unit, wash water pump, conditioning tank, feed pump, polymer storage tank and pump, belt conveyor, and electrical control panel. Machines are generally sized using metric dimensions and are rated on the basis of sludge flow in gpm/m of belt width. For mixtures of digested primary and secondary sludges, a value of 3.2 l/s/m (50 gpm/m) of belt width is a typical loading recommendation, and was used in the conceptual layouts used in the cost development. Higher loadings are possible in some cases if the sludge can be easily dewatered.

Estimated construction costs are presented in Figure C-10 as a function of total installed machine capacity.

C.5.2 Operation and Maintenance Cost

Process energy requirements were developed from the total connected horsepower for the belt drive unit, belt wash water pump, conditioning tank, feed pump, polymer pump and tanks, belt conveyor, and electrical control panel. A belt filter loading of 3.2 l/s/m (50 gpm/m) of machine width was used in selecting unit sizes and determining power requirements. Twenty-two hours of continuous operation with 2 hr of downtime for routine maintenance was assumed in calculating process energy requirements.

Labor and maintenance requirements were estimated from information provided by equipment manufacturers, as well as information from plants operating belt filter presses. The maintenance material requirements assume the replacement of a set of belts every 6 months in continuous service.

Figures C-11 and C-12 present operation and maintenance requirements for the belt filter press. As operation and maintenance costs vary widely depending on the nature and solids concentration of the sludge being processed, and adjustments to these O&M requirements may have to be made on a case-by-case basis. Conditioning chemical costs are not included in the total annual O&M cost curve.

C.6 Vacuum Filters

C.6.1 Construction Cost

Costs for vacuum filter installations are presented in Figure C-13. The costs include the vacuum filter, conditioning tank, vacuum and filtrate pump assemblies, vacuum receiver, a short belt conveyor for the dewatered sludge, feed sludge piping, lime and ferric chloride storage and feed facilities, electrical controls, and necessary housing for the entire assembly.

C.6.2 Operation and Maintenance Cost

Electrical energy curves are presented for both process and building energy. Process energy is for vacuum filter drum drive, cake discharge roller, vacuum and filtrate pumps, tank agitators, and the dewatered sludge belt conveyor. Process energy requirements were calculated for a sludge solids loading of 8.3 kg dry solids/sq m/hr (1.7 lb/sq ft/hr). Building sizes are based upon conceptual layouts for various total filter areas, and energy requirements are based upon 904 kwh/sq m of building/year (84 kwh/sq ft/yr).

Labor and maintenance material requirements are based upon operating experience at operating dewatering facilities. Labor requirements are based upon 24 hour per day operation, and will have to be adjusted if filters are operated for only one or two shifts per day. Maintenance material costs are for periodic repair and replacement of equipment. Costs are not included for purchase of the lime or ferric chloride utilized for conditioning, since chemical requirements are highly variable from sludge to sludge, and are not generally a function of vacuum filter surface area.

Electrical energy and maintenance material costs are shown in Figure C-14, and labor and total O&M costs are shown in Figure C-15. Total O&M costs were calculated using a rate of $0.05/kwh for electrical energy and a rate of $12/hr for labor. Conditioning chemical costs are not included in the total O&M cost.

C.7 Filter Press - Recessed Plate

C.7.1 Construction Cost

The recessed plate filter press has gained popularity for dewatering sludges because it can produce a high solids content cake suitable for incineration or any other subsequent process requiring a high solids content sludge. The introduction of semi-automatic and fully automatic presses along with other labor and maintenance saving improvements has further stimulated interest in filter presses.

Construction costs, as shown in Figure C-16, were developed for a series of single and multiple recessed plate filter press systems ranging in size from 0.12 to 25.4 cu m (4.3 to 896 cu ft). The largest single press utilized in the cost estimates had a capacity of 6.3 cu m (224 cu ft). The construction costs include the filter press, feed pumps (including one standby), a lime storage bin and feeders, ferric chloride liquid solution storage and feeders, a sludge conditioning and mixing tank, an acid wash system, and housing. Housing costs are for a two story, concrete block building, with the filter press located on the upper floor and discharging through a floor opening to a truck located on the lower level.

C.7.2 Operation and Maintenance Cost

Operation and maintenance costs were developed for a filter loading of 80 to 90 kg dry solids/cu m/hr (5 to 5.6 lb/cu ft/hr), a dry solids density of 1030 kg/cu m (64 lb/cu ft), and 19 hr of operation/day. The remaining 5 hr/day would be devoted to press preparation, sludge removal, cleanup, and press maintenance.

Most of the process energy consumed by the filter press is related to operation of the sludge feed pump. Energy is also consumed by the open-close mechanism and the tray mover. Pumping power requirements were calculated for a solids loading of 4 percent at a cycle time of 2.25 hr, with a 20 minute turnaround time between cycles. Power required for chemical preparation, mixing, and feeding is also included in process energy. Energy requirements related to building heating, cooling, lighting, and ventilation were based upon a usage of 904 kwh/sq m/yr (84 kwh/sq ft/yr).

Maintenance material costs and labor requirements were estimated based on manufacturers' experience and data from a number of operating installations.

Process and building electrical requirements and maintenance material requirements are shown in Figure C-17, and labor and annual O&M costs are shown in Figure C-18. Annual O&M costs do not include the cost for lime and ferric chloride conditioning chemicals.

C 8 Filter Press - Diaphragm

C.8.1 Construction Cost

The diaphragm filter press has several operational advantages over a conventional recessed plate type filter press. One of the more important advantages is the production of a higher solids content cake, often up to 8% solids higher. Other advantages include more positive cake release, a shorter overall cycle time, lower pumping pressure for sludge fed to the press, and the ability to successfully dewater poorly conditioned sludges. Diaphragm type presses are generally fully automatic, including automatic cloth washing. The product cake solids content is varied by changing the time of compression, with compression being created by inflating the diaphragm.

Construction costs shown in Figure C-19 are for diaphragm presses with press areas between 111 and 1398 sq m (1200 and 15,050 sq ft). The largest machine manufactured is 557 sq m (6000 sq ft), and the larger areas shown in Figure C-19 are for multiple presses. The construction costs shown include the diaphragm press, feed pump, pumps for the diaphragm and cloth washing, vacuum pumps, an air compressor and receiver, lime and ferric chloride storage and feed facilities, and all electrical and controls necessary for complete automatic operation. Housing is for a two story, concrete block building, with the filter press discharging through an opening, in the floor to a truck on the lower level.

C.8.2 Operation and Maintenance Cost

Operation and maintenance costs were developed for a 4% feed of anaerobically digested sludge, chemically conditioned with 5% ferric chloride and a 20% lime. Press loading was 4.9 kg/sq m/hr (1.0 lb/sq ft/hr), without chemicals, and cake discharge was taken at 35%. Press operation time was 19 hours per day, with the remaining time dedicated to press cleanup and maintenance.

Process energy requirements are for the sludge feed pump, the air pump for inflating the diaphragm, and a vacuum pump for removal of liquid sludge remaining in the internal piping prior to opening the press. Energy is also required to open and close the press, for cloth washing, and for conditioning chemical preparation and feed. Building energy requirements are based upon 904 kwh/sq m/yr (84 kwh/sq ft/yr).

Maintenance material costs consist principally, over 90%, of replacement of diaphragms and filter cloths. Other costs are for miscellaneous equipment parts and for miscellaneous electrical components.

Labor required is for both operation and maintenance, with the majority of the labor devoted to operational requirements. Labor requirements are based upon operational experience of the manufacturer.

Electrical requirements for process energy and building energy, as well as maintenance material requirements are presented in Figure C-20. Labor and annual O&M costs are shown in Figure C-21. Conditioning chemical costs are not included in the annual O&M cost, since they vary widely between different sludges. Chemical costs must be added separately to arrive at a total annual O&M cost.

C.9 Sand Drying Beds

C.9.1 Construction Cost

Sand drying beds are an economical method of producing a dry sludge cake from digested sludge. Sludge thickening prior to application on the drying beds is not required, although thickening will decrease the area of beds required, and will also decrease the time required for sludge drying. Dewatering on the sand beds is by a combination of draining and air drying, and beds perform best when both of these processes are optimized. Removal of dried sludge is normally accomplished by front-end loader. Although sand drying beds offer a low-cost approach to sludge drying, this advantage may be offset by the amount and cost of the land area required and poor performance during cold and/or wet periods.

Cost estimates are for uncovered and unlined sand drying beds. The estimates include the sludge distribution piping, 23 cm (9 in) of sand media overlying 23 cm (9 in) of gravel media, 0.6 m (2 ft) high concrete dividers between beds, and an underdrain system to remove percolating water. Land costs and lining to prevent downward percolation are not included in the cost estimates. If bed lining or land purchase are required, the costs would have to be adjusted accordingly.

Construction cost estimates are presented in Figure C-22.

C.9.2 Operation and Maintenance Cost

Diesel fuel requirements are for a front-end loader to remove dried sludge from the beds and to prepare the bed for the next sludge application. A cleaning and preparation time of 3 hr for a 372 sq m (4,000 sq ft) bed, a diesel fuel consumption of 15 l/hr (4 gal/hr), and 20 cleanings/bed per year were used to calculate fuel requirements.

Maintenance material requirements are for replacement of sand lost during bed cleaning. One-quarter inch of sand loss per cleaning was used to calculate maintenance material costs.

Labor costs are for sludge removal, bed preparation, and changing of valves to direct sludge flow to different drying beds. Labor costs were based upon experience at a number of different locations.

The diesel fuel and maintenance material requirements are presented in Figure C-23 and labor and total annual O&M cost are presented in Figure C-24. Total annual O&M cost is based on a labor rate of $12/hr and a diesel fuel cost of $0.30/l ($1.15/gal).

C.10 Sludge Dewatering Lagoons

C.10.1 Construction Cost

Sludge dewatering or storage lagoons are used at many plants to receive, store, and partially dewater waste sludge before further treatment or ultimate disposal. Depending on the climate for solar/air drying and the ability of water to percolate from the lagoon, sludge can thicken to a solids content of 15 to 40 percent (20 to 25 percent average) during 6 months of storage. Generally, when sufficient land area is available, lagooning represents the lowest cost system for sludge dewatering. Other factors must also be considered however, particularly aesthetics.

Construction costs are for unlined lagoons with a 3 m (10 ft) sludge depth and a 0.6 m (2 ft) freeboard depth. Dikes were assumed to have a 3 m (10 ft) crest width and 3:1 side slopes. It was assumed that the excavation volume is equal to the dike fill volume. Lagoons were designed with an inlet structure that would prevent disturbance of settling material, and an outlet structure to skim clarified water.

Construction costs are presented in Figure C-25. The costs are shown as a function of effective volume, which is the volume of the lagoon minus freeboard volume. The costs do not include land cost or pond lining.

C.10.2 Operation and Maintenance Cost

Operation and maintenance requirements are primarily associated with sludge removal from the lagoons. Removal is generally done with a front-end loader or with dragline dredging. Dredging is used to allow further dewatering by air drying on the lagoon periphery. After air drying, the concentrated sludge is removed by a front end loader. The costs and requirements presented are for a combination of these approaches. Sludge was assumed to be removed from a lagoon, on the average of once every 2 years, and hauled in dump trucks to within 1 mile of the lagoons. If a further haul distance is required, the additive cost of this hauling must be added.

Energy costs are for diesel fuel for the front end loader and the dragline, as well as for trucks to haul sludge one mile from the lagoons. Requirements are for removal of 20% sludge, which is generally the lowest concentration that sludge is removed from a lagoon. Requirements are expressed in terms of the volume of sludge removed annually.

Periodic repair and maintenance of the lagoon dikes and the roadway at the top of the dike is required. These costs comprise the maintenance material costs.

Labor requirements consist of labor required for sludge removal from the lagoons, loading the sludge into dump trucks, hauling the sludge 1.6 km (1.0 mi) from the plant site, and maintenance of the roadways.

Figure C-26 presents diesel fuel and maintenance material costs, while Figure C-27 presents labor and total annual O&M costs. Cost for total annual O&M is based on $0.30/l ($1.15/gal) for diesel fuel and $12/hr for labor.

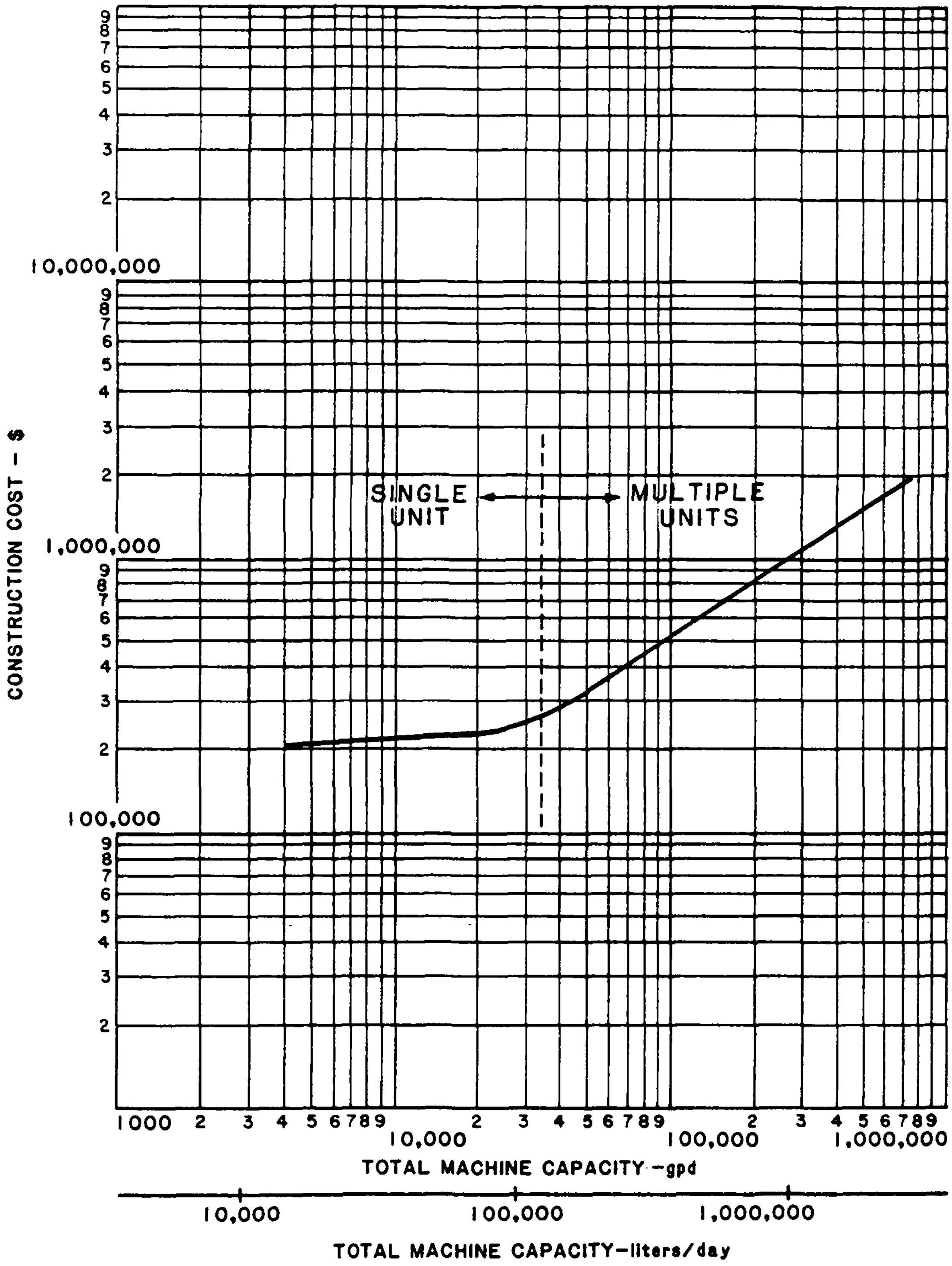

Figure C-1.
Construction cost for basket centrifuges

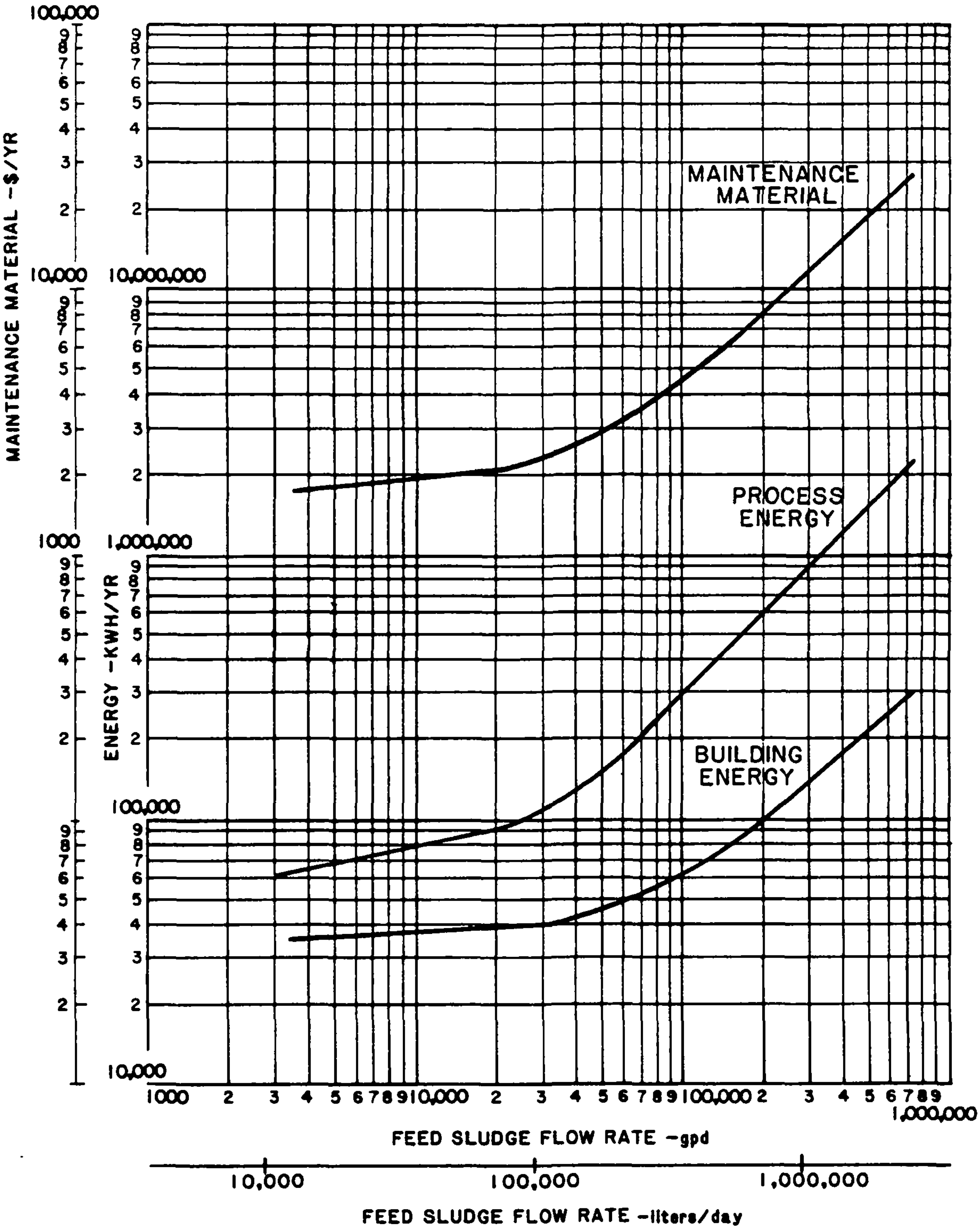

Figure C-2.

Basket centrifuges - building energy, process energy and maintenance material requirements

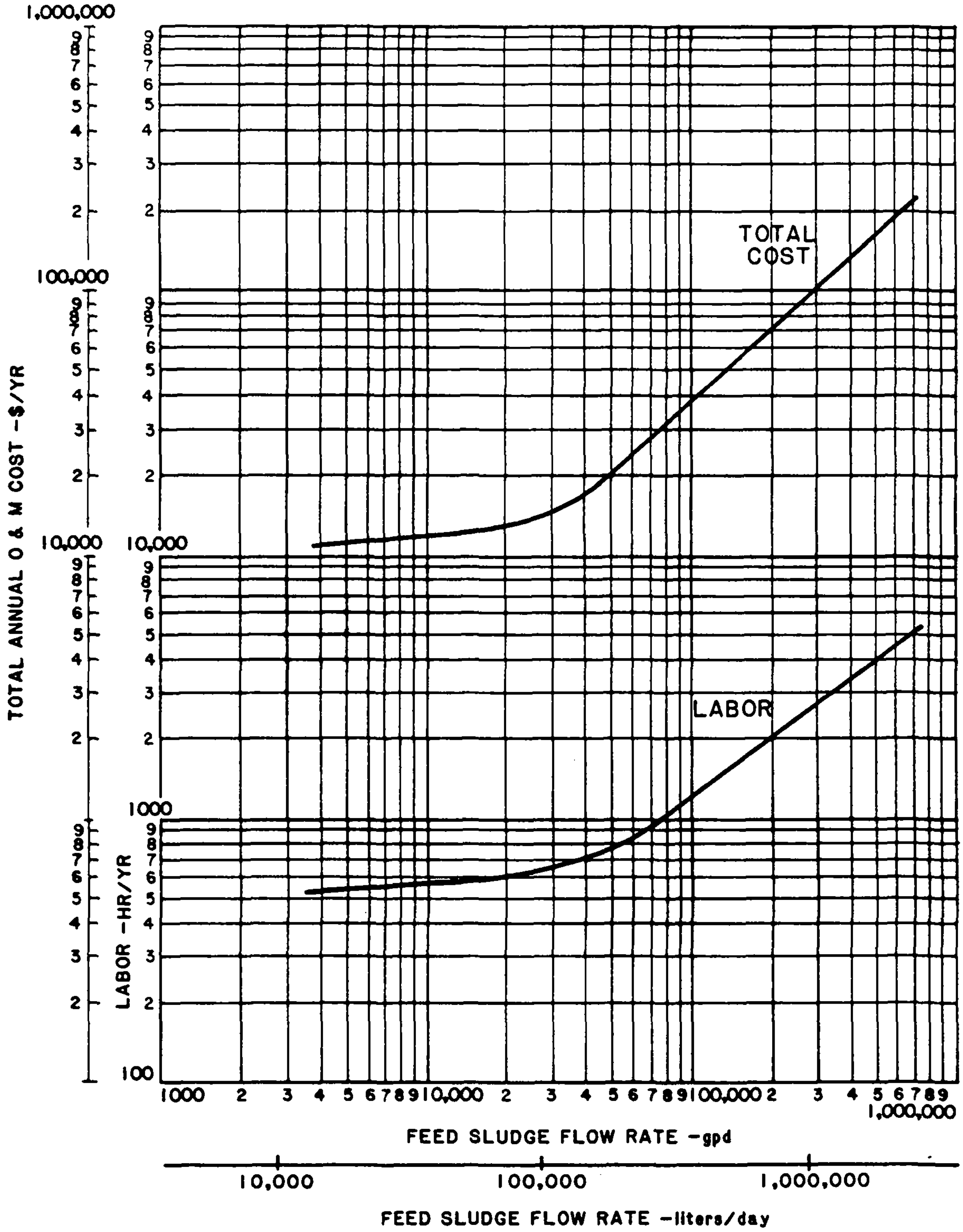

Figure C-3.
Basket centrifuges - labor and total annual operation and maintenance cost

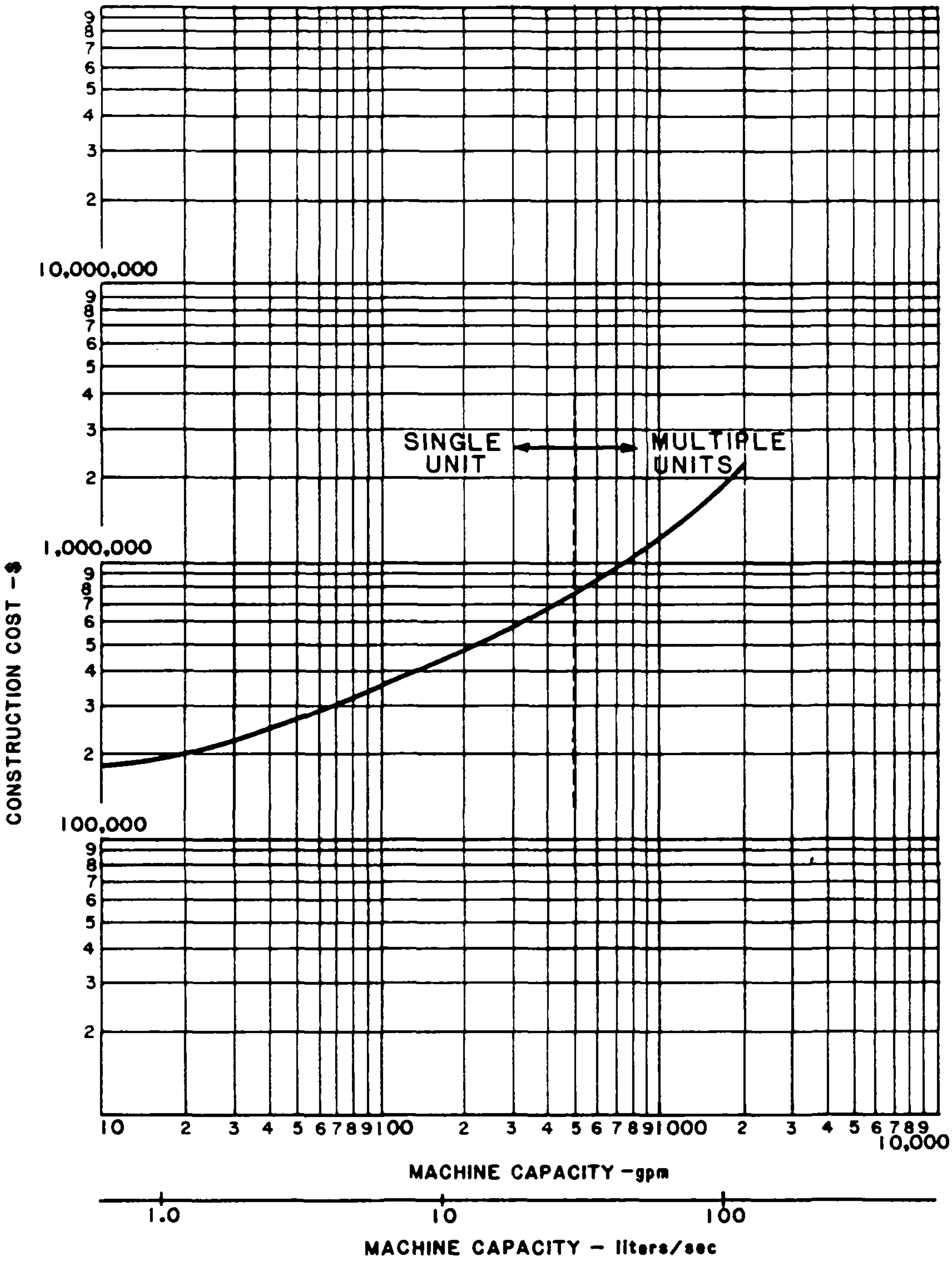

Figure C-4.
Construction cost for low G solid bowl centrifuges

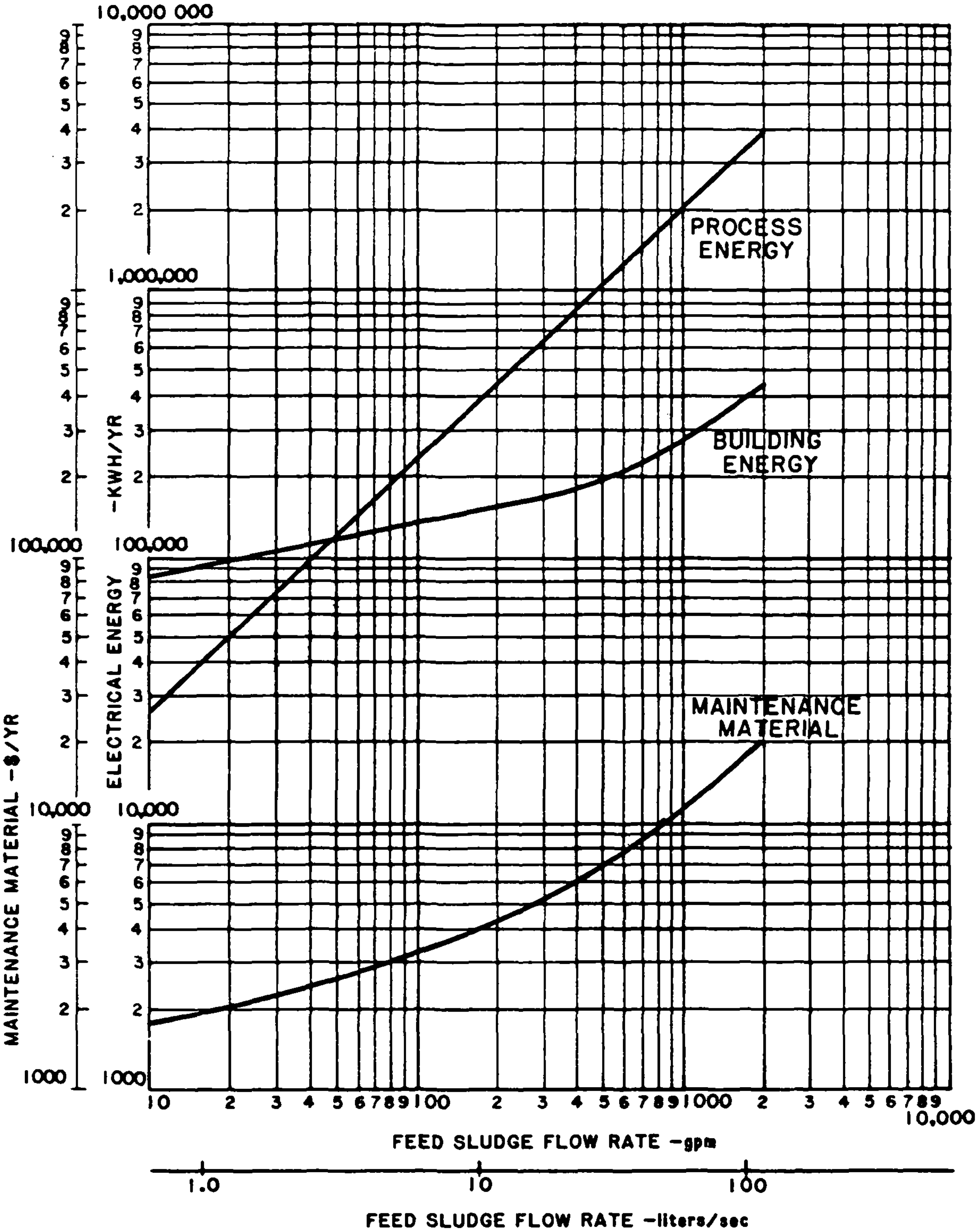

Figure C-5

Low G solid bowl centrifuges - building energy, process energy and maintenance material requirements

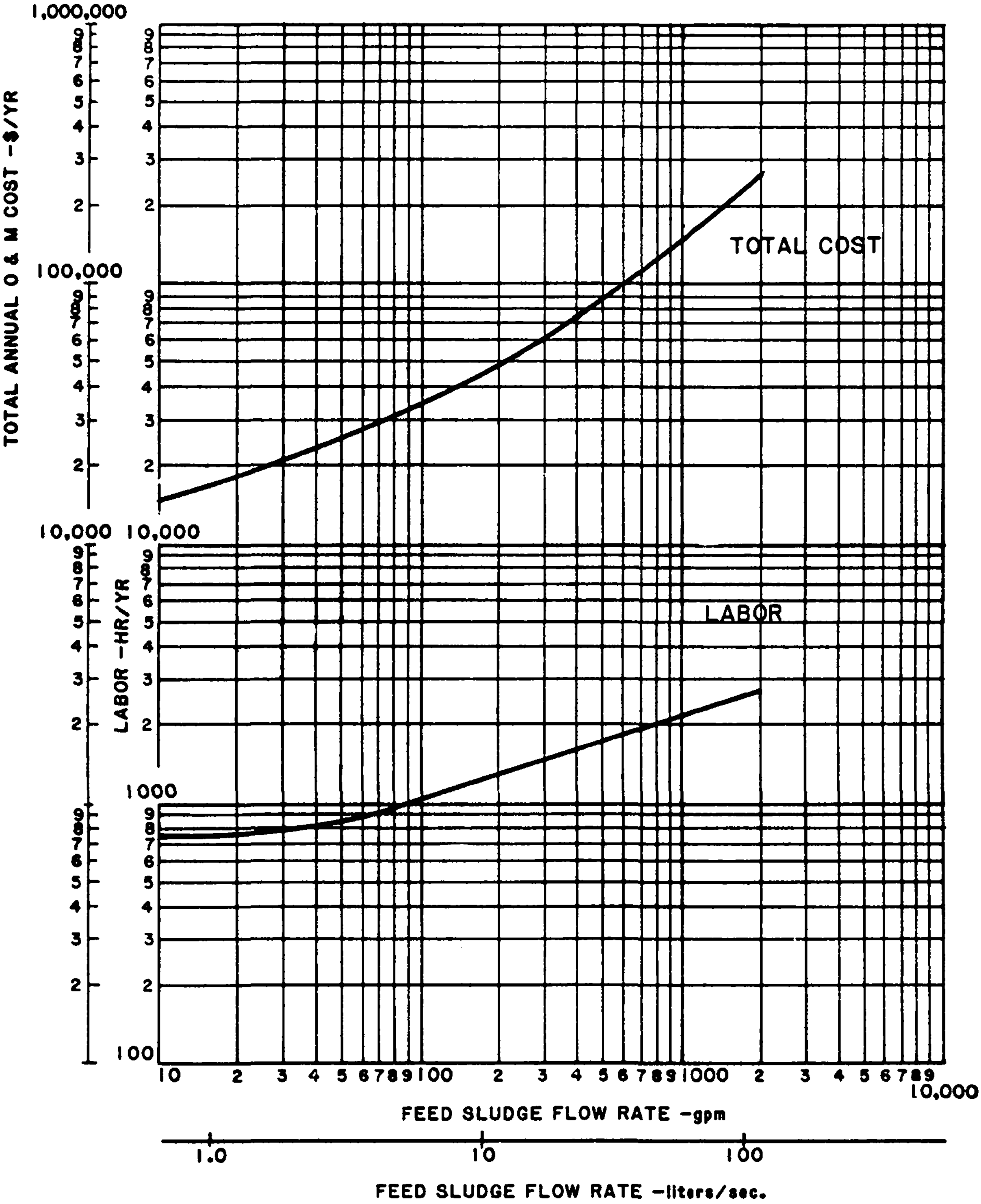

Figure C-6

Low G solid bowl centrifuges - labor and total annual operation and maintenance cost

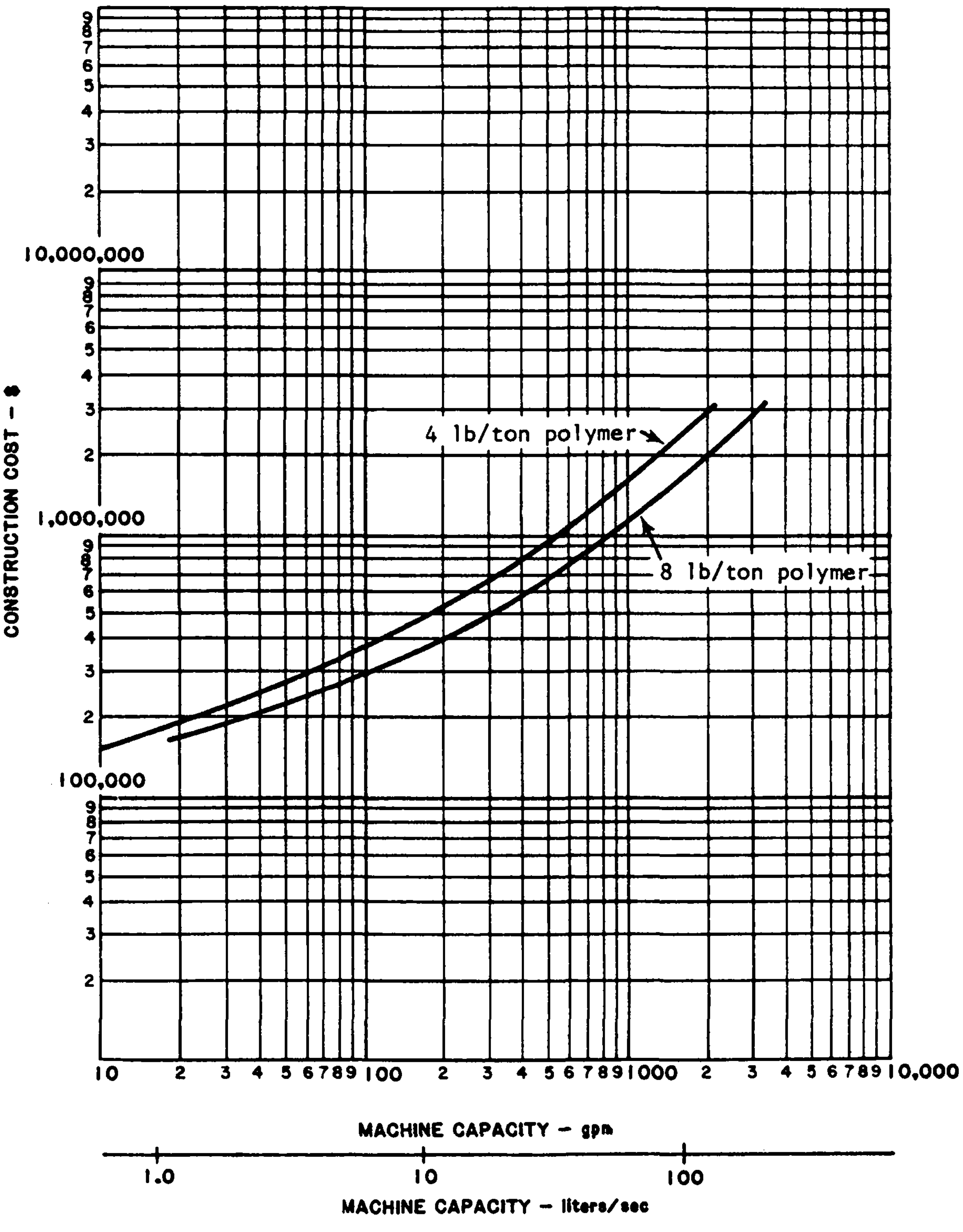

Figure C-7
Construction cost for high G solid bowl centrifuges

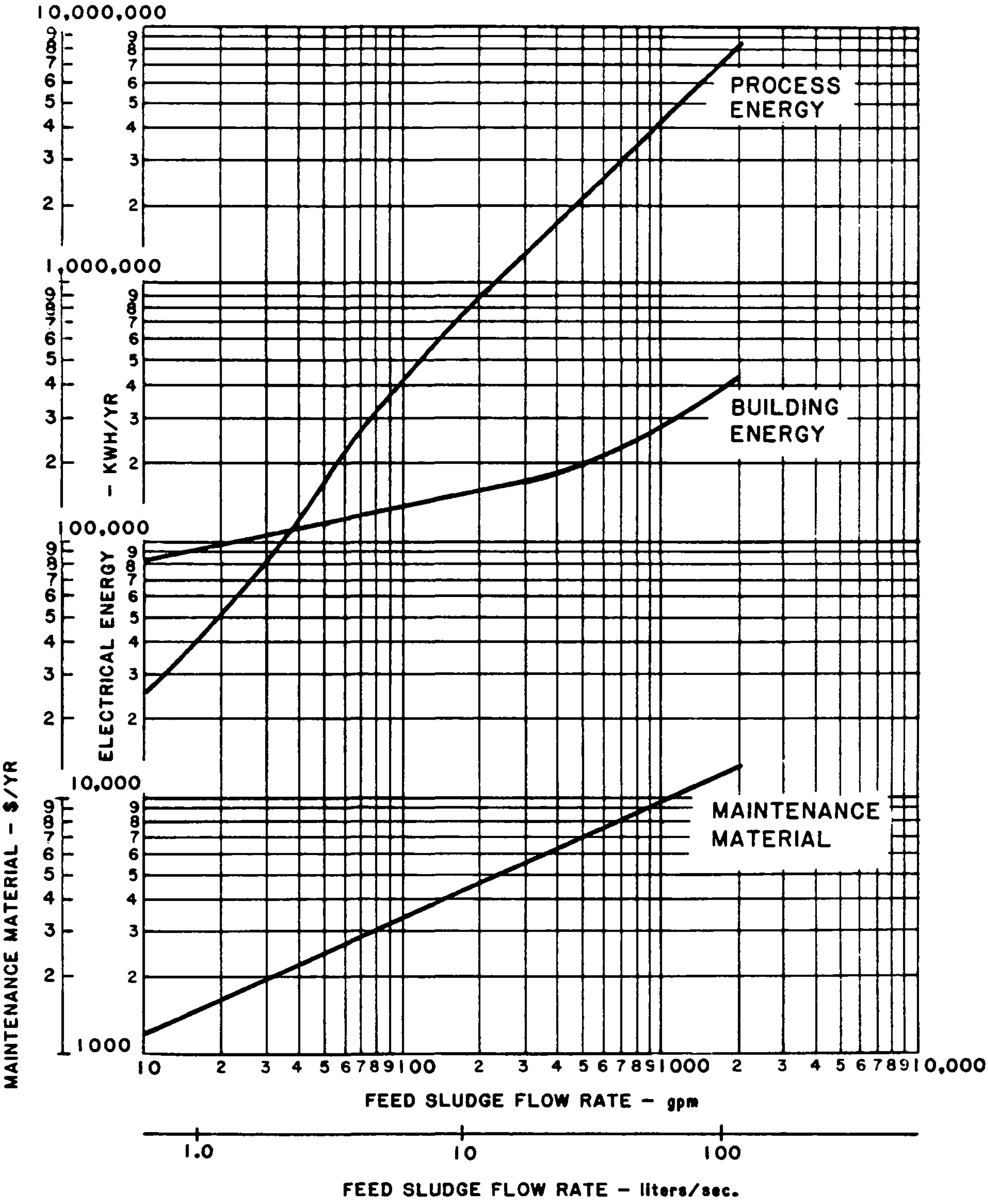

Figure C-8

High G solid bowl centrifuges - building energy, process energy and maintenance material requirements

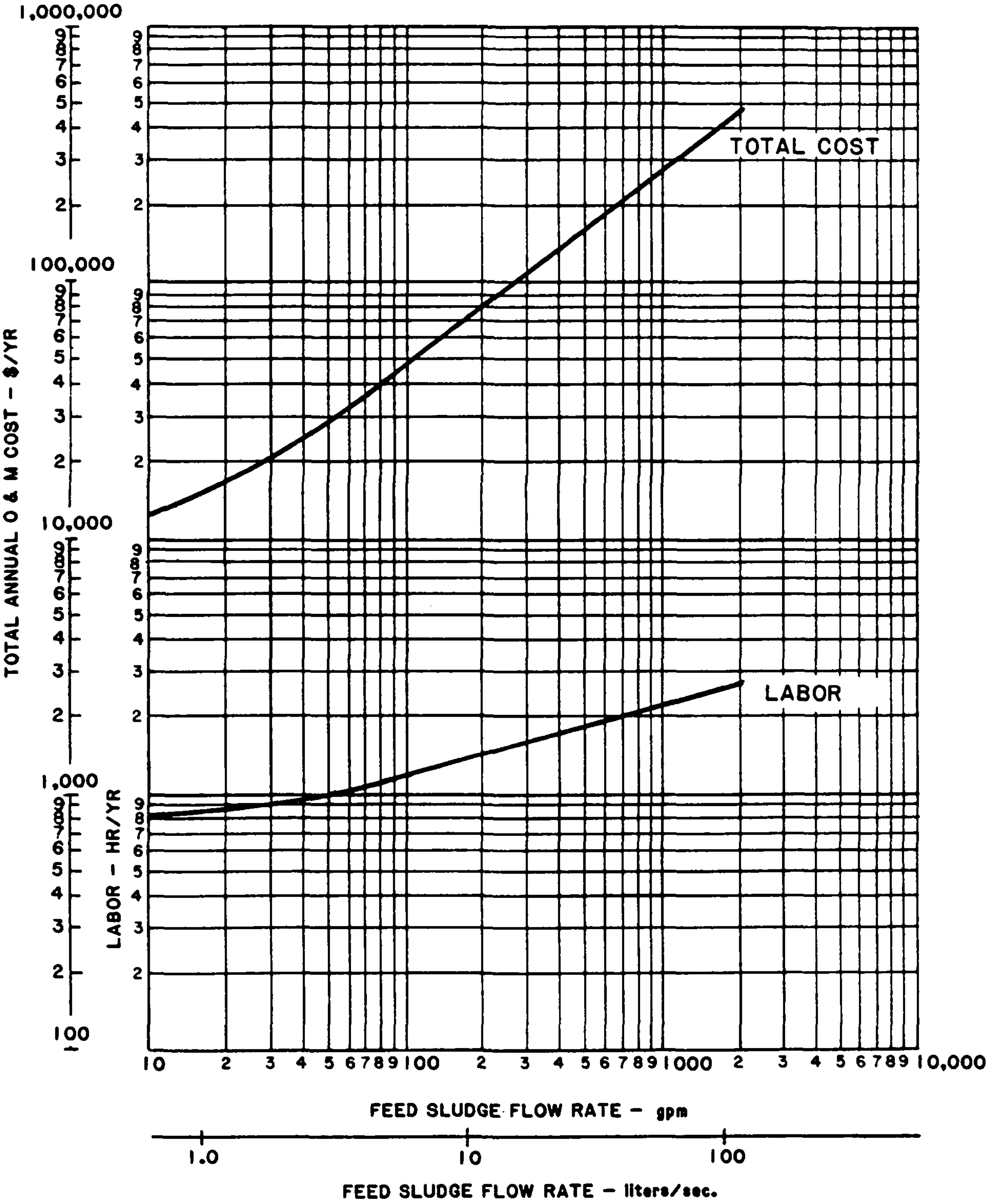

Figure C-9

High G solid bowl centrifuges - labor and total annual operation and maintenance cost

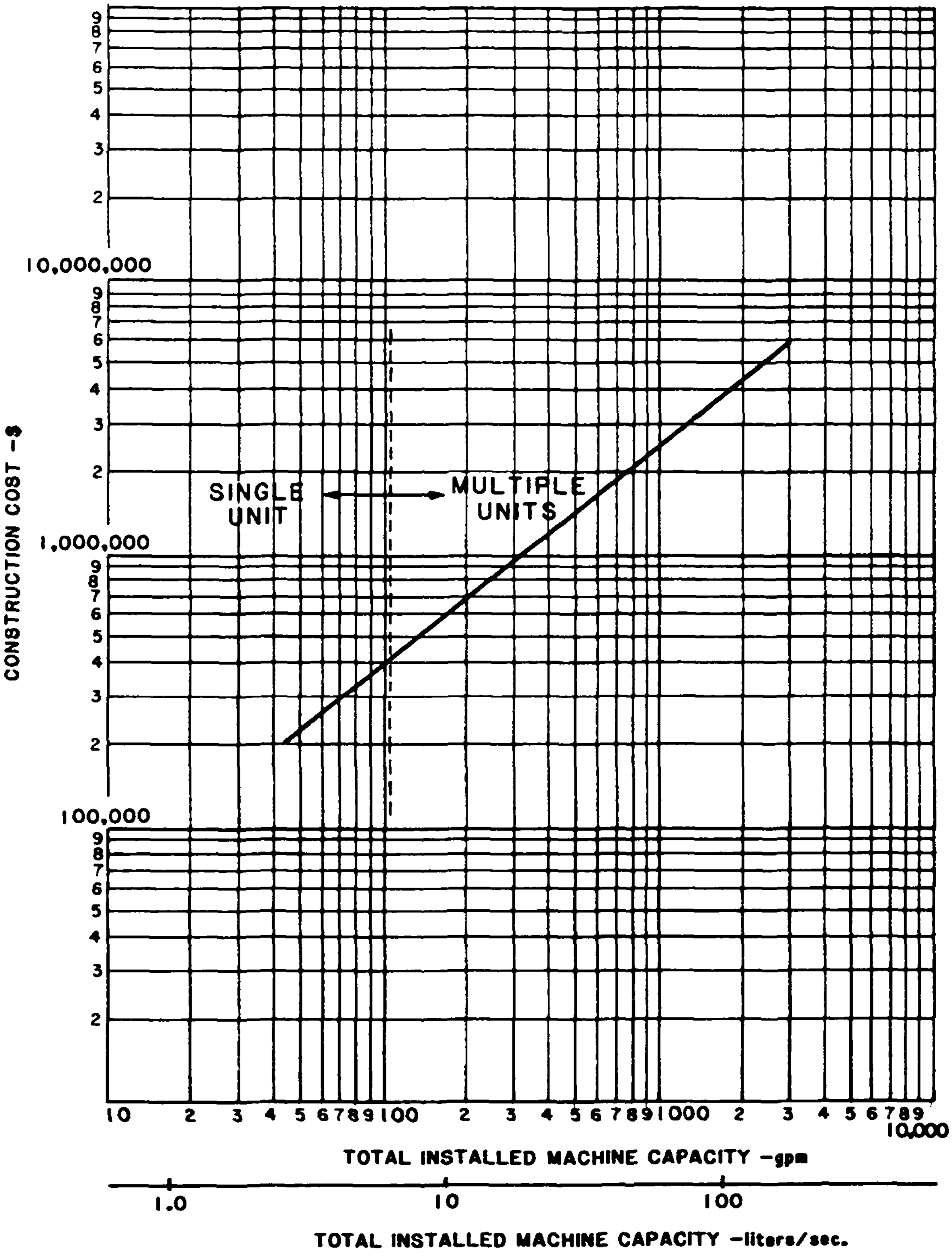

Figure C-10
Construction cost for belt filter press

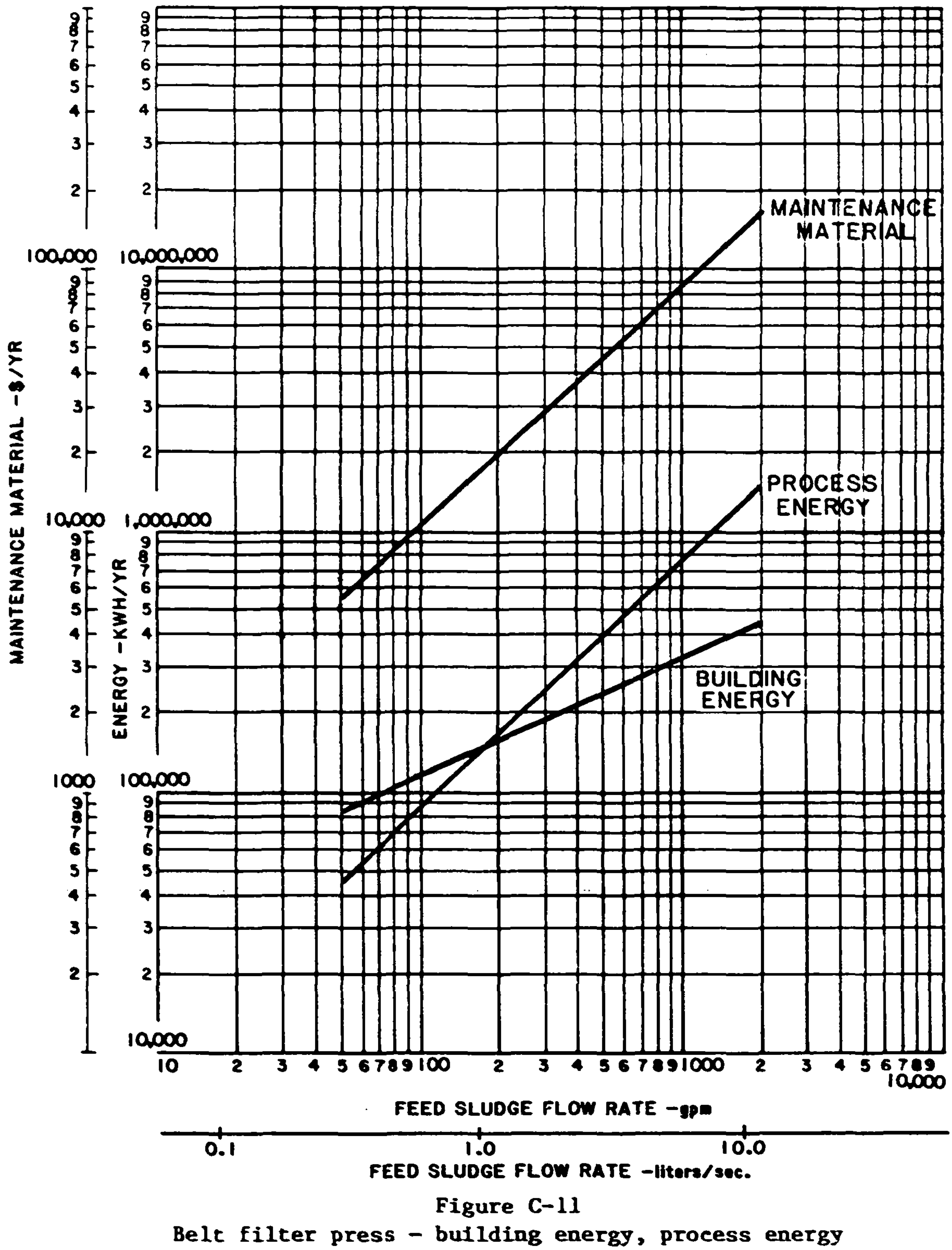

Figure C-11
Belt filter press - building energy, process energy and maintenance material requirements

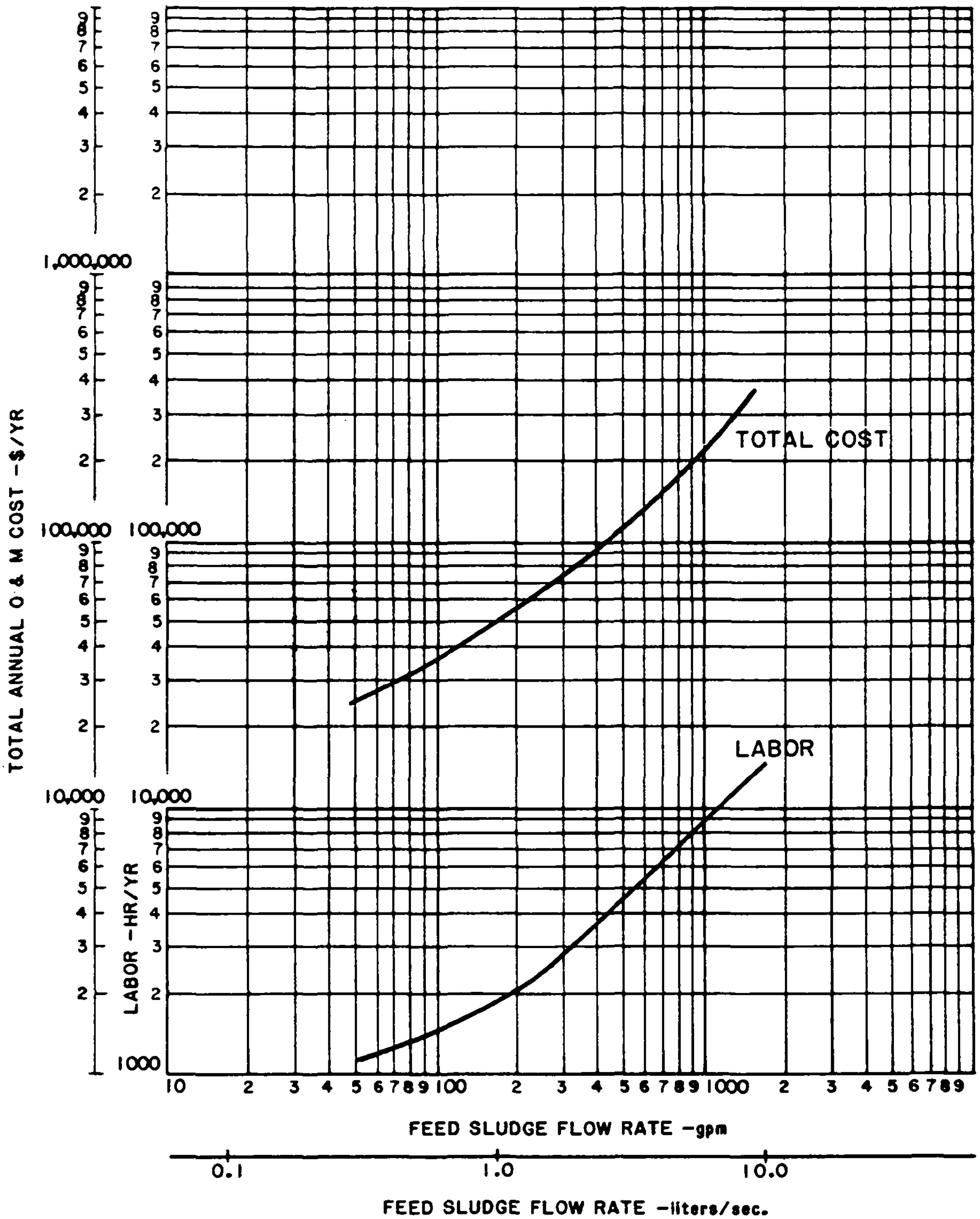

Figure C-12
Belt filter press - labor and total annual operation and maintenance cost

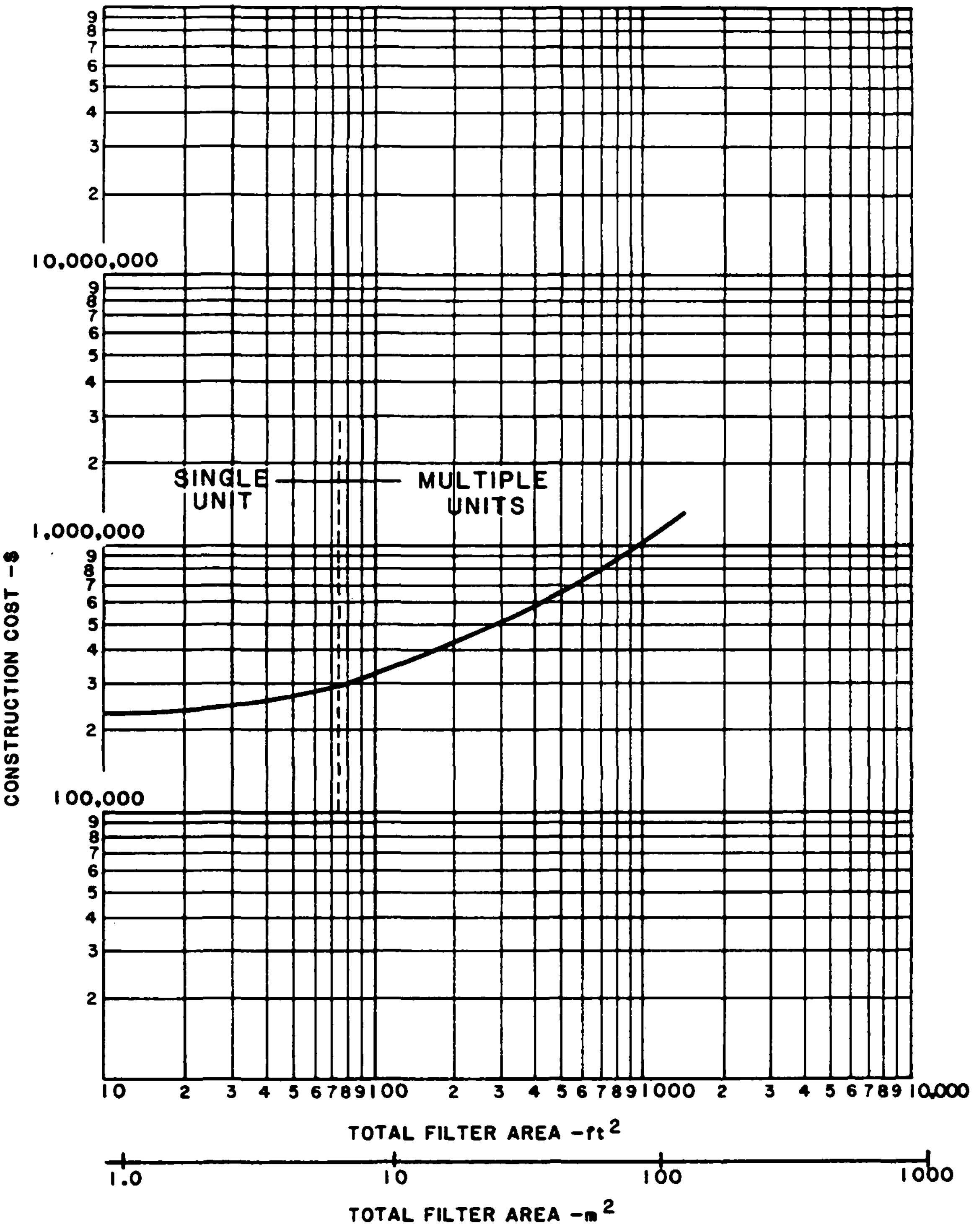

Figure C-13
Construction cost for vacuum filters

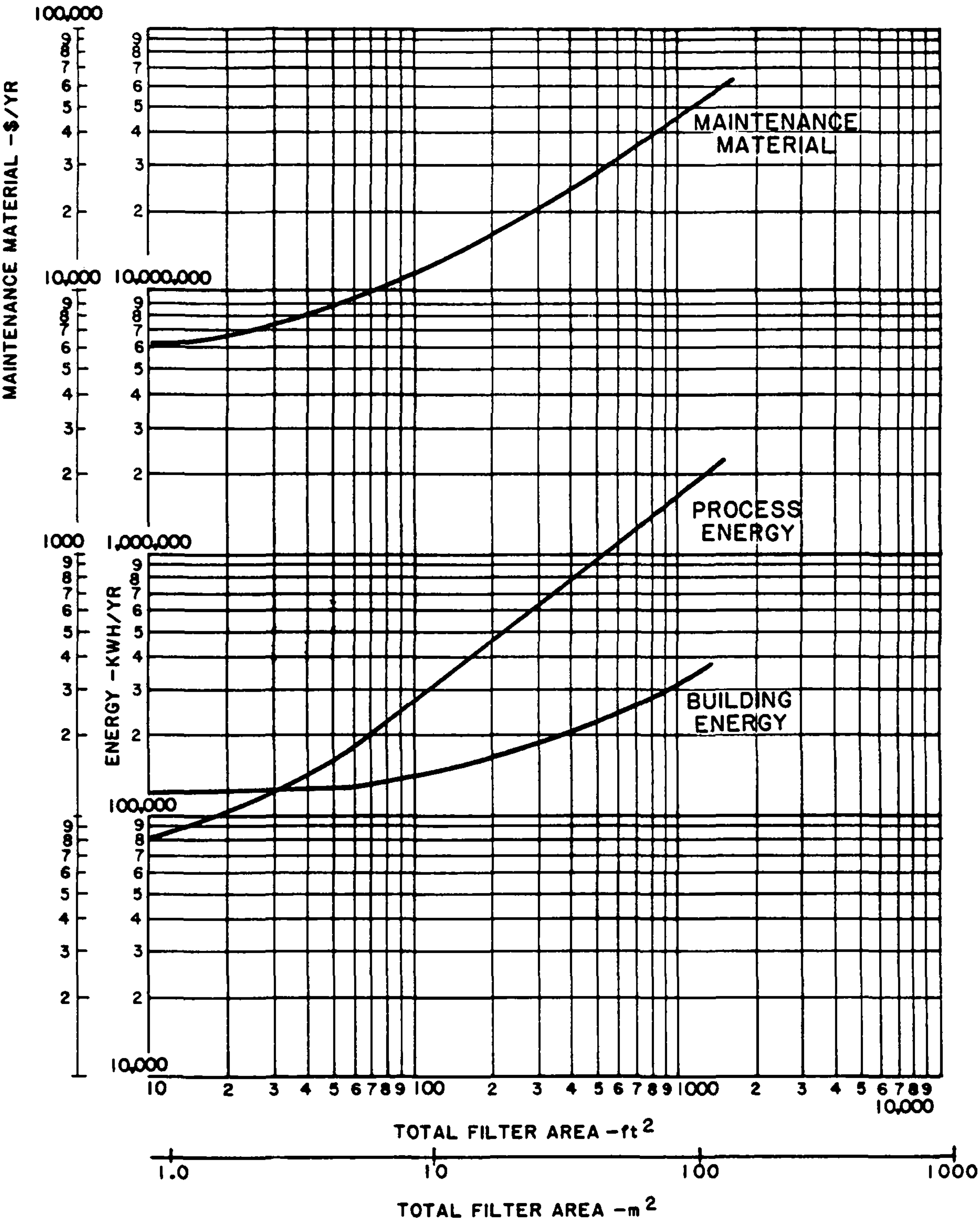

Figure C-14
Vacuum filters - building energy, process energy and maintenance material requirements

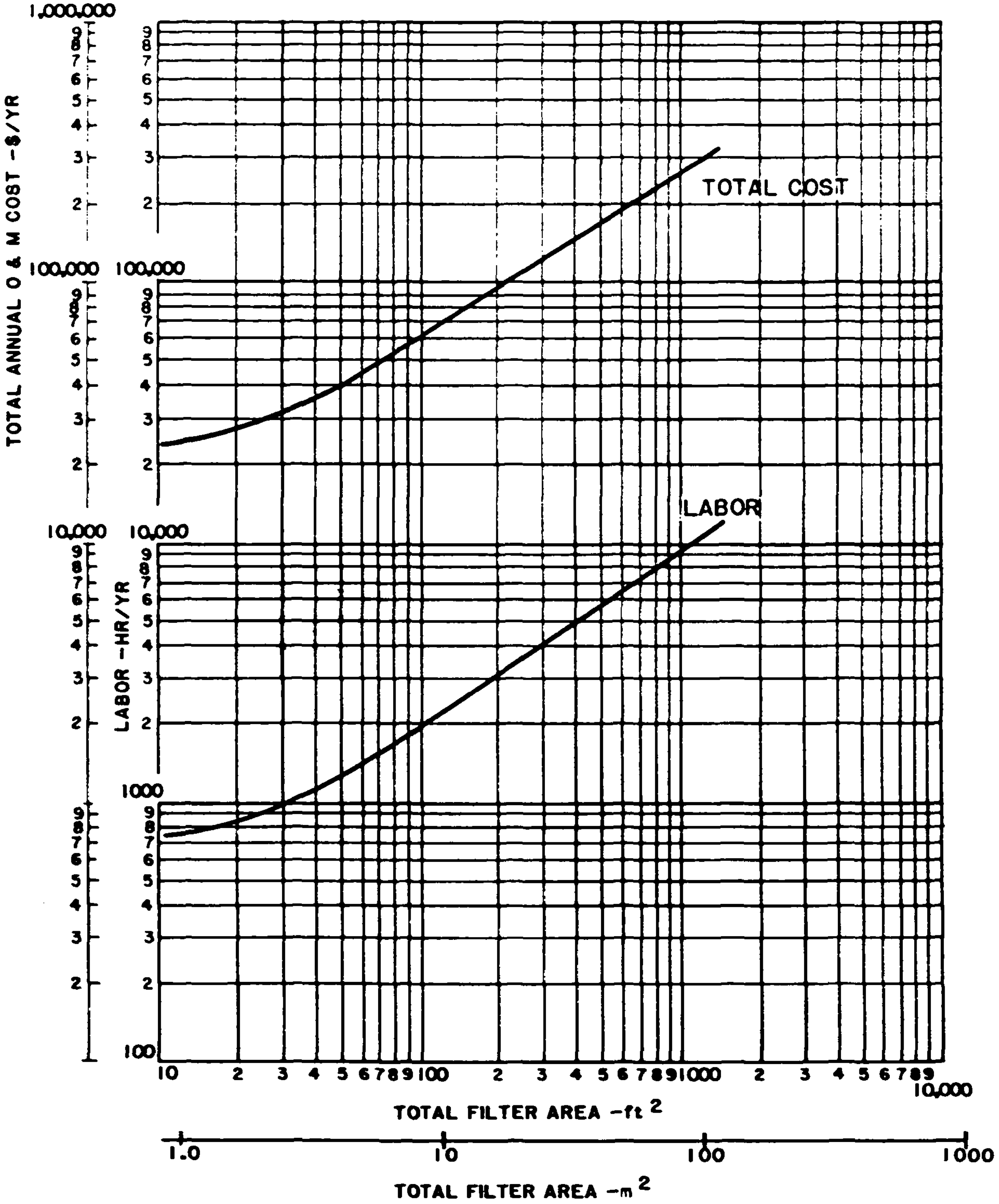

Figure C-15

Vacuum filters - labor and total annual operation and maintenance cost

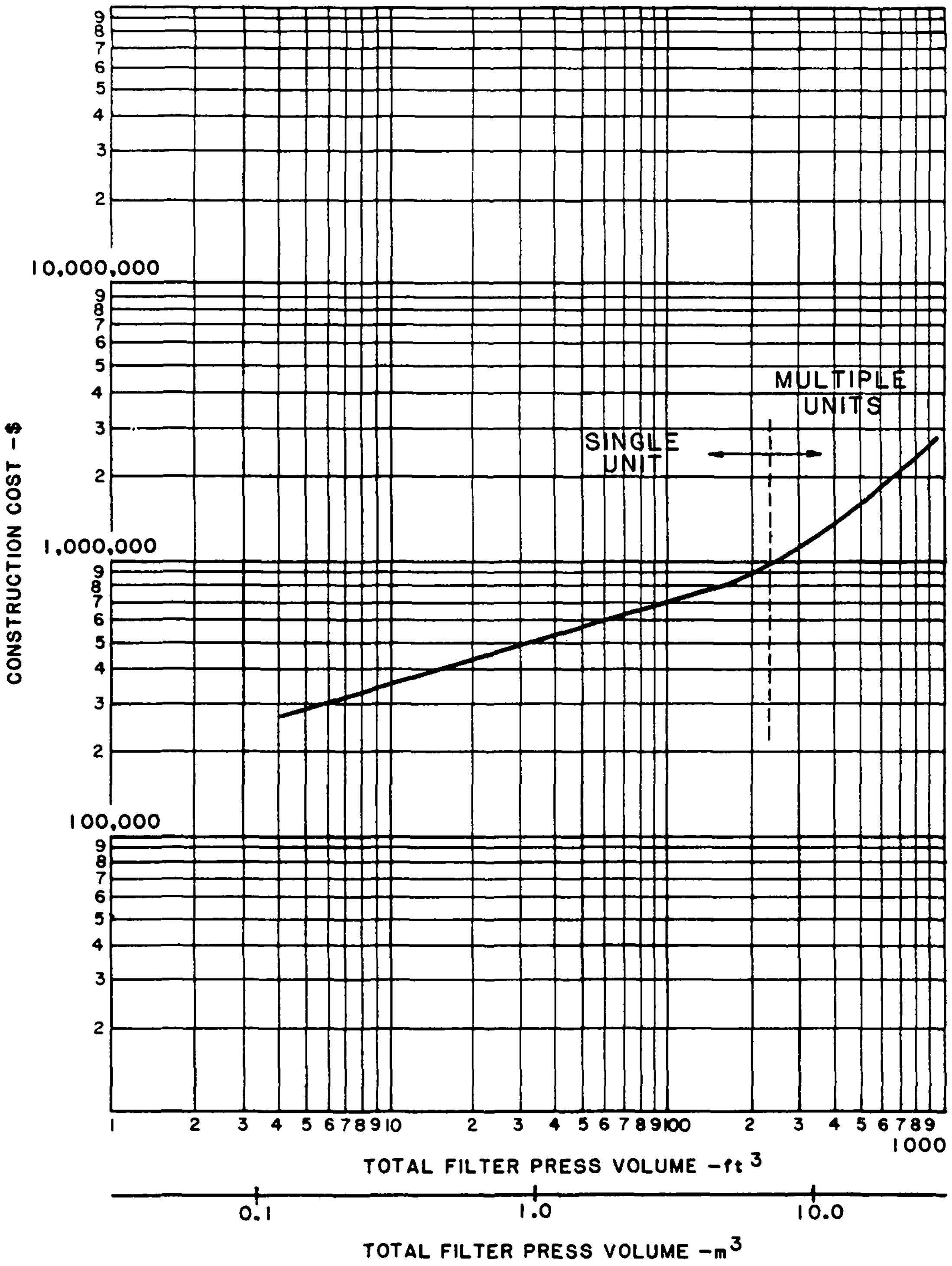

Figure C-16
Construction cost for recessed plate filter press

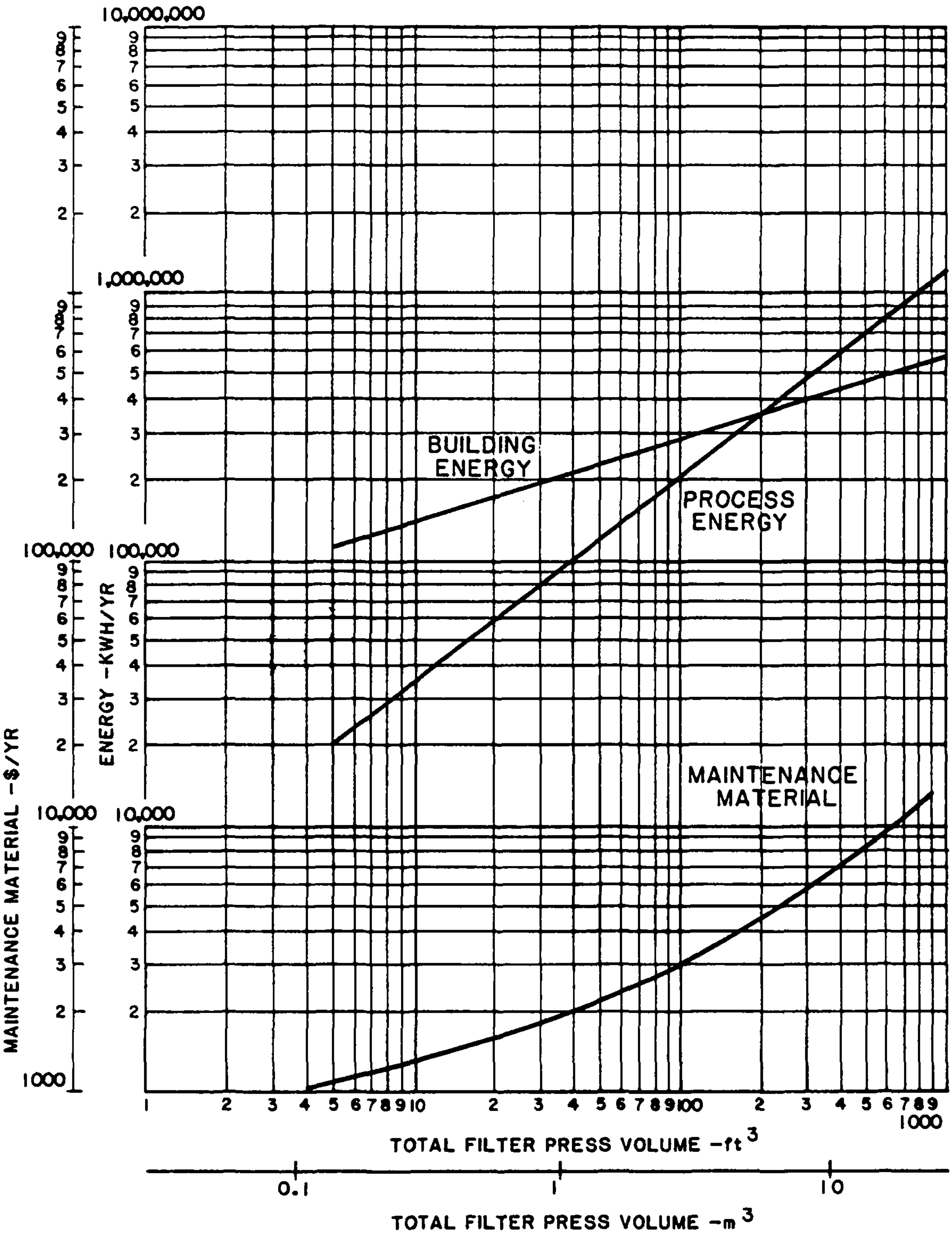

Figure C-17

Recessed plate filter press - building energy, process energy and maintenance material requirements

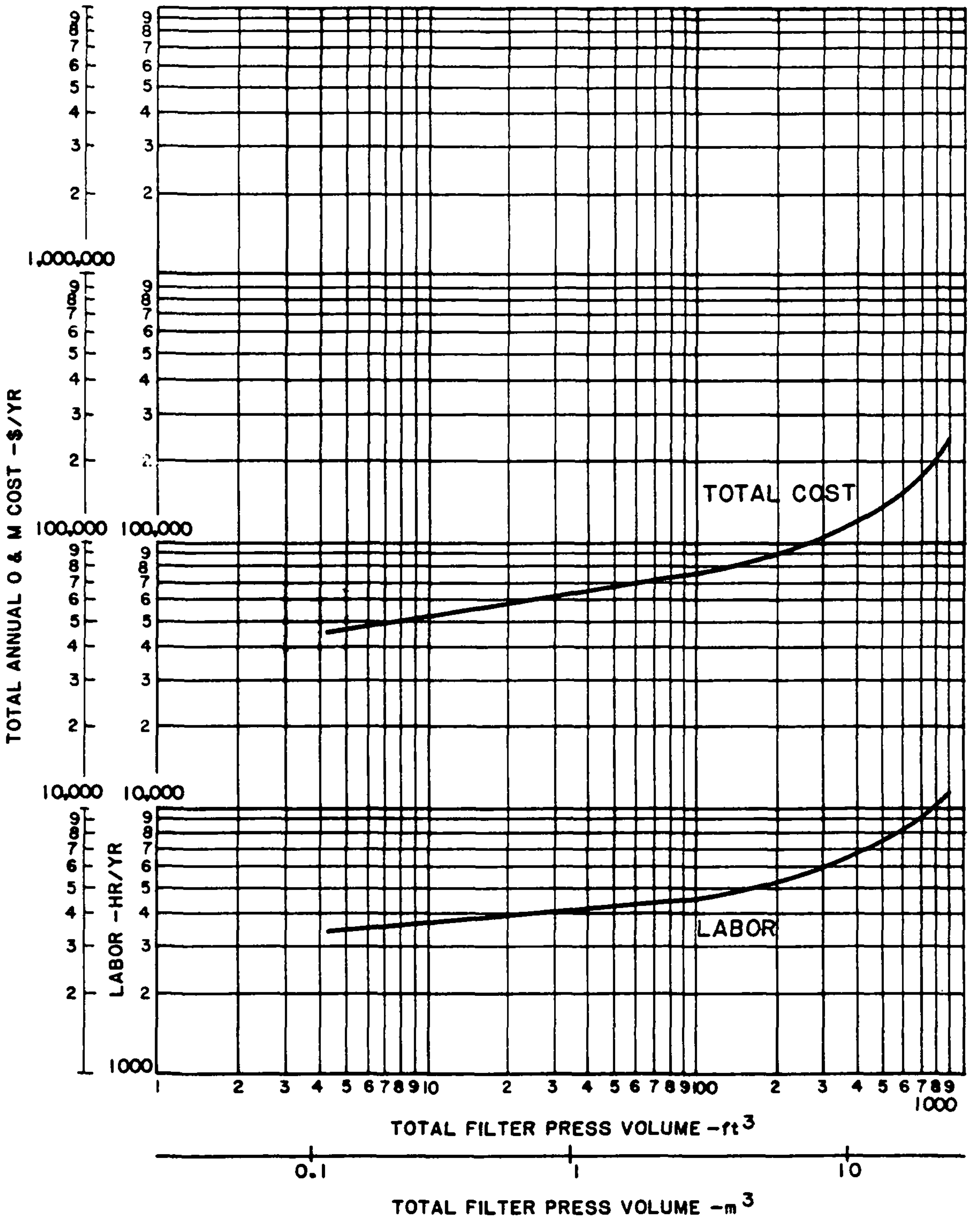

Figure C-18

Recessed plate filter press - labor and total annual operation and maintenance cost

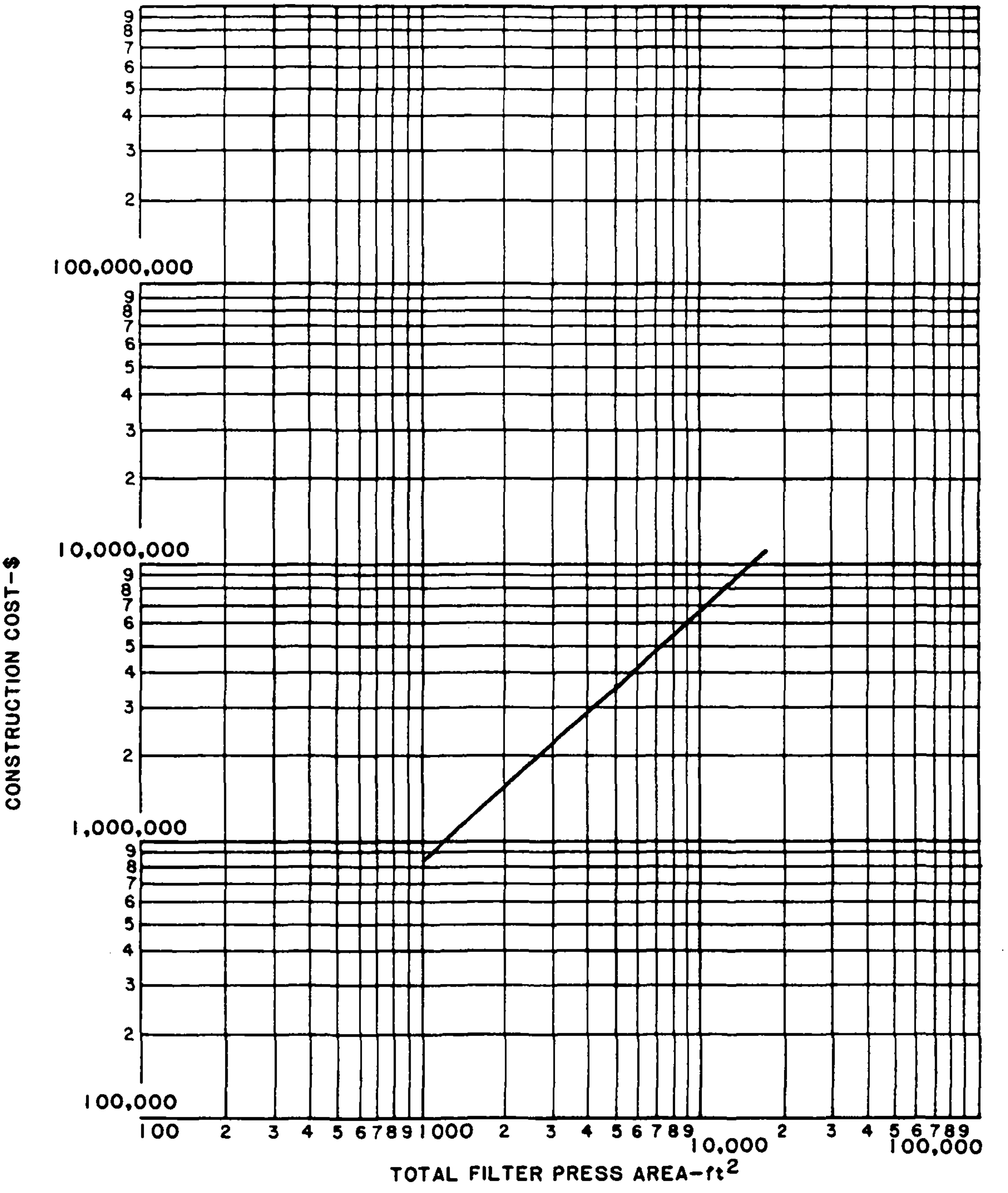

Figure C-19
Construction cost for diaphragm filter press

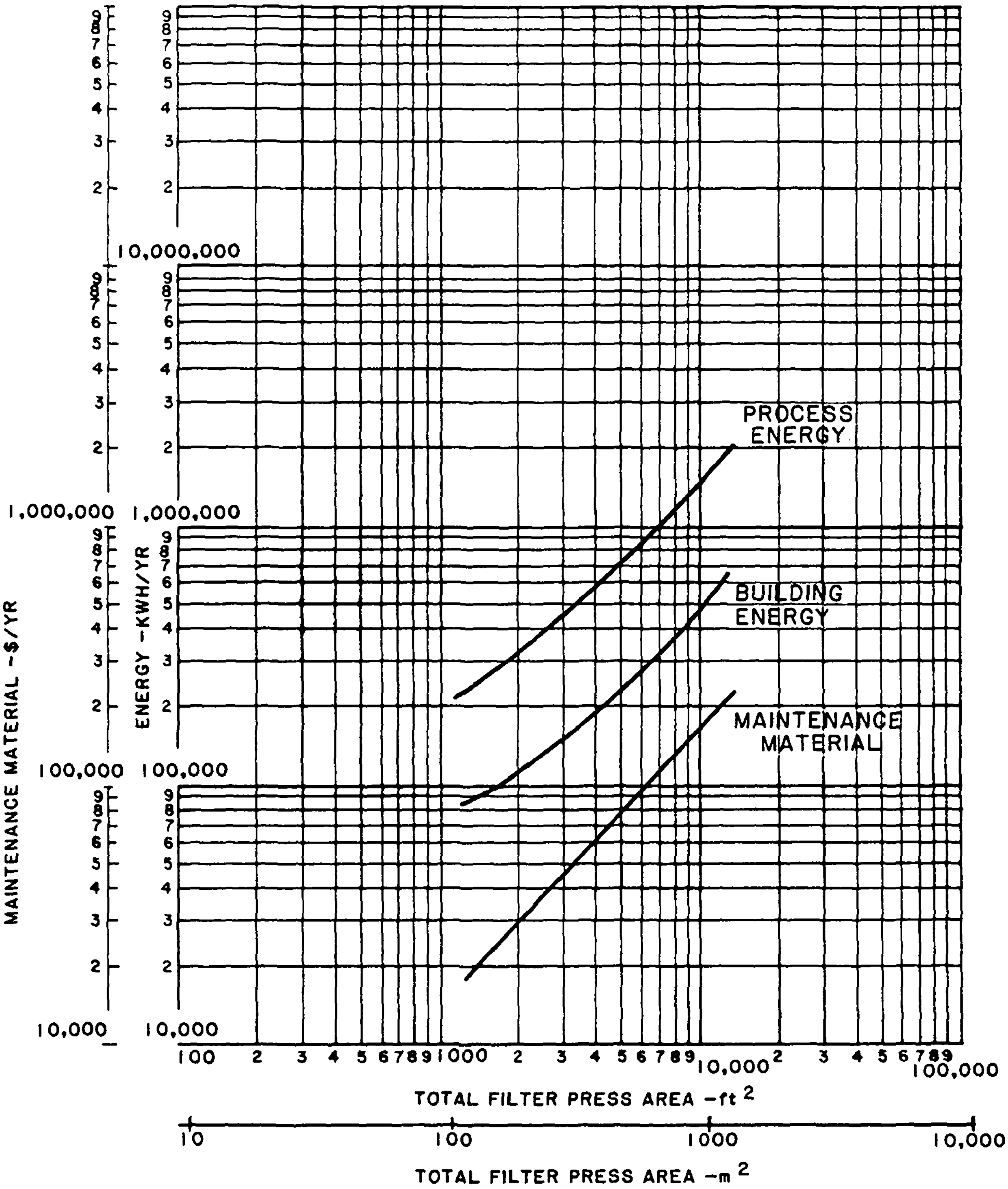

Figure C-20
Diaphragm filter press - building energy, process energy and maintenance material requirements

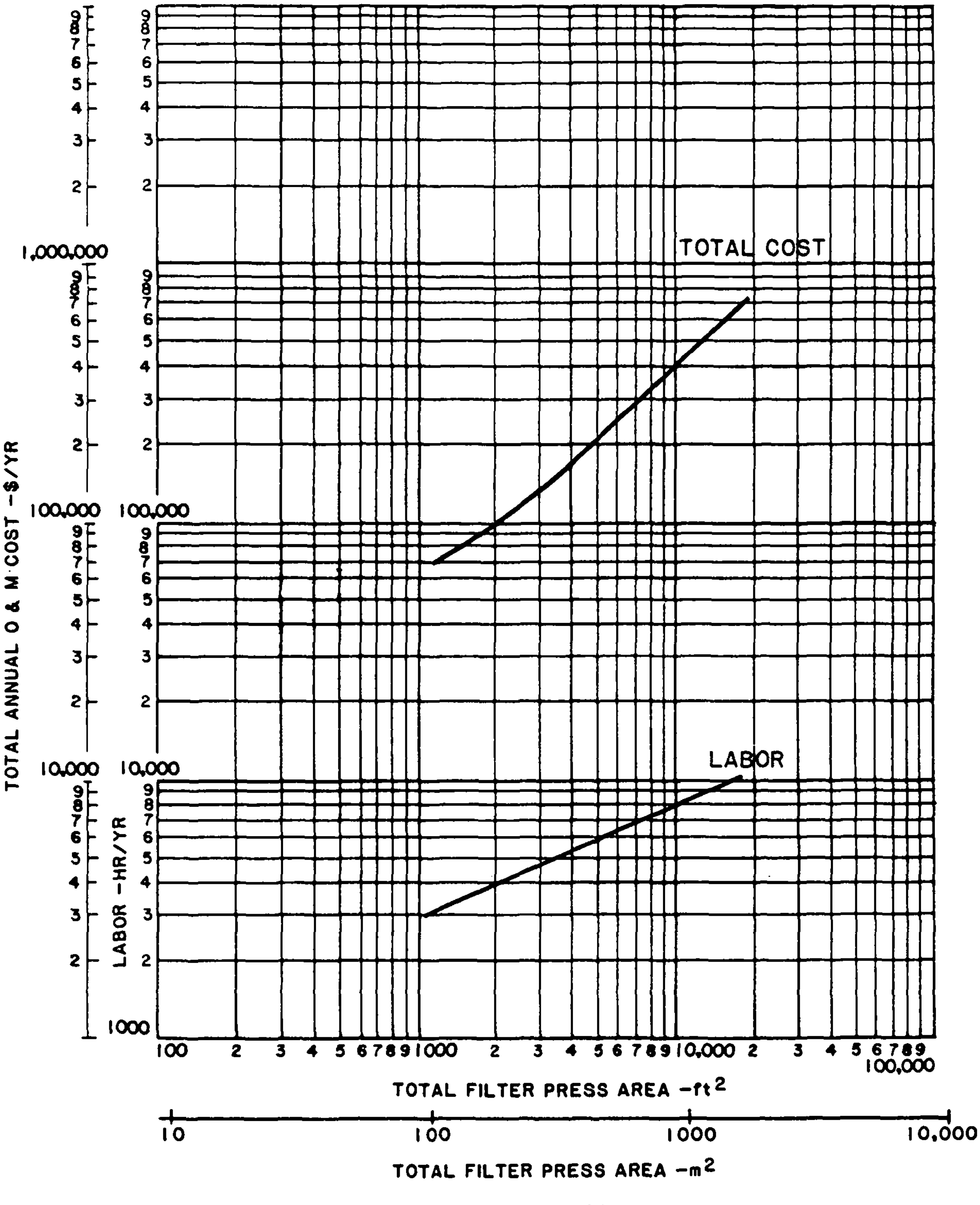

Figure C-21

Diaphragm filter press - labor and total annual operation and maintenance cost

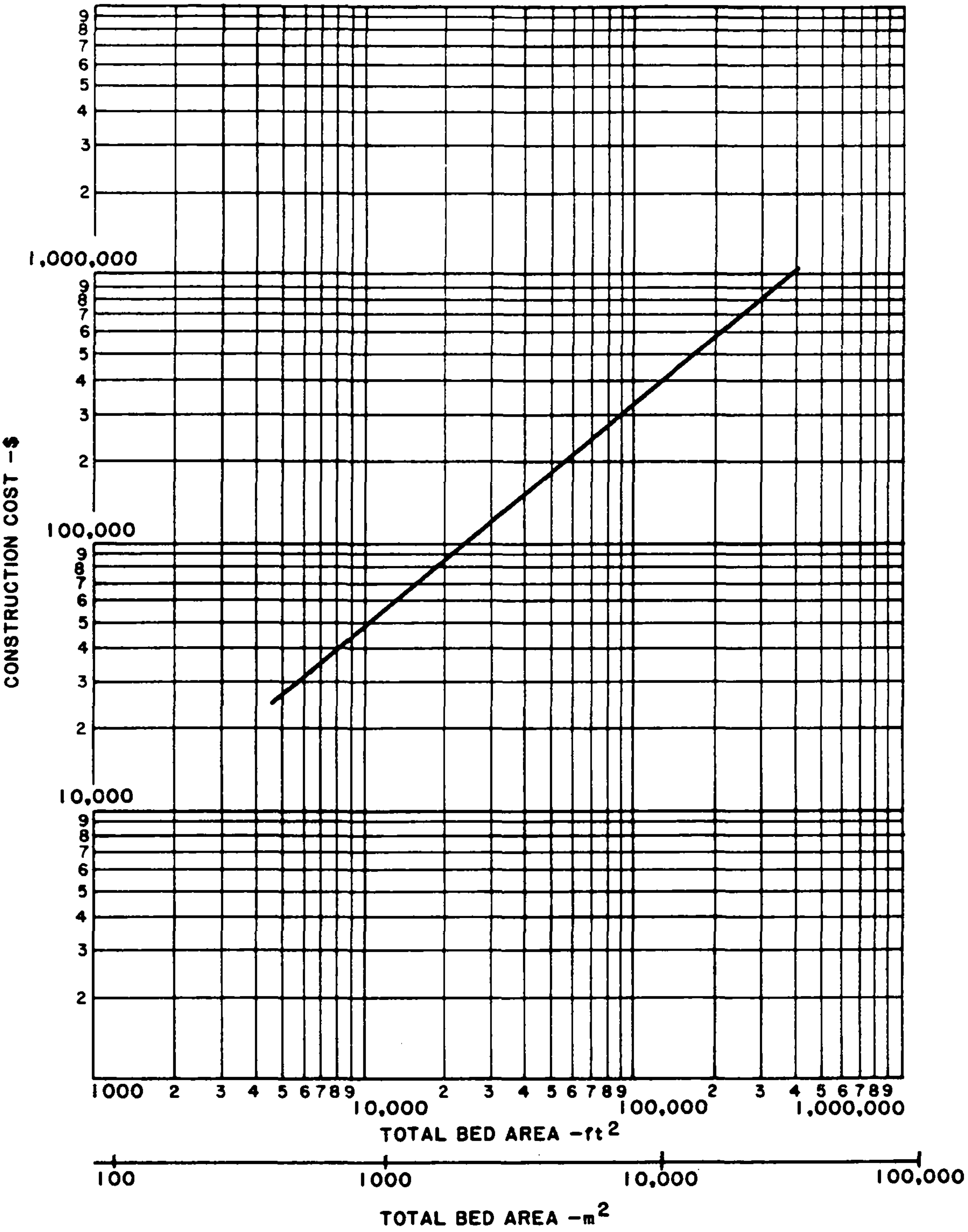

Figure C-22
Construction cost for sand drying beds

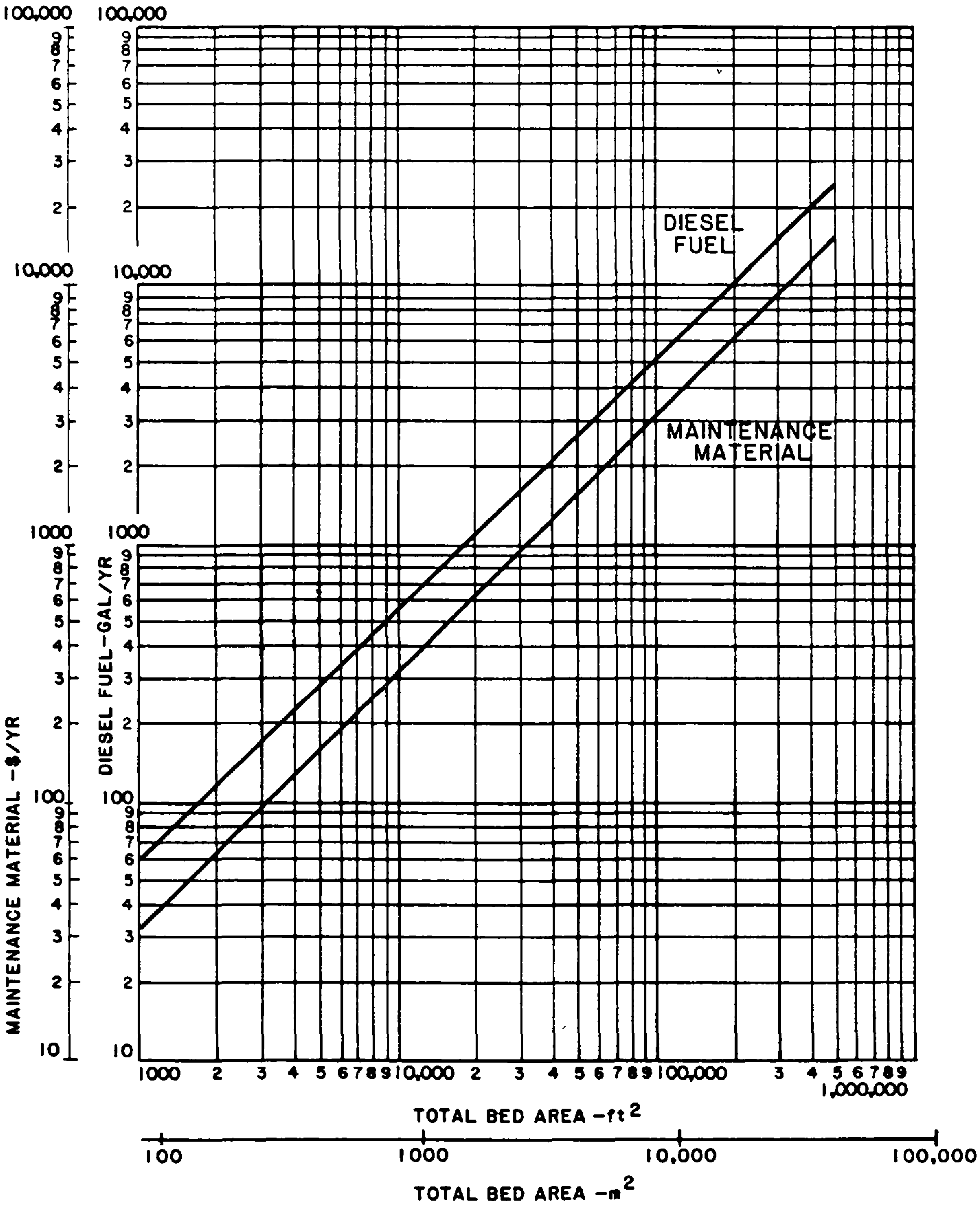

Figure C-23

Sand drying beds - diesel fuel and maintenance material requirements

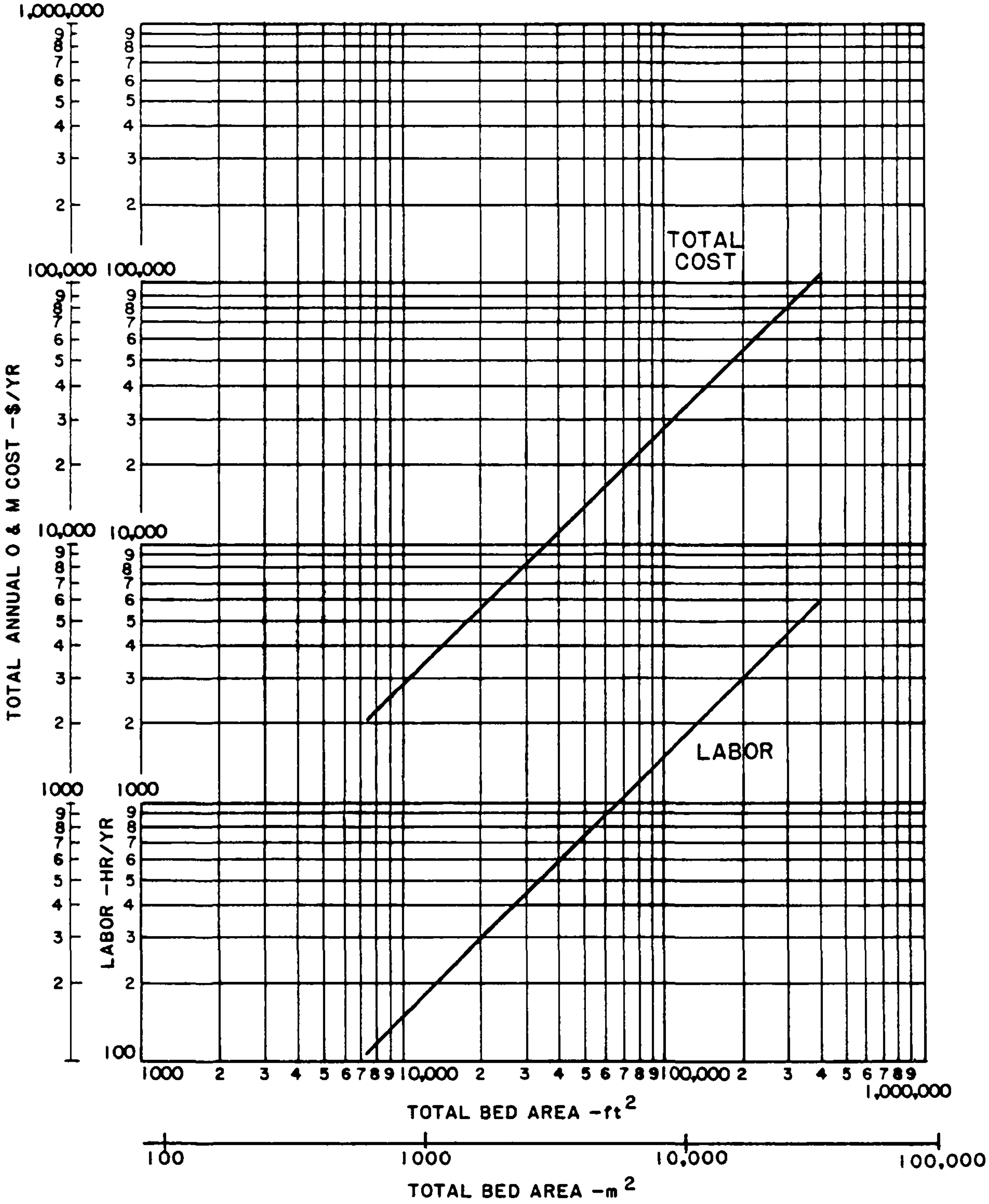

Figure C-24

Sand drying beds - labor and total annual operation and maintenance cost

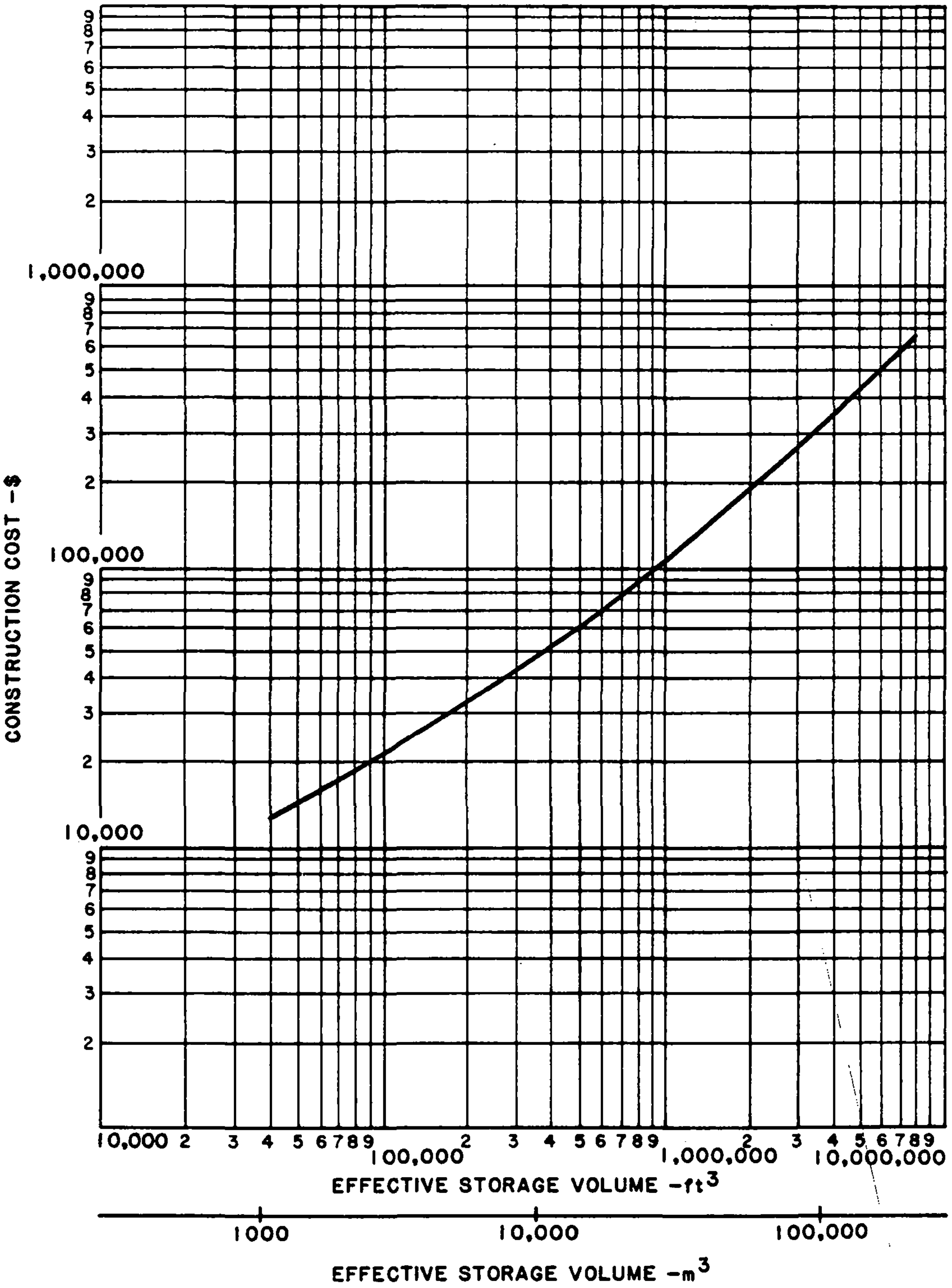

Figure C-25
Construction cost for sludge dewatering lagoons

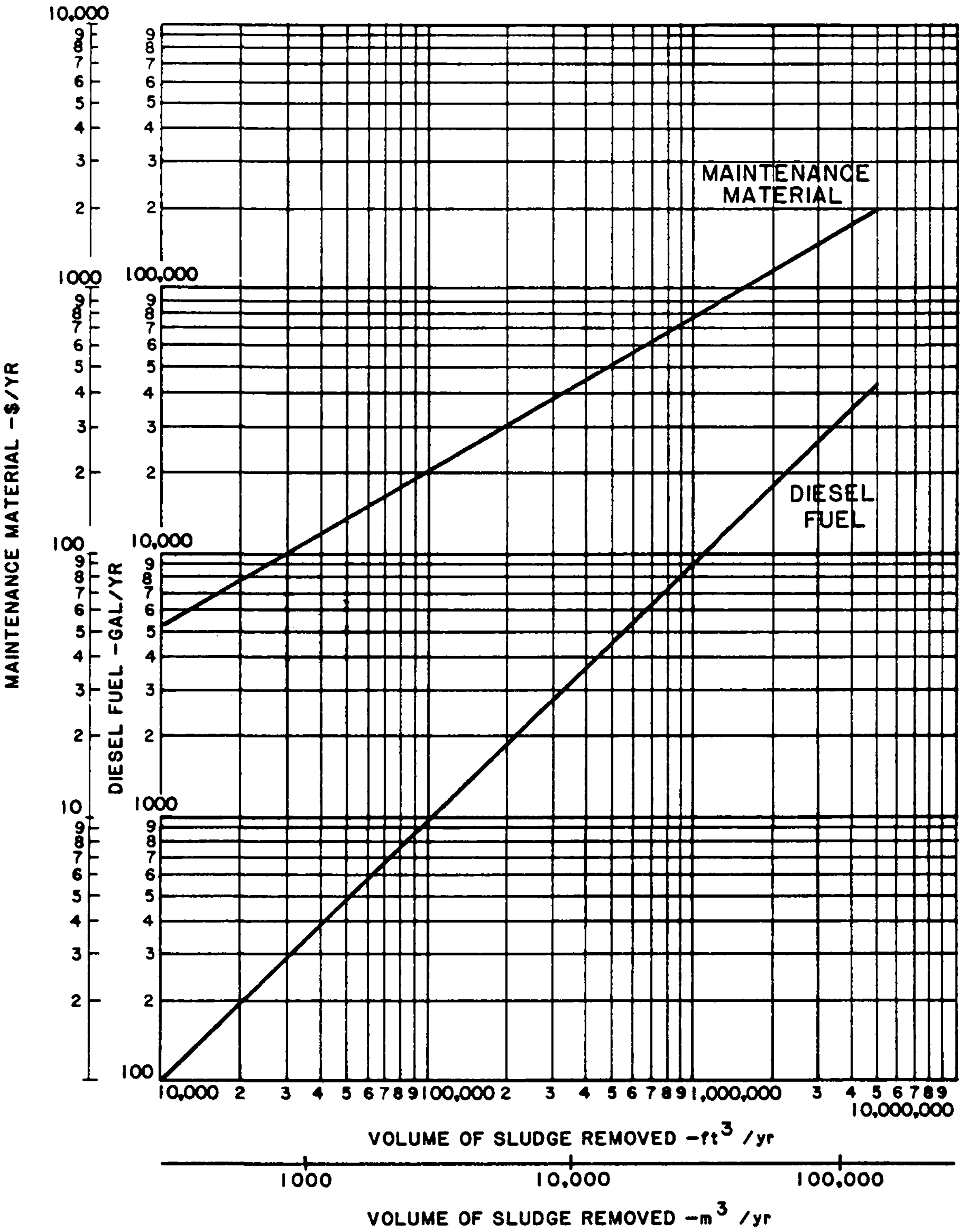

Figure C-26

Sludge dewatering lagoons - diesel fuel and maintenance material requirements

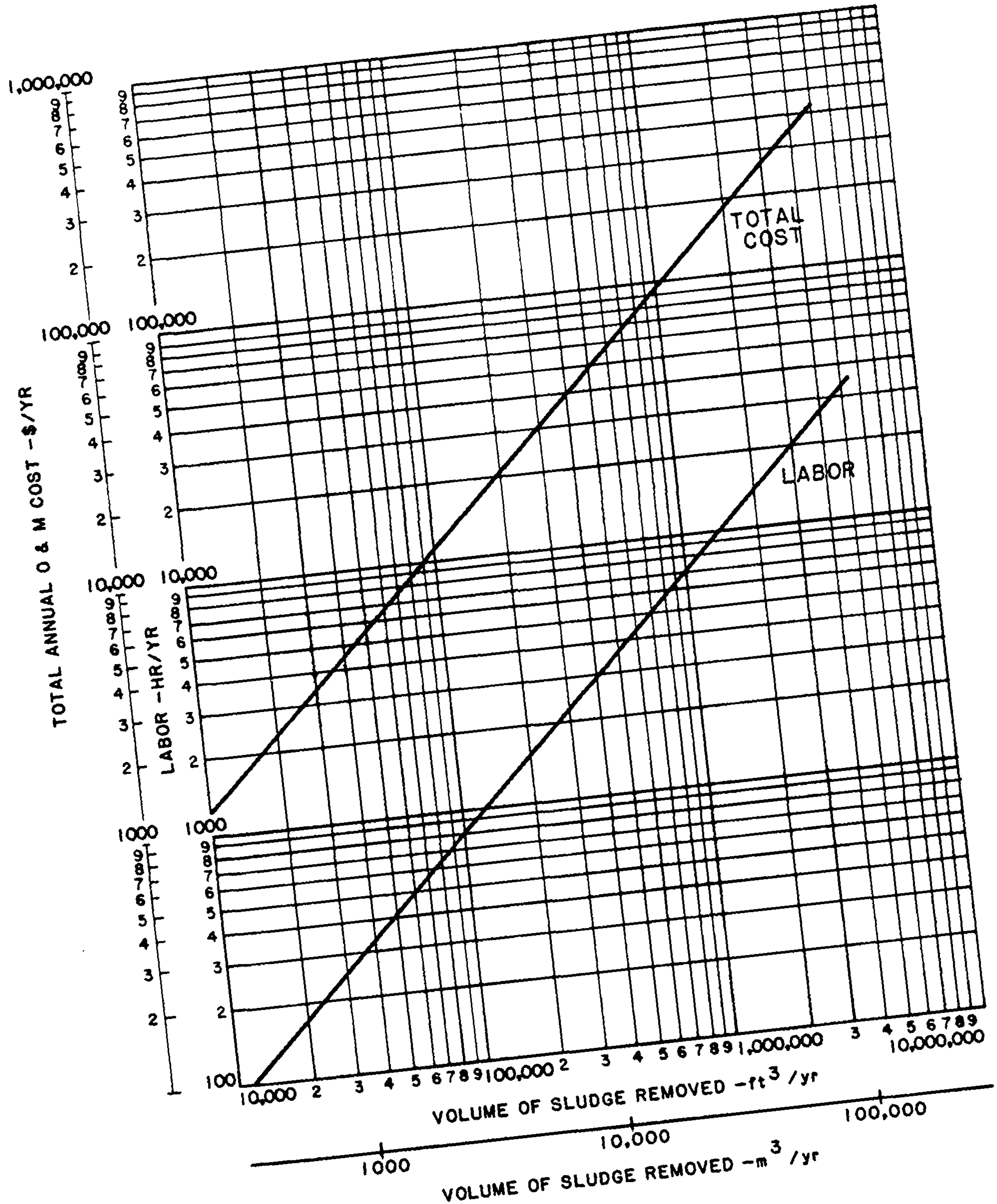

Figure C-27

Sludge dewatering lagoons - labor and total annual operation and maintenance cost

BIBLIOGRAPHY

Adam, F., "Dehydration of Fine Suspensions by Means of the Settling Centrifuge," Environmental Protection Engineering (Ger.), Vol. 3, p. 7, January/February, 1977; Chem. Abs., Vol. 89, 11610.

Adam, F., "Dewatering of Fine Suspensions by Means of Settling Centrifuge Plant II--Dewatering Plant for Municipal and Industrial Sludges." Environmental Protection Engineering (Ger.), Vol. 4, p. 5, January 1978; Poll. Abs. 79-01809.

Agrawal, S., and Goyal, A., "Vacuum Filtration Calculation," Poll. Eng., Vol. 10, p. 60, March 1978.

Alt, C., "Pusher Centrifuges--Optimum Conditions," Filtration and Separation, Vol. 17, p. 47, 1980.

Ames, R. K., et al., "Sludge Dewatering/Dehydration Results with Mini-B.E.S.T.," Proc. 30th Ind. Waste Conf., Purdue Univ., Ann Arbor Sci. Publ., Inc., Ann Arbor, Mich., 897, 1977.

"Areawide Assessment Procedures Manual - Volume III, Municipal Environmental Research Laboratory, Cincinnati, Ohio 45268, EPA 600/9-76-014, July 1976.

Atwell, J. S., "Sludge Dewatering Techniques Must Meet Pollution Control Requirements," Pulp & Paper, Vol. 42, p. 180, November 1978.

Austin, E. P., "The Filter Belt Press - Application and Design," Filtration and Separation, p. 320, July/August 1978.

Bassett, D. J., et al., "Performance Comparison of Filter Press, Belt Press and Centrifuge Units for Dewatering of Citrus Processing/Activated Sludge," Proc. 33rd Ind. Waste Conf., Purdue, Univ., Ext. Ser., 1978.

Basso, A. J., "Getting the Most Out of Filter Aids," Chemical Engineering, p. 185, September 1977.

Beardall, L. R., and Scarlett, B., "Separation and Classification on Rotating Surfaces," Filtration & Separation, Vol. 17, p. 248, 1980.

Beardsley, J. A., "Sludge Drying Beds are Practical," Water and Sewage Works, Part 1, p. 82, July; Part 2, p. 42. August 1976.

Bechir, M.H., and Herbert, W.A., "Sludge Processing Using Som-A-Press," Presented at the New England Water Pollution Control Association, October 1976.

Bell, J.A., Higgins, R., and Mason, Donald G., "Dewatering, a New Method Bows," Water and Wastes Engineering, April 1977.

Bennett, E. R., Rein, D. A., and Linstedt, K. D., "Economic Aspects of Sludge Dewatering and Disposal," Journal of the Environmental Engineering Division ASCE, Vol. 99, p. 55, 1973.

Bergstedt, D. C., and Swanson, G. J., "Evaluation of a Twin-Roll Continuous Press For Municipal Sludge Dewatering." Presented at the 49th Annual Conference Water Pollution Control Federation, Minneapolis, MN, October 1976.

Bizjak, G. J., and Becker, A. E., Jr., "Wausau Solves Dual Problem by Using Filter Press," Water and Wastes Engineering, p. 28, February 1978.

Brown and Caldwell Consulting Engineers, "Study of Wastewater Solids Processing and Disposal," Prepared for the Sacramento Regional County Sanitation District, June 1975.

Camp, Dresser & McKee, Inc., "Centrifugal Dewatering of Waste Activated Sludge," Report on testing and equipment proposals for Jones Island Wastewater Treatment Plant, Milwaukee, Wisconsin, October 1977.

Cassel, Alan F., and Iwata, N., "Operation of a Pilot-Scale Diaphragm-Type Filter Press," Proc. 3rd National Conf. on Sludge Management Disposal and Utilization, Information Transfer, Inc., Rockville, Md., p. 188, 1977.

Cassel, Alan F., and Johnson, Berinda P., "Evaluation of Filter Presses to Produce High Solids Sludge Cake," Jour. New England Water Poll. Control Assn., Vol. 12, p. 137, February 1978.

Cassel, Alan F., and Johnson, Berinda P., "Toward Better Incineration: New Press Evaluated," Water and Sewage Works, Vol. 125, November 1978.

"Centrifugal, Dewatering of Sludges," Environmental Poll. Mgmt., Vol. 8, June 1978.

Cherry, G. B., and Walton, M., "A New Concept in the Use of Filter Presses: Development of the 'Six Eye' Plate and Frame," Filtration & Separation, Vol. 17, p. 209, 1980.

Clark, E. I., and Fisk, B., "Dewatering Mixed Sludges," Water Poll. Control, Vol. 77, p. 509, 1978.

Clarke, W. N., et. al., "Digested Sludge Dewatering Experiences at Orange County, California," Journal Water Pollution Control Federation, Vol. 53, p. 530, May 1981.

Clewett, M. A., and Handyside, R. N., "Asphaltic Concrete Sludge Drying Beds," Water, (Austral.), Vol. 3, p. 15 (1976); Water Res. Abs., Vol. 10, p. 11, W77-05525, 1977.

"Construction Costs for Municipal Wastewater Treatment Plants," U.S. EPA, Office of Water Program Operations, Washington, D.C. 20460, MCD 37, January 1978.

"Cost of Landspreading and Hauling Sludge from Municipal Wastewater Treatment Plants," Office of Solid Waste, Washington, D.C. 20460, EPA 530/SW-619, October 1977.

Cox, C. H., "Sludge Dewatering," U. S. Patent No. 4,041,854 (August 16, 1977); Water Res. Abs., Vol. 10, p. 24, W77-12951, 1977.

Creek, John, "Tait Andritz SDM Sludge Dewatering Machine," WWEMA Conference paper, April 20, 1977, Atlanta, GA.

Culp, G. L., "Handbook of Sludge Handling Processes - Cost and Performance," Garland STPM Press, New York, 1979.

Culp, G. L., et. al., "Evaluation of Sludge Management Systems - Evaluation Checklist and Supporting Commentary," Office of Water Program Operations, Washington, D.C., 20460, EPA 430/9-80-001, February 1980.

Culp, Gordon L., and Heim, Nancy Folks, "Performance Evaluation and Troubleshooting at Municipal Wastewater Treatment Facilities," Office of Water Program Operations, Washington, D.C. 20460, EPA 430/9-78-002, February 1978.

Culp/Wesner/Culp, "Energy Considerations in Wastewater Treatment," Presented at CWC's Ninth Annual Wastewater and Water Treatment Seminar, September 1980.

Dembitz, A. E., "Belt Filter Press: A New Solution to Dewatering?" Water and Wastes Engineering. p. 36, February 1978.

"Dewatering Sewage Sludge by Electro Osmosis, Part I - Basic Studies, Part II - Scale Up Data," Prepared by the Electricity Council Research Centre, Capenhurst, England, NTIS PB-276 and NTIS PB-276 412, 1975 and 1976.

Edmondson, B. R., and Brooks, D. R., "The Membrane Filter Plate," Water Serv., (G.B.), Vol. 81, p. 975, 272, 1977.

Eichmann, Bruce W., "Dewatering Machine Solves Sludge Drying Problems," Water and Sewage Works, October 1977.

Famang, M. A., and Martire, A. A., "A Disposal-Costing Method for Evaluating Sludge Dewatering Chemicals," Journal Water Pollution Control Federation, Vol. 53, p. 162, February 1981.

Fernbach, E. and Tchobanoglous, G., "Centrifugal Screen Concentration for Activated Sludge Process.," Water and Sewage Works, Part I, January; Part II, February 1975.

Fischer, R., "An Economic Process for Drying Sewage Sludge," Environmental Poll. Management, Vol. 6, p. 5, January 1976.

Galloway, F. R., "Cost Cutting is in the Basket," Water & Waste Engineering, Vol. 15, p. 10, 1978.

Gasper, H., "Selection of Equipment for Dewatering Sewage Sludge," Filtration & Separation, Vol. 16, p. 23, 1979.

Goodman, B. L., and Higgins, R. B., "A New Device for Wastewater Treatment Sludge Concentration," Water and Wastes Engineering, August 1970.

Guidi, Eugene J., "Growth and Benefits of Low-Speed Centrifuges," Water and Sewage Works, Vol. 124, June 1977.

Gulas, Victor; Bond, Marvin; and Benefield, Larry, "Use of Exocellular Polymers for Thickening and Dewatering Activated Sludge, Journal WPCF, pp. 798-807, April 1979.

Gwilliam, R. D., "The E.C.C. Tube Filter Press," Filtration and Separation, March/April 1971.

Hagstroem, L. G., "Two-Stage Sludge Dewatering with Decanter and Basket Centrifuge," Environ. Poll. Mgmt., Vol. 8, p. 1, January 1978.

Halde, R. E., "Fundamental Principles of Sewage Sludge Filtration," Vatten (Swed.), Vol. 35, p. 200, 1979; Poll. Abs. 80-03310.
"Handling and Disposal of Sludges From Combined Sewer Overflow Treatment Phase III - Treatability Studies," Environmental Protection Technology Series, Office of Research and Development, Cincinnati, Ohio 45268, EPA-600/2-77-053C, December 1977.

Harnson, J. R., "Belt Filter Presses: Varieties to Choose From," Ind. Wastes, Vol. 25, p. 40, March 1979.

Howard, M. G., "The Economics of Horizontal Leaf Pressure Filter Design and Operation," Filtration & Separation, Vol. 16, p. 150, 1979.

"Innovative and Alternative Technology Assessment Manual," USEPA Office of Water Program Operations, Washington, D.C., 20460, MCD 53, February 1980.

Jaeger, E. A., "The Geometry of Scroll Centrifuges," Filtration & Separation, Vol. 16, p. 244, 1979.

Jeffrey, E. A., "Dewatering Rates for Digested Sludge in Lagoons," Journal Water Pollution Control Federation, Vol. 32, p. 1153, 1960.

Johnson, A. F., et al., "Construction, Operation and Performance of a New Vacuum Pressure Filter," Filtration & Separation, Vol. 17, p. 268, 1980.

Jordon, J. L., "Process for Sludge Disposal and Circular Landfill System," U. S. Patent No. 4,016,073 (April 5, 1977); Water Res. Abs., Vol. 10, p. 24 W77-12920, 1977.

Joyce, T. W., et al., "Factors Affecting Dewaterability of Primary Sludges," Tappi, Vol. 63, p. 73, March 1980.

Karr, P. R., and Keinath, T. M., "Limitations of the Specific Resistance and CST Test for Sludge Dewatering," Filtration & Separation, Vol. 15, p. 543, June 1978.

Kavanagh, B. V., "The Dewatering of Activated Sludge: Measurement of Specific Resistance to Filtration and Capillary Suction Time," Water Poll. Contr., Vol. 79, p. 388, 1980.

Keener, Phillip M., and Metzger, Larry R., "Startup and Operating Experience With a Twin Wire Moving-belt Press for Primary Sludge," Vol. 60, No. 9, September 1977, TAPPI.

Kini, A. D., and Nayak, S. L., "Optimising Vacuum Filtration of Sewage Sludge," Filtration & Separation, Vol. 17, p. 313, 1980.

Kurita, T. and Suwa, S., "Filtration and Expression of Municipal Sludges by the Automatic Press," Filtration & Separation, Vol. 17, p. 242, 1980.

Kurita, T., and Suwa, S-I., "How the Fully Automatic Filter Press Has Developed," Filtration & Separation, Vol. 15, p. 109, February 1978.

Leary, R. D., Ernest, L. A., Douglas, G. R., Geinopolos, A., and Mason, D. G., "Top-feed Vacuum Filtration of Activated Sludge," Journal Water Pollution Control Federation, Vol. 46, p. 1761, 1974.

Lee, S., "Diatomite Vacuum Filtration Improves Sludge Handling," Chem. Proc., Chicago, Vol. 42, p. 28, January 1979.

Leonard, R. J., and Parrott, J. W., "Sludge Dewatering at the Rohn and Haas Houston Plant," Proc., 33rd Ind. Waste Conf., Purdue Univ., Ext. Ser., 1978.

Marecek, J. and Novotny, P., "Optimizing the Performance of Leaf Filters," Filtration & Separation, Vol. 17, p. 34, 1980.

Masters, A. L., "Filter Aids," Solid-Liquid Separation, Butterworths, Inc., Ladislav Svarovsky, editor, 1977.

Miner, R. E., et al., "Pilot Investigation of Secondary Sludge Dewatering Alternatives," EPA-600/2-78/014, PB-280 982/OWP, 1978.

Moll, R. T., and Letki, A. G., "The Role of Centrifuges in Minimizing/Eliminating the Use of Chemical Additives in Dewatering and Thickening of Industrial Wastes," Proc. 34th Ind. Waste Conf., Purdue Univ., (Ann Arbor Science, Ann Arbor, Mich.) 1979, p. 606, 1980.

Morris, K., "Microcomputers and Microprocessors in Filter Design and Control," Filtration & Separation, Vol. 17, p. 109, 1980.

Murkes, J., and Carlsson, C-G., "Mathematical Modeling and Optimization of Centrifugal Separation," Filtration & Separation, Vol. 15, p. 18, January 1978.

NCASI, "A Pilot Plant Study of Mechanical Dewatering Devices Operated on Waste Activated Sludge," Prepared for National Council of the Paper Industry for Air and Stream Improvement, Technical Bulletin 288, November 1976.

NCASI, "A Review of the Operational Experience with Belt Filter Presses for Sludge Dewatering in the North American Pulp and Paper Industry," Prepared for National Council of the Paper Industry for Air and Stream Improvement, Technical Bulletin 315, October 1978.

Nelson, John K., and Tavery, Mary Ann H., "Chemical Conditioning Alternatives and Operational Control For Vacuum Filtration," Journal WPCF, pp. 507-517, March 1978.

Nelson, O. F., "Operational Experience with Filter Pressing," Water Pollution Control Federation - Deeds and Data, March 1978.

Nilsson, P., "Sludge Dewatering with Roto-Sieve," Vatten, (Swed.), Vol. 32, p. 253, March 1976; Chem. Abs., 86, 16, 1977.

Novak, J. T., and Haugan, B., "Mechanisms and Methods for Polymer Conditioning of Activated Sludge," Journal Water Pollution Control Federation, Vol. 52, p. 2571, October 1980.

Novak, John T., and Langford, Mark, "The Use of Polymers for Improving Chemical Sludge Dewatering on Sand Beds," Journal AWWA, pp. 106-110, February 1977.

Ohara, G. T., Raksit, S. K., and Olson, D. R., "Sludge Dewatering Studies at Hyperion Treatment Plant," Journal WPCF, pp. 912-925, May 1978.

Ohmiya, K., "Engineering Evaluation of New Sludge Treatment Facilities," Journal Water Pollution Control Federation, Vol. 52, p. 943, 1980.

Osborne, D. G., "Screening," Solid-Liquid Separation, Butterworths, Inc., Ladislav Svarovsky, editor, 1977.

Pearse, M. J., and Barnett, J., "Chemical Treatment for Thickening and Filtration," Filtration & Separation, Vol. 17, p. 460, 1980.

"Pilot Investigation of Secondary Sludge Dewatering Alternatives," Industrial Environmental Research Lab, Cincinnati, Ohio 45268, NTIS PB-280-982, February 1978.

"Pressure Filtration of Wastewater Sludge With Ash Filter Aid," Office o Research and Development, Cincinnati, Ohio 45268, EPA-R2-73-231, 1973.

Prinssen, A. A. J. A., "Vacuum Belt Filters," Filtration & Separation, Vol. 16, p. 176, 1979.

"Process Design Manual - Municipal Sludge Landfills," EPA-625/1-78-010, SW-705, October 1978.

Purchas, D., "A Practical View of Filtration Theory," Filtration & Separation, Vol. 17, p. 147, 1980.

Purchas, D. B., "Solid Sludge Liquid Separation Equipment: A Preliminary Selection Programme," The Chemical Engineer, Vol. 47, p. 1, 1978.

"Recommended Standards for Sewage Works," Great Lakes/Upper Mississippi River Board of State Sanitary Engineers, 1971.

Regan, J. M., "Filter-Presses--Still Alive and Kicking!" Filtration & Separation, Vol. 14, p. 485, 1977.

"Review of Techniques for Treatment and Disposal of Phosphorus-Laden Chemical Sludges," Office of Research and Development, Cincinnati, Ohio 45268, EPA 600/2-79-083, February 1979.

Rodman, C. A., "Filter Media Performance and Fibre Morphology," Filtration & Separation, Vol. 17, p. 543, 1980.

Rush, R. J., "Natural Freeze-Thaw Sewage Sludge Conditioning and Dewatering," Canada Environ. Prot. Ser. Tech. Dev. Rep. EPS 4-WP-79-1, 1979.

Rushton, A., et al., "Shear Effects in Cake Formation Mechanisms," Filtration & Separation, Vol. 16, p. 456, 1979.

Salmi, M. W., "Choose Dewatering Unit According to the Type of Sludge," Water & Wastes Eng., Vol. 16, 1979.

Sandstedt, H. N., "Non-Wovens in Filtration Applications," Filtration & Separation, Vol. 17, p. 358, 1980.

Shaw, F. J., "Filter Press Feed Systems," Filtration & Separation, Vol. 17, p. 454, 1980.

"Sludge Dewatering and Drying on Sand Beds," Office of Research and Development, Cincinnati, Ohio 45268, EPA-600/2-78-141, August 1978.

"Sludge Filter Bags," Water & Water Trt. Jour. (G.B.), Vol. 21, p. 47, September 1978.

"Sludge Handling and Conditioning," Special Issue of Water and Wastes Engineering, February 1978.

Sludge Handling and Disposal Practices at Selected Municipal Wastewater Treatment Plants," Office of Water Program Operations, Washington, D.C. 20460, MCD 36, April 1977.

Stahl, W., "Cost/Performance Comparisons between Disk and Drum Filters," Filtration & Separation, Vol. 15, p. 38, January 1978.

Svarovsky, L., "Filtration Fundamentals," Solid-Liquid Separation, Butterworths, Inc., Ladislav Svarovsky, editor, 1977.

Svarovsky, L., "Hydrocyclones," Solid-Liquid Separation, Butterworths, Inc., Ladislav Svarovsky, editor, 1977.

Syal, R. K., "Compare Sludge Handling Alternatives," Water and Wastes Engineering, Vol. 16, p. 60, March 1979.

Szymanski, J. R., "Evaluation of a Belt Filter Press," Jour. New England Water Poll. Control Assn., Vol. 12, p. 155, February 1978.

Taylor, J. A., "Evaluation of Somat Som-A-System Dewatering Method for the Norwich Water Pollution Control Plant, Norwich, Connecticut," Somat Corporation, Pomeroy, Pennsylvania, July 1978.

Tiller, F. M., "Characteristics of Staged Delayed-Cake Filters," Filtration & Separation, Vol. 15, p. 204, March 1978.

Vesilind, P. A., "Characterizing Sludge for Centrifugal Dewatering," Filtration & Separation, Vol. 14, p. 115, 1977.

Viraraghavan, T., and Landine, R. C., "Economic Evaluation of Four Sludge Dewatering Devices," Pollution Engineering, September 1978.

Wakeman, R. J., "Pressure Filtration," Solid-Liquid Separation, Butterworths, Inc., Ladislav Svarovsky, editor. 1977.

Wakeman, R. J., "The Performance of Filtration Post-Treatment Processes. 1. The Prediction and Calculation of Cake Dewatering Characteristics," Filtration & Separation, Vol. 16, p. 655, 1979.

Walker, J. T., "Unique Sludge Handling System Chosen in Dubuque," Water & Wastes Eng., Vol. 15, p. 20, February 1978.

Walski, T. M., "Mathematical Model Simplifies Design of Sludge Drying Beds," Water and Sewage Works, p. 64, April 1976.

Wiksell, H., and DeBesche, S., "Automatic Control of a Centrifuge Process," Vatten (Swed.), Vol. 34, p. 10, January 1978; Chem. Abs., Vol. 89, 117097.

Wilhelm, J. H., "The User of Specific Resistance Data in Sizing Batch Type Pressure Filters," Jour. Water Poll. Control Fed., Vol. 50, p. 471, 1978.

Young, R. A., "Cat Finds the Track to Sludge Disposal," Poll. Eng., Vol. 10, p. 55, October 1978.

Yukawa, H., et al., "Fundatmental Study on Electroosmotic Dewatering of Sludge at a Constant Electric Current," Jour. Chem. Eng. of Japan, Vol. 9, p. 402, May 1976; Chem. Abs., Vol. 86, p. 26, 194497m (1977).

Zacharias, D. R., and Pietila, K. A., "Full-Scale Study of Sludge Processing and Land Disposal Utilizing Centrifugation for Dewatering," presented at the 50th Annual Meeting of the Central States Water Pollution Control Association, May 18-20, 1977, Milwaukee, Wisconsin.

Zenz, David R., Sawyer, Bernard, and Watkins, Robert, "Evaluation of Dewatering Equipment For Anaerobically Digested Sludge," Journal Water Pollution Control Federation, Vol. 50, p. 1965, August 1978.

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