A DESCRIPTION OF SEDIMENT DEWATERING METHODS

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ABSTRACT

Whether motivated by a need for disposal of contaminated sediment, a reduction in the size of confined disposal areas, or the scarcity of acreage adjacent to dredge sites, solids containment and dewatering practices have increased in importance in recent years. The material handling aspect of a dredging project must now be regarded as a solids dewatering project. The selection of equipment and chemical additives designed to optimize the sediment dewatering process plays a critical role in project production rates and profitability.

Environmental engineering firms, government agencies, and dredging companies have become increasingly aware of dewatering processes used by industrial and municipal entities and the economic benefits derived from them. However, the results from adapting these technologies to sediment dewatering have not always been favorable. With several different dewatering methods available, the selection process can be a difficult and arduous task requiring the investigation of many influencing variables. In an effort to simplify the decision-making process, the authors endeavor to provide some basic information to assist the end-user in the selection of mechanical dewatering technology.

Typically, sediment dewatering requires that the dredged solids be screened of large detritus, collected in a staging area, and thickened prior to dewatering. This paper will briefly describe the various types of equipment used in solids dewatering – including Belt Filter Press, Plate and Frame Press, Screw Press, Centrifuge, and Geotube® – and the chemical additives used to improve their operating performance.

Keywords: Solids handling, solids dewatering, chemical additives, chemical treatment.

INTRODUCTION

Since the early 1970's, heightened environmental awareness has led to the promulgation of several regulations designed to protect natural resources. Two such laws, the Clean Water Act and the Comprehensive Environmental Response Compensation and Liability Act (also known as the Superfund Act), have had a significant impact on the dredging industry. With the enactment of these and similar regulations, and an industry focus on the environmental remediation of rivers and waterways, the management of dredged sediment has become much more important. The removal and treatment of contaminated sediment from remediation sites, the scarcity of acreage adjacent to dredge sites, the reduction in capacities at disposal sites, and limited project funding have all contributed to this increased importance in sediment dewatering.

When properly employed, the application of mechanical and dewatering technologies have proven effective in managing the solids handling needs of a dredging project. In the equipment and chemical treatment selection process, it is helpful to think of a dewatering project as comprised of three distinct stages:

- Removal of Oversized Materials
- Settling and Thickening
- Solids Dewatering

The first stage, Removal of Oversized Material, can often be addressed in a relatively straightforward and systematic manner. The second stage, Settling and Thickening, can be addressed by a modest degree of sample analysis and laboratory testing for the selection of a chemical treatment program designed to aid the process.

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However, the third stage – Solids Dewatering – is a more complex process requiring carefully engineered studies that consider the many variables affecting the dynamics of equipment and chemical performance, the impact on project economics, and the overall success of the project.

In order to derive the greatest benefit from these technologies, it is important to understand the conditions and variables for which they are designed while also considering what can be done at the dredge site to best replicate those ideal conditions, the characteristics of the dredged sediment, and the overall project objectives.

A GENERAL DESCRIPTION OF SOLIDS HANDLING PROCESSES

Although waterways and rivers tend to sort sediments through varying flow regimes forming somewhat uniform deposit environments, it is common for a dredging project to require equipment capable of segregating and processing a wide range of materials. A system frequently used for the classification of solids is PIANC (Permanent International Association of Navigational Congress), represented in Table 1 (Hunter, et al., 2006). This classification system is useful in describing the types of materials commonly encountered in a dredging project and can serve as a reference when considering solids handling options.

Table 1. PIANC classification of soils by sieve size and 10^{-6} meters.

Soil Type	Particle Size – microns (10^{-6} meters)	Sieve Size
Boulders	>200,000	6 in
Cobbles	60,000 – 200,000	3 – 6 in
Gravel (Coarse)	20,000 – 60,000	¾ - 3 in
Gravel (Medium)	6,000 – 20,000	¼ - ¾ in
Gravel (Fine)	2,000 – 6,000	# 7 Sieve – ¼ in
Sand (Coarse)	600 – 2,000	# 25 - # 7
Sand (Medium)	200 - 600	# 72 - # 25
Sand (Fine)	60 - 200	# 200 - # 72
Silt (Coarse)	20 - 60	Passing # 200
Silt (Medium)	6 - 20	Passing # 200
Silt (Fine)	2 - 6	Passing # 200
Clays	<2	Passing # 200

Equipment used in the dewatering of sediments is designed to achieve optimum performance under steady-state operating conditions with minimal variance in solids loading (the weight of solids in suspension per unit of time), flow rate, and particle size distribution. Producing these conditions in the field often proves difficult and may require several types of equipment in series, or in parallel, at varying stages designed to remove solids that are larger in particle size than the dewatering equipment is capable of processing and solids that readily fall from suspension under gravitational forces.

The removal of oversized material (such as detritus, gravel, and sand) is conducted in an incremental manner starting with boulders and debris, then diminishing in size to medium or even fine-grained sands. These materials are removed from the dredged sediments by mechanical processes using an assortment of rugged equipment that classifies the solids by sorting them through a succession of progressively smaller screen apertures. Coarse, medium, or fine grained sands, representing the smaller particle sizes in this range, are sometimes removed through the use of equipment that separates them from water by introducing centrifugal forces that act upon density.

The solids fraction remaining in suspension after the first stage removal of large materials is composed of dredging "fines" – solids that pass through a No. 200 mesh sieve (0.075mm or 75 microns). The behavior of solids in this size range, commonly referred to as suspended solids, is greatly influenced by electrostatic forces that develop on their surface. This electrostatic force disrupts the normal gravitational settling process by creating a state of repulsion between the suspended particles. Due to the relatively high surface area-to-mass ratio that increases as particulate sizes decrease, sediments in this size range are predisposed to forming suspensions. As can be seen in

Table 2, (Stocks, 2006), these small particles exhibit slow settling rates that result in the need for large detention areas to provide quiescent conditions for settling and thickening to occur.

Table 2. Sedimentation rate dependant upon particle size.

Solids Type	Diameter μm	Diameter mm	Time to Settle One Meter
Gravel	10^4	10	1.5 seconds
Sand	10^3	1.0	6 seconds
Fine Sand	10^2	0.1	3 minutes
Silt	10	0.01	3 hours
Clay	1.0	10^{-3}	300 hours
Clay	0.1	10^{-4}	5 years
Colloids	0.01	10^{-5}	500 years

All forms of agitation – whether induced by flow rates, equipment performance, or wind disturbing the surface of the water – will impart energy to the suspended particulates that will increase settling time in a settling or containment area and must be accounted for. The tendency for “fines” to remain in suspension and resist the forces of attraction that bring about the agglomeration of particles (through processes known as coagulation and flocculation) poses a significant problem to dredging projects during the Settling and Thickening and Solids Dewatering stages. Rather than providing the physical space and time needed for the agglomeration of solids to occur naturally, it is often advantageous to induce agglomeration through the introduction of chemical additives. Chemical additives include a wide range of products ranging from natural organic compounds (such as chitin), to inorganic products (such as lime, ferric chloride, and aluminum sulfate), to synthetic organic compounds known as polymers (such as coagulants and flocculants).

Coagulants are cationic (positively charged) chemicals that serve to reduce the electrostatic forces responsible for repulsion thereby allowing the suspended particles to agglomerate. As the particles come together, their effective size is increased resulting in accelerated sedimentation rates. The size of the agglomerated particles, however, remains relatively small and the bonds holding the particles together are weak. Coagulants are most often used during the Settling and Thickening stage and may be sufficient for confined and upland disposal applications. Coagulants are generally not used during the Solids Dewatering stage as the shear forces exerted by these processes can physically break the electronic bonds holding the solids together and result in the re-suspension of solids.

Flocculants are synthetic polymers made from long chains of polyacrylamide. The length of the chain is indicative of the polymer’s molecular weight and the polymer is engineered to have a characteristic electrical charge that may be anionic (negative charge), non-ionic (neutral charge), or cationic (positive charge). The number of charged sites along the polymer chain is also engineered into the polymer resulting in the availability of a wide range of polymers characterized by molecular weight and charge density. When a polymer flocculant is added to slurry containing suspended particles, the particulates are attracted to the charged sites while the polymer chain forms a physical bridge between the solids. This serves to bind the solids together and prevents shear forces or excessive turbulence from re-suspending the solids.

The use of coagulants and/or flocculants is often the only viable method through which the Solids Dewatering project can be successfully completed in a cost-effective manner. A clear definition of coagulant and polymer chemistries, and the means by which suspensions of particulates are influenced by these chemicals, can be found in Hunter, et al., (2006).

The extent to which a relatively small amount of chemical additives can influence the behavior of suspended particulates must not be underestimated. When properly applied, improvements to solids settling rates, thickening, compaction, volume reduction, and water release are profound and have a positive effect on project economics. The degree of agglomeration and the behavior of the solids when conditioned with a given chemical must be carefully evaluated as these factors will differ with varying sediment types and may preclude the use of some types of equipment due to the rate of water release, the size of the agglomerated solids, and the shear resistance that can be achieved. As there are a wide variety of chemical additives available, the selection of the best chemical for a given substrate is not easy and requires consultation with, and laboratory evaluations by, a qualified chemical treatment specialist. Additionally, the equipment used for chemical additive preparation (make-down), storage, metering into the slurry line, and control are all important considerations that have a direct impact on solids dewatering optimization and must be included in the evaluation.

Depending on the availability of land, settling and thickening can take place within large environmentally isolated ponds. When land is scarce, this process can take place within mechanical devices known as Thickeners. In each case, the process is engineered to accommodate the introduction and mixing with the selected chemicals and provides an environment conducive to solids settling. The primary objective of the Settling and Thickening stage of a dewatering project is to produce a homogeneous concentration of uniform solids at a constant rate and to release excess volumes of water.

Further water removal, solids compaction, and solids volume reduction occurs during the Solids Dewatering stage. This is achieved by pre-conditioning the thickened slurry with chemical additives and using equipment that is specifically designed to dewater solids by physically removing the bulk of the remaining water through predominately mechanical processes. By conducting preliminary studies of the sediment characteristics, choosing the appropriate chemical treatment program, and selecting the appropriate type of dewatering equipment, it is possible to design a system that will capture as much as 99.9% of the particulates, reduce the solids volume, and allow the contractor to return a clean, solids-free effluent to the receiving body of water while also producing dewatered solids (cake dryness) that can be as high as 70% Total Solids (measured as percent Total Solids by weight).

VARIABLES INFLUENCING THE SELECTION OF EQUIPMENT AND CHEMICAL TREATMENT

Due to the great variability in sediment characteristics that occur from site to site, the nature of contaminants that may be contained within them, and the availability of local resources, the equipment and chemical treatment selection process must be initiated as early as possible. It should begin with an in-depth understanding of the required performance standards as they may impose limitations that will directly impact the types of equipment and chemical treatment programs that can be used. Some of the variables to be considered are:

- Production capacities and the sizing of the equipment will be governed by the amount of sediment to be recovered, the duration of the project, and the acreage available for use as a staging ground.
- The need for processing contaminated solids may raise concerns of employee exposure and require the use of personal protective equipment and enclosed operations.
- Limited access to a clean water source may eliminate considerations for equipment that require large volumes of wash water.
- Particle size distribution will dictate the types of equipment or sequence of processes required to limit the size of the solids entering the dewatering equipment.
- High organic, clay, or oil and grease fractions will influence the types of filters or cloth media to be considered in the dewatering equipment as they may press into pore spaces and reduce the release of water by blinding the media.
- Environmental regulations governing the discharge of effluent into receiving bodies of water may limit the types of chemical additives that can be used.
- The ability of agglomerated solids conditioned with chemicals to withstand the shear forces exerted by the dewatering equipment may preclude the selection of some types of machinery.
- Variations in the types of sediments to be dredged may require that more than one type of chemical additive be available at the site.
- The volume of chemical additives needed for establishing and maintaining steady state thickening and dewatering conditions may require automated chemical make-down equipment that ensures a continuous supply of ready-to-use product and to help free up manpower.
- Anticipated variations in thickened slurry concentrations and flow rates may require the installation of specialized equipment to measure these changes and automatically adjust the chemical additive feed rate to conserve chemical use and maintain optimum dosing levels.
- Environmental regulations restricting the amount of TSS (Total Suspended Solids) released in effluent waters may require the use of processes capable of achieving high solids capture rates.
- Landfill or beneficial re-use requirements may be such that a maximum limitation is imposed on the permissible water content of the dewatered solids (sludge cake).

The preceding is only a partial list and is intended to illustrate the importance of gathering representative sediment samples and conducting in-depth evaluations in order to provide a methodical approach to selecting the best technologies required for the successful completion of a project.

The economic benefits derived from using the right equipment and chemical treatment for a project are significant, especially in situations where there is a need to transport dewatered sediment off-site. Reasons for transporting dewatered sediment away from the project site may be driven by the need to dispose of contaminated sediment, the absence of acreage adjacent to the dredge site, the need to re-use the land within a short amount of time or in cases where confined disposal and containment is limited or undesirable. In all these instances, the selection of the appropriate dewatering technology must be based on the equipment capabilities and limitations, the sediment characteristics, the chemical treatment required for dewatering optimization, and the site objectives evaluated in terms of overall project economics. The economic impact of establishing an effective sediment dewatering program can readily be seen by examining the relationship of transportation costs versus cake dryness, as shown in Table 3 and expressed graphically in Figure 1. In the example, the disposal cost for 100,000 dry tons of solids costing $15.00 per wet ton for transportation is considered.

Table 3. Cake dryness vs. transportation cost for 100,000 dry tons.

Cake Dryness %	Wet Tons	Transportation at $15 per Wet Ton	Savings for Cake Dryness > 20%	Rate of Change in $ Saved
20%	500,000	$7,500,000		
25%	400,000	$6,000,000	$1,500,000	$1,500,000
30%	333,333	$5,000,000	$2,500,000	$1,000,000
35%	285,714	$4,285,714	$3,214,286	$714,286
40%	250,000	$3,750,000	$3,750,000	$535,714
45%	222,222	$3,333,333	$4,166,667	$416,667
50%	200,000	$3,000,000	$4,500,000	$333,333
55%	181,818	$2,727,273	$4,772,727	$272,727
60%	166,667	$2,500,000	$5,000,000	$227,273
65%	153,846	$2,307,692	$5,192,308	$192,308
70%	142,857	$2,142,857	$5,357,143	$164,835
75%	133,333	$2,000,000	$5,500,000	$142,857
80%	125,000	$1,875,000	$5,625,000	$125,000

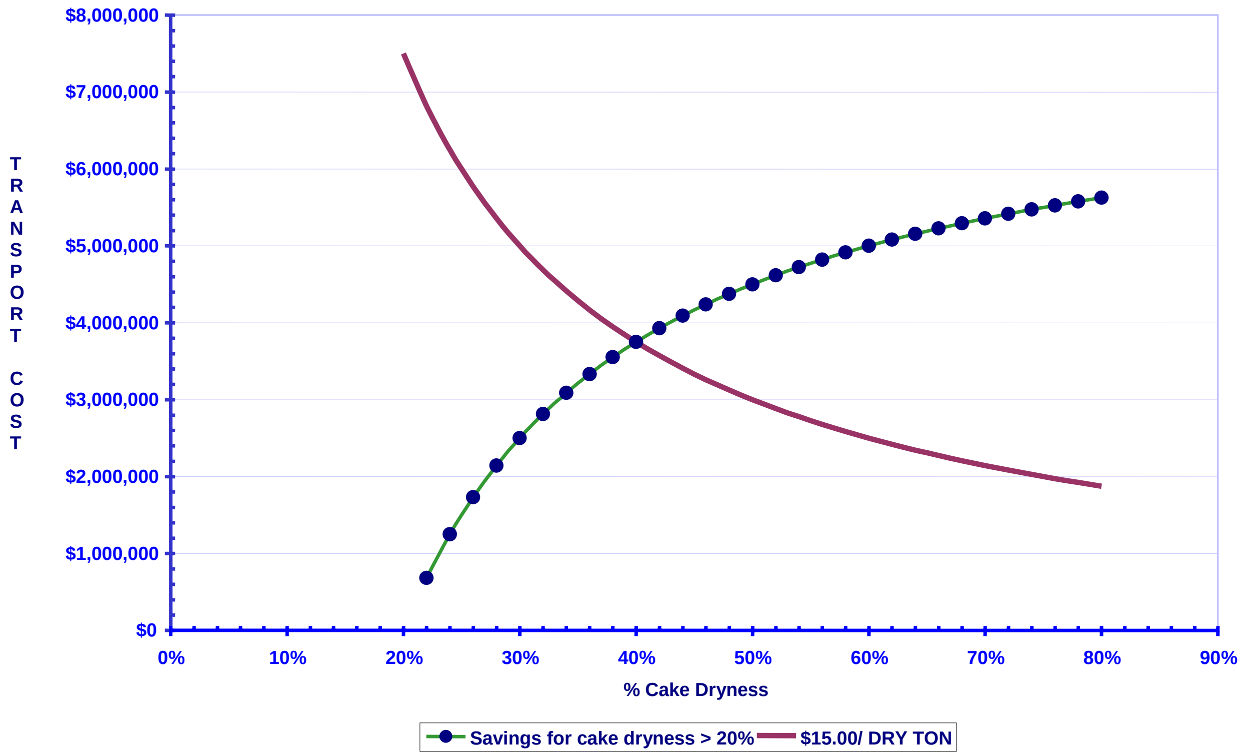


Figure 1. Cake dryness vs. transportation cost for 100,000 dry tons.

The values and representations in Table 3 and Figure 1 are meant for illustration purposes only. It is important to evaluate each solids dewatering project independently as sediment characteristics may vary significantly from one project to another.

It should also be noted that the relationship between cake dryness and transportation cost is non-linear. At the onset, incremental increases in dryness significantly reduce transport costs. However, as cake dryness increases the rate of cost reduction for each incremental improvement provides a diminishing economic benefit. This fact may strongly influence the dewatering technology decision-making process. Every effort should be made to explore all of the variables influencing cost for each type of dewatering method considered, as processing costs for an incremental increase in cake dryness may negate a perceived reduction in transportation costs.

Solids Dewatering Technology

Thickeners often increase solids concentrations to 20% Total Solids or more. The solids can be pumped to a holding area where they are allowed to desiccate through compaction, by overburden (the gravitational forces exerted by weight), and by exposure to air. This approach, however, requires the availability of large amounts of land and time, and the effluent quality may be poor resulting in the need for additional water treatment processes. Additionally, the solids may still contain an appreciable amount of water adding weight to the solids. This, as previously seen in Table 3 and Figure 1, has a negative economic impact on transportation costs.

The most effective means of preparing solids for transport is by running them through a process that yields further water release, compaction, and volume reduction. Most often, this process consists of the addition of appropriately selected chemicals to the thickened solids to create an agglomeration of "fines" accompanied by rapid water release. The process can take place within a variety of equipment types that allow the released water to escape while retaining the solids. As the water evacuates the interstitial pore space, the machinery exerts forces that can press the solids into the void areas resulting in compaction and volume reduction. The process employing the use of chemical additives working in concert with machinery is referred to as the "Dewatering" process.

The equipment used may be a Belt Filter Press, Plate and Frame Press, Screw Press, Centrifuge, or Geotube®. As referenced earlier, the selection of the appropriate dewatering technology for a given site must be based on the equipment capabilities and limitations, the sediment characteristics, the chemical additive dose required for dewatering optimization, and the site objectives evaluated in terms of overall project economics.

Once these variables have been quantified, the contractor can review the capabilities of various dewatering technologies and select a few for initial evaluation. At this time, it is also prudent to initiate the selection of chemical additives that are best suited for producing flocculated solids that have characteristics which provide optimum dewatering conditions for the type of equipment being considered.

The means by which chemical additives are prepared and introduced to the thickened slurry as it enters the dewatering machinery is also important. Whether the chemical of choice is in a dry or liquid form, it typically cannot be used until it has been diluted to a specific concentration with water. The process of dilution is referred to as make-down and is a critical step that directly influences the ability of the chemical to mix with the thickened slurry and bring about the agglomeration of the solids and a rapid water release.

The prerequisites required for each mechanical dewatering device to operate effectively must be reliably reproduced under field conditions – often a difficult task when considering the fact that flow rates and slurried solids concentrations are subject to frequent and rapid changes. Whenever possible, it is best to use equipment that can sample the slurry, sense changes in density and flow rates, and automatically adjust the chemical dose through a computer interface. The use of equipment with these capabilities, as seen in Figure 2, ensures that the chemical treatment dose is kept to a minimum, stabilizes the mechanical dewatering performance, provides maximum production rates, and produces a predictable dewatered end product (see U.S. patent number 5,902,487 for additional information regarding this process).

Figure 2. ALCOTECH® DWU dry polymer make-down unit (left) and ALCOTECH® DS Polymer Dose Control and Metering Pump System (right).

Dewatering Equipment

Machine selection and sizing requires input from the manufacturer as each type of device has volumetric limitations that are dependent on hydraulic and solids loading. Depending on complexity, each device requires varying degrees of operator training. Site personnel must be prepared to ensure that proper procedures are followed and mechanical adjustments are made in the effort to optimize performance. Precautions must be taken to avoid the introduction of oversized or sharp objects as they may damage the equipment and result in expensive and time consuming maintenance. Additionally, a thorough understanding of the factors that provide the greatest benefit for a given application must be developed. Some of the factors to be considered (and which will be discussed in more detail later in this paper) are: cake solids, capture rate, solids loading, polymer dose, overall footprint, operating mode (continuous or batch), ease of operation, noise levels, vapor or fume emission, capital cost, power cost, labor cost, maintenance cost, and overall cost.

Belt Filter Press

The Belt Filter Press, as seen in Figure 3, is sometimes used in the dewatering of dredged solids. In its mode of operation, solids are conveyed through three dewatering zones and are pressed between two woven monofilament filter cloths (US EPA 2000, EPA 832-F-00-057). The belt filter cloths are continuously washed by a high pressure spray to discourage blinding of the weave – a condition in which a porous filtrate medium becomes plugged with solids or mineral deposition to where water flow becomes inhibited – and promote good drainage.

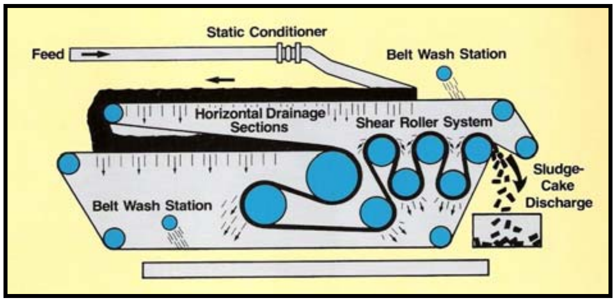
- In the first zone, chemically conditioned solids are evenly distributed onto the top belt filter cloth in a gravity drainage deck and passed through a set of rakes known as chicanes. As the sludge passes through the chicanes, it is tumbled across the upper cloth enabling as much as 50% of the free water released during the flocculation process to drain through the weave, effectively increasing the solids concentration.

- In the second dewatering zone, the solids are dropped onto the lower belt filter cloth and conveyed into a wedge shaped zone where it is compressed between the upper and lower cloths as they travel between two large rollers. This zone is where the initial cake formation takes place and is referred to as the low pressure zone.

- The third and final zone is the high pressure shear zone where the belt filter cloth passes through a series of small diameter rollers. Compressive forces are increased and the belts are configured in such a way that they move through the roller at slightly different speeds. The differential speed of the belts traveling through the rollers exerts a shear to the solids between them and forces additional water release.

Many of the variables affecting the dewatered solids output and filtrate quality are controlled by the operator taking clues from routine visual surveillance and making adjustments to the sludge feed rate (gallons per minute), belt speed, belt tension/pressure, and chemical feed rate. When properly operated under optimum chemical dose conditions, medium to high cake solids and capture rates are typically achieved; however, these results will vary with the nature of the sediments being dewatered, and are also dependant upon the size of the press (usually determined by the width of the belts or by their overall surface area).

The Belt Filter press is capable of supporting relatively high production rates and is generally regarded as being reliable and adaptable to changing conditions. As the filter cloths move through the machine on a continuous basis, large volumes of high pressure wash water are used to clean the weave and discourage particulates from getting trapped. Even so, sludge containing high concentrations of oil and grease or mineral content can permeate the weave and reduce water drainage.



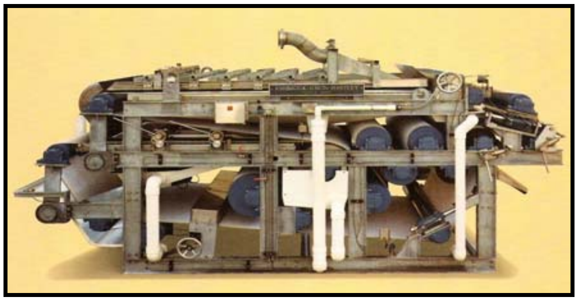


Figure 3. Belt filter press schematic (left) and belt filter press (right), (Courtesy of Ashbrook-Simon Hartley).

Plate and Frame Press

The Plate and Frame Press, as seen in Figure 4, dewaters slurry by loading and trapping them between horizontally stacked filter media and creating hydraulic pressure resulting in a differential that can be as high as 220 psi (Bassett, 1986). As the cake between the plates thickens, the cake captures a significant amount of fine particulates resulting in a clean filtrate. In order to retain the maximum volume of slurry and produce a permeable cake that will allow water to escape, it is essential to pre-condition the slurry with chemical additives. In some cases it may be necessary to pre-coat the filter media with diatomaceous earth or fly ash to discourage the migration of fines into the filter weave which results in the diminished ability for water to drain. The filtration cycle is comprised the following four steps:

- Filling – through the use of a hydraulic ram, the press is closed and tightly sealed. The flocculated slurry is then pumped into the press through a center port running through the length of the filter plates until all of the air is evacuated and the press is filled.
- Filtration – as the pump filling the press feeds the slurry, filtration begins to occur while forcing a steady increase in pressure, until a constant pressure is achieved. While at a constant pressure, the filtration rate begins to diminish at the same time as the cake begins to consolidate. When the full volume of the press is occupied, the pumping process is stopped. Depending on the press and the type of solids being dewatered, the press may remain pressurized from one to four hours.
- Blow down – in many instances, air is blown through the press drainage ports to depressurize the press, remove any filtrate remaining within the press, and to remove solids from the center core.
- Discharge – each individual plate is slid open so that the cake can be dropped to the ground, a conveyor, or a receiving bin beneath the press. Following the discharge of the cake, the filter media are cleaned, as necessary, and the press is reassembled and readied for the next dewatering cycle.

The Plate and Frame Press can produce high cake solids and high capture rates. Achieving these results, however, requires a reliable and well planned thickened solids strategy and continuously optimized chemical treatment program. Chemical dosing can take place within a batching tank or injection into a solids slurry stream. Since the apparatus is operated in a batch mode and the filter membranes are washed intermittently between pressing cycles, it is essential that strict operating standards be maintained.

With the appropriate filter media in place, the device can be adapted to dewater a wide spectrum of sediment types. On small projects, the effective dewatering volume can be decreased by placing a blank plate in the machine to section off a smaller working volume. Large projects, however, may require the availability of a large staging ground and the use of several units and/or batching tanks in order to maintain an uninterrupted dredging program.

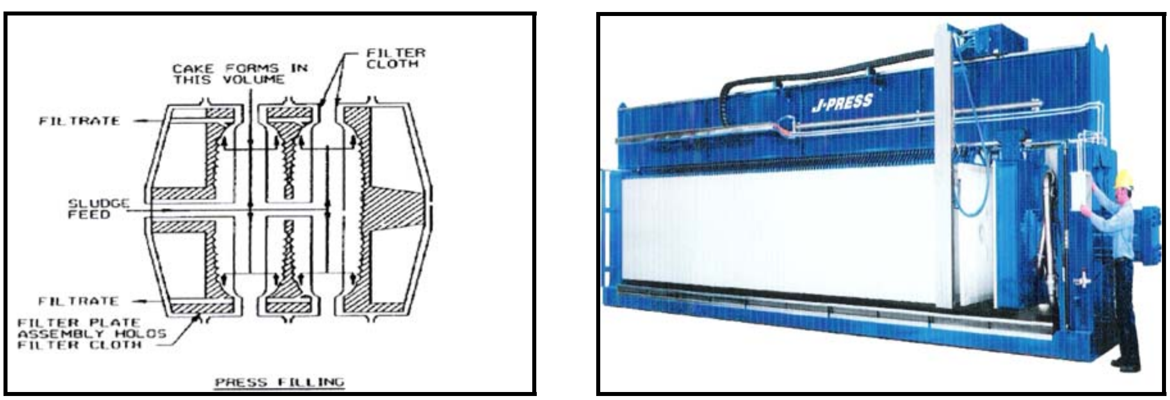


Figure 4. Plate and frame press schematic (left) and plate and frame press (right) (Army plate and frame filter press UFC 2003), (Courtesy of U.S. Filter).

Screw Press

The Screw Press, as seen in Figure 5, is a fairly uncomplicated piece of machinery designed to dewater solids by transporting them in a helical path along the length of a tapered screw encased within a screened housing. As solids are slowly moved from the entry zone towards the discharge zone, they are conveyed through a cavity of diminishing volume resulting in compressive forces. As the solids are compressed, water is extruded and decanted after passing through the screened housing. In the dewatering sequence, solids are advanced through three processes:

- Feed – flocculated slurry is gravity fed into an inlet hopper where free water escapes through the screened housing.
- Low Pressure Zone – compression occurs as the screw vanes advance the solids through a fixed diameter screen, the screw shaft diameter increases resulting in a gradually diminishing void space. As the void space is diminished, the solids are gradually compressed causing the release of additional water.
- High Pressure Zone – the discharge orifice at the end of the screw length is equipped with an adjustable pressure cone or choke plate that controls the size of the orifice opening. A small orifice opening yields a reduced rate of solids discharge and exerts a back pressure on the solids resulting in an increased pressure that yields higher cake dryness values.

Many factors, including screw length, taper, pitch, screen type and diameter, solids characteristics, and chemical additive selection influence the cake solids and capture rate generated by a Screw Press. Ideal conditions generally occur while dewatering fibrous and/or inorganic solids and can produce medium-high cake solids. Non-cohesive, non-fibrous materials (i.e., highly organic substrates) may produce lower cake solids and less than ideal filtrate quality.

A Screw Press configuration for a given project requires extensive chemical additive laboratory testing and empirical evaluation through pilot testing. Most dredging projects will require the use of several presses as the total solids throughput is relatively low when compared to other types of dewatering equipment.

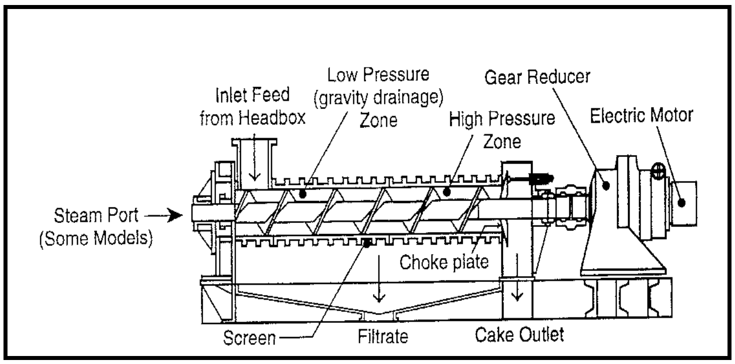


Figure 5. Screw press (Water Environment Federation 1994).

Centrifuge (Horizontal)

The Centrifuge is a complex piece of equipment designed to employ gravitational forces to separate solids and liquids (Sullivan and Vesilind, 1986). In simple terms, a Centrifuge functions very much like a clarifier in that the conditions within the centrifuge allow for solids and free water to be collected and drawn off separately. This is achieved by spinning solids slurry outward from a horizontal axis within a confined space at rates that may be as high as 4,500 rpm. The heavier, dense solids are slung outward to the inner wall of the bowl and the free water separates into a layer closer to the horizontal axis of rotation. In order to introduce the slurry into the centrifuge and to accommodate the high rotational speeds and forces exerted, the basic components of the Centrifuge, as seen in Figure 6, are as follows:

- Slurry Feed Pipe
- Bowl
- Scroll (Screw Conveyor)
- Beach
- Liquid Discharge Port
- Solids Discharge Port

There are two basic types of horizontal Centrifuges in use. A co-current centrifuge processes the treated slurry by conveying it horizontally forward through the bowl and discharges the dewatered solids through a port at the opposite end of the unit from the slurry feed pipe. Conversely, a counter-current centrifuge pushes the dewatered solids through the bowl towards a discharge port located at the same end as the slurry feed pipe as illustrated in Figure 6.

The operating requirements for both types of centrifuges are such that properly flocculated slurry must be pumped into the mechanism while it is being operated on a continuous basis in order to undergo centrifugal forces that result in the separation of the solid and liquid phases. There are two main moving parts: the bowl and the screw conveyor (scroll), each operating at different speeds. The process of separation occurs in the following manner:

- Sludge enters into the center of the bowl through ports in the hollow shaft of the screw conveyor. As the rotational speed of the sludge increases, it is thrust up against the inside of the rotating bowl where centrifugal forces act to separate the solids from the water.
- As the solids level builds, the screw conveyor (scroll) rotates at a different speed than the bowl and transports the compacted solids away from the water by pushing them up the tapered end of the bowl, known as the beach, where they are allowed to further dewater on the way to the discharge port. As the solids layer becomes denser and percent Total Solids increases, it imposes resistance to the rotation (i.e., torque) of the machine.
- As the tapered end of the bowl narrows, rotational speed is increased causing additional solids compaction and liquid release. The solids then exit the bowl through a port at the end of the tapered section and are generally dropped onto a conveyor for removal.
- As the water level builds, it flows within the unit and is discharged as "centrate" through ports located at the end of the bowl, opposite the tapered beach end.

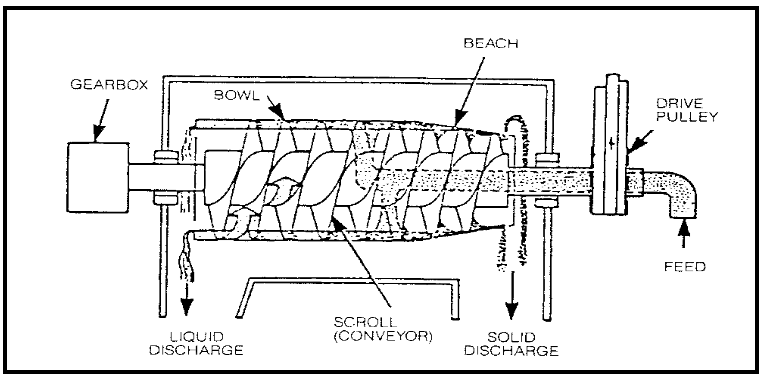


Figure 6. Solid bowl centrifuge (Water Environment Federation, 1996).

Maintaining optimum conditions for a Centrifuge requires skilled operators who fully understand its functions and who are capable of making adjustments to optimize its operation. The differential rotational speeds of the bowl and the screw conveyor, along with chemical dose and sludge feed rates, are key variables that influence the forces exerted on the solids. All four of these variables are intimately related and an adjustment to any one of them may cause a change in the other three.

When properly operated, a Centrifuge is capable of delivering moderately high cake solids and high solids capture rates. Often, the Centrifuge is selected when processing sludge containing high levels of oil and grease as they are most easily separated through centrifugal forces and do not pose a blinding problem. However, due to the complexity of these machines, maintenance can be problematic and often requires the installation of additional backup units on site to ensure dredging production is not compromised by machine downtime. Also, abrasives can cause excessive wear on a Centrifuge. Very fine particles or sediments with low inorganic or fiber content may experience problems while being centrifugally dewatered, especially with regards to cake solids or centrate quality.

Geotube®

The Geotube®, as seen in Figure 7, is a bladder shaped container designed to trap and retain solids while allowing water to filter through its permeable wall. Geotubes are manufactured from woven polypropylene or polyester multifilament yarns rendering it environmentally inert and impervious to attack by chemical contaminants such as alkalis and acids. The woven textile is sewn together using proprietary techniques to produce a container with high tensile strength capable of being filled with a large volume of sediment. The weave spacing allows water to escape while trapping the solids inside the bladder. Each tube can be custom manufactured to pre-specified dimensions with multiple fill ports along the top. By doing so, the flow of slurried solids can be directed to several ports simultaneously to encourage a homogeneous distribution of solids during the fill process. Additionally, the tubes can be stacked on top of each other to help conserve acreage at the staging ground. Straw bales can be placed in the spaces between the lower levels of tubes to provide a level surface for the successive layers to rest on. The basic sequence of events that take place when using Geotubes is as follows:

- A planned and sized pad, incorporating water drainage and collection channel, is cleared, leveled and lined.
- The Geotubes are laid out and piping is connected to the fill ports through the use of a valved manifold so that the slurry flow can be simultaneously directed to one or more fill ports or Geotubes.
- Chemically treated slurry is pumped into the ports and the solids level is allowed to build while the water drains away through the Geotube wall. The solids level building at the ports is monitored and allowed to attain a height of a few feet before the slurry flow is directed to alternate ports to facilitate an even distribution of solids through the tube and to utilize the greatest possible surface area for drainage.
- Operators may in some cases agitate the outer surface of the tube to discourage blinding and encourage continuous rapid dewatering rates by sweeping the tube with coarse brooms, walking on the top surface of the tubes, or using any convenient means to physically disturb the bladder wall to break surface tensions that develop in the pore spaces and inhibit free drainage. As the tube begins to near its fill capacity, slurry pumping is stopped and directed to an alternate tube while the sediment is allowed to drain more completely. Slurry feed is then resumed providing the operator with the opportunity to top off the tube and optimize the available dewatering space.
- After the Geotube has been filled, it is retired and allowed to lay at rest for a period of time while water continues to be released, sediment samples are collected, and cake dryness determined. Once the desired cake dryness is achieved, the tube is cut open and the dewatered sediment is transported to a landfill or a site for additional treatment or beneficial reuse.

The extent to which the solids concentration increases and develops into a consolidated dry cake is directly related to the ability of the water to freely flow through the pore spaces between the solids. Dewatered cake solids are dependent on sediment characteristics and can be expected to approach or exceed in-situ values when conditioned with appropriate chemical additives. In instances where relatively clean sands or gravels are being dewatered, there may be no need for chemical addition. However, when dewatering particulates that are less than 75 microns in size, chemical additives are often required to facilitate agglomeration. The conditioning of the “fines” slurry with chemicals and the formation of agglomerated solids as they enter the tube are critical factors to the success of the application and must be closely monitored. Failing to do so will result in fine particulates migrating to the inner wall of the woven fabric where they collect and blind the weave causing the water drainage to cease. It is therefore good practice to include a sample valve between the point of chemical addition and the fill port to allow visual inspection of the conditioned solids and enable the operators to fine-tune the chemical dose.

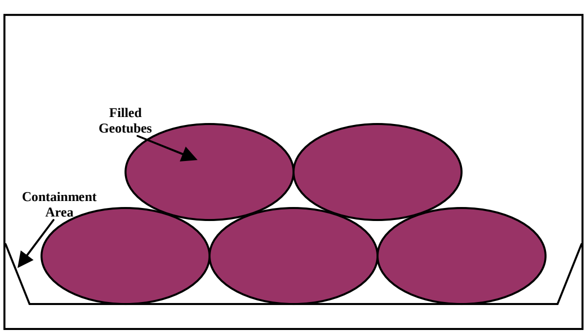


Figure 7. Geotube end view (left) and stacked geotubes (right).

OPERATIONAL OVERVIEW

The variables that influence equipment choices are many and must be considered in conjunction with the overall objectives of a given sediment dewatering project. It is prudent for the contractor to become familiar with all of the equipment options available, to seek advice from the manufacturers' representatives, and to solicit opinions from other contractors who have had personal working experience with the equipment in treating dredged substrates. Although qualitative in nature, Table 4 provides a brief summary of some of the variables to be considered when investigating the use of dewatering technologies covered in this paper. These variables were previously mentioned on pages 7 and 8 as "factors that provide the greatest benefit for a given application" and they appear in the left hand column of the table below. Many of these variables are assigned a relative ranking between "low" and "high" that serves to qualitatively compare and contrast the different dewatering methods.

Table 4. Comparison of sediment dewatering devices.

	Belt Filter Press	Plate and Frame Press	Screw Press	Centrifuge	Geotube®
Cake Solids	Medium-High	High	Medium-High	Medium-High	High
Solids Capture	Medium-High	High	Medium	High	High
Solids Loading	Medium	Medium-High	Low-Medium	Medium-High	High
Chemical Dose	Medium	Low	High	Medium-High	Low
Overall Footprint	Small-Medium	Large	Medium	Medium	Large
Type of Operation	Continuous	Batch	Continuous	Continuous	Continuous
Ease of Operation	Easy-Moderate	Moderate-Difficult	Moderate	Difficult	Easy
Noise Levels	Low-Medium	Medium	Low-Medium	High	Low
Vapors/Fumes	High	Low-Medium	Medium	Medium-High	Low
Capital Cost	Medium	Medium-High	Medium-High	High	Medium
Power Cost	Medium	Medium	Medium-High	High	Low
Labor Cost	Low	Low-Medium	Low	Low-Medium	Medium-High
Maintenance Cost	Medium	Medium-High	Medium-High	High	Low
Overall Cost	Medium	Medium-High	Medium-High	High	Low-Medium

From the data in Table 4, we see that the highest cake solids are generated by the Plate and Frame Press and Geotube. This is due to the length of time the solids are exposed to hydraulic pressures and the relatively low shear forces exerted during their use. For the same reasons, the solids capture rate is also high for both of these technologies. The Centrifuge is capable of delivering high capture rates as the forces governing solids and water separation can be controlled by adjusting the scroll speed which in turn influences both torque and slurry residence time within the bowl. There is, however, an ideal balance point between the cake solids dryness, the solids capture rate, the throughput of the sludge being dewatered, and the degree of chemical conditioning required that is empirically derived while operating a centrifuge. Generally, efforts to improve capture rates and centrate quality will tend to produce a wetter cake.

Solids loading – or the amount of solids a dewatering method is capable of processing over a given interval of time – is greatest for the Geotube as the fill ports can be sized to order (generally in the 6” to 12” range), several ports can be in service simultaneously, and the tubes can be manufactured to very large dimensions. The greatest limiting factor with regards to solids loading for a Geotube is the upstream process pumping capacities. All of the other referenced dewatering technologies are volumetrically limited due to constraints on variables such as machine processing speed, feed solids concentration, hydraulic loading, residence time, and shear forces. Shear forces are also an important factor to consider when evaluating the relative chemical dose required to adequately condition the solids slurry. The single greatest factor dictating the amount of chemical required to produce an acceptable agglomeration of solids is the concentration of solids suspended in the slurry. However, consideration must also be give to the type and amount of chemical used and to the degree of shear force impacting the agglomerated solids. Generally, the amount of chemical additive required is reduced under conditions producing the lowest shear forces. Therefore, it is reasonable to expect that chemical dosing will be lowest for both the Geotube and Plate and Frame Press.

In evaluating the overall footprint variable, one must not only consider the physical dimensions of the equipment, but also its processing or solids loading capacity and its mode of operation. Although the loading capacity may be rated as medium for the Belt Filter Press, it has a relatively small foot print, is operated in a continuous mode, and is capable of sustaining high production rates for its size. The Screw Press has a moderate foot print and is also operated in a continuous mode; but it is limited by its loading rate and more than one unit may be required to match the production rate achieved by a belt filter press. The Centrifuge is capable of sustaining high production rates and may be the unit of choice in instances where solids capture is of greater concern. However, it is often necessary to install two Centrifuges, where only one Belt Filter Press might normally be required, due to the difficulties associated with maintenance. Although Geotubes are capable of sustaining the highest production rates, their footprint is relatively large requiring significantly more acreage. The Plate and Frame Press is operated in a batch mode and the solids must be physically discharged between each pressing cycle which limits its production rate and results in the need for several units operating concurrently in order to sustain high production rates.

The ease of operation variable for the dewatering technologies discussed is dependent on the operating complexity of each and is rated highest for the Geotube as there are no moving parts. When dewatering clean sands or gravels, there may be no chemical treatment requirements and the tube can be filled with minimal oversight. In instances where particulates < 75 microns in size are dewatered and chemical treatment is required, oversight must be provided to ensure optimal chemical dosing and pre-conditioning of the solids.

Noise levels vary for each of the technologies as all but the Geotube must be energized in order to operate. The decibels generated while in operation may be of concern when considering personnel exposure and the proximity to public spaces – especially when considering centrifuges.

Vapor and fume emissions are lowest for the Geotube as the solids are contained within the tube and the free water tends to gently cascade downwards along the outer boundary of the bladder wall. Emissions are greatest for the Belt Filter Press as there are no enclosed parts and high pressure wash water is continuously sprayed across the filter cloths.

Capital costs for the purchase of dewatering equipment is impacted, for the most part, by the number of units required to support the production rates needed to complete the project within the allotted time frame and the necessary ancillary equipment and infrastructure that may need to be included.

Power costs vary greatly with the Centrifuge rated highest due to the size of the motors required to sustain high rotational speeds. Conversely, the Geotube is rated lowest as it is not energized and relies on hydraulic pressures exerted by pumping the slurried solids into the bladder and gravity for the dewatering process to take place.

The labor cost variable is dependent on the manpower required to operate and manage the dewatering process. It is lowest for the Belt Filter Press and the Screw Press as one operator is capable of managing the operation of several presses running simultaneously.

Maintenance cost is not only impacted by the day-to-day needs for continuous operation, but also the spare parts inventory that must be available and the man-hours required to conduct the maintenance. It is lowest for the Geotube due to the lack of moving parts and highest for the Centrifuge due to the complexity of the unit and the difficulties of accessing its parts.

Lastly, the overall cost variable is influenced by all of the above listed factors as well as the ancillary needs required to support each of the applications. As an example, in instances where several units must be used it is also necessary to consider the means by which chemical additives will be delivered to the slurried solids, the number of chemical injection points, and the pumping requirements to feed the chemicals. When all of the variables have been analyzed and quantified, it is then possible to economically evaluate the benefits that can be derived by employing each of the technologies and to make an educated, fact-based decision as to which process will deliver the greatest cost-performance for a particular sediment dewatering project.

CONCLUSION

Depending on the nature of the sediments at any given dredging project, there may be several preliminary steps that need to be addressed in order to establish the conditions necessary to operate a dewatering process efficiently. The variables that influence the selection of one technology over another are many. The decision-making process requires a clear understanding of the project objectives and must begin at the earliest possible opportunity in order to provide ample time for the development of an informed decision. The selection of the dewatering method to be used is a complex process that relies on an interactive relationship between the capabilities – and limitations – of the type of processing method chosen and the type of chemical treatment program (if any) needed to be most cost-effective for the particular project. The degree to which chemical additions influence dewatering performance, however, cannot be underestimated and may prove critical to the successful use of any and all dewatering methods.

As the volumes of contaminated sediments being dredged increase, as the availability of confined disposal areas decrease, and as acreage adjacent to dredge sites becomes increasingly more expensive and/or scarce, the need for dewatering sediments using various technologies, as outlined in this paper, may certainly rise in significance. The proper selection of dewatering equipment and chemical treatment (along with related equipment) can provide substantial economic benefits to dredging projects and can be the key to successful implementation and completion. Solids processing rates can be increased by enhancing solids-liquid separation which may also dramatically impact project duration, footprint of the processing/staging area required, and overall costs. Volume reduction and minimization of materials requiring transportation from the project site could directly influence hauling, disposal, and/or post-handling costs. And lastly, but surely not least in importance, by properly selecting the correct dewatering process and associated chemical treatment program (if necessary) for a given application, contractor risk is minimized with regard to safety, health, and environmental issues.

It is hoped that this paper has provided the reader with a sufficient overview of the different types of dewatering technologies available, rather than limiting our focus to one type. Hopefully, in doing so, you can find the right fit for the needs of your particular project and continue to do so for other considerations that may come your way in the future.

REFERENCES

Ashbrook-Simon Hartley (1987) Klampress Belt Filter Press Technical Information, Houston, Texas

Atkinson, S. (1995) "An Early History of Filtration". Filtration and Separation, Volume 30, Issue 5, June 1995, pp39

Bassett, G.L. (1986) "Recent Technical Advances of Filter Presses" International Conference on Recent Advances in Solid/Liquid Separation, Columbus, Ohio

Culp, R.L.; Wesner, G.M.; & Culp, G.L. (1978), Handbook of Advanced Wastewater Treatment (2nd ed.) New York, NY: Van Nostrand Reinhold Company

Hunter, D.W (2006) "The Positive Impact of Polymers on Sediment Treatment and Handling." Proceedings of the Western Dredging Association Twenty-Sixth Technical Conference

Stocks, P. (2006) "Paste and Thickened Tailings", Second Edition, Australian Center for Geomechanics

Sullivan, D.E. and Vesilind, P.A. "Centrifuge Trade-Offs, Operation Tips for Sludge Handling, Operations Forum 1986, pp 24-27

Ten Cate Nicolon (2002) http://www.nicolon.com

United Facilities Criteria (2003), Army Plate and Frame Press UFC 3-280-03

United States Environmental Protection Agency (2000) “Biosolids Technical Fact Sheet-Belt Filter Press” EPA 832-F-00 -057, Office of Water, Washington, D.C.

U.S. Filter, (2004). http://www.usfilter.com

Water Environment Federation (1996), Operation of Municipal Wastewater Treatment Plants – Manual of Practice – MOP11 (5^{th} ed.) Alexandria, VA

Water Environment Federation (1994), Pretreatment of Industrial Wastes – Manual of Practice – FD-3 (pp. 85, 90) Alexandria, VA

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