You Don't Know What You're Missing: Designing a Grit Removal System That Works

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Meeting regulatory requirements for treated effluent and solids quality has been the major focus for wastewater treatment facilities. Grit is often treated as an afterthought, and yet, wastewater treatment plants are significantly impacted by grit. A nuisance material, grit causes abrasive wear and tear to mechanical equipment, increases maintenance and operational costs, and accumulates in processes throughout the plant, which all reduce processing capacity and efficiency over time.

It's common to find operator dissatisfaction with grit removal systems; the design of grit removal processes has been labeled as inadequate, neglecting, and misunderstood. Conventional design guidelines target removal of grit larger than 210 micrometres (μm), while minimizing organic content. In fact, many wastewater treatment plants across the United States find that over 50 percent of their influent grit is smaller than 210 μm.

In addition to designing for inadequate removal based on size alone, other factors contribute to grit system failure. Conventional engineering practices assume that municipal grit behaves like clean sand particles in clean water. Grit removal systems are traditionally based on settling velocities of perfect spheres of clean silica sand particles with a 2.65 specific gravity (SG) in clean water. In reality, wastewater grit is comprised of silica sand, as well as asphalt, limestone, concrete, and various other materials that do not have an SG of 2.65.

Grit particles are not all perfect spheres, and further, wastewater grit is exposed to fats, oils, greases, and soaps in the collection system, which coat the grit and alter its settling velocity. The cumulative result is inadequately performing grit removal systems that allow grit to be carried over to downstream processes and equipment.

Grit systems can work as intended when designed with an accurate understanding of the nature and characteristics of the grit arriving at the treatment plant and how this grit actually behaves in wastewater. An effective system addresses size as well as settleability, produces a clean dry product for landfill, and minimizes deposits and accumulations in the plant.

This article discusses why conventional grit system design criteria are ineffective and provides guidelines for determining design requirements. Also discussed are types of grit collection, washing, and the dewatering equipment and processes that are available and their effectiveness.

The reduction in processing capacity can affect a plant's ability to achieve process design goals, such as reduced methane production or increased alkalinity in digesters, and increase operational costs, such as horsepower requirements in aeration basins. Accumulations happen gradually and continuously, and they often go unnoticed until a process is completely overwhelmed and needs to be shut down to manually remove the deposited grit, which is a labor-intensive and costly operation. When a process must be taken offline, the entire plant flow must be diverted. This requires building excess plant capacity to use as grit storage, which can significantly increase the size and cost of the plant

The main focus in the design of a wastewater treatment plant is meeting regulatory requirements for treated effluent and solids quality. Traditionally, the design intent of grit removal systems, based on information from Metcalf & Eddy and the Water Environment Federation Manual of Practice No. 8, has been to target grit at 210 µm and larger (with an SG of 2.65). This design criterion has been more focused on producing a product with low organic content in order to make it acceptable at a landfill than it is on a specific target for removal efficiency of the grit itself. Producing a product with low organic content is a goal to keep in mind when designing a grit removal system. Organics create odor issues and increase volume and water content, which can make the product unacceptable at a landfill

The wastewater industry has not taken much more than a cursory view of grit removal design criteria and the characteristics of the grit entering wastewater treatment plants. Unfortunately, the result of this approach has resulted in the capture of less than 50 percent of the grit entering a plant. As the industry moves toward higher-performing processes, effective grit removal will become a more important criterion in treatment plant design.

The acceptance of membrane bioreactor (MBR) technology brings the need for advanced grit management systems into consideration for effective pretreatment processes. The MBR technology requires extensive screening pretreatment, which often allows elimination of primary clarification. Without the

Figure 1. Grit deposition in fine bubble aeration basin.

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protection of primary clarification, advanced grit removal should also be part of an effective MBR pretreatment system design. Ideally, grit should not be entering a MBR plant where it can damage the membranes, which are the most expensive component of the plant.

Even as upgrades are made from coarse bubble aeration to fine bubble aeration, the potential for grit deposition increases as the scouring velocities in the basins change (Figure 1). In conventional plants, where primary clarifiers are eliminated and aeration basins are converted to fine bubble aeration, the aeration basin directly follows the headworks. An ineffective grit removal process presents a new maintenance challenge as diffusers cover the full floor of the basin, which restricts the ability to clean the basin, making the cleaning process more operator intensive and expensive. Diffusers covered with grit are less effective and additional horsepower may be required to achieve desired results.

A major reason that conventional grit removal systems do not work is a lack of understanding of how municipal grit actually behaves in wastewater. Since grit is not well understood, it is often erroneously treated as clean sand particles. This is a major reason why most grit removal systems fail to capture the quantity and sizes of grit for which they were designed. Understanding the actual characteristics of grit at a particular plant helps determine the size and type of grit removal system that is needed to remove it.

Conventional design criteria have made the assumptions of dealing only with silica sand having an SG of 2.65. Each particle is assumed to be a perfect sphere settling in a quiescent basin of clean water. Ideal assumptions rarely work in municipal wastewater; in reality there are a variety of materials with a variety of SGs. The particles vary in shape and many plants have noted that much of their larger grit is flat. A flat particle will display much different settling characteristics than a sphere, and, while in the collection system, the grit particles are exposed to fats, oils, greases, soaps, and scum, which attach to the grit particles and alter the particles settling characteristics.

Looking strictly at the size, and comparing the distribution, of grit from a variety of plants around the U.S., there are many plants where 50 percent of the incoming grit is smaller than the conventional design cut point of 210 µm (Figure2). Therefore, based solely on size distribution, half of the incoming grit is missing. If the design criteria are modified to remove 90 percent of the incoming grit, the design cut point needs to be changed to somewhere between 70-150 micron, depending on the endemic grit gradation.

The conventional design criterion of 210 µm removal has allowed passage of a large amount of small grit into wastewater treatment plants; larger material is often found downstream of the grit removal process as well. The larger material that passes must be accounted for based on different criteria. One reason is that municipal grit is comprised of various materials and is not only silica sand. Table 1 shows the list of various materials that are likely to be constituents of grit that enters a wastewater treatment plant. None of the materials listed have an SG of 2.65.

At the East Bay Municipal Utility District wastewater treatment plant in the Oakland, Calif., area, it was determined that the SG of its influent grit ranged from 1.95-1.6, with an average of 1.35. The settling velocity of a 1.35-SG particle is vastly different than a 2.65-SG particle. A 100-micron particle having an SG of 1.35 will take over four times longer to settle just 1 ft than the same size particle with an SG of 2.65. This is an important fact considering that grit collection devices predominately rely on gravity to make the separation. Additionally, attached fats, oils, greases, soaps, etc., coat the grit particles and change their settling velocity. As grit is more closely examined for its makeup and factors that affect settling velocity, it is easy to see that influent grit does not settle like clean sand in clean water.

Determining grit-size distribution and settling velocity is not an easy task. First, there is no industry standard method for measuring

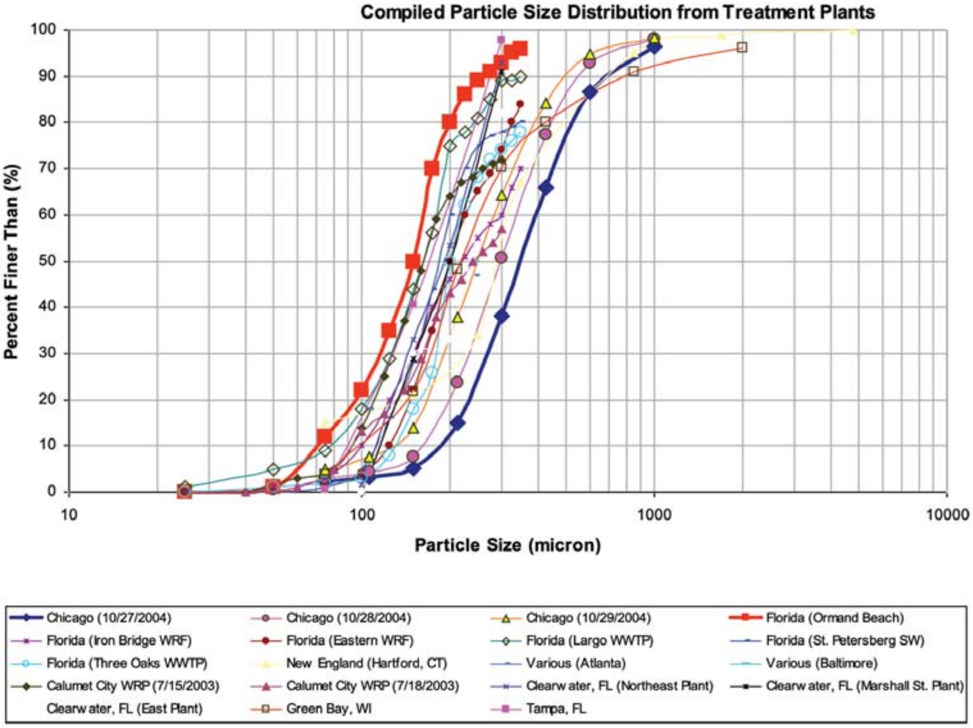

Figure 2. Compiled Particle Size Distribution from Treatment Plants

Table 1. Specific Gravity of Various Materials

Quartz Sand	1.2	Earth	1.4
Limestone	1.55	Granite	1.65
Clay	1.8	Red Brick	1.9
Sand, wet	1.92	Gravel	2
Asphalt	2.2	Concrete	2.4

grit and obtaining a representative sample is difficult because grit does not flow evenly into the plant. It tends to travel in a higher concentration at the bottom of the channel; volume fluctuates with diurnal flow variations and grit volume significantly increases during wet weather events. Because of these variations, testing should occur over several days and ideally include a wet weather event, if possible.

During peak wet weather events, grit volume entering the plant can be 20-40 times higher depending on peak-to-average flow ratio, age, and type of collection system. As much as 70 percent of the annual grit load can be received at the plant during a handful of first-flush events. These peak periods frequently overload poorly performing systems. Once sampling is complete, the size distribution must be determined, and in order to have the most accurate data upon which to base a design, the settling velocity or SG should be determined.

Since conventional design guidelines continue to prove ineffective, a more comprehensive design guideline should be used. Several factors should be considered when designing a grit removal system, starting with a full-characterization endemic grit, including grit load, size distribution, and SG. With good data of the endemic grit, a cost-benefit analysis can be determined, evaluating grit removal efficiency as compared to cost. Other considerations include upstream screening requirements, maintenance requirements, space, and headloss.

Technology Review

There are three basic types of grit collection systems: gravity sedimentation, aerated grit basins, and vortex grit basins. Gravity sedimentation systems, which include velocity control channels and detritus tanks, are the oldest types of systems. Maintaining a constant channel velocity or overflow rate at wide rages of flows can be a challenge. To maintain a balance, the system may be undersized at peak flows and oversized at low flows. These systems can be designed to effectively capture grit; however, when sized for a high-capture efficiency, organics will be captured along with the grit and an effective washing and dewatering system is needed.

As organics in the captured grit became a nuisance, aerated grit systems became popular. The addition of air helped to reduce the amount of organics captured with the grit and provided preaeration to the incoming flow stream. Air, which is introduced into a basin via diffusers located near the bottom, creates a spiral roll pattern directing grit to the bottom for collection, while keeping organics in suspension. There is conflicting research as to what constitutes optimum aerated grit basin geometry and aeration rate. As a result, there are many improperly functioning systems.

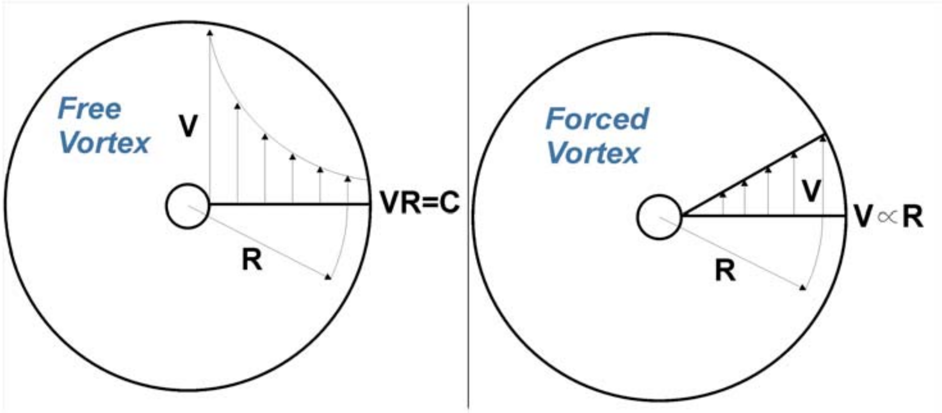

Figure 3. Free Vortex and Forced Vortex Measures

There are many improperly functioning aerated grit removal systems that lead to the popularity of vortex systems. In addition, in the U.S., many plants are large and significant cost savings can be realized using vortex basins in lieu of the constant cost of energy required to induce air into an aerated grit basin. Vortex basins are classified as either a forced vortex or free vortex. Both take advantage of centrifugal force to assist in grit removal, but the flow regimes are very different (Figure 3).

In a forced vortex, the fluid rotates as a solid body with a constant angular velocity. Circumferential velocity is lowest at the center of the tank creating a quiescent zone at the center. The grit migrates to the center and is collected into a sump located at the bottom of the unit. In the open or free vortex, the centrifugal velocity increases as the flow migrates toward the center of the unit. In a free vortex vessel, the grit is thrown to the outside of the vessel, or held in suspension, then settles to the bottom where it is captured in the boundary layer and swept to the center of the unit for collection. The forced vortex flow regime is characterized by low headloss, with wall velocities being highest and decreasing performance as flows increase. In contrast, open or forced vortex flow regimes are characterized by high headloss, with wall velocities being lowest and increasing performance as flows increase.

Several types of vortex technologies are available; mechanically-induced vortex, structured flow vortex, and stacked tray vortex are all examples of forced vortex technologies. Forced vortex systems are predominantly gravity-based systems, as gravity tends to be the dominating force. Because of the head requirement and size restrictions, the free vortex products have limited application in grit collection. Free vortex devices are more commonly applied in mountainous areas where natural head is available or when the flow is pumped to an elevated headworks. These open vortex units offer the benefit of collecting and washing the grit in a single step. Due to the headloss requirement, the open vortex design is more commonly used for grit washing.

The mechanically-induced vortex unit is popular. Characterized by low headloss, typically < 15cm (6 in.), removal efficiency is generally based on larger particles, 95 percent removal of 300 micron, and lesser removal of smaller size fractions. It is not uncommon for the design engineer to add a safety factor of 1.5-2 to the basin sizing recommended by manufacturers. The manufacturer sizing does not seem to be consistent across unit sizes with varying overflow rates and detention times. Plants have reported varying success with this technology.

A laminar flow pattern into the basin is needed with approach channels typically four to seven times the channel width; flow discharges from the perimeter of the unit and a specific downstream channel configuration or effluent weir are required. In the center of the chamber a rotating paddle maintains circulation within the chamber, lifting organics out of the grit sump. Grit is collected in a center sump and pumped from the unit intermittently.

The structured flow unit has proven to be effective at removing grit as small as 106 micron. Headloss through this type of unit is slightly higher, in the range of 15-30cm (6-12 in.). Internal components structure the flow regime, taking full advantage of the area within the ves-

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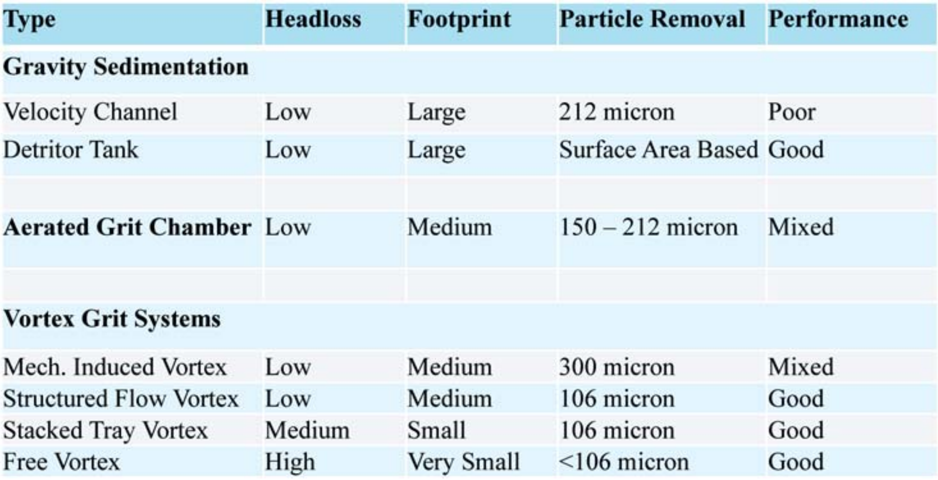
Table 2. Technology Summary



Type	Headloss	Footprint	Particle Removal	Performance
Gravity Sedimentation				
Velocity Channel	Low	Large	212 micron	Poor
Detritor Tank	Low	Large	Surface Area Based	Good
Aerated Grit Chamber	Low	Medium	150 – 212 micron	Mixed
Vortex Grit Systems				
Mech. Induced Vortex	Low	Medium	300 micron	Mixed
Structured Flow Vortex	Low	Medium	106 micron	Good
Stacked Tray Vortex	Medium	Small	106 micron	Good
Free Vortex	High	Very Small	<106 micron	Good

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sel and eliminating short circuiting. A downward spiral is created at the outside of the unit, encouraging grit toward the bottom of the unit. Near the bottom of the unit, flow direction changes, creating a shear zone that has near-zero velocity, allowing grit to fall out and be captured in the bottom of the unit beneath an inverted cone. Flow must exit the unit near its center and within the dip plate. The dip plate helps to structure the flow and increase residence time of the grit, providing time for it to settle. All flow passes through the zero velocity zone prior to discharge ensuring effective removal. Grit is collected in a sump at the bottom of the unit, fluidizing water is added intermittently to remove organics, and the grit slurry is then intermittently pumped to a dewatering unit.

The stacked tray vortex unit utilizes the simple principles of surface area, settling velocity, and overflow rates. Flow is evenly distributed via a distribution header to stacked, multiple, conically-shaped trays. Trays are available in several diameters and can be supplied in stacks up to 12 trays tall. Tangential feed to the stacked trays provides the vortex flow pattern. Solids have a very short distance to settle before they are captured in the boundary layer, swept to the center of the tray, and fall through a common opening to a grit sump located at the bottom of the unit. Design headloss is 30 cm (12 in.) at peak flow and headloss is less at lower flows. Particle settling velocity and overflow rates or surface area loading rates are used for sizing with proven capture efficiency as small as 75 micron. The grit slurry captured in the grit sump is typically pumped continuously to washing and dewatering.

A summary of the technologies is listed in Table 2.

When designing a grit removal system, the washing and dewatering component must be as effective as the collection device, otherwise the overall system efficiency will suffer. A system approach is best. A study done in Fox Lake, Ill., showed that while the aerated grit basin removed 58 percent of total grit volume entering the plant, the cyclone/screw conveyor washing and dewatering equipment only retained 17 percent of what it received. The loss of grit in the washing and dewatering step reduces the system's overall efficiency to only 10 percent. Cyclones partnered with screw classifiers have traditionally been the technology of choice for washing and dewatering, without much evaluation of their effectiveness.

Both technologies are borrowed from the mining industry. When applied in mining, a slurry is delivered to the equipment with a specific cut point particle in mind. The slurry is relatively consistent in flow and concentration. Flows of collected grit are not consistent in concentration. The material to be separated included fine and coarse grit, as well as fine and coarse organics. The goal is to retain all grit, both large and small, while discharging most organics. In these systems, the larger organics tend to be captured with the grit and grit fines are lost back to the system.

The cyclone operates with a free vortex flow regime; headloss is high, and therefore, the flow is typically pumped to the unit. Grit is forced to the outside of the unit and concentrated as is sours down the tapered sides through the apex valve at the bottom of the unit. The apex valve is a fixed orifice and restricts the volume that can be discharged.

Wet weather events, when the grit load can be 20 to 40 times the normal volume, present problems for cyclones. The increased volume of grit cannot physically pass through the apex valve. Since what goes in must come out, the grit that cannot physically pass through the apex valve discharges out of the top of the unit and ends up in downstream processes or the valve plugs.

Other free vortex units available possess a larger diameter body, providing a larger capacity for grit during these wet weather events. The larger diameter free vortex units utilize a pan-shaped bottom. A boundary layer develops at the bottom of the unit sweeping the settled grit toward a center collection and discharge point. The boundary layer is effective for retaining even the fine grit particles, but because it is thin, the larger organics that will tend to settle with the grit are too large to remain in the boundary and are swept back into the rotating vortex above and ultimately discharged.

Screw classifiers have conventionally been sized on the capacity of the rotating screw. The overflow rate of the clarifier section is often overlooked. When the classifier is fed with a high-surface loading rate, most organics overflow out of the system along with the fine and lighter grit, yet some of the larger organic particles are retained with the captured grit. Volatile solids discharged from these systems typically range from 25-35 percent, with some plants seeing volatile solids concentrations as high as 70 percent.

In addition, screw speed is often overlooked. For example, a screw with a 30-cm (12 in.) diameter rotating at only four revolutions per minute (rpm) has a tip speed roughly equivalent to the settling velocity of a 400-micron particle. As the screw rotates, it suspends the finer material, both organics and grit alike. As additional flow is fed to the clarifier, the smaller particles that are in suspension are lost over the weir and end up in downstream processes.

Clarifier overflow rates should be considered in the design of the classifier, especially following effective washing. The screw must run slowly so as not to resuspend the captured material. In lieu of a rotating screw, a slow-moving belt can be utilized so as not to resuspend the grit, but gently raise settled grit out of the clarifier to a discharge point at the top of the unit, which deposits the dewatered grit into a dumpster.

Test results on the large-diameter free vortex unit, coupled with the dewatering device with a large clarifier area and slow moving belt, are excellent, generally delivering a product with fewer than 20 percent volatile solids and >60 percent total solids.

Conclusions

It is not uncommon to find operator dissatisfaction with grit removal systems. Many installed grit systems fail to keep depositable grit out of the plant; in fact, they fail to remove the sizes and amounts of grit they were designed to capture. Grit system failure happens primarily due to a faulty assumption that municipal grit behaves like clean sand particles in clean water. The failure of many traditional grit removal systems has led to the misconception that grit removal systems cannot work, and that the only option is to deal with the grit deposits downstream of the headworks and the abrasive wear from grit by increasing maintenance and operational budgets.

In order to design an effective system, design guidelines should be more comprehensive than referring to an industry standard that has been labeled as inadequate, neglecting, and misunderstood. A clear understanding of the grit entering the plant that includes grit load, size distribution, and settling velocity is needed. Only with a clear understanding of the material to be removed can a system be designed to achieve specified results.

Table 3. Design Guidelines

- ☐ **Define Design Requirements:**
  - **Grit Particle Size Analysis**
  - **Settling Velocity or SG**
  - **Required System Removal Efficiency**
  - **Screening Requirements**
- ☐ **Evaluate Equipment**
  - **Removal Efficiency/Performance**
  - **Equipment Design/Features**
  - **Space**
  - **Headloss**
  - **Cost: Capital, Installed, Operational**
  - **Maintenance Requirements**

A grit removal system is just that, a system. All components of the system must be effective in order for the overall system efficiency to yield the desired results. Improving grit collection only to lose a major portion of it back to the process in the washing and dewatering step is detrimental to overall results. Capturing a high percentage of the incoming grit load, along with a high concentration of organics, yields a product difficult to landfill and can starve the biological processes.

Each step of the grit removal process is important. Grit systems can work as intended when designed with an accurate understanding of the nature and characteristics of the grit arriving at the treatment plant and how this grit actually behaves in wastewater. An effective system addresses size as well as settling velocity or SG, produces a clean dry product for landfill, and minimizes deposits and accumulations in the plant.

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