Grit – You don't know what you're missing!

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Abstract

Grit removal is a long established practice within the UK wastewater industry with a number of technologies having evolved to address the challenges of grit removal at wastewater treatment plants. The question however is that do these systems really work? Are grit removal systems being designed optimally? Aeration lanes suffer from a build-up of grit and often require draining down and cleaning. Anaerobic digesters also have to be routinely taken out of service to have deposited grit removed. These operations are expensive and time consuming, as well as having a major impact on the efficiency and productivity of the wastewater treatment plant.

Is the assumption of a 2.65 specific gravity, 200 micron particle size typically used in design adequate?

This paper examines what we are missing when we consider grit removal and how that may be avoided. Drawing on experiences with reference to particles size analysis work carried out in the US and UK, it outlines what can and should be done to prevent grit from entering the wastewater treatment works and causing the downstream problems observed.

Keywords

Grit removal, particle size analysis, specific gravity, anaerobic digester cleaning

Introduction

Grit removal as part of the wastewater treatment process is a long established practice within the UK water industry; grit causes problems with down-stream plant such as pumps and valves by causing undue wear and tear, it blocks pipes and channels and reduces the capacity of aeration tanks and anaerobic digesters.

The removal of grit is based on the ability of the process to remove an identified particle from the water by establishing a steady, stable and predictable flow regime, which allows the particle to settle and be removed from the bulk flow without being re-entrained.

In many cases the suggested ideal target grit particle is a spherical, homogenous, 200 micron sized particle with a specific gravity of 2.65, but the question really is "how accurate are these assumptions and is this the grit particle to target"? What are the consequences and effects if these parameters are wrong?

Other questions to be considered are what effect does varying flow have on the process? How should the consequences of this flow variance be handled?

This paper examines these questions from a fundamental perspective including assessing properties, characteristics and their effect on the sizing consideration of the grit removal system.

The "Ideal" Particle

Based on the industry established calculation of drag coefficient in accordance with a curve fit devised by Turton and Levenspiel (1986), If we take a 200 micron, 2.6 s.g. spherical, homogenous particle as our "ideal" grit particle for removal, this will settle at 17 mm/s (at 4 degrees centigrade). This predictable settling rate allows the design of a system capable of removing that particle at a given flow rate over a given period of time. Examining these assumptions allows a new look at whether this is the correct approach for sizing our grit removal systems or whether a new standard is required in order to protect our wastewater plants from the problems associated with grit and sand.

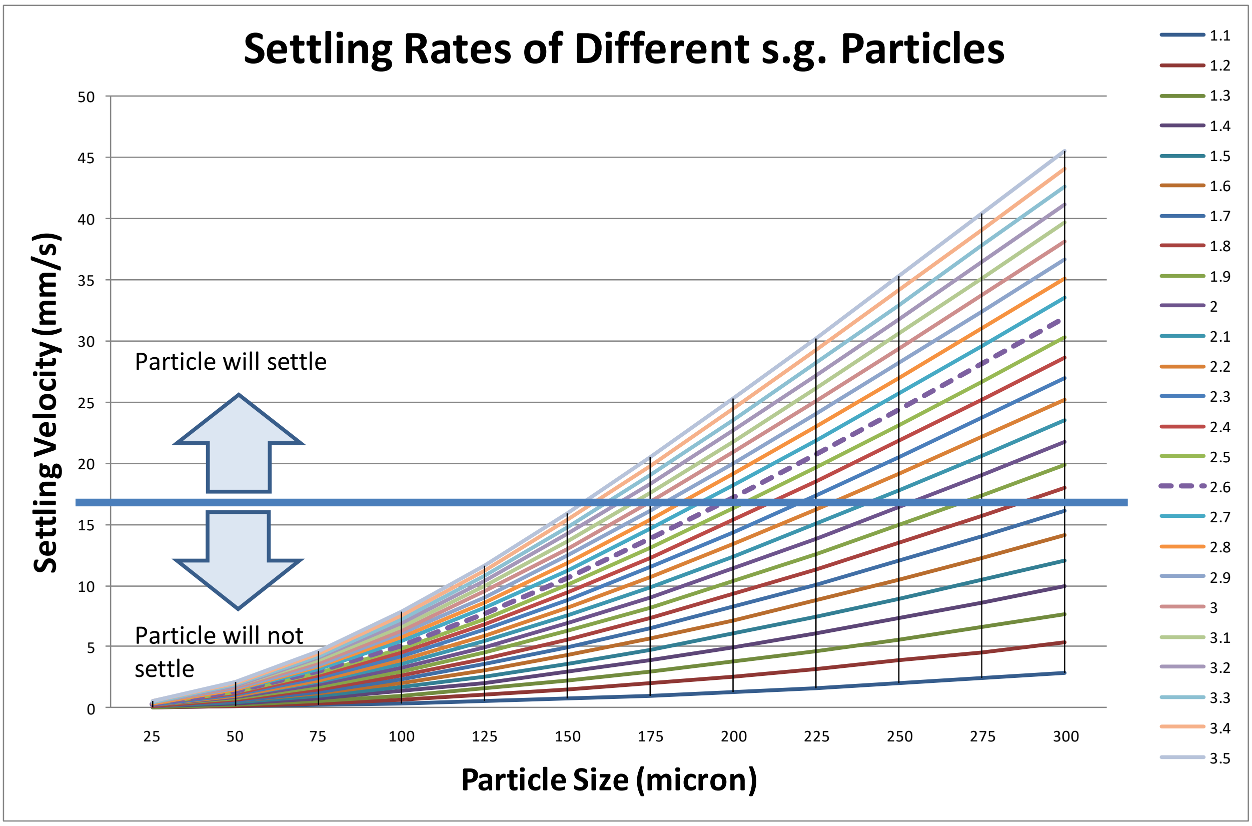
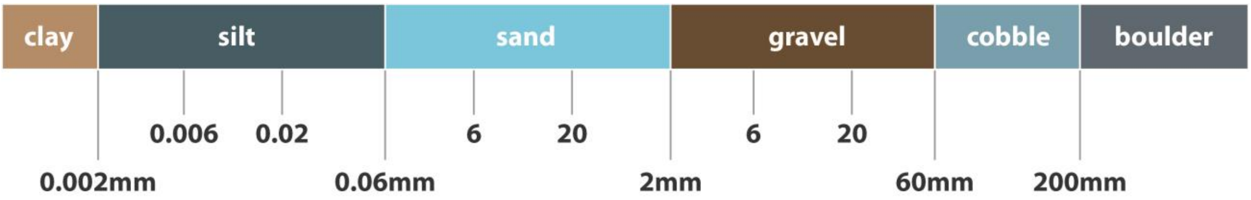


Figure 1: Settlement rates of different particle sizes and different specific gravities

Any particle with a settling rate higher than the target particle rate of 17 mm/s should be removed from the flow, whilst any particle with a lower settlement rate should be retained with the wastewater.

Particle Size

Generally most Wastewater companies in the UK target removal of a 200 micron particle, but what percentage of inorganic particles are smaller than this size, and what are their chances of settling out in a later process causing problems for the anaerobic digester or activated sludge plant?
The inorganic particles that make up soil can be sub-divided into 6 main categories.



(Atkinson 2000)

Figure 2: Soil size grades

Of these we are normally interested in the silt, sand and gravel ranges for grit removal. Cobble and boulder (60 mm and above) should already be removed and clays at 2 micron or less are in the powder range and far too small.

For an understanding of whether 200 micron diameter is adequate we need to know the composition of grit arriving at the inlet works and not just the grit captured by the existing removal process.

Inlet Grit Sampling

The way the sample is taken is vitally important if the sample is going to be truly representative of the nature and characteristics of the grit in the inlet flow. Sampling techniques that concentrate on the bottom of the inlet channel would favour heavier particles leading to a bias therefore an accurate sample would include the whole tank height. The inlet geometry should also be considered: any channel curves or baffles will distort the flow pattern and could potentially bias the particles to follow a particular streamline. Sampling points should be picked which are free from this type of interference.

Work has been conducted in the USA by Grit Solutions (Griffiths and Book 2011) using a sampling method which shows that in contrast to the commonly held belief, a great deal of influent grit can be in the sub 200 micron category. On one site the percentage of sub 200 micron grit varied from 36 to 69 % cumulative over the 5 day trial period.

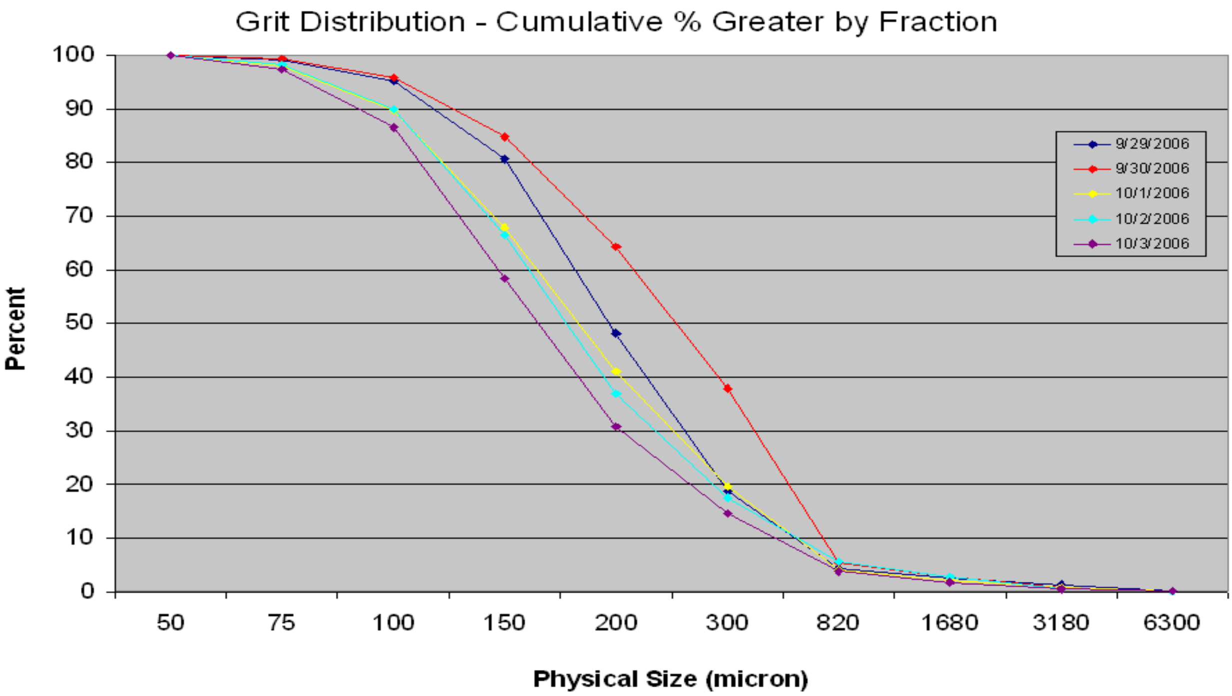


Figure 3: Grit Distribution – Cumulative % Greater by Fraction (Griffiths and Book 2011)

Potential places where grit can accumulate at wastewater treatment plants include activated sludge tanks and anaerobic digesters. Grit often found here has bypassed, or has not been captured by, the grit removal stage of the treatment process.

Results from a recent test show that around 30 to 35 percent of the inorganic solids present during a digester clean up were in the sub 200 micron category. This fraction may be distorted if the tested plant receives sludge from other sites which do not have any form of grit removal or suffers from an inefficient grit removal process.

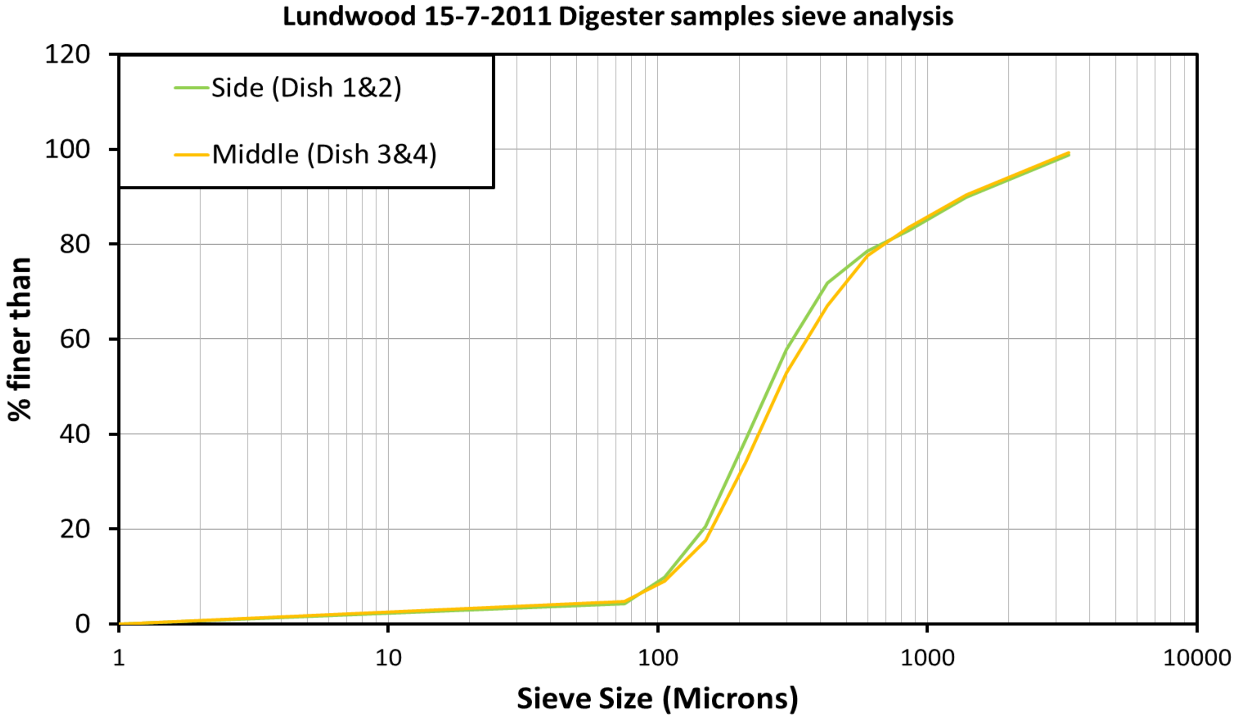


Figure 4: **Lundwood Anaerobic Digester Grit Samples**

Hydro International has gathered inlet data from a number of U.S. based works. This shows that the fraction of inlet grit which is sub 200 micron varies enormously. Some sites have almost no sub 200 micron grit, whilst others show nearly all of the inlet grit in the sub 200 micron category.

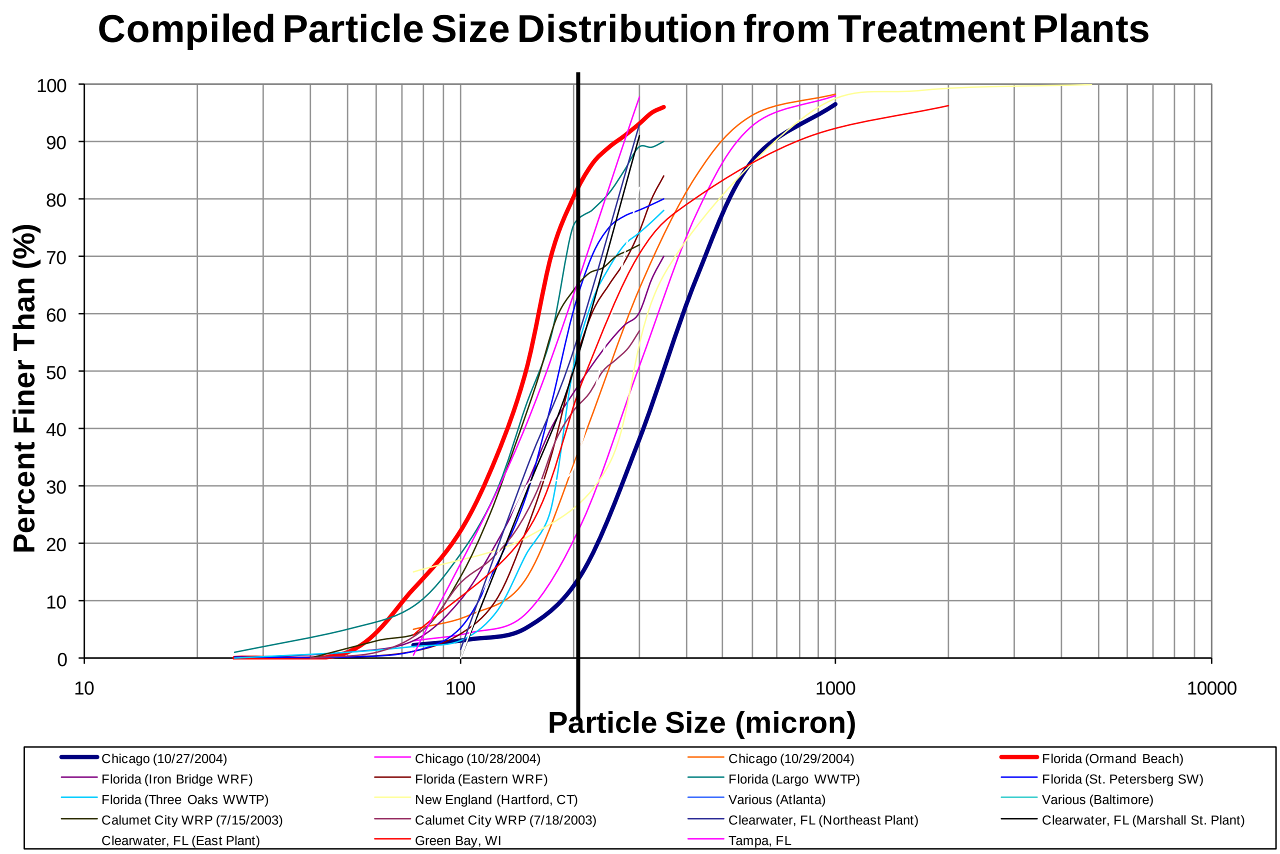


Figure 5: Compiled Particles Size Distributions from U.S. based treatment Works

Homogenous Materials

Grit is assumed to be homogenous in nature but sewage grit is inevitably made up of a number of different substances. Even if the primary inorganic particle is sand, there is a good chance, in sewage flow, that other particles are attached that could make the particle lighter, such as fats and greases.

Examining this from a mathematical view point, if you view the grit particle as a solid sphere with a fine layer of fat attached to the outside, it is clear that there would be a dramatic effect on the overall specific gravity of the particle.

Taking the s.g. of sand as 2.6, and of fat (lard) as 0.92 (Wikipedia 2011), and looking at a small covering (1 to 5 micron) around the particle:

Table 1: The Specific Gravity of a Particle due to a coating of Fat or Grease

Particle Size	Fat/grease layer (micron)					
Micron	0	1	2	3	4	5
70	2.6	2.51	2.41	2.32	2.24	2.15
80	2.6	2.52	2.44	2.36	2.28	2.21
90	2.6	2.53	2.45	2.38	2.31	2.25
100	2.6	2.53	2.47	2.40	2.34	2.28
110	2.6	2.54	2.48	2.42	2.36	2.31
120	2.6	2.54	2.49	2.44	2.38	2.33
130	2.6	2.55	2.50	2.45	2.40	2.35
140	2.6	2.55	2.51	2.46	2.41	2.37
150	2.6	2.56	2.51	2.47	2.43	2.38
160	2.6	2.56	2.52	2.48	2.44	2.40
170	2.6	2.56	2.52	2.48	2.45	2.41
180	2.6	2.56	2.53	2.49	2.45	2.42
190	2.6	2.56	2.53	2.50	2.46	2.43
200	2.6	2.57	2.53	2.50	2.47	2.44
210	2.6	2.57	2.54	2.51	2.47	2.44
220	2.6	2.57	2.54	2.51	2.48	2.45
230	2.6	2.57	2.54	2.51	2.49	2.46
240	2.6	2.57	2.54	2.52	2.49	2.46
250	2.6	2.57	2.55	2.52	2.49	2.47
260	2.6	2.57	2.55	2.52	2.50	2.47
270	2.6	2.58	2.55	2.53	2.50	2.48
280	2.6	2.58	2.55	2.53	2.51	2.48
290	2.6	2.58	2.55	2.53	2.51	2.49
300	2.6	2.58	2.56	2.53	2.51	2.49

As you would expect as the particle size decreases, and the fat layer increases, the overall s.g. of the particle drops as the proportion of fat to sand increases.

This lowering of overall specific gravity has lead to the introduction and use of the term sand equivalent size (SES). SES is "the sand particle size, measured in microns, having the same settling velocity as a more buoyant grit particle" (Griffiths and Book 2011) (Wilson et al. 2007)

On the above theoretical basis particle sizes with a small fat layer have an SES of:

Table 2: Sand Equivalent Size due to Fat Layer

Particle Size	Size of Fat Layer (micron) with result showing SES particle (micron)				
(Micron)	1	2	3	4	5
100	98	96	93	91	89
150	148	145	143	141	139
200	198	195	193	191	189
250	248	246	243	241	239

Even a small layer would mean that the particle size targeted would no longer be captured.

The contamination of the grit particle may not be fat and grease, but organic matter; this again is much lighter than the grit particle and would therefore lower the overall s.g. of the particle making it less likely to be captured.

Field trials in the U.S. (Griffiths and Book 2011) show that whilst at least 65% of all incoming "grit" to a plant was 200 micron or larger, only 45% had a SES of 200 micron or larger. Therefore the grit removal plant was missing a significant amount of the larger particles

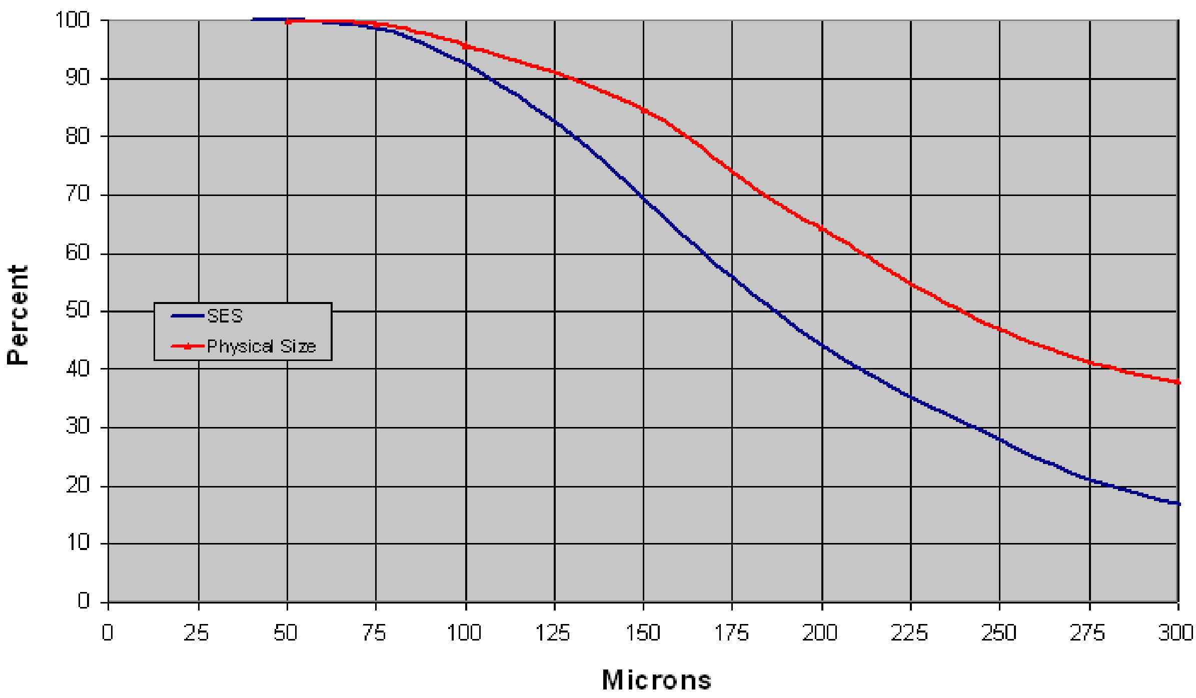


Figure 6: **Comparison of Physical Size and Sand Equivalent Size Influent Grit** (Griffiths and Book 2011)

As further evidence of this Hydro International have used a novel particle imaging instrument called FlowCAM® which uses a high speed camera to photograph individual grit particles in a water sample. This shows that a typical wastewater grit particle has a fuzzy outline suggesting another material has attached itself to the grit, this is most likely to be fats, grease, or biomass.

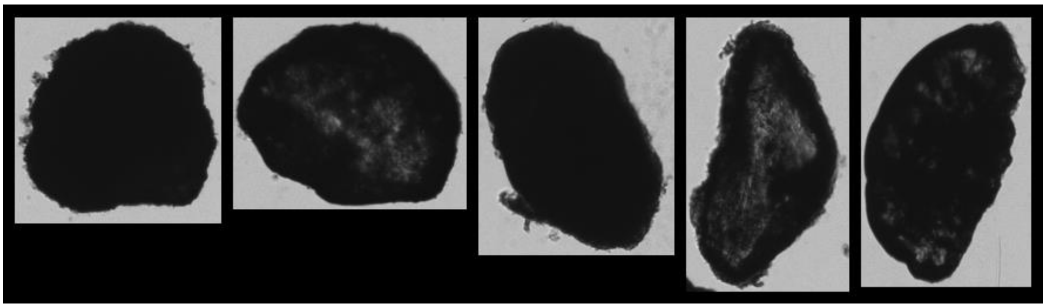


Figure 7: Fuzzy grit as viewed by the FlowCAM

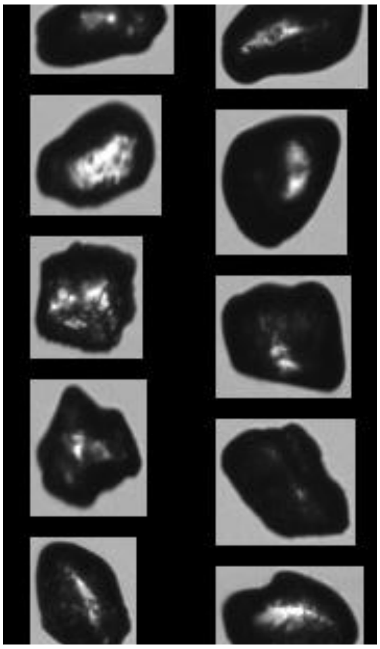


Figure 8: Sand Particle as viewed by the FlowCAM

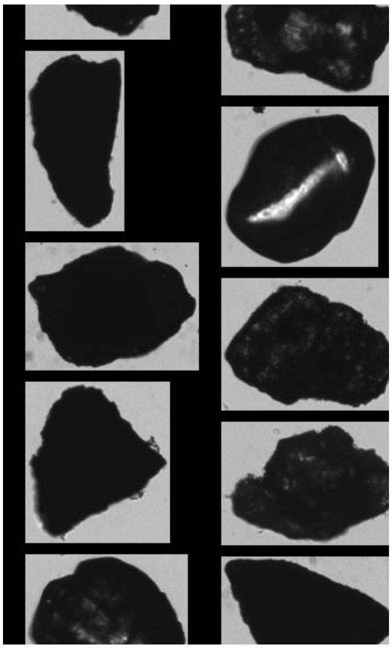


Figure 9: Wastewater Grit Particles as viewed by the FlowCAM

Particle Specific Gravity

Most inorganic particles that are targeted are between 2.6 and 2.7 specific gravity (s.g.), but some are outside that range. In addition if the particle is a composite of several materials its specific gravity could be significantly lower.

Bulk density and specific gravity

Specific gravity is the mass per unit volume compared to water at 4 degrees centigrade, and is dimensionless.

When considering settling velocity the specific gravity will in part determine the ultimate settling velocity, however specific gravity is not the same as bulk density and many information sources quote bulk density stating them as specific gravity. Bulk density is the weight of the item in a defined volume. For a liquid or gas it is the same as the specific gravity, however for a solid bulk density allows for the small spaces between particles as they are stacked together. Bulk density will always be less than specific gravity depending on the void space between the particles.

Table 3: Specific Gravities and Bulk Density of Various Materials

Material	Specific Gravity	Bulk Density
Silica Sand	2.6	1550
Copper Pellets	8.9	3840
Cryolite	3.0	1380
Quartz 12mm screened	2.6	1280 to 1440
Asbestos Powder	2.4-2.5	450
Clay (Kaolin)	2.6	770

(K-Tek 2011)

Many soils have a specific gravity in the range 2.64 to 2.72 (Atkinson 2000)

From the above data the specific gravity of the inorganic particles likely to be found in municipal wastewater are in the range 2.6 to 2.7, but the dirty nature of the particle will lower the overall s.g. as discussed previously.

Shape

The grit particle is assumed to be spherical when calculating settling velocities but particles are normally any number of different, irregular shapes which can have a negative or positive effect on settling velocity.

Table 4: The shape factor used in the calculation of settlement velocities varies with the shape

Shape	Shape Factor	Settling Velocity (200 micron particle 4^{o}C)	SES
		mm/s	Micron
Sphere	0.524	17.24	200
Cube	0.696	22.03	234
Tetrahedron	0.328	11.40	156
Rounded	0.54	17.69	203

Grit particles are irregular, but in the absence of detailed information about a particular site it would be prudent to assume they are typically spherical or rounded.

Flow rate and Turndown

Grit removal systems are sized at a particular design flow rate which is usually the peak flow to be treated. However, during conditions where the system is operating below the design flow, particles with lower settling velocities will settle in a proportionate manner.

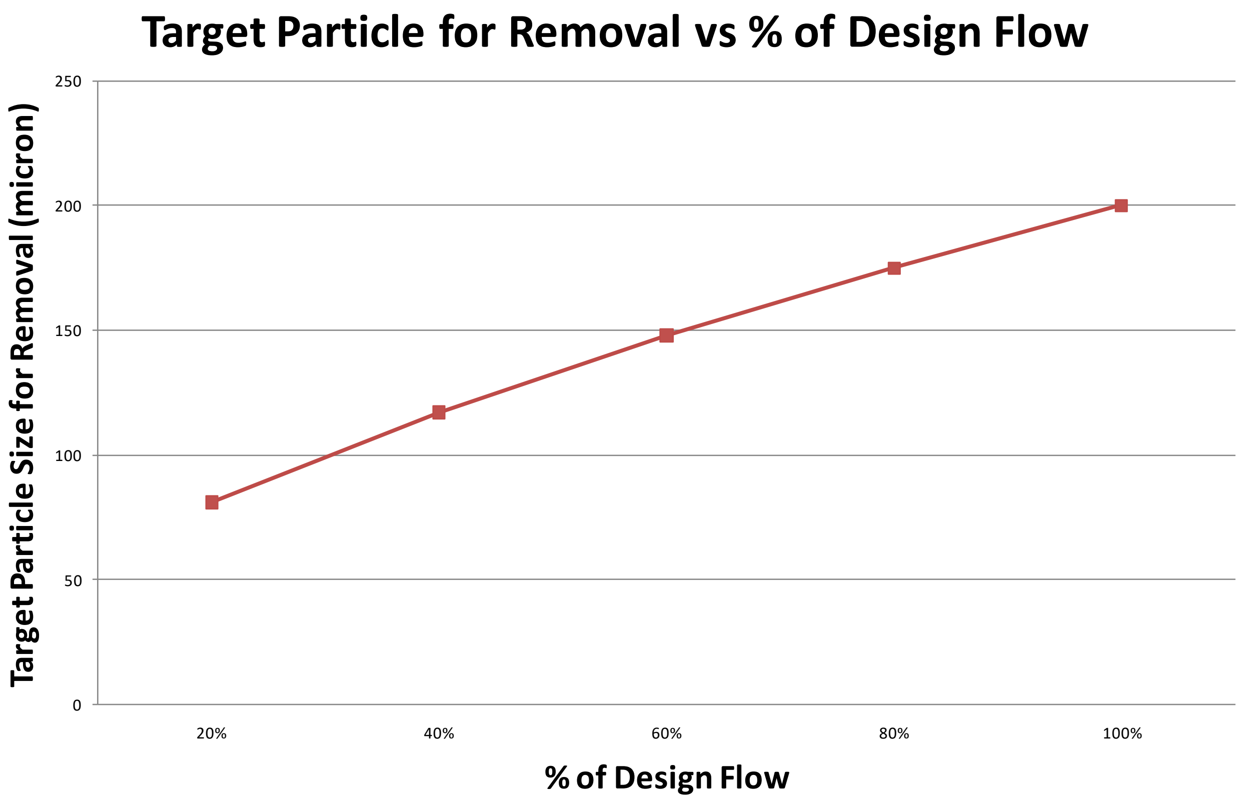


Figure 10: How target particle size and flow are related

Therefore the grit process will remove smaller particles at the average flow to the works. At these lower flow rates smaller particles will be removed by the grit system. As a consequence, the system will also remove large organic particles with the same settlement rate even when they are not attached to grit particles. This means that the collected grit is dirty and subsequent grit treatment processes are required to clean the grit so that the organics can be returned to the treatment stream.

One might conclude that smaller particles should only be targeted at lower flow rates and accept that at peak flow rates these smaller particles will carry through the system. This is misguided because of the enormous loads on the grit plant during first flush where the plant receives not only the full design flow, but also the majority of the grit.

First Flush

The first flush of a sewerage system after a period of dry weather can put a shock load into the works; this is especially true of grit where the load can increase by up to 40 times.

The grit remains in the collection system prior to the rain fall event, but as the rain falls and the flow increases, the stored grit is picked up and carried to the treatment works. At West Point WWTP in Washington the load per 1000m^3 of wastewater increased from 6 kg at average flow to 240 kg at peak flow. This load can account for 70% of the total grit to enter the plant.

Table 5: How Grit Load increases due to Wet Weather at West Point WWTP, WA

	Flow	**Grit Load**	**Days / Year**	**Annual Load**	**% of Total**
	1000m^3/d	Kg/1000 m^3	Days	T/year	%
Average	360	6	359	775.4	27.2
Peak	1440	240	6	2073.6	72.8
Total			365	2849	100

When considering the amount of grit likely during a first flush event Hydro International have noticed a correlation between the Hydraulic peaking factor and the grit load: As the design flow to average flow ratio increases the grit load factor also increases. This could be explained by the collection system being designed for high peak flows and therefore more likely to deposit grit at average flows.

Table 6: Hydraulic Peaking Factors effect Grit Load

Hydraulic Peaking Factor	First Flush Grit Load Factor
2	10 times
2.5	20 times
3	30 times
4	40 times

Therefore the grit system in its entirety must be designed to handle these peak loads as well as the everyday loads received.

Summary

Systems may well be designed to remove an "ideal" target particle from the wastewater flow, but not just grit may be present. In addition, many sites have significant quantities of grit in the sub 200 micron category. As the particle size distribution varies with each site, the target particles size should also vary. What is apparent from the data collected is that 200 microns removal is not adequate for a great many sites leaving over 50% of the grit in the flow in most cases.

The grit when it arrives at the wastewater treatment facility is unlikely to be clean, and is likely to be an amalgam of grit, fat, grease, and organic matter. These constituents cause the particle to have a significantly lower s.g. than a pure clean grit particle and is therefore likely to settle at a slower rate. By looking at the particle's Sand Equivalent Size (SES), and targeting removal on that basis, a lower cut point would serve to capture these larger dirty grit particles.

The specific gravity of the clean grit particles is likely to be around that already stated 2.6 to 2.7 as this seems to cover most of the inorganic substances to be removed. However, when looking at specific gravities it is important not to get these confused with the bulk density which is often quoted erroneously.

The shape of the particle will have a bearing on the settling velocity; however, a spherical shape is a good approximation in most cases unless there is a particular application where other regular shaped particles are common. For municipal applications this is unlikely.

As grit systems are designed to handle the full flow to the works, at lower flow rates they capture some of the slower settling particles and other larger organic particles that settle at the same rate. The collected grit will require cleaning before dewatering and disposal. However, we cannot ignore the smaller particles at high flows because a great deal of the grit received by a wastewater treatment works will be received during the first flush event.

Conclusion

With grit removal technology you "Don't know what you're missing" because it is rarely measured but we do see the results in terms of clogged up channels and pipes, excessive wear on pumps, and reactor tank capacity taken up with inert inorganic material adding cost, reducing efficiency and reducing benefits.

Many sites have a significant proportion of grit that settles at a slower rate than the target cut point particle. This is mainly because there are lots of particles smaller than 200 microns and even particles larger than 200 microns have settling rates slower than a clean 200 micron grit particle because of the attached organics.

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