Grit particle characterization: influence of sample pretreatment and sieving method

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ABSTRACT

Grit causes problems in water resource recovery facilities (WRRFs): clogging pipes, damaging pumps, and reducing the active volume of aeration tanks and anaerobic digesters by grit accumulation. Grit chambers are built to remove these particles. However, no standardized methodology exists to characterize grit particles for grit chamber design and operation despite the large observed variability in grit composition. Therefore, this paper proposes a combination and adaptation of existing methods to sample and characterize grit particles in view of proper grit chamber design and its modelling to ultimately optimize the efficiency of this important WRRF unit process. Characteristics evaluated included particle size distribution from sieving after different sample pretreatments, organic/inorganic fractions, and density.

Key words | grit composition, grit density, particle size distribution, settling velocities, sieving tests

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INTRODUCTION

Grit accumulation and grit-induced damage can be reduced by installing a grit chamber at the headworks of a water resource recovery facility (WRRF). However, for this treatment to be successful, grit chambers should be designed and operated properly (WEF 2010). Commonly, for grit chamber design, grit is defined as inorganic settleable particles larger than 0.21 mm with a specific gravity of 2.65 or higher such as sand, gravel, cinders or other heavy materials (US EPA 2004). Moreover, since a discrete settling process is observed in a grit chamber and the settling velocity is thus the key parameter, this last parameter is generally estimated through Newton's or Stokes' Laws (Tchobanoglous *et al.* 2014; WEF 2016). Despite the fact that Newton's Law is more accurate to estimate the settling velocity of a grit particle taking into account the shape and the turbulent flow conditions, Stokes' Law is presented for an easier interpretation of the results presented in this paper:

$$v_s = \frac{g \times (\rho_p - \rho_w) \times d_p^2}{18 \times \mu} \tag{1}$$

where v_s is the settling velocity (m/s), g the acceleration due to gravity (m/s^2), ρ_p the particles' specific gravity (kg/m^3), ρ_w the specific gravity of water (kg/m^3), d_p the diameter of the particles (m), and μ the water viscosity (kg/(m·s)).

Recent studies start to question whether the definition of grit based on particle sizes (bigger than 0.21 mm) and the sand specific gravity (bigger than 2.65) is correct to estimate the settling velocity of grit particles, and subsequently, for grit chamber design (Barter & Sherony 2011; Herrick *et al.*

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2015). For example, Barter & Sherony (2011) conclude that grit settles at a lower rate because of the organic matter attached to the inorganic particles. Thus, the settleability of grit particles (and consequently the efficiency of the grit chamber) varies with the density, depending on the particle's composition.

Hence, for proper design and operation of grit chambers, grit particles should be well-characterized and representatively sampled. Currently, there is a wide diversity of grit characterization procedures and of variables to be determined to characterize grit (WEF 2016). Surprisingly, however, no standard peer-reviewed characterization and sampling protocols exist yet (WEF 2016). The diversity in procedures can be explained by the difficulty in obtaining a representative sample and the unclear grit definition (Reddy & Pagilla 2009; Rife & Botero 2012).

Added to the lack of standard characterization and sampling protocols, the characteristics of the particulate pollutants at the streams around a grit chamber (inlet, outlet and underflow) are hardly documented and the efficiency of grit removal is uncertain since grit particles are still found in the downstream processes where they cause long-term problems (Andoh & Smisson 1996; McNamara *et al.* 2014).

Recently, the Water Environment Federation's grit task force suggested a new definition of grit based on the settling velocity of the particle as it exists in the raw wastewater (WEF 2016). Also, WEF (2016) added that specific gravities can lie between 1.1 and 2.65. Thus, a wide heterogeneity of the particles is observed, and it creates a vertical stratification in the raw wastewater arriving at the grit chamber, inducing sampling problems (Ashley *et al.* 2005; WEF 2016).

Due to the diversity of grit definitions and the concepts included in those definitions, i.e. particle size, specific gravity and settling velocity, a wide diversity of characterization methods exists (WEF 2016). For example, to characterize the particles' sizes, generally two different tests are used: dry and wet sieving. For dry sieving tests, the sample is dried at 105 °C before the test. In the case of wet sieving, the sample is fresh. Also, several sieving methodologies are used, for example stacked sieves and individual sieves, as well as different sample pretreatments, such as removing the excess water of the sample, washing the sample to remove small particles and burning the sample to remove the organic fraction (Reddy & Pagilla 2009; WEF 2016).

The objective of this study was to evaluate the performance of the different sieving methods and the different sample pretreatment approaches that are currently in use to characterize grit particles, while keeping in mind that a good sieving test should be safe, repeatable, and allow sample storage for some time in order to facilitate the analysis of many samples at the same time. This study has been based on the particles settling and retained in grit chambers, accepting the fact that some grit particles will have escaped from the treatment unit.

MATERIAL AND METHODS

In this study, fresh grit particles removed by two different types of grit chambers (an aerated and a vortex grit chamber) at two different WRRFs in the Québec City area treating combined sewage have been sampled and characterized. The particles studied were collected at the outlet of the grit classification unit, before they fell into the grit bin, providing a representative sample of settled grit under known conditions.

To evaluate the influence of the sample pretreatment on the characteristics of the grit particles, three parameters were studied: the particle size distribution (PSD), the composition (in terms of organic/inorganic fractions) and the density.

Particle size distribution

The PSD of the collected particles was studied by using the two basic sieving methods that are currently in use: dry and wet sieving (Reddy & Pagilla 2009; WEF 2016). In both sieving tests, the indications suggested by WEF (2016) were followed. Fourteen stacked sieves with openings between 75 μm and 13.5 mm were used. The collected grit particles were distributed on the top of the sieve series and the sample passed through all of them. For dry sieving tests, to favour the particle size separation, the sieves were shaken with an automated shaker (Ro-tap Model B) for 15 minutes. For the wet sieving, the collected sample was also placed on the top of the sieve series. However, water at low pressure was sprayed over the sieves for particle classification, forcing the particles rolling on each sieve. After the particle classification, the mass retained on each sieve was collected separately, weighted and further characterized by ashing.

Composition

The composition of the classified grit particles was determined in terms of inorganic (IS) and organic (volatile solids, VS) fractions. This estimation was done following the Standard Methods presented by APHA *et al.* (2012) drying the solids at 105 °C for the total solids estimation and burning them at 550 °C for the IS and VS fractions estimation.

Density

The third parameter studied, the density, was determined for three selected particle classes with a helium pycnometer based on the ASTM (2014) norm. The classes were selected to reflect the variety of composition and size.

Sample pretreatment

Several sample pretreatments were compared to evaluate how they can influence the grit characteristics in terms of the PSD, the composition of the particles and their density. Different combinations of washing the sample were applied to remove the particles smaller than 75 μm, drying the sample at 105 °C, and/or burning the sample at 550 °C to remove the organic fraction. An overview of the experimental plan that was used to study these pretreatments is presented in Figure 1. For the comparison, the wet sieving was considered as the reference method since the impact on the particles is lower compared to other pretreatments.

After the sieving tests, the IS fraction and the density were characterized for each particle class. This experimental plan was repeated for 10 samples collected under dry weather conditions (seven samples collected on a vortex grit chamber and three samples on an aerated grit chamber). Moreover, on three different occasions triplicates for the different tests were performed to assess the uncertainty of the methods.

RESULTS AND DISCUSSION

Particle size distribution

Two examples of PSD curves obtained with the different pretreatment protocols for dry weather samples are shown in Figures 2 and 3 (vortex and aerated grit chambers respectively).

For the vortex grit chamber case (Figure 2), clear differences on the PSD are observed between the pretreatments studied. Particles are markedly smaller when the sample is burnt ('ashed grit'), since the organic fraction is removed and particles disaggregate. When the sample is not washed, bigger particles are observed. This is possibly due to aggregation of particles. No significant differences were observed for dry sieving of dry washed grit and non-washed grit. With dry sieving of wet washed grit and wet sieving, the results obtained are between the PSD curves of ashed grit and dry sieving of dried and non-washed grit. This can be due to the effect of washing the sample, which removes smaller particles and might break up some aggregates. However, the effect observed is less severe than the effect of burning the grit particles before the dry sieving (ashed grit). Moreover, the results indicate that, generally, the effect of drying the sample at 105 °C facilitates aggregation that was not present in the original sample.

Comparing the differences between the curves, they are about a factor 5 on a logarithmic scale. Thus, if the PSD curve obtained is used to calculate the settling velocity of the grit particles through Stokes' Law (Equation (1)), the results obtained can differ by a factor of up to 25 (since the diameter appears in Stokes' Law at the power of 2).

The second example presented in Figure 3 corresponds to the studied aerated grit chamber. In this case, it was again observed that the PSD curve of ashed grit is significantly different from the rest of the PSD curves: particles are considerably smaller after removing the organic fraction. For the rest of the sieving tests, fewer differences are observed. The particles observed on a dry sieving test without

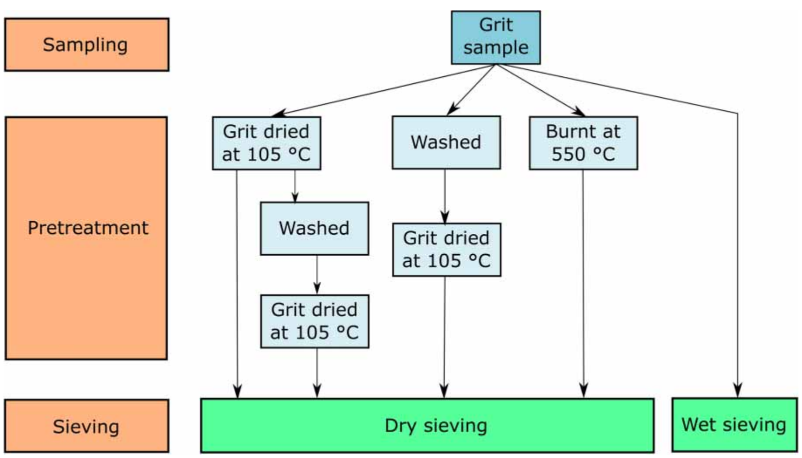

Figure 1 | Experimental plan to determine the influence of the sample pretreatments to characterize the particle size distribution of the final grit product by sieving tests.

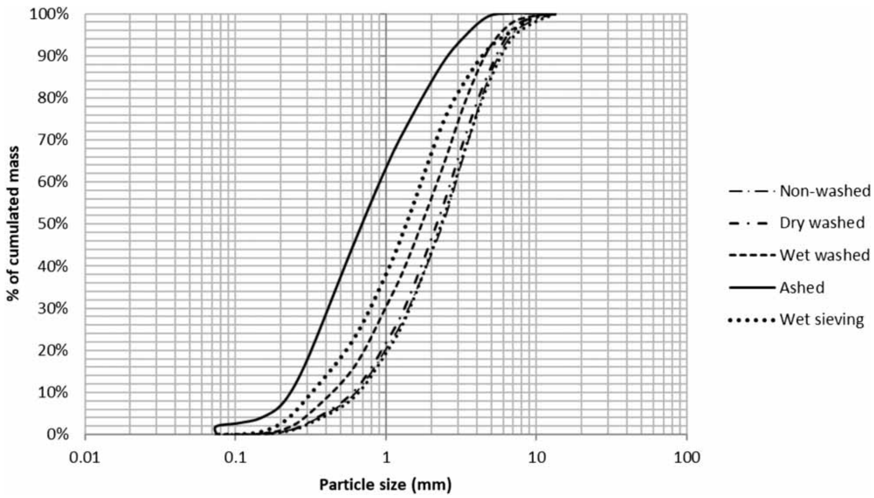

Figure 2 | Granulometric curves for different pretreatments at the studied vortex grit chamber under dry weather conditions.

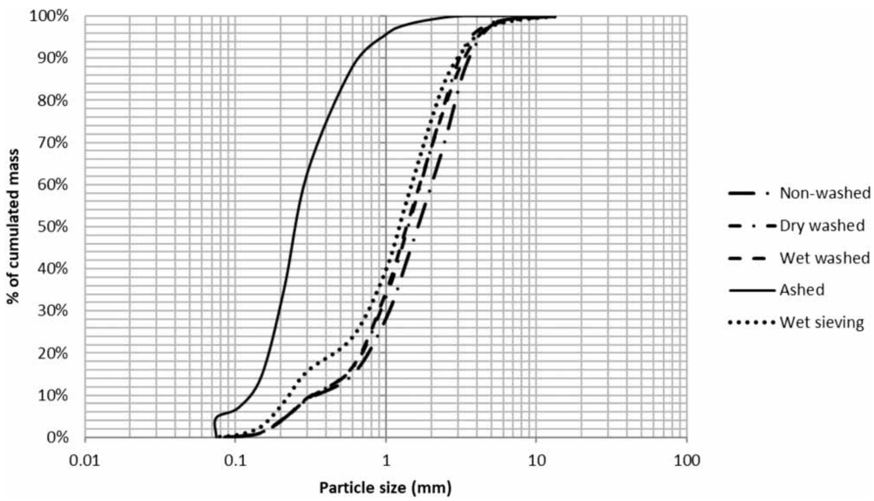

Figure 3 | Granulometric curves for different pretreatments at the studied aerated grit chamber under dry weather conditions.

previously washing the grit are still bigger than the ones in the other tests, possibly because of aggregation of particles. The PSD curve after wet sieving is found between the PSD curves of ashed grit and dry sieving of non-washed grit. However, it is closer to the latter. The PSD curves of dry sieving of wet and dry washed grit are between the wet sieving and the dry sieving of non-washed grit and mostly overlap.

In this case, the differences between the curves in Figure 3 are about a factor of 9. Thus, the estimation of the settling velocity through Stokes' Law can be up to a factor of 81. This can lead to large uncertainties in the design of a grit chamber.

Composition

The sieving tests have also been evaluated through the composition of the particles in terms of the inorganic and organic fractions of each particle size class. Figures 4 and 5 show the results for vortex and aerated grit chambers respectively. The dry sieving test of ashed grit was not included in the comparison since the organic fraction was previously removed.

First of all, for any of the sieving tests (except for the ashed grit) it was observed that small particles (except for the smallest class) were more inorganic than large particles. This inorganic fraction represented more than 50% for the small particle classes, whereas for the bigger particles, it represented less than 20%. However, the inorganic fraction of the smaller particles was significantly higher for the aerated grit chamber than the vortex girt chamber. This fraction was ranging between 80 and 90%.

Comparing the results for each particle size class after dry sieving of the vortex grit chamber samples, small

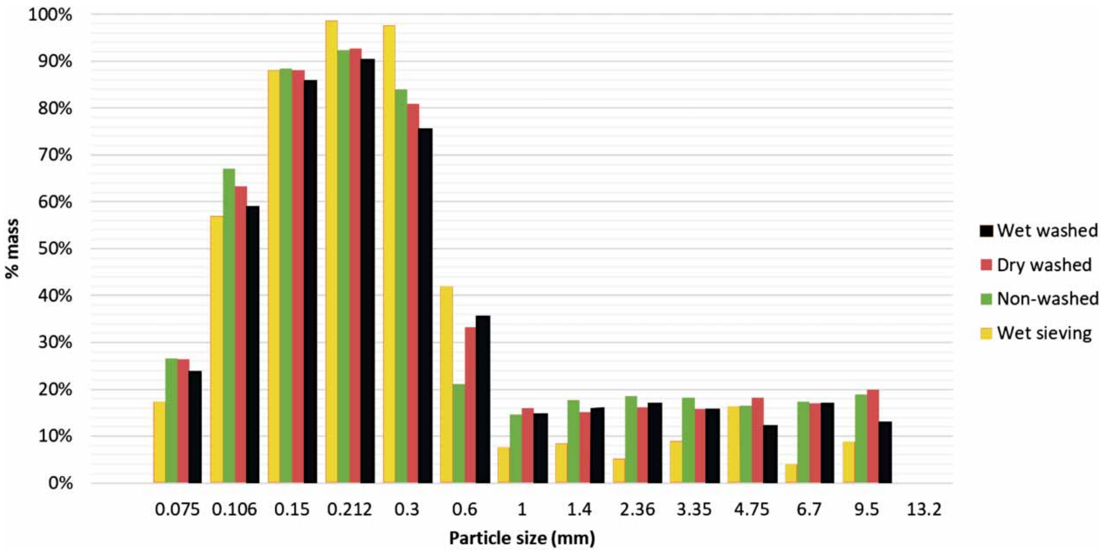

Figure 4 | Inorganic fractions for different pretreatments of dry sieving and a wet sieving from the samples at the studied vortex grit chamber under dry weather conditions.

differences were found between the different pretreatments (i.e. non-washed grit particles, dry washed and wet washed grit) (See Figure 4).

However, when comparing wet sieving (considered as the reference test) with dry sieving of wet washed grit (test with the PSD closest to the one of the wet sieving) for the vortex grit chamber, the observed differences are more marked (Figure 4). Generally, small particles are a bit more inorganic for the wet sieving than for the dry sieving of wet washed grit. For the bigger particles, it was observed that they are a bit more inorganic for the dry sieving. In this case, these differences vary between 2% and 20%.

Similarly, in the case of the aerated grit chamber, no significant differences in the composition were observed between the different pretreatments (results not shown). However, the differences between wet and dry sieving observed are smaller than for the case of the vortex grit chamber (Figure 5). For the smaller particles, almost no

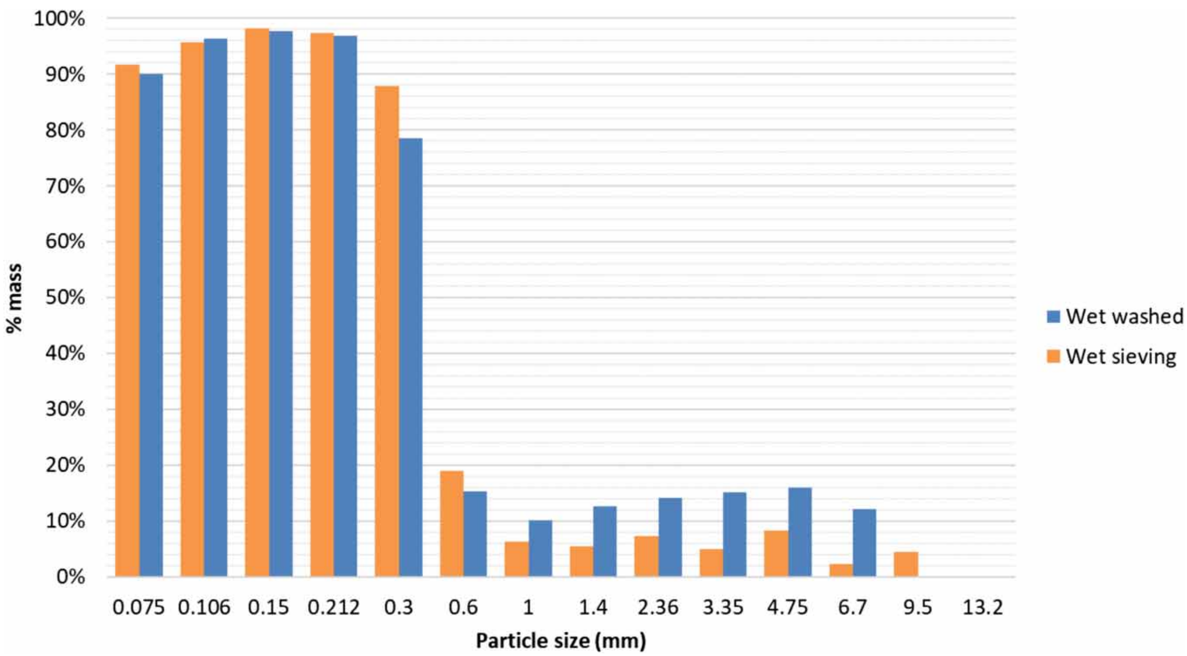

Figure 5 | Inorganic fractions for dry sieving of wet washed grit and wet sieving from the samples at the studied aerated grit chamber under dry weather conditions.

Table 1 | Densities measured, the inorganic fraction, density estimated and the difference between the densities for three different particles classes at the studied vortex and aerated grit chambers

	Vortex grit chamber				Aerated grit chamber			
Particle size (mm)	Density measured (g/cm^3)	% IS	Density estimated (g/cm^3)	Difference (%)	Density measured (g/cm^3)	% IS	Density estimated (g/cm^3)	Difference (%)
4.75	1.51	26%	1.50	1	1.28	12%	1.29	−1
1.4	1.50	26%	1.50	0	1.33	13%	1.30	3
0.212	2.57	97%	2.60	−3	2.65	97%	2.60	5

differences were observed between both sieving tests, varying between 1% and 5%. For the bigger particles, bigger differences were observed ranging between 4% and 10%.

Density

The density of three different particle classes was determined with the helium pycnometer for the two studied grit chambers. The results obtained are presented in Table 1. It was observed that small inorganic particles can have a density above 2.50, whereas big organic particles have a density around 1.50 for the vortex grit chamber and around 1.30 for the aerated grit chamber. The inorganic fraction is different for each grit chamber and they cannot be compared.

From the results presented, a simple relation was developed to estimate the density for the grit particles depending on their composition:

$$\rho_{estimated} = F_{inorganic} \times 2.65 + (1 - F_{inorganic}) \times 1.10 \qquad (2)$$

where $\rho_{\text{estimated}}$ is the estimated specific gravity of the grit particles, and $F_{\text{inorganic}}$ is the inorganic fraction of the grit particles studied. The value of 1.1 was estimated on the basis of the data in Table 1. It is noteworthy that the specific-density found for the inorganic and organic fractions coincides with the range of densities mentioned by WEF (2016).

The densities of the three particle classes characterized previously with the pycnometer were estimated according to Equation (2). The results are shown in Table 1. It is observed that it is possible to estimate the density of the grit particles within ±5%. With this, the density was estimated for all particle classes to compare the influence on the density of the wet sieving and the dry sieving of wet washed grit tests.

Regarding the estimated density values for the different sieving tests; generally, the small inorganic particles have a density higher than 2.40 while large organic particles have a density below 1.40 (Figure 6).

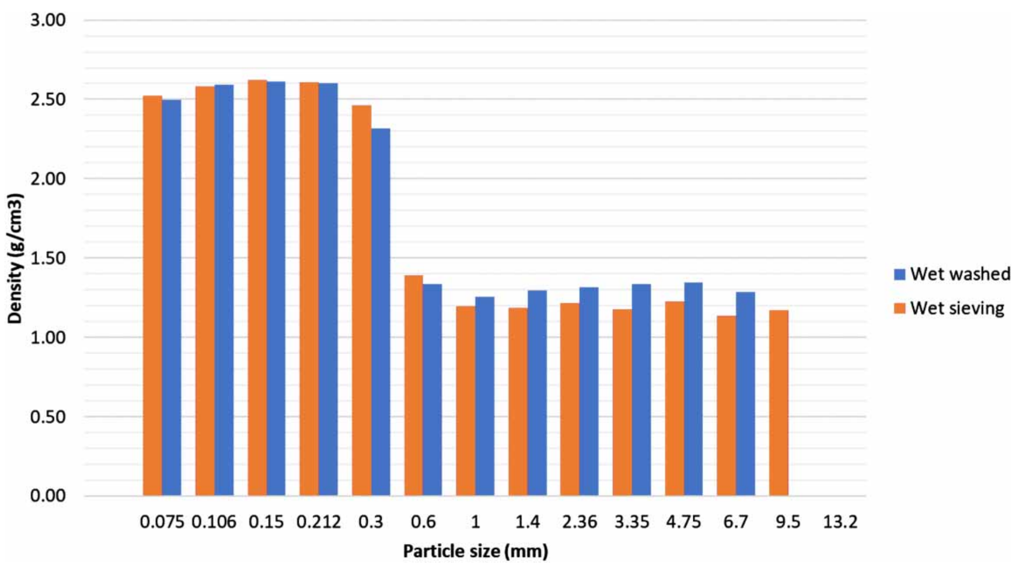

Figure 6 | Estimated densities for dry sieving of wet washed grit and wet sieving from the samples at the studied aerated grit chamber under dry weather conditions.

CONCLUSIONS

The characteristics of the grit particles removed in grit chambers can be influenced by the type of sieving method used and the sample pretreatment applied.

When the grit particles are not washed prior to sieving, the particles are larger, probably due to aggregations, and when grit is burnt, smaller particles are observed because the organic fraction is removed and thus particles disaggregate.

Wet sieving can be considered the reference method since particles are not modified by sample pretreatment. However, this test is less repeatable, less safe (since grit is considered as a biorisk) and a sample cannot be stored for later analysis (the test has to be done within 24 h after sampling). Also, more personnel are needed to perform the test and it requires more time than the dry sieving tests. Thus, dry sieving of washed wet grit is suggested as the preferred method to characterize the PSD because it is safe, repeatable and allows sample storage.

The study of the PSD and grit composition for each particle class showed that smaller grit particles are more inorganic in nature whereas bigger aggregates are more organic. Density measurements of different particle classes illustrated that these differences in composition have an important effect on the particles' density. This will be reflected in the settling velocity.

An empirical equation was developed to more accurately estimate the density of a particle based on its composition in terms of inorganic and organic fractions. This would help to more accurately estimate the settling velocities of the grit particles. Thus, the type of particles that settle in a grit chamber can be better described.

Comparing both WRRFs studied, some differences have been observed. However, it is not possible to associate these differences only to the type of grit chamber since they could also be due to other influences such as the type and size of the sewer system, land use in the catchment studies, wastewater composition (e.g. industry), etc.

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