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Characterizing the settleability of grit particles

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Abstract

Grit chambers are installed at the headworks of a water resource recovery facility (WRRF) to reduce the impact of grit particles to the equipment and processes downstream. This settling process should thus be designed and operated in an efficient way. Despite the importance of knowing settling characteristics for design and operation of grit chambers, previous grit definitions have been based only on particle size characteristics, and not on settling velocities. Thus, this study presents an evaluation of the performance of two promising settling velocity characterization methods, ViCAs and elutriation, to characterize wastewater particles in view of the design and the optimization of the efficiency of the grit removal unit. © 2019 Water Environment Federation

Practitioner points

- Settling characteristics are the governing parameter for grit chamber design. Since grit particles are vastly heterogeneous, it is preferred to measure these characteristics directly rather than to estimate them from particle size (and assumptions of density, form factor, …).
- More detailed settling information about grit particles can improve grit chamber design and estimation of removal performance.
- Adapted ViCAs and elutriation methods for faster settling particles allow studying the particle settling characteristics in a grit chamber. These methods are simple, fast, and cheap and only require small wastewater samples.
- A relationship was found between the influent TSS concentration and the location of the PSVD curve, with higher TSS concentrations corresponding to higher settling velocities.
- It was demonstrated that the dynamics of the wastewater characteristics under dry, wet, and snowmelt weather conditions influence grit settling characteristics.

Key words

elutriation; measurement methods; particle settling velocity distribution; settling tests; ViCAs

Introduction

Background

Grit chambers, which can be found at the headworks of most water resource recovery facilities (WRRFs), are meant to reduce grit accumulation and grit-induced damage in processes downstream of the unit (Tchobanoglous, Burton, & Stensel, 2014; Wilson, Tchobanoglous, & Griffiths, 2007). However, despite their important role in a wastewater treatment chain, the interest to study these units has been lower than for any other unit because it has been considered that grit chambers have a low influence on the secondary treatment (WEF, 2016). Thus, the characteristics of particulate pollutants at the inlet, outlet, and underflow streams of grit chambers are rarely documented, and their removal efficiency is often questioned (Reddy & Pagilla, 2009; WEF, 2016).

Grit particles removal is not simply achieved by installing a grit chamber at the headworks of the WRRFs. It must also be designed and operated in a highly efficient way (WEF, 2010). Thus, grit particles should be well characterized and representatively sampled. Surprisingly, no standard peer-reviewed characterization and sample protocols exist yet (Reddy & Pagilla, 2009; WEF, 2016).

Grit characteristics

Grit removal is a sedimentation process induced by gravity, helical flow, or centrifugal forces (Tchobanoglous et al., 2014). Hence, the governing characteristic for this process is the particle settling velocity. Tchobanoglous et al. (2014) suggests a settling velocity of 70 m/h for typical grit chamber design, which means that particles with a settling velocity of 70 m/h and more are removed at 100%.

Regardless of the importance of the settling characteristics for sedimentation based on gravitational forces (Camp, 1936), previous grit definitions have focused on particle size characteristics considering only the inorganic fraction and assuming that particles are homogeneous spheres with a specific gravity of 2.65 (U.S. EPA, 2004). Then, according to this definition, the settling velocity of the grit particles is estimated from particle size analysis and applying Stokes' Law:

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

where v_s is the settling velocity (m/s), g gravitational acceleration (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)).

However, in reality, grit particles are heterogeneous particles that do not have a single representative value of specific gravity and should not be considered inorganic homogeneous spheres (Herrick, Neumayer, & Osei, 2015; Plana et al., 2018).

An increasing number of studies question whether the conventional definition of grit is a proper approximation (Barter & Sherony, 2011). Thus, the Water Environment Federation's Grit Task Force has suggested a definition that considers the settling velocity of the grit particle as it exists in the raw wastewater (WEF, 2016). In addition, it is now recognized that the organic fraction of the grit particles is significant, and the specific gravity is variable and lies between 1.1 and 2.65 (Plana et al., 2018; WEF, 2016).

Measurement of particle settling velocity distribution

Thus, there is a necessity to improve the knowledge on particle settling velocities, especially considering that this characteristic depends on the particle's size, density, and shape (Aiguier, Chebbo, Bertrand-Krajewski, Hedges, & Tyack, 1996; Marsalek, Krishnappan, Exall, Rochfort, & Stephens, 2006). Several methods are currently in use to determine particle settling velocities by trying to deduce them from other properties. For example, sieving methods study particle sizes from which settling velocities are estimated presuming homogeneous particle specific density and shape.

With the increasing interest in characterizing the settleability of grit particles, two devices have been proposed and tested for fast settling particles. The first device consists in a square settling column presented by Hydro International plc (Osei, Gwinn, & Andoh, 2012) which has been tested separately with several sand and grit particle sizes. The second device, presented by Gerges, Omae, and Martinez (2018), is based on a single dynamic settling column allowing separating particles depending on the upflow velocity into the column. Thus, particles are classified according one settling velocity per test.

True settling characterization methods experimentally fractionate the total suspended solids (TSS) in different settling velocity classes, where each fraction is characterized by a settling velocity v_s. Hence, as a result, a particle settling velocity distribution (PSVD) is obtained. These methods can be classified in the following: (a) static settling devices in which the liquid is under quiescent conditions, such as settling columns (Aiguier et al., 1996); and (b) dynamic settling devices in which the liquid is flowing, like elutriation devices (Krishnappan et al., 2004).

Over the years, several static settling columns have been developed, for example, Aston column (Tyack, Hedges, & Smisson, 1993), Umwelt- and Fluid-Technik (UFT) column (Michelback & Wöhrle, 1993), CERGRENE protocol (Chebbo, 1992), U.S. EPA column (O'Connor et al., 2002), and the newer ViCAs protocol (Chebbo & Gromaire, 2009). The height of these settling columns varies between 0.2 and 1.8 m, with sample volumes ranging between 1 and 40 L. Also, some protocols include a sample preparation step applying a pretreatment such as sieving or settleable solids preselection (Aiguier et al., 1996; Lucas-Aiguier, Chebbo, Bertrand-Krajewski, Gagné, & Hedges, 1998). In addition, on several occasions, these methods have been compared and the results show different PSVD curves (Aiguier et al., 1996; Krishnappan et al., 2012; Lucas-Aiguier et al., 1998). Lucas-Aiguier et al. (1998) pointed out that these differences are probably due to the different sizing of the columns.

As dynamic settling devices, several systems have been proposed. Mainly, two different setups can be found in literature: (a) modified settling columns with the addition of oscillating grids to create turbulence, for example, Rasmussen and Larsen (1996) device; and (b) the elutriation apparatus, firstly developed by Walling and Woodward (1993), and later updated by Krishnappan et al. (2004) and Marsalek et al. (2006).

Objective of the study

Given the importance of the settling velocity for grit particle characterization and for grit chamber design, and the lack of standard and accepted methods for this characterization, the objective of this study was to evaluate the performance of two settling velocity characterization methods in use today to characterize wastewater particles.

Methodology

Case studies

The inlet of a grit chamber at two different WRRFs was sampled and characterized on several occasions. Both WRRFs located nearby Québec City treat combined sewage: one, with a treatment capacity of 270,000 people with an average design flow of 230,700 m^3/day, and the other one, with a capacity of 36,000 people for an average design flow of 18,800 m^3/day.

Sampling methods

For sampling, a multipoint sampler was used in both cases. Considered as a representative method to sample the inlet channel (WEF, 2016), different sampling intakes were installed

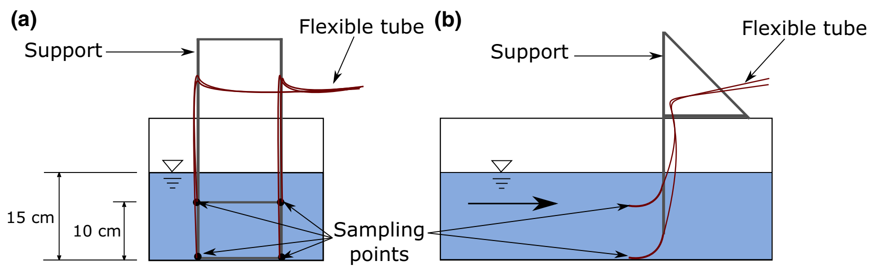

Figure 1. Schema of the multipoint sampler used at the small studied WRRF. (a) Cross-section of the channel; (b) Profile of the channel.

at several points distributed uniformly over the cross-section of the channel. Then, the samples from each intake were homogenized. For example, at the small WRRF studied, four sampling intakes were placed with the openings oriented against the incoming flow as presented in Figure 1. In case of the large WRRF studied, nine intakes were placed to cover the cross-section of the sampled channel.

The samples were collected during 10 min with multihead peristaltic pumps and collected into 20-L containers for easy management and transport. With these pumps and tubes with a Ø = 1 cm, the flow velocity into the tubes was about 1,900 m/hr, thus allowing to collect particles with high settling velocities such as grit. In addition, while sampling, 3 backwashes were performed for 20 s to avoid clogging the openings of the tubes.

Measurement of the particle settling velocity distribution

The particle settling velocity distribution (PSVD) was assessed with two peer-reviewed methods currently in use for raw wastewater samples (e.g., at the inlet of WRRFs and in sewer systems): the experimental protocol ViCAs (a French acronym for settling velocity in wastewater) developed by Chebbo and Gromaire (2009) as a static settling device, and the elutriation method (Krishnappan et al., 2012) as a dynamic settling device. Both methods have been extensively used and applied to characterize stormwater, sewage, and wastewater along the WRRFs treatment chain. Moreover, their reliability and reproducibility have been proven (Bachis et al., 2015; Berrouard, 2010; Maruéjouls, Lessard, & Vanrolleghem, 2014). In this case, no sample pretreatment was applied to not modify the raw sample and to not loose any particles.

The ViCAs batch settling protocol consists in quickly filling a settling column (H = 70 cm, Ø = 7 cm) with a homogenized sample (Figure 2a). Settling solids are recovered in cups at the bottom of the column at different time intervals (t = 1, 3, 5, 10, 20, 35, and 60 min) and analyzed for TSS ($d_p \geq 1.2$ µm). Then, with the cumulated mass of settled particles over the experiment time, it is possible to estimate the distribution of the settling velocities. In this study, according to the time intervals over which cups are accumulating TSS, this distribution corresponds to velocities of 42, 14, 8.4, 4.2, 2.1, 1.2, and 0.7 m/hr, respectively.

However, while the ViCAs settling column has been applied before to study the PSVD of wastewater particles in sewer systems and in WRRFs, the 70 cm-ViCAs column did not allow studying settling velocities above 40 m/hr. Thus, the standard design was modified and upgraded to a 2 m column with a Ø = 8 cm to better study fast settling particles such as grit particles (Figure 2b). The time intervals used to collect the settled solids were kept the same as for the 70 cm-column test leading to the corresponding distribution of settling velocities of 120, 40, 24, 12, 6, 3.4, and 2 m/hr, respectively. For this updated ViCAs setup, 15 L rather than 4 L of sample is needed.

The elutriation system is built as a series of columns with increasing diameters (Ø = 3.4, 4.3, 7, 10.5, 14.3, and 19.7 cm) (Figure 3). The sample enters close to the bottom of each column going upward and leaves the column close to the top (Krishnappan et al., 2004). Thus, the upflow velocity decreases as the water moves downstream along the set of the columns, allowing the particles with a settling velocity higher than the upflow velocity to remain at the bottom of the column. Then, the particles settled in each column are collected separately and quantified as TSS. In this study, the elutriation protocol was adapted adjusting the pumped flow for fast settling velocities. Thus, the test was operated at 1.6 L/min with six columns with upflow velocities of 104, 65, 24, 11, 6, and 3 m/hr. The volume of the samples was variable depending on the samples' TSS concentration to obtain sufficient particles in each column. In this study, samples of a minimum of 20 L were used for the test.

Quality control of the results

To assure the reliability of the obtained results, quality control was implemented. Fortunately, for both methods, a mass balance check can be performed after the test. Only tests with an error on the mass balance lower than 15% have been considered as suggested by Chebbo and Gromaire (2009) for the 70cm-ViCAs columns. For new operators, such good results can easily be achieved after 2 or 3 tests.

Results And Discussion

Reproducibility

First, since the standard methods have been modified and adapted for grit characterization, the reproducibility of the upgraded ViCAs column and the elutriation device with the adjusted flow were evaluated. To evaluate the method precision, triplicate samples were analyzed by each method separately.

To evaluate the reproducibility of the ViCAs test, two samples of 45 L were taken and evaluated on two different days under dry weather conditions; the samples collected between 8 a.m. and 10 a.m. under different flow conditions and with corresponding TSS concentrations of 200 and 300 mg/L. Each sample was split in three subsamples of 15 L. Then, the

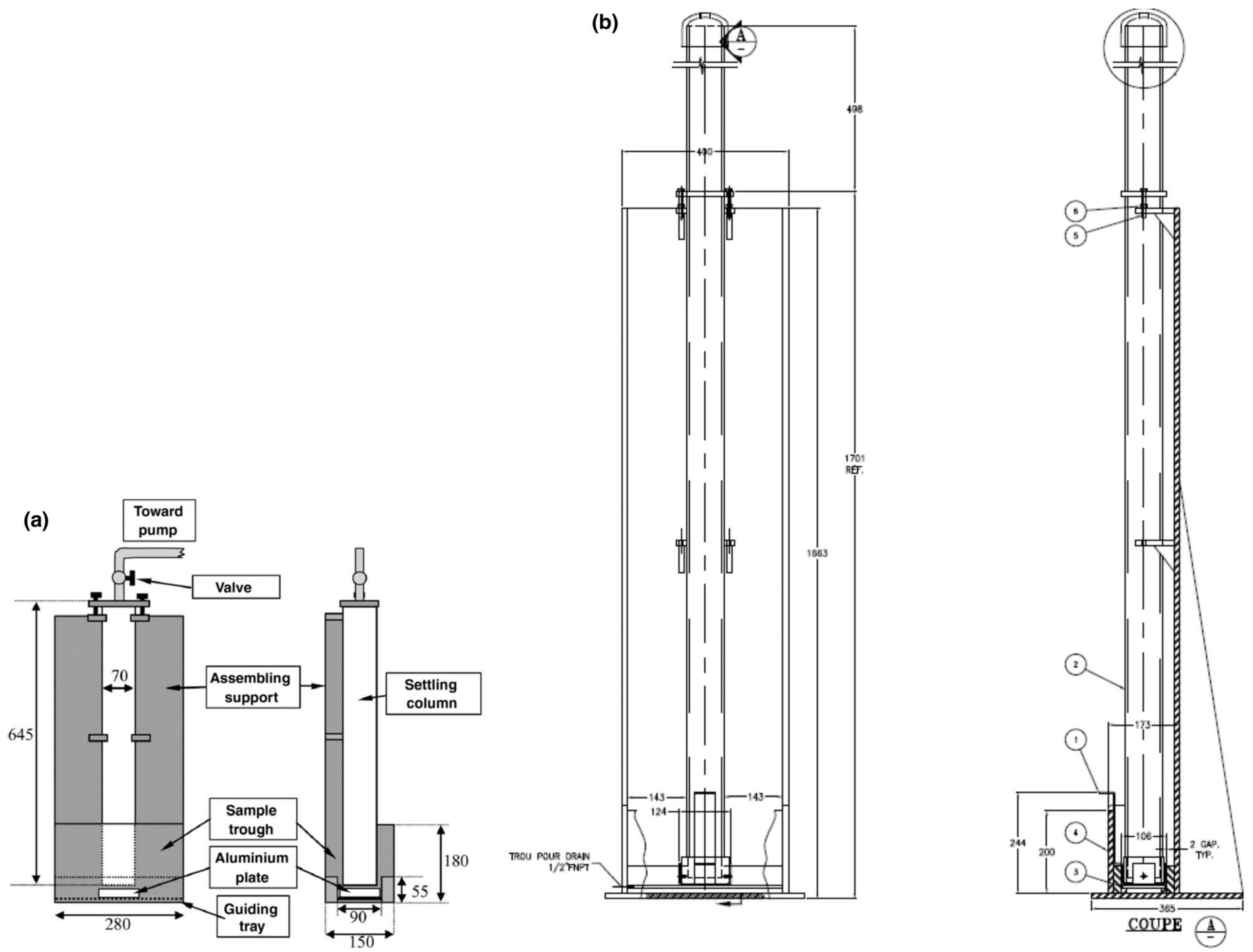

Figure 2. Schema of the ViCAs experimental setup. (a) original 70cm ViCAs column (Chebbo & Grommaire, 2009) (b) adapted 2m-ViCAs column.

particles' fractionation according to their settling velocity was performed following the ViCAs protocol adapted for the 2 m column. The results obtained in both tests were very similar and are considered valid with a mass balance lower than 15%

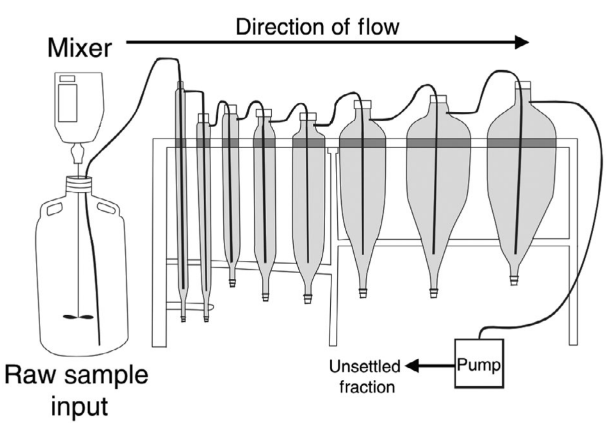

Figure 3. Schema of the elutriation system used (Krishnappan et al., 2012).

for the three tests. Figure 4 depicts the average of the results for the 300 mg/L sample together with the 95% confidence interval over the triplicates. It is observed that the variability of the results is lower for high settling velocities (i.e., lower than 1%) than for low settling velocities (i.e., lower than 5%).

As for the ViCAs test, to evaluate the reproducibility of the elutriation device, a sample of 60 L was also taken under dry weather conditions between 8 a.m. and 10 a.m. with a TSS concentration of 240 mg/L. This sample was split in 3 subsamples of 20 L, and the particles' fractionation for each sample was performed following the elutriation protocol adapted for fast settling particles. The results obtained with a mass balance lower than 15% for the three tests are presented in Figure 5. It is observed that the elutriation setup is reproducible since the variation in the results is minimal. However, again, for low settling velocities, the variability of the results appears higher, that is, lower than 10%.

Comparison between 2m ViCAs and elutriation device

Ten 60 L samples with TSS concentrations ranging between 60 and 360 mg/L were collected at the studied WRRFs. For

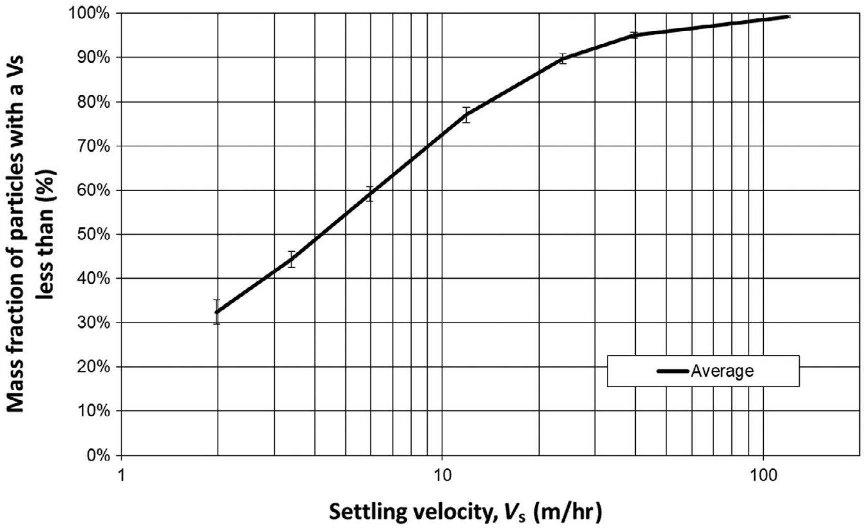

Figure 4. Average of the ViCAs triplicate test with bars representing the 2σ (95%) confidence interval over the triplicates.

each test, the samples were well mixed and split: 15 L for the 2m-ViCAs test and 30 L for the elutriation test. The time each test took, considering the time to prepare the sample, to run the test, and to clean the equipment, was 1.5 hr for each ViCAs test and 4 hr for each elutriation test.

Figure 6 shows three examples of results obtained at the small WRRF studied with concentrations of 60, 250, and 310 mg/L, respectively, from the 2m ViCAs column together with the elutriation results. As mentioned, thanks to the changes of equipment used, the PSVD studied ranges between 2 and 120 m/hr. Thus, both setups allow studying the settling velocities of interest for grit particles (considering the typical design overflow rate of 70 m/hr as depicted in red on Figure 6).

The 2m-ViCAs column and the elutriation method gave very similar results. The small differences can be explained by the fact that for the ViCAs protocol, the PSVD curve is obtained after numerical adjustment of a smooth continuous function whereas for the elutriation method, the curve is not smoothed.

For the samples collected at the large WRRF studied, similar results were again observed at different concentrations (Figure 7). Despite the observation that the particles collected at the inlet of the large WRRF studied are settling faster than those of the small one, the PSVD curves from the 2m-ViCAs and the elutriation device behave similarly. Again, the differences between both methods are mainly due to the mathematical adjustment to obtain the ViCAs curve, making it much smoother than the elutriation result.

Observed relation between TSS concentrations and the PSVD curves

Over time, TSS concentrations vary, as do the PSVD curves. A relation between both variables was observed and is discussed

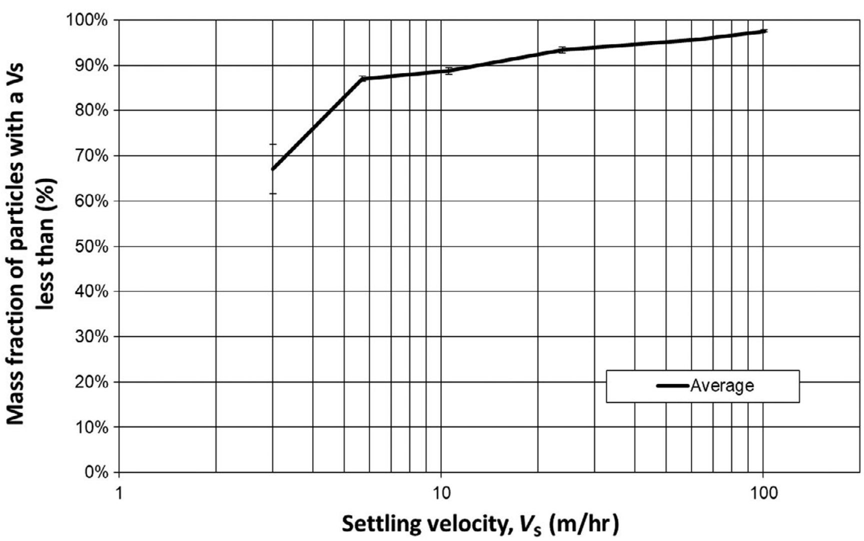

Figure 5. Average of the elutriation triplicate test with bars representing the 2σ (95%) confidence interval over the triplicates.

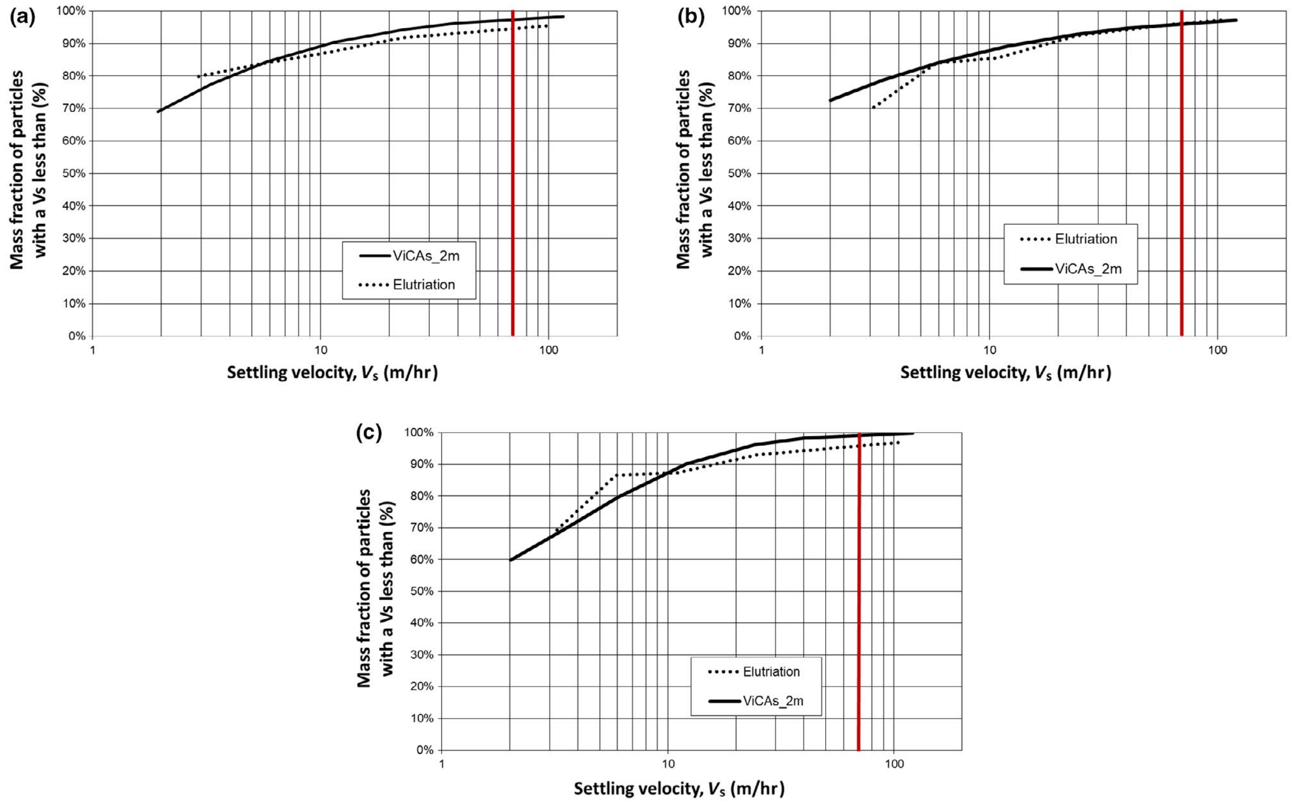

Figure 6. PSVD curves obtained with the ViCAs column and the elutriation system with a sample at the inlet of the grit chamber of the small WRRF studied with a TSS concentration of (a) 60 mg/L, (b) 250 mg/L, and (c) 310 mg/L. The vertical line represents the design overflow rate of 70 m/hr.

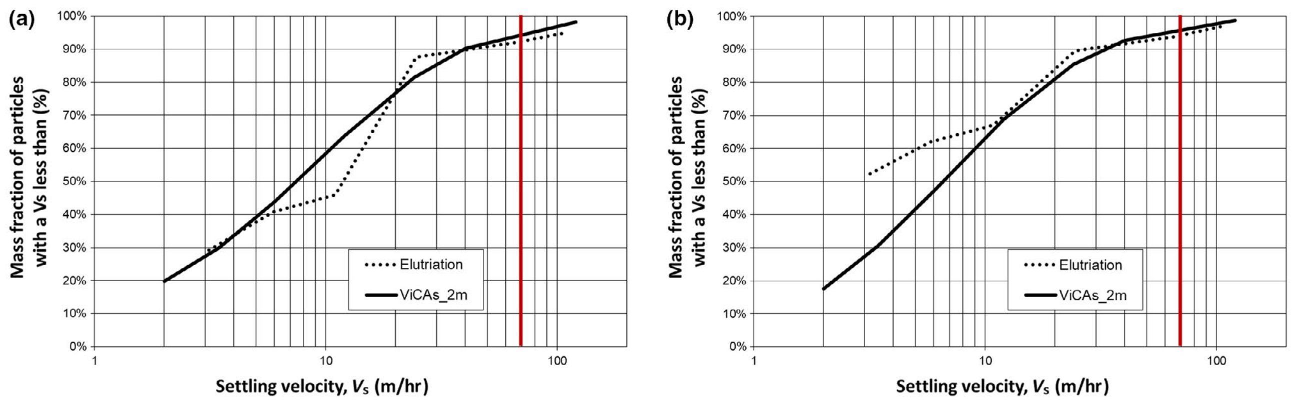

Figure 7. PSVD curves obtained with the ViCAs column and the elutriation system with a sample collected at the inlet of the grit chamber of the large WRRF studied with a TSS concentration of (a) 300 mg/L and (b) 360 mg/L. The vertical line represents the design overflow rate of 70 m/hr.

here. Considering the above conclusion that both setups provide similar results, only the ViCAs protocol was applied because it is faster and requires less sample.

Samples at different TSS concentrations were collected under dry weather conditions. In this case, 16 tests were accepted as valid and considered for the evaluation. The results obtained are presented in Figure 8. It is noticed that most of the PSVD curves follow a similar shape. However, the fractions at each settling velocity vary. Generally, at low TSS concentrations, the PSVD curves are located higher in the graph, and on the contrary, at high TSS concentrations, the PSVD curves are lower in the graph. This means that at high TSS concentrations, the fraction of fast settling particles is higher. For example, from a TSS variation from 100 to 330 mg/L, the fraction fast settling particle may increase 5%, whereas the fraction of low settling particles may increase up to 30%. A possible explanation for

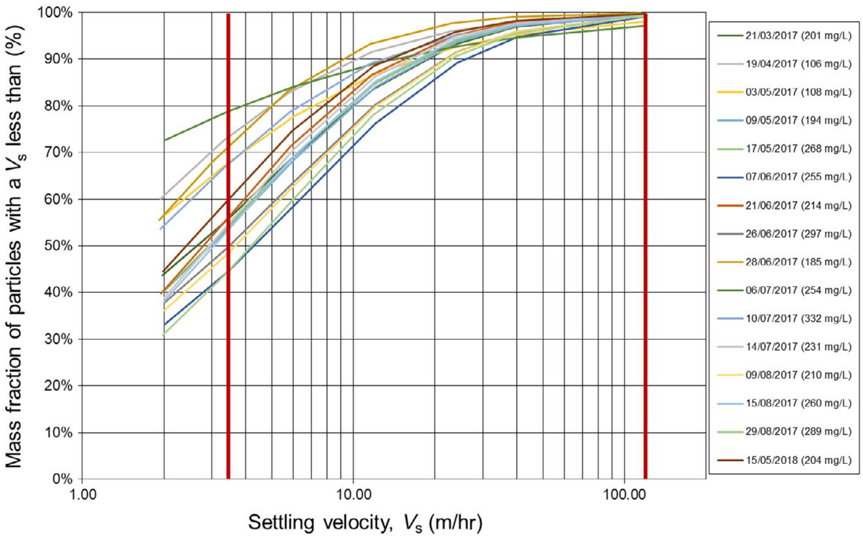

Figure 8. Ensemble of PSVD curves obtained with the ViCAs column from 16 samples collected under dry weather at the inlet of the grit chamber of the small WRRF studied. Vertical lines indicate the settling velocities of 3.4 and 120 m/hr, respectively.

this observation is that, at higher flows, more particles are transported into the WRRF (higher TSS) and that generally these particles are characterized by higher settling velocities because these higher flows have more energy, allowing to resuspend these faster settling particles.

Given these variations, the relationship between TSS concentrations and PSVD curves was further studied. The interest to relate TSS to PSVD is that TSS concentrations are easy to measure (even online), whereas PSVD curves are not. Having a relationship allows for calculating a PSVD curve from the set of collected PSVD curves.

To determine how the PSVD varies with the TSS concentrations, the settling class fractions were plotted together with the TSS concentration of the collected sample. For example, in Figure 9 and in Figure 10, the PSVD fractions are depicted versus the TSS concentrations for the settling velocities of 120 and 3.4 m/h, respectively. In both cases, a linear tendency can be observed similar to the relations observed in previous studies (e.g., Maruéjouls, Lessard, and Vanrolleghem (2015) and Bachis et al. (2015)). This tendency also confirms that at higher TSS concentrations, the fraction of fast settling particles is higher (i.e., lower PSVD curves).

Impact of the weather conditions on the PSVD curves

The PSVD curves were also studied for samples collected under other weather conditions than the dry weather conditions reported so far. In this part of the study, and considering that both setups provide similar results, only the ViCAs protocol was applied because it is faster and requires less sample. Several samples were collected under different weather conditions. In this case, 22 tests with a mass balance error less than 15% were considered: 16 under dry weather, 4 under wet weather, and 2 under snowmelt conditions. In Figure 11, all of the obtained PSVD curves are presented. The lines are the average PSVD curves for each of the weather conditions. The colored zones represent the distribution of all obtained curves for each condition. For the samples under snowmelt conditions, both results have been depicted individually.

Under dry weather conditions, it has been noticed that PSVD curves vary within the day. And, as observed in other studies, for example, Bachis et al. (2015) and Maruéjouls et al. (2015), this variation is correlated with the TSS. At low TSS concentrations, there are less particles that settle at high settling velocities. On the contrary, at high TSS concentrations, there is a higher fraction of particles that settle at high settling velocities. This phenomenon can be explained by the diurnal flowrate variation in the sewer system, with higher flowrates leading to the advection of resuspended faster settling particles compared to low flow conditions.

Generally, it is observed that on average, the particles are settling faster under wet weather conditions than under dry weather conditions. However, comparing the range of the PSVD curves, the range of the PSVD curves under dry weather is larger than under wet weather, and the range of the wet weather samples is mostly included in the dry weather range. This, however, may be due to the fact that less samples were obtained under wet weather conditions.

During the snowmelt period, the percentage of particles that are settling fast is higher than under dry and wet weather conditions. This coincides with the increasing quantity of grit particles collected at the bin during the spring period when the snow melts in the Québec area. Moreover, the PSVD curve obtained can be very variable depending not only on the snowmelt conditions (i.e., the temperature) but also on rain events occurring during the snow melt period (see Figure 11). When occurring together with the snowmelt, a rain event can mobilize the particles used in winter road maintenance to improve traction and transport them to the WRRF. Despite the considerable differences that have been observed between the snowmelt period with rain, the dry and the wet weather conditions, only two samples were collected for the snowmelt period. One should therefore be careful when drawing general conclusions. The effect of the dry, wet, and snowmelt

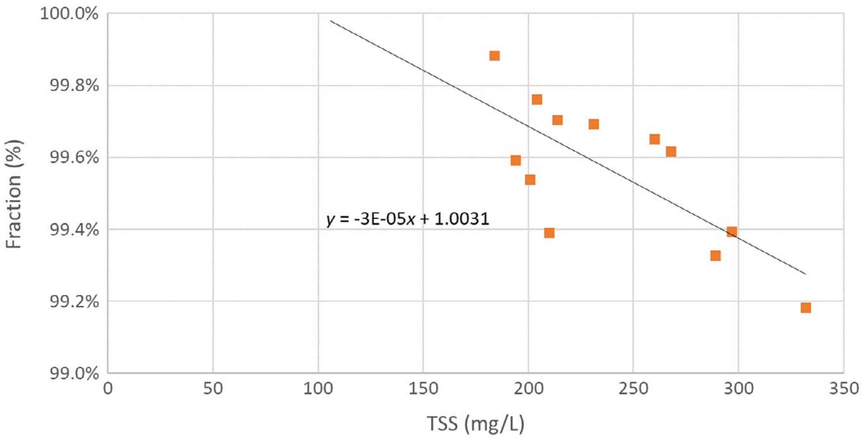

Figure 9. Mass fractions of particles with a settling velocity less than 120 m/hr as function of the TSS concentration of the collected sample under dry weather.

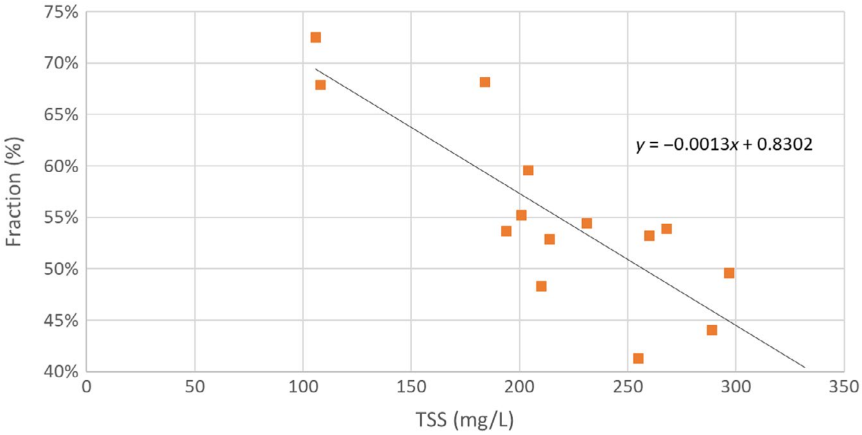

Figure 10. Mass fractions of particles with a settling velocity less than 3.4 m/hr as function of the TSS concentration of the collected sample dry weather.

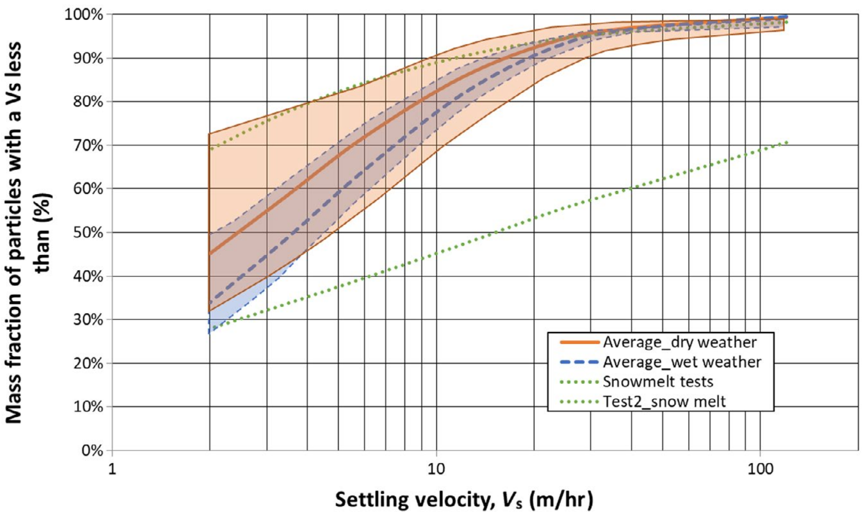

Figure 11. PSVD curves under different weather conditions: Solid lines represent the average and the boundaries under dry weather conditions; dashed lines represent the average and the boundaries under wet weather conditions; and the dotted lines represent the two curves obtained under snowmelt conditions with rain.

conditions was already observed on the particle size distribution in a previous study (Plana et al., 2017).

Conclusions

In conclusion, since grit is highly heterogeneous, the study of the PSVD provides key information on the settleability of the particles as they exist in raw wastewater and, thus, provides a better knowledge of the particle characteristics and a better estimation of the grit chamber performance. However, existing PSVD methods, such as the ViCAs, have to be adapted for fast settling particles, like grit particles.

More importantly, since the organic fraction of removed grit is significant and variable (Plana et al., 2018), and since the density of the particles is thus variable, direct measurement of the governing characteristic, particle settling velocity, should be pursued, rather than using particle sizing that cannot easily be translated into settling characteristics. Hence, the study of the PSVD allows better estimation of the grit chamber performance and, consequently, has the potential of promoting better designs.

Both methods, the 2m-ViCAs test and the elutriation test, are reproducible methods and allow obtaining the same PSVD (i.e., lower than 5% variation for the ViCAs tests and lower than 10% variation for the elutriation tests, in the worst cases). However, the ViCAs require less sample volume and experimentation time, and it therefore the preferred method.

Finally, it was observed that the dynamic characteristics of the wastewater and weather conditions have an important impact on the PSVD curves. First, at high TSS concentrations, there are more particles that settle fast compared to low TSS concentration samples (e.g., fractions possibly being 5% lower for fast settling particles and up to 30% lower for slow settling particles for TSS concentrations varying from 100 to 330 mg/L). Then, generally, particles are settling slower under dry weather conditions. The fraction of fast settling particles increases under wet weather, and this fraction might even increase further, under snowmelt conditions combined with rain event. However, further studies should be performed to confirm the weather conditions' impact.

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References

Aiguier, E., Chebbo, G., Bertrand-Krajewski, J. L., Hedges, P., & Tyack, N. (1996). Methods for determining the settling velocity profiles of solids in storm sewage. *Water Science and Technology*, *33*(9), 117–125. https://doi.org/10.2166/wst.1996.0190

Bachis, G., Maruéjouls, T., Tik, S., Amerlinck, Y., Melcer, H., Nopens, I., … Vanrolleghem, P. A. (2015). Modelling and characterization of primary settlers in view of whole plant and resource recovery modelling. *Water Science and Technology*, *72*(12), 2251–2261. https://doi.org/10.2166/wst.2015.455

Barter, P., & Sherony, M. (2011). Grit – you don't know what you're missing! In *5th European Water & Wastewater Management Conference*, 26–27 September 2011, London, United Kingdom.

Berrouard, É. (2010). *Caractérisation de la décantabilité des eaux pluviales.* MSc thesis, Université Laval, Québec, QC, Canada. In French.

Camp, T. R. (1936). A study of the rational design of settling tanks. *Sewage Works Journal*, *8*(5), 742–758.

Chebbo, G. (1992). *Solides des rejets pluviaux urbains: caractérisation et traitabilité.* PhD thesis, Ecole Nationale des Ponts et Chaussées, Marne-la-Vallée, France. In French.

Chebbo, G., & Gromaire, M.-C. (2009). ViCAs—An operating protocol to measure the distributions of suspended solid settling velocities within urban drainage samples. *Journal of Environmental Engineering*, *135*(9), 768–775. https://doi.org/10.1061/(ASCE)0733-9372(2009)135:9(768)

Gerges, H., Omae, A., & Martinez, U. (2018). An innovative and simple approach to grit evaluation – New settling velocity test replaces sieve analysis. In *91st Water Environment Federation Technical Exhibition and Conference; WEFTEC2018; 29 September - 3 October, New Orleans, LA, USA*, pp. 2692–2698.

Herrick, P., Neumayer, A., & Osei, K. (2015). Grit particle settling – Refining the approach. *Water Online March 1–7*.

Krishnappan, B. G., Exall, K., Marsalek, J., Rochfort, Q., Kydd, S., Baker, M., & Stephens, R. P. (2012). Variability of settling characteristics of solids in dry and wet weather flows in combined sewers: Implications for CSO treatment. *Water, Air & Soil Pollution*, *223*(6), 3021–3032. https://doi.org/10.1007/s11270-012-1085-9

Krishnappan, B. G., Marsalek, J., Exall, K., Stephens, R. P., Rochfort, Q., & Seto, P. (2004). A water elutriation apparatus for measuring settling velocity distribution of suspended solids in combined sewer overflows. *Water Quality Research Journal of Canada*, *39*(4), 432–438. https://doi.org/10.2166/wqrj.2004.054

Lucas-Aiguier, E., Chebbo, G., Bertrand-Krajewski, J. L., Gagné, B., & Hedges, P. (1998). Analysis of the methods for determining the settling characteristics of sewage and stormwater solids. *Water Science and Technology*, *37*(1), 53–60. https://doi.org/10.2166/wst.1998.0014

Marsalek, J., Krishnappan, B. G., Exall, K., Rochfort, Q., & Stephens, R. P. (2006). An elutriation apparatus for assessing settleability of combined sewer overflows (CSOs). *Water Science and Technology*, *54*(6–7), 223–230. https://doi.org/10.2166/wst.2006.570

Maruéjouls, T., Lessard, P., & Vanrolleghem, P. A. (2014). Calibration and validation of a dynamic model for water quality in combined sewer retention tanks. *Urban Water Journal*, *11*, 668–677. https://doi.org/10.1080/1573062X.2013.847462

Maruéjouls, T., Lessard, P., & Vanrolleghem, P. A. (2015). A particle settling velocity-based integrated model for dry and wet weather wastewater quality modeling. In Proceedings *WEF Collection Systems Conference 2015*; April 20–22, Cincinnati, OH, USA.

Michelbach, S., & Wöhrle, C. (1993). Settleable solids in a combined sewer system, settling characteristics, heavy metals, efficiency of storm water tanks. *Water Science and Technology*, *27*(5–6), 153–164. https://doi.org/10.2166/wst.1993.0495

O'Connor, T. P., Fischer, D., Field, R., Cigana, J., Gagné, B., & Couture, M. (2002). *Testing solids settling apparatuses for design and operation of wet-weather flow solids-liquid separation processes* (pp. 136–196). US EPA report no. EPA/600/R-02/090. October 2002. Cincinnati, OH, USA.

Osei, K., Gwinn, A., & Andoh, R. Y. G. (2012). Development of a column to measure settling velocity of grit. In *World Environmental and Water Resources Congress 2012, Crossing Boundaries,* pp. 1327–1333. ASCE, May 20–24, Albuquerque, NM, USA.

Plana, Q., Carpentier, J., Tardif, F., Pauléat, A., Gadbois, A., Lessard, P., & Vanrolleghem, P. A. (2017). Influence of sample pretreatment and weather conditions on grit characteristics. In *Proceedings 90th Water Environment Federation Technical Exhibition and Conference; WEFTEC2017*; 30 September – 4 October, Chicago, IL, USA.

Plana, Q., Carpentier, J., Tardif, F., Pauléat, A., Gadbois, A., Lessard, P., & Vanrolleghem, P. A. (2018). Grit particle characterization: Influence of sample pretreatment and sieving method. *Water Science & Technology*, *78*(6), 1400–1406. https://doi.org/10.2166/wst.2018.412

Rasmussen, M. R., & Larsen, T. (1996). A method for measuring sludge settling characteristics in turbulent flows. *Water Research*, *30*(10), 2363–2370. https://doi.org/10.1016/0043-1354(96)00145-5

Reddy, M. P., & Pagilla, K. (2009). *Integrated methods for wastewater treatment plant upgrading and optimization.* Technical report, Water Environment Research Foundation and IWA Publishing, Alexandria, VA, USA.

Tchobanoglous, G., Burton, F., & Stensel, H. (2014). *Wastewater engineering: Treatment and reuse* (5th ed.). Boston, MA: McGraw-Hill.

Tyack, J. N., Hedges, P. D., & Smisson, R. P. M. (1993). A device for determining the settling velocity grading of storm sewage. In *Proceedings, 6th Int. Conf. on Urban Storm Drainage, Niagara Falls, Ontario, Canada*, pp. 1805–1810.

U.S. EPA (2004). *Screening and grit removal.* Technical report, U.S. Environmental Protection Agency, Washington, DC, USA.

Walling, D. E., & Woodward, J. C. (1993). Use of a field-based water elutriation system for monitoring the in-situ particle size characteristics of fluvial suspended sediment. *Water Research*, *27*(9), 1413–1421. https://doi.org/10.1016/0043-1354(93)90021-9

WEF (2010). Design of municipal wastewater treatment plants: Manual of practice 8 (5th ed.). WEF Manual of Practice and ASCE Manual and Report on Engineering Practice. McGraw-Hill Education. Alexandria, VA, USA.

WEF (2016). *Guidelines of grit sampling and characterisation*. Alexandria, VA: Water Environment Federation.

Wilson, G., Tchobanoglous, G., & Griffiths, J. (2007). *The Grit book*. Hillsboro, OR: Hydro International.