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Influence of composite particle formation on the performance and economics of grit removal

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ABSTRACT

Grit is routinely removed at the headworks of municipal wastewater treatment works to limit its onerous impact on downstream processes. Grit separation technologies are normally based on sedimentation of a homogeneous material (usually sand). However, in practice inorganic grit particles are likely to be combined with organic matter, such as fats oils and grease (FOG), producing a composite particle whose settling properties vary with the inorganic/organic content.

A study of the impact of particle composition on its sedimentation has been conducted encompassing theoretical description (for particle settling in transitional flow), practical measurement and economic analysis. Practical measurement included sedimentation tests of homogeneous and composite particles along with characterisation of accumulated granular material sampled from actual municipal wastewater treatment works. The economic assessment was based on data from full-scale installations in the UK and US pertaining to remedial measures undertaken as a result of grit impacts, primarily accumulation in vessels and channels and damage of mechanical equipment through abrasion.

Practical tests revealed coating of the sand grains with a FOG analogue (candlewax) to generate composite particles containing 45% wax by weight. The coated particles were then 30% less dense, 22% larger and 14% less settleable, on average, than the uncoated particles. Samples of accumulated grit taken from anaerobic digesters and aeration lanes from a full-scale plant indicated a FOG content (43%) similar to that of the waxed particles in the bench-scale tests, thus leading to a similar grain retardation of 14% assuming the FOG to be entirely associated with the grit. An assessment of the impact of the consequential breakthrough of grit particles due to buoyancy generated by composite particle formation indicated a \$1.1 increase in operating costs per megalitre (ML) wastewater.

1. Introduction

Particle sedimentation in water forms a key part of subject areas such as powder technology (Shahi and Kuru, 2015; Terfous et al., 2013) and river bed sediment hydraulic characterisation (Maggi, 2013; Cuthbertson and Ervine, 2007). The modelling of particle settlement generally, and in turbulent flow (Mazzuoli et al., 2014; McNair and Newbold, 2012) specifically, remains a challenge for researchers in this area. Analytical expressions defining particle settlement, primarily through the drag coefficient, have been presented in research literature dating back several decades, with recent papers summarising the various equations developed (Betancourt et al., 2015; Yang et al., 2015; Terfous et al., 2013). Indeed, a series of papers authored by Concha and co-workers providing theoretical particle settlement expressions covering a wide range of conditions have been published since 1979 (Betancourt et al., 2015; Concha and Almendra, 1979). The majority of the modelling approaches are ultimately designed to reconcile the dependence of the drag coefficient on both the flow regime (within the transitional region) and the particle characteristics, in generating analytical expressions.

Whilst numerous theoretical and semi-empirical expressions of particle settlement have been presented the practical implications of these with reference to grit removal systems specifically appears to have been largely overlooked. A review of the SCOPUS database

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reveals that there are approximately 60 papers dedicated to the removal of grit from wastewaters, with less than 40% of these appearing in index-linked journals. Around 25% of the total number concern hydrodynamic modelling (Dutta et al., 2014; Munoz and Young, 2009), and a further 60–65% are based grit characterisation (Sherony and Herrick, 2015; Hafiz, 2013; Osei et al., 2012) and degritter performance evaluation (Yan et al., 2014; McNamara et al., 2012), a significant proportion of the latter being site specific. Notwithstanding the apparent paucity of research into degritting technology *per se*, the vast majority of large municipal wastewater treatment works (WwTWs) are fitted with degitters whose operation is based on sedimentation of entrained heavy suspended solids.

Grit in wastewater takes the form of inorganic solid particles in the 0.2–4 mm size range of density predominantly above 1800 kg/m^3 (Table 1). Whilst organic matter is retained in the grit waste, degritters are intended to selectively remove solids, which may otherwise impair downstream processes through abrasion (of mechanical equipment or concrete channels) or accumulation, most typically in anaerobic digesters (ADs) or aeration lanes. This stipulates the larger inorganic solids, and the standard performance criteria used for the degritter technology is 95% removal of such solids above 210 μm in size, based on national standards (USEPA, 2003). However:

a) recent reported practitioner accounts and experiences (Sherony and Herrick, 2015; Flanagan, 2014; McNamara et al., 2013, 2012) suggest that grit entrainment imposes a challenge even for degritters apparently meeting the specification, with significant adverse consequences for downstream unit process and equipment, and
b) the combination of grit with organic matter, and specifically fats, oils and grease (FOG), whilst being noted in WwTW grit samples (Flanagan, 2014) has never been quantified with respect to its extent and calculable impact on grit removal efficacy.

The study aims to investigate both the impact of coating of grit particles on sedimentation and the cost associated with residual grit on downstream wastewater unit processes. The work described provides:

1. Experimental determination of the impact of FOG coating of granular solids to form composite particles on their settling velocity;
2. Comparison of the recorded trends with those of model composite spherical particles;
3. Determination of the composition of grit accumulated within components of full-scale municipal WwTWs; and
4. The use of real-life economic data to determine the cost of retarded settling.

2. Materials and methods

2.1. Grit samples and physical models

Real and model homogeneous and composite grit samples took the form of:

a) microsphere standards (Table 2), supplied by *Cospheric*, CA, USA,
b) fractionated sand grains of mean material density 2650 kg/m^3,
c) coated fractionated sand, using candlewax as a FOG analogue, and
d) whole samples of accumulated solids extracted from unit processes (ADs and aeration lanes) from four different UK sites (Table 3).

The microspheres were of three different materials and particle sizes, with the material density generally decreasing with increasing size (Table 2) to mimic the effect of the coating of grit

Table 2
Model and sand particles.

Material	Code	Specific gravity (–)	Dia., (mm)
Microspheres			
Polyethylene	*PE*	1.09	0.55
Cellulose acetate	*CA,1*	1.3	1
Cellulose acetate	*CA,1.2*	1.3	1.2
Soda lime glass	*SLG,0.65*	2.54	0.65
Soda lime glass	*SLG,0.69*	2.54	0.69
Barium titanate	*BaT,0.27*	4.15	0.27
Barium titanate	*BaT,0.52*	4.15	0.52
Sand grains			
Sand	*Sand*	2.65	1.21
Coated sand	*Waxed sand*	1.86	1.48

Table 1
Grit size range, specific gravity, shape, source, estimated settling velocity.

Grit component	d_p, μm	Specific gravity (–)	Source	Shape	v_s, mm/s
Quartz Sand [a,c,g,h]	212–300	1.2	Infiltration	Granular	28–40
Limestone in grit [a,c,g]	500–1000	2.85	Infiltration	variable	30–60
Granite (fractured) [a,g,h]	1000–2000	2.66	erosion	Angular	50–100
Gravel (granular) [b,d,f,g]	2000–4000	2.0	erosion	variable	50–100
Clay [a,c,d,g]	<5.0	1.8	Infiltration	sphere	<4.5
Sand, wet [a,c,e]	190–275	1.92	Infiltration	variable	24–39
Silt [a,c,e]	5.0–80	2.5–2.6	Municipal waste	variable	4.7
Organic waste [a,c,h]	300–6720	0.72	Municipal waste	variable	9–12
Inorganic food waste [d,g,h]	100–840	1.07–2.2	Municipal waste	variable	1–10
Undigested organics (bones, teeth, etc.) [d,f,g]	3.0–1000	0.8–0.9	Mixed waste	variable	1–10
Fats, oils & grease [d,f,g]	Various	0.5–0.7	Mixed waste	Mild	–
Mixed grit [a,c]	>210	2.65	Mixed waste	variable	1.4–14

[a] Aidun, 2013.
[b] Csgnetwork, 2016.
[c] Flanagan, 2014.
[d] Maggi, 2013.
[e] Sherony, 2014.
[f] Simetric, 2016.
[g] Sperling, 2007.
[h] Yesiller et al., 2014.

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