Pergamon

Wat. Sci. Tech. Vol. 33, No. 9, pp. 127–134, 1996.

0273–1223/96 $15·00 + 0·00

PII: S0273-1223(96)00378-2

THE PRACTICAL USE OF WASTEWATER CHARACTERISATION IN DESIGN

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ABSTRACT

The design of conventional settlement devices used for primary treatment at wastewater treatment works has traditionally been based on generalised loading criteria. These generalised loadings do not necessarily take into account the nature and settling characteristics of the suspended material in influent wastewater streams.
The paper describes the practical use of wastewater characterisation, in the form of settling velocity distributions, for the design of primary sedimentation devices, such as the hydrodynamic separators used in the Swirl-Flo™ process.

Results of settling velocity distributions for diverse wastewater sources (including municipal and industrial sources) are presented together with comparisons between steady-state model predictions with observed performance for waste streams at different sites. The observed differences in settling characteristics for the wastewater streams investigated, together with the implications these have for design and performance assessment, are used as basis for advocating the need to incorporate wastewater settling characteristics in the design process for wastewater sedimentation devices.

KEYWORDS

Hydrodynamic separator; sedimentation; settling velocity; sewage grading; wastewater characteristics; vortex.

INTRODUCTION

The European Council (EC) Urban Wastewater Treatment Directive (UWWTD; *91/271/EEC)* defines Primary Treatment as: *"a means of treating urban wastewater by a physical and/or chemical process involving settlement of suspended solids, or other process in which the BOD_5 of the incoming wastewater is reduced by at least 20% before discharge and the total suspended solids of the incoming wastewater are reduced by at least 50%"*. Conventional primary sedimentation tanks (PSTs) have been designed on the basis of parameters such as surface loading rates and retention times. The general view is that well designed primary sedimentation tanks should achieve 65% suspended solids and 35% total BOD_5 removals from a screened and degritted sewage *(Boon and Dolan, 1995)*. This suggests that conventionally designed primary sedimentation tanks should achieve the primary treatment requirements as defined in the UWWTD. Recent studies by a number Water Companies in the UK have shown that on the contrary, conventional primary sedimentation tanks at many sites do not achieve the UWWTD primary treatment standard.

Unfortunately, very little inter-process stream data at wastewater treatment works (WWTW) incorporating primary sedimentation tanks is generally available primarily because the main attention and focus, until recent times, has been on the treatment works final effluent quality. What little data that exists, have often been derived from infrequent simultaneous spot samples of influent and effluent streams. These simultaneous spot samples are unlikely to be representative of sedimentation tank performance on account of dynamical lag times (especially for units with significant retention times). Also, such spot samples take no account of the highly variable nature of influent wastewater feed characteristics.

This paper describes how the design of sedimentation devices can be improved based on knowledge of the wastewater's settling characteristics and a mathematical model of the sedimentation device's separating characteristics.

WASTE WATER CHARACTERISTICS

Pollutants in wastewater include floating matter, solids in suspension, colloidal solids and matter in solution. Suspended solids can range in size from sub-micron sized particles to solids of the order of several 100s of millimetres. Figure 1, showing the size spectrum of solids encountered in wastewater together with the effective unit process for treatment, suggests that sedimentation is appropriate only down to particle sizes of the order of 30 microns.

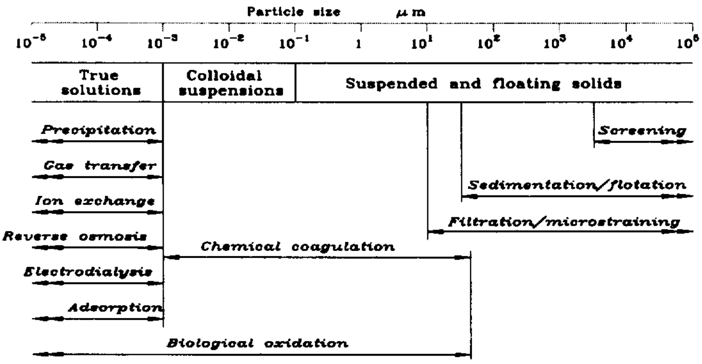

Figure 1 - Particle Size and Unit Processes ; *After Tebbut (1992)*

Given that the pore size of filter papers used for the standard tests for suspended solids are usually of the order of .45 to 1.2 microns, this suggests that the effluent suspended solids concentration from an efficient sedimentation device will tend towards a limiting suspended solids concentration relating to the non-settleable (fine solids) fraction of the waste stream typically less than 100 microns particle size.

Table 1 - Effects of Decreasing Size of Spheres on Settling

Diameter of Particle		Order of Size	Time Required to Settle (SG = 2.65)	Time Required to Settle (SG = 1.2)
mm	microns			
10	10,000	Gravel	0.4 sec	1.2 sec
1	1,000	Coarse Sand	3.0 sec	9 sec
0.1	100	Fine Sand	34 sec	5 min
0.01	10	Silt	56 min	8 hours
0.001	1	Bacteria	4 days	32 days
0.0001	0.1	Colloidal	1 year	9 years
0.00001	0.01	Colloidal	> 50 years	> 50 years
0.000001	0.001	Colloidal	> 50 years	> 50 years

Table 1 gives the time taken by spherical particles of different size and specific gravities (SG = 2.65 and 1.2) to settle under quiescent conditions through approximately 300 mm of water under gravity assuming Stoke's Law. A specific gravity of 2.65 represents an inert grit/sand like particle whereas organic solids tend to have a specific gravity of the order of 1.02 - 1.2. Though Stoke's Law gives a representative indication of orders of magnitude of terminal settling velocities, it cannot accurately predict real life settling phenomena on account

of the effect of complex processes such as turbulence, re-suspension, adsorption and flocculation.
It is clear however, from Table 1 that suspended solids with sizes less than fine sand and silts do not settle within practical time scales.

With regard to sedimentation, the aggregate effect of importance is the settling characteristics of the suspended material in the waste stream. Given that the complex interactions that occur with the highly variable composition of the wastewater cannot be predicted, "lumped effects/measures" are needed to characterise the wastewater.

Currently, several techniques *(Michelbach and Wohrle, 1992; Tyack et al., 1993)* exist for measuring the settling velocity distribution (or profile) of representative samples of wastewater streams and this is the subject of on-going research. A technique developed at Aston University *(Tyack et al., 1993)* includes a measurement procedure enabling the settling velocity distributions for both the settling and floating fractions of the waste stream to be determined. The floating fraction being those with negative settling velocities.

Typically, settling velocity distribution curves are produced as cumulative graphs which show the proportion of material by weight with settling velocities less than a given settling velocity. Sample grading of wastewater for a number of urban catchments and Industrial effluents are presented in Figures 2 and 3 respectively. These clearly shows differences in settling characteristics of wastewater from different sources. The grading gives a good indication of the relative proportion of solids in the colloidal non-settleable range reflected by the proportion with settling velocities less than about 0.01 cm/s. The grading curve in the region above 0.1 cm/s reflects the fraction of the suspended material that will settle ***rapidly*** within practical time scales.

Figures 2 and 3 show that the non-settleable fraction can range from less than 10% (eg. Eastbourne and Brewery wastewater) to greater than 50% (eg. Totnes and the Fish waste). A waste stream with a settling velocity profile showing greater than 50% of the suspended solids (SS) to be non-settleable, for example, would suggest that no matter how large a sedimentation device was built to handle this waste stream, no greater than 50% SS removals would be achieved. ***This has cost and other implications relating to either the sizing of any subsequent (eg. biological) treatment stage or the provision of say physico-chemical treatment to enhance the SS removal.*** Observed removals (in terms of percentage removals) for suspended solids and other pollutants associated with these solids, depends on the distribution of solids in the waste stream and what fraction is represented by settleable solids.

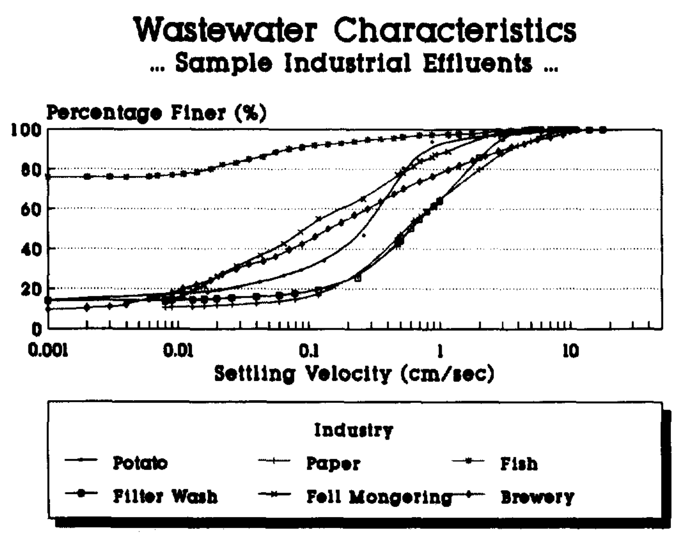

Figure 2 Settling Characteristics of Sample Industrial Effluents

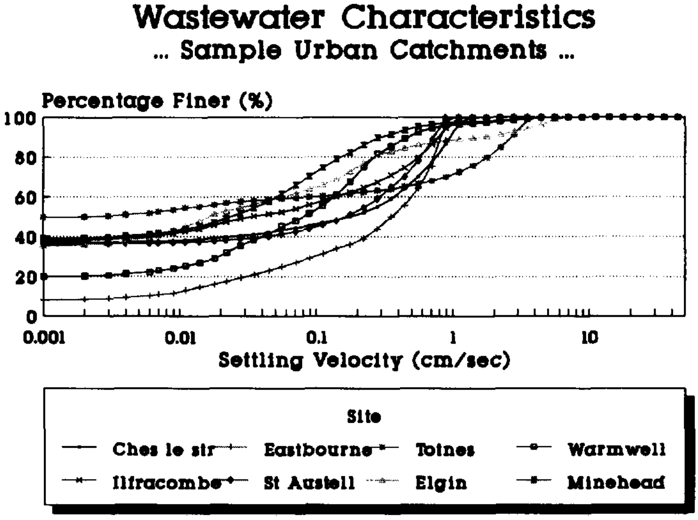

Figure 3 Settling Characteristics of Sample Urban Catchments

The settling characteristics of wastewater can vary significantly depending on the contributing sources. The feed stream to the 'Primary Removal' stage at a wastewater treatment works, for example, is typically derived from combinations of crude sewage (from municipal and industrial sources), rainfall runoff from the contributing catchment or recycled flows (return liquors) from within the treatment works site. All of these sources have differing proportions of settleable and non-settleable particulate solids with varying physico-chemical properties all of which will affect the sedimentation efficiency observed for sedimentation devices.

Relating the observed settling characteristics with the information presented in Table 1, it can be surmised that *within extensive sewerage networks, the large organic solids typically discharged at the top end of the system, in water closets, are degraded into smaller sized particles with age and transport through the sewerage network. This is especially the case where there are ancillary components such as pumping stations which create hydraulic regimes with high turbulence and shear.* It would seem logical, therefore, that wastewater discharged at the end of extensive sewerage networks will have a higher proportion of smaller sized solids. These smaller sized solids tend to be less readily settleable and have a greater proportion of associated pollutants such as heavy metals and polycyclic aromatic hydrocarbons (PAHs). ***This suggests that it may be more effective to treat wastewater as close to the source as possible.***

SEDIMENTATION DEVICES

Sedimentation theory suggests that, for discrete particles, sedimentation efficiency is a function of the overflow rate in the device. In practice, the hydraulic regime in sedimentation devices deviates from the ideal with clearly identifiable concentration zones and profiles (e.g. influx zone and sludge zone) and stratification and re-circulatory flow regimes. These deviations from the ideal serve to reduce sedimentation efficiency. As a consequence sedimentation devices have differing efficiency characteristics on account of their differing hydraulic flow regimes and effective acceleration force fields. A comparison between conventional PSTs and rotary flow sedimentation in hydrodynamic separators is given in another paper *(Andoh and Smisson, 1994).*

The design of conventional PSTs, based on generalised loading rates, suggests an ***inherent assumption that urban wastewater characteristics are invariant from site to site.*** In reality, influent streams to sedimentation devices are highly variable in quantity, quality and settling characteristics as shown in Figures 2 and 3. It stands to reason therefore, that the performance of any settling device in terms of percentage removals for the solids fraction in its feed waste stream will vary in accordance with the relative contributions from the diverse waste sources. In this regard, observed performances are likely to be highly variable on account of the highly variable nature of the feed stream coupled with the separating characteristics of the sedimentation device.

A review of data obtained for hydrodynamic separator trials at a number of sites in the UK shows that the "Primary" treatment level as defined in the UWWTD (ie. 50% SS removals) is achieved at some sites whereas at others, the nature and characteristics of the influent wastewater is such that, this level of treatment is not achieved. This observation is confirmed by monitoring undertaken by a number of Water Companies in the UK on the performance of existing PSTs at a number of works sites which illustrate that some sites do not achieve the UWWTD primary treatment levels.

DESIGN CONSIDERATIONS

Hydrodynamic separator design is based on a semi-empirical mathematical model derived from first principles relating to sedimentation theory and calibrated with data from prototype units *(Andoh and Smisson, 1994)*. The design equations used, predict the separator's removal efficiencies at differing settling velocities. Combining this with a knowledge of the settling velocity distribution of the incoming feed enables predictions to be made of overall removal efficiencies based on input design parameters and data on wastewater settling characteristics (sewage grading). Figure 4 shows an example of the use of wastewater settling characteristics in the design of the Hydrodynamic Separator. The separator's separating characteristics at different aspect ratios for given input parameters are shown superimposed on the wastewater's settling characteristics. Combining these characterisation results in predictions of efficiency.

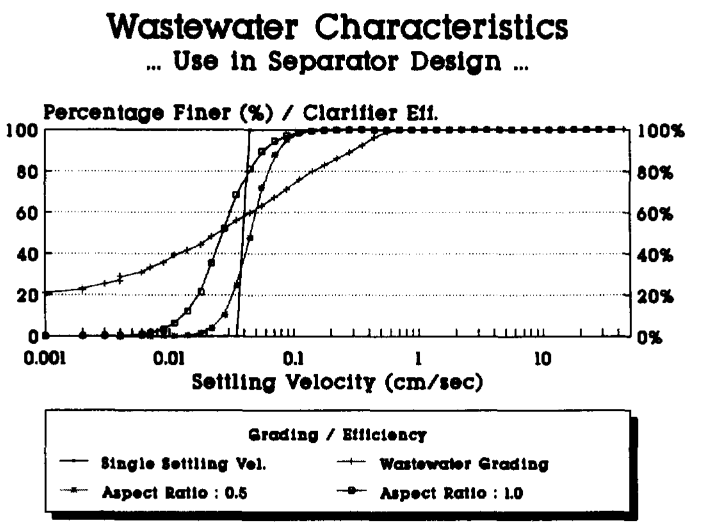

Figure 4 Use of Wastewater Characterisation in Separator Design

Using the techniques outlined above, it has been possible to make comparisons of observed and predicted performances for the hydrodynamic separator at a number of works as presented in Table 2. This clearly shows the closeness of the predictions of hydrodynamic separator performance with observed removals. Also shown in Table 2 are the results for different sample streams within the same site (Totnes). The results at this site show that sample streams including recycle flows from the works (from the biological treatment stage and sludge treatment plant) have relatively higher proportions of settleable material compared with the crude sewage only.

Table 2 - Comparisons of Observed and Predicted Performances for Sedimentation in Hydrodynamic Separators

Site	Surface Loading (m/hr)	Suspended Solids Removals (%)	
		Observed	Predicted
Backwell	8.0	25	28
Frome	3.6	51	51
Countess Wear	4.3	51	47
Totnes (Crude only)	2.1	47	44
St Austell / Par	3.2	65	68
Motney Hill	1.5	52	50
Totnes (Crude & Recycle)	3.4	64	67

Table 3 shows the predicted performance for a hydrodynamic separator loaded at an overflow rate of about 5 m/hr (based on overall plan area) for waste streams from a number of sites in the UK (the settling velocity gradings for some of these sites are presented in Figure 2).

Table 3 - Predicted Performance for Sedimentation in Hydrodynamic Separators for Different Waste Streams

Site	Predicted Removals (%)	Site	Predicted Removals (%)
Legbourne (with humus returns)	82	Warmwell	45
Eastbourne	69	Ilfracombe	43
Swanage	63	Elgin	34
St Austell	54	Motney Hill	34
Chester-le-Street	53	Minehead	27

These results clearly show the differences in solids removals likely to be achieved owing to differences in settling characteristics of the waste streams from the different sites. With some waste streams, the UWWTD primary treatment levels are predicted to be achieved (eg. Eastbourne and Swanage) whereas others (eg. Minehead and Motney Hill) would not be expected to achieve this level with sedimentation only. This suggests that wastewater characteristics, such as settling velocity distributions, have a significant bearing on the likelihood of achieving the UWWTD primary treatment levels at a given site.

A case study is presented demonstrating the relevance of wastewater characterisation in the evolution of appropriate process configurations to achieve the differing requirements of the UWWTD.

CASE STUDY

Totnes is an old rural town with a creamery as the only major industry discharging its wastewater into the Totnes WWTW. Outlying villages are sewered to the WWTW through an extensive sewer system with all flows pumped. The works also serves as the disposal point for tankered wastewater from the area and includes sludge digestion and belt pressing. In 1992, the Water Research Centre (WRc) in the UK as an independent body, were commissioned by South West Water plc to evaluate the performance of the hydrodynamic separators (Swirl-Flo™ process) installed at this site. A description of the Swirl-Flo™ process and the results obtained are presented elsewhere (*Andoh and Harper, 1994*). Details of chemical types that have been trailed with the Swirl-Flo™ process and summary cost of chemicals for treatment are presented in *Helliwell and Harper (1993)*.

Table 4 showing a comparison of the characteristics of the crude sewage at Totnes with typical values given in the literature for municipal wastewater, suggests that the crude at Totnes has a relatively high proportion of carbonaceous organics.

Table 4 - Comparison of Characteristic of Totnes Crude Sewage

Waste Stream	**Ratio of Typical Average Concentrations**			
	BOD/NH_3	**COD/NH_3**	**SS/NH_3**	**NH_3/NH_3**
Totnes Crude	15.3	32.4	12.75	1
Typical Crude *(after Tebbut, 1992)*	7.5	17.5	10.0	1
Typical Crude *(after Metcalf and Eddy, 1991)*	8.1	20.0	7.0	1

Settling velocity grading of the crude wastewater (see Figure 2) show a large proportion of non-settleable solids, presumably derived from the creamery wastewater. This is backed by results of quiescent settlement tests (*Andoh and Smisson, 1994*) which show that less than 50% of the suspended solids settle out even after close to 24 hours of quiescent settlement. These results suggest that in order to achieve greater than 50% SS removals at the primary treatment stage for this site, physico-chemical or other enhanced primary treatment would be required.

The Swirl-Flo™ installation at Totnes WWTW was designed to allow trials with chemicals to be undertaken on a full-scale operational plant and comprises two parallel process trains which enabled a comparative assessment of "no-chemical" and "with-chemical" (physico-chemical) treatment modes for the same influent waste stream. A summary of the results obtained during the WRc monitoring programme is presented in Table 5. The efficacy of the process is realised when the 47% suspended solids removals achieved in the "no-chemical" mode is compared with the less than 50% removals obtained for the quiescent settlement tests. The solids removals observed in the "no-chemical" mode represents over 94% of the settleable solids fraction in the crude sewage.

Table 5 - Summary of Results of Trials at Totnes WWTW

Process Mode	**Observed Average Percentage Reduction (%)**				
	Suspended Solids	**Total BOD**	**Phosphorus**	**Oils, Fats and Grease**	**Total Coliform**
No Chemical	47	23	-	61	-
"Low Removals - Chemical"	55	37	37	82	-
"High Removals - Chemical"	92	73	97	97	99

In the physico-chemical mode, an increasing proportion of the non-settleable colloidal fraction is converted into settleable solids with increasing chemical dose levels, reflected in the 55% and 92% suspended solids removals observed for the "low" and "high" removal chemical modes respectively. These results show that the nature and characteristics of the waste stream arriving at this site is such that "plain" physical sedimentation on its own would not have achieved the UWWTD primary treatment levels irrespective of the type of sedimentation device implemented. The "low removals chemical" mode (chemically assisted sedimentation) achieves the UWWTD primary treatment levels. The observed performance for this mode is however less than the 65%:35% (SS:BOD) levels assumed for primary sedimentation in the UK. The "high removals chemical" mode achieves secondary treatment levels as defined in the UWWTD.

SUMMARY AND CONCLUSIONS

The discussions on wastewater characteristics together with the results presented in the case study clearly highlight the importance and relevance of wastewater settling characteristics in process design and selection for sedimentation devices. The ability to predict likely process performance from a knowledge of the wastewater characteristics (such as the settling velocity distributions of a waste stream), and the performance characteristic of a separating device should lead to optimisation of both design and operation of sedimentation devices. Also, better knowledge of the characteristics of the waste stream should aid in the selection of the most appropriate unit process for effecting solids removal in urban wastewater treatment.

The nature and characteristics of suspended particulate matter in municipal wastewater depends very much on its various sources and the transformation processes occurring during its ingress and conveyance to a wastewater treatment works site. Observations suggests that though the suspended solids in urban waste water streams are diverse species from various sources, the characteristics of a wastewater stream of relevance to sedimentation can effectively be determined from the settling velocity distribution or profile and, combining this with the separating characteristics of sedimentation devices enables predictions to be made of overall solids removal efficiencies.

There is the need, therefore, to move away from the use of generalised loading criteria for the design of primary removal system to the use of reliable and representative characterisation of wastewater as a basis for design and process selection.

Physico-chemical treatment processes such as the Swirl-Flo™ offer the flexibility of achieving the differing treatment level requirements defined in the EC Urban Wastewater Treatment Directive.

ACKNOWLEDGEMENTS

The authors would like to thank South West Water Plc for permission to publish data used in this paper. The views expressed are those of the authors and not necessarily those of South West Water Plc.

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