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Wastewater Treatment Using Hydrodynamic Vortex Separators

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ABSTRACT

Hydrodynamic vortex separators are compact, low energy solid-liquid separation systems that have been applied extensively in the field of wastewater treatment. Presenting major benefits compared to ‘conventional’ solutions, they have additionally been applied for combined sewer overflow treatment, stormwater treatment and industrial effluent treatment.

The paper provides an overview of the technology, covering its development, operating principles and performance characteristics, and includes a number of installation case studies, focusing in particular on wastewater treatment related applications.

The paper concludes that such systems represent an effective and economical alternative to ‘conventional’ approaches, presenting major opportunities for cost savings.

KEY WORDS

Hydrodynamic vortex separators, wastewater treatment, grit removal, primary sedimentation, solid-liquid separators

INTRODUCTION

Hydrodynamic Vortex Separators (HDVSs) are compact, low energy solid-liquid separation systems that utilise the dynamic energy in a flowing effluent to perform their function. Operating hydraulically, they have been used for applications ranging from removal of coarse solids from an effluent (e.g. removal of grit from sewage), through to primary sedimentation (e.g. of municipal and industrial effluents). They have also been used in conjunction with settlement aids such as coagulants and flocculants, and also chemical disinfectants, allowing further enhancements in treatment performance to be achieved.

With driving head requirements of typically less than 150mm, HDVSs operate effectively within the context of a gravity-fed treatment facility, where they have no external power requirements. Combined with the fact that they have no moving parts, and therefore minimal maintenance requirements, operating costs tend to be low.

The principle of hydrodynamic separation was first observed by Bernard Smisson, an Engineer from Bristol (UK), who later spent a lifetime researching the principle, and applying it to the practical problem of Combined Sewer Overflow (CSO) treatment [1]. Following initial research work in the UK during the 1950's and 1960's, he continued his work in the USA as a consultant on an American Public Works Association (APWA) research programme, which culminated in the development of the US EPA 'Swirl Concentrator' [2], a predecessor to the enhanced systems of today.

Since the further development and subsequent commercialisation of HDVSs in the 1980s, such systems have been the subject of numerous performance evaluation programmes in Europe, North America and Japan [3][4][5][6][7][8][9][10].

By the early 1990s, applications of HDVSs had extended beyond use solely for CSO treatment, to include municipal wastewater treatment [6], industrial effluent treatment [10] and stormwater treatment [11]. To date, over 1500 HDVSs have been installed worldwide, ranging in size from 0.75m up to 16m in diameter, with facility treatment capacities of in excess of 4 m^3/s.

This paper provides an overview of hydrodynamic separation, its capabilities, and how it has been applied. Particular attention is paid to its application for wastewater treatment.

THE PRINCIPLES OF HYDRODYNAMIC SEPARATION

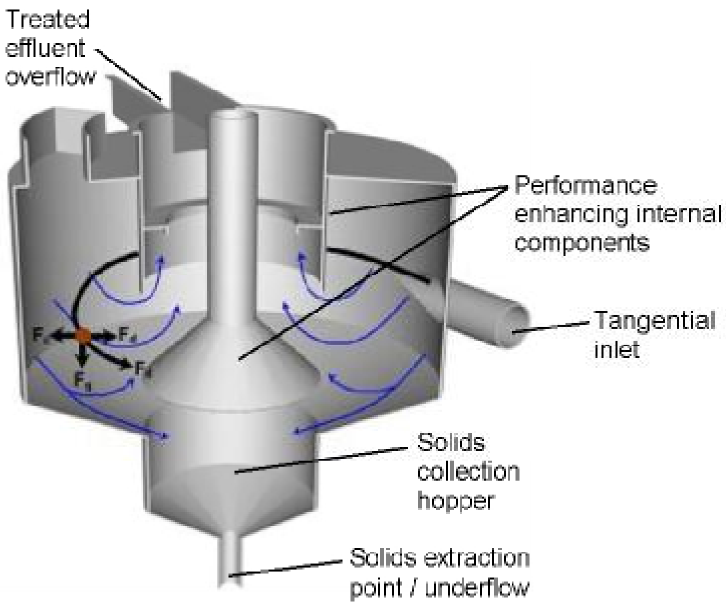

Figure 1 Schematic Representation of a Hydrodynamic Vortex Separator (HDVS)

An HDVS, as shown schematically in Figure 1, comprises of a cylindrical chamber with a tangential inlet, an overflow channel or pipe, a solids collection hopper with extraction facility, and an array of specially designed internal components. In operation, the objective is to separate and concentrate solid material from the entering flow into a small proportion of the total, and to remove this through the underflow. The treated flow, typically accounting for in excess of 90% of the inflow, is then allowed to pass to the overflow, either for release into a watercourse, or for further treatment, depending on the application.

Idealised sedimentation theory would suggest that a particle entering a settlement chamber will become separated if its settling velocity is greater than the velocity of fluid rising to the overflow. However, in real systems, operation is far more complex.

When flow enters a HDVS, it causes the contained flow to rotate about the chamber axis. The result of this is that the flow follows a very long, spiral flow path through the system, initially spiralling down the outer wall towards the base, then reversing direction and spiralling upwards, closer to the centre, towards the overflow. Entrained particles will be subject to a number of forces, including those due to gravity, fluid drag and centrifugal acceleration. It is the balance of these forces that will determine particle trajectories, and hence whether or not they are separated. While spiralling and settling under the force of gravity, entrained particles will tend to migrate to a radial location at which radial drag towards the centre and outwardly acting centrifugal forces are equal. Heavy particles will tend to migrate to an outer radial position, enabling them to continue to settle towards the base, while light particles will tend to migrate towards the centre, where they will be subject to the drag of flow rising towards the overflow. Once on the base, settled particles will be swept towards the central collection hopper by secondary flow currents, a phenomenon that can be replicated by stirring a cylindrical vessel containing water and a small quantity of sand.

Adjustment of the hydraulic loading rate of a separator will impact upon the balance of forces acting on a particle, which will in turn determine which sizes and densities of particle are separated, and which are not. Typically, as flowrates are reduced, particle removal rates tend to increase.

The high fluid retention times that result from the flow motion described above correlate to the high levels of performance that are observed in practice, as particles have a long period of time within which to settle. Research work has demonstrated that other more 'conventional' types of sedimentation system (e.g. rectangular tanks) tend to have shorter retention times, implying reduced treatment capabilities [12]; Figure 2 presents data outputs from a programme of Computational Fluid Dynamics (CFD) analysis to support this. Figure 3 presents graphical outputs, showing flowfield and fluid pathline predictions for an HDVS.

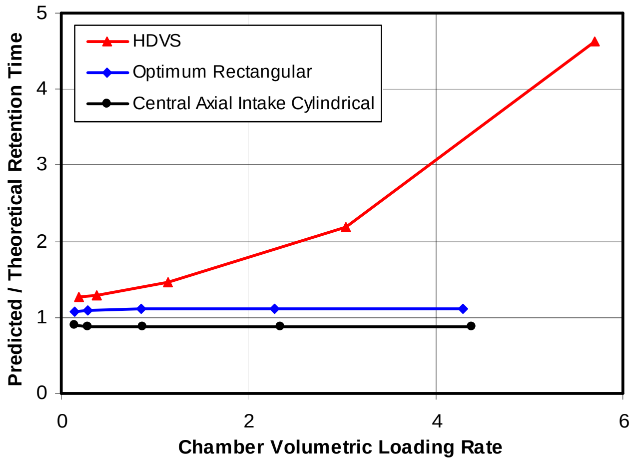

Figure 2 Mean Retention Time Predictions for Different Configurations of Chamber (based on the average time for a neutrally buoyant particle to pass through the system)

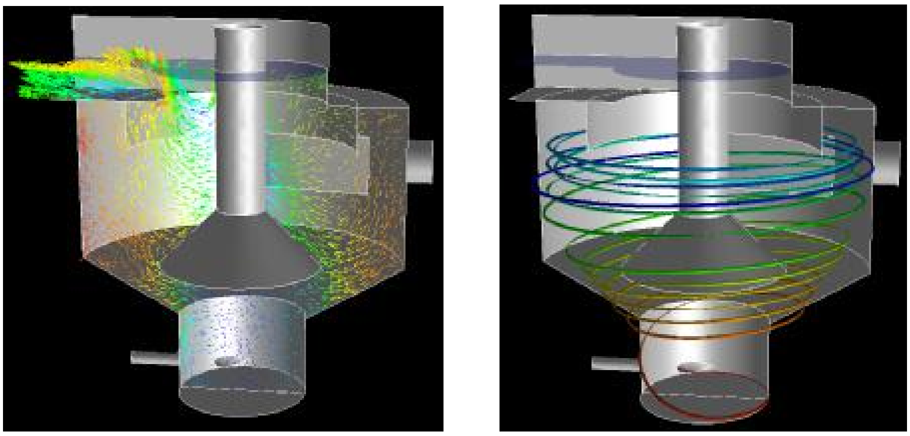

Figure 3 CFD Predictions of Flowfields in an HDVS

HYDRODYNAMIC SEPARATION IN PRACTICE

The Importance of Internal Component Design

Real flows tend to be far more complex than implied by some of the descriptions provided above. In particular, vortex flows, if not adequately controlled, can become unstable, which, in the context of a separation system, can actually be detrimental to performance. A known weakness of the original US EPA Swirl Concentrator was that material tended to settle out on the base, rather than passing to the extraction point at the centre [(2)].

The modern systems of today, often termed 'advanced vortex separators', have evolved to overcome the difficulties mentioned above. Optimal design of the internal components helps to control flow patterns, so as to enhance the quality of separation performance. In the context of stormwater treatment applications, a body of research has developed to demonstrate how internal components are important in ensuring that captured solids are not subsequently re-entrained and lost following their initial separation, a phenomenon that would appear to explain shortfalls in the performance of many alternative designs of system [(13)(14)].

The result of many years of evolution and refinement of hydrodynamic separator design is that the systems of today are both effective and economical, presenting potential for reduced land-take requirements, and hence reduced construction costs compared to other more conventional solutions.

Design Based on Effluent Characteristics

The absolute performance of an HDVS (e.g. in terms of total suspended solids removal), while depending on system design and hydraulic loading rates, will also be dependent upon the characteristics of the effluent itself [(15)]. Characterising parameters can include particle size and density, or, incorporating these two, particle settling velocity. Generally, for large inorganic particles (e.g. sand or grit) it is often most convenient to work on the basis of particle sieve gradings and density measurements. However, for organic, slow settling velocity effluents, this type of information is difficult, if not impossible to obtain, and in this case, a preferred method is to perform a detailed settling velocity analysis.

A useful technique for characterising effluents involves the use of a 'swing' settling column, shown in Figure 4. This technique is described in detail elsewhere [16]. The result of the swing column test is a settling velocity grading characteristic, examples of which are shown in Figure 5.

Figure 4 Settling Column Apparatus for Effluent Characterisation

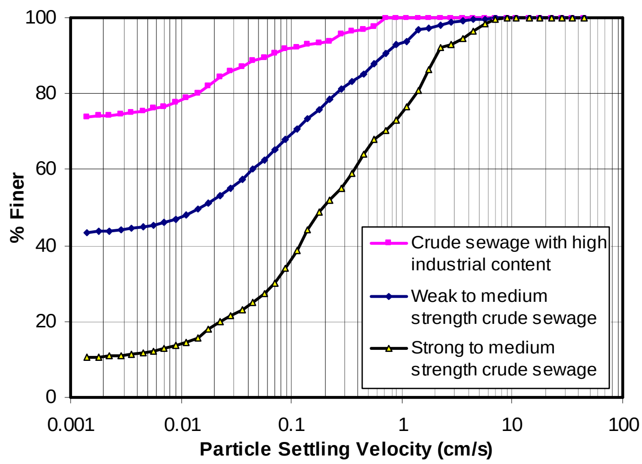

Figure 5 Range of Settling Velocity Characteristics for Municipal Sewage

The following relationship has been developed to enable the prediction of the performance of an HDVS based on effluent settling velocity grading [17];

$$\frac{D^2 V_s}{Q} = K_a^{K_b} \sqrt{\frac{N}{R}\left(\frac{1-P}{P}\right)}$$

D=diameter; V_s=settling velocity; Q=flowrate
N=ratio of (solids in underflow/solids in overflow)
R=ratio of (overflow rate/underflow rate)
P=underflow proportion; K_a & K_b= constants

This approach to separator performance prediction has been validated on several occasions. It has been reported that, in seven separate cases, the prediction was found to be within 5 percentage points of actual suspended solids removal [18].

Tolerance to Variations in Effluent Concentration

Performance evaluation studies have demonstrated that HDVSs are extremely tolerant of 'shock loads' or 'spikes' in the influent characteristic (19). Figure 6 presents outputs from trials of a separator designed for primary sedimentation of municipal sewage, for which influent and effluent solids concentrations were monitored over time. Fluctuating influent concentrations and percentage removals are shown, along with a relatively stable effluent concentration.

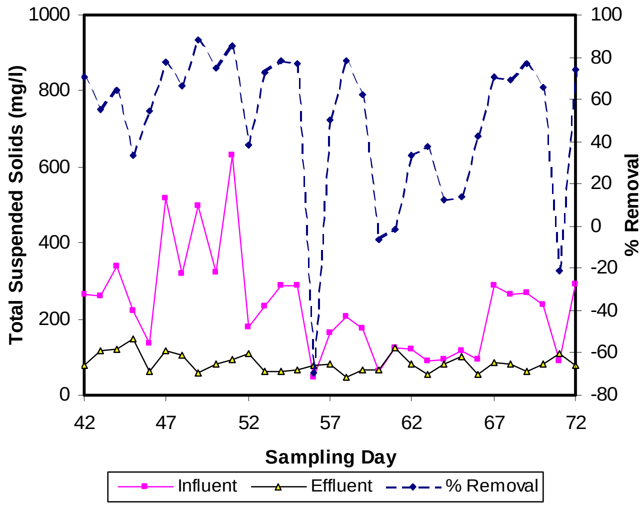

Figure 6 Outputs from an HDVS Test Programme

Separator performance data has often been misinterpreted. A common practice has been to focus on percentage removal efficiencies, shown in Figure 6, which can lead one to view that performance is highly unstable. However, if effluent concentrations are considered instead, a high degree of consistency is generally found, also shown in Figure 6.

This is explained by examining the characteristics of a typical (e.g. municipal sewage) effluent. Many effluents have a component that is not practically settleable (i.e. typically, particles between 1 and 30 microns in size). This component tends to be relatively consistent in terms of concentrations over time. However, total suspended solids concentrations can vary over time. Often, this variability is attributable to variations in concentrations of the settleable, rather than non-settleable component.

When passed through an efficient sedimentation process such as a properly configured HDVS, the majority of settleable particles will be removed, regardless of actual concentrations. Hence, the treated effluent will comprise largely of the stable, unsettleable component. This explains the relative consistency of the effluent trace shown in Figure 6. Clearly, this also suggests that, when influent solids concentrations are low and particles are less settleable, absolute efficiencies will also appear low, for example, as observed on day 56 in Figure 6.

Enhanced Performance Modes

As discussed above, HDVSs can be designed to remove particles with a size or settling velocity above a particular reference point (for example, grit removal specifications often call for removal down to 150 microns), and can also be designed to remove the majority of particles that are practically settleable.

In order to enhance performance further, HDVSs can be used with chemical coagulants and flocculants. A number of trials have been carried out in this context. One such trial was that carried out at Totnes WwTW in the 1990's in which a HDVS was tested under both hydraulic and chemically assisted operating regimes (6). Figure 7 presents data outputs for this trial. The major enhancement in performance due to the use of chemicals is clearly evident.

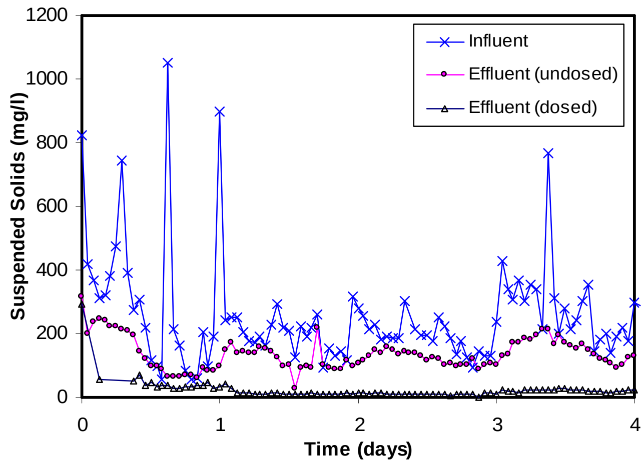

Figure 7 Outputs from Chemically Assisted HDVS Testing

HDVSs have also been used with chemical disinfectants (5)(8), an area that has also been studied through a number of academic research projects (20)(21). Such systems are well suited to this type of application, due to their long fluid residence times and hence chemical contact times.

APPLICATION CASE EXAMPLES

Overview of Applications

As discussed previously, HDVSs have been applied for a range of applications, including those relating to CSO treatment, stormwater treatment and industrial effluent treatment. In the area of wastewater treatment, specifically municipal wastewater treatment, they have been used for the removal of grit from sewage, for primary sedimentation and for the recovery of filter media from plant backwash water.

A number of 'wastewater treatment' related installation case studies are presented in the following sections. Further case studies relating to wastewater treatment and other application areas, as outlined above, can be found elsewhere (5)(6)(10)(19).

Sewage Grit Removal at Kinneil Kerse Wastewater Treatment Works

As part of a programme of improvements at Kinneil Kerse Waste Water Treatment Works, Falkirk, Scotland, two 5.2m diameter 'Grit King®' HDVS systems were installed to remove grit and sand from the incoming sewage. The objective of this type of installation is to remove particles that might either lead to wear in pumps and valves, or that might accumulate in downstream process chambers. A view of the Kinneil Kerse site during commissioning in 2002 is shown in Figure 8.

Figure 8 Grit King® Installation at Kinneil Kerse WwTW Showing HDVS Vessels and Screw Classifiers

Operating at peak flowrates of 889 l/s, the units were designed to remove at least 95% of particles larger in size than 200 microns. Two screw classifiers, each equipped with an HDVS grit-washer, were used to condition and dewater the grit, providing a final product containing less that 5% faecal organic material. Feedback from the site has been extremely positive.

Primary Treatment at Kinnegar Wastewater Treatment Works

In 2000, two 16 metre diameter 'Swirl-Flo®' primary sedimentation HDVSs were installed at Kinnegar Wastewater Treatment Works in Belfast, Northern Ireland, designed to handle an effluent flow of around 450 l/s. Hydro International supplied the stainless steel internal components, which were fitted into pre-prepared concrete shafts. A photograph of one of the units during installation of the internal components is shown in Figure 9.

Figure 9 Internal Components Being Lowered into a 16m Diameter Swirl-Flo® HDVS

Prior to Hydro International's involvement, two traditional circular primary settlement tanks had been proposed, each with a diameter of 32 metres, sized based on identical criteria. The reduction in size requirements, enabled through the use of HDVS units, lead to substantial cost savings on the project, without compromising in terms of performance capabilities.

In May 2001 following installation, an intensive sampling and monitoring campaign was undertaken, with the objective of assessing the settleability of the incoming waste stream compared to that analysed before the project commenced (i.e. that carried out to provide data for sizing purposes), thereby allowing the system performance to be verified.

The measured sewage grading characteristic, presented in Figure 10 along with other 'typical' gradings, corresponds closely with information obtained from earlier trials, suggesting that, on average, only around 25-40% of the suspended solids was practically settleable (i.e. settling velocities above 0.1 cm/sec). However, on an individual daily basis, TSS removals of up to 70% have been observed.

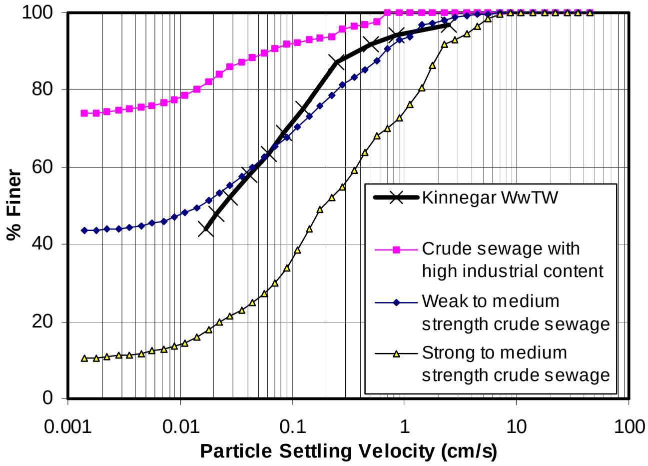

Figure 10 Kinnegar Sewage Grading Compared to Other 'Typical' Gradings

Summary outputs from the verification trials are presented in Table 1. The average solids removal efficiency of 32% reflects the high unsettleable component of the effluent at the site. With this level of performance, the system is satisfying the treatment objectives specified.

Table 1 Average Influent and Effluent TSS Outputs and Calculated Removal Efficiency

24 hour composite sample outputs	
Average Influent TSS (mg/l)	108.8
Average Effluent TSS (mg/l)	74
Average TSS Removals (%)	32#

 # - from sewage of which ~60-75% was 'unsettleable'

CONCLUSIONS

Hydrodynamics Vortex Separators (HDVSs) represent a compact, effective and economical solution to a range of wastewater treatment related problems. They have been applied for combined sewer overflow (CSO) treatment, stormwater treatment, industrial effluent treatment, and as focused upon in the paper, municipal sewage treatment.

With no moving parts and no power requirements, they are economical in terms of initial installation costs in addition to operating and maintenance costs, in particular, compared to ‘conventional’ solutions, where potential for substantial cost savings is presented.

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