The use of hydrodynamic vortex separators and screening systems to improve water quality

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Abstract The paper reviews the evolution of Hydrodynamic Vortex Separators (HDVS) in the context of their application as high rate rotary flow separators for achieving water quality improvements to meet with regulatory requirements in Europe and North America. The types of HDVS and their application for the control of wet-weather discharges such as combined sewer overflows (CSOs), sanitary sewer overflows (SSOs) and stormwater are outlined and a number of myths surrounding their use, dispelled. Reference is made to outputs of peer reviewed comprehensive monitoring, evaluation and demonstration projects on pilot and full-scale installations to demonstrate the efficacy and extensive track record of these systems.

Recent developments and innovations in HDVS technologies are discussed, focusing on their combined use as solids liquid separators, contact vessels for wastewater disinfection, the incorporation of self-cleansing screening devices for the control of aesthetic pollutants (e.g. floatables) and the use of computational modelling for optimisation.

Keywords CSO; disinfection; sediments; self-cleansing screens; SSO; stormwater; vortex separators

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Introduction

The history of Hydrodynamic Vortex Separators (HDVS) dates back to the early 1960s when Bernard Smisson built and tested the very first full-scale vortex type combined sewer overflow unit at Bristol in the UK. This first generation separator was found to be effective in retaining 70% of the pollution load (Smisson, 1967).

Smisson's pioneering work was followed by the development in the 1970s, of the USEPA Swirl Concentrator – a second generation HDVS, by the American Water Works Association and EPA, with Mr Smisson acting as a consultant (Field, 1972). A third generation of HDVS was subsequently developed in the UK in the early 1980s, with Bernard Smisson's assistance, to overcome identified shortcomings with the EPA Swirl Concentrator, particularly shoaling of solids on the base, reduction of headloss at high flows and to further improve performance. This configuration was subsequently patented and commercialised with the trade name Storm King® Overflow. Work in Germany in the mid to late 1980s, focussing on reducing turbulence in the Swirl Concentrator at high flows, resulted in the development of the German version of the HDVS – Fluidsep™ (Brombach, 1992).

Since their development and subsequent commercialisation in the 1980s, HDVSs have been the subject of numerous performance evaluations in Europe, North America and Japan (Brombach, 1992; Hedges *et al.*, 1993; Averill *et al.*, 1997; Arnett and Gurney, 1998; and Okamoto *et al.*, 2002). A number of these included an assessment of influent solids and their settling characteristics, which in turn highlighted the relevance, and importance of wastewater characteristics (especially settling velocity distributions) in assessing device performance (Tyack *et al.*, 1992; Andoh and Smisson, 1994).

By the early 1990s, applications of HDVSs included their use as water quality control devices for combined sewage (e.g. Storm King® Overflow, Swirl Concentrator and Fluidsep™), stormwater treatment (eg. Downstream Defender® and Vortechs™ System) and wastewater treatment (eg. Grit King® Separator and Swirl-Flo™ Clarifier). The technology was also adapted for physico-chemical wastewater treatment at municipal wastewater treatment works sites (Andoh *et al.*, 1996) and in the mineral and extractive industry (eg. Eff-Pac™ and Silt-Pac™).

The introduction of the Urban Wastewater treatment Directive in Europe in the early 1990s and its interpretation and subsequent enactment into UK legislation resulted in the AMP2 (Asset Management Plan) regulatory requirements for intermittent wet-weather discharges. The AMP2 requirements focused on aesthetic pollutants particularly the more objectionable items such as sanitary and personal hygiene items (e.g. condoms and panty liners), which cause the greatest public concern. Aesthetic solids of neutral buoyancy are not separated effectively in HDVSs and conventional gravity based devices (Saul, 1998).

In the late 1990s, HDVS technology evolved further in the UK in response to the AMP2 requirements with the incorporation of a non-powered self-cleansing screening system to address the issue of total capture of neutrally buoyant aesthetic solids greater than 6 mm in two dimensions (Smith and Andoh, 1997; Andoh and Saul, 2000).

To date over 1,500 HDVSs have been installed worldwide for stormwater, combined sewage and wastewater treatment with device configurations adapted to the specific application area. For example when used in the CSO or SSO environment in the form of the Storm King® Overflow, Swirl Concentrator or Fluidsep™, the HDVS has an underflow component to return concentrated solids to a wastewater treatment plant through the collection system. Such configurations practically have no sumps (Andoh, 1998). These are contrasted with the application of the HDVS as a Stormwater treatment device (e.g. Downstream Defender®) where the device is configured with a sump to provide isolated storage zones for the collection of separated sediments and their associated pollutants (Deahl and Faram, 2002).

Despite the extensive body of reported work confirming the efficacy of HDVSs, to some extent they are still considered novel with mixed views regarding their effectiveness. This paper addresses some of the myths associated with HDVSs.

Description, differentiation and myths

Hydrodynamic vortex separators

HDVSs are characterised by tangential flows into a cylindrical vessel, which in turn creates a complex rotary flow regime. Different configurations have evolved and are differentiated by the nature and type of internal flow modifying components and the location of inlets and outlets. The effectiveness of a given type of HDVS depends on the nature and characteristics of the rotary flow regime established and the degree to which complex swirls generated are structured and stabilised. This depends on the nature and placing of the internal components. Figure 1 shows a cut-away view of the Storm King® Overflow HDVS with a number of internal components highlighted.

In this configuration of the HDVS, the Inlet Deflector Plate for example minimises headloss by streamlining the incoming flows as it enters the main vessel body and joins with the mass of fluid circulating within the vessel. The Cone shields separated solids in the underflow region thereby reducing the risk of re-entrainment. Details of HDVS configurations, the role of internal flow modifying members and their use for improving environmental quality is described elsewhere (Brombach, 1992; Andoh and Smisson, 1994; and Andoh, 1998).

Rotary flow devices (e.g. HDVS) have been found to be generally more efficient than conventional chambers (Averill *et al.*, 1997; Arnett and Gurney, 1998). A vortex chamber

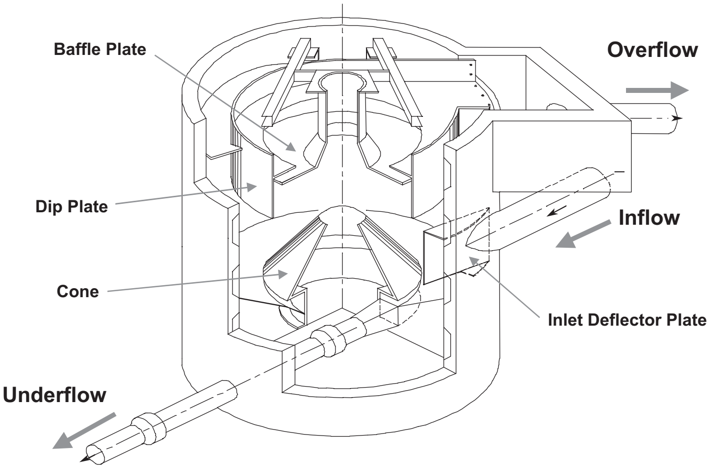


Figure 1 Cut-away view of Storm King® overflow HDVS

tends to increase the time a particle stays in a confined space since the helical path from entrance to outlet is much longer than the straight distance between them. The configuration shown in Figure 1 for example further enhances this effect by creating an axial return flow above the cone region in the form of an inner helical vortex. This increases the overall path-line between inlet and outlet and reduces the scope for short-circuiting.

Though HDVSs belong to the same family of devices and differ from Hydrocyclones and Centrifuges in that HDVS are relatively "low energy" rotary flow devices with pressure drops (i.e. head loss) typically less than 1 m compared with several tens of meters for cyclones, different configurations have differing efficiency characteristics (Saul *et al.*, 1993). Faram and Harwood (2002) describe the pollutant removal and retention effectiveness of different HDVS configurations used in stormwater treatment.

Myths

Over the years, following their first use within sewerage systems, a number of myths relating to the efficacy of HDVSs have evolved. These have mostly been due to a lack of understanding of what these devices are coupled with monitoring and evaluation exercises that have either failed to appreciate their correct application or have used inappropriate analyses techniques and methodologies to evaluate device performance. Two of these myths – "High Headloss" and "Variable Performance" are addressed in this paper.

Myth 1 – "high headloss". The notion that HDVSs have high headlosses is derived from a number of views. One commonly held view is that HDVSs are akin to hydrocyclones. This fails to recognise that they operate at a significantly lower energy level compared with cyclonic type devices. Some HDVS configurations have inlets located around their mid-barrel depth with an underflow at a lower level around the base region of the separator (e.g. see Figure 2). Headloss for these configurations have been wrongly defined as the drop in level between the inlet and the underflow (shown as H in Figure 2). The true headloss across the separator is the difference in water level in a standpipe on the inlet and the top water level in the separator (shown as h_f in Figure 2).

The results of headloss measurements for a full-scale HDVS undertaken under controlled conditions in the hydraulics laboratory of Hertfordshire University in the UK showed maximum headloss at peak design flows of less than 150 mm (6 inches). The variation of measured headloss with increasing flow is shown in Figure 3. The configuration of

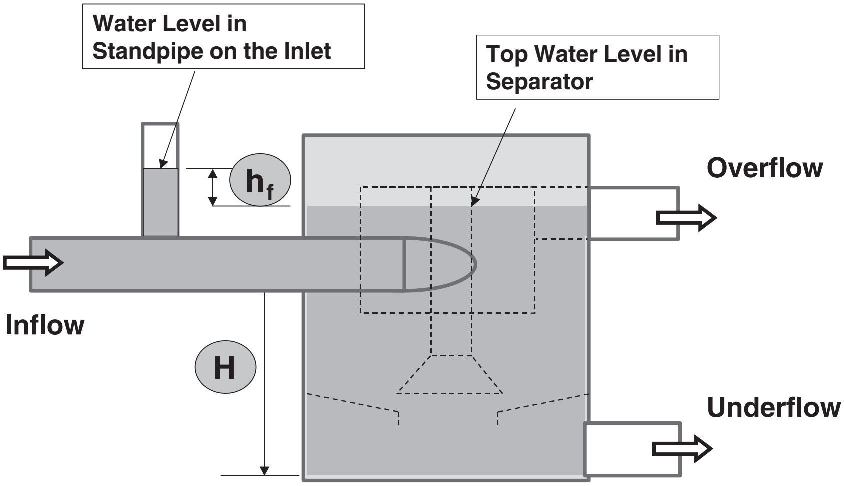


Figure 2 Section through HDVS showing headloss definition

HDVS tested is the Grit King® Separator used at wastewater treatment works sites for removing grits, sands and other inert solids. The separator was a 1.6 m diameter unit with a peak design flow of 55 l/s. Figure 3 shows headlosses around 100 mm (4 inches) at the peak design flow.

HDVS applications for removal of settleable organic solids (eg. Storm King® Overflow and Swirl-Flo™ Clarifier) operate at hydraulic and volumetric loading rates which are typically half to a tenth of those for the Grit King® Separator and as such have headlosses typically less than 100 mm hence the ease with which they can be retrofitted or incorporated into existing sewerage systems.

Myth 2 – variable performance. HDVSs are high rate rotary flow sedimentation/floatation devices particularly suited to the separation of materials that have specific gravities (relative densities) which differ significantly from that of the suspending medium. The performance of water quality treatment devices has traditionally been measured in terms of the removal efficiency for a given determinant of interest (e.g. Total Suspended Solids – TSS). This is often assessed by determining the proportion of the Influent concentration of the determinant removed by the device as follows:

(%) Removal = [(Influent TSS – Effluent TSS)/Influent TSS] × 100

Table 1 shows the results of such an analysis for 7 days of 24 hour composite sampling for an HDVS. Observed removal efficiencies range from –57% to over 89%. Looking at the

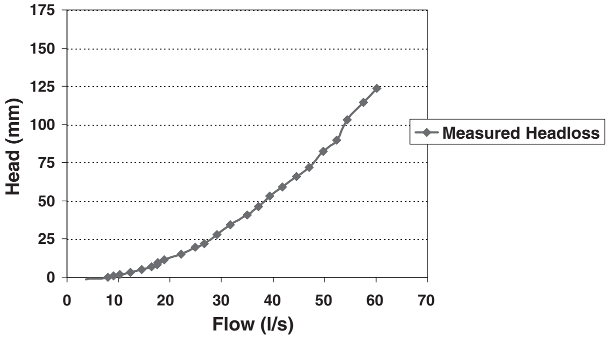


Figure 3 Measured headloss for a Grit King® Separator HDVS

Table 1 Results of seven days of 24-hour composite sampling for an HDVS

Day number	Influent TSS	Effluent TSS	(%) removal
10	256	140	45.3
11	214	160	25. 2
12	930	97	89.6
13	174	60	65.5
14	688	86	87.5
15	106	166	–56.6
16	120	73	39.2

numbers down the (%) Removal column in the table suggests that the process in question gives very variable performance and in one instance negative removal.

Figure 4 shows the long-term trace (over several months) of influent and effluent TSS concentrations based on 24 hour composite samples for the same site as presented in Table 1. This shows relatively consistent effluent suspended solids concentrations despite a highly variable influent trace.

Figures 5a, 5b and 5c show time plots and derived efficiencies in terms of percentage removals for the period from day 42 to day 72. The right hand y-axis relates to (%) Removals. The plots show that when influent suspended solids concentrations are high the corresponding percentage removals are high whereas when the influent solids concentrations are low, percentage removals are correspondingly low, marginal or negative. Figure 5b and 5c highlight the fact that percentage removal is strongly correlated with the influent concentrations and that any variability in influent characteristics is reflected as variability in the removal efficiency whereas the effluent trace shows a relatively constant concentration level with no discernable direct correlation with (%) Removal.

The reason for this is that the effluent TSS from an efficient sedimentation process such as a properly configured HDVS usually reflects a threshold of the non-settleable suspended solids (i.e. the fraction typically between 1~30 μm particle size). High influent concentrations are associated with an increased fraction of settleable solids whereas when influent concentrations are low, the corresponding fraction of settleable solids is low and hence marginal removal efficiencies are observed (as there are no settleable solids to be taken out).

Because of cost constraints, sampling programs are usually conducted over relatively short time periods. This coupled with a focus on percentage removal as a performance measure can in instances lead to erroneous conclusions being drawn regarding a device's efficacy.

Period of marginal removals due to relatively low influent levels

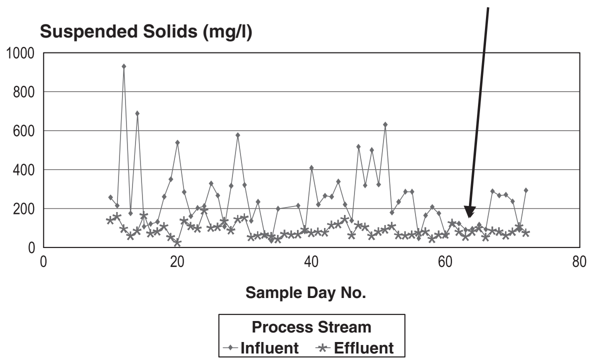
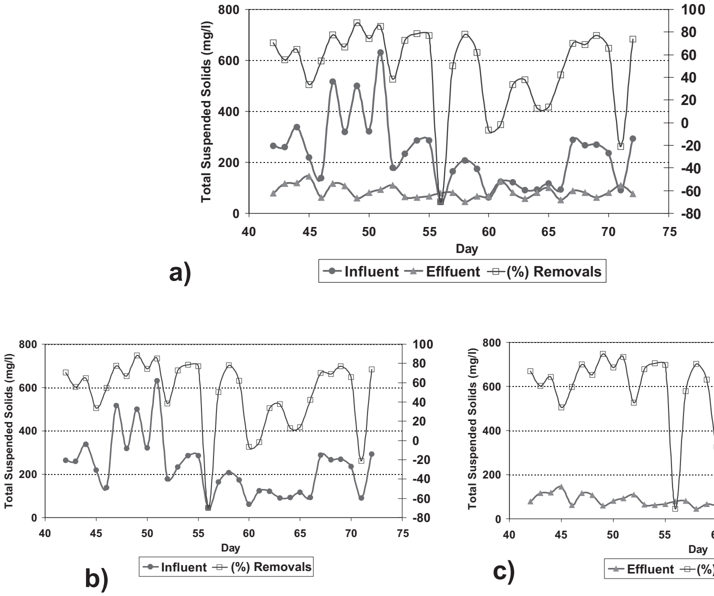


Figure 4 Time plot of 24 hour composite samples for an HDVS



a)

b)

c)

Figure 5 Time series and removal efficiency plots for days 42 to 72

The plots shown in Figure 5 highlight the importance of not focusing solely on percentage removals as a performance measure especially for processes that have highly variable influent solids characteristics. Percentage removal on its own is therefore an inappropriate measure of performance for devices such as HDVSs that produce a relatively consistent effluent quality from a highly variable influent.

Monitoring and evaluations

General

HDVSs have been the subject of several monitoring and evaluation programs. In general these all confirm the efficacy of HDVS although in some instances, issues such as the variable performance myth outlined above and the use of inappropriate protocols and assessment methodologies have resulted in mixed reviews. Conventional monitoring equipment typically used in water quality sampling was developed initially for monitoring treatment works effluents. Sample locations and velocities in sampling tubes often result in non-isokinetic samples, which in turn leads to significant bias. The need for using depth-and width-integrated isokinetic sampling to obtain representative samples is highlighted in Horowitz (1991).

Conventional samplers rarely provide representative samples of the bed load sediment and gross solids – the solids spectrum that tends to produce a chronic impact on receiving waters and is effectively removed by HDVSs. A number of monitoring and evaluation projects highlighting the effectiveness of HDVS in improving environmental quality are summarised below.

Egerton Park Streams, UK

The study conducted by Southern Water in the UK involved an analysis of the impact of stormwater discharges from a HDVS on a small urban stream classified as a fragile ecosystem. The results showed that an improvement in the diversity of species had occurred over the period demonstrating that the HDVS were preventing the discharge of material which would normally deposit on the stream bed, inhibit ecological development and cause chronic impacts (Southern Water Authority, 1989).

Scarborough, Ontario, Canada

Towards the end of the 1990s extensive field demonstration of the Storm King® Overflow HDVS was conducted at Scarborough, Ontario, Canada as part of a multi-agency project sponsored by the great Lakes 2000 Cleanup Fund, Municipality of Metropolitan Toronto and the City of Scarborough with participation by the Ontario Ministry of Environment. This work confirmed the higher rate removals in HDVSs compared with conventional clarifiers and also highlighted the significance and relevance of wastewater characterisation. Characterisation of the wastewater in terms of its settling profiles showed the waste stream at the particular site to have poor settling characteristics (Averill, *et al.*, 1997). The ability to markedly improve removals with the addition of chemicals was also demonstrated.

Extensive monitoring including velocity profiles and head loss measurements confirmed the complex stable flow regime and the fact that headloss across HDVS units are relatively low. A lamella clarifier was also evaluated both in series and in parallel with the HDVS. The series arrangement demonstrated that the HDVS removed practically all the settleable TSS with no significant additional removals achieved in the lamella clarifier receiving overflows from the HDVS. In the parallel arrangement, the HDVS achieved equal to or better performance compared with the lamella clarifier.

Columbus, Georgia, USA

An evaluation and demonstration of CSO treatment technologies has been on-going at Columbus, Georgia, USA since December 1995 with over 5 years of intensive monitoring. The CSO technology-testing program included an array of side-by-side full-scale processes for solids separation and disinfection including screening, vortex separation, grit separation, and compressed media filtration. Disinfection alternatives included sodium hypochlorite, chlorine dioxide, peracetic acid and UV processes. The study has provided protocols for pollutant characterisation, technology performance evaluation and design methodologies for wet weather applications.

The HDVS units at Columbus include 12 Storm Kings® Overflows and 3 Grit King® Separators. Summaries of the findings to date can be found on the web at *www.wwetco.com*. The results confirm the efficacy of the HDVS units for the capture and removal of gross solids (including sediments and associated pollutants) and as contact vessels for disinfection.

The five-year program of operations and performance testing of the full-scale facilities has not only shown that this system is equivalent or better than primary clarification, but that it costs one-half and occupies one-tenth the footprint. An assessment of the Capital and Maintenance and Operational costs show the potential for up to 50% savings in the estimated $44 billion required to resolve CSO problems in the USA (Turner and Boner, 1998). In 2001, the US EPA awarded Columbus Water Works first place in the USEPA CSO Control Awards as part of the National Wastewater Excellence Awards.

Recent developments

Devices that rely on gravity or assisted gravity sedimentation or floatation (e.g. Conventional Clarifiers, Sedimentation Tanks and Hydrodynamic Vortex Separators) are not very effective at removing material of neutral buoyancy since these material neither settle nor float. Solid materials in sewerage systems include neutrally buoyant aesthetic solids (e.g. condoms and panty liners) that have generally been termed floatables. These neutrally buoyant solids tend to go with the flow and as such are not separated effectively. To achieve total capture of a more complete spectrum of solids in urban wastewater, there is a need for the combination of effective sedimentation/ floatation and screening.

The current generation of HDVS for CSO and SSO application incorporates a self-cleansing screening system (Swirl-Cleanse™). This new configuration has no moving parts and utilizes a novel air-brake siphon to effect a cyclical backwashing process to keep the mesh screen clean. The mesh typically has an aperture of 4 mm (1/6 of an inch). The device therefore removes sediments, gross settleable solids, floatables and neutrally buoyant aesthetic solids from combined sewage – the complete spectrum of sewer solids (Andoh and Saul, 2000).

Computational Fluid Dynamics (CFD) is increasingly being used as a tool for assessing and optimising HDVS configurations (Harwood, 1998; Faram and Harwood, 2002; and Okamoto *et al*., 2002). For example work has been undertaken at Sheffield University in the UK to develop a simplified version of the HDVS for CSO application (Harwood, 1998). This configuration incorporating the self-cleansing screening system (Andoh and Saul, 2000) has undergone initial trials at the UK National CSO test facility at the Wigan Wastewater Treatment Works site and has been shown to be equally effective.

Conclusions

Hydrodynamic Vortex Separation is a proven technology with an established track record for improving urban water quality (including CSOs, Stormwater and Wastewater). The relatively recent incorporation of the rotary self-cleansing screening system has resulted in a new generation of HDVS devices that capture a more complete spectrum of sewer solids and their associated pollutants.

The unique hydrodynamic flow regime in the HDVS also ensures that these systems can also be utilised effectively as contact vessels for disinfection (Alkhaddar *et al*., 2000) or buffering tanks for conservative pollutants. This provides the scope for integrating a number of unit processes within the same vessel thereby significantly reducing the number of vessels (or tankage) necessary at a site to effect water quality improvements.

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