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SWIRL TECHNOLOGY: PROPER DESIGN, APPLICATION, AND EVALUATION

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INTRODUCTION

Swirl and vortex technologies have been with us for over thirty years now, ever since Bernard Smisson incorporated a cylindrical vortex-type combined sewer overflow (CSO) regulator/settleable-solids concentrator into the Bristol, England sewerage system back in the early 1960's. In the early 1970's the U.S. Environmental Protection Agency (EPA) conducted a series of projects to develop and demonstrate swirl flow regulator/settleable-solids concentrator (*swirl*) technology. These projects resulted in the EPA swirl and helical-bend flow regulators/settleable-solids concentrators and the swirl degritter. New generations of this technology emerged after the EPA versions were developed including the Fluidsep™ and the Storm King™ vortex-hydrodynamic separators. However, despite different designs and applications, the main intent of the technologies are the same, i.e., to use the forces that arise from a change in flow direction to enhance settleable-solids separation from the storm flow. A variety of opinions have developed regarding the application of these technologies varying from overwhelming support to detractions that question their effectiveness. This abstract will show that proper design and placement in the sewerage system results in effective use of swirl technology.

Reliable swirl pollution control efficiency determination is principally dependent on proper sampling and suspended- and settleable-solids analysis techniques of the influent and effluent. Simultaneous flowrate measurement is also important. Without the complete capture of heavy and stratified suspended solids (SS) across the influent flow channel or water column, the apparent performance of the swirl will be less than the actual. Particle-settleability tests which are presented, must be conducted before and after installation, but especially before in order to decide if the inertial characteristics of SS in the storm flow warrants the use of a swirl.

General Description. Swirl SS separation performance depends upon its design flowrate, Q_d and the fraction of separable solids included in the total storm-flow influent SS. The swirl was developed through hydraulic modeling studies which used representative settleable particles (based on the Froude Number and Stokes Law) to simulate grit and organics with specific gravities (SG) = 2.65 (fine sand) and 1.2, respectively and effective diameters (d_e) from 0.2 to 5 mm. It is important to appreciate this aspect of the swirl's development and not expect significant removals of fine-grained and/or low-specific gravity particles. Floatables were simulated with a SG range between 0.9 and 0.96 and d_e's between 5 and 500 mm.

Figure 1 is an isometric of the swirl. Flow enters the swirl tangentially and follows the peripheral wall of the cylindrical shell (vortex chamber) creating a swirling-flow pattern. The swirling action causes separable solids to be concentrated at the bottom of the unit. The underflow (6 to 10% of the inflow at Q_d) containing the concentrated separable solids discharges through a foul-sewer outlet in the bottom, while the clarified supernatant exits the top through an annular overflow weir and weir-plate arrangement into a central downshaft for storage, treatment, or discharge. A baffle configuration captures floatables in the supernatant and directs them for containment under the weir plate and weir skirt. The floatables are carried out in the underflow as the storm flow subsides and the water level in the swirl falls. During low- and dry-flow conditions all flow discharges from the bottom foul-sewer outlet. Design information for the swirl is contained in the EPA publication "Design Manual: Swirl and Helical Bend Pollution Control Devices" (Sullivan *et al.* 1982). The design hydraulic loadings (HL) of the swirl typically ranges from 30 to 60 gpm/ft^2 and may vary as a function of the particle-settling-velocity distribution and associated SS removal objectives.

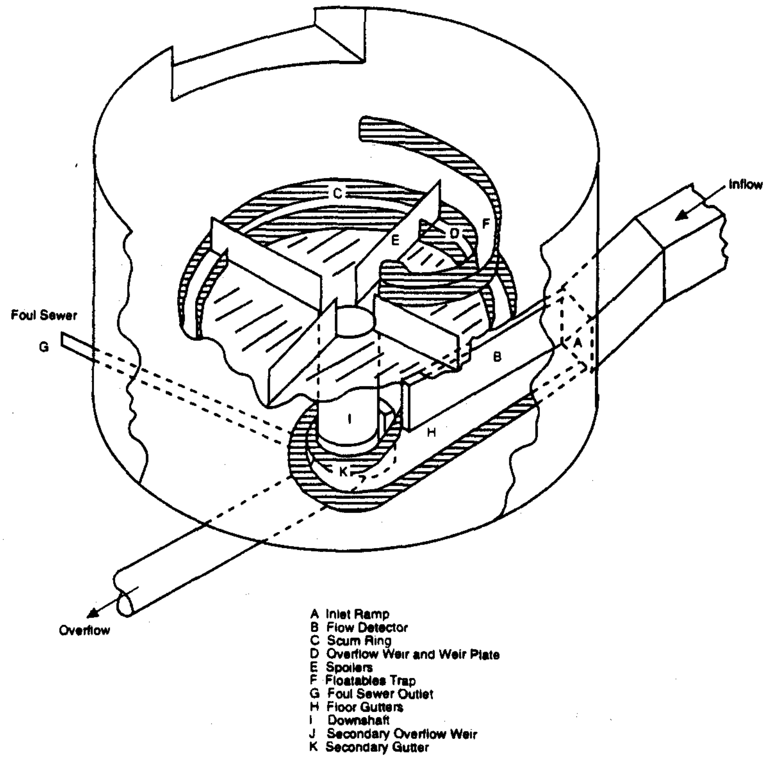

Figure 1. Isometric Drawing of Swirl (Sullivan et al. 1982)

Advantages of the swirl include the three simultaneous functions of flow regulation, settleable-solids concentration, and floatables capture, static operation (no moving parts to induce vortex-flow patterns), and high-rate operation (smaller size and lower cost than sedimentation). Comparatively, Storm King™ and Fluidsep™ designs are deeper and flow regulation is not a primary function. Disadvantages include potential underflow pumping requirements (especially for the Storm King™ and Fluidsep™ due to their relative depth) and a relatively dilute underflow which requires further treatment. Since the foul-orifice diameter is large enough to avoid blockages (> 1 ft diameter), pretreatment by coarse screening is unnecessary (unless the foul underflow is pumped).

Figure 2 is an elevation view of the swirl degritter. The swirl degritter (Shelley *et al.* 1981 and Sullivan *et al.* 1974a, 1977 and 1982) is a variation of swirl technology which does not have a continuous underflow to the wastewater treatment plant (WWTP). Instead a relatively dry mass of settleable solids (grit/detritus) collects in a 60° conical-bottom hopper for intermittent removal.

METHODOLOGY

To properly incorporate swirl and vortex technologies into a combined-sewerage or stormwater-drainage system, their limitations, control functions, applicability, and design idiosyncrasies must be clearly understood. Two major problems that continue to occur, which hinder the effectiveness and reputation of swirl and vortex technologies are: (1) inadequate or faulty sampling techniques for assessment of their applicability, design, and control performance evaluation; and, (2) their inappropriate application or placement in the sewerage system.

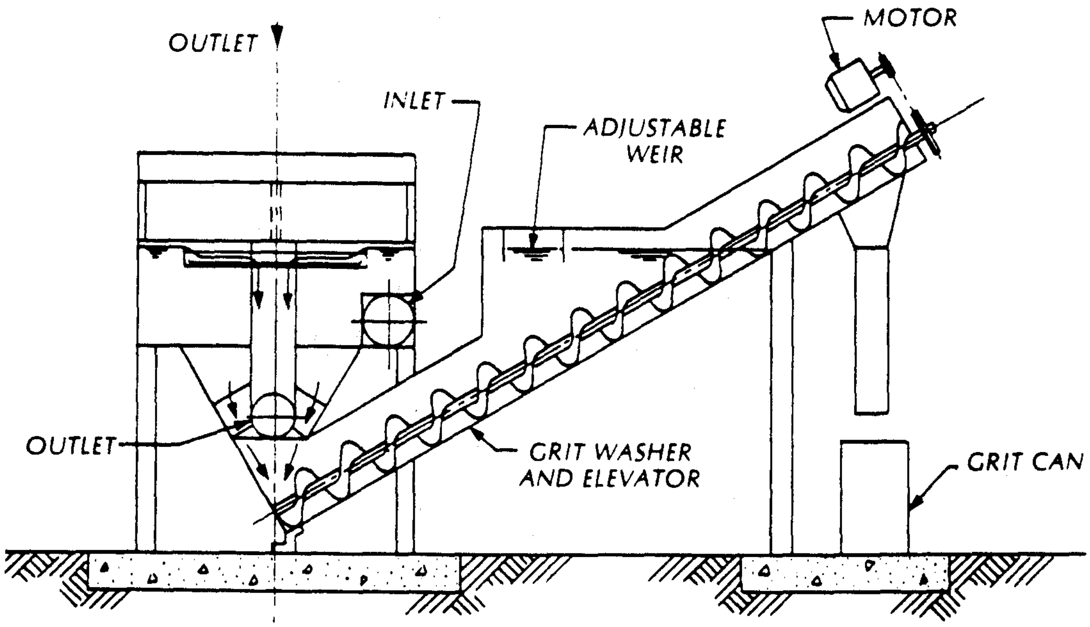

Figure 2. Elevation View of Swirl Degritter (Sullivan *et al.* 1982)

Proper sampling, flow measuring, and analyzing is a must for swirl application assessment, design, and treatability evaluation. The monitoring and analyses needed to properly assess potential application, design, and evaluate the removals of and by a swirl are expensive and complex; however, it may save additional construction costs. Money spent on monitoring and analyses that effectively assesses settleable solids concentration and expected swirl performance may result in lower long-term cost by eliminating unnecessary swirl facilities and/or additional controls.

<u>Design</u>. Prior to selecting the swirl for a combined-sewerage or separately-sewered-stormwater system, representative samples, collected by use of appropriate sampling techniques, should be analyzed for particle-settling-velocity distribution versus SS and associated pollutant content. This analysis will afford the proper assessment of the swirl's applicability. If the storm flow does not contain enough particulate matter with the associated settling velocities of grit-like particles (SG $\geq$ 2.65 and $d_e \geq$ 0.2 mm) and swirl separable-organic particles (SG $\geq$ 1.2 and $d_e \geq$ 1.0 mm), then application of the swirl will prove futile and alternative technologies should be used, e.g., standard, lower-cost flow regulators for situations where flow regulation is the basic objective.

If particle-settling velocities indicate that swirl technology is applicable then, hydrological and hydraulic studies must be conducted to determine the Q_d. This analysis of flow must be done on a long-term basis to achieve the best Q_d and settleable-solids removal prediction by directly measuring flowrates and mathematically modeling for calibration and verification. The use of the design storm concept for flowrate determination and the "polluted segment" for settleable-solids analysis will not give a proper design. To best determine whether the swirl is suited for a particular site, pilot-scale testing should also be conducted. While this increases preliminary design costs, it is only a fraction of the overall construction cost. A pilot test can be set up by diverting a pilot stream from the storm-flow mainstream. A pilot test is the only way of providing direct analyses of swirl treatability.

Under-designing the swirl will lead to poor treatability, while over-designing will lead to a costly and partially useless facility. Q_d selection should also consider the use and advantage of the secondary-overflow weir (emergency spillway) located on the periphery of the swirl. The secondary- overflow weir provides flow relief to maintain a level of settleable-solids separation by decreasing internal vortex flow. Design of secondary-weir elevation should limit the flowrate to the central downshaft to about twice Q_d and allow overflows a few (two to six) times a year while also alleviating upstream flooding.

If site constraints are encountered, the swirl affords some flexibility in its sizing. Depending on depth (e.g., difference in elevation between the trunk combined sewer and the interceptor) and area constraints of the site, the height to diameter configuration of the swirl can be adjusted, i.e., by using a greater diameter for a lesser height (Sullivan *et al.* 1974b and 1982). Design flexibility is also given for separable-solids removal as a function of swirl size, i.e., the greater the removal the larger the required size. Accessibility must also be included for the purposes of maintenance and monitoring. A careful assessment of additional cost requirements must be made before applying the swirl when underflow pumping is required.

Treatability Evaluation. To determine the swirl's settleable-solids treatment effectiveness, sampling techniques have to provide the representative fraction of relatively heavy SS in the influent and effluent channels. Some of the equipment and strategies recommended to achieve this goal are:

1) taking grab samples or 0.2 mm aperture screening (at intermittent, short intervals) of the treated overflow effluent. These samples should not contain significant amounts of grit-like or relatively large organic particles. Capture of theoretically-separable solids indicates poor treatability.
2) sampling for influent SS. To do this properly, samples must be taken across the flow's entire cross-section. This entails having a sampling system with intake velocities greater than the main stream velocity to draw up the heavier particles (particles to be separated out by the swirl) and multi-leveled ports to capture stratified heavy particles. This is essential for determining the SS separation performance of the swirl. Alternatively a "slice-sampler" capable of automatically taking a cross-sectional slice or segment of the whole influent pipe cross-section can be used.
3) performing SS analyses. Four recommended methods of SS analyses are: one for settleable solids (gravimetrically) (Standard Methods 1985) and three for settling-velocity distribution (classical, Brombach or German, and NIVA).

The first item (above) seems obvious but is never practiced. The second is complex and costly; however, without proper and comparative sampling techniques, reliable data and a base of results and performance cannot be established.

Samples taken of the influent and effluent have to be properly analyzed for SS and associated pollutants. A gravimetric (mg/l) settleable-solids analysis (Standard Methods 1985) should be conducted. Three methods for determining the particulate-settling-velocity distributions are the: classical, Norwegian Institute for Water Research (NIVA), and Brombach or German. The Brombach and NIVA methods specifically designed for the relatively high concentration of heavier particles in storm-generated flows, require less analyses, smaller testing volumes (column heights of 60 and 70 cm, respectively compared to 5 ft or greater for the classical method), and are amenable to field use. They also provide better representation of high-settling velocity SS at the test starting time, t_o since the samples are released into a settling column containing tap water from an elevated reservoir. It is almost impossible to attain a homogeneously mixed sample at t_o using a classical settling column.

Floatables Capture Analysis. Besides settleable solids, the swirl also removes floatable matter. A reliable analysis for the removal of floatables has not been done. These analyses are recommended for the assessment of swirl floatables capture ability: eyeball the floatable capture effectiveness; capture of the influent floatables with a coarse screen; and capture of the downstream clarified effluent with a coarse screen.

Placement and Application. Where the swirl is placed in the control system affects its pollutant removal effectiveness. Swirls have been improperly placed in certain projects. Swirls should not be placed downstream of storage/sedimentation basins or after a grit chamber since swirls were developed to remove the relatively heavy particulate matter that would be removed by upstream sedimentation. Effective placement or application of the swirl includes:

- upstream of a CSO storage/sedimentation facility. The swirl reduces the operation and maintenance necessary to remove grit and sludge from the storage facility as the heavier settleable solids are diverted directly to the WWTP.
- downstream of in-line or in-sewer CSO storage. An automated system will be able to maintain an optimum flowrate ($\leq$ twice Q_d) to the swirl which will increase its design effectiveness.
- as a CSO flow regulator/settleable-solids concentrator alone with the relatively clear effluent discharging directly to the receiving water. This applies only to cases where the receiving water can tolerate a partially treated CSO and still meet its water quality objectives.
- upstream of CSO tunnel storage to eliminate the grit removal burden.
- upstream of created wetlands to alleviate settleable and floatable solids problems.
- using the swirl degritter when coarse or preliminary treatment of CSO is the objective and flow regulation or splitting is not required.
- using the swirl degritter on the swirl foul-sewer underflow pipe to remove detritus, especially in cases requiring pumping (Pisano *et al.* 1984) and where the interceptor has a relatively flat slope to decrease wear and sedimentation, respectively.
- as separate stormwater discharge control.

RESULTS

The following case studies demonstrate some of the principles mentioned above. One of the most common occurrences is not making use of settling-velocity data before the swirl is selected for an application. This was inadvertently demonstrated at San Francisco, CA, where a small pilot-scale swirl was tested on dry-weather sanitary sewage. The swirl, as predicted, was not suitable since the settling velocities of the SS in the sanitary sewage were too low and not in the swirl's range of concentrating effectiveness.

In another case, the Northeast Boundary swirl facility in Washington D.C. (O'Brien and Gere 1992) (comprised of three 57-ft diameter swirls each having a Q_d = 133 MGD, with a nominal HL = 35 gpm/ft^2) averaged 38% SS-mass loading *Removal* for all the storm events; however, most of this removal, i.e., 26% was accomplished by direct foul-underflow diversion to the WWTP or *Reduction* and not by the swirl concentrating effect. *Efficiency* (= *Removal* - *Reduction*) was less than expected, averaging 12%. The primary cause of low *Efficiency* was the relatively low SS-settling velocities of particles in the influent CSO (based on settling-velocity-distribution analyses).

The previously mentioned "slice-sampler" was specially constructed during a 1980-81 demonstration in Lancaster, PA (Pisano *et al.* 1984). Prior to using the slice-sampler, the Lancaster swirl had shown "...negligible to negative solids treatment efficiency..." and further that "...samples taken manually for settleability analyses typically contained SS concentrations much lower than concentrations of samples..." taken by the slice-sampler. As compared to a Manning model 6000 sequential sampler, the slice-sampler collected samples 1.5 to 7 times more concentrated with SS. The non-flow weighted average SS *Removal* and *Efficiency* were 55% and 37%, respectively.

A demonstration in Syracuse, NY (Drehwing *et al.* 1979) using a 12 ft diameter swirl having a Q_d = 6.8 MGD with a nominal HL = 40 gpm/ft^2 was evaluated by samplers with an adequate intake sampling technique. SS Mass loading *Removal* and *Efficiency* averaged 52 and 18%, respectively.

CONCLUSIONS

Certain procedures must be followed to maximize swirl application including:

- predetermination of the particulate-settling-velocity distribution of representative samples and/or a pilot study to assess treatment suitability;
- proper placement of the swirl as part of the storage/treatment system (e.g., not downstream of a storage/sedimentation basin, grit chamber, or flow regulator);
- proper selection of Q_d based on a long-term hydrological/hydraulic study;
- use of the secondary- (emergency-) overflow weir on the swirl chamber's outside cylindrical wall to enhance separable-solids concentration at high influent flowrates;
- capture of heavy and sometimes stratified particles for treatability and suitability assessment; and
- applying the right technology, e.g., using the swirl degritter when treatment alone is the objective.

The swirl is a high-rate, relatively small and low-cost device which serves three simultaneous functions: flow regulator, settleable-solids concentrator, and floatables-material collector. The performance of swirl devices is dependant on the settling characteristics of the SS and fraction of dissolved solids in the storm flow. When correctly combined with other controls of the combined-sewerage or separately-sewered-stormwater system, swirl devices will serve a beneficial purpose.

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