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# Ecological aspect in combined sewer overflows chamber design

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## Abstract

In 2005 one of major Czech manufacturers of glass reinforced plastic pipes asked the Department of Sanitary and Ecological Engineering to develop a new type of combined sewer overflows (CSO) chamber that could become a part of their manufacturing programme. The main requirements were economy of production, easy and fast installation on the field and increased protection of receiving waters.

A simple object consisting of a pipe placed above another one was designed. The object begins with a stilling chamber formed by a conical expansion of the inlet pipe. It is separated from the overflow object itself by a downflow baffle designed to trap floating objects. The CSO chamber is equipped by a flow regulation device (e.g. vortex valve or throttle pipe) at the end. Excess water flows through a slit in the top of the bottom pipe into the upper pipe and from there to the receiving water.

More than 15 prototypes were already installed in the Czech and Slovak Republics and more than 20 are planned to be built in Europe. We hope this type of CSO CHAMBER will help to decrease the cost of construction of new sewers and reconstruction of old ones. Its higher efficiency of separation of suspended particles might also contribute to the improvement of the quality of receiving water bodies according to Water Framework Directive 2000/60/EC.

**Key words:** CFD, combined sewer overflow, decreasing pollution, receiving water bodies, urban drainage

## INTRODUCTION

The conception of ecological integrity (ecological condition) of streams is one of the subjects of the current Water Framework Directive (CEC, Directive 2000/60/EC establishing a framework for the Community action in the field of water policy). Surface runoff, as well as outfalls of storm water drainage channels (from separate sewer system) and mainly outfalls of Combined Sewer Overflows (CSOs) (from combined sewer systems) have a great ecological impact on receiving waters during rainfall periods. Overflow from a CSO chamber can form up to 50% of pollution in small urban creeks. CSOs used to be designed solely on the basis of their primary function – to distribute water in a certain ratio, discharging only certain amounts to the underlying sewer network.

This view of the matter takes into account only the quantity, disregarding the quality of the separated water. With the environmental aspects divided into several basic categories, it is necessary to take an innovative approach to the manner of designing new CSOs or modifying the current ones, aiming at improving the removal of particulate substances with specific pollutants (i.e. heavy metals) bound to them, which decrease the pollution in receiving water bodies.

A tremendous number of CSOs geometrical configurations were developed during last decades worldwide. Often, the geometry of CSO chamber is given by regional development routine and varies in a wide range even within individual countries. The CSOs design itself should take into account different criteria such as hydraulic behaviour, discharge distribution, energy losses, separation of floating solids, cost-effectiveness etc. In addition, the efficiency of separation of the

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suspended solids content can be increased using the optimal hydraulic condition and flow pattern distribution. The newly developed design of the CSO chamber increases the efficiency of separation of suspended solids – meaning less pollution to receiving water bodies compared to common types.

## DESIGN DESCRIPTION AND OPERATIONAL PRINCIPLE

As mentioned above, the CSO chamber should not only perform the function of protecting the sewer system against overloading, but also serve as a point of rough wastewater pre-treatment. Mathematical modelling indicates that such particles are washed out of the sediments in common CSOs chambers with side overflow lips and that they are more likely to flow into receiving water. The efficiency of separating suspended solids should be better with vortex separators.

When constructing new CSOs, the above-mentioned preconditions should be applied to the maximum possible extent. The parameters to be met by the CSO chamber should be reflected in its design. Obviously, it is not always possible to comply exactly with all the requirements; nevertheless, good results may be obtained by making appropriate compromises. Cooperating with the HOBAS Company, our laboratory developed a new type of CSO chamber (Figure 3). According to all the preliminary evaluations, this type meets the above-described requirements in an optimal way. The name is 'Tube' CSO – 'CSO-T'.

The CSO chamber distinguishes itself by being based on a very simple principle; in fact, it consists of two pipes positioned one above the other (Figure 2). The object begins with a stilling chamber (2) formed by conical expansion of the inlet pipe. The inlet part of the CSO chamber (1,2) is provided with a downflow baffle (3) preventing floating contaminants from flowing into the receiving water. The upper slit (upper overflow lip) (4) serves for a storm water outflow. Positioning the slit atop of the inlet pipe aims at improving the transverse flow, which influences the separation of suspended solids in a positive way – it directs them to the outflow (6). The lower pipe is equipped by a flow regulation device (e.g. vortex valve or throttle pipe) at its end (6). The height of the overflow slip is determined by embedding the upper pipe. Its simple design provides for reducing the total construction costs. The convenient placement of the overflow pipe (above the inlet one) facilitates ground work. The simple construction of the CSO chamber using standard pipes makes both the production and laying simpler and less expensive.

This type is suitable for flat terrains due to the advantage of the inlet pipe retention. The inlet pipe can be designed as pressure-type so as to improve the flow and increase its retention capacity. Another advantage consists in catching the first flush in the retention area. After the rain is over, the CSO chamber is rinsed automatically as the surface of its walls is smooth, which contributes to a better runoff of sediments.

## EXPERIMENT

An experimental model of the CSO chamber was made from Plexiglas (Figure 1). Two calibrated electromagnetic flow meters (KROHNE DN 200, DN 50) were installed for continuous discharge measurements on the inflow and outflow pipes. The free surface in the overflow pipe above the overflow silt was measured with a needle gauge.

Five types of the overflow slit were tested and simulated (Figure 2). Each type of the overflow silt was tested with three types of flow regimes ($Q_{\mathrm{inflow}} = 6$ l/s, $Q_{\mathrm{outflow}} = 0$, 1, 2 l/s). The measurement of velocity was done in plane under the overflow slit. This was compared with a mathematical model.

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**Figure 1** | Hydraulic model of measured CSO chamber.

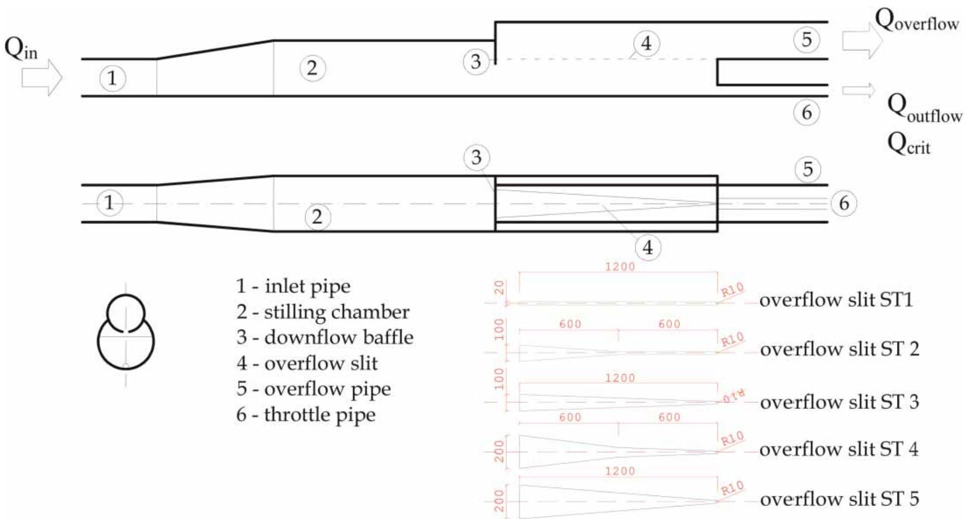


**Figure 2** | Ground plan and sectional view of CSO chamber. Five versions of the overflow slit.

## FLOW PATTERNS ESTIMATION

### Mathematical modelling

For the mathematical simulation of CSO chamber behaviour, k-ε model was used due to its stability, robustness and calculation time requirements. Calculation was done in the FLUENT program. The free surface was simulated as a wall without friction. The position of the free surface was taken from the experiment. A tetrahedral mesh with varying density was used due to the necessity of increasing the precision in the overflow silt.

The basic design of the CSO chamber is quite simple. However, great attention was paid to the size and the position of all parts, especially the overflow slit and the down flow baffle. The main aim was to achieve homogeneous distribution of flow inside the chamber, thus achieving the lowest up flow velocities and the best separation of coarse particles. These impacts were studied

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in mathematical model. Several modifications (different sizes of the downflow baffle and different shapes of the slit) were first modelled on a computer using computational fluid dynamics. Three different shapes of the slit were chosen based on preliminary studies and were examined in more detail. Three different flow states were modelled for each of them and the trajectories of particles of several sizes and densities were determined. The efficiency of suspended particle elimination was then estimated based on the total number of particles in the overflow and in the outflow (throttle pipe).

For comparison of the separation of suspended solids with other types of the CSO chamber we used particles with different sizes and density. Theoretical sedimentation velocities of these particles were calculated using the formulae mentioned below (Tchobanoglous *et al.* 2003).

$$u_s = \sqrt{\frac{4g}{3C_D}\left(\frac{\rho_s - \rho_w}{\rho_w}\right) d_s} \qquad (1)$$

$$C_D = \frac{24}{\mathrm{Re}} + \frac{3}{\sqrt{\mathrm{Re}}} + 0,34 \qquad (2)$$

$$\mathrm{Re} = \frac{u_s d_s}{\nu} \qquad (3)$$

where $u_s$, sedimentation velocity [m/s]; $g$, gravitational acceleration [m/s$^2$]; $\rho_s$, density of particles [kg/m$^3$]; $\rho_w$, density of water [kg/m$^3$]; $d_s$, diameter of particles [m]; $C_D$, drag coefficient; Re, particle Reynolds number; $\nu$, kinematic viscosity [m$^2$/s].

## RESEARCH RESULTS

### Geometrical configuration of CSO chamber

The main task of the hydraulic modelling was the evaluation of the influence of geometrical configuration (sizes, position of the overflow pipe, shape of the slit, etc.) on the velocity distribution. Moreover, the results of hydraulic modelling should be used for the calibration and verification of the mathematical model. Particularly, the vertical velocity components were identified with respect to wash out of suspended solids through the CSO chamber to the receiving water. In case of crest configuration ST1 (Figure 2), the formation of a wake ($x \approx 400$ mm) is clearly visible. In case of ST1 and ST2, short circuit flows are visible in the area 200–400 mm. The vertical distribution of vertical velocity components $v(y)$ shows the worst behaviour in ST1.

On the other hand, the influence of a scumboard on a dead zone behind it is increasing with extending of the overflow crest. Vertical distributions of horizontal velocity components $u(y)$ indicate the size of the dead zones for geometrical configurations of the crest ST1-ST3. Velocity profiles $u(y)$ at the coordinate $x = 600$ are more or less identical. In case of ST3, the dead zone between $x = 0$–600 mm is evident. However, this geometrical configuration provides the best results in case of vertical velocity components $v$.

### Verification of mathematical model

The results of measurements were used as verification parameters for three-dimensional mathematical modelling. The mathematical model clearly estimates the influence of scum board on the dead zone downstream. On the other hand, the physical model has a different flow field in the overflow crest (Pollert *et al.* 2008). This can be explained by two reasons – the k- ε mathematical model is isotropic

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and the density of the mesh is too low in the above-mentioned region. In the middle of the chamber, the difference between the velocities is negligible.

## INSTALLATION

The first 15 prototypes of this new CSO chamber 'CSO-T' were installed in the Czech Republic and the Slovak Republic. The first prototype was in Moravský Krumlov (Figure 3) (April 2007). The inlet pipe of DN 800 has a large slope, so it is followed by a stilling chamber for dissipating kinetic energy. The CSO-T itself begins immediately after that chamber. The rest is a standard solution with a temporary bypass, a scum board that can be changed into temporary boards.

**Figure 3** | CSO-T Moravský Krumlov.

The possibility to install the object in a very short time proved to be very valuable especially in Děčín (Figure 4). The object is located in a street with busy traffic, so minimizing the time of enclosure was very important. The installation of the CSO chamber with a DN1000 inflow pipe was completed overnight. The design of this CSO chamber also saved the installation space and dig needs. In cities (streets) this is a very good argument for using this type of CSO chamber. The whole structure is prepared in company, so it decreases the cost and the building time as well. The lower price is one of the advantages of this type besides the precleaning principles described below.

### Mathematical model of the CSO-T

The separation efficiencies of particles of six different diameters (50, 100, 150, 200, 250, and 300 μm) and a density of (1,300, 1,800 and 2,650 kg/m$^3$) were simulated using a 3d mathematical model in the Fluent software (Figure 4) as a representative pollution in sewers (Pollert & Stránský 2003).

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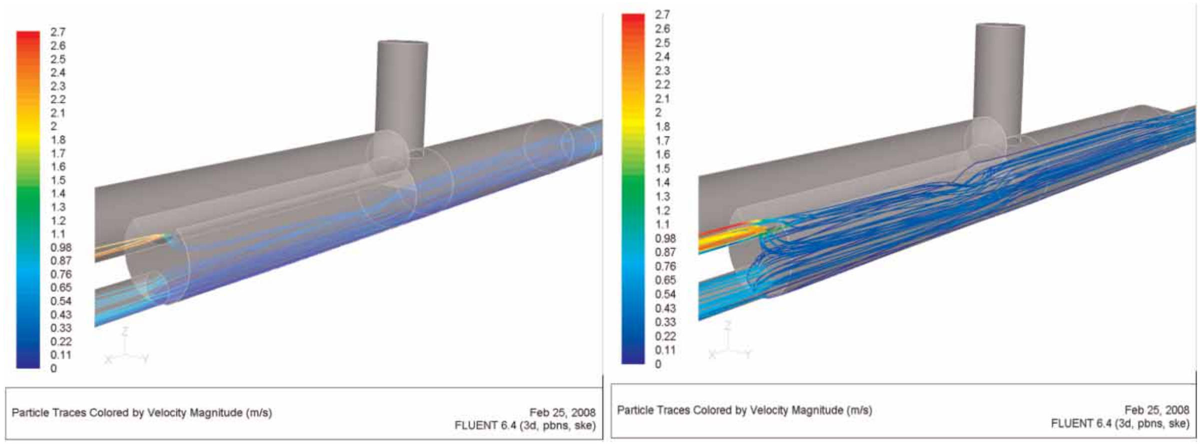


**Figure 4** | Simulation of separation efficiencies in CSO-T Děčín (path lines of particles coloured by velocity magnitude $d = 150$ (left) and 50 (right) µm, $\rho = 1{,}800$ kg/m$^3$).

Particles were distributed uniformly at the inlet and their trajectories were simulated using a Lagrangian approach. Separation efficiencies were determined by comparing the concentration of particles at the inlet and overflow boundaries. The following chart shows the simulated separation efficiencies of the CSO-T installed in Děčín for three different flow rates (Figure 5) and dependency to the sedimentation velocity of the particles, which has main impact to the separation efficiency. The flow rates are expressed as multiples of the critical flow rate ($Q_{crit}$ is maximal $Q_{outflow}$ – when the overflow begins) through the throttle pipe to the continuing sewer. From these results we are calculating the overall efficiency of the CSO chamber (Figure 8) (Pollert & Stránský 2003). According to our methodology, we focused on these fractions of suspended solids: F1 - 1,00E-06m, 1,300 kg/m$^3$; F2 - 1,00E-05m, 1,800kg/m$^3$; F3 - 1,00E-04m, 2,600 kg/m$^3$; F4 - 1,00E-03m, 2,600 kg/m$^3$. Each fraction was simulated separately under different flow conditions, which can be compared using the flow ratio.

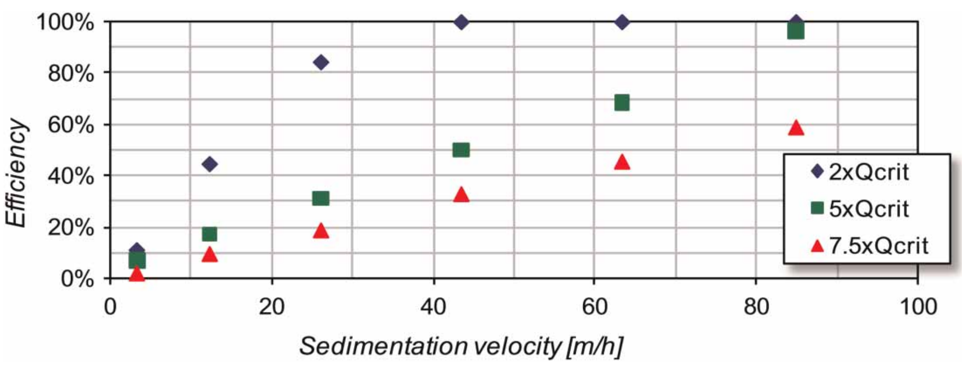


**Figure 5** | Particle separation efficiency of CSO chamber CSO-T in Děčín for different flow rates.

## COMPARISON WITH REALITY – FIELD MEASUREMENT

A comparison of the separation efficiency of the suspended solids was done for all mentioned CSO chambers (Pollert *et al*. 2008). For the CSO-T it was done as well (Figure 6) in the years 2008, 2010, 2011, and 6 overflows events were caught. From the chart (example from 2008) a detailed overflow in time during one storm event can be seen. The difference between inflow and overflow concentration of suspended solids gives the efficiency for separation of the suspended solids. For this event example the efficiency was 72%.

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All measured events were compared with the mathematical model (Figure 7) described above. In reality the quality of the waste water is very different and dependent on the conditions. That is why the measured efficiency is not so consistent.

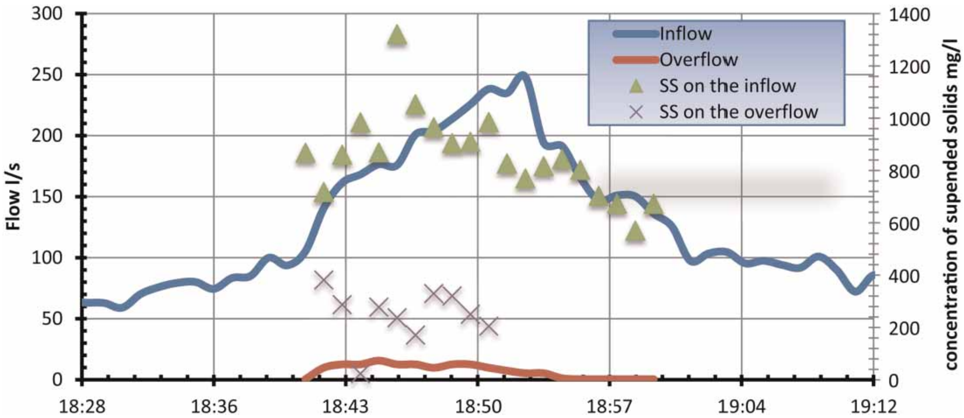


**Figure 6** | Concentration of suspended solid on CSO-T Děčín.

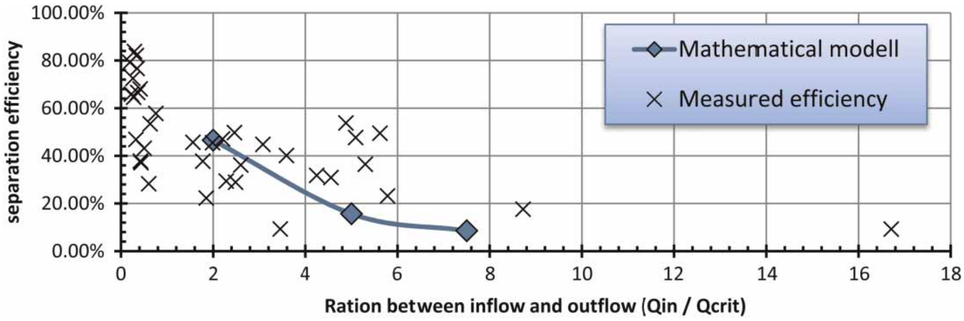


**Figure 7** | Comparism between field results and mathematical model on CSO-T Děčín.

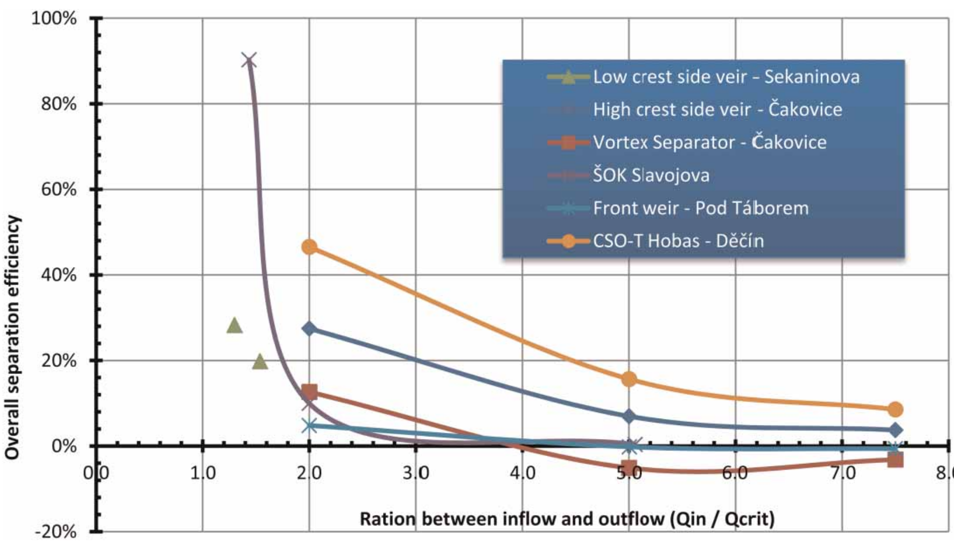


**Figure 8** | Overall separation efficiency for several different types of the CSO chamber.

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## COMPARISON WITH OTHER TYPES OF CSO CHAMBER

From our previous research based on our evaluation methodology of CSO chamber (Pollert & Stránský 2003) we also compared this new type with other types (Figure 8). For all these CSOs, the separation efficiency of 'typical wastewater particles' was also calculated. The results are from a calibrated mathematical model similar to that used in the CSO-T Děčín case. The reasons for using a mathematical model are comparable flow conditions ($Q_{in}/Q_{crit}$) and the same waste water structure (suspended solids).

## CONCLUSION

The first prototypes (15 pieces) of this new CSO chamber (it was named 'CSO-T') were successfully installed in the Czech Republic and the Slovak Republic. The installation shows great potential due to short construction time and easy setup on the field. A mathematical model shows that the 'CSO-T' has a better separation efficiency than conservative types. Field measurements confirm that theory (Figure 8). Using a smart design for the separation of suspended solids, we can see great potential for decreasing pollution in receiving water bodies. It can be achieved without expensive solutions. CSO-T is just an example.

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