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DESIGN CRITERIA OF UNDERFLOW BAFFLES FOR CONTROL OF FLOATABLES

J. Cigana*, G. Lefebvre**, C. Marche** and M. Couture*

** John Meunier Inc., 6290 Périnault, Montréal, H4K 1K5, Canada*
*** École Polytechnique of Montréal, C.P. 6079, Montréal, Succ. Centre-Ville, H3C 3A7, Canada*

ABSTRACT

Underflow baffles have gained in popularity over the last few year as a viable means to intercept floatables in Combined Sewer Overflows (CSOs). This has happened although the efficiency of underflow baffles has never been clearly proven. Furthermore, there are no guidelines helping planners in the correct and efficient design of underflow baffles. This article proposes design criteria deduced from pilot scale essays performed in a 17 meters basin at various flowrates. These new informations can be used in two different ways. First, these criteria can be used to correctly design a new overflow chamber. Secondly, these criteria can be used to evaluate the efficiency of existing overflow chambers. Preliminary analysis of existing chambers show that interception efficiency of floatables can be very low. © 1998 Published by Elsevier Science Ltd. All rights reserved

KEYWORDS

Underflow baffles; floatables; CSOs; design; efficiency.

INTRODUCTION

According to US EPA, there are approximately 11 000 CSOs in 1100 American cities and towns. (EPA, 1994) As part of long-term solutions to the pollution problem caused by CSOs, some of them will be eliminated, but a great number will remain. The removal of floatables from these remaining CSOs is one of the Nine Minimum Controls required under the April, 1994 EPA CSO Control Policy.

Preliminary searches show that there are no references in the technical literature on how to assess the efficiency of the underflow baffles. Furthermore, no guidelines or instructions presently exist to guide the correct design of underflow baffles.

In this context, we have been actively pursuing the study of floatables in CSOs. The objective of this article is to present a general overview of the flotation of CSOs and the criteria leading to a good design of the outfall chamber and the underflow baffle.

Design and efficiency. The trajectory of the floatable solid rising to the surface of the flow is shown on Figure 1. In designing a new outfall facility all of these dimensions are to be determined.

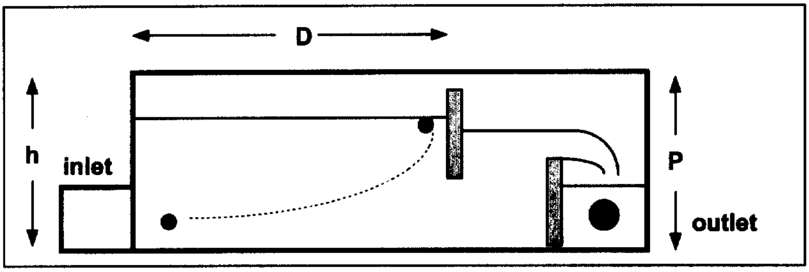

Figure 1. Schematic view of an overflow chamber.

These dimensions will depend upon:

- Design flow
- Desired removal efficiency
- Available space

Although the design flow will cover a wide range of overflow frequencies and conditions, the desired removal efficiency is the key to the design of a baffle. The complete design process we propose establishes a first step for the designer that allows the regulating authority to set goals for efficiency or alternately establish compromise between cost and efficiency. The designer will also have to take into account local restrictions and site specific physical limitations that may limit the width of the basin and sometimes its depth or length. To establish the relationship between the efficiency and the vertical velocities of floatables, we sampled the CSOs of two outfalls in the Greater Montreal area and measured the vertical velocities of the collected floatables in still water. (Paradis *et al.*, 1996). According to Figure 2, about 21% of the floatables have a vertical velocity of 7 cm/s or less in the Greater Montreal area. This means that an overflow basin equipped with underflow baffles would have a theoretical efficiency of 79%, if designed for a vertical velocity of 7 cm/s.

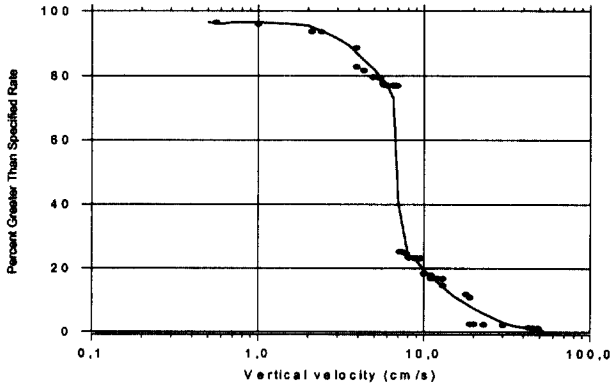

Figure 2. Distribution of the vertical velocity for floatables in the Montreal Area (adapted from Paradis *et al.*, 1996).

Theory of suspension. A suspension occurs when a material reaches an equilibrium state between gravity and buoyancy forces and is not in contact with the free surface or the bottom of the channel. The effective vertical velocity of a floatable in a suspension (w') is obtained by subtracting the influence of the turbulence from the vertical velocity of the floatable in still water, w.

$$w' = w - w\,(turbulent) \tag{1}$$

The influence of turbulence is given in relation to the Rouse number (Z) as described by Simons *et al.* (1977). Indeed,

$$Z = \frac{w}{\kappa U^*} \tag{2}$$

where

k = Van Karman constant = 0.4
w = Vertical velocity of a floatable in still water (m/s)

$$U^* = \text{Root-Mean Square turbulent velocity component} = Vn\sqrt{\frac{g}{R_h^{1/3}}} \tag{3}$$

and

n = Manning coefficient = 0.017 for our concrete basin
g = Gravity accelaration = 9.8 m/s^2
R_h = Hydraulic radius of the cross section of the basin, in (m)

We thus find :

$$w' = w - kZ_{CR}U^* \tag{4}$$

or

$$w = w' + kZ_{CR}U^* \tag{5}$$

If a floatable is intercepted by a baffle in a given horizontal distance D when its horizontal velocity is V and the vertical distance to travel is h, then the effective vertical velocity w' becomes:

$$w'(D) \geq \frac{hV}{D} \tag{6}$$

Equation 5 can be rewritten as:

$$w = \frac{hV}{D} + \kappa Z_{CR} U^* \tag{7}$$

The literature shows that values of Z_{CR} range from 1 to 4 (Van Rijn, 1984), thus yielding values of w ranging from :

$$w = \frac{hV}{D} + 0.4U^* \quad \text{to} \quad w = \frac{hV}{D} + 1.6U^* \qquad \text{(8 and 9)}$$

Our objective, from this theoretical development, is to validate these relations and derive design criteria.

METHOD

The design of a control device for a CSO outfall requires a site-specific characterisation of the problematic floatables found in the CSO. The first analysis necessary to correctly understand the vertical velocity of a floatable (w) is to graph the relation between the Rouse number (Z) as a function of the critical vertical velocity not to exceed, to obtain a desired efficiency, in our case, 80%, w'(8/10). This relation was obtained by submitting different categories of floatables to a vertical velocity test, in a 17 m channel, while varying the horizontal velocity of the flow, thus producing varying turbulent velocities U*. Representative floatables were obtained from 8 sampling campaigns collected in the Montreal region. (Paradis *et al.*, 1996) This method, its origin and applications are explained in greater length in Cigana *et al.*(1997).

RESULTS AND DISCUSSION

Vertical velocity and turbulence. Figure 3 represents a graph of Z as a function of w'(8/10) for the above mentioned floatables. Equations 6, 7 and 8 predict a linear relationship between the vertical velocity of floatables (w) and the root-mean square turbulent velocity, U*. Our results show that an exponential relation between Z and U* exists, as shown by Figure 3.

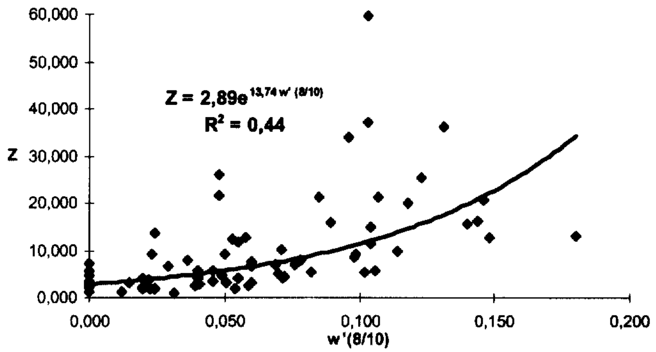

Figure 3. Graph of the Rouse number (Z) in function of w'(8/10).

The phenomenon becomes much more complex than previously thought. Equation 6 can be amended with our new results :

$$w = \frac{hV}{D} + 2.89e^{13.74w(8/10)}\kappa\, U^* \tag{10}$$

This last equation can be simplified by considering only the intercept $Z_{CR} = 2.89$, that gives the following equation :

$$w = \frac{hV}{D} + 1.2\, U^* \tag{11}$$

As we can see, Equation 11 falls in the range of values cited in the literature and in Equations 8 and 9. The complete form of the relation in Equation 11 is much more complex than previously thought. This must be kept in mind when designing overflow baffles. It nonetheless represents a quick and easy way to exploit these innovative results, as we will show in an example of application.

Chamber length design. The length of the chamber is the most important of the three lengths required for an adequate design.
Indeed:

$$D = L_{cr} + l_{baffle} + l_{exit} \tag{12}$$

Where:
D = minimum required length of the basin;
l_{baffle} = distance from the underflow baffle to the weir;
l_{exit} = distance from the weir to the downstream wall of the basin;
L_{cr} = critical distance from the entrance to the basin to the underflow baffle.

This critical distance, L_{CR}, is the minimum length that would allow the design floatable to rise to the surface, where it should be retained by the baffle. As we will see in an example of application, the distance L_{CR} overshadows greatly the other two smaller dimensions. After selecting the width "B" and the depth "d", the designer can calculate the minimal length of the basin with the following equation:

$$L_{CR} = V \frac{h}{w'_{(8/10)}} \tag{13}$$

Where:

V = average flow velocity = $\frac{Q_{design}}{B*d}$, in ; (m/s);

h = maximum vertical water depth a floatable would have to travel (m);

$w'_{(8/10)}$ = vertical velocity to obtain a removal efficiency of 80% of the floatables, in (m/s);

Location and depth of the baffles. There is no consensus among the designers on the location of the baffles. In fact, there are no credible studies on the subject. It seems, the efficiency of the system is affected by the location and depth of the baffle. Figure 4 shows the removal efficiency of baffles of different lengths for varying horizontal velocities. The depth of the baffles tested were 15, 30 and 50 cm from the water surface with a constant water depth of 1m. We can see from this figure that for smaller horizontal velocities, removal efficiency can be doubled by using a 50 cm baffle versus a 15 cm baffle. At higher horizontal velocities, removal efficiency quickly becomes nil no matter what baffle length is used.

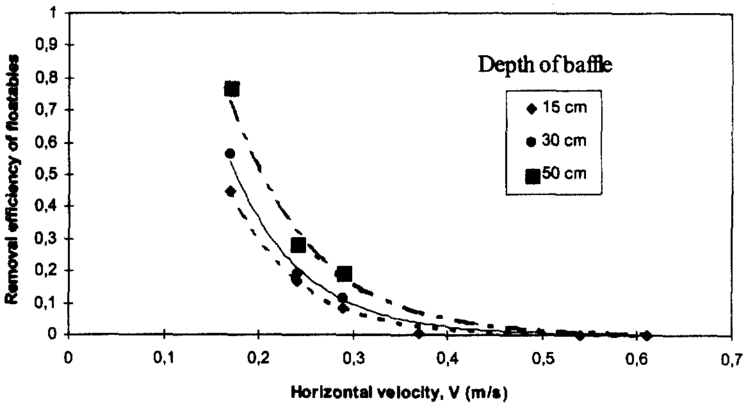

Figure 4. Graph of the removal efficiency of floatables as a function of the horizontal velocity, V.

However, setting the baffle too deep, i.e. its tip too close to the bottom of the basin, would create a restriction of the flow underneath the baffle with three undesirable results:

- Considerable increase of the local velocity and turbulence under the baffle and, consequently, a decrease of the efficiency by re-introducing floatables already intercepted by the baffle;
- Significant increase in the head loss of the flow passing underneath of the baffle.
- Possible basement flooding in residences because of the restricted flow

Transition between the sewer and basin. The width of a properly designed overflow basin, equipped with underflow baffles, will be considerably larger than the diameter of the incoming combined sewer. If there is no smooth transition between the two, the flow entering the basin will be subjected to a sudden enlargement. In order to remedy these problems, the sudden enlargement at the entrance of the basin should be eliminated and replaced by a gradual enlargement. This would mean the addition of a transition between the sewer and basin. Ideally, this transition should be formed by double curvatures. However, in practice, a gradual enlargement with straight lines is acceptable.

Example of application. A 1m (h=1m) deep chamber overflows at an horizontal velocity of 0.7 m/s (V=0.7m/s). The most problematic floatables are sanitary applicators which have a vertical velocity of 0.07 m/s. (w =0.07 m/s). What is the critical length the chamber should have to insure an interception of 80% of the sanitary applicators ?

The critical length of the chamber is calculated using Equation 13, where: $L_{cr} = \frac{hV}{w'_{(8/10)}}$

The value of w' $_{(8/10)}$ is obtained with Figure 3. By calculating the Rouse number for this flow and relating it to the equation of the regression, we can find w' $_{(8/10)}$.

We calculate the turbulent velocity, as expressed in Equation 3:

$$U* = Vn\sqrt{\frac{g}{R_H^{1/3}}} = 0.7m/s \cdot 0.017 \cdot \sqrt{\frac{9.8m/s^2}{(0.25m)^{1/3}}} = 0.047m/s$$

The Rouse number can now be calculated as:

$$Z = \frac{w}{\kappa U*} = \frac{0.07m/s}{(0.4)\cdot(0.047m/s)} = 3.72$$

The equation of the regression curve found in Figure 3 is :

$$Z = 2.89e^{13.74[w'_{(8/10)}]}$$

By introducing the calculated value of Z=3.72 in this last equation, we can thus find that the value of w'$_{(8/10)}$ that satisfies this equation is 0.018 m/s.

The calculated value of the critical length of the chamber is thus :

$$L_{cr} = \frac{hV}{w'_{(8/10)}} = \frac{1m \cdot 0.7m/s}{0.018m/s} = 39m$$

In order to correctly take into account the influence of the critical horizontal velocity and to maintain a removal efficiency of 80% of the sanitary applicators, we see that the length of the chamber has to be at least of 39 m or 128 feet. No overflow chambers presently constructed or to be constructed are this big. Obviously, any floatables with w > 0.07 cm/s would be intercepted at a greater rate than 80 %. The length of the overflow chamber and the removal efficiency being directly related, any overflow chamber smaller than 39 m would dramatically reduce the efficiency removal of the floatables. In order to maintain the 80% efficiency of the overflow chamber in a smaller chamber, the only alternative is to reduce the horizontal velocity or the water depth, or both. These two actions would only reduce the flow treated at the overflow point, which is contrary to the objective of these chambers.

CONCLUSIONS

Design criteria and efficiency studies for underflow baffles are scarce and far between. The objective of this article was to lay the foundation of the correct design strategy for underflow baffles. We have shown that an exponential relation exists between the vertical velocity (w) and the turbulent component of the horizontal velocity (U*), as shown in Equation 10. For the first time, these results were applied in dimensioning a chamber to render effective an underflow baffle. The example of application presented in the last section shows that when this relation is introduced, chamber length quickly becomes very large. Two conclusions come to mind, in light of these results. If underflow baffles are chosen for new outfall chambers and the criteria we put forward followed, the overflow chambers will be very large and require much civil engineering work to respect an interception rate of 80%. The corollary to this affirmation is that present overflow chambers, where an underflow baffle is simply added before the weir, are probably ineffective and inadequate to intercept 80% of the floatables, if any. Utilities and consultants would be better advised to install sturdier and efficient field equipment, like bar screens, to insure the correct interception of floatables in combined sewer overflows.

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