Enhancement of Settling Tank Efficiency Using Inclined Tube Settlers

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ABSTRACT

This paper deals with an improvement of settling tank performance. The new equipment is proposed and the usefulness of this method is confirmed. In combined sewerage systems, storm waters often exceed the capacity of the treatment plant, which may cause environmental problems. To meet this problem, the enhancement of the settling tank capacity is an important and urgent issue to the sewage treatment plant in the city. Although the lamella settler is widely used to improve the settling performance of the space limited settling tank, the capacity of this method is limited by the surface area of the tank, since the parallel plates are arranged horizontally. The newly developed settler is an improvement of the lamella settler, which arranges the inclined parallel plates in the vertical direction. In this method, the separated clear water is removed directly by suction from the top end of the parallel plates. For the removal of clear water, the right and left edges of the plates are closed, to make a tube with rectangular cross section. These are the unique and original points of our equipment. Since each settling tube acts as a small settling tank, the treatment power is proportional to the number of the settling tube. Furthermore, this system is less restricted by the surface area of the tank, since the tubes are arranged vertically. It was shown from our laboratory and onsite experiments, that the new system can enhance the capacity of the settling tank more than 5 times greater than the conventional one.

KEYWORDS
Settling tank, inclined settling tube, Boycott effect

INTRODUCTION

In combined sewerage systems, storm waters often exceed the capacity of the treatment plant, which may cause environmental problems. To meet this problem, the enhancement of the settling tank capacity is an important and urgent issue to the sewage treatment plant in the city. Although the lamella settler is widely used to improve the settling performance of the space limited settling tank (for example, Binder, et al., 1983, Pasinski, et al., 1980), this method is restricted to the water surface area of the tank, since the parallel plates are arranged horizontally.

The newly developed settler is an improvement of the lamella settler, which arranges the inclined parallel plates in the vertical direction. In this method, the separated clear water is removed directly by suction from the top end of the parallel plates. For the removal of clear water, the right and left edges of the plates are closed, to make a tube with rectangular cross section. These are the unique and original points of our equipment. Since each settling tube acts as a small settling tank, the treatment power is proportional to the number of the settling tube.
Furthermore, this system is less restricted by the surface area of the tank, since the tubes are arranged vertically. In the following, the results of our laboratory and onsite experiments are described to show the usefulness of this method.

**SIMPLE MODEL OF INCLINED SETTLING TUBE**

In the ideal rectangular settling tank, the following well known overflow rate theory is widely used, thus

\[
W_o = \frac{Q}{S} = \frac{U_0 \cdot H \cdot W_d}{W_d \cdot L} = U_0 \cdot \frac{H}{L}
\]  

(1)

where \(Q\) is the treatment capacity (\(m^3/s\)), \(U_0\) is the inflow velocity (\(m/s\)), \(H\), \(W_d\) and \(L\) are the height (\(m\)), the width (\(m\)) and the length (\(m\)) of the tank respectively. \(W_0\) is the fall velocity of sediment (\(m/s\)) and \(S\) is the water surface area of the tank (\(m^2\)). The above Eq.1 means that the treatment capacity is proportional to the surface area of the tank.
This idea is applied to the inclined thin settling tank, as illustrated in Figure 2. For the comparison with a conventional settling tank (Figure 1), the settling tube are rotated clockwise at angle $\theta$, as shown in Figure 3.

If we define the physical quantities as given in Figure 3, then we obtain

$$\frac{d}{W_0 \cdot \cos \theta} = \frac{L_c}{u_0 - W_0 \sin \theta}$$  \hspace{1cm} (2)

Each term of above equation, means the retention time of sediment particles in this tube in the ideal case. The expression with respect to $W_0$ is given by

$$W_0 = \frac{u_0 \cdot d}{d \sin \theta + L_c \cos \theta}$$  \hspace{1cm} (3)

The above Equation (3) is the basic equation of this case and it corresponds to Eq.(1) in the rectangular settling tank. Here we consider the vertical arrangement of these parallel inclined plate. In addition, the both right and left sides are closed so that they make a tube with rectangular cross section. The separated clear water is discharged by suction from the each settling tube. Thus, the each settling tube acts as a small independent settling tank, which means the treatment capacity is proportional to the number of the settling tube in a tank.

**EXPERIMENTS AND DISCUSSION**

**Test with sand particles**

To make clear the basic properties of this inclined pipe settler, a simple experiment was done. A model settling tube was set in a tank with 0.8m length, 0.45m height and 0.135m width. In this tank, 20 – 74µm sand particles were suspended and its concentration is 0.1% by weight. The cross section of this settling tube is rectangular, whose width is 0.04m and thickness 0.01m. From the top of the settling tube the cleared water is sampled and it’s suspended solid concentration is measured after drying. The results are demonstrated in Figure 5. This Figure shows that suspended solid concentration increases with suction velocity. While if $u<0.0015m(=0.15cm/s)$, the usefulness of this inclined pipe settler is confirmed.

The maximal fall velocity of sediment particles that is contained in the sampled water
is shown in Figure 6. The horizontal coordinate is the mean flow velocity \( u_0 \) in a settling tube and solid line is obtained from Eq. 3. The prediction gives reasonable agreement. Although Eq. (3) is derived from the condition of ideal state, Eq. (3) may be useful under these experimental conditions.

**Settling behavior of waste activated sludge**

Beside the secondary settling tank of the sewage treatment plant, a box type tank was set for the on-site experiment with use of real waste activated sludge. The cross section of this box is 0.45m × 0.6m and height is 1.6m. The box has a valve for discharge the deposited sludge at the bottom and the suspension level is kept constant with over flow pipe. By setting the one or several inclined tube settlers in this box, effect of some factors on the enhancement of waste activated sludge was investigated.

**Effect of settling tube clearance, \( d \)**

The effect of tube clearance \( d \) on the suspended solid concentration in separated water is shown in Figure 7. In general, when the tube clearance or thickness \( d \) is small, the settling efficiency becomes high, however deposited sludge is easy to be picked up, which results in the low efficiency. Within the experimental condition, these data shows not so clear difference, which may be due to the combined action of above-mentioned two factors. These data are obtained after 10-20 minutes from the start of the settling experiment, the time variation must be measured for detailed work.

**Vertically arranged multi-pipe settler**

Many inclined tube settlers are arranged vertically and set in the settling box, and the time variation of the suspended sediment concentration in a separated-water were measured. The length of the pipe is 0.6m,
width is 0.2m, distance between upper and lower plates are 0.02m and inclination angle is 60°. The numbers in Figures 8-1 to 8-5 mean the order from the top. As a whole, there are not so big differences by the location of pipe on the treatment efficiency. In this experiment, as the sediment concentration at the tube entrance increases in the deep location, the suction velocity is adjusted with the depth of each pipe. However, in the case of No.10 that is the lowest tube, the breakthrough is observed.

**Growth of the sludge zone**

In a practical settling tube, the settling phenomenon may be complicate one, though we employed very simple assumption in the analysis. For example, slide down of deposited sludge, settling velocity variation with local concentration of sediment and the effect of turbidity current (Acrvos, et al., 1979, Awaya, et al, 1977) are to be considered for more detailed analysis. To this end, a settling tube is attached on the inner wall of a tank that is made of glass and the time growth process is observed directly as shown in Figure 9.

The waste activated sludge taken from a municipal sewage treatment plant is used as suspended matter. The settling tube used has 0.5m length, 0.2m width and 0.02m thickness. If the suction velocity \( u_0 \) is less than 0.0006m/s, the continuous operation is possible, since the sludge zone growth is negligible. While if the
velocity \( u_0 \) is greater than 0.002 m/s, the breakthrough occurs within a short time.

**NUMERICAL EXAMPLE**

Consider a rectangular settling tank whose properties are given in Table 1. The properties of a single settling tube are written in Table 2. To treat a quantity of 750 m\(^3\)/day per unit width, we must obtain the treatment capacity of this single settling tube \( q \).

\[
q = u_0 \times d \times B = W_o (d \sin \theta + L \cos \theta)B \quad (4)
\]

Substituting the numerical values given in Table 2, we obtain \( q = 9.86 \) m\(^3\), therefore the total number of settling tube \( n \) is given by

\[
n = \frac{Q}{q} = \frac{750}{9.86} = 76 \quad (5)
\]

If we make a module by vertical arrangement, the relationship between the height of a module \( h \) and the number of the settling tube \( p \) is given by
\[ h = L \sin \theta + p \times \frac{d}{\cos \theta} = 0.70 \times 0.866 + p \times 0.05/0.5 \]  

If we set \( h = 2.5 \) m, then \( p = 18.9 \). In the case of a module is composed by 19 single settling tubes, the total number to be needed per unit width of rectangular settling tank is \( 76/19 = 4 \). The longitudinal space for one module is given by (see Fig. 10)

\[ d \times \sin \theta + L \cos \theta = 0.05 \times 0.866 + 0.7 \times 0.5 = 0.393 \text{ m} \]

Figure 10. Settling tank with inclined settling tubes

In the practical case, the marginal space must be taken at the bottom and top side of each settler. Thus if we take 0.7 m distance for each module, \( 0.7 \times 4 = 2.8 \) m may be enough to set all settling tube. Since the length of the original settling tank is 30 m, a great amount of space saving will be done. The above mentioned discussion is schematically given in Fig. 10.
CONCLUDING REMARKS

To increase in the treatment efficiency, a new device is developed that applies the idea of lamella settler. The new device is an arrangement of inclined tube settler with rectangular cross section. Since the separated clear water is removed from each settling tube, the treatment capacity is proportional to the number of settling tubes. In addition, this system is very effective for saving the space of settling tank, as the tubes are arranged vertically.

Using sand particles, at first, the usefulness of this devise was investigated. It is found that the settling mechanism in this inclined parallel tube can be approximated by overflow rate theory. From the experiment on the settling of waste activated sludge the following results are obtained. To the effect of settling tube thickness, d, there are not so clear difference within our experimental condition, 2<d<6cm. This may be due to the pick up effect of deposited sediment. The treatment efficacy is influenced by sediment concentration at the inlet of the tube settler that is the lower end. For more detailed analysis, the time growth process of sludge zone in settling tubes is observed and the relationship between the breakthrough and the suction velocity in a tube are obtained.

A numerical example of the application of this system to the practical settling tank is also given. It is shown that this new system has a possibility to enhance the tank capacity more than 5 times larger than the conventional one.

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REFERENCES