Improvement of settling tank performance using inclined tube settlers

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Abstract

The newly developed settler is an application of the lamella settler, which arranges inclined parallel plates in the vertical direction, contrary to the usual horizontal arrangement. 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 a rectangular cross section. These are the unique and original features of the equipment. Since each settling tube acts as a small settling tank, the treatment capacity is proportional to the number of settling tubes. Based on the results of the laboratory and on-site experiments, it is shown that the new tube settler system is very effective for the enhancement of settling tank performance. It is also shown from a numerical estimation that the settling tank installed with the new system has extremely high performance compared with the conventional settling tank.

Keywords: settling tank, tube settler, lamella settler, overflow rates, treatment capacity.

1 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 settling tank capacity is an important and urgent issue to the sewage treatment plant in the city. To improve the performance of the space limited settling tank, the lamella settler is widely used (for example, Takayanagi et al [1], Bridoux et al [2], Daligault et al [3], Kolisch and Schirmer [4]).
This method, however, is restricted by 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 features 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.

The objective of this study is to investigate the usefulness of this high-speed tube settler system. For several types of tube settlers, we obtained the relationship between the suction velocity and suspended sediment concentration of effluent. In the following, based on the results of the laboratory and on-site experiments, the unique properties of the tube settlers will be demonstrated. In addition a numerical example of the capacity enhancement of the settling tank that is equipped with tube settlers is also given.

![Figure 1: Rectangular settling tank.](image)

### 2 Theory of tube settler

Using the definition as shown in fig.1, the well-known overflow rate theory to the ideal rectangular settling tank is given by eqn. (1)

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

(1)

where \(Q\) = the treatment capacity (m³/s), \(U_o\) = the inflow velocity (m/s), \(H\), \(W_d\) and \(L\) = the height (m), the width (m) and the length (m) of the tank respectively. \(W_o\) = the fall velocity of sediment (m/s) and \(S\) = the water surface area of the tank (m²). The above eqn. (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 fig.2. If we define the physical quantities as given in fig.2, then we obtain

\[
\frac{d}{W_o \cdot \cos \theta} = \frac{L_s}{u_o - W_o \sin \theta}
\]  

(2)
where \( d \) = the depth of the tube settler, \( L_* \) = the length of the tube, \( u_0 \) = the suction velocity in this tube settler and \( \theta \) = the angle of inclination to the horizontal line. Each term of above equation, equals to the retention time of sediment particles in this tube in the ideal case. The expression with respect to \( W_0 \) is given by

\[
W_0 = \frac{u_0 \cdot d}{d \sin \theta + L_* \cos \theta}
\]  

This equation (3) is the basic equation of this case and it corresponds to eqn. (1) in the rectangular setting tank. If we assume that the width of tube is unit length, the right hand terms of eqn. (3) means the entered volume flow rate of suspension divided by the horizontally projected surface area of the tube settler. This means that the above-mentioned overflow rate theory can be applicable to the case of inclined tube settler (Binder & Wiesmann [5]). Since the overflow rate theory assumes the ideal case, such as, no wall friction, no density effect, no turbulence, we must check the applicability of this idealized theory, especially to the settling of waste activated sludge.

3 Laboratory experiment

To make clear the basic properties of this inclined pipe settler, a simple experiment was performed. A model settling tube was set in a tank with 0.8m lengths, 0.5m heights and 0.01m thickness. In this tank, as shown in fig.3, sand particles of 20 – 74\( \mu \)m size ranged were suspended with a concentration of 0.1%. The cross section of this settling tube is rectangular, whose width is 0.04m and thickness is 0.01m.
Figure 3: Laboratory experiment setup (unit: m).

Figure 4: Maximum fall velocity of particles in effluent.

Figure 5: Setup of the on-site experiment (unit: mm).
The maximal fall velocity of sediment particles that is contained in the effluent is shown in fig. 4. The horizontal coordinate is the suction velocity, that is, the mean velocity in a settling tube, and solid line is obtained from eqn. (3). The numerical prediction gives reasonable agreement. Although eqn. (3) is derived with an assumption of ideal state, eqn. (3) may be useful under these experimental conditions, such as settling of sand particles without flocculation and at low particle Reynolds number.

4 On-site experiment

4.1 Experimental set-up

Most experiments were carried out at H sewage treatment plant in Kitakyushu City. Near the inside wall of the final settling tank, a tube settler is fixed to support structure F, as shown in fig. 5. Since this equipment is set near the entrance of the tank, the vertical variation of sediment concentration in the tank is very sharp. Therefore, by changing the depth of the entrance of the tube settler, we can easily get the desired sediment concentration, as an experimental condition.

The effluent that is separated clear water is discharged by suction from the top end of this tube settler. Under the various suction speeds, the concentration of SS in effluents was measured. The types of settling tube are shown in fig. 6. Type I and IV are circular and type II and III have a rectangular cross section. Each tube settler is fixed to the support with a previously determined angle $\theta$.

Table 1 shows the experimental condition together with a part of the results. The concentration of sludge at the inlet of tube is denoted $C_0$ in Table 1. The mean value of activated sludge properties are in the H plant; MLSS=1100mg/L, SVI=200mL/g, and in the S Plant; MLSS=1800mg/L, SVI=490mL/g.

Experiments Runs No. 41-44 were executed in an aeration tank. This experiment studies the possibility of direct removal of clear water from an aeration tank.
Figure 7: Relationship between SS concentration in effluent and suction velocity $u_o$. 

Type I 55mm dia

Type II 6×20 cm

Type III 1.5×20 cm

Type IV 70mm dia
4.2 Experimental results

The relationships between suction velocity $u_o$ and suspended solid concentration of effluent, SS are demonstrated in figs. 7.1-7.4. These figures show that the SS in effluent increase gradually in the early stages. The SS values suddenly increases when suction velocity $u_o$ exceed a certain value, where the brake-trough occurs.

<table>
<thead>
<tr>
<th>Run No</th>
<th>Co(mg/L)</th>
<th>Uc(cm/s)</th>
<th>Type</th>
<th>site</th>
<th>incl. angle</th>
</tr>
</thead>
<tbody>
<tr>
<td>11</td>
<td>200</td>
<td>0.7</td>
<td>I</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>12</td>
<td>220</td>
<td>0.7</td>
<td>I</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>13</td>
<td>750</td>
<td>0.4</td>
<td>I</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>14</td>
<td>450</td>
<td>0.6</td>
<td>I</td>
<td>Settling tank H</td>
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<tr>
<td>15</td>
<td>320</td>
<td>0.5</td>
<td>I</td>
<td>Settling tank S</td>
<td>60°</td>
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<tr>
<td>21</td>
<td>1000</td>
<td>0.1</td>
<td>II</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>22</td>
<td>300</td>
<td>0.2</td>
<td>II</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>23</td>
<td>240</td>
<td>0.4</td>
<td>II</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>24</td>
<td>218</td>
<td>0.3</td>
<td>II</td>
<td>Settling tank H</td>
<td>60°</td>
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<tr>
<td>25</td>
<td>240</td>
<td>0.5</td>
<td>II</td>
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<tr>
<td>26</td>
<td>240</td>
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<tr>
<td>27</td>
<td>24</td>
<td>0.7</td>
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<td>60°</td>
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<tr>
<td>31</td>
<td>350</td>
<td>0.2</td>
<td>III</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>32</td>
<td>216</td>
<td>0.4</td>
<td>III</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>33</td>
<td>100</td>
<td>1.2</td>
<td>III</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>34</td>
<td>250</td>
<td>0.6</td>
<td>III</td>
<td>Settling tank H</td>
<td>60°</td>
</tr>
<tr>
<td>41</td>
<td>1260</td>
<td>0.15</td>
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<td>45°</td>
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<tr>
<td>42</td>
<td>920</td>
<td>0.25</td>
<td>IV</td>
<td>Aeration tank H</td>
<td>45°</td>
</tr>
<tr>
<td>43</td>
<td>1070</td>
<td>0.15</td>
<td>IV</td>
<td>Aeration tank H</td>
<td>60°</td>
</tr>
<tr>
<td>44</td>
<td>1030</td>
<td>0.05</td>
<td>IV</td>
<td>Aeration tank H</td>
<td>75°</td>
</tr>
</tbody>
</table>

Figure 8: Critical suction-velocity $U_c$. 
4.3 Discussion

Figure 8 shows the relationship between sludge concentration at the inlet zone of tube settler, Co and the critical velocity uc mentioned above. The critical velocity is defined as the value of uc that the SS value exceeds 10mg/L for the settling tank and 100mg/L also for the aeration tank. The critical velocity decreases with increase of the sediment concentration at the inlet of tube. The settling velocity of sludge increases when the concentration becomes small [6,7]. Therefore, if we set tube settlers to a lower concentration zone, higher capacity will be achieved.

The vertical axis in fig.9, wa, is calculated from eqn. (3) with substitution uc in place of uo. The value wa corresponds to an apparent fall velocity in each settling tube experiment and also to the overflow rate of the tube settler. This figure suggests that settling velocity of activated sludge increases with the diameter of tube settler. This may be a unique property of an activated sludge. At the same time, the settling time increases with a tube diameter. These reversal effects make it difficult to determine the optimal distance of tube settlers.

5 Numerical example

As an example, consider the case of the installation of tube settlers in a rectangular settling tank in the H treatment plant. The properties of the tank are given in Table 2. The overflow rate Wo=26.8m/day. The properties of a single settling tube are designed as given in Table 3. To begin with, we must obtain the treatment capacity of the single settling tube, q.

<table>
<thead>
<tr>
<th>Type</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co (mg/L)</td>
<td>125</td>
<td>100</td>
<td>75</td>
<td>50</td>
</tr>
<tr>
<td>Wa (m/day)</td>
<td>25</td>
<td>25</td>
<td>25</td>
<td>25</td>
</tr>
</tbody>
</table>

Figure 9: Apparent settling velocity Wa.

Table 2: Properties of settling tank.

<table>
<thead>
<tr>
<th>width (m)</th>
<th>length (m)</th>
<th>depth (m)</th>
<th>capacity (m³/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>50.0</td>
<td>3.35</td>
<td>24120</td>
</tr>
</tbody>
</table>
Substituting the numerical values given in Table 3 into eqn. (4) and using eqn.(3), we obtain \( q = 21.6 \text{m}^3/\text{day} \), therefore the total number of settling tubes \( n \) is given by

\[
q = u_o \times d \times B \times W_o (d \sin \theta + L_\ast \cos \theta) B
\]

(4)

Substituting the numerical values given in Table 3 into eqn. (4) and using eqn.(3), we obtain \( q = 21.6 \text{m}^3/\text{day} \), therefore the total number of settling tubes \( n \) is given by

\[
n = Q/q = 24120/21.6 = 1116.6
\]

(5)

If we make a module by vertical arrangement, the relationship between the height of a module \( h \) and the number of the tubes of a module \( p \) is given by

\[
h = L_\ast \times \sin \theta + p \times d \times \cos \theta = 0.70 \times 0.866 + p \times 0.05/0.5
\]

(6)

If we set \( h = 2.0 \text{m} \), then \( p = 14 \). In the case of a module is composed by 14 single settling tubes, the total number needed per unit width of rectangular settling tank is \( 1120/14 = 80 \). The water surface area for one module is given by

\[
(d \times \sin \theta + L_\ast \times \cos \theta) \times B = (0.05 \times 0.866 + 0.7 \times 0.5) \times 1 \text{m} = 0.393 \text{ m}^2
\]

(7)

Since the number of modules for the treatment of the equal volume to this tank is 80, the net water surface area to set the tube settler modules, \( S_a \) is

\[
S_a = 0.393 \times 80 = 31.44 \text{m}^2
\]

(8)

The water surface area of this conventional tank \( S_c = 18 \times 50 = 900 \text{m}^2 \). The ratio of surface area \( S_a/S_c \) is very promising. Even if, we take the marginal space for the module and many other safety factors into consideration, a great amount of space will be saved.

6 Concluding remarks

To increase settling tank efficiency, a new device is developed. The new device is a vertical arrangement of inclined tube settler. Since the separated clear water is discharged from each settling tube, the treatment capacity is proportional to the number of settling tubes. Therefore, in this system, the most essential factor
to determine the capacity of a settling tank is not the water surface of the tank but the tank volume.

For the several types of tube settlers, the relationship between the suction velocity and suspended sediment concentration of effluent were investigated. Based on the results of these laboratory and on-site experiments, it is shown that the new tube settler system is very effective for the enhancement of settling tank performance. A numerical example of the application of this system to the practical settling tank is also given and how this new system can enhance the tank capacity is demonstrated.

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References


