Using of Plate Settlers for Wastewater Grit Removal

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استخدام ألواح الترسيب لإزالة الرمال من مياه المجارى

يتم إزالة الرمال من مياه الصرف الصحى لحماية الأجزاء الميكانيكية المتحركة مثل الطلمبات من التآكل و لتقليل انسداد القنوات و المواسير. يوجد أكثر من شكل لأحواض إزالة الرمال والتى يمكن تقسيمها الى ثلاث أشكال رئيسيه هى :- أحواض ذات سرعة ثابتة، الأحواض المهواه وأحواض ترسيب الرمال ذات منسوب المياه الثابت.
إن استخدام ألواح ومواسير الترسيب يمكن أن يكون فى شكل من ثلاث أشكال وذلك حسب توافق اتجاه سريان المياه خلالها مع اتجاه ترسيب المواد العالقة حيث يمكن أن يكون اتجاه سريان المياه مع اتجاه الترسيب أو معاكس له أو عمودى عليه.
فى هذا البحث تم مناقشة اقتراح بادراج ألواح الترسيب فى أحواض ترسيب الرمال ذات السرعة الثابتة بالشكل الذى يحقق سريان المياه العمودى على اتجاه ترسيب الرمال حيث أن الفائدة من ذلك تتمثل فى تقصير طول للحوض ، رفع كفاءة الإزالة و تسهيل عملية إخراج الرمال من الحوض.

Abstract

Grit is removed from a wastewater system to protect moving mechanical equipment from abrasion and wear, to reduce conduit clogging, and to prevent loading of treatment works with basically inert matter. There are many different types of wastewater grit removal chambers. They can be divided into three basic types: velocity controlled, aerated, and constant level short term sedimentation tanks.

Inclined plate and tube settlers are constructed to be used in one of three ways with respect to the direction of liquid flow relative to the direction of particle settlement: countercurrent, cocurrent, and cross-flow.

In this paper the installation of cross-flow inclined plates in velocity controlled grit removal chambers to reduce chamber length, improve removal efficiency and facilitate cleaning of chamber from deposited grit has been suggested and discussed.

Key Words: Wastewater grit removal chamber, Plate settlers.

Introduction

Use of basic settling concept first set forth by Hazen (1904) permits the placement of sloping plates and tubes of various shapes in sedimentation zone to remove the suspended, settleable solids more rapidly from the liquid. Once the solids have settled onto the plate, they will slide down to the basin bottom. The use of large number of such plates or tubes greatly increases the effectiveness of any sedimentation zone, permitting higher surface overflow rates. This concept was first used by an engineer in removing and concentrating slimes from mining wastes in 1913. The installation of such sloping plates in the sedimentation zone of an upflow settling tank was patented by Green 1947.

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Recently numerous proprietary designs of such plates and various shaped tubular configurations can be installed in existing clarification units to upgrade the overflow rate, and to obtain thicker sludge. They are well suited for water treatment settling units, however, their use on secondary settling units for handling activated sludge solids has not been without problems because of the tendency of biological flocs to stick to surfaces and because of slime growth on the surfaces (WPCF and ASCE, 1991).

Inclined plate and tube settlers are constructed to be used in one of three ways with respect to the direction of liquid flow relative to the direction of particle settlement: countercurrent, cocurrent, and cross-flow.

In this paper author suggests installation of cross-flow inclined plates in velocity controlled grit removal chambers to reduce chamber length, improve removal efficiency and facilitate cleaning of chamber from deposited grit.

Wastewater Grit Removal

Wastewater grit materials are characterized as non-putrescible, having a subsiding velocity substantially greater than that of organic putrescible solids, and generally discrete as opposed to flocculent in nature. Materials falling into these categories are particles of sand, gravel, other minute pieces of mineral matter, and non-putrescible organic such as coffee grounds, fruit rinds, and seeds. Grit is removed from a wastewater system to protect moving mechanical equipment from abrasion and abnormal wear, to reduce conduit clogging caused by deposition of grit particles in pipes or channels, particularly at changes in direction, and to prevent loading of treatment works with basically inert matter that might interfere with the operation of treatment units.

Differential sedimentation is a successful mechanism for the removal of grit because of difference in the rate of settling of organic putrescible solids and particles of grit. Richards (1908) explored that in the process of differential settling, there are actually two processes at work. The first is caused by different specific gravitates of organics and inorganics which cause different settling velocities. The second process is that of " bottom scour", which is effective in separating any organics that settle with the grit to the bottom of chamber.

Hazen`s report (1904) on subsidence of quartz sand having a specific gravity of 2.65 and 0.1 to 1.0 mm in size has been a basis for grit-chamber design. Camp (1942) recommended grit chamber to remove all particles with nominal diameter of 0.2 mm or larger with a specific gravity of 2.65. The settling velocity of these particles at 10°C is usually taken to be 2.3 cm/s.

Sometimes grit removal devices are designed to remove 0.15 mm sand particles with settling velocity of 1.3 cm/s taken from Campe`s curves. Camp has shown that the scouring process itself determines the proper velocity of flow through the unit. This way be explained by the fact that there is a critical flow velocity, over which particles of a particular size and density, once settled, may be again be placed in motion and reintroduced into the stream flow. Camp derived that the critical velocity for grit particles 0.2 mm in diameter and with a specific gravity of 2.65 is 0.23 m/s (WPCF and ASCE, 1991). It is common practice to maintain a horizontal flow velocity between 15 and 30 cm/s to keep organic particles in suspension. A velocity of 38 cm/s will scour 0.2 mm diameter quartz particles or organic particles up to a nominal diameter of 1.5 mm (Droste, 1997).

The many different types of wastewater grit chambers that have been used differ primarily in the methods of velocity control and grit removal. They can be divided into three basic types. Velocity controlled, aerated, and constant level short term sedimentation tanks (WPCF and ASCE, 1991).

Velocity controlled grit removal chambers are the oldest one. These units were designed to maintain a velocity as close to 0.3 m/s as practical and to provide sufficient time - typically one minute for girt particles to settle to the bottom of channel. Smith, E.G. (1943), Lee, M. and Babbitt, H.E. (1946), and Rao, N.S.L. and Chandrasekaran, D. (1972) proved that a control section on the downstream side of the channel must be employed to vary the depth of flow in the channel as the flow changed, thus providing relatively uniform velocities through a wide range of flow. A proportional weir, such as the Sutro weir, is frequently used as a control device. The length of channel will be governed by the depth required by the settling velocity and the control section, and the cross-sectional area will be governed by the rate of flow and by the number of channels. Allowance should be made for inlet and outlet turbulence; at least a 50 percent increase in the theoretical length is recommended (Metcalf and Eddy,1991). In this chamber grit removal is accomplished usually by a conveyor with scrapers, buckets, or plows.

In aerated grit chambers a spiral flow pattern is induced in the sewage as it moves through the tank by supplying air from a diffuser located on one side of the tank. The air supply must be adjustable to provide the " optimum" roll velocity for different conditions. The WPCF and ASCE (1991) state that a minimum hydraulic detention time of 3 minutes at maximum instantaneous flow rates will capture 95% of 0.21 mm diameter grit. Baffle and diffuser locations and air flow rate are more important design parameters than detention time.

The constant-level short term sedimentation tanks are also known as detritus tanks in which both grit and heavy organic solids alike settled out. The influent enters through baffles along one side of the tank and the effluent exits over a weir on the apposite side. These basins are designed to maintain detention time of one minute at maximum day flow. The area of the tank is based on the grit particle size desired to be removed. A safety factor of 2 is generally applied to theoretical surface overflow rate to allow for inlet and outlet turbulence in addition to short circuiting that will occur in the basin (WEF and ASCE, 1992). Hydraulic retention of the liquid within these tanks varies directly with the flow rate. This is a disadvantage because, particularly at low flow rates, significant quantities of organic material will be removed with the grit. It is necessary to use a grit washing device on the material collected from the detritus tank.

Inclined Tube and Plate Settlers

Culp et at. (1968) assumed that a uniform flow velocity would exist through out the tube and plate settlers. So a straight line trajectory will be followed by the particles in the tube settlers. Then the time T taken for a particle to settle the vertical distance between two parallel inclined surfaces is :

$$T = \frac{w}{V_s \cos\theta} \qquad (1)$$

where, w = perpendicular spacing between surfaces; V_s = particle's settling velocity, and θ = angle of surface inclination. The length of surface L_p needed to accommodate this time, when the liquid velocity between the surfaces is V_o , depends on the direction of flow as follow :

a) for countercurrent (Fig. 1-a)

$$L_p = \frac{w(V_o - V_s \sin\theta)}{V_s \cos\theta} \qquad (2)$$

b) for cocurrent settling (Fig. 1-b)

$$L_p = \frac{w(V_o + V_s \sin\theta)}{V_s \cos\theta} \qquad (3)$$

c) for cross - flow settling (Fig. 1-c)

$$L_p = \frac{wV_o}{V_s \cos\theta} \quad \text{..(4)}$$

The angle of inclination depends on the application, the need for self-cleaning, and the flow characteristic of sludge on the inclined surface. If the angle of inclination of surfaces is great enough, generally greater than 50 to 60°, self-cleaning of surfaces occurs (Yao,1973).

Yao (1970) made comprehensive theoretical analyses of the various flow geometries. Yao (1973) considered the parabolic velocity profile for the laminar flow regime across the tube and its affect on the particle trajectory. Yao recommended multiply the average flow velocity by the constant S_c. This constant is a shape factor dependent on the tube cross-sectional shape, and on the relative length of the flow system (L/w). The constant S_c represents the area under the fully developed parabolic velocity profile divided by the area under the uniform velocity profile. Yao found the S_c value to be 1.0 for parallel plates, 11/8 for square tubes and 4/3 for circular tubes. Yao also recommended that the required tube length be equal to the summation of the length calculated by Eq. 2-4 (multiplying V_o by content S_c) and a transition length L^* calculated by use of the Langhaar (1942) equation :

$$L^* = 0.058\frac{V_o d^2}{\nu},$$

where, ν is the fluid kinematic viscosity.

Yao suggested that the tube length should be equal to twice the length calculated by Eq.2-4 (multiplying V_o by constant S_c) if the transition length is longer that the calculated length. Fadel (1985) developed a model for predicting the velocity profiles at different distances along the circular tube length. He studied the affects of the velocity profiles on both the particle trajectory and the required tube settling length. Fadel also proved experimentally that the Yao mode slightly overestimates the required particle settling length, and Yao recommended design length is very conservative.

The main challenge in inclined settler development has been to obtain settling efficiencies close to theoretical. Considerable attention must be given to providing equal flow distribution to each channel, producing good flow distribution within each channel, and collecting settled sludge while preventing its resuspension (ASCE and AWWA, 1990).

Grit Removal Using Horizontal Flow Plate Settlers

Horizontal flow grit removal chamber is a special settling tank where not only the surface overflow loading but also the horizontal flow velocity should be specified for design propose. It is recommended to consider the wastewater peak flow (Q_{peak}) at the design the surface area of the chamber and built-in down-stream control section for holding the constancy of the designed horizontal flow velocity at various flow rates. So this chamber can easily be considered as open channel in which horizontal flow velocity is fixed by the control weir and independent of variation of wastewater flow rate.

For specified surface overflow rate V_s and horizontal flow velocity V_o the required surface area (L *x* B) and cross section area (d *x* B) are:

$$L.B = \frac{Q_{peak}}{V_s} \qquad (5)$$

$$d.B = \frac{Q_{peak}}{V_o} \qquad (6)$$

where, L = length; B= width; d= depth of sedimentation zone in the grit removal chamber.

Dividing Eq. 5 by Eq. 6

$$\frac{L}{d} = \frac{V_o}{V_s}.$$

$$L = d\frac{V_o}{V_s} \qquad (7)$$

shows that the required chamber length (L) is a direct proportion to the depth of sedimentation zone. So, where the minimum depth of sedimentation zone can be used, the minimum length can be achieved as clear in the case of using cross flow plate settler d= w = 25 - 50 mm. The other two plate settler patterns of flow geometries (countercurrent & cocurrent) have not be used because the horizontal flow velocity through them can not be controlled.

For illustration the effect of the installation of inclined plates on the length and performance of the horizontal flow grit chamber, we will design the chamber without and with installation of the inclined plates using the following data: diameter of grit to be completely removed= 0.2 mm, settling velocity for these particles (V_s)= 0.02 m/s, horizontal flow velocity (V_o) = 0.3 m/s, peak wastewater flow (Q_{peak}) = 200 l/s.

Conventional Velocity-Controlled Grit Chamber Design

1. Cross Section Dimensions Determining

Assuming a rectangular cross section with depth (d) = 1.5 times the width (b) at maximum flow, so from Eq. (6):

$$bd = (b)(1.5b) = 1.5b^2 = \frac{Q_{peak}}{V_o}$$

$$1.5b^2 = \frac{0.2m^3/s}{0.3m/s} = 0.67m^2,$$

therefore, b = 0.65 , d = 1.03

2. Length Determining

From Eq. (7):

$$L = d\frac{V_o}{V_s} = 1.03\frac{0.3}{0.02} = 15.45m$$

Take L =23 m to provide a 50% safety factor. Assuming 0.47 free broad, therefore, the tank dimensions are b= 0.65m, H (total height) = 1.5m, L = 23m.

3. Flow state determining

Reynolds number $(R_e) = \frac{V_o R}{\nu}$.

where, hydraulic radius $(R) = \frac{b.d}{b+2d} = \frac{0.65}{0.65+2(1.03)} = 0.24m$

at 20 °C ν as kinematics viscosity = 1.139 x 10^{-6} m^2/s,

therefore, $Re = \frac{0.3x0.24}{1.139x10^{-6}} = 63200$

Froude number $(Fr) = \frac{V_o^2}{gR}$,

where, (g) is the gravity constant = 9.81 m/s^2

$$\therefore \text{Fr} = \frac{(0.3)^2}{9.81 + 0.24} = 0.038$$

Plate Settlers Grit Chamber Design (Fig. 2)

1. Plates Length Determining

From Eq. (4) :

$$L_p = \frac{wV_o}{V_s Cos\theta} ,$$

assuming that the angle of inclination (θ) = 60° in order to achieve self cleaning and the perpendicular spacing between surfaces (w) = 50 mm,

therefore, $L_p = \frac{0.05x0.3}{0.02Cos60} = 1.5m$.

Take L_p = 2.25 to provide a 50 % safety factor.

2. Plenum Cross Section Determining

Assuming that the thickness of plate = 2.5 mm, so the ratio $(F)_a$ of the cross section area of channel (Plenum) to the actual cross section area of flow is :

$$F_a = \frac{50 + 2.5}{50} = 1.05$$

So $$b.d = 1.5b^2 = F_a \frac{Q_{peak}}{V_o} ,$$

$$1.5b^2 = 1.05x\frac{0.2m^3 / s}{0.3m / s} = 0.7m^2 ,$$

therefore, b = 0.7m , D = 1.0 m

Assuming 0.20 ms free side space for sand dropping and 0.5 ms free broad, therefore, plenum dimensions are b`(total width) = 0.9 m, H (total depth) = 1.5m , L_t (total length of plenum)) = 2.25 + 2d = 4.25 m (a transition section of length equal to 2d between the end of inclined plates and the proportional weir have been considered)

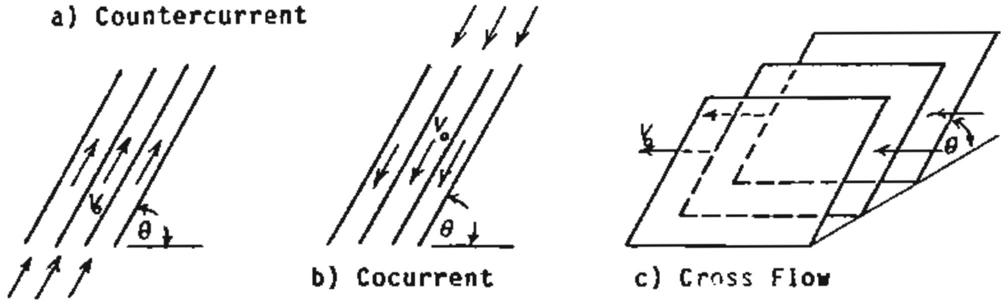


Fig.1 Basic flow geometries for inclined settling systems

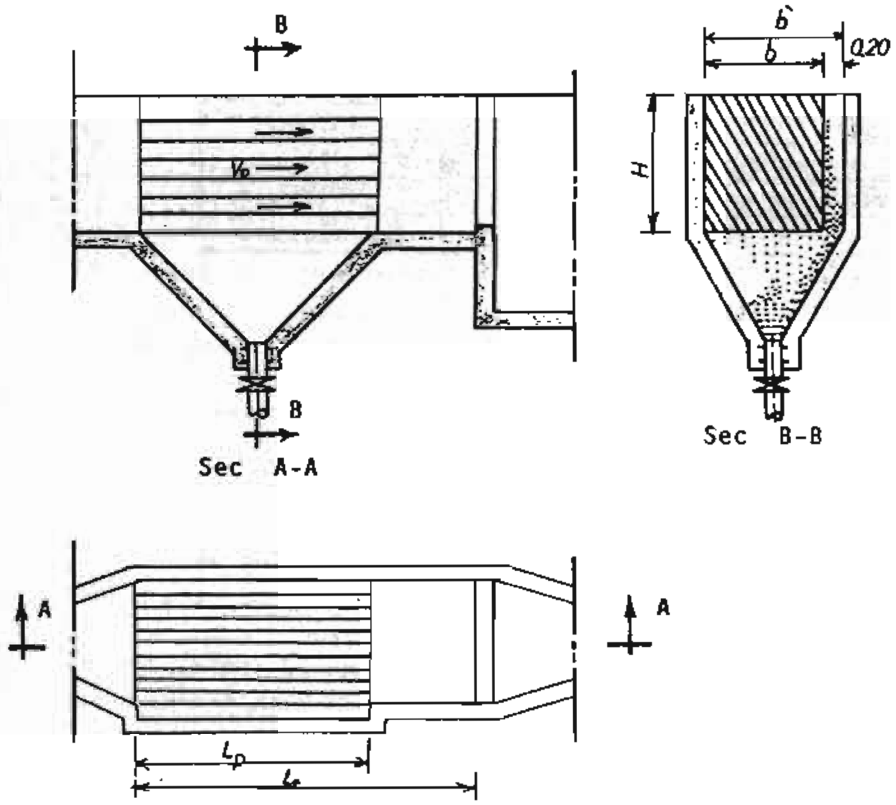
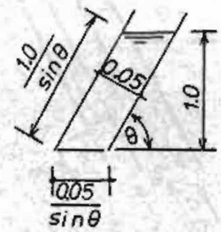


Fig.2 Plate settlers grit removal chamber

3. Flow State Determining

$$\text{The hydraulic radius } (R) = \frac{\frac{0.05}{\sin 0}x1.0}{\frac{0.05}{\sin 0} + 2x\frac{1.0}{\sin 0}} = \frac{0.05x1.0}{2.05} = 0.0244$$



$$\text{Reynolds number } (\text{Re}) = \frac{V_a R}{\nu} = \frac{0.3x0.0244}{1.139x10^{-6}} = 6430$$

$$\text{Froude number } (Fr) = \frac{V_a^2}{gR} = \frac{(0.3)^2}{9.81x0.0244} = 0.376$$

Comparison

Comparison between the dimensions and states of flow under the previous conditions is presented in the following table :

item	grit chamber without plates	grit chamber with plate settlers
width	0.65 m	0.90 m
height	1.5 m	1.5 m
length	23 m	4.25 m
Reynolds number	63200	6430
Froude number	0.038	0.376
Use of scrapers	necessary	not necessary

The figures in table show that the length of chamber with plate settlers is 5.4 times shorter than the length of chamber without plates and turbulency and stability of flow through grit chamber with plate settler is approximately 10 times better than that of grit chamber without plates. The chamber with plate settler can be made with steep bottom slopes (60-75°) that tend to move settled grit to a central point for removal without using scrapers.

Conclusion

The use of inclined plates or tube settlers greatly increases the effectiveness of any sedimentation zone. They can be used in one of three ways: countercurrent, cocurrent, and cross-flow.

Grit is removed from a wastewater system to protect moving mechanical equipment, to reduce conduit clogging and to prevent loading of treatment works with basically inert matter that might interfere with the operation of treatment units. The main different types of wastewater grit chambers are velocity controlled, aerated, and constant level short term sedimentation tanks.

The advantages of suggested construction of velocity controlled grit removal chambers with installation of cross-flow inclined plates are:

1. shortening the length of the grit chamber,
2. improvement the state of flow through the chamber- decreasing of Reynolds number and increasing of Froude number, and
3. simplicity of collecting the settled sand.

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