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ABOUT SEDIMENTATION PROCESS IN SECONDARY CLARIFIERS

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ABSTRACT: Secondary clarifiers are equipment used in wastewater treatment plants for gravitational separation of solid particles from water. As this process is chemically activated by adding flocculants to improve the settling, a mathematical model may be developed considering a mixture model and taking into account the relative velocity between the solid phase and the liquid one. This study presents issues regarding mathematical modeling of sedimentation process in secondary clarifiers.
Keywords: wastewater treatment, secondary clarifier, sedimentation, mixture flow

1. INTRODUCTION

In a waste water treatment plant, the role of secondary clarifiers is to retain the sludge formed previously in the biological treatment stage (i.e. treatment in biological filters or in aeration basins with activated sludge [1-4]), figure 1 [4].

Usually are used circular secondary clarifiers in which water flows in horizontal direction. Also known as Dorr clarifiers, they are composed of (see figure 2): settling basin made of concrete, wastewater inlet system positioned centrally (1), clean water peripheral outlet (2) and a sludge outlet system at bottom (3).

This study is centered on dimensioning secondary clarifiers and on mathematical method to model the mixture behavior inside secondary clarifiers, to improve their efficiency.

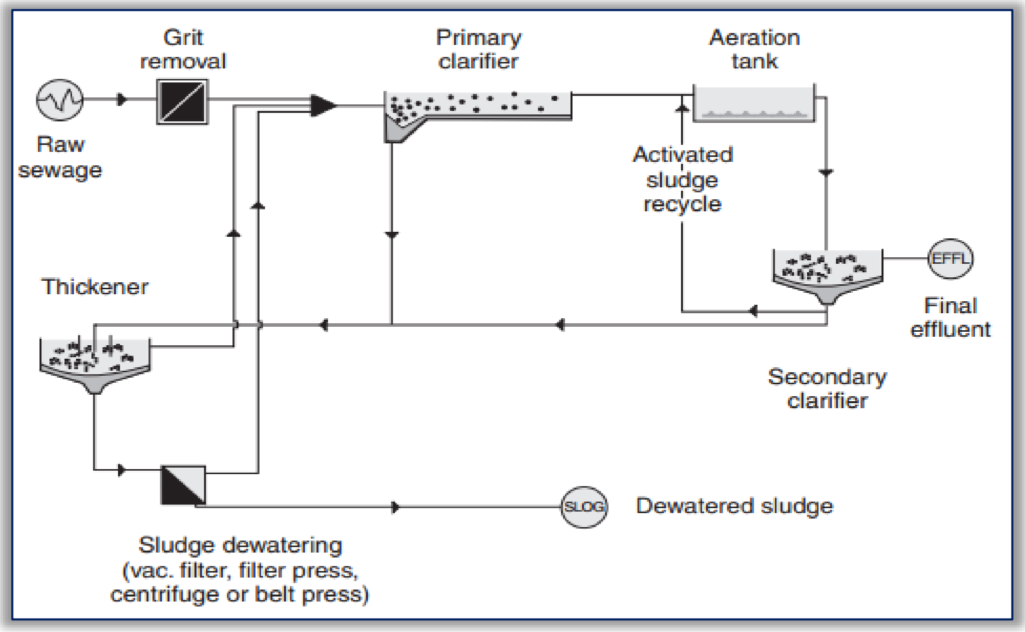
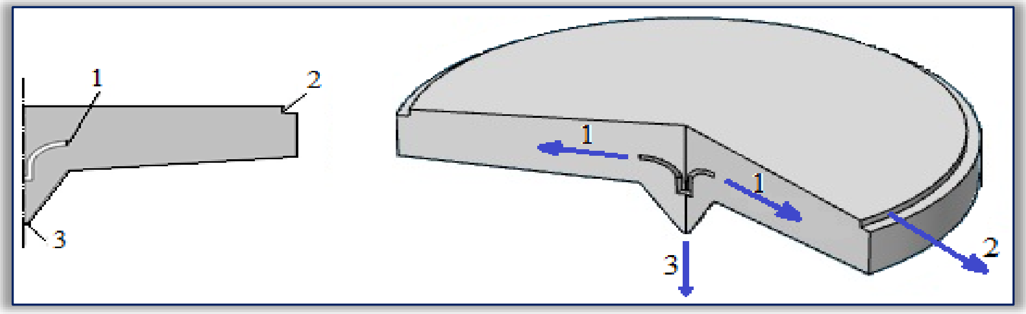


Figure 1. Schematic representation of a wastewater treatment plant equipment [4].



a) b)

Figure 2. Secondary clarifier scheme:
a) half cross-section, b) general view
1-wastewater inlet; 2- clean water peripheral outlet; 3- sludge outlet.

2. CIRCULAR CLARIFIERS FUNCTIONING AND DESIGN SPECIFICATIONS

As shown in figure 2, the wastewater enters centrally the clarifier, travels the basin in horizontal direction, while the solids settle to the bottom forming the sludge. Clear water is evacuated all over the clarifier peripheral surface area, while the sludge is evacuated at bottom being guided to the center of basin by a rotating scrapper [1-3].

Main geometrical dimensions of circular secondary clarifiers may be determined by the formulas [1-3]:

- volume:

$$V = Q \cdot t\,[m^3] \tag{1}$$

where: Q $[m^3]$ is wastewater flow rate, t[h] is settling time.

- aria:

$$A = \frac{Q}{v}\,[m^2] \tag{2}$$

where: v [m/h] is wastewater velocity in horizontal direction;

- height:

$$H = \frac{V}{A}\,[m] \tag{3}$$

- diameter:

$$D = \sqrt{\frac{4 \cdot A}{\pi}}\,[m] \tag{4}$$

- sludge retraction volume:

$$V_{sludge} = \frac{\eta \cdot c}{\rho_s} \cdot Q \cdot \frac{100}{100-p}\,[m^3/day] \tag{5}$$

where: η [%] is sedimentation efficiency; c $[\frac{kg}{m^3}]$ is solids initial concentration in wastewater; ρ_s $[\frac{kg}{m^3}]$ is sludge specific weight (1000–1200 kg/m³); Q $[m^3/day]$ is wastewater flow entering the clarifier; p[%] is sludge moisture (95%).

Also, some dimension limitations are stipulated as that circular clarifiers are constructed with maximum diameter of 50 m but no less than 15 m and their height is in range 2.5 ÷ 4 m [1].

The inlet system must provide a uniform water flow and its end positioned at 20 ÷ 30 cm under the water level [3].

According to Romanian standard no. 3620 [2], the settling velocity, flow velocity in horizontal direction, settling time and efficiency of secondary clarifiers are:

$$u = 0.8 \div 2.1\ m/s,\ v = 5 \div 10\frac{mm}{s},\ t_d = 1.5 \div 2.5\ h \text{ and } \eta = 80 \div 90\%.$$

3. MATHEMATICAL MODELLING OF SEDIMENTATION IN SECONDARY CLARIFIERS

3.1. Governing equations

In order to model the sedimentation process in secondary clarifiers, a multiphase (*solid particles* as dispersed phase and liquid as continuous phase) flow must be defined and the governing equations solved probably with a software involving finite element analysis [5-8]. Also, the model may be created in 2D dimension, which may enable solutions for half geometry along a symmetric vertical axis (as in figure 1, a).

So, the following equations describing the multiphase flow model must be solved [5-8]:

» The momentum transport equation:

$$P\frac{\partial U}{\partial T} + P(U\cdot\nabla)U = -\nabla P - \nabla\cdot(P\cdot C_D(1-C_D)U_{SLIP}U_{SLIP}) + \nabla\cdot T_{GM} + PG \quad (6)$$

» The continuity equation:

$$(P_C - P_D)[\nabla\cdot(\Phi_D(1-C_D)U_{SLIP} - D_{MD}\nabla\Phi_D)] + P_C(\nabla\cdot U) = 0 \quad (7)$$

» The mass conservation equation:

$$\frac{\partial}{\partial T}(\Phi_D P_D) + \nabla\cdot(\Phi_D P_D U_D) = 0 \quad (8)$$

where: $u(m/s)$is mixture velocity, $\rho(kg/m^3)$ is mixture density, $p(Pa)$ ispressure, $c_d(kg/kg)$ is mass fraction of the solid phase, $u_{slip}(m/s)$ is the relative velocity between the two phases, $\tau_{Gm}(kg/(m\cdot s^2))$ is the sum of viscous and turbulent stress, $g(m/s^2)$ is the gravity vector.
In equations (6)-(8) subscript “d” denotes dispersed phase (solid particles) and “c” denotes continuous phase (liquid, i.e. water).
The mixture velocity is:

$$U = \frac{\Phi_C P_C U_C + \Phi_D P_D U_D}{P}\ (\frac{M}{S}) \quad (9)$$

where: ϕ_c and $\phi_d(m^3/m^3)$ are volume fractions of the liquid (continuous phase) and solid (dispersed phase), respectively, $u_c(m/s)$ is liquid-phase velocity, $u_d(m/s)$ is solid-phase velocity, $\rho_c(kg/m^3)$ is liquid-phase density, $\rho_d(kg/m^3)$ is solid-phase density.
The relation between the velocities of the two phases is:

$$u_d - u_c = u_{cd} = u_{slip} - \frac{D_{md}}{(1-c_d)\phi_d}\nabla\phi_d \quad (10)$$

where the particle dispersion coefficient is:

$$D_{MD} = \frac{H_T}{P\cdot\Sigma_T}\ (M^2/S) \quad (11)$$

andη_T (Pa·s) is turbulent viscosity, $\sigma_T$is (dimensionless) turbulent Schmidt number, which usually takes the value of 0.35 [5].
For the slip velocity (velocity difference between the two phases), the Hadamard-Rybczynski drag law for solid particles have the expression:

$$u_{slip} = -\frac{(\rho-\rho_d)d_d^2}{18\cdot\rho\cdot\eta}\nabla p\ \ [\frac{m}{s}] \quad (12)$$

where: $d_d(m)$ is diameter of the solid particles.
For the mixture dynamic viscosity (Krieger type) and density, the expressions are:

$$H = H_C\left(1 - \frac{\Phi_D}{\Phi_{MAX}}\right)^{-2.5\Phi_D}\ \ [\frac{N\cdot S}{M^2}] \quad (13)$$

$$P = \Phi_C P_C + \Phi_D P_D\ [\frac{KG}{M^3}] \quad (14)$$

where: $\phi_{max} = 0.62$ is solid phase maximum packing concentration.
Solvers involving the Mixture Model application mode have the above equations as a predefined model [5]. If no other conditions are needed (e.g. slip velocity defined by another drag law or Boussinesq approximation correlated with mixture gravity), further, users must provide to the model initial parameters (physical properties of the two phases) and boundary conditions.

3.2. Defining initial parameters and boundary conditions

As initial parameters must be defined the following: density and viscosity of liquid phase (water), density and diameter of suspended solids, and also inlet and outlet (at clarifier bottom) mixture velocities in vertical direction [5]. At both inlet and bottom outlet, the mixture velocity in horizontal direction must be set at 0 value.
Initially, for the entire model domain which contains the mixture are considered: zero velocity, zero solid phase volume fraction (ϕ_d), with the hydrostatic pressure acting within as $p = \rho_c \cdot g \cdot h$ (Pa) , h(m) being the domain height. Also, at the peripheral outlet, the pressure must be set at zero value [5].

4. CONCLUSIONS

Secondary clarifiers are used as final stage in wastewater treatment, so on their efficiency depends the final effluent properties. For dimensioning the settling basin initial parameters are: wastewater flow rate, flow velocity in horizontal direction and settling time.
Also, for gravitational settling in secondary clarifiers a model may be developed by defining the mixture properties which is composed of a continuous phase (liquid) and a dispersed one (solid

particles). The slip velocity law (velocity difference between the two phases) also must be specified.

Obtained results depending on time refers to: mixture velocity, solid phase volume fraction, mass flux of the dispersed phase at inlet, peripheral outlet and central outlet [5].

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