Aalborg Universitet

Development of a Numerical Model for Secondary Clarifiers

Dahl, Claus; Larsen, Torben; Petersen, Ole

Published in:
International Association for Hydraulic Research, XXIV Congress, Madrid, Sep 1991

Publication date:
1991

Document Version
Peer reviewed version

Citation for published version (APA):
Dahl, C., Larsen, T., & Petersen, O. (1991). Development of a Numerical Model for Secondary Clarifiers. In
International Association for Hydraulic Research, XXIV Congress, Madrid, Sep 1991 Madrid: Madrid.

DEVELOPMENT OF A NUMERICAL MODEL
FOR SECONDARY CLARIFIERS

by

Claus Dahl

I. Krüger AS, Gladsaxevej 363, DK-2860 Søborg, Denmark

Torben Larsen and Ole Petersen

Department of Civil Engineering, University of Aalborg

Sohngaardsholmsvej 57, DK-9000 Aalborg, Denmark

Summary

A numerical model of flow and sedimentation in secondary clarifiers is presented. The numerical model is an attempt to describe the complex and coupled hydraulic and sedimentation phenomena in secondary clarifiers by describing the turbulent flow field and the transport/dispersion of suspended solids. The numerical model is discussed, and compared with full scale measurements. The achived results should be understood as the first step towards a numerical model for secondary clarifiers and further research will be necessary.

Introduction

Sedimentation or settling of suspended solids (SS) by gravity in clarifiers is the most common treatment process for separation of SS from wastewater. Sedimentation is used in wastewater treatment to remove particulate matter in primary clarifiers and biological flocs, from activated sludge processes, in secondary clarifiers. The particulate matter in the inflow can be characterized as a non-cohesive material while the biological flocs from the treatment process is a highly cohesive material. These differences gives significant differences in the process of suspended solids removal in the two tank types.

Numerical models for calculating flow-field and SS-concentration field in primary clarifiers have been presented by several researchers, e.g. by (Stamou, 1989), where the numerical models have shown a good agreement with measurements. Development of numerical models to describe the coupled hydraulic and sedimentation phenomena in secondary clarifiers seems to be limited despite the fact that the efficiency of the secondary clarifiers are important to the resulting effluent quality. In the thesis by the first author (Dahl, 1990) a first step was taken towards the formulation and implementation of a numerical design tool for secondary clarifiers. This paper presents the ideas behind the work and gives a summary of some of the achieved results.

Qualitative overview

Some of the observed phenomena in secondary clarifiers have been described qualitatively by Lumley (Lumley, 1990) who suggested a division into different transport zones, each with their own characteristics in terms of flow and sedimentation behaviour.

Some of the predominant phenomena are the heavy density current along the top of the sludge blanket where a substantial part of the solids are removed and the formation of the sludge blanket below with high SS concentrations of which result in inter particle forces important to sludge thickening and consolidation.
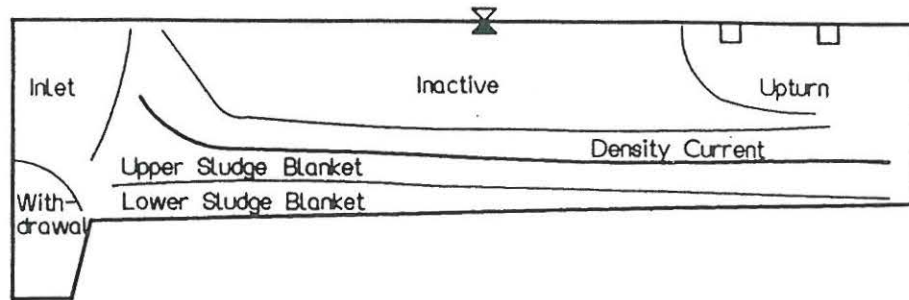

Figure 1.   Transport zones in secondary clarifier. After (Lumley, 1990).

One objective of the numerical model of secondary clarifiers is to provide a realistic description of these transport zones and the transitions between them.

The subject of the present study has been a secondary clarifier, located at the 175,000 pe. wastewater treatment plant in Herning, Danmark. The plant operates in accordance with the BIO-DENITRO method from I. Krüger AS which includes an activated sludge process and separate secondary clarifiers (Tetreault, 1987).

The geometric configuration of the rectangular clarifier and the simplifications used in the numerical model is seen in Fig. 2.
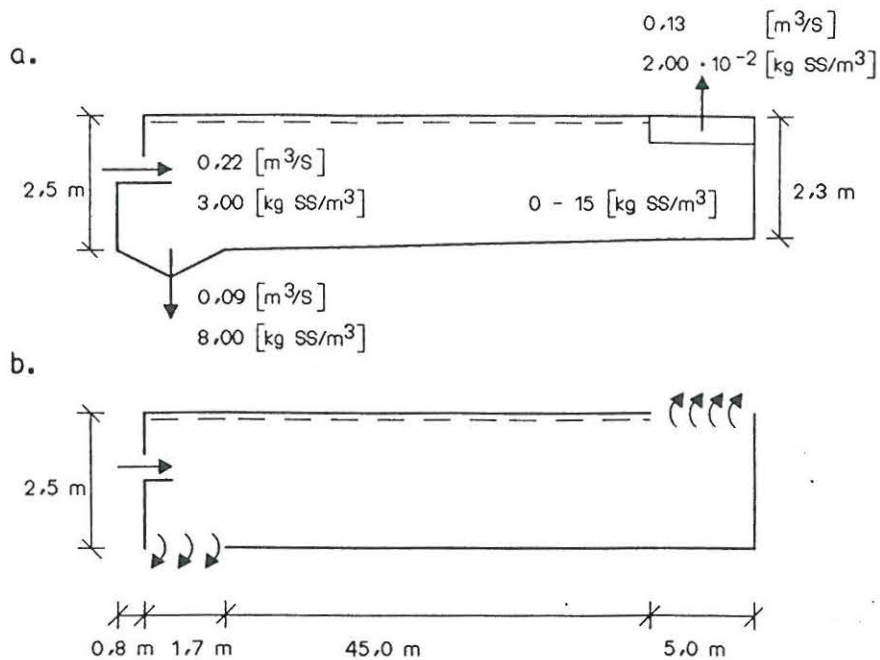

Figure 2.   a. Geometric configuration of secondary clarifier, Herning.
             b. Simplification of geometric configuration used in the numerical model.
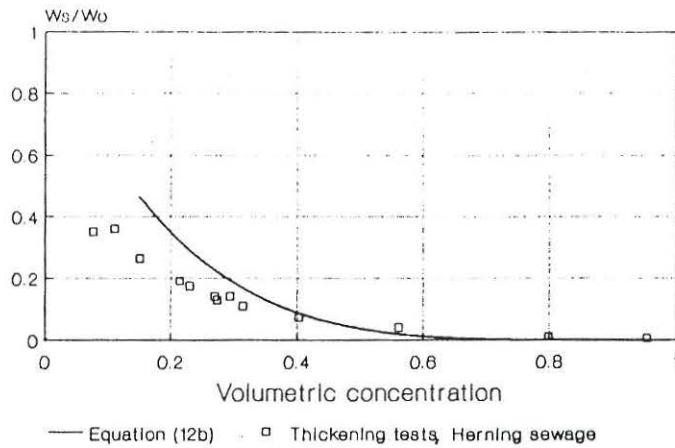
Figure 3. W_s / W_o versus ϕ.

The equations are solved on a cartesian staggered grid using an iterative method which retains all couplings between the variables. The resolution used here is 0.4 - 7.0 m i x-wise direction and 0.1 - 0.25 m in z.The numerical solution was implemented as an extension to the PHOENICS program. (Rosten, 1987).

Application of the numerical model

The results from the numerical model are compared with measurements of velocities, suspended solids concentrations and "Flow Throug Curves" on the Herning wastewater treatment plant made during the spring 1990.

Measured and predicted profiles of horizontal velocities in three sections are shown in Fig. 4 and 5 for two different dates. Although there is some discrepancy on the actual figures, the model gives an accurate prediction of the location of the density and return currents. Part of the deviation can probably be attributed to three-dimensional effects, although the measurements indicated that these were of minor importance, apart from very close to the end walls.
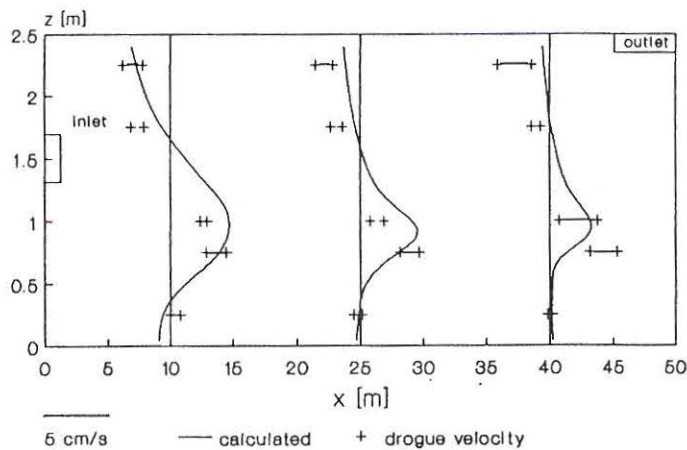

Figure 4.   Velocity profiles. Date 6 March, 1990.
Hydraulic load: 0.218 (m³/s).
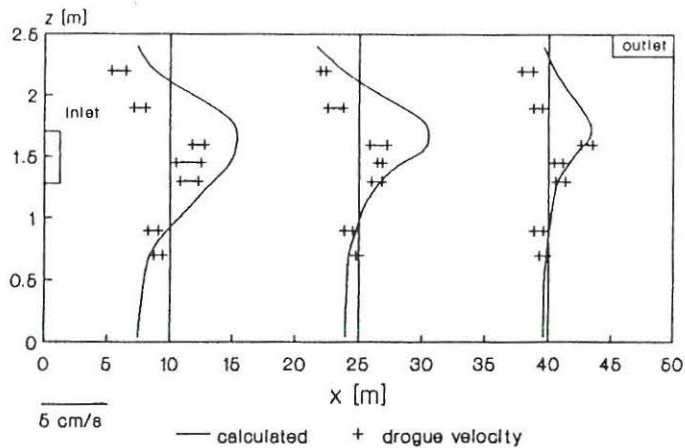SS load: 3.07 (kg/m³).

3

Figure 5.   Velocity profiles. Date 4 April, 1990.
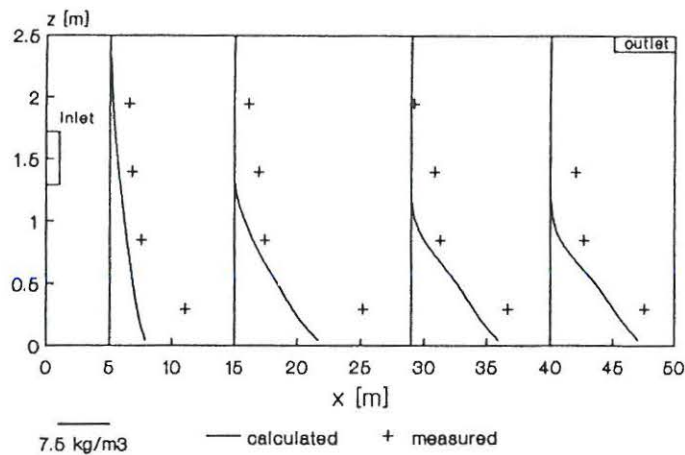   Hydraulic load: 0.218 (m³/s)
             SS load: 3.02 (kg/m³)

Figure 6.   Suspended solids concentration. Date 4 April, 1990.
             SS load: 3.02 (kg/m³).

Noting the difficulties in obtaining accurate measurements under field conditions, the predicted vertical profiles of suspended solids in Fig. 6 show at least a qualitative agreement. But due to the relative high hydraulic loads, no distinct sludge blanket was detected. The apparent difference in the total mass was attributed to the simplified description of the complex lower boundary where the sludge consolidates and is removed by scrapers.

The transport of dissolved substances through the clarifier seems reasonably well predicted as shown in Fig. 7 which compares calculated and measured "Flow Through Curves". Both dispersion and residence times from calculations and measurements, respectively, show similar values.

To further illustrate the results from the numerical model the distribution of SS is shown in Fig. 8 and the distribution of the turbulent eddy viscosity in Fig. 9. From the plots it appears how the relativly high SS concentrations near the bottom have the effect of rapidly consuming turbulence, leading to the small values of turbulent eddy viscosity.

Numerical model

The numerical model presented here is based on two sub-models: a flow model which solves the flow field equations and a SS-transport model based on the transport/dispersion equation for the SS-concentrationfield.

The basic assumptions are that the flow can be described as a suspension where relative density differences induced by contents of suspended solids are small. It is further assumed that all turbulent fluxes can be described by an eddy diffusivity or viscosity.

Flow-model

The flowmodel determines the horizontal velocity (U), the vertical velocity (W), the pressure (P) and the turbulent eddy viscosity (υ_t). The flow-field is described as a 2 dimensional, inhomogeneous, turbulent and buoyancy effected flow. The flow-field equations are the continuity equation, the average Navier-Stoke's equations, the K-ε model equations and an equation of state, linking the density of the suspension to SS-concentration.

Continuity

$$\frac{\partial U}{\partial x} + \frac{\partial W}{\partial z} = 0 \tag{1}$$

Momentum

$$\frac{\partial U}{\partial t} + \frac{\partial U^2}{\partial x} + \frac{\partial UW}{\partial z} = -\frac{1}{\rho_r}\frac{\partial P}{\partial x} + 2\frac{\partial}{\partial x}\nu_{eff}\frac{\partial U}{\partial x} + \frac{\partial}{\partial z}\nu_{eff}\frac{\partial U}{\partial z} + \frac{\partial}{\partial z}\nu_{eff}\frac{\partial W}{\partial x} \tag{2}$$

$$\frac{\partial W}{\partial t} + \frac{\partial UW}{\partial x} + \frac{\partial W^2}{\partial z} = -\frac{1}{\rho_r}\frac{\partial P}{\partial z} + 2\frac{\partial}{\partial z}\nu_{eff}\frac{\partial W}{\partial z} + \frac{\partial}{\partial x}\nu_{eff}\frac{\partial W}{\partial x} + \frac{\partial}{\partial x}\nu_{eff}\frac{\partial U}{\partial z} + g\frac{\rho - \rho_r}{\rho_r} \tag{3}$$

K - ε turbulence model

$$\nu_{eff} = \nu + \nu_t = \nu + C_\mu\frac{k^2}{\varepsilon} \tag{4}$$

$$\frac{\partial k}{\partial t} + \frac{\partial Uk}{\partial x} + \frac{\partial Wk}{\partial z} = \frac{\partial}{\partial x}\frac{\nu_t}{\sigma_k}\frac{\partial k}{\partial x} + \frac{\partial}{\partial z}\frac{\nu_t}{\sigma_k}\frac{\partial k}{\partial z} + P_r + G_k - \varepsilon \tag{5}$$

$$\frac{\partial \varepsilon}{\partial t} + \frac{\partial U\varepsilon}{\partial x} + \frac{\partial W\varepsilon}{\partial z} = \frac{\partial}{\partial x}\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial x} + \frac{\partial}{\partial z}\frac{\nu_t}{\sigma_\varepsilon}\frac{\partial \varepsilon}{\partial z} + C_{1\varepsilon}\frac{\varepsilon}{k}P_r + C_{3\varepsilon}\frac{\varepsilon}{k}G_k - C_{2\varepsilon}\frac{\varepsilon^2}{k} \tag{6}$$

$$P_r = \nu_t\left(2\left(\frac{\partial U}{\partial x}\right)^2 + 2\left(\frac{\partial W}{\partial z}\right)^2 + \left(\frac{\partial U}{\partial z} + \frac{\partial W}{\partial x}\right)^2\right) \tag{7}$$

$$G_k = \frac{g}{\rho_r}\frac{\nu_t}{\sigma_T}\frac{\partial \rho}{\partial z} \tag{8}$$

$$\rho = f(SS) \tag{9}$$

The set of constants appearing in the model are those cited in (Rodi, 1984).
The high concentrations of SS under the sludge blanket is known to influence the viscosity heavily. The effective viscosity is implemented as a sum of υ_t and υ which is determined by a empirical relation between υ and SS concentration (Bokil, 1972).

$$\frac{\upsilon}{\rho} = 3.273 \; 10^{-3} \; 10^{0.132\,C} \tag{10}$$

where C represents suspended solids concentration [g/l].

SS transport model
The distribution of SS concentration is described by a transport/dispersion equation.

$$\frac{\partial C}{\partial t} + \frac{\partial UC}{\partial x} + \frac{\partial WC}{\partial z} = \frac{\partial}{\partial x}\frac{\upsilon_t}{\sigma_T}\frac{\partial C}{\partial x} + \frac{\partial}{\partial z}\frac{\upsilon_t}{\sigma_T}\frac{\partial C}{\partial z} + \frac{\partial}{\partial z}w_s C \tag{11}$$

The downward flux of SS due to settling is described as a combination of free and hindered settling, dependend on the volumetric concentration of SS, $\phi = SVI \; x \; C$ where SVI is sludge volume index.

$$w_s = w_o \qquad \qquad for \qquad 0 < \phi < 0.15 \tag{12a}$$

$$w_s = w_o(1-\phi)^{4.7} \qquad for \quad 0.15 < \phi < 1 \tag{12b}$$

(Mandersloth, 1986)
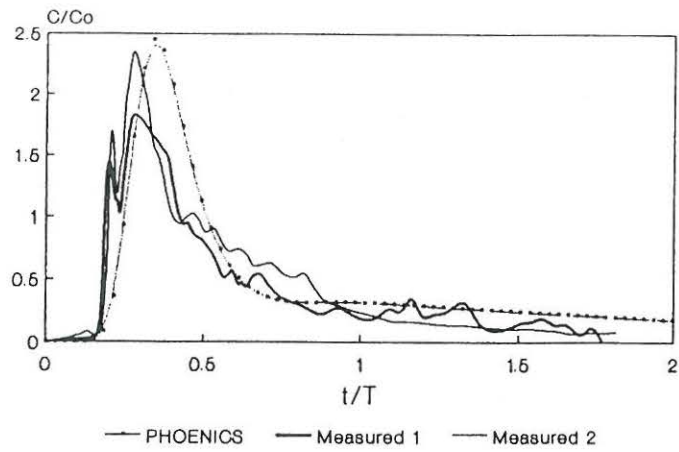
Fig. 3 shows (12b) compared with measurements.

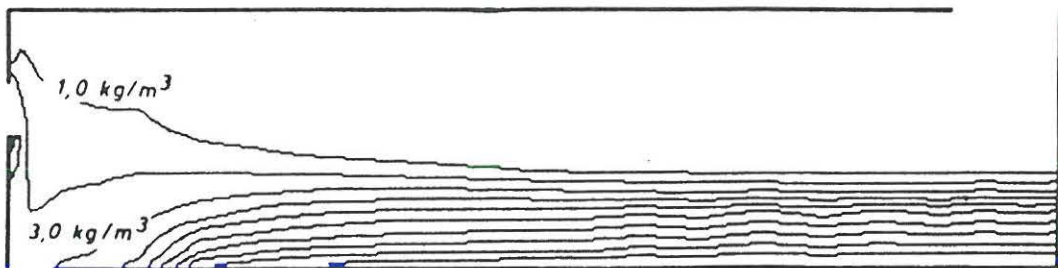Figure 7.   "Flow Through Curves" of pulse injection of Rodamin B in inlet. Date 6 March. 1990. T = 1.27h.

Figure 8.   Calculated distribution of SS. [kg SS/m³].
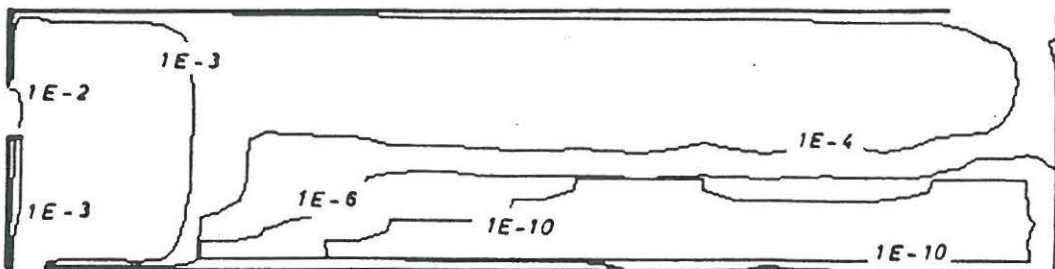

Figure 9.   Calculated turbulent eddy viscosity. [m²/s].

Discussions and conclusions

The results from the numerical simulations show qualitative agreements with the clasification in transport zones from Fig. 1. This means that the numerical model to some extent can reproduce motions in secondary clarifiers. However, in zones like the inlet zone, the withdrawal zone and the lower sludge blanket zone there is a need of further development before an acceptable description can be presented.

During development of the numerical model some phenomena is found to be of high importance for prediction of the flow field and sedimentation in secondary clarifiers. One of these phenomena is the density differences of suspensions which create a division of the clarifier into different transport zones. Another important phenomenon is the change in suspension rheology due to high differences in SS concentrations which is a difficult phenomenon to examine and describe in a numerical model. Finaly, the sedimentation velocity of cohesive suspended solids at different SS-concentrations is a very important phenomenon to describe realisticly in the description of activated sludge sedimentation. The results presented here should be understood as the first step towards a numerical design model for secondary clarifiers. A joint 2-year research program by I. Krüger AS and The University of Aalborg is expected to bring the modelling from research to engineering practice.

References

Bokil, S.D., Bewtra, J.K. 1972. "Influence of Mechanical Blending on Aerobic Digestion of Waste Activated Sludge." 6 th. Int. Conf. on Water Pollution Research, Jerusalem, Israel, 1972.

Dahl, C.P., Kjelds, J.T., Sørensen, H.R., 1990. "Numerical Modelling of a Secondary Clarifier". University of Aalborg, Master Thesis in Environmental Engineering, June 1990 (in Danish).

Larsen, P., 1977. "On the Hydraulics of Rectangular Settling Basins, Experimental and Theoretical Studies". Report No. 1001, Department of Water Resources Engineering, Lund Institute of Technology, Lund, Sweden, 1977.

Lumley, D.J. and Balmér, P., 1990. "Solid Transport in Rectangular Secondary Settlers". Water Supply, Vol. 8, Jönköbing pp 123-132, 1990.

Mandersloat, W.G.B., Scott, K.J. and Geyer, C.P., 1986 "Sedimentation in the Hindered Settling Regime." Advance in Solid-liquid Separation edited by H.S. Muralidhara. Batelle Memorial Institute, Ohio, 1986.

Rodi, W. 1984 "Turbulence models and their applications in hydraulics". IAHR. Delft, Holland.

Rosten, H.J. and Spalding, D.B., 1987 "The PHOENICS Reference Manual". Cham Ltd. London, Report TR/200, 1987.

Stamou, A.I., Adams, E.W., Rodi, W. 1989 "Numerical Modelling of Flow and Settling in Primary Rectangular Clarifiers". Journal of Hydraulic Engineering, ASCE Vol. 27, No. 5, 1989.

Tetreault, M.f., Rusten, B, Benedict, A.H. Kreissel. f.F. 1987 "Assesment of Phased Isolation Ditch Technologies". Journal WPCF, September 1987.