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SIMULATION OF A SECONDARY SETTLER BASED ON SEDIMENTATION CURVES

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The settlers of wastewater treatment plants are of the same importance as the activated sludge tanks. This role manifests in the course of simulating wastewater treatment systems as well. Several models describing the process of sedimentation were developed of which the one-dimensional models dividing the settlers into given layers are wide-spread.

In this paper the parameter dependence of the Takács-model was studied. Samples were taken from the wastewater arriving to the secondary settler at different times in order to determine the settling profiles belonging to different concentrations. The Vesilind function and the maximum practical settling velocity were derived base on these data. Using three sets of measurement data the Takács model was fitted by modifying certain parameters.

The simulation results gave an overestimation on the concentrations of the effluent in all three cases and there were differences of a few percents in the lowest layer as well. Taking the changes in the order of magnitude of the suspended solids concentration into consideration in the process of sedimentation i.e. it had to be decreased from 4000–6000 g/m^3 to 8–12 g/m^3 the higher values in the effluent layer are acceptable until they are below the permissible limit.

Key-words: settling velocity, Takács-model, wastewater, Vesilind-function

Introduction

The phase separation units of wastewater treatment plants, the settlers share the same importance as the activated sludge reactors [12]. This feature appears in modelling wastewater treatment sytems, too. Of the many models developed in order to describe the processes of sedimentation, the one dimensional settler models with given number of layers are popular [5, 6, 13]. These models while adequately predicting the main functionalities of the settlers do not add significant computational load to the process model of the wastewater treatment plant [3]. Even when such a model is used, proper calibration of parameters is vital. Beside modifying the effluent quality the settler influences the results of the biological model through the returned sludge concentration. False settler values deteriorate the results of the whole model of the wastewater treatment plant.

The one-dimensional models are based on the simplifying assumption that the horisontal velocity profiles are uniform and that the horizontal concentration gradients are negligible [4, 6, 8]. This concludes that only vertical solids movement is modeled. The settler cylinder is taken as a continuous flow reactor. At the inlet section, the inflow together with the introduced suspension are homogeneously spread over the horizontal cross section. The mixed liquor concentration is modified by convection and other transport processes. The flow is divided into a downward flow towards the underflow exit at the bottom, and an upward flow towards the effluent exit at the top [7]. At the bottom of the reactor the solids flux due to gravitation is taken zero.

The premise of the research was supplied by the dissertation of Holenda [4]. He examined six different one-dimensional settler models based on literature data. The results were not validated on a real settler but it became clear that the different models gave different output values using the same input. Other works [2, 13] highlighted that the model parameters depend on the given systems and have to be altered according to the actual load.

In this paper the parameter dependency of the most wide-spread model of wastewater treatment simulation practice, the Takács-model [13] was examined by modeling the secondary settler of a regional municipal wastewater treatment plant. There are several parameters in the applied equation that can not be measured directly and even if they can be, the measurement results are burdened with observational errors.

The focus of the research was on how the parameters affect the effluent and returned sludge suspended solids concentration and whether and to what extent can one set of parameters be used for different sets of input values with similar incoming concentrations.

Materials and methods

The double exponential velocity function of Takács [13] was used for modelling but the maximum practical velocity was determined with the Vesilind function [14]. Sampling from the mixed liquor arriving to the secondary settler of the examined wastewater treatment plant was repeated for several different times. The multiple samples resulted in sedimentation curves for different suspended solids concentrations.

Settler models

There are four different types of sedimentation characteristics depending on the quality and the concentration of the suspended solids [13]:

1. Discrete particle settling: It is characterized by solids which settle individually without any significant interaction.
2. Flocculent particle settling: It is characterized by the flocculation of solid particles while they settle through the water column.
3. Hindered settling: The mass of particles settles as a unit, the interaction between the particles hinder the settling process.
4. Compression settling: The decrease of the interface level is achieved by the compression of the mass of particles.

The most widespread model that is used to describe the ongoing processes in a settler unit is the Takács-model. The used equation is based on the model of Vesilind [14]. Beside the hindered settling described by the function developed by Vesilind, Takács et al. [13] added a second term to implement the effect of the flocculent particle settling as well. They hoped to create a function that is able to give a more realistic estimate on the effluent suspended solids concentration. The double exponential equation settling velocity of Takács is as follows [13]:

$$v_s = \max\left\{0, \min\left[v_0', v_0\left(e^{-r_h(X-X_{\min})} - e^{-r_p(X-X_{\min})}\right)\right]\right\}$$

where

v_0 practical maximum (Vesilind) settling velocity (m/d),
v_0' theoretical maximum settling velocity (m/d),
r_h hindered zone settling parameter (m^3/g),
r_p flocculent zone settling parameter (m^3/g),
$X_{\min}$ minimum attainable suspended solids concentration (g/m^3)

$$X_{\min} = f_{ns} X_f$$

where

f_{ns} non-settleable fraction (-) and
X_f mixed liquor suspended solids concentration entering the settler (g/m^3).

While the Vesilind function is [14]:

$$v_s = v_0 e^{-p_{hin} X}$$

where

v_s actual settling velocity (m/d),
v_0 starting settling velocity at 0 g/m^3 theoretical suspended solids concentration (m/d),
p_{hin} hindered zone settling parameter
X suspended solids concentration (g/m^3)

In cases of small (0–1500 g/m^3) concentrations the Vesilind function can be interpreted only mathematically. The settling velocity in this range is either immeasurable or the results show great uncertainty.

Features of the wastewater treatment plant

The capacity of the examined wastewater treatment plant is 21,000 m^3/day. There are two parallel biological lines capable of enhanced biological phosphorous removal. Each train ends in a Dorr-type secondary settler having 5100 m^3 volume, a diameter of 40 m and 2.8 m depth. The samples were taken from line I. At the time period examined the weather was dry therefore the effect of rainfall did not have to be taken into consideration. Since the typical sludge age of the plant is around 20 days it can be assumed that the quality and so the settling characteristics of the sludge did not change significantly therefore the samples taken at different times and the results derived from them can be compared to each other. The data used for the research are shown in *Table 1.*

Table 1: Sets of measurement data used for the experiment

	Sludge concentration			Flow	Excess sludge removal
	Aerobic tank	Top of the settler	Bottom of the settler		
	g/m^3	g/m^3	g/m^3	m^3/day	m^3/day
1. set	4316	8	9000	7030	200
2. set	5039	12	7900	6954	250
3. set	3892	8	6600	6993	250

Preparation for modeling

Samples from the last section of the aerated tank were taken for three different occasions in order to receive different suspended solids concentrations. The sedimentation curves of the three homogenized samples were measured by registering the height of the sludge-water interface in a 1000 cm^3 cylinder in the function of time. Each sample was diluted to approximately half of the original concentration and the measurement process was repeated. The results are shown in *Fig. 1*.

In order to determine the settling velocity belonging to each SS concentration the linear section of the curves had to be specified. *Fig. 2* shows a general sedimentation curve where each section is numbered (the linear section is labelled as No.2).

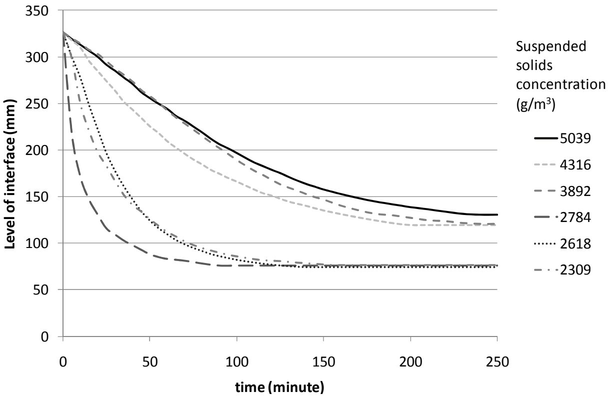

Figure 1: Sedimentation curves of samples with different suspended solids concentrations

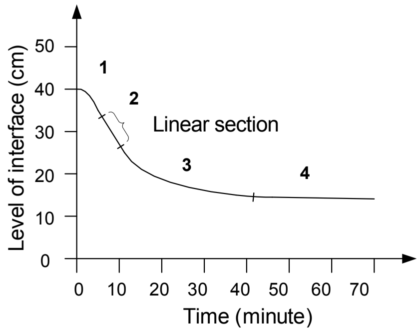

Figure 2: Sedimentation curve [3, 9]
1 – flocculation zone, 2 – hindered settling zone, 3 – transitional zone, 4 – compression zone

The linear section which is the phase of the hindered sedimentation provides the constant settling velocity that can be coupled with a certain concentration. The precision of the examination relies on the recognisability of this phase on the real sedimentation curves. Beside the uncertainty of the measurement a great hindrance can be when the interface is not well determinable, for example if the sludge is subject to bulking or foaming.

After determining the linear sections the settling velocities of the different samples could be calculated. The settling velocities plotted in function of the suspended solids concentration are shown in *Fig. 3*. The exponential curve fitted on these values is described with an equation identical to the Vesilind equation therefore it provides the maximum practical settling velocity ($v_0 = 15.101$ m/d). This value was used in the Takács-model but other parameters were estimated in the course of modelling.

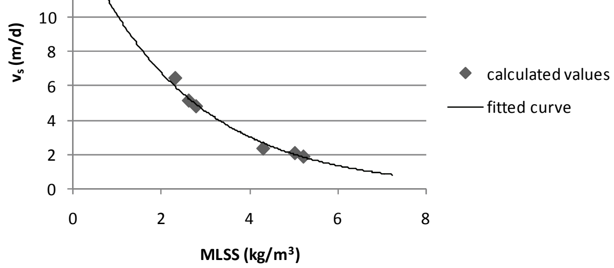

Figure 3: Determining the Vesilind curve based on the measured linear settling velocities

Results

The measurement results of the three samples without dilution and the calculated Vesilind settling velocity was used for fitting the Takács-model by adjusting the other parameters.

The model development was done using MATLAB/ Simulink R2007b program package. The program package offers the utilization of graphical interfaces beside the freedom of creating codes in several languages [10, 11]. The combination of these features makes the MATLAB/Simulink environment favourable among researchers from other fields than computer science (see for example [1]).

Three parameters were altered in an iterating process to converge modeling results to the suspended solids concentration of the treated water (top layer) and the returned sludge (bottom layer). These were as follows: non-settleable fraction (f_{ns}), the hindered zone settling parameter (r_h) and flocculent zone settling parameter (r_p).

The beginning values were:

$f_{ns} = 2.28 \cdot 10^{-3}$;
$r_h = 5.76 \cdot 10^{-4}$;
$r_p = 2.86 \cdot 10^{-3}$.

The following values were found satisfactory for fitting measurement results:

$f_{ns} = 1.00 \cdot 10^{-4}$;
$r_h = 3.10 \cdot 10^{-5}$;
$r_p = 8.00 \cdot 10^{-2}$.

The suspended solids concentration values for the top and bottom layer and the difference between calculated and measured results after parameter estimation are shown in *Table 2*. The iterative process was stopped when further improvement in converging to the three sets of goal results could not be achieved. the main focus was on to receive such parameters that can used for estimation in all three cases. If the scenarios were looked at separately better fitting could have been achieved but the aim was to use one set of parameters for all three cases.

Table 2: Result of the highlighted layers after parameter fitting

	top layer g/m³	difference %	bottom layer g/m³	difference %
1. measurement	13.58	69.78	7242.26	-19.53
2. measurement	14.39	19.93	8412.36	6.49
3. measurement	12.02	50.26	6497.79	-1.55

The simulation with the applied parameters overestimated the suspended solids concentration in all three cases. The greatest difference was received in the first measurement scenario. The values in percentage are somewhat deceptive since the measured concentration was 8 g/m³ which a very good quality but the same could be said if it was 14 g/m³ as the simulation calculated. A difference of 6 g/m³ in case of suspended solids concentration should not be considered as a significant calculation error taking into consideration the input value was three orders of magnitude greater. It has to be mentioned the the strictest limit value allows 35 g/m^3 suspended solids concentration in the effluent.

The difference in case of the bottom layer concentration of the first scenario (20% lower than measured) proved to be a greater error. This and the fact that in the other cases the differences were within the margin of error shows that one set of parameters cannot be applied to all cases. It also has to be mentioned that the samples taken from the end of the aerated tank to determine the suspended solids concentration entering the settler and to calculate the settling velocity were point samples while the other data, i.e. effluent and returned sludge flow SS concentration and the flow rates were provided by the plant management and were daily average values. This fact could contribute to the errors discussed above.

Nonetheless the inaccuracy of the Takács-model is underpinned by the results shown in *Fig. 4*. It is clearly visible that the concentrations calculated in layers 6–9 are equal to each other. This situation could not occur in reality as the concentration would increase in function of depth due to the effect of compression. The concentration in the bottom layer was higher in the model only because the gravitational settling velocity was taken zero by definition.

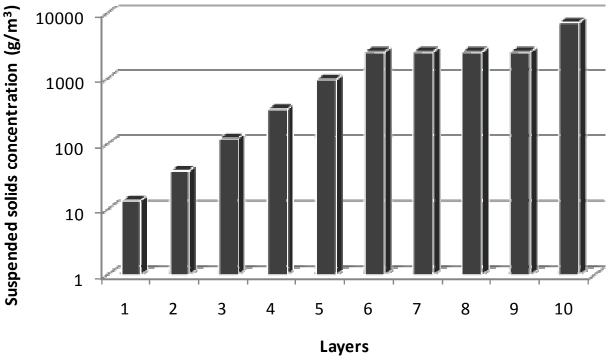

Figure 4: Calculated suspended solids concentration in different layer of the model settler

Conclusions

As the results of the simulation show the Takács-model may be adequate after parameter estimation but it must be noted that one set of parameter that is capable to describe one situation may not be appropriate for another.

According to the results presented in this paper other one-dimensional models will be examined and compared to each other from the aspect of accuracy based on averaged measurement results.

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