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WASTEWATER TREATMENT PLANT HYDRAULIC PERFOMANCE IMPROVEMENT

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Abstract. Sloka WWTP case study. The effluent suspended solids concentration is important parameter as the high fraction of organic matter, nitrogen and phosphorus are in suspended form, and to avoid suspended solids particle escaping from process tanks, thus preventing the waterbodies from point source pollution. The analysis of results from field studies show that treated wastewater effluent quality from clarifiers is unstable during the operation and activated sludge particle variation in concentration and size in effluent launder exist. The aim of study was to examine the individual effect of the scouring on sludge particle escaping from clarifier due to variation of incoming flow rate. The study describes results of a full-scale clarifier test for the design flow rate 250 m^3/h, simulation results for the emergency flow 750 m^3/h, when in operation only one process line. The results of practical application show, that to control the activated sludge particle escaping from secondary clarifier the local velocity profiles per each clarifier working zones can be used.

Key words: wastewater treatment plant, clarifier, hydraulic, suspended solids.

1. Introduction

To study the activated sludge particle movement mechanism there majority of literature has been published on sedimentation via sludge flux theory, but local velocity influent on disperse particle travelling from clarifier dilution or clarification zones to effluent weir has few studies yet, while other subjects were under research. Equations describing the conditions of local scour at sludge flux are complex and hence the initial research into the problem was empirical. More recently, attempts have been made at analytical solutions, but these have to rely on the results from experiments. Thus, there is no rigorous theoretical solution to the problem.

The local velocity development in time for wastewater treatment plant process tanks has not been studied; therefore the aim of this study was to prevent this process development in the existing wastewater process tanks. The scouring law governs the sediment resuspension in tanks, and based on local velocity value, can grow or stop.

The incoming flow rate, operation practice of gravity settling tanks may settle or resuspend particles from traditional working zones influencing the treated wastewater quality, but the sediment blanket level in clarifiers and grit tanks is subject to continuous change.

The existing grit or sedimentation tank calculation method is based on simplified parameters, such as detention time and hydraulic load on surface area assuming that the fluid distribution and particle settling in the clarifier is uniform, with a known suspended solids particle settling velocity and therefore the ideal horizontal flow reactor theory for the design practise is used.

The results of analysis from Sloka WWTP field studies show that effluent quality from gravity type clarifiers is unstable during the operation and the knowledge of the particle scouring can be as the sedimentation performance improvement instrument.

A most of research has been undertaken on sand and activated sludge particle sedimentation, but only few has been done on resuspension of sediment particle in tanks. Literature analysis shows that there is no one opinion which velocity is forming particle scouring from clarifier working zones and no methods for computing local scour development during the time. In formulas or methods for calculation of particle sedimentation are used mean velocities of approach flow or mass flux and Froude number with that velocity. Thus, there is no rigorous practical solution to the particle resuspension problem.

2. Materials and methods

The experimental data were obtained from the Sloka wastewater treatment plant located in Jurmala town, Latvia. This WWTP was rated to treat a 9000 m3/day, but freaquently had dificulties in handling hydraulic overloads during rainstorm periods when Q>13530 m3/day. The plant has conventional primary treatment without primary settling, activated sludge process for enchanced biological phosphorus and nitrogen removal and sludge treatment by mechanical thickening and dewatering.The activated sludge process consists of two ring type biological reactors with a total volume 9700 m3 and in midle located secondary clarifier radial type with area 650 m2 each. The diameter of basin 27 m and edge water depth 3.5 m. The MLSS suspension flows from the last biological reactors to clarifiers, which are situated in the center of the basin structures. The sludge suspension flows to the center of the basin and clarified water leaves it from the outer edges as overflow. Clarified water is then led to the overflow well, from which the effluent flow is measured. The temperature and pH are measured and sample taken prior treated water flows to the distribution chamber. The sample taking is done according to set time (hourly) or proportioned according to effluent flow and if the flow is very small, below set flow value, the sampler will work according to timer control. The plant operator additional measured effluent and dilution zone suspended solids concentartion and Qi, Qr every hour. The sludge settling properties and the SVI were measured with 1 l graduated cylinder within 30 min for SVI determination (ATV standard)

The aim of study was to determine the local velocity influence on activated sludge particles in dilution and clarification zones. The sludge particles was controlled by SVI value and effluent suspended solids concentration.The local velocitys was controlled by field measurements and velocity profiles was constructed per each clarifier working zones.

The activated sludge flocs was an important research subject, as their physical state and properties influence effectiveness of separation, therefore the overall wastewater treatment process performance was control by laboratory analysis, and calibrated biological treatment process modell (AQUA,ver.1.4), with the aim to keep the obtain SVI in range of research.

3. Flow velocity measurements

A measurement grid was established within a cross-section of the secondary clarifier. Velocity measurements at fixed location of the grid were made in order to establish a velocity profiles. The grid consisted of 30 points for measurements. Velocity measurements were taken at 1.0, 2.0, 3.0, 4.0, 5.0, and 6.0 m from the clarifier outlet baffle, at depths of 0.5, 1.0, 1.5, 2.0, and 2.5 m below the water surface (Figure 1). Additional measurements were taken at effluent weir wall, at depths of 0.5, 1.0, 1.5 m below the water surface.

The local flow velocities were measured for flows 250 m^3/h and 500 m^3/h with calibrated ultrasonic water current meter and modelled for emergency flow 750 m^3/h. Since measurements were made with regard to the depth from the water level for different flow rates, the location of fixed measuring points was not changed during the test period, but water level in the effluent weir was always under the changes.

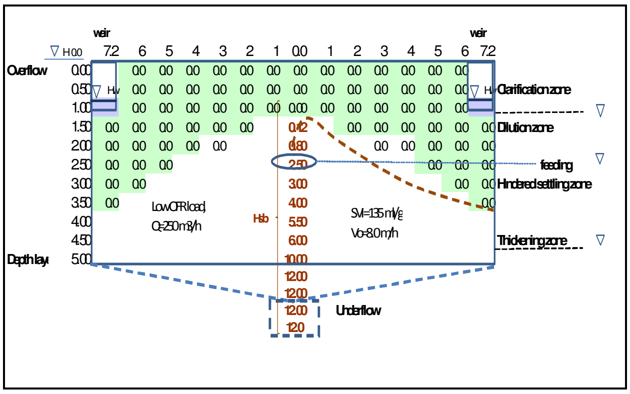

Fig 1. The locations of the cross sections used for velocity measurements

4. Clarifier performance control

The wastewater treatment plant process control was based on system mass balance presenting by equation (Tchobanoglous and Burton 1991):

$$\frac{dX}{dt} = (Q_i + Q_r) \cdot X_i - Q_r \cdot X_r - Q_e \cdot X_e - Q_w X_w \quad (1)$$

where: X_i, X, X_f, X_e, X_w the sludge concentration mg/l in influent, process tank, dilution zone, effluent, Q_i, Q_r, Q_e, Q_w flow rates m3/h at inflow, recycle flow, effluent and waste sludge.

The masses of suspended solids in the effluent and the wastage flows are ignored, i.e. because $Q_w << Q$, $Q_w << Q_r$, $X_e << X_i$ and $X_e << X_r$; thus, X_e and Q_w are not involved in the modelling procedure.

The recycle sludge X_r, mg/l concentration was calculated by (Tchobanoglous and Burton 1991):

$$X_r = \left(\frac{Q_i + Q_r}{Q_r} \right) \cdot X_i . \quad (2)$$

The efficiency of secondary treatment traditionally assessed by solids removal efficiency and compared to the over flow loading rate – *OFR*, m^3/m^2 *h*. Using the traditional approach for assessing clarifier performance, the suspended solids removal efficiency was compared to over flow loading rate (Figure 2).

The effluent suspended solids removal efficiency *E, %* were calculated by equation:

$$E = \frac{X_i - X_e}{X_i} \cdot 100\% \quad (3)$$

The scattered data reveal week correlation between overflow rate loading and removal efficiency. Similar observations has made by other researchers (Stamou *et.al.* 1989). It was hypothesized that the absence of correlation could be explained by the fact that removal efficiency is affected by a number of factors such as the concentration

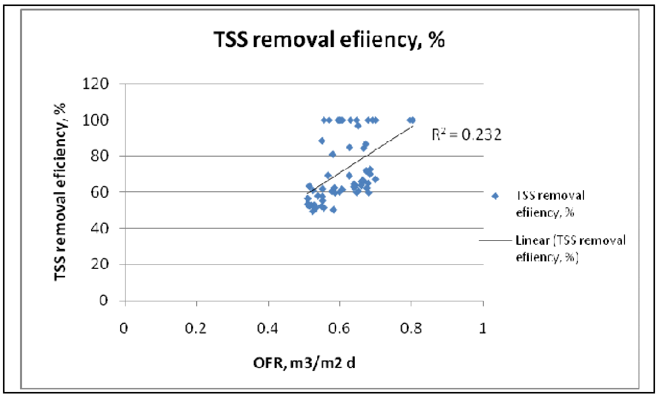

Fig 2. The effect of hydraulic loading rate on suspended solids removal efficiency

of non settle able solids, sludge blanket depth, and local flow velocity features of the clarifier. Thus, the cumulative effect of these factors on removal efficiency may exceed the effect of hydraulic loading; therefore in this study the suspended solids concentration on effluent as a control parameter was used.

5. Sludge particle size and settling velocity

The amount of the solids and the particle size of the solids that do not settle are in some way related to how well the activated sludge is flocculated. In Sloka wastewater treatment plant effluent suspended solids concentration where low, the sludge is considered to well flocculate. If the effluent suspended solids concentration be high and the effluent clear, the individually visible particles pinpoint flock are being produced. If the effluent suspended solids concentration is high and the supernatant and effluent are turbid the deflocculating occurs.

Despite several investigations of the flocculation of activated sludge and a number of different possible theories there is still not generally accepted explanation of why activated sludge flocculates. The performance of the activated sludge process is limited by many factors. They are concerned with the biological activity of sludge micro organisms, hydraulic disturbances within the system that affect the ability of the clarifier to separate and concentrate the activated sludge from the effluent.

The traditional sludge volume index (*SVI*) is performed in this study. The test is easily performed and has a widespread use in routine process control. The test apparatus was a 1-liter sedimentation vessel. Normally the test was performed without stirring although stirring is recommended by the Standard Methods, after (Hultman and Hultgren 1980). In the study the *SVI* index was in range from 50 till 150 ml/g, which accord to the settling velocities V_0 in the range from 1 till 6 m/h (Figure 3).

From the literature empirical correlation between *SVI* and sludge settling exist. The following Eq. (4) developed by (Vaccari and Christodoulatos 1990) was used.

$$V_0 = [10.86 + (0.1854 \cdot SVI)] \cdot e^{(SVI/62.5)} \qquad (4)$$

where: V_0 = sludge particle settling velocity in m/h; *SVI* = sludge volume index.

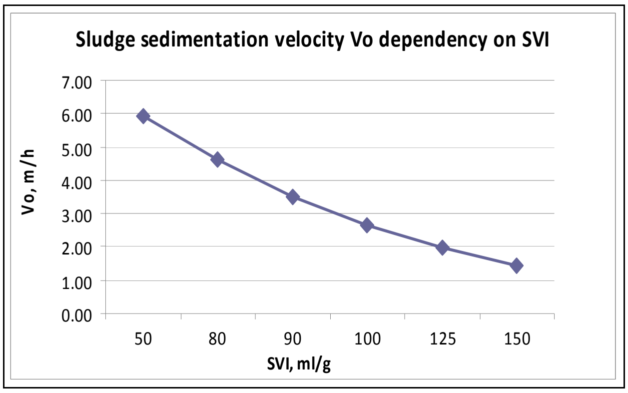

Fig 3. Sludge sedimentation variation vs. SVI

6. Relation between effluent suspended solids concentration and SVI

The Eq. (4) currently is the best available; however, needs to be field calibrated. Particles at low solids concentrations settle as separate entities and do not move together in a visible layer. This makes it hard to measure the settling velocity at low solids concentrations.

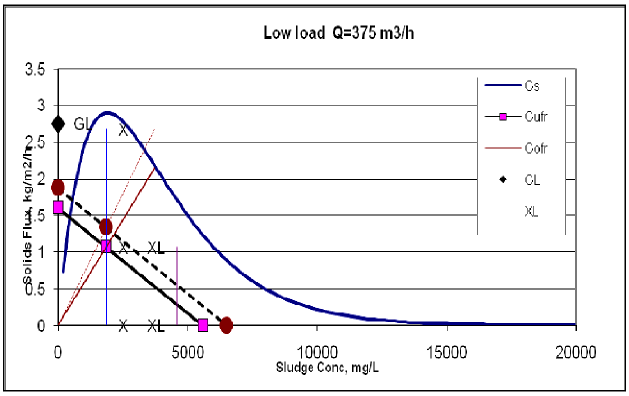

Fig 4. Low load flux scenario

The Figures 4, 5, and tables 1, 2, illustrates the effluent suspended solids concentration (X_e) variations for the flow rates 250 m3/h and 500 m3/h. These figures show that high variation exists for flow rate 500 m3/h, but always was $X_f > X_e$. When the *SVI* is kept in highest level 135 mg/l, there have no possibility for scoring, but when the smaller range *SVI=60* ml/g, then scouring can occur and suspended solids concentration in effluent was investigated.

Table 1. Relation between effluent TSS and SVI for low load conditions

OFR, m^3/m^2 d	SVI=135	SVI=100	SVI=60	TSS, mg/l
0.583	4.32	5.83	9.72	2.1
0.642	4.75	6.42	10.69	3.0
0.700	5.19	7.00	11.67	3.2

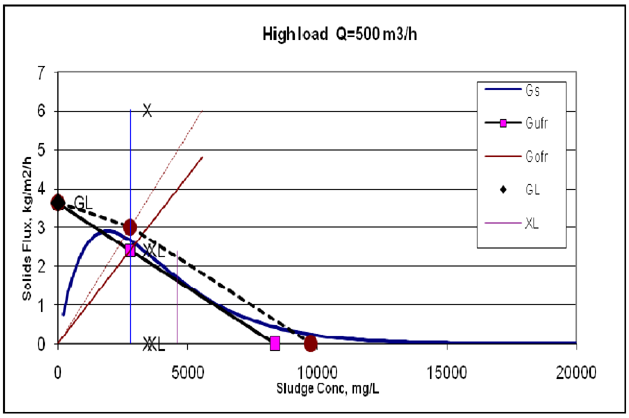

Fig 5. High load flux scenario

Table 2. Relation between effluent TSS and SVI for high load conditions

OFR, m^3/m^2 d	SVI=135	SVI=100	SVI=60	TSS, mg/l
22.08	6.80	9.19	15.31	7.5
24.24	7.49	10.10	16.84	11.0
26.40	8.17	11.02	18.37	14.2

The perform tests show no significant impact on suspended solids concentration in effluent within the flow variations.

7. Effluent hydraulic

The researchers (Vaccari and Christodoulatos 1990) studying clarifiers have proposed that the effluent suspended solids concentration is highly sensitive to the effluent hydraulics. Upon viewing the velocity profiles, it is clear that the calculation models predict a greater fluid velocity in the effluent zone when the over flow rates increases. There is a very strong correlation between the effluent fluid velocity and the over flow rate. Figure 5 plots the fluid velocity over the effluent weirs versus the over flow rate. The results are a strongly linear correlation, which has a statistical R squared value of 0.98. This is expected because of the continuity condition imposed in the solution. The volume of fluid (minus the *recycle flow*-Q_r) was equal the volume flowing over the effluent weirs.

However, like the over flow rate, the results do not suggest a strong correlation between the effluent fluid velocity and the effluent suspended solids concentration for all the data. Some field tests in the past have suggested that suspended solids concentration is dependent on the effluent zone hydraulics, yet the data results do not provide support or disagreement with this correlation.

It appears that the suspended solids concentration is more sensitive to other parameters such as the solids SVI, flow rate, and the location and magnitude of clarification or hindered settling zones and that induce sludge particle scouring.

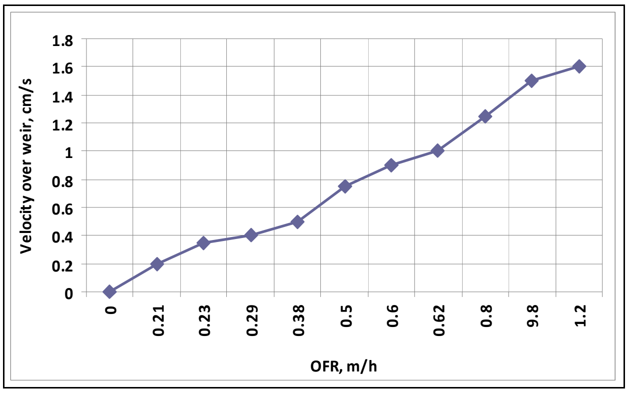

Fig 6. Flow velocity versus OFR

The suspended solids concentration in effluent was always controlled by measurements, but treatment process by laboratory measurements and modelling, in this way to avoid situations, when particle sedimentation depends upon process performance, therefore in studies was included measurements and model, to keep good correlation between, substrate utilization rate and organic loads to insure for each flow rate scenario the sludge particles with known settling velocity V_0.

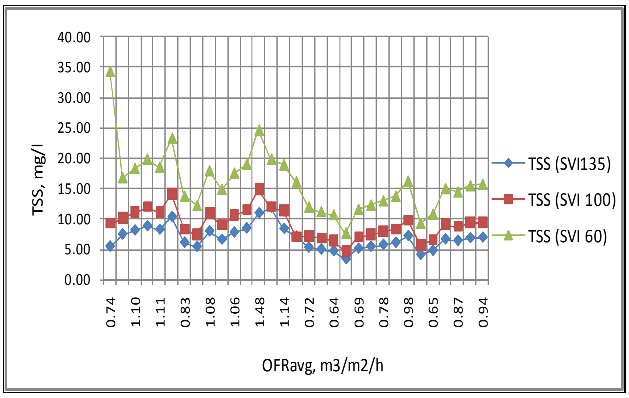

Fig 7. OFR versus effluent TSS

The Figure 6 illustrate that effluent suspended solids concentration be sensitive to the clarifier geometries at the low and high solids loading rates, due to SVI variations.

For each surface overflow rate, there is a range of measured and simulated suspended solids concentration. Figure 7 displays the effluent suspended solids concentration versus the surface overflow and illustrate not a very strong correlation between the two. This graph suggests that increasing of the loading rate will increase the suspended solids concentration, and that the surface overflow rate is not a significant parameter within the tested range. In fact, the curves of the two different surface overflow rates lay close on top of each other. This agrees well with the results of calculation, the effluent suspended solids concentration was not affected significantly by the surface overflow rate until it was greater than 1.0 m/h. The results illustrate almost slight dependence of the effluent suspended solids concentration increase on the surface overflow rate within the entire range tested of 0.52 to 1.15 m/h. Also, the effluent solids concentration did not show a dependence on the solids loading rate until the high loading of 5.10 kg/m^2/h was used.

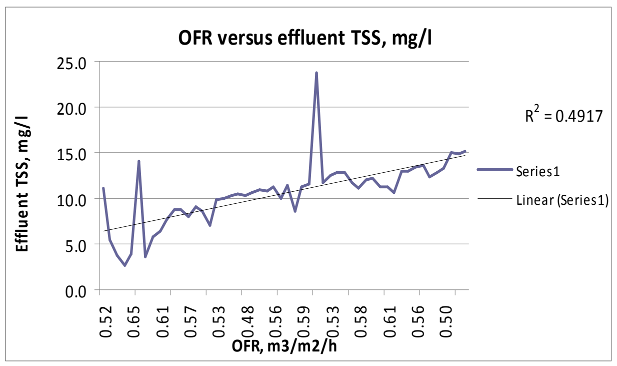

Fig 8. Suspended solids perfomances vs. OFR flowrate

8. Sludge blanket height H_{sb} and concentration X_{sb}

For the calculation of sludge blanket concentration X_{sb} combination equations was taken from (Stamou *et.al.* 1989) and following equation was used:

$$X_{sb} = \frac{X_r}{\sqrt{1 + \frac{H_{sb}}{H} \cdot \frac{Q}{Q_r} \cdot \frac{SVI}{X_r}}} \tag{5}$$

where *SVI* = Sludge volume index, H, Hsb=water level and sludge blanket height, m.

The boundary condition is a function of the ratio of the downward settling flux (deposition) and the upwards-turbulent flux (resuspension).

The presence of a high sludge blanket will inevitably mean failure for the clarifiers operation. As the sludge blanket moves lower, there is less of a scouring effect from the influent flow rate. However, if a feed well baffle is present and the sludge blanket levels are high, the flow dispersed flocculated particles, or forced under the baffle at a higher velocity, which then further scours to the sludge blanket and resuspends the flocculated sludge particles. Also, even though the magnitude of the scouring is not as great when the influent waterfall has less distance to travel before encountering the sludge blanket, the scouring occurs at a higher elevation, and consequently closer to the effluent weir. When this happens, the resuspended solids have less of a travel distance to the effluent weirs, which affect to higher suspended solids concentrations in effluent.

To avoid and control the scouring effect from sludge blanket on effluent suspended solids concentration, the height of sludge blanket H_{sb} where calculated and following mass balance were written by (Stamou *et. al.* 1989):

$$M_{sb} = X_{sb} \cdot V_{sb} = X_{sb} \cdot A_{sb} \cdot H_{sb} \tag{6}$$

where M_{sb} = mass of suspended solids in sludge blanket (kg); X_{sb} = average concentration of suspended solids in the sludge blanket (kg/m^3); V_{sb} = volume of the sludge blanket (m^3); and A_{sb} = surface area of the sludge stock (m^2).

9. Dilution zone concentration X_f

In steady state conditions X_f can be determined using the mass balance in the inlet zone Eqs. (7-9), which is written as follows (Tchobanouglous and Burton 1991):

$$(Q_i + Q_r) \cdot X_i = (Q_r + V_s \cdot A) \cdot X_f \tag{7}$$

and

$$X_f = \frac{Q_i + Q_r}{Q_r + V_s \cdot X_i} \cdot X_i \tag{8}$$

$$X_f = \frac{\left(1 + \frac{Q_r}{Q_i}\right) \cdot X_i}{\frac{Q_r}{Q_i} + \frac{V_s \cdot A}{Q_i}} \tag{9}$$

where V_o = settling velocity of the sludge particle (m/d); OFR_{avg} = Q_i / A = overflow rate (m/d); and $V_s/(Q_i/A)$ = H_a = Hazen Number.

In Eqs. (7–9) the process of settling is modelled as a flow of the suspended solids in the direction of gravity with velocity V_s. In simple mathematical models, V_o is assumed to be constant. A more realistic approach is to use a Settling Velocity Curve (SVC), in which, the suspended solids are divided into classes, due to the variation of particle sedimentation characteristic, each having a discrete settling velocity (Stamou *et al.* 1989). In practice, however, it has been found that V_0 is a function of the local suspended solids concentration (*Xi*) and belongs to the hindered settling, due to the agregadation of particles (Takacs *et al.* 1991).

In this study the small flocculated sludge particle was found also in the clarification and dilution zones, which form the suspended solids concentration in effluent, launder.

To use the V_0 velocities, this strongly depends on SVI and is in range from 4 till 8 m/h for the upper layers (clarification or dilution zones) was not possible, as there size of smaller particles was detected.

In this study find that only for clarifier hindered settling and thickening zones Eq. (4) (Vaccari and Christodoulatos 1990) to calculate sludge particle sedimentation velocity V_0, valid, and data good correspond to author results, but suspended solids concentration value correlation for clarification and dilution zones was not satisfactory.

The sludge particle sedimentation velocity was in the range from 0.1 till 0.05 m/h, and is by far smaller then V_0, what was from 4 m/h till 8 m/h, depending on existing

SVI value. To overcome this difficulty a simple approach was adopted to calculate the suspended solids concentration in dilution or clarification zones, the system mass balance was used, but the local velocities was calculated and measured by separate layers each on site.

The following mass balance equation for dilution zone was used (Stamou *et al.* 1989):

$$X_f = \frac{Q_i Q_r}{Q_r + V_s \cdot X_i} \cdot X_i \quad (10)$$

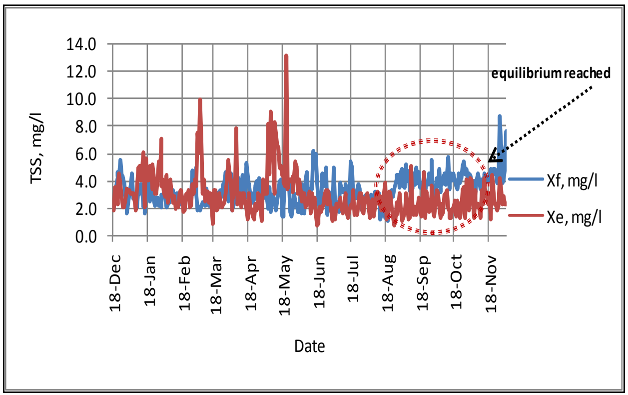

Fig 9. Xf variations for design flow rates

Figure 9 illustrate the X_f variations for flow rates 250 m3/h till 500 m3/h.

When the *SVI* is kept in highest level 135 mg/l, there have no possibility for particle scoring, but when *SVI=60* ml/g was in range, the scouring can occur and increase of suspended solids concentration in effluent was detected.

10. The scouring velocity determination

In the existing wastewater treatment plants the hydraulic load for the clarifiers is chosen independently per tank providing only the average value of velocity per tank.

If the flow actual velocity in the tank is too high and it exceeds the settling velocity of settled solids, particles can be scoured from the zones.

The settling velocity for microflocs was calculated by after (Hultman and Hultgren 1980) and presented model covers both the free settling zone and the hindered settling zone and therefore it has an increasing settling velocity for increasing concentrations at low suspended solids concentrations and a decreasing settling velocity for increasing concentration at high suspended solids concentration and following formula was used:

$$V_x = V_0 \cdot \exp\left[-0.5\left[\frac{\ln\left(\frac{X_{ss} + X_{pp}}{n_1}\right)}{n_2}\right]\right] \quad (11)$$

where V_s = settling velocity for microflocs, m/h; V_0 = maximum settling velocity for macroflocs, m/h; X_{ss} = macrofloc concentration in the settling tank, g/m3; X_{pp} = concentration of primary particles in the influent to the settling tank, g /m3; n1, n2 = sludge characterization constants.

If the settling velocity of a particle is smaller than critical velocity, then it may or may not settle out depending on its starting position. This situation implies that particles with a higher initial position than this particle will all escape, and those with lower initial position will all settle out. The ratio of settling can be calculated as described earlier, by Eq. (10) and must be $V_o > V_s$.

11. Discussion

The aim of study was to examine the individual effect of the flow velocity on sludge particle escaping from clarifier due to variation of incoming flow rate. The study describes results of a full-scale clarifier test for the design flow rate 250 m^3/h, simulation results for the emergency flow 750 m^3/h, when in operation one process line and the variations of effluent suspended solids concentration per each scenario.

The influent hydraulics is largely governed by the hydraulic loading, which is the sum of the influent flow *Qi* and the recycle flow *Qr* per unit of clarifier surface area.

The clarifier geometry, such as the side water depth and the outlet bafle size also affect the influent hydraulics. All studies have high sludge blanket levels, which cause the influent flow to become moved upward. When the flow is directed upward, in some cases it creates a short-circuiting flow-path to the effluent weirs. In others, it creates additional recirculation zones that are highly unstable to develop in the settling zone. In field study two recirculation zones were found in the settling zone, which increases the effluent suspended solids concentration.

The suspended solids concentration distributions and velocity profiles for investigated secondary clarifier, provide a typical illustration how the particle scouring process occurs for different investigated flow rates. This suggests that the underflow flow rate is a one of main parameter in keeping the sludge blankets in design height, thus, preventing a clarifier from failing.

12. Effluent suspended solids variation

The scoring process develops within a time. The previously performed calculations, of which only for high flow rate 500 m^3/h was reached equilibrium and produced permanent effluent suspended solids concentrations, while the other two were unstable and did not reach equilibrium within the time. Each calculation was run for time steps ranging from one to several hours. For the emergency flow the effluent suspended solids increases considerably within a time as the scouring process develops.

However, it was observed that by decreasing the flow rate, the effluent suspended solids concentration would decrease more, more slowly. Nevertheless, an equilibrium result of effluent suspended solids concentration is sensitive to the time steps, as it accord to scouring calculation method. The Figure 10 shows the performance of effluent suspended solids increase due to local velocity.

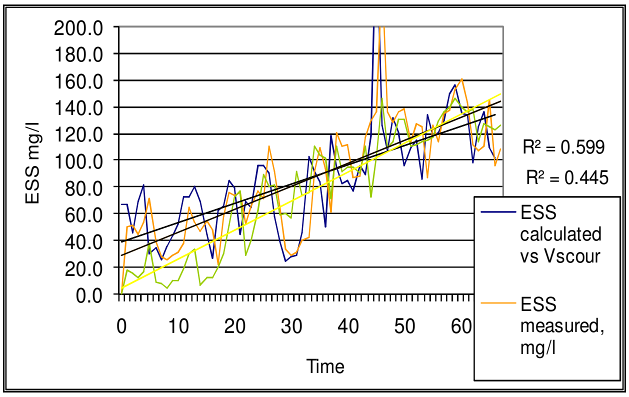

Fig 10. Effluent suspended solids concentration variation for emergency flow

13. Conclusions

The effluent suspended solids concentration still is important parameter as the high fraction of organic matter, nitrogen and phosphorus are in suspended form, and to avoid suspended solids particle escaping from process tanks, thus preventing the waterbodies from point source pollution.

The following summary and conclusion was drawn on the basis of this observation:

- To examine the secondary clarifier hydraulic flow pattern it must be always linked with activated sludge process results, to keep adequate sludge settling parameters for define wastewater and flux flow rates.
- The activated sludge particle velocity is governed by the local velocities, which develops, stay at equilibrium or stops.
- In studies the equilibrium between scouring and sedimentation is reached for flow rate 500 m^3/h and development for emergency flow 750 m^3/h.
- The increase of suspended solids concentration in effluent was originated by increase of the local velocities at outlet pipe baffle forming the geometric elliptic shape profile, and similar to the effluent weir.
- When the local velocities develops the small sludge particle was observed in clarification zone, and flocculated particle break up occurs.
- The local velocity must be taken in consideration for design of new WWTP or rehabilitate the existing units.

References

Hultman B.; Hultgren J. 1980. Deviations from the Kynch theory in thickening sludge's from wastewater treatment plants, *Tribune du Cebedeau* 33(441-442): 375–3 89.

Neilands R.; Klīve G.; Gjunsburgs B.; Neilands R. j. 2005. Management and protection of the trans-national rivers Lielupe and Venta in the Baltic region. In *Proc. of International Conference River Basin Management – progress towards implementation of the European Water Framework Directive*, Budapest, Hungary, 2005. Hungary: Hungarian Academy of Science, 345–353.

Stamou A. I.; Adams E. W.; Rodi W. 1989. Numerical modeling of flow and settling in primary rectangular clarifiers; *Journal of Hydraulic Research* 27(5): 665–682.

Takács I.; Patry G. G.; and Nolasco D. 1991. A dynamic model of the clarification-thickening process, *Journal of Water Research* 25(10): 1263–1271.

Tchobanoglous G.; Burton F. L. 1991. *Wastewater Engineering: Treatment, Disposal and Reuse*. 3rd.;Ed.; Metcalf & Eddy Inc: McGraw Hill, 1334 p.

Vaccari D. A.; Christodoulatos C. 1990. Estimation of the Monod Model Coefficients for Dynamic Systems using Actual Activated Sludge Plant Data, *Water Science Technology* 10: 449–454.

ATV. *2000. German ATV-DVWK Rules and standards, Standard ATV-DVWK-A 131E, Dimensioning of Single-Stage Activated Sludge Plants*, German association for water, wastewater and waste, May 2000.

ATV (Abwassertechnische Vereinigung). 1976. *Erlauterungen und Erganzungen zum Arbeitsbericht des ATV-Fachausschusses 2.5 Absetzverfahren*. Die Bemussung der Nachklarbecken von Belebungsanlangen. Korrespondez Abwasser 23 (8), 231–235.

ATV (Abwassertechnische Vereinigung). 1973. *Arbeitsbericht des ATV-Fachausschusses 2.5 Absetzverfahren.* Die Bemussung der Nachklarbecken von Belebungsanlangen. Korrespondez Abwasser 20 (8), 193–198.