Journal of Achievements in Materials and Manufacturing Engineering
VOLUME 53
ISSUE 1
July
2012

Flow modeling in a laboratory settling tank with optional counter-current or cross-current lamella

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Received 12.05.2012; published in revised form 01.07.2012

Analysis and modelling

ABSTRACT

Purpose: Design of laboratory lamella settling tank used in the laboratory researches of sedimentation process, optionally in either cross-current or counter-current.

Design/methodology/approach: This paper presents a selection of geometric parameters of the device made using numerical methods to analyze the flow in designed settling tank.

Findings: As a result of analyses, of the final device design was developed that allows it to obtain the proper distribution of flow velocity. The simulations allowed the selection of the proper construction of the tank, in which the velocity distributions in successive channels are comparable to the fulfillment of lamella, which will allow it to charge uniform stream of liquid (suspension).

Practical implications: The use of numerical methods of modeling the flow in the settling tank allowed to fine-tune the design of the device at the early stage, and in particular the parameters of the distribution of suspension.

Originality/value: The settling tank allows sedimentation to take place in both configurations with the preservation of an identical sedimentation surface. This concept allows a comparison of processes in these systems at a given identical surface load.

Keywords: Multiflux sedimentation; Compact settling tank; Counter- and cross-current multiflux sedimentation; Flows modeling

Reference to this paper should be given in the following way:
K. Kołodziejczyk, M. Banaś, P. Warzecha, Flow modeling in a laboratory settling tank with optional counter-current or cross-current lamella , Journal of Achievements in Materials and Manufacturing Engineering 53/1 (2012) 28-36.

1. Introduction

Multiflux sedimentation is an established technique for the intensification of separation of sediment phases used in many industrial processes, process engineering and environmental protection [1-3]. According to Hazen's theory it is the surface, not the tank depth that determines the result of the process of sedimentation. There are several options for building a large surface sedimentation settler [4,5] - lamella settlers, of which the most widely used system is the counter-current one. The cross-current option allows for a very large area of sedimentation, which according to Hazen theory provides a good effect of the process. Devices using both variants of the process were the focus of research [4,6], but the effects of other factors than the surface of sedimentation on the course of sedimentation occurring in them were never compared. From the practical point of view it would be interesting to obtain information whether under the same conditions to the process (the type of suspension, sedimentation surface, and surface load) and the cross-current and counter-current systems give a similar effect.

It was assumed that a comparative analysis of the sedimentation process implemented in the cross-current and counter-current systems would be performed in a specially designed and built laboratory clarifier.

The conceptual framework assumed that the test settling tank will consist of one sedimentation chamber, where optionally lamella sedimentation in a cross-current or counter-current system will occur. This concept assumes that in a single device with the same external geometric parameters and identical sedimentation surface, and merely different implementation of the process, it would be possible to conduct research comparing the cross-current and counter-current sedimentation process.

Such a formulation of the problem stems from the fact that so far most of sedimentation analyses were carried out in one particular system (cross-current, counter-current, or co-current) [3-5]. Furthermore, according to Hazen theory it was assumed that in the case of free sedimentation (low concentration), systems operating at the same load surface will give the same final effect (measured e.g. by the efficiency of sedimentation) - regardless of the implementation of the process.

The use of one and the same sedimentation device for the sake of comparison between the process of sedimentation in cross-current and counter-current systems, has several advantages. It allows one to eliminate errors that could have occur with comparing two different settling devices designed exclusively for implementation of cross-current or counter-current sedimentation, respectively. Using the same sedimentation chamber for the two systems frees the analysis e.g. from the impact of the autocoagulation effect which may occur in the settling tank, the variety of delivery and reception systems, etc [7,8]. By using the same suspension sedimentation chamber, we can provide the same residence time for the suspension in the settling tank, and the same conditions for the possible occurrence of the autocoagulation process.

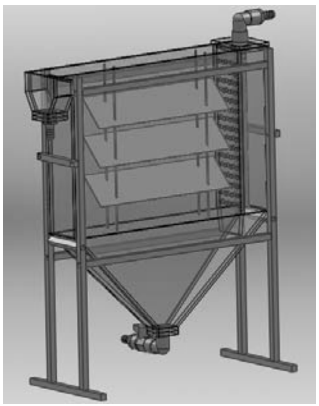

Fig. 1. Laboratory multi-flux settling tank with fitted cross-current lamella

This proposal, unfortunately, is not without drawbacks. The basic problem of implementing such a concept is to design the suspension distribution and sludge collection systems from the sedimentation area to ensure proper operation in both systems.

The main criterion adopted in the design and evaluation of the correct operation of both systems was the velocity distribution in the sedimentation chamber, namely individual sedimentation channels. It was decided to use numerical methods allowing the performance of flow simulation in the settling device in order to obtain velocity distribution over the clarifier [9-12].

The use of numerical methods of modeling the flow in the settling tank also allowed to fine-tune the design of the device at the early stage, and in particular the parameters of the distribution of suspension [13].

2. Settling tank conceptual design

The basic parameter assumed in the design of the settling device is sedimentation surface, which is 337 cm^2 in the whole separator and its volume, which amounts to 3.6 dm^3. The assumptions about these parameters result from the use of the settling device for laboratory testing, which entails the use of very large volumes of test suspension. Therefore, also its dimensions should not be too large: the suitable height was at 450 mm, length 330 mm and width 76 mm.
The proposed construction of settling tank is shown in the Fig. 1 and Fig. 2; it consists of a sedimentation chamber of the settler, in which optionally there will be mounted a lamella pack for counter-current sedimentation (Fig. 2

Fig) or cross-current sedimentation (Fig. 1). On the right side of the sedimentation chamber, the suspension distribution system is located Fig. 3. The system has been fitted with a perforated tube (Fig. 4), serving to distribute the suspension evenly along the settling device height, and in a perforated septum (Fig. 5), serving to homogenize the distribution of velocities of suspension incoming to the sedimentation chamber.

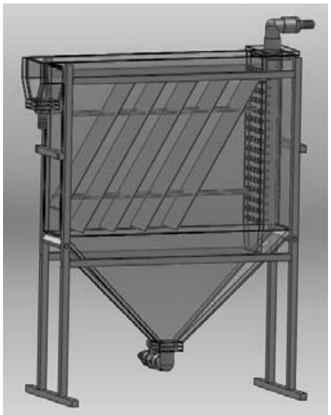

Fig. 2. Laboratory multi-flux settling tank with fitted counter - current lamella

The main problem at the design stage of the settling device is a suitable choice of parameters for suspension distribution system construction, so that eventually the whole area of sedimentation is evenly loaded with the stream of flowing suspensions.

During the selection of system parameters, one can modify a few elements of the distribution system, such as:

- suspension distribution tube diameter,
- diameter and distribution of holes in the distribution tube,
- number of holes in the distribution tube,
- number of holes and their distribution in the perforated septum.

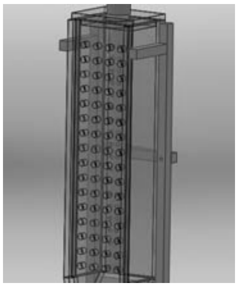

Fig. 3. Suspension distribution system

In addition to the above, other geometrical parameters of the system could be modified, but these seemed to be of greatest importance in view of getting an evenly loaded device.

Fig. 4. Perforated tube - Suspension distribution system

Moreover, the device was equipped with a scum hopper, located along the clarifier. In the counter-current system, the upper part of the effluent area also serves partly as a suspension disperser. However, in both systems, the primary task of the scum hopper is the collection of sludge accumulating in the tank, and draining it out through the outlet drain. The last element of the described settling device is the overflow drainage system, which includes the space above the lamella pack, allowing drainage of the treated liquid over a Thomson weir to the effluent box and then to the effluent outlet.

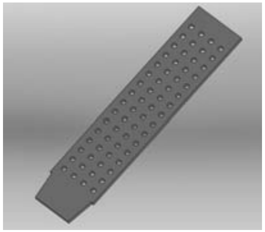

Fig. 5. Perforated septum - Suspension distribution system

2.1. Suspension distribution system

Spreading the suspension in the settling tank is accomplished by the distribution system which consists of two components: a perforated pipe and a perforated septum. The device was designed to replace/modify each of these elements. During the selection of design parameters of the devices different versions of both the distributing tube and the perforated septum were used. In the process of selecting the system parameters, modeling of flow was performed for different variants of the suspension feeding tube and for the perforated septum with holes of the following diameters.

- 5 mm, arranged in four columns and 16 rows,
- 8 mm, arranged in four columns and 16 rows,
- 12 mm, arranged in four columns and 13 rows.

Sample perforated septum with 5 mm holes has been presented in the Fig. 5.

2.2. Lamella packs

The settling device was subsequently fitted with two types of lamella packs to be interchangeably mounted. The packs were designed to have an identical sedimentation surface. The cross-current pack (Fig. 6) consisted of 3 plates with the dimensions of 50 mm x 198 mm angled at 45° to the bottom, 50 mm from one another vertically. In effect, the total sedimentation surface was 210cm^2 (1).

$$F_s = 3\cdot 50\cdot 198\cdot \cos(45) = 21001 mm^2 = 210 cm^2 \quad (1)$$

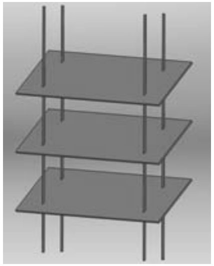

Fig. 6. Lamella packs - cross-current system

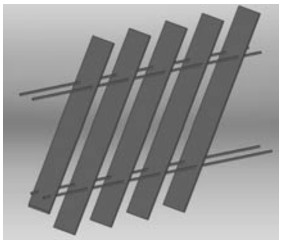

Fig. 7. Lamella packs - counter -current system

While filling countercurrent (Fig. 7) consists of the 5 plates (4 - Sediment and 1 - working as a handlebar), which after insertion form 4 sedimentation channels. Sedimentation plates with dimensions of 210 mm x 50 mm are set at an angle of 60° relative to the bottom, at a distance of 40 mm from each other measured along the horizontal axis. The package of this construction has an area of sedimentation (2) of 210 cm^2.

$$F_s = 4 \cdot 50 \cdot 210 \cdot \cos(60) = 21000 mm^2 = 210 cm^2 \quad (2)$$

Thus, according to the assumption made, both surfaces of the lamella sedimentary systems are virtually identical. The settling device total sedimentation surface was calculated as the sum of the lamella packs and the cross-section of the clarifier chamber with dimensions a=50 mm x b=255 mm and at the base (3) 337.5 cm^2.

$$F_{so} = F_{sp} + a \cdot b = 210 cm^2 + 5 cm \cdot 25.5 cm = 337.5 cm^2 \quad (3)$$

3. Modeling of flow in the settling tank

At the design stage of the settling device it was assumed that the verification of the velocity distribution will be made using the numerical modeling of flow through the settling tank with CFX Ansys module. It was assumed that the modeling of the distribution of velocities in the settler will be calculated only for water as the medium flowing through the device, not for suspension. This assumption allows obtaining information about the distribution of flow velocity of pure liquid. The omission of the distribution analysis for multiphase suspension was intentional. The first main factor determining the resignation from modeling of a multiphase system [14] was the significant simplification of the analysis, thus shortening the time of its implementation and the elimination of a number of uncertainties and errors in the modeling process of sedimentation. Conducting flow analysis using water as a medium withdraws the results on the concentration of slurry fed into the device. This is an undoubted advantage for the analysis of the velocity distribution and the choice of design solution for the settler, while its disadvantage is "losing" information on the impact that the solid fraction contained in the suspension has on the velocity distribution. For very low and low concentrations, as far as free sedimentation is concerned, the effect of the solid fraction on the global velocity distribution will be small or even negligible, but with increasing concentration, especially in the sludge zone, it will be important. Unfortunately, the currently achieved accuracy [15,16] during the process of numerical sedimentation simulations it differed significantly from the desired level of convergence and was fitted into the range of not less than a few percent. Moreover, the implementation of numerical simulations for the suspension is closely related to the necessity of model validation based on laboratory data.

3.1. Numerical model - boundary conditions

In order to analyze the distribution of velocity profile in the settling device a numerical model of flow was developed. The numerical simulations included the total settling tank capacity filled with fluid (Fig. 8). It was assumed that the analysis would be performed without taking into account the heat exchange and the influence of convective motions in the velocity distribution in the tank. Therefore, the numerical simulations omitted the walls and supporting structure of the settler - the spaces after the removal e.g. of the lamella are empty. In the numerical simulations, the boundary condition was attributed to fluid surface: a "wall", except for the inlet, outlet, and the surface of the liquid. It was decided that the modeling of flow through the settling device, boundary conditions would be provided at the settler inlets and outlets as velocity values.

The settling device was designed to undergo studies concerning surface loads between 0.1 m/h and 1m/h. Due to the above it was assumed that the choice of suspension dispersion system would be done at the surface load of q=0.5 m/h. On this basis, the equation (4) provided the feed stream provided to the device at the load of 0.5 m/h was calculated to equal $Q_N = 16.88\ 10^{-3}\ m^3/h$.

$$Q_N = q \cdot F_{so} = 0.5 \tfrac{m}{h} \cdot 33.75 \cdot 10^{-3}\, m^2 = 16.88 \cdot 10^{-3} \tfrac{m^3}{h} \quad (4)$$

It was further assumed that in the system, the stream velocity at the outlet would equal 10% of the feed stream, therefore the overflow (5) equals $Q_P = 15.87\ 10^{-3}\ m^3/h$, and respectively the outflow stream (6) equals $Q_W = 1.688\ 10^{-3}\ m^3/h$.

$$Q_P = 90\% \cdot Q_N = 0.9 \cdot 16.88 \cdot 10^{-3} \tfrac{m^3}{h} = 15.87 \cdot 10^{-3} \tfrac{m^3}{h} \quad (5)$$

$$Q_W = 10\% \cdot Q_N = 0.1 \cdot 16.88 \cdot 10^{-3} \tfrac{m^3}{h} = 1.688 \cdot 10^{-3} \tfrac{m^3}{h} \quad (6)$$

Given the cross-sectional areas of the inlet tube, the outlet drain, and the surface through which the flow is received (Fig. 8) were calculated respectively for the feed velocity $v_N = 0.165\ m/s$ for the flow $v_P = 0.0812\ m/s$ and for outflow $v_W = 0.00596\ m/s$, which were assigned as boundary conditions in the numerical model in accordance with the indication given in Fig. 8. The surface area of the liquid was modeled as a slip - as a result, there is no friction on the wall. In the simulations, free liquid surface modeling was abandoned in order to simplify the calculation.

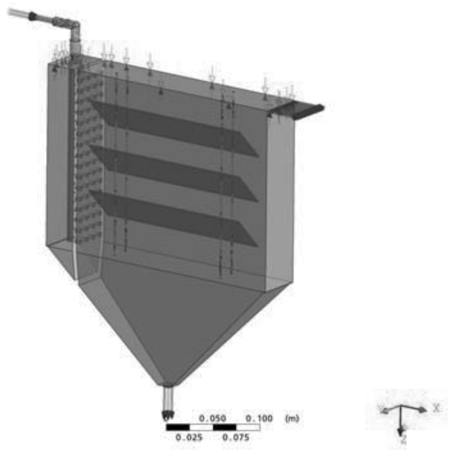

Fig. 8. 3D model for numeric calculations

3.2. Numeric model - mesh

Since the area of computing, despite its regular external shape had a number of inner surfaces; it was decided to use a tetrahedral mesh with the size of elements ranging from 0.5 mm to 5 mm. The result was a model built with about tetrahedral 430,000 items. The subsequent simulations carried out, the number of model elements was slightly different, e.g. due to differences in the geometry of the system. In the Fig. 9 a model of the generated mesh with the applied lamella structure is presented.

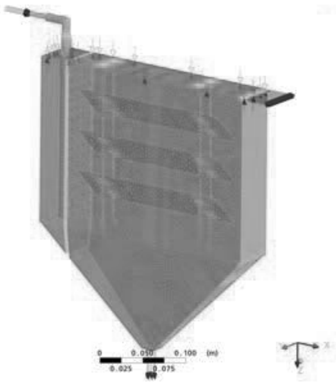

Fig. 9. Model - mesh

3.3. Numeric calculations carried out

During the selection of geometric parameters for the suspension distribution system in the settling device, a number of flow simulations were performed for different solutions of the suspension feeding tube and the perforated septum in both counter-current and cross-current systems. The article presents only a selection of simulations, with the final accepted solution. The calculations were performed with the use of turbulence models k-ε and SST for flow parameters constant in time [17].

Counter-current system

The first system of analysis was a counter-current system. The first simulations performed for this system assumed the use of full septum between the sedimentation chamber and the suspension distribution chamber and total suspension feed under the lamella through a scum hopper. However, this solution proved to be extremely unfavorable as the stream flowed through the closest sedimentation tube to the weir system, and also nearest to the suspension distribution system, the flow of suspensions occurred in the opposite direction than intended.

Configuration no. 1

Another simulation assumed the use of perforated septum (as in Fig. 5), and the use of a perforated tube distributing the suspension from two columns of holes with the diameter of *φ=5mm* angled 90° relative to each other and pointing in the opposite direction than the settling chamber (Fig. 10) - such targeting of the movement was aimed at precipitating the energy stream flowing out of the tube distributing the slurry.

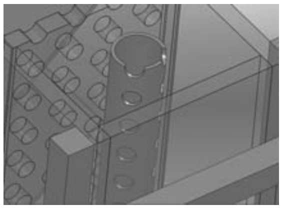

Fig. 10. Configuration no. 1 of the suspension distribution system - configuration 1

The results of flow simulation for configuration no. 1 used a perforated septum with holes of *φ=5mm* in diameter, are shown in Fig. 11- velocity distribution in the vertical plane passing through the middle of the settling device showing vectors indicating the direction of flow, and Fig. 12 - velocity vectors shown in several cross section planes of the settling device. Analyzing the results, we see that in the settling device occurs a stream, beginning in the lower end of the distribution chamber, which passes through the center of the hopper reaching the sedimentation tube closest to the overflow weir system. The result is a flow in which there are two negative elements. The first is the uneven load on the lamella pack - in the ideal arrangement, the slurry stream flowing through each of the wires should be identical. The second element is the presence of a stream at the bottom of the hopper - which in the case of sedimentation would result in lifting of the sludge accumulating in the hopper snap.

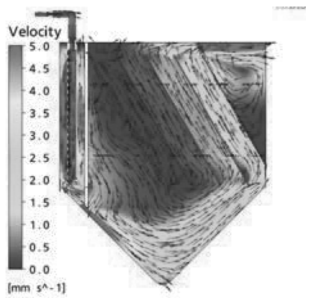

Fig. 11. Velocity distribution along the settling chamber q=0.5 m/h - configuration 1

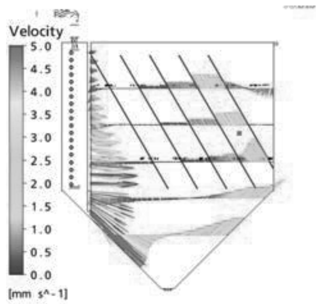

Fig. 12. Velocity vectors in several planes in the settling device q=0.5 m/h - configuration 1

After analyzing the obtained results it was found that the adverse effect of the presence of a strong downward flow (i.e. the scum hopper) is based on two elements. The first one is too large holes in the suspension distributing tube. As a result, fluid leaking from the feeding holes has a downward velocity towards the tank, which causes the formation of a strong downward stream. The second element conducive to the formation of the flow is directing the flow in the opposite direction than the perforated plate - which resulted in a pre-focused flow that was not diffused by a perforated septum, and also by returning from the front panel was headed down the trap.

Configuration no. 2

Based on these experiences changes were made in the design concept for the system of distribution of the suspension. The size of holes in the feeding pipe was reduced, while increasing their number. Instead of two columns of holes facing the outer wall, three columns of holes facing the perforated septum were introduced (Fig. 13).

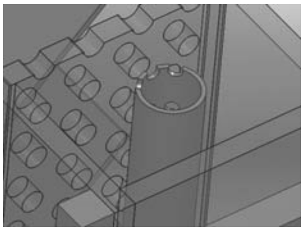

Fig. 13. Modified configuration of the suspension distribution system - version 2 of the configuration

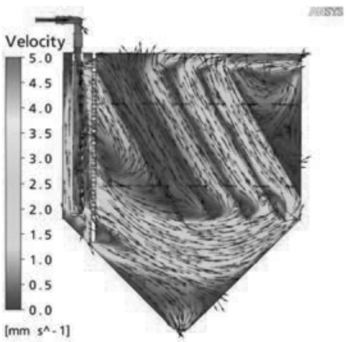

Fig. 14. Velocity distribution along the settling chamber q=0.5 m/h - configuration 2

The results of flow simulation for the two configurations described above, with holes of diameter at φ=3 mm in the feeding tube at the surface load of 0.5 m/h are shown in the figures: Fig. 14 - velocity distribution in the vertical plane passing through the tank showing vectors indicating the direction of the flow, and Fig. 15- velocity vectors shown in several planes traversing the tank. The presented results clearly show that in the effect of the changes made, the strong stream at the lower part of the hopper has been eliminated, reducing the uneven load on individual sedimentation lamellas. However, there still remains a significant difference in velocity between the extreme channels, where for the one closest to the distribution system the maximum value of velocity was 0.03 mm/s, while in the case of the most remote one, the analogical flow velocity was at 1.7 mm/s. Further adjustment of the system could consist of such a modification of the foundation of individual plates of sediment, which would favor increasing the slurry flow in the channels closer to the distribution system. It should be remembered that the aim was even distribution of suspension flow, which is a two-phase system which favors homogenization of the flow.

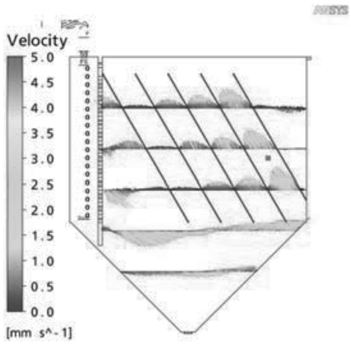

Fig. 15. Velocity vectors in several planes in the settling device q=0.5 m/h - configuration 2

Despite the presence of uneven velocity distribution in the various parts of the sedimentation structure it was assumed that due to significant decrease in the flow through the feeding tube, the system is suitable for the process and can be verified in the laboratory.

Counter-current system

The second system, where an analysis of the velocity distribution was conducted was a settling device with a cross-current lamella structure, characterized by the direction of treated suspension flowing perpendicularly to the direction of the settling sludge. Additionally, for this system a series of numerical simulations of flow was performed, which finally enabled the selection of optimal geometric parameters of the settling device.

The initial design concept of the distribution system for the suspension for the countercurrent system selected was used as a starting point in choosing the parameters of suspension distribution for the settlement tank with a cross-current lamella pack. A series of numerical simulations were performed by modifying the perforated septum and suspension distributing tube.

The flow modeling results in the cross-current device for the surface load amounting to *0.5m/h*, and for the slurry distribution system shown in Fig. 13, in the form of velocity distribution in the symmetry plane of settler along the settling chamber is presented on the Fig. 16. While the Fig. 17 contains the velocity distribution in the perforated septum at the entrance to the settling chamber. The posted results clearly show that in the whole sedimentation space a relatively homogeneous distribution of velocities is obtained, with no visible overloaded or under loaded areas. Velocity distribution at the entrance to the sedimentation chamber

(Fig. 17) holds a virtually identical value along the entire height of the tank.

For more detailed analysis of the velocity distribution in the chamber, a sedimentation velocity chart with values drawn in the plane of symmetry passing along the settler for the three lines arranged vertically in the device was prepared (Fig. 18). The first line at the beginning of lamella pack - solid line, the other mid-tank - dashed line, the third at the outlet of the settler - dotted line. The velocity is marked on the vertical axis, whereas the horizontal axis of the chart is the height inside the tank, which covers the space from the top of the hopper to the liquid surface. The graph presented shows that the velocities of flow in the lamella package were at the level of 0.5 mm/s to 1 mm/s. For the first channel, located at a distance of 3 cm from the perforated septum (solid line), irrespective of the amount in the tank, we observed a similar sedimentation velocity in neighboring channels. For the line located in the middle of the pack - at a distance of 11 cm from the perforated septum (dashed line), one may notice a slight increase in the velocity values in consequent sedimentation channels coming closer to the liquid surface. While at the end of the package (chart at the distance of 21 cm from the perforated septum), a clear increase is observed in the rate of sedimentation in the following channels - which results from the location of the effluent outlet.

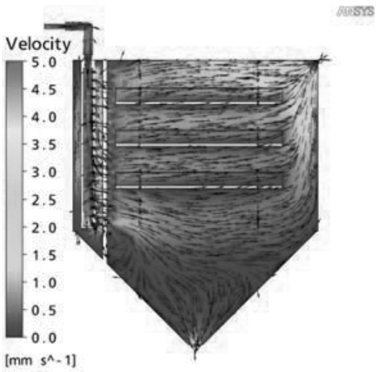

Fig. 16. Distribution of velocities along the settling chamber - q=0.5 m/h - cross-current pack

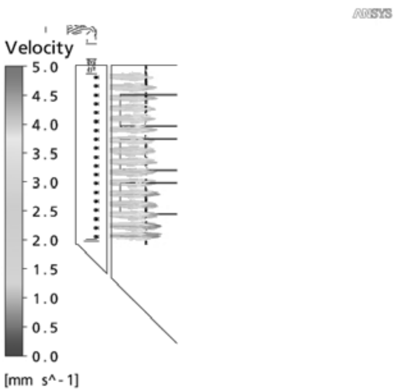

Fig. 17. Velocity vectors in the perforated septum - cross-current pack

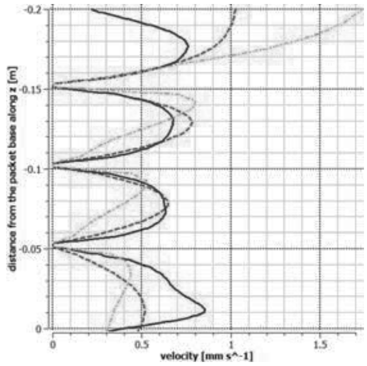

Fig. 18. Velocity flow chart inside the pack: solid line - at the entrance to the package, dashed line - in the middle of the pack, dotted line - the output of the package

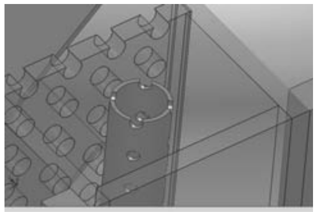

Fig. 19. Configuration no. 3 of the suspension distribution system

For comparison, the results of the velocity distribution were presented (Fig. 20), velocity profile at the entrance to the sedimentation chamber (Fig. 21), and velocity graphs (Fig. 22) as described above, obtained with identical surface load as in earlier simulations, amounting to 0.5m/h, and for the modified suspension distribution system (Fig. 19). The modification consisted of applying four columns of holes with a diameter of $\varphi=2mm$ holes evenly spaced (at 90°) along the perimeter of the distributing tube, instead of three.

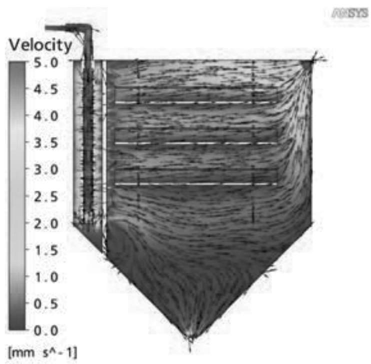

Fig. 20. Distribution of velocities along the settling chamber- q=0.5 m/h - cross-current pack

Based on the results, one can conclude that there are no major differences in the use of the settling device with the cross-current lamella pack system, for slurry distribution shown in Fig. 13 and Fig. 19. Velocity distributions in the plane of symmetry of the device, as well as velocity distributions at the entrance to the chamber and velocity diagrams in the three sections of the settler are similar, and in fact it does not matter which variant of the design is be used in the settling device.

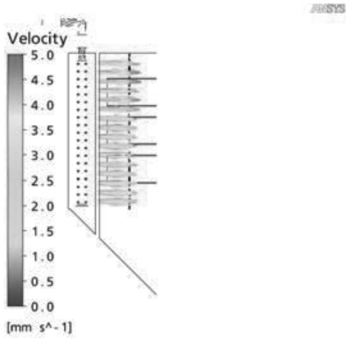

Fig. 21. Velocity vectors in the perforated septum - cross-current pack

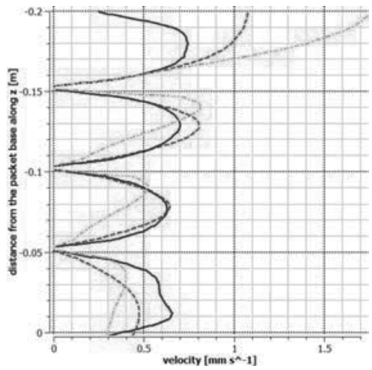

Fig. 22. Flow chart in the lamella pack: solid line - at the entrance to the package, dash line - in the middle of the pack, dotted line - at the output of the package

4. Visualization of flow in the settling tank

Verification of numerical simulations was carried out as a visualization of flow in a laboratory model of the settler - which was built on the basis of earlier numerical simulations. The flow visualization was based on the observation of the boundary between a clear medium (water), a medium with an optical marker pumped through the laboratory separator set up as in actual testing of sedimentation. Visualizations were made for a settling device configuration with the two variants of lamella pack fitted, with the surface load of 0.5 m/h.

In the Fig. 23 the distribution of velocities profile in the settling device is presented with the configuration using a counter-current lamella pack, with the slurry distribution system as shown in Fig. 13.

In the Fig. 24 contains the distribution of velocity profile in the cross-section settling tank packed with a slurry distribution system as shown in Fig. 19.

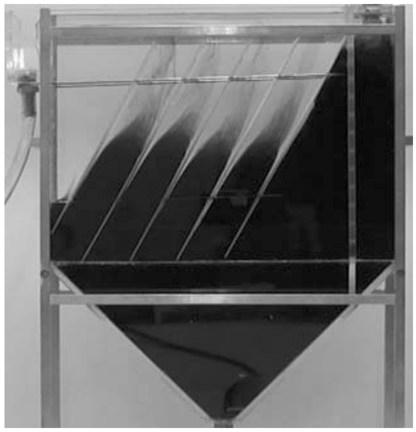

Fig. 23. Visualization of counter-current flow for q=0.5 m/h

Fig. 24. Visualization of cross-current flow for q=0.5 m/h

The observed shapes of flow distributions are consistent with the images of distributions from numerical simulations. This occurs both in the case of the counter-current and cross-current variant.

Such a distribution of flows (relatively even load on the consecutive plates of the lamella) confirms that the design of the settling device in both variants is adjusted properly, and the tested process would be representative for both the settler and selected pieces of the lamella packs.

5. Conclusions

As a result of the works, geometric parameters were selected for the distribution of suspension in a laboratory designed sedimentation tank for sedimentation applied either in a counter-current or cross-current system.

The use of numerical methods of modeling the flow in clarifying equipment allows fine-tuning it at the design stage of both the counter-current and cross-current systems.

It arises from the analysis that the main factor determining the velocity distribution in the clarifier system is distribution of suspension. Proper selection of geometric parameters for this system allows loading the device evenly. The even distribution along the height of the settling tank is largely determined by the diameter of the holes in the tube distributing the suspension, with assumed constant diameter of the inlet. For the pipe distributing suspension with a 16 mm outer diameter and wall thickness of 2 mm (the pipe used in the analyzed system) holes with a diameter of 3 mm and smaller allow for even distribution of velocities along the pipe distributing the suspension; this effect was particularly evident in the case of perpendicular current filling. The use of holes with larger diameters in the suspension distributing tube resulted in channeling the flow in the direction of the scum hopper, which ultimately led to the unequal load on the settling device.

From the analyses of the suspension it shows that the distribution of the applied version of the perforated septum with properly chosen tube distributing the suspension is of secondary importance for this system.

The resulting distributions of the medium flow in the clarifier during laboratory flow visualization for both variants of the lamella structure are roughly consistent with the corresponding numerical simulations. Optimization of the settling device design was performed through the selection of appropriate options and verification of the shape of the flow in the numerical model. This allowed avoiding of several consecutive physical models, in favor of just one final model. This confirms the excellent suitability of numerical methods in the design of sedimentary units.

In the future, in numerical simulations instead of a single-phase medium, a two-phase medium could be introduced: a suspension; however, this involves the consideration of many additional aspects, such as information on its granulometric composition, or interparticle interactions (autocoagulation), which due to the significant complication of the model not only prolongs the calculations, but will also cause additional errors, which numerical simulations are sensitive to.

References

[1] W.P. Kowalski, Investigation of fine grains distribution using the sedimentation analysis, Journal Of Materials Processing Technology 157 (2004) 561-565.

[2] W.P. Kowalski, Lamella sedimentation - The state of art and directions of development, Chemical and Process Engineering 25/3 (2004) 1163-1170.

[3] K. Kołodziejczyk, T. Zacharz, The suspension purification in the combined co-current and counter-current sedimentation process - Empirical model, Chemical and Process Engineering 25/3 (2004) 1107-1113.

[4] W.P. Kowalski, R. Mieso, Regresion models of lamella cross-current sedimentation process, Chemical and Process Engineering 22/3C (2001) 783-788.

[5] W.P. Kowalski, K. Kołodziejczyk, T. Zacharz, The investigations of a lamella concurrent sedimentation process, Chemical and Process Engineering 22/3C (2001) 777-782.

[6] K. Kołodziejczyk, The modelling of laboratory multiflux settling tank work, Polish Journal of Environmental Studies 20/4A (2011) 130-135.

[7] M. Banaś, The dependence of sedimentation efficiency on suspension concentration, Chemical and Process Engineering 25/3I (2004) 659-664.

[8] M. Banaś, Computer simulations of the sedimentation process model which considers internal interactions among solid phase particles, Chemical and Process Engineering 25/3I (2004) 665-671.

[9] A.M. Goula, M. Kostoglou, T.D. Karapantsios, A.I. Zouboulis, A CFD methodology for the design of sedimentation tanks in potable water treatment, Chemical Engineering Journal 140 (2008) 110-121.

[10] F. Rostami, M. Shahrokhi, Md Said, R. Abdullah, Syafalni, Numerical modeling on inlet aperture effects on flow pattern in primary settling tanks, Applied Mathematical Modelling 35/6 (2011) 3012-3020.

[11] K. Samaras, A. Zouboulis, T. Karapantsios, M. Kostoglou, A CFD-based simulation study of a large scale flocculation tank for potable water treatment, Chemical Engineering 162 (2010) 208-216.

[12] S. Xanthos, M. Gong, K. Ramalingam, J. Fillos, A. Deur, K. Beckmann, et. al., Performance Assessment of Secondary Settling Tanks Using CFD Modeling, Water Resources Management 25/4 (2011) 1169-1182.

[13] T. Bajcar, F. Steinman, B. Sirok, T. Preseren, Sedimentation efficiency of two continuously operating circular settling tanks with different inlet- and outlet arrangements, Chemical Engineering Journal 178 (2011) 217-224.

[14] R.M. Bowen, Theory of mixtures, A.C. Eringen (Ed.), Continuum Physics, Academic Press, New York, 1976.

[15] D. Gidaspow, R. Bezburuah, J. Ding, Hydrodynamics of Circulating Fluidized Beds, Kinetic Theory Approach, In Fluidization VII, Proceedings of the 7th Engineering Foundation Conference on Fluidization, 1992, 75-82.

[16] W.P. Kowalski, K. Kołodziejczyk, T. Zacharz, Application of CFdesign software to visualization of flow suspension in a prototype settling tank, Proceedings of the 7th International Conference The Experience of Designing and Application of CAD Systems In Microelectronics, 2003, 473-477.

[17] S.V. Patankar, Numerical heat transfer and fluid flow, Hemisphere Publishing, New York, 1980.