

# Implementation of Thickener Feedwells Upgraded Using CFD-PBM Method at UC RUSAL

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## Abstract

Gravity settling of the slurries in the thickeners is a common process solution at alumina refineries. Thickener efficiency influences the potential capacity of the entire refinery. Upgrade of the feedwell design is one of the means to enhance the performance and improve slurry separation providing for the better mixing of the slurry with reagents to stimulate residue settling. For this task UC RUSAL's specialists use computational modelling with a verified in-house method of slurry flocculation modelling, i.e. CFD-PBM. The paper discusses the method of slurry flocculation modelling and elaborates on the approaches and criteria for designing the feedwell of the thickener. Furthermore, it presents the results of testing the thickener design options at UC RUSAL's alumina refineries.

**Keywords:** CFD, PBM, Thickener, Feedwell, Flocculation.

## 1. Introduction

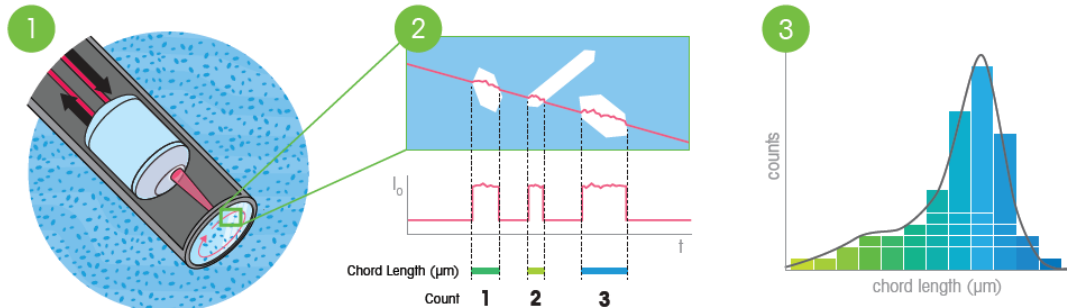
In hydrometallurgy, of great importance in separation of suspension into liquid and solid components is a thickener. Thickener efficiency influences the potential capacity of the entire refinery and cash cost of the products. Therefore, one of the ways to raise efficiency of a thickener is to upgrade feedwell design. A feedwell is one of thickener structural units where feed flow energy is dissipated and a feed slurry is mixed with chemical reagents, i.e. a flocculant or coagulant to improve the settling rate of the slurry in the thickener. Flocculation is essentially a process of particles aggregation in flocs accompanied by simultaneous growth and breakage for the account of shear stress in liquid. It is a dynamic process with the rate depending on properties of particles, flocculant and mixing conditions. Improper flocculation process decreases the efficiency of solids settling thus degrading the quality of the overflow and deteriorating the sand compaction. The prevailing means to improve thickener performance at alumina refineries is increasing the flocculant dosage, as it is the commonly available solution. However, as experience shows this method does not necessarily improve the sedimentation process, leads to excessive floc consumption (expenses for the flocculant can amount to up to USD > 1.5 per 1 tonne of alumina), and can result in excessive foam formation in the feedwell.

This paper presents the methods of studying the flocculation process and analyzing the performance efficiency of the thickener feed unit using mathematical modelling. Besides, the paper elaborates on the approaches and criteria for selecting/determining the design of a thickener feedwell. Finally, it discusses the results of testing the upgraded thickeners at UC RUSAL's refineries.

## 2. Laboratory Study of the Flocculation Process

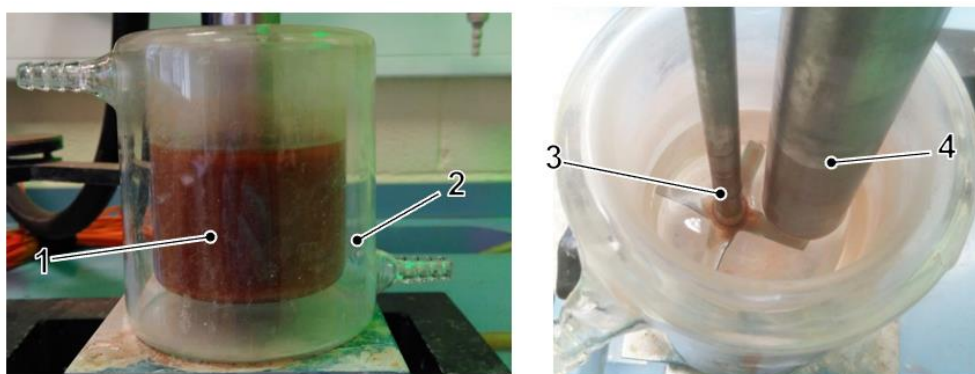
As has been mentioned before, flocculation is promoted by the shear stresses in the flow. Shear stresses provide for thorough mixing and high probability of collisions between particles and, therefore, rapid growth of flocs.

One of the most efficient methods of flocculation monitoring is Particle Track tool with FBRM technology. This tool provides for online monitoring of changes in particle size and structure in the system, thus enabling to get more insight into the behavior of the system and impact of various process parameters on flocculation efficiency. FBRM tool uses a rotating laser beam to contact the particles. Figure 1 shows a principle of FBRM functioning. References [1, 2] give a detailed description of FBRM technology.

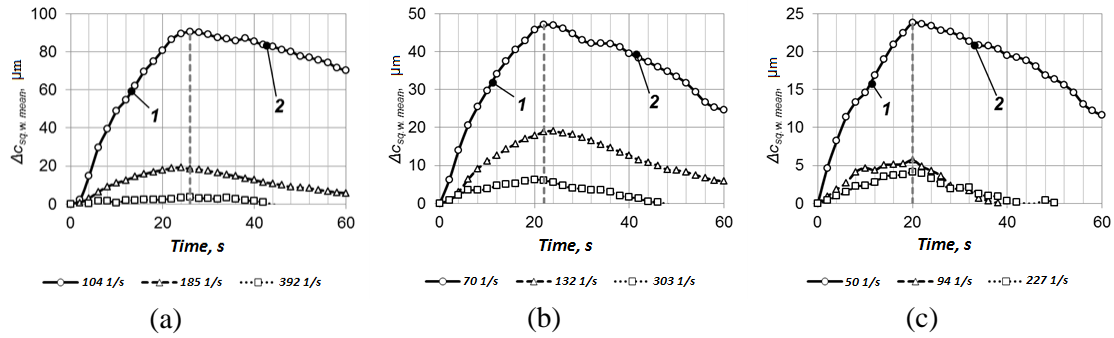


**Figure 1. Principle of FBRM functioning.**

FBRM technology was used to study the flocculation of the nepheline mud slurry from JSC RUSAL Achinsk. Flocculation process was simulated in a 250 ml beaker equipped with a FBRM probe and a mixer to improve the mixing of the slurry with the flocculant (Figure 2). The impact of shear rates on the floccule growth and breakage was investigated. Figure 3 shows the dependences of changes of the mean lengths of chords under different flocculation conditions. The graphs demonstrate two stages of the flocculation process, i.e. in the beginning of the flocculation process particles quickly aggregate, however, when flocs become larger, their susceptibility to breakage increases. The data presented indicate that the largest flocs were obtained at the shear rates of 50–100 s<sup>-1</sup>. As can be noted, floccule active growth lasted for a little over 20 s.



**Figure 2. The laboratory set-up for the mixing of the slurry and flocculant.  
1 – slurry, 2 – container, 3 – impeller, 4 – FBRM probe.**



**Figure 3. The dependences of changes of the mean length of chords on the time under different flocculation conditions. a – 60 g/L solids, b – 130 g/L solids content, c – 200 g/L solids content. 1 – floccule growth, 2 – floccule degradation.**

The drawback of the Particle Track system is its high price. Besides, mixing of slurry with a flocculant by means of a mixing device in a beaker takes place in a wide range of shear rates that brings inaccuracies in the study of shear rates impact on aggregation and breakage rate of flocs. A laboratory bench to study the process of settling of polydisperse slurry (further SPS) was developed to improve the accuracy of physical simulation of the process of slurry flocculation, where mixing of slurry with flocculant occurs in a vessel with Taylor flow, and settling of slurry takes place in a graduated column [3]. Taylor flow enables to maintain a narrow range of shear rates within the mixing of the slurry with the flocculant while the graduated column allows evaluating the flocculation results by the settling rate, which determines the floccule size.

Table 1 presents the testing results of sodium carbonate slurry from RUSAL Krasnoturyinsk carried out using the SPS laboratory bench.

**Table 1. Results of study of sodium carbonate slurry flocculation.**

Test #	Solids in the slurry	Flocculant dosage	Shear rate	Period of mixing the slurry with flocculant	Slurry settling rate
	g/L	g/t mud	s <sup>-1</sup>	s	mm/s
1	100	0	38	51	0.5
4	100	25	76	10	6.0
8	100	25	190	25	6.4
3	100	25	76	25	6.9
9	100	25	190	17	6.9
2	100	25	76	51	7.5
5	100	25	114	25	7.5
6	100	25	152	25	7.5
7	100	25	38	51	8.2

The tests showed that the settling rate of the flocculated slurry ranged from 6 to 8.2 mm/s, and the settling rate of the unflocculated slurry amounted to 0.5 mm/s. Under said conditions of the mixing, the flocculant addition enabled to significantly improve the slurry settling rate.

Qualitative analysis of the results of slurry flocculation tests showed that the best settling rate of the slurry was achieved at long-lasting mixing of slurry with flocculant (51 seconds) under conditions of minor shear rates, below 100 s<sup>-1</sup> (test 2 and test 7). With the shorter mixing period (25 s and 10 s in test 3 and test 4 respectively) at a fixed minor shear rate (76 s<sup>-1</sup>) the settling rate of the slurry decreases due to low agglomeration rate of the flocs.

At high shear rates ( $> 180 \text{ s}^{-1}$  in test 8 and test 9) the situation is reverse, i.e. the slurry settling rate increases while the period of mixing of the slurry with the flocculant decreases. Under high turbulence conditions, long-lasting mixing is not recommended as said conditions have a significant impact on the flocs agglomeration rate as well as their breakage.

Based on the results obtained in the laboratory tests the required conditions for the mixing of the slurry with the flocculant were determined as follows:

- shear rates in the feedwell shall not exceed  $100 \text{ s}^{-1}$ ;
- residence time of the particles in the feedwell shall be within 30–50 s.

### 3. Mathematical Modeling of a Thickener Feed Unit

To evaluate the performance of the thickener feed unit a mathematical model was developed based on the methods of computational fluid dynamics (CFD) and population balance model (PBM).

The flow inside the thickener feed unit is turbulent so two-equation turbulence model  $k-\varepsilon$  is used in the model. The slurry was simulated by Euler-Euler approach of the *Mixture* model. The secondary phase is set with *granular* option to determine its dispersion. Distribution of the solid phase by fractions was set by means of a homogeneous discrete population balance method. In calculations, 41 fractions (bin) having minimum diameter  $1 \mu\text{m}$  and double change of interval of particles volume was used. The drag force with interphase interaction was set by *Syamlal Obrien* model with a correction factor. Said correction factor shall compensate for the error caused by the assumption on the spherical shape of particles.

The equation of population balance is based on Smoluchowski's equation [4], which describes the flocculation dynamics considering effects of coagulation and breakage of particles:

$$\frac{dn_i}{dt} = \frac{1}{2} \sum_{j+k=i} \alpha \beta(u_j, u_k) n_j n_k - n_i \sum_{k=1}^{max} \alpha \beta(u_k, u_i) n_k - S_i n_i + \sum_{j=i}^{max} \gamma_{i,j} S_j n_j \quad (1)$$

where:

$n_i$  number density of flocs of the size  $i$ ,  $\text{m}^{-3}$

$t$  time, s

$\alpha$  capture efficiency factor or share of the collisions leading to coagulation;

$\beta(u_j, u_k)$  frequency of collisions of particles having volumes  $u_j$  and  $u_k$ ,  $\text{m}^3/\text{s}$

$S_i$  frequency of breakage of flocs of the size  $i$ ,  $\text{s}^{-1}$

$\gamma_{i,j}$  function of distribution of fragments defining volume fraction of fragments of size  $i$  arriving from flocs of size  $j$

Index *max* represents the largest size of particles formed at breakage of flocs of size  $i$ . The first summation in the right hand side of the equation 1 is formation of particles consisting of  $i$  primary particles at collision of smaller particles of  $j$  and  $k$  sizes. The second member in the right hand side of the equation designates the loss of particles of  $i$  size in collision with particles of any other size. The third member in the right hand side of the equation describes the loss of particles of  $i$  size due to their breakage, and the fourth member in the right hand side of the equation describes formation of particles of  $i$  size by breakage of larger particles.

Agglomeration and breakage kernel describe physics of the process of flocculation and are the most important equations in the model of population balance.

Frequency of collisions for coagulation of particles caused by turbulent shear stress was offered by Saffman and Turner [5, 6, 7].

$$\beta(V_i, V_j) = 0,31G\alpha(V_i^{\frac{1}{3}} + V_j^{\frac{1}{3}})^3 \quad (2)$$

where:

$G$  Shear rate,  $s^{-1}$   
 $\alpha$  capture efficiency factor

The nucleus of flocs breakage used in the paper was proposed by Kapur's function from the volume of flocs [8]:

$$S_i = AV_i^a, \quad (3)$$

where:

$a$  equal to 1/3  
 $A$  factor of flocs breakage rate

Factors of agglomeration and breakage kernel in the model of population balance are different for different systems of slurry-flocculant. They can be determined by the following research procedure:

1. Laboratory. Determination of physical properties of the slurry, i.e.
  - density of liquid and solid phases;
  - liquid viscosity;
  - fraction distribution of slurry solids.

Carrying out a number of tests on the mixing of the slurry with flocculant followed by settling of the slurry in a graduated cylinder. Based on the test results the curves of slurry clarification are generated. To achieve more even distribution of the shear rates inside the area of the mixing of the slurry with flocculant a Taylor-Couette reactor shall be used instead of a standard agitated beaker.
2. Analysis. Processing of settling tests results. Drawing up a table of dependency of a mean flocs diameter on the shear rate and time of the mixing of the slurry with flocculant. Determination of flocs fractal structure [9].
3. Modeling. A computational model of the reactor of the mixing of the slurry and flocculant is developed. Agglomeration and breakage kernel are set by the iterative approximation of the calculated results to the test data.
4. Simulation. The obtained parameters of the model are used for simulating the gravity or wash thickener.

The calculation of the dynamics of the floc size changes requires much computational work so to save time on determining the best design option of the feedwell the models are preliminary analyzed as per the following parameters:

- *Dilution factor* shows the secondary flows (backflow from thickening to the feedwell and other liquids) incoming the feedwell along with the feed slurry, and is determined by the ratio of volumetric flow rates of the slurry from the feedwell to the feed rate.

$$K_{dil} = \frac{G_{feed} + G_{sec}}{G_{feed}} \quad (4)$$

where:

$G_{feed}$  volumetric flow rate of the feed flow, m<sup>3</sup>/h

$G_{sec}$  volumetric flow rate of the secondary flows, m<sup>3</sup>/h

— *Factors of momentum diffusion and kinetic energy diffusion* show the intensity of the slurry flow energy diffusion in the feedwell volume.

$$K_{m.d.} = \frac{\rho_{sl} \cdot U_{out}}{\rho_{sl} \cdot U_{in}} \quad (5)$$

where:

$\rho_{sl}$  slurry density, kg/m<sup>3</sup>

$U_{out}$  slurry flow rate at the exit from the feedwell, m/s

$U_{in}$  slurry flow rate at the entry to the feedwell, m/s

$$K_{k.d.} = \frac{\rho_{sl} \cdot U_{out}^2}{\rho_{sl} \cdot U_{in}^2} \quad (6)$$

— *Volume averaged shear rate* in the feedwell. The calculation of this parameter is complicated as slurry solids in the feedwell volume split into layers due to the centrifugal force. Solid particles are accumulated near the feedwell walls, so shear rates in the center of the feedwell do not influence the flocculation. Control volume is calculated as the feedwell volume with solids volumetric fraction of > 0.01.

$$\dot{\gamma} = \frac{1}{V} \int \dot{\gamma} dV \quad (7)$$

where:

$\dot{\gamma}$  shear rate, s<sup>-1</sup>

$V$  feedwell volume with solids volumetric fraction of > 0.01

— *Part of outflow face of the feedwell with the shear rate of > 100 s<sup>-1</sup>* shows the uneven turbulence distribution at the exit from the feedwell and defines the area with excessive floc breakage.

$$\varphi_{out} = \frac{A_{sh}}{A_{out}} \quad (8)$$

where:

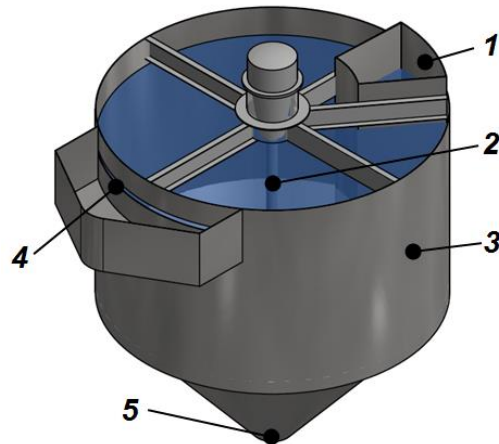
$A_{sh}$  outflow face of the feedwell with the shear rate of > 100 s<sup>-1</sup>, m<sup>2</sup>

$A_{out}$  outflow face of the feedwell, m<sup>2</sup>

#### 4. Upgrade of the Nepheline Mud Thickener at JSC RUSAL Achinsk

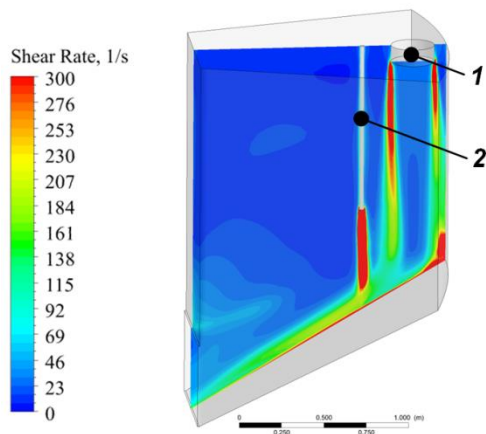
##### 4.1 Upgrade of the Feed Unit of the Nepheline Mud Thickener

The nepheline mud thickener is of irregular design (Figure 4). The feed unit is a box installed outside the vessel.

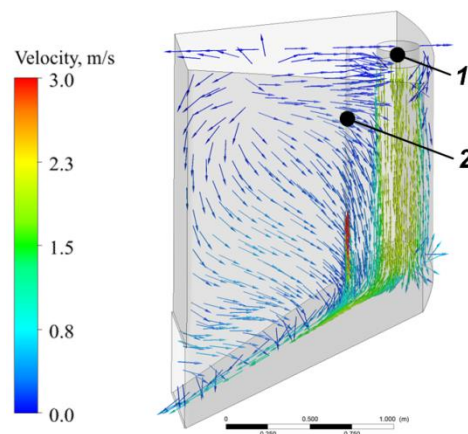


**Figure 4. Nepheline mud thickener. 1 – feedwell, 2 – agitator, 3 – vessel, 4 – overflow discharge, 5 – cone with underflow (sands) discharge.**

CFD models of the thickener were calculated for the feed slurry flow rate of 360 m<sup>3</sup>/h and solids content of 160 g/L. Figure 5 and Figure 6 show the fields of the shear rates and velocities in the model of the original thickener feedwell.



**Figure 5. Contour field of shear rates in the original thickener feedwell. 1 – slurry feed pipe, 2 – flocculant feed pipe.**

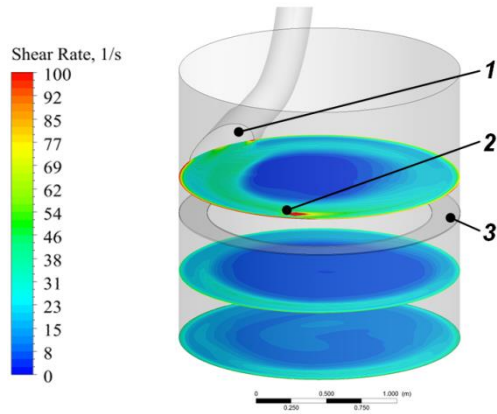


**Figure 6. Vector field of velocities in the original thickener feedwell. 1 – slurry feed pipe, 2 – flocculant feed pipe.**

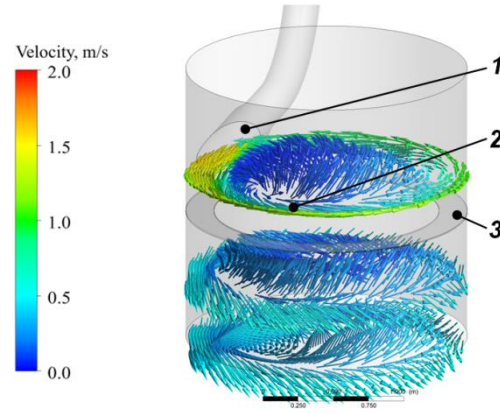
CFD simulation of the original design of the thickener revealed a number of drawbacks in the flow fluid dynamics, i.e.

- high shear rates in the area of the main slurry flow inside the feedwell (approx. 200 s<sup>-1</sup>) that as lab tests show results in rapid flocs breakage;
- short residence time of 50 % solids in the feedwell (< 1.5 s) that hinders the accurate dosing of the flocculant thus reducing its efficiency.

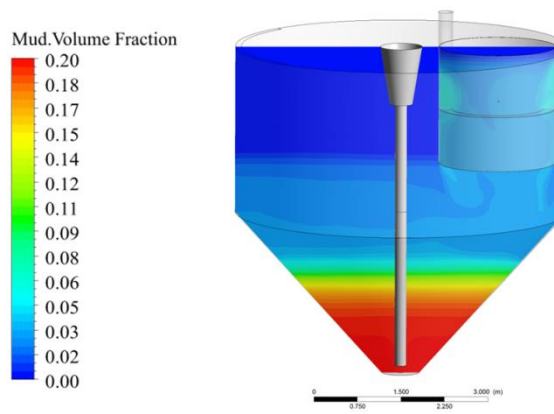
To eliminate said drawbacks of the feedwell structure and to ensure the optimum slurry flocculation conditions a cylindrical feedwell with one tangential input and a construction inside the well in a form of a shelf (to improve the residence time of the particle inside the feedwell) was considered. Figures 7–10 show the results of simulation of said design.



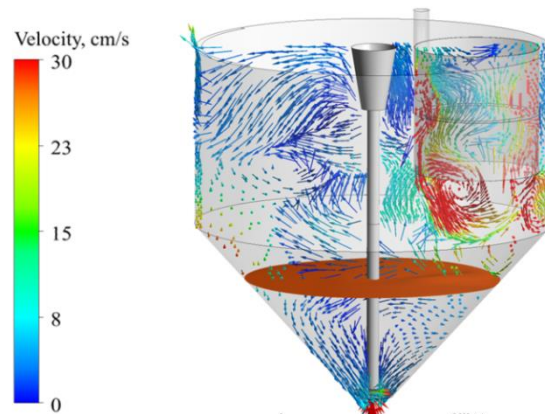
**Figure 7. Contour field of shear rates in the upgraded thickener feedwell. 1 – slurry feed pipe, 2 – flocculant feed point, 3 – shelf.**



**Figure 8. Vector field of velocities in the upgraded thickener feedwell. 1 – slurry feed pipe, 2 – flocculant feed point, 3 – shelf.**



**Figure 9. Contour field of mud volumetric fraction distribution in the thickener with the upgraded feedwell.**



**Figure 10. Vector field of velocities in the thickener with the upgraded feedwell**

The shelf in the feedwell separates it into two zones. The zone above the shelf is an area of elevated shear rates where the slurry is mixed with the flocculant and flocs start to grow. In the zone below the shelf flocs continue growing, and minor shear rates reduce the probability of floc breakage. The optimum width of the shelf to provide for the required residence time of the slurry inside the feedwell was determined by iteration. The width of the shelf is equal to 10 % of the feedwell diameter.

The diameter of the feed pipe at the entry to the feedwell was enhanced to reduce the shear rates inside the feedwell. Said pipe size provides for the average slurry flow rate at the entry to the feedwell of about 1.5 m/s under the considered operating parameters of the thickener.

The upgraded feedwell of the thickener provides for moderate mixing of the slurry and flocculant, besides, the shear rates inside the vessel do not exceed  $100 \text{ s}^{-1}$ , and 95 % of particles exit the feedwell within 32 s. Feedwell performance complies with the required parameters obtained in the laboratory tests of slurry flocculation.

#### 4.2 Industrial Testing of the Upgraded Nepheline Mud Thickener

The feedwell of a proposed upgraded design was mounted and tested at one of the nepheline mud thickeners. One thickening line comprises three parallel thickeners that are fed by gravity from the splitter box.

During the tests average solids in the thickener overflow amounted to 2.2–3.7 g/L that complies with the process specification (max. 10 g/L). Said solids content in the overflow of the upgraded thickener is lower by 58 % as compared with other thickeners. Moreover, flocculant consumption in the upgraded thickener decreased by 15 %. Despite the achieved positive testing results it should be noted that the feed slurry flow rate is affected by structural design of the splitter box, lock valves, lines as well as feed pipe condition. As thickener feed lines are not equipped with the flow meters it is hard to accurately determine the overall impact of the upgraded thickener feed unit and measure the slurry flow rate differences among the vessels. The benefits of the upgraded thickener can be assessed after revamping of the splitter box and upgrade of the remaining thickeners.

Table 2 discusses average thickener performance data during the tests.

**Table 2. Average performance data of nepheline mud thickeners during the tests.**

Parameter	Upgraded thickener	Remaining thickeners	Percentage difference, %
Solids in the feed slurry, g/L	132	103	
Density of the discharge sands, kg/dm <sup>3</sup>	1.41	1.44	
Flocculant consumption, L/h	<b>153</b>	179	<b>-15</b>
Solids in the overflow, g/L	<b>2.2</b>	5.3	<b>-58</b>

As nepheline mud is characterized by increased scaling on the surfaces, to assess the possible scaling in the feedwell the photos thereof were taken before and after the testing. Figure 11 shows said photos. It is evident that no scaling that can affect the flow fluid dynamics built up during the testing.



**Figure 11. Feedwell. Left: before testing, Right: after testing.**

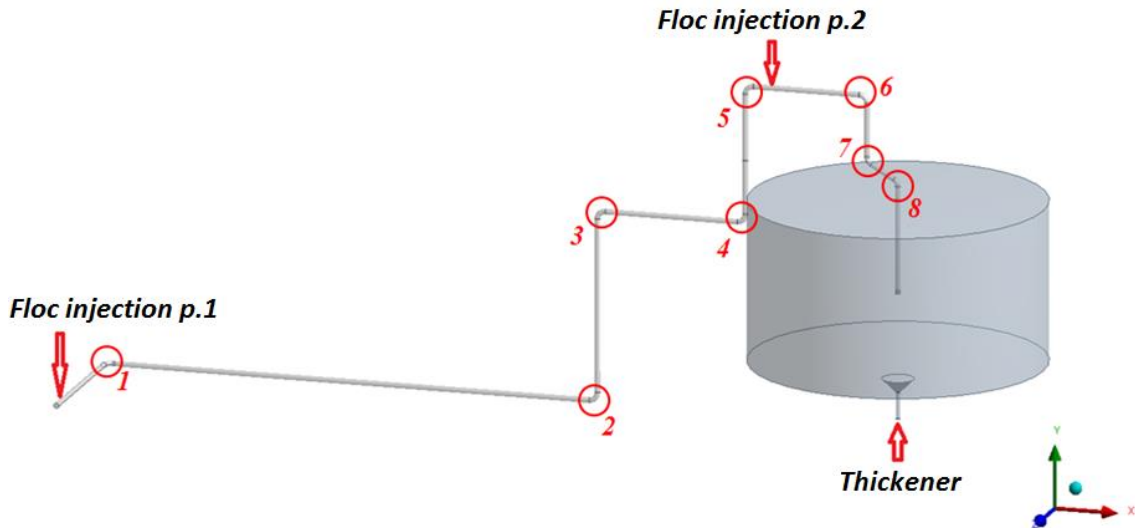
### 5. Upgrade of a Sodium Carbonate Thickener at RUSAL Krasnoturyinsk

#### 5.1 Upgrade of the Feed Unit of the Sodium Carbonate Thickener

The original design of a sodium carbonate thickener does not foresee the feedwell. The feed pipe is placed in the thickener 4 m below the liquor surface. The slurry flows through the cuttings in

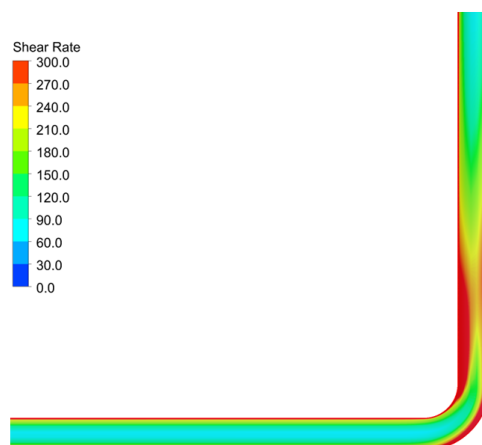
the sides of the feed pipe. The flocculant is supplied to the feed pipe in two points, i.e. 10 and 50 m before the thickener entry point.

For this reason, slurry flocculation process inside the feed slurry was studied. Figure 12 shows 3-D geometric model of the pipeline, which simulates all bends of the existing line.

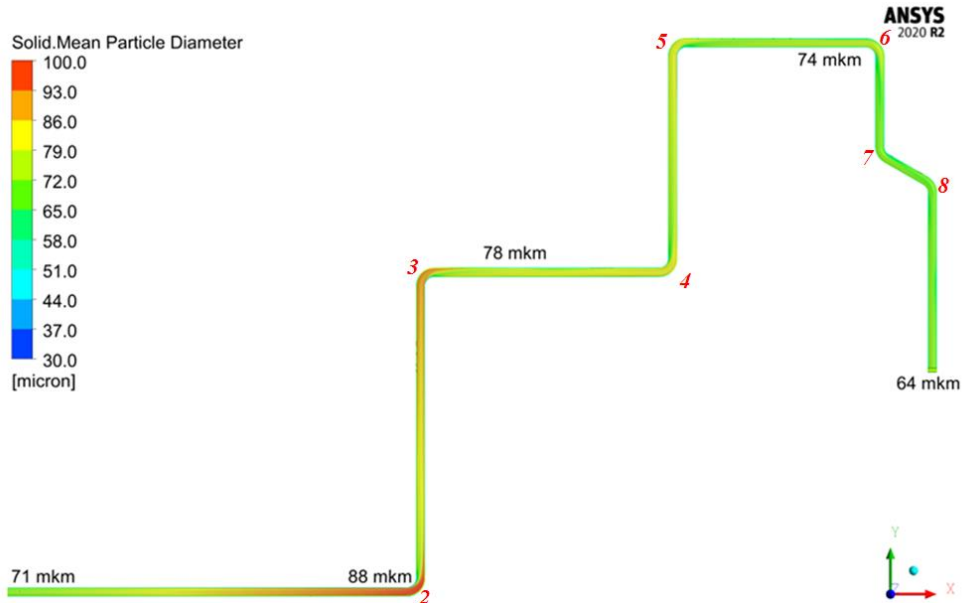


**Figure 12. Geometric model of the pipeline of thickener.**

The pipeline has 8 bends before the thickener entry point. As Figure 13 shows, each bend is characterized by elevated shear rates. Said rates have positive effect on the floc growth only after the first two bends of the line; furthermore, breakage kernel starts to prevail over agglomeration kernel and the size of the flocs decreases (Figure 14). Figure 15 shows the changes of floccule PSD at the exit from the feed pipeline in relation to the initial PSD when the flocculant is added in point 1. There are minor changes in the average particle diameter ( $d_{32}$ ), i.e. from 34 to 64  $\mu\text{m}$ . Such behavior of the population balance model indicates that breakage forces prevail over the agglomeration forces, hence the current system of flocculant injection into the feed line in not effective.



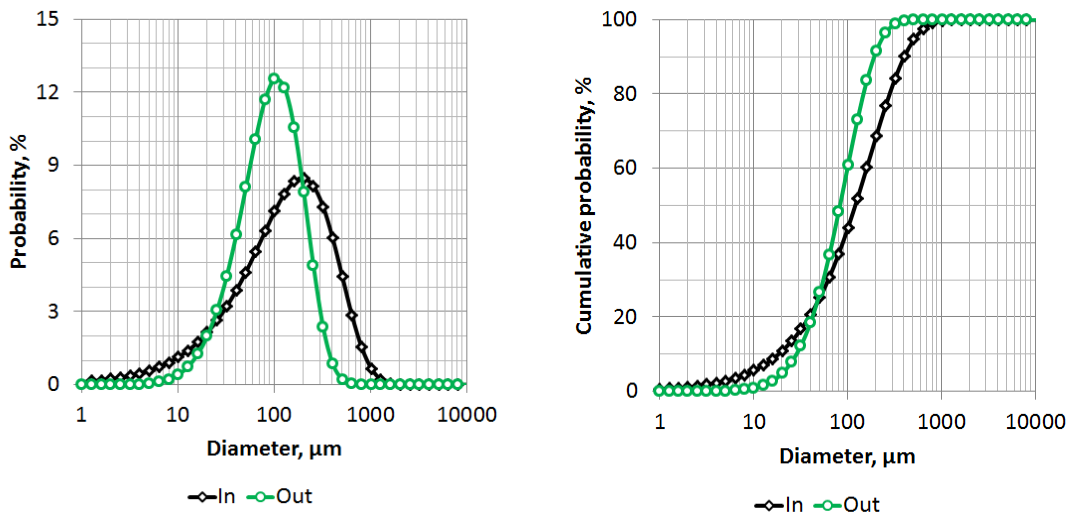
**Figure 13. Contour field of shear rates over the bend on the feed line of the sodium carbonate thickener.**



**Figure 14. Contour distribution of average floc sizes in the feed line of the sodium carbonate thickener.**

An option including a standard cylindrical feedwell with flocculant injection therein was considered. Cylindrical feedwells with one tangential input and various constructions inside the well in a form of shelves and baffles of various forms were considered. Table 3 and Figure 16 present geometric features of the proposed feedwell options.

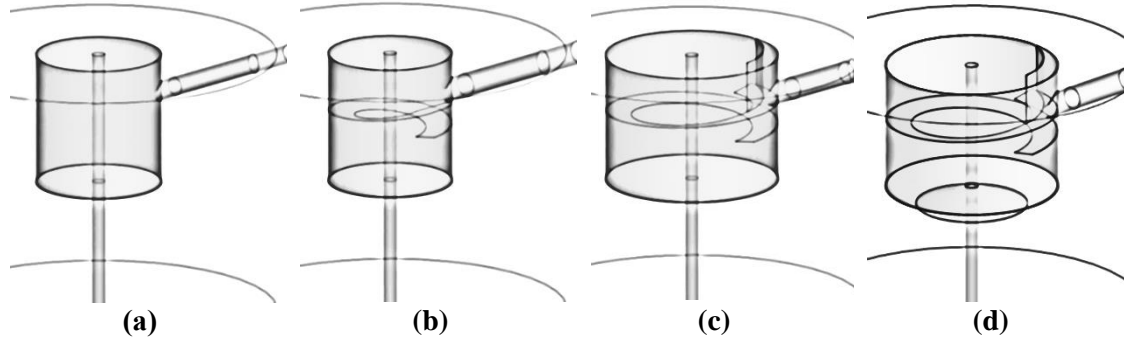
The shelf inside the feedwell ensures the required residence time for the flocculation process inside the feedwell. A spiral shelf showed good performance: the solids sliding from the said shelf do not generate high local shear rates. To prevent accumulation of the solids on the shelf, it (the shelf) is installed at an angle of 10 degrees. The baffle installed above the shelf in the point of slurry entry into the feedwell ensures that the slurry that has circulated above the shelf does not influence the input flow.



**Figure 15. Flocs PSD in the sodium carbonate thickener feed line model.**

**Table 3. Geometric parameters of the design options of sodium carbonate thickener feedwells.**

Option	Feedwell diameter, mm	DN of the feed pipe	Spiral shelf	Cone	Baffle above the shelf
1	1400	200	No	No	No
2	1400	250	Yes	No	No
3	2000	250	Yes	No	Yes
4	2000	250	Yes	Yes	Yes



**Figure 16. Geometric models of sodium carbonate thickener feedwell options. a – Option 1, b – Option 2, c – Option 3, d – Option 4.**

Table 4 introduces the results of calculation of the significant fluid flow parameters for the proposed options of the sodium carbonate thickener feed units.

**Table 4. Parameters of feedwell options.**

Option	Feed slurry flow rate	Backflow factor	Momentum diffusion factor	Kinetic energy diffusion factor	Average shear rate in the flow	Part of outflow face of the reactor with the shear rate of $> 100 \text{ s}^{-1}$	Average output diameter of flocs
	Target values						
	1...1,5, m/s	min	max	max	60...100, s <sup>-1</sup>	min, %	max, $\mu\text{m}$
1	2.04	1.56	0.280	0.079	188	12.6	906
2	1.27	1.17	0.366	0.136	106	18.2	1670
3	1.27	1.39	0.217	0.047	87	1.5	907
4	1.27	0.53	0.283	0.096	71	4.3	1710

Figures 17–19 show contour fields of the flocs, shear rates and vertical velocity. Due to centrifugal forces in the swirling flow the slurry solids move towards the thickener around the circumference of the feedwell and in the center of the feedwell a natural seeping of the slurry from the thickener to the feedwell occurs (Figure 19). The backflow of the slurry (from the thickener to the feedwell) is similar to, and in some cases exceeds, the feed rate (backflow factor  $> 1$ ). To reduce the backflow, option 4 foresees the cone in the lower part of the feedwell. The cone prevents the backflow from entering the feedwell. The higher is the cone diameter, the lower is the slurry dilution factor; however in this case the shear rate at the exit from the feedwell

increases due to a lower exit area. The calculations indicate that for the feedwell with a diameter of 2 m and a spiral shelf the cone base diameter should be 1–1.3 m.

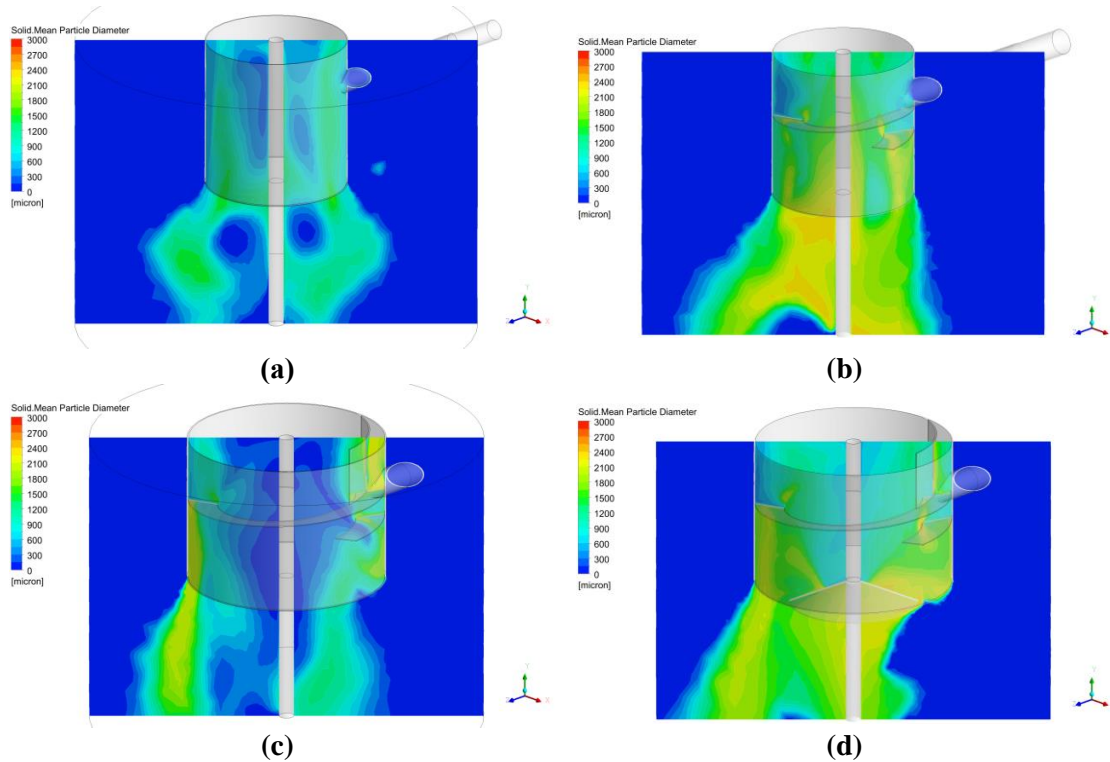
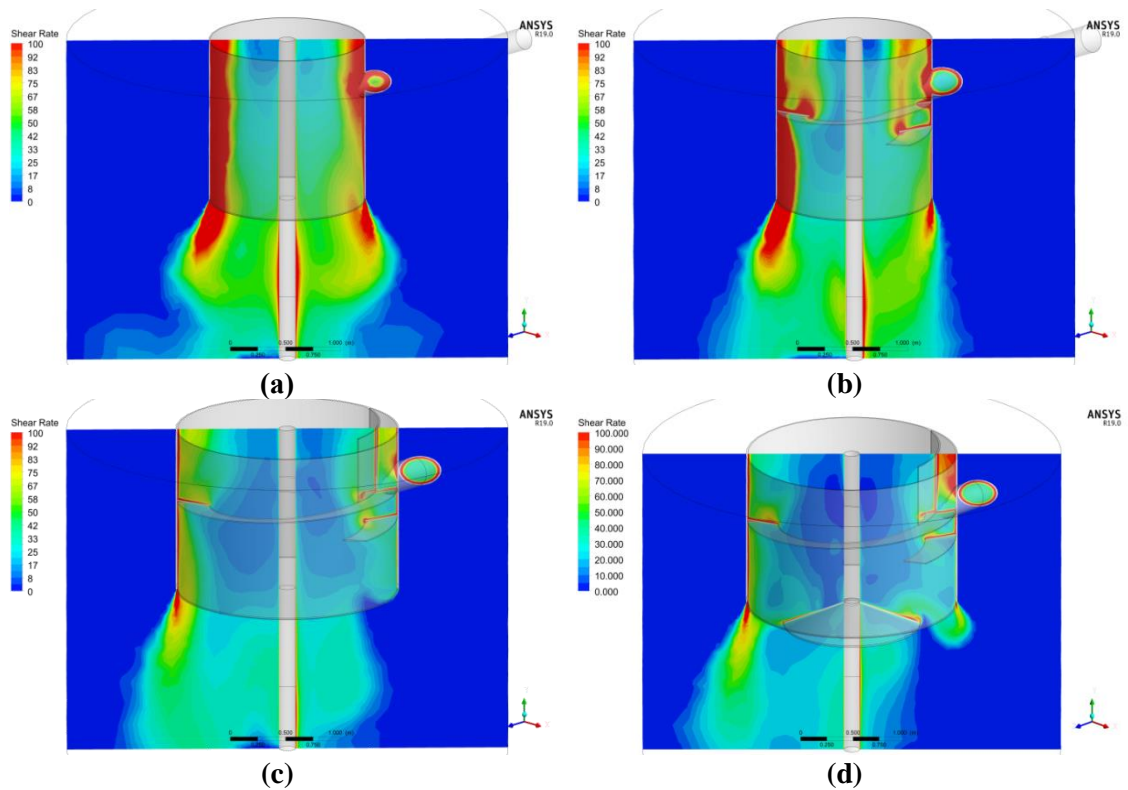
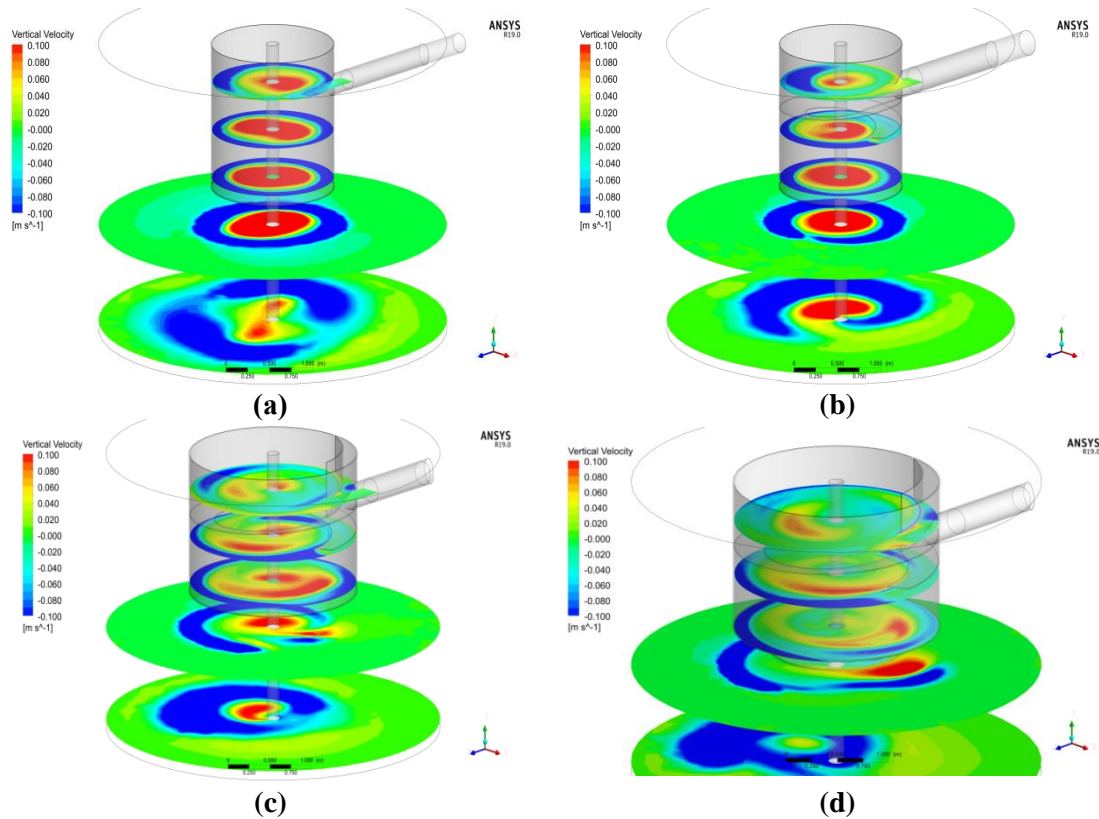


Figure 17. Floccule size distribution in different sodium carbonate thickener feedwell options. a – Option 1, b – Option 2, c – Option 3, d – Option 4.

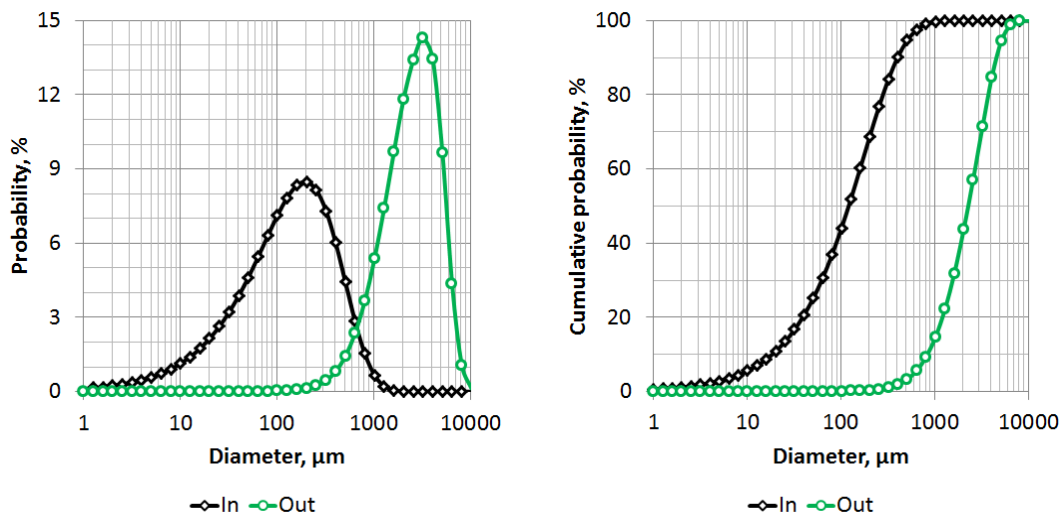


**Figure 18. Distribution of shear rates in different sodium carbonate thickener feedwell options. a – Option 1, b – Option 2, c – Option 3, d – Option 4.**



**Figure 19. Distribution of vertical velocities in different sodium carbonate thickener feedwell options. a – Option 1, b – Option 2, c – Option 3, d – Option 4.**

Option 4 showed the best performance in terms of the specified properties. The feedwell provides for the inside conditions required for efficient slurry flocculation. The average size of particles increased from 125 to 2000  $\mu\text{m}$ . Figure 21 displays the curves of the changes in floccule PSD at the exit from the feedwell as compared with the initial PSD values.



**Figure 20. PSD at the entry to and at the exit from the feedwell. Option 4.**

## 5.2 Industrial Testing of the Upgraded Sodium Carbonate Thickener

Feedwell design option 4 was implemented in the soda thickening area at RUSAL Krasnoturyinsk alumina refinery. Two thickeners having the same performance parameters are available in the thickening area fleet; therefore, one vessel was chosen for upgrade with the other as a reference vessel.

Figure 21 shows the inside of the sodium carbonate thickener feedwell upgraded in compliance with the proposed solutions.

The upgraded sodium carbonate thickener testing was carried out within the period characterized by a high content of carbonates in the spent liquor (~ 17 %) and low caustic concentration in the evaporated liquor ( $\text{Na}_2\text{O}_{\text{caus}} = 278 \text{ g/L}$ ) that suggests the presence of a large amount of fine sodium carbonate in the thickener feed, which is much more difficult to settle.

Table 5 presents the results of testing the upgraded sodium carbonate thickener. The discharge density from the thickener was high (average solids in the sands amounted to 407 g/L). Average solids in the overflow of the upgraded sodium carbonate thickener amounted to 45 g/L, i.e. 25 % lower as compared with a similar thickener with the feed unit of original design (average solids in the overflow of such thickener amounted to 60 g/L). Average flocculant dosage was 25 g/t per a sodium carbonate thickener. It should be noted that better performance was achieved in spite of the fact that during the testing period the slurry load of the upgraded sodium carbonate thickener was by 34 % higher as compared with the reference thickener. The inspection of the feedwell after the slurry discharge and before filling the thickener with condensate showed a satisfactory condition of the feedwell components. Scaling of the feedwell surface after one month of continuous operation is insignificant and does not affect the feedwell performance.

The test results prove that the upgraded feedwell provides for better performance and more stable operation of the thickener.



**Figure 21. Feedwell (inside view).**

**Table 5. Average performance indicators of the sodium carbonate thickener during the test period.**

Average solids in the feed flow	Upgraded thickener				Reference (original) thickener				Percentage difference of solids content in the thickener overflow
	Feed slurry flow rate	Solids in the overflow	Solids in the discharge	Flocculant dosage	Feed slurry flow rate	Solids in the overflow	Solids in the discharge	Flocculant dosage	
g/L	m <sup>3</sup> /h	g/L	g/L	g/t mud	m <sup>3</sup> /h	g/L	g/L	g/t mud	%
113	188	<b>45</b>	407	25	140	<b>60</b>	408	27	<b>-25</b>

## 6. Conclusion

Methods of analysis and computational simulation/modeling of slurry flocculation and settling processes elaborated by the specialists of RUSAL Engineering and Technology Center (RUSAL ETC) enable to numerically forecast the performance of thickeners and washers with any slurries, suspensions and liquors of alumina production. The unique laboratory bench allows testing any process stage within the shortest period, while computational software available at the RUSAL ETC's CFD simulation center provides for successful solution of any task on design\structure upgrade and vessel operation/performance.

Flocculation and thickening processes are difficult to simulate due to the multi-stage interaction of the flocculant, solid particles, and the liquor/slurry. The practices developed in the RUSAL ETC ensure successful solution of this task using CFD-PBM method. Unlike less sophisticated techniques the CFD-PBM method provides for detailed study of the flocculation and sedimentation processes inside the vessels and the impact of geometrical and physical parameters on their performance.

UC RUSAL uses this method for the upgrade of the bauxite residue thickeners at the Bayer alumina refineries or sodium carbonate and nepheline mud thickeners at the refineries that use a sintering process. Industrial testing of the upgraded thickeners and washers showed that the performance benefits are expressed by capacity improvement by 15–30 %, reduction of solids in the overflow by 25–50 %, and lower flocculant consumption by 10–15 %. In each case, the economic benefits can significantly exceed the expenses for R&D and upgrade of the equipment. In certain cases, some additional research might be needed to improve the accuracy of the thickening mathematical model and enhance the predictability of the performance benefits from the proposed process solutions.

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