Comparison of Impeller-Baffle Interactions in Alumina Precipitators

René Rödenbeck[1], Detlef Klatt[2] and Janin Klatt-Eberle[3]
1. Project Engineer
2. Managing Director
3. General Manager
STC-Engineering GmbH, Waldenburg, Germany
Corresponding author: r.roedenbeck@stc-engineering.de

Abstract

Worldwide there are various open stirred systems for precipitators in use which are different in technical design, mixing quality as well as investment and operational costs. A review of the best known ones provides a good overview of advantages and disadvantages of the same. Derived from this and further new investigations into the baffle influence on mixing quality, this article gives an outlook on the future for open precipitator systems.

Keywords: Precipitator; impeller; baffle; mixing quality; investment; operational costs

1. Introduction / Mixing Basics

To design technically appropriate and reliable mixing equipment it is necessary to firstly have a close look at the physical properties of the liquid to be mixed. The essential parameters to pay attention to are:

- Rheology and mass fraction
- Homogenising and bottom off criteria
- Impeller design, type, shape, diameter
- Power input and required tip speed
- Descaling intervals due to scaling at the vessel wall and the apparent wall velocity

In this presentation, the important basics are shown and summarized and shall form a review of the current state of the art in precipitator stirring. The most common designs in operation are analyzed and possible variations are highlighted. Typical composition and properties for precipitators are shown in Table 1.

Table 1. Precipitator Slurry Properties.

Precipitator slurry data			
Solids density trihydrate	ρ_S	[kg/m³]	2,420
Continuous phase density	ρ_L	[kg/m³]	1,270
Slurry density	ρ_{SL}	[kg/m³]	1,650-1,750
Solids mass concentration	C_G	[%]	55
Solids volume concentration	C_V	[%]	40
Solid mass	C_{ms}	[g/l]	900 – 1,000
Particle size 80 % passing	d_P	[µm]	110-120

All slurries are in general polydisperse, with a broad particle distribution. Those data shall constitute the basis of the following considerations, knowing well that there is a wide variety of deviations in the one and other direction.

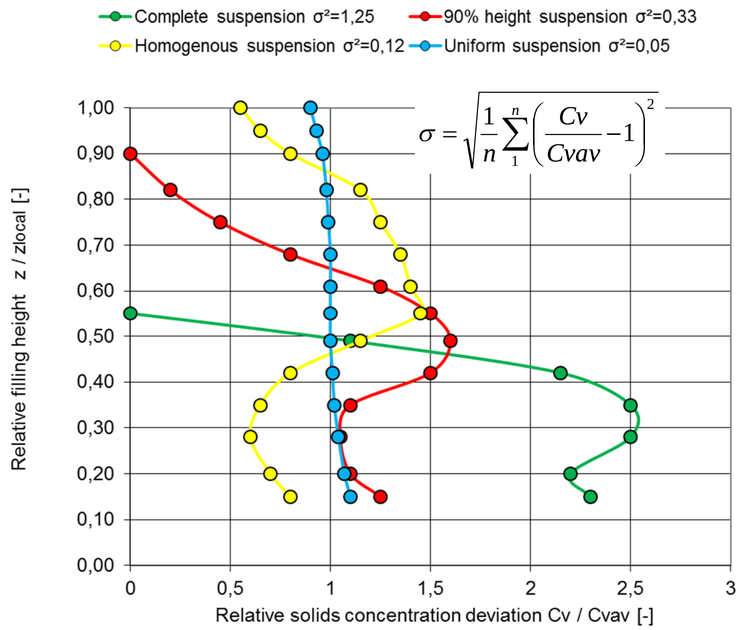


Figure 1. Solid Content Distribution.

To deal with suspension mixing tasks it is important to understand the behavior and flow pattern of the solids [3] [5] [8] [10] [12]. In Figure 1 solid distributions at different shaft speeds in relation to the solid concentration deviation are shown for different suspension criteria. Poorly mixed areas are in the bottom center below the impeller and relatively independent of the impeller type (Figures 2 and 3).

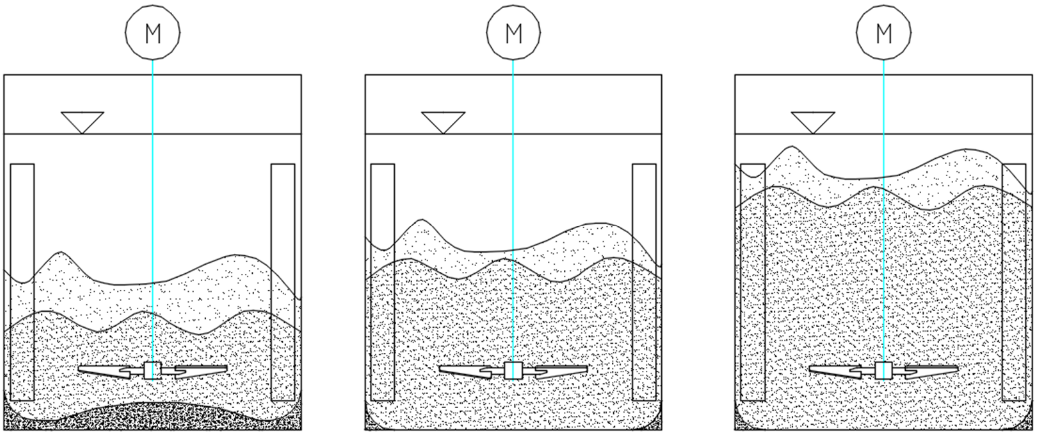


Figure 2. Suspension Criteria.

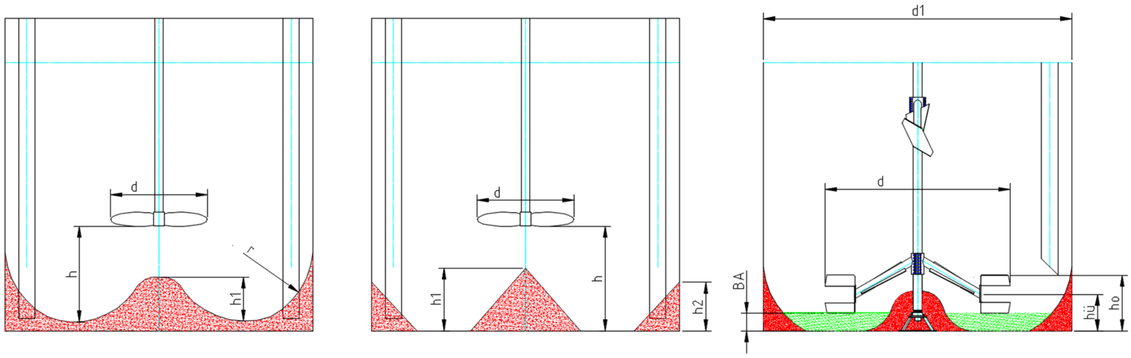


Figure 3. Sedimentation.

Due to low wall velocities and the flow pattern of the liquid mixed, sedimentation occurs at the outer edge of the vessel and below the bottom stage impeller. When you put emphasis on these vessel "dead-areas" you will come to the same regions for almost every application. Furthermore, by de-seeding or falling below a certain wall velocity, massive scaling effects occur (Figures 4 and 5). Different control mechanisms determine different scaling properties such as A to D, shown in Figure 4. A is mass transfer, B chemical reaction control, C is scale suppression by erosion and D is erosion damage. Maintenance and cleaning intervals decrease and on the opposite hand, costs increase. Up to now minimum sedimentation and homogeneous particle distribution from bottom to top are paid for dearly by increasing the power input.

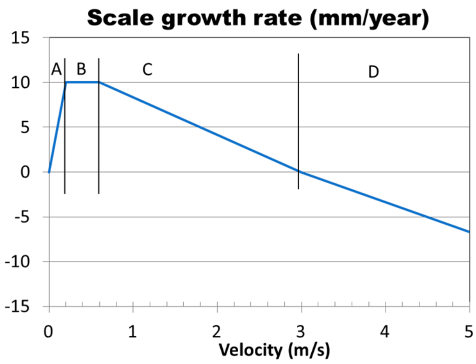
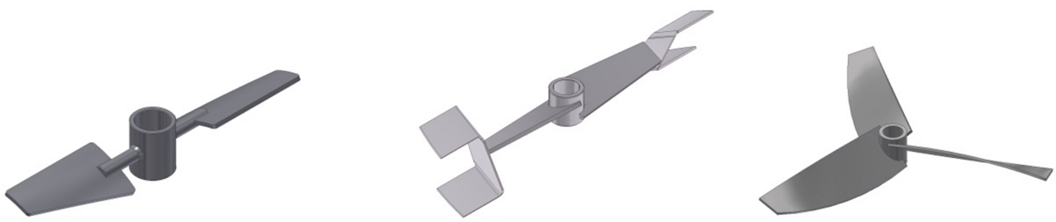


Figure 4. Scaling and Erosion.

Figure 5. Scaling.

Different impeller types are used around the world (Figure 6) to achieve the requested industrial performance. From classical pitched bladed design with low angles of attack, to counter flow impellers, to modifications and combinations of the same.



Twin bladed hydrofoil counter flow three bladed hydrofoil

Figure 6. Different impellers used.

2. Present Status of Precipitation Mixing

The following compares three well known applications widely in use (Figures 7 to 9) with different design philosophies to show the wide range of parameters. All variations are in practical use, from a low speed impeller with very large diameter ratio to high speed modifications with smaller impeller.

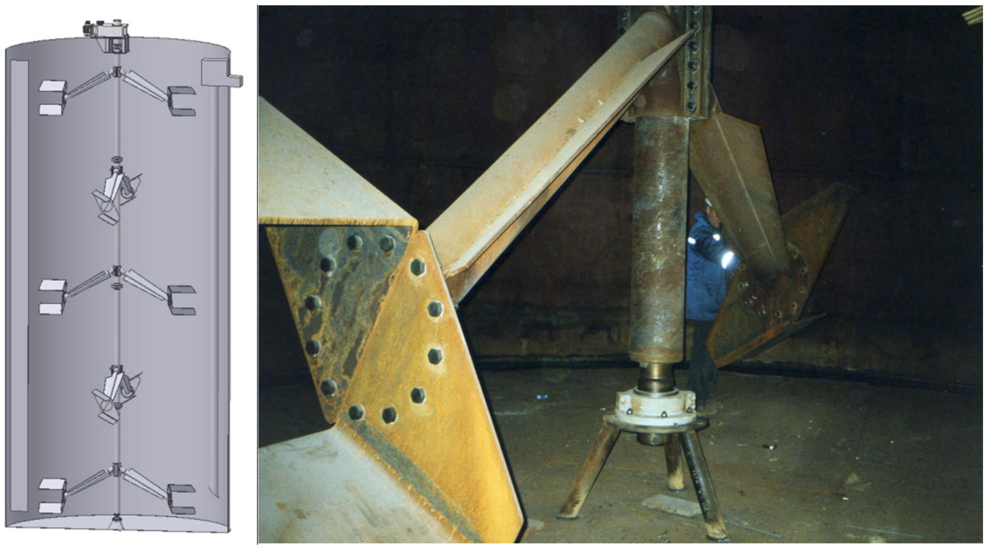


Figure 7. Application I.

Figure 8. Application II.

Figure 9. Application III.

Table 2. Technical data from different applications.

		Application I	Application II	Application III
Volume	[m³]	4,500	4,500	4,500
Tank diameter	[m]	14,000	14,000	14,000
Power	[kW]	55	75	55
rpm	[1/min]	3.4	9.4	6,5
Impeller dia	[mm]	9,800	5,590	8,400
Impeller tank ratio	[-]	0.7	0.4	0.6
Tip speed	[m/s]	1.74	2.75	2.86
torque	[Nm]	154,485	76,197	80,313
Investment cost	[-]	--	-	-
Operational cost	[-]	-	--	-

As we can see from the technical data in Table 2, the installed power and / or torque are comparable. For application I and III power is comparable, for application II and III the resulting torque is similar. Application I requires a “high-torque” design with large shaft resistance, high impeller blade thickness and heavy hub and couplings. All in all it requires major investment cost and operating costs due to high power consumption and in case of repair and maintenance, large handling requirements. A correlation between operational and investment cost as a function of impeller/vessel diameter ratio are displayed in Figure 10. Slow agitation and large diameter led to high torque and high investment costs. Fast agitation with small diameters has less torque but requires more power and speed, resulting in operational cost increases. As reports show, with regard to cleaning cycle however, application I clearly has an advantage.

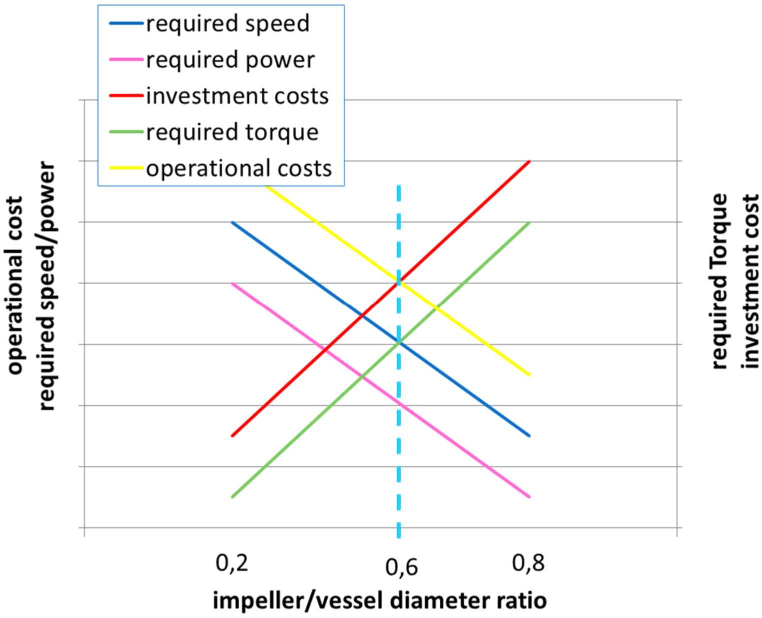


Figure 10. Operational and investment cost.

A minimum of investment and operational costs can be found at a diameter ratio of approx. 0.6.

The interaction between impeller, baffle design and bottom clearance has recently become more important for addressing sedimentation issues and to suspend and swirl up particles, but is not yet widely considered specifically for alumina precipitators.

3. Literature / Baffle Modification

Based on the effects and experience with sedimentation and scaling, new investigations on the baffle influence on mixing quality were carried out. From work by Zhao et al [1] [2], reproduced in Figures 11 and 12, different impeller and baffle modifications are shown. The work nominated about 65 % of the power consumption of the counter flow design (similar to application I) compared with the design similar to application III. Furthermore, the baffles had been sloped and the outer blade of the lowest impeller stage altered in diameter. Several modifications and adaptions appear to have been made in one step, making it difficult to point out which part has which effect, and which is negligible. In any case, to modify the baffle length, shape and quantity seems to have large potential to increase mixing quality without increasing shaft power [4, 6, 7, 9, 11].

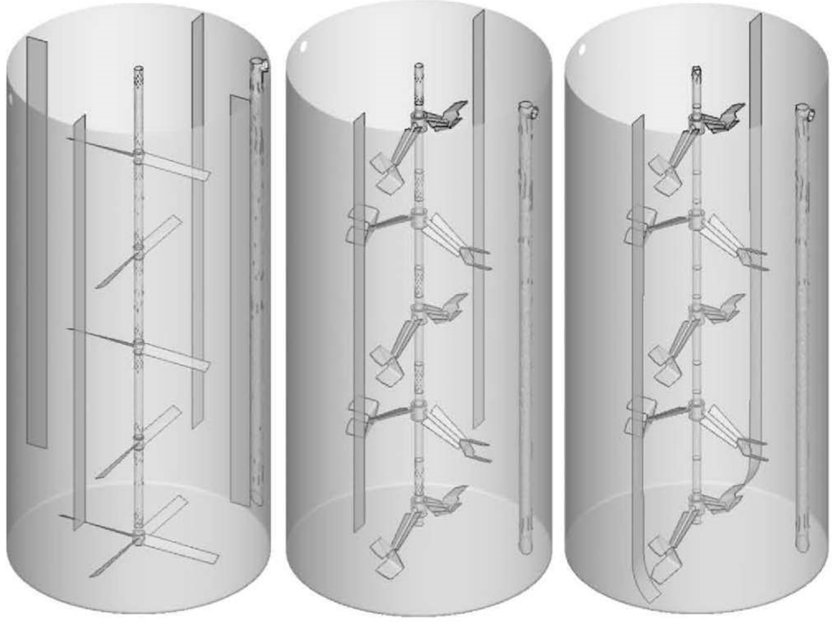


Figure 11. Structures of Robin, Ekato, I-Ekato seed precipitation tanks [1].

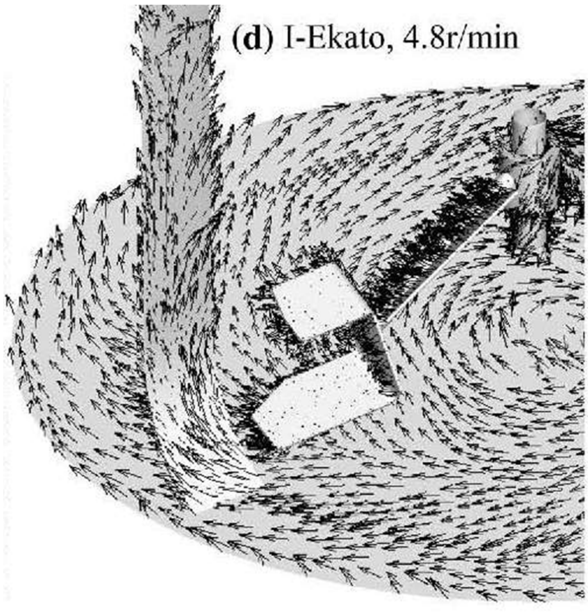


Figure 12. Velocity vector distribution at the tank bottom [1].

4. Laboratory Scale Tests

To focus on baffle influence and interaction the following simple lab test procedure was carried out to verify the work of Zhao, Liu, et al. One twin bladed hydrofoil with 0.6 diameter to the vessel ratio was tested with the typical baffle configuration. Here the bottom clearance was modified and an optimized clearance fixed. With this clearance different baffle quantities and types were evaluated. The assessment criterion was the minimum rotation speed and power consumption to achieve the bottom off criteria.

Below you can find the test arrangement (Figures 13 and 14), as well as the procedure. The lab scale test matrix is laid out in Table 3.

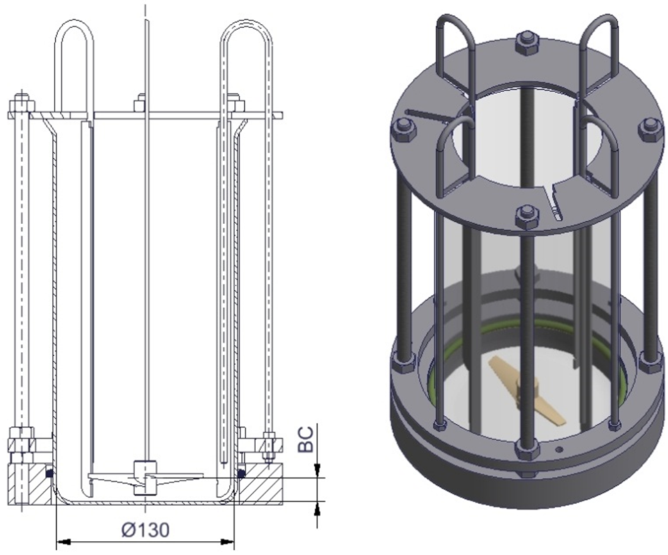


Figure 13. Sketch lab scale test arrangement.

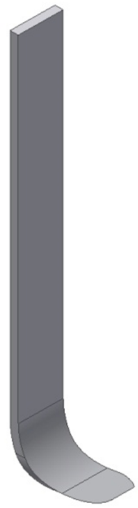


Figure 14. Sloped baffle.

Table 3. Overview of lab testing.

Test		1	2	3	4	5	6	7	8
Vessel diameter T	[mm]	130							
Filling height	[mm]	130							
Bottom		flat							
Impeller		2-bladed, axial pumping, 25 °pitched						Rushton	
Impeller Diameter d2	[mm]	84						60	
d2/T	[-]	0,65						0,46	
Bottom Clearance BC	[mm]	17	22	43	17	17	17	43	17
BC/T	[-]	0,13	0,25	0,33	0,13	0,13	0,13	0,33	0,13
Baffle quantity	[-]	2	2	2	4	2	4	4	4
Baffle width	[mm]	10							
Baffle shape	[-]	flat	flat	flat	flat	sloped	sloped	sloped	sloped
Solid density	[g/cm³]	1,41							

Some images of the flow pattern for flat and sloped baffles are presented in Figures 15 to 18. Results, required power consumption and necessary rotational speed are shown in Table 4 and Figures 19 and 20.

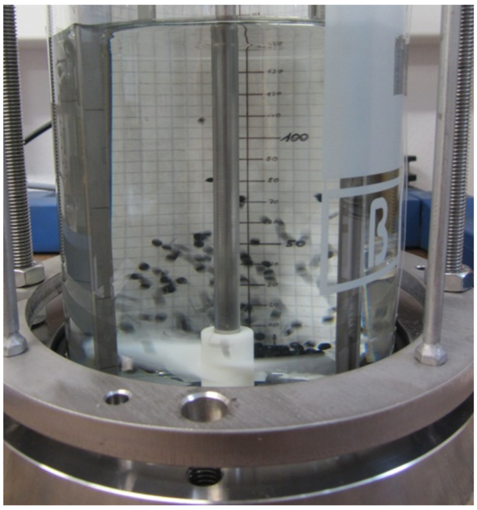


Figure 15. Lab test 4 at 300 rpm.

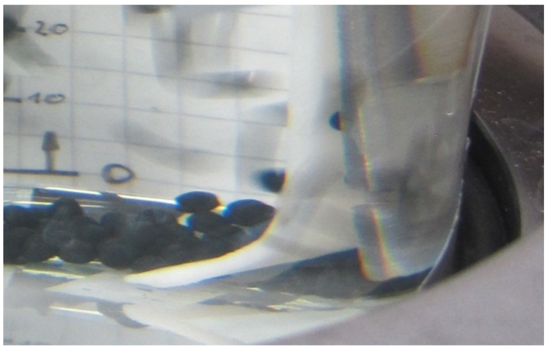


Figure 16. Sloped baffle with solids.

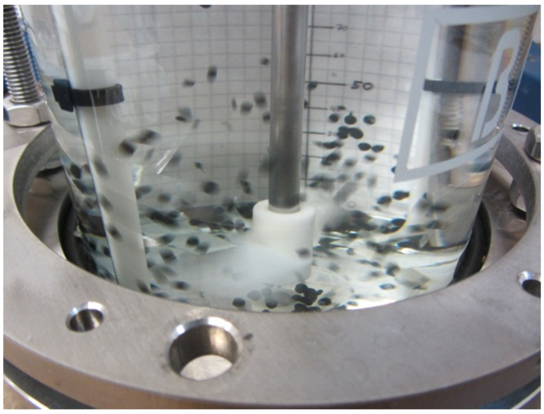


Figure 17. Lab test 5 at 350 rpm.

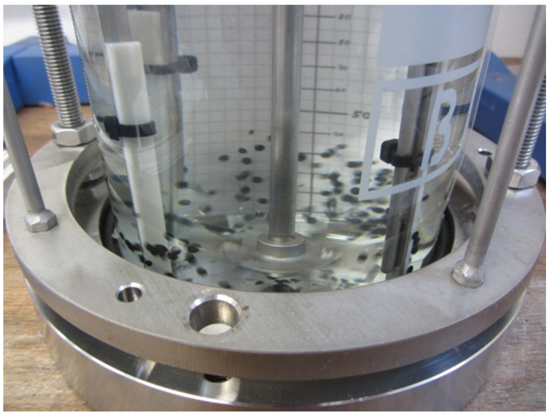


Figure 18. Lab test 8 at 125 rpm.

Table 4. Lab Test Results.

Lab Test	Distribution height single particle / main content [mm]	Required rpm	Tip speed [m/s]	Power consumption [W]	Remarks
1	110 / bottom	350	1,539	0,1868	up to 300 rpm only slow movement at bottom
2	n.a.	600	2,639	0,9410	at 350 rpm much less particles lifted, main solids sedimentation at bottom center
3	n.a.	600 +	2,639	0,9410	similar to test 2 but even less particles
4	100 / 50	275	1,210	0,1007	axial circulation lubes, circulating, about 40 % remain longer than 1s at bottom
5	105 / 30	300	1,319	0,1176	similar to test 1, baffle contact to bottom, higher retention time at baffle, no main axial flow pattern, but less required power, a little more bottom off
6	80 / 50 homogeny	250	1,100	0,0756	circulating clusters, little retention time at baffles
7	BC	250	0,785	0,2531	radial pumping, typical BC, sedimentation bottom center, single particle up to impeller stage
8	40 almost all particles	125	0,393	0,0316	low BC, radial pumping flow pattern toward sloped baffle, homogeneous circulation, barely baffle retention time

We see that much less single particles are lifted very fast. But the main solid content needs higher power input to be lifted. At several test conditions approx. 2 % of the particles are distributed up to 90 % of the filling height, while the rest is barely moved or distributed. The required rotation and power consumption are rather different. The typical arrangement with 2 flat baffles shows the highest required power input. The effect of sloped baffles according to Zhao, Liu, et al could be verified. Furthermore, using 4 baffles instead of 2 reduces the necessary speed and power also. When we follow the idea of designing sloped baffles it might be useful to change pumping direction and therefore the flow pattern of the bottom impeller. Although the tested Rushton turbine has a substantially larger power number it requires by far the smallest necessary rotational speed. With a classical diameter ratio of 0.45, it goes along with the idea of designing a smaller impeller diameter and increasing rotational speed. By choosing the most effective impeller type and arranging the impellers in a clever way, it should possible to keep or even decrease the installed drive power.

All lab test runs were carried out at a very small scale and observed visually in a simple way. Given this, some other effects and deviations are expected in scaling up. The results however, show real potential. To be confirmed, these effects have to be considered and evaluated in more detail in further investigations, at larger scale, and be supported by CFD investigations.

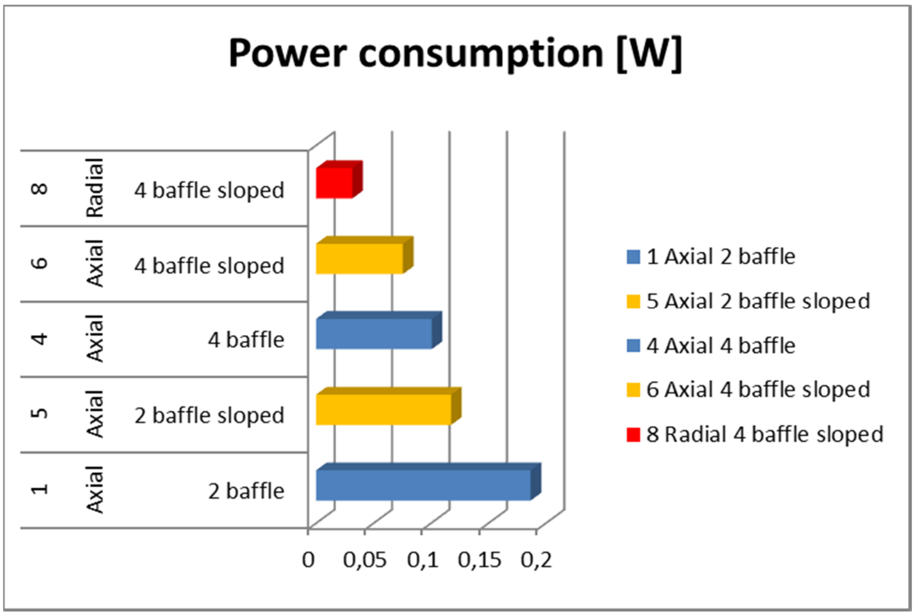


Figure 19. Power consumption to achieve bottom off criteria.

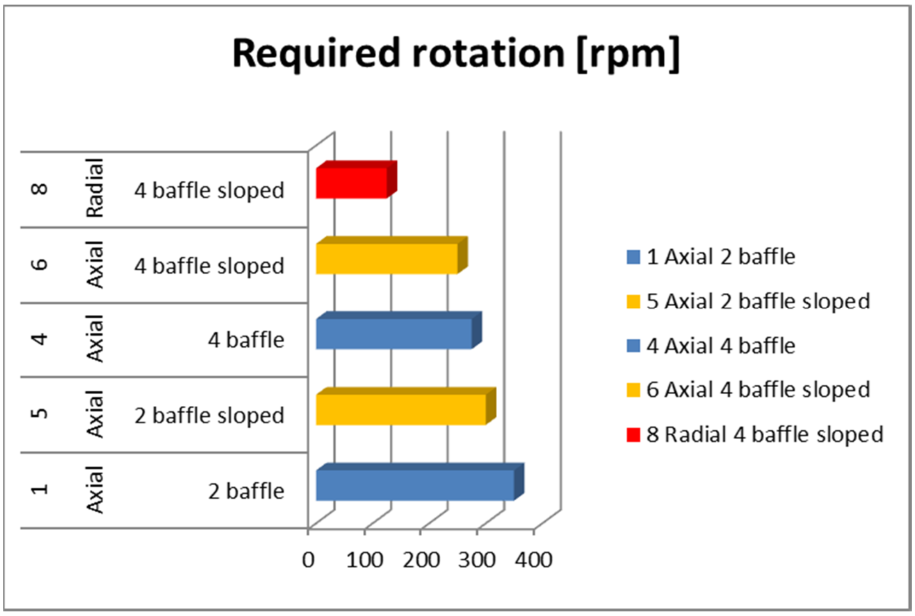


Figure 20. Required rotation [rpm] to achieve bottom off criteria.

5. Conclusions

- Almost all present precipitators in operation, no matter how they are designed, cannot be considered ideal.
- First steps are made to improve mixing quality without increasing drive power by using better baffle arrangement interactions.
- Quantity, type and arrangement of baffles and impellers should be considered carefully.
- Further investigations should put emphasis on innovative and well-informed choice and arrangement of the impeller, and adaption to the baffle design.

- Probably by using smaller impeller diameters, higher speeds and possibly even changing the impeller flow pattern partly to radial pumping may help to reduce investment, operational and maintenance costs.

6. References

1. Hong-Liang Zhao et al, Computational Fluid Dynamics (CFD) Simulations on multiphase flow in mechanically agitated seed precipitation tank, *The Minerals, Metals & Materials Society*, 2014.
2. Hong-Liang Zhao et al, Numerical simulations of solid-liquid stirred tank with an improved Intermig impeller, *American Institute of Physics*, 2013.
3. Inci Ayranci, Suzanne M. Kresta, Critical analysis of Zwietering correlation for solids suspension in stirred tanks, *Chemical Engineering Research and Design*, 2014.
4. Vakili M.H., Nasr Esfahany M., Effect of baffle arrangement on turbulent flow field in a stirred tank, *5th International Chemical Engineering Congress and Exhibition*, 2008.
5. M. Špidla et al, Effect of Baffle Design on the Off-bottom Suspension Characteristics of Axial-flow Impellers in a Pilot-scale Mixing Vessel, *Department of Chemical Engineering, Institute of Chemical Technology,* 2005.
6. C. Devarajulu, M. Loganathan, Effect of Impeller Clearance and Liquid Level on Critical Impeller Speed in an Agitated Vessel using Different Axial and Radial Impellers, *Journal of Applied Fluid Mechanics*, 2016.
7. Jie Dong et al, The Effect of Bottom Shape and Baffle Length on the Flow Field in Stirred Tanks in Turbulent and Transitional Flow, *International Journal of Mechanical, Aerospace, Industrial, Mechatronic and Manufacturing Engineering Vol:10, No:9,* 2016.
8. Yuan fa Ding et al, Experimental Study of Solid Dispersion in a Seeded Precipitation Tank with Slight Agitation for Gibbsite Crystallization, *Applied Mechanics and Materials Vol 456 (2014) pp 537-540,* 2014.
9. Piero M. Armenante, Ernesto Uehara Nagamine, Effect of low bottom impeller clearance on the minimum agitation speed for complete suspension of solids in stirred tanks, *Chemical Engineering Science, Vol. 53, No. 9, pp. 1757-1775,* 1998.
10. A. Tamburini et al, CFD Simulations of dense solid-liquid Suspensions in baffled stirred tanks: Prediction of solid particle Distribution, *Chemical Engineering Journal, 223 (2013) 875–890,* 2013.
11. Zhang Ting-an et al, Physical Simulation and Numerical Simulation of Mixing Performance in the Seed Precipitation Tank with a Improved Intermig Impeller, *Light Metals 2011*, 2011.
12. Hong-Liang Zhao et al, Process Optimization of Seed Precipitation Tank with Multiple Impellers Using Computational Fluid Dynamics, *The Minerals, Metals & Materials Society,* 2015.