Optimization of Alumina Precipitation Circuit Arrangement using Simple Modelling Tool

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Abstract

Some fifty years ago, most alumina plants had precipitation circuit operating in batch. For reasons of efficiency and productivity these were converted to what has been called since then Continuous circuit. From that point on all new refineries were built in such a way, somewhat forgetting that despite its negative aspects (operation complexity, manpower, etc), the precipitation rate is always at its highest during batch operation. The tendency to build bigger tanks to save on capital costs and also installing some of tanks in parallel, is moving away from optimum which is a large number of small cascading tanks (quasi plug flow or batch operation). Of course, the losses from this optimum are at least partly offset by the gains in operation simplicity. For some refinery, parallel tanks are a way to reduce slurry bypass for instance. This paper shows how simple mathematical tool can be used to quantify the deviation from optimum and for conceptual stage find the optimum arrangement of tanks and their sizes depending of the classification strategy and cooling capacity.

Keywords: Optimization, Alumina, Production, Precipitation, Modeling.

1. Introduction

The Alumina industry is now well into its century of history and improvements to every aspect of the process are too many to count. In the early years of alumina industry, the possibility of pneumatic or electric control were only used in area where it was needed, like high temperature and pressure. The precipitation area was run in a much simpler way using batch tanks. Changes happened gradually facilitated as technology allowed to reduce cost and increase productivity: either simplification of the process or reduction in manpower requirements. The major change in the precipitation area from batch operation to continuous operation achieved both.

From that point in time, mid-seventies, all new plants were built with a continuous precipitation circuit with tanks progressively bigger as technology allowed [1]. The justification for bigger tank is a significant reduction in capital cost and allowing longer precipitation time, hence higher productivity. But bigger tanks caused problems of civil and mechanical engineering, that needed to be addressed in the same time as the requirement to maintain an adequate slurry suspension in the precipitators. Scaling in the tank became an issue at high supersaturation at the front of the circuit, and many configurations were designed over the years to solve all of the issues [2]. But in the same time as resolving these some precipitation efficiency got lost. This paper describe how it might have happened.

2. Aspect of the Precipitation Circuit that can be Optimized

In order to optimize the precipitation circuit, it is important to understand what drive the precipitation rate of the reaction. As it has been documented in many articles [3], the reaction depends mostly on supersaturation (second order) temperature and seed surface. The latter being a factor that is much harder to try to influence.

By far the strongest factor is the supersaturation which means that basically as the solution is depleted progressively in alumina, the reaction slows down until the solution reaches the solubility. But in industrial practice this never happens as it would take too long a residence time; which would not be economical.

Temperature is also a strong driver and has two antagonist/contrary effects, one on the reaction rate (higher temperature is faster) and the other via the supersaturation (higher temperature lower supersaturation). This means that for a given aluminate concentration there is an optimum temperature.

Another factor that is often overlooked is the reactor type, batch or continuous, as this choice is normally part of the design/history of the plant. Basically, the reaction is always faster in batch mode as it has the highest supersaturation all the time as the reaction proceed. Continuous reactor can approach this rate if they are close to Plug Flow. This can be achieved using a multitude of very small reactors.

The reason behind this is that the reaction rate is averaged for the whole residence time in a continuous reactor and this concentration reached at steady state is lower than what would be achieved for the same time in batch mode, and the difference is also more important for a reaction of the second order. This has been well documented in reactor technology [4] and is illustrated in figure 1, where a succession of two reactors of 4000 m^3 is compared to one big tank of 8000 m^3 and the corresponding reaction time in a batch reactor 3.5 hr. The highest A/C ratio (lowest productivity) is achieved with the single tank at 0.557. The ratio after the second small reactor is significantly lower at ~0.537 and the batch reactor is by far the lowest at 0.503. However, one can already see that this difference is getting smaller for the 3rd small tank.

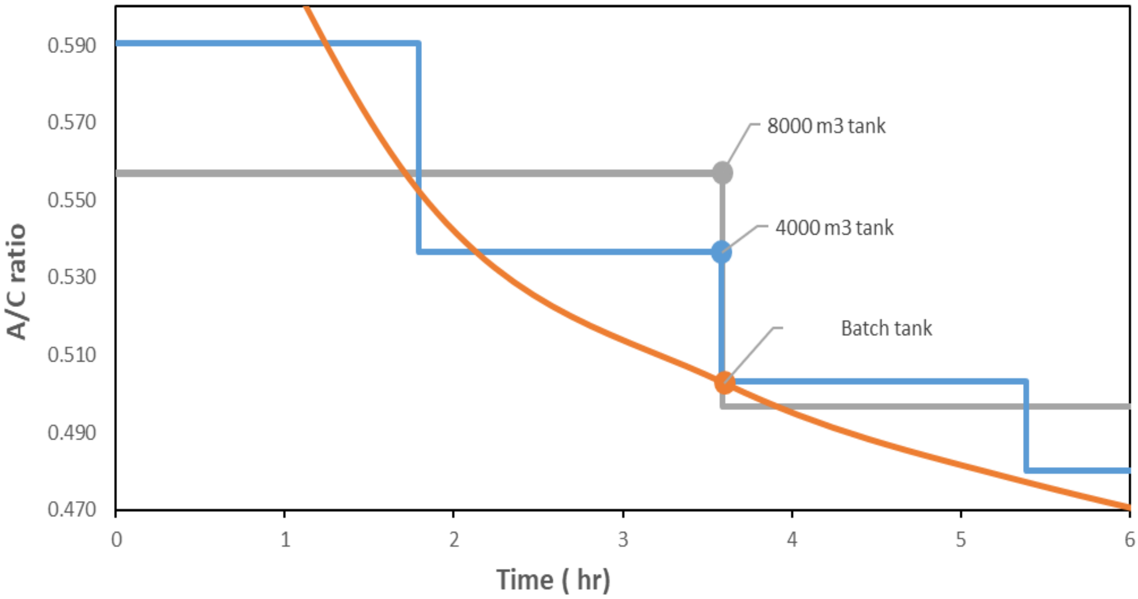


Figure 1. Comparison of ratio changes with time with different tank sizes.

The next graph, figure 2, is done for a succession of small tanks of 4000 m^3 to illustrate this latest point. Hence, the difference between the line and the series of tank is becoming smaller and smaller towards the end of the series. Which means that for a longer residence time, or a liquor with less impurities, the difference between the two modes becomes less significant, but still exists.

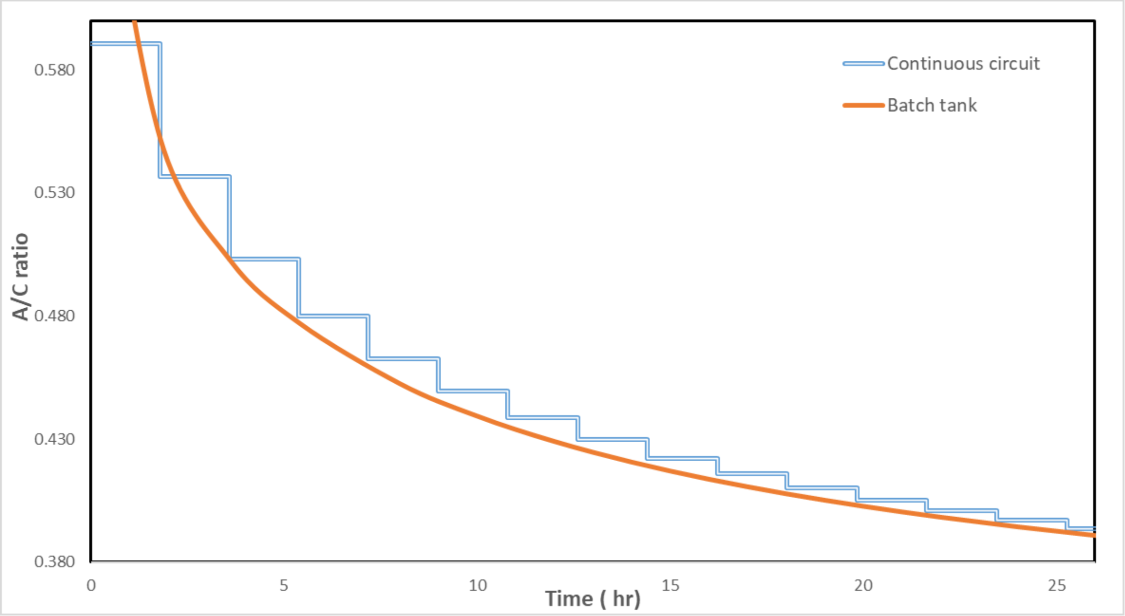


Figure 2. Comparison of the De-supersaturation Curve for a Series of Continuous Tanks and a Batch Tank.

3. Methodology Used for this Study

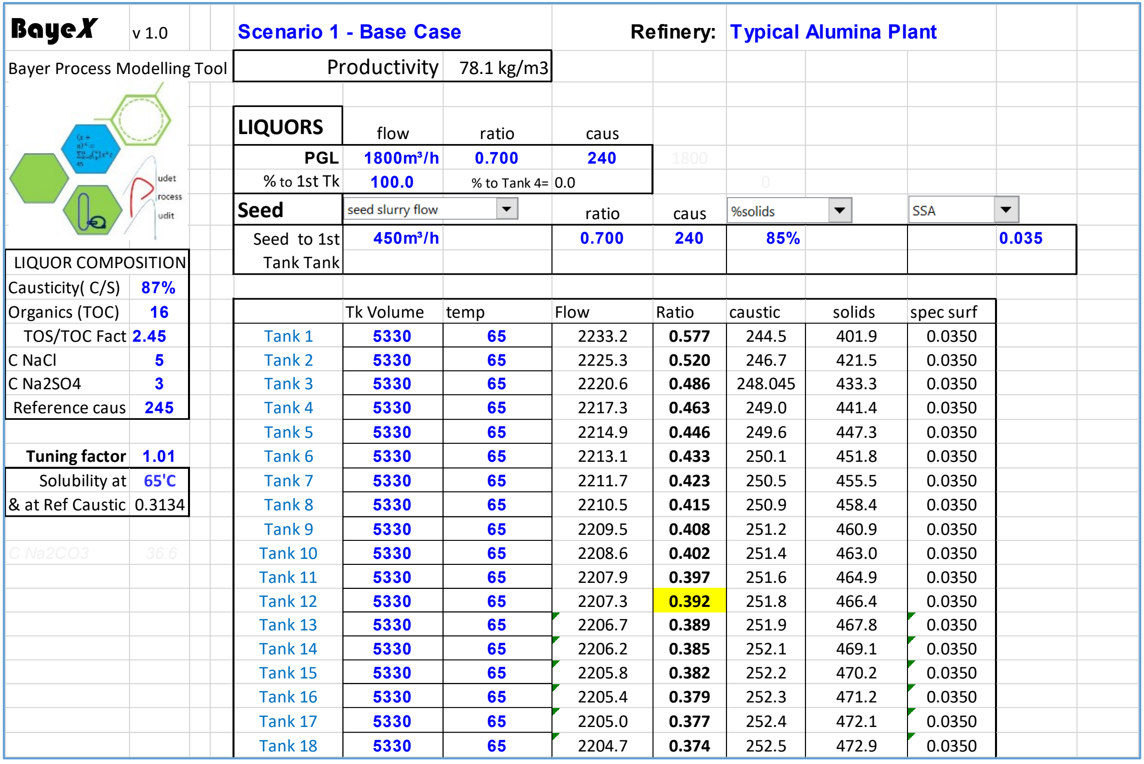
For this study, a series of comparison between various tank arrangements, tank sizes, temperature, etc were done in a spreadsheet using a tool that was previously described in another paper [5]. The tool used, called BayeX spreadsheet model, allows to simulate a basic precipitation circuit for a chosen set of conditions: flows, solids concentration and liquor composition (impurity included). BayeX comes as an Excel ™ Add-in with a set of functions that make it possible to simulate a precipitation circuit, like function for mixing slurry streams, continuous tank and batch precipitation tanks.

The flowsheet has been deliberately kept very simple: a series of cascading tanks all same size, with only one type of seed (no classification), a quite long residence time and typical organic and inorganic impurity content. These choices are quite arbitrary but were made to allow for easy comparison.

The total residence time for all scenarios has been kept the same at 43.4 hrs. This rather long residence time was also chosen to show the less bad cases as with shorter residence time the difference would be bigger.

Each scenario being studied is typically done in a single sheet of the spreadsheet. This sheet can then be copied to make incremental changes and quantify the effect of these changes. An example of this is shown in Table 1, which is a screen capture of the base case for an isothermal temperature of 65 ºC for the medium tank size.

Table 1. Example of Printout from the Simulation Sheets.



BayeX v 1.0

Bayer Process Modelling Tool

Scenario 1 - Base Case

Refinery: **Typical Alumina Plant**

Productivity	78.1 kg/m3

LIQUORS	flow	ratio	caus	
PGL	**1800m³/h**	**0.700**	**240**	1800
% to 1st Tk	**100.0**	% to Tank 4= 0.0		0

Seed	seed slurry flow		ratio	caus	%solids		SSA	
Seed to 1st Tank Tank	**450m³/h**		**0.700**	**240**	**85%**			**0.035**

LIQUOR COMPOSITION	
Causticity(C/S)	**87%**
Organics (TOC)	**16**
TOS/TOC Fact	**2.45**
C NaCl	**5**
C Na2SO4	**3**
Reference caus	**245**
Tuning factor	**1.01**
Solubility at	**65'C**
& at Ref Caustic	0.3134
C Na2CO3	36.6

	Tk Volume	temp	Flow	Ratio	caustic	solids	spec surf
Tank 1	**5330**	**65**	2233.2	**0.577**	244.5	401.9	0.0350
Tank 2	**5330**	**65**	2225.3	**0.520**	246.7	421.5	0.0350
Tank 3	**5330**	**65**	2220.6	**0.486**	248.045	433.3	0.0350
Tank 4	**5330**	**65**	2217.3	**0.463**	249.0	441.4	0.0350
Tank 5	**5330**	**65**	2214.9	**0.446**	249.6	447.3	0.0350
Tank 6	**5330**	**65**	2213.1	**0.433**	250.1	451.8	0.0350
Tank 7	**5330**	**65**	2211.7	**0.423**	250.5	455.5	0.0350
Tank 8	**5330**	**65**	2210.5	**0.415**	250.9	458.4	0.0350
Tank 9	**5330**	**65**	2209.5	**0.408**	251.2	460.9	0.0350
Tank 10	**5330**	**65**	2208.6	**0.402**	251.4	463.0	0.0350
Tank 11	**5330**	**65**	2207.9	**0.397**	251.6	464.9	0.0350
Tank 12	**5330**	**65**	2207.3	**0.392**	251.8	466.4	0.0350
Tank 13	**5330**	**65**	2206.7	**0.389**	251.9	467.8	0.0350
Tank 14	**5330**	**65**	2206.2	**0.385**	252.1	469.1	0.0350
Tank 15	**5330**	**65**	2205.8	**0.382**	252.2	470.2	0.0350
Tank 16	**5330**	**65**	2205.4	**0.379**	252.3	471.2	0.0350
Tank 17	**5330**	**65**	2205.0	**0.377**	252.4	472.1	0.0350
Tank 18	**5330**	**65**	2204.7	**0.374**	252.5	472.9	0.0350

3.1. Effect of Tank Size for Isothermal Conditions

In this series of comparison, three different rows of precipitators are compared but all with the same total residence time. The tanks are ranging from 4000 m^3, 5333 m^3 and 8000 m^3 with respective number of tanks of 24, 18 and 12 tanks. The three scenarios are done with a same temperature for each tanks (isothermal) to facilitate the comparison, although in real life it wouldn't be possible for multiple reasons, heat of reaction being the main one. But in older refineries located in part of the world with a mild climate, or with tank in close arrangement with little natural cooling, the profile can be close to isothermal if no cooling has been installed.

Looking at the figure 3, it is clear that with bigger tanks (longer residence time per tank) that the overall de-supersaturation curve is higher and ends up with a lower productivity than the two other rows, with the one with the smallest tanks having the best performance. The consequences on productivity is also quite significant with the best productivity being 78.4 g/l with the small tanks and 78.1 and 77.6 g/l for the two others showing the impact that the choice of tank size can be important.

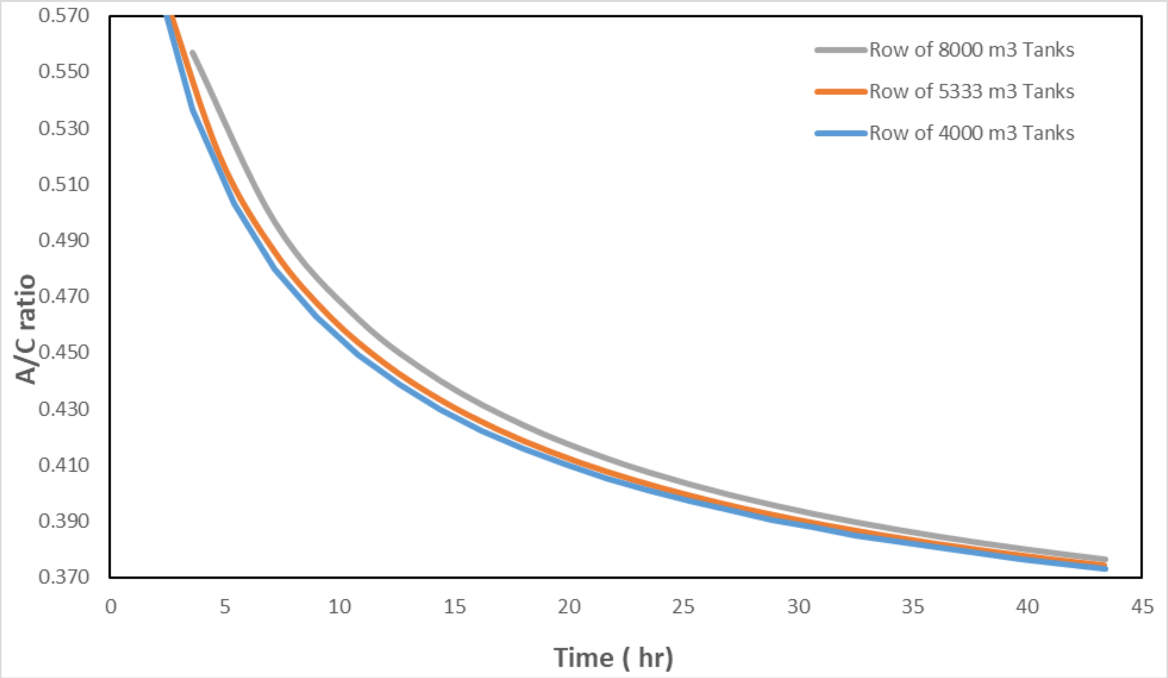


Figure 3. Effect of the Tank Size on De-supersaturation Curve for Isothermal Profile.

It is also important to note that several refineries have tried to optimise tank sizes by having smaller tank sizes at the front and bigger at the back end where it has less impact [6]. A fair amount of optimisation can be done here where capital cost and maintenance cost (chemical cleaning) will both play a role. Finally, this also illustrates why having tanks in parallel, which is equivalent to having a much bigger tank, is so detrimental to productivity. Often this is done in order to have much lower growth rate (to control crystal morphology) [7], to reduce the upward velocity and hence achieve some level of classification or some solids retention [8].

3.2. Effect of Tank Size for Steep Temperature Profile

The Same comparison was done this time with a steep temperature profile corresponding to what would be achieved in colder climate in winter with some level of in-tank cooling. At first glance of figure 4 the effect seems to be similar, although only 2 tank sizes were used for the comparison this time (4000 and 8000 m^3). Looking at the number, confirms this as the difference between the big tanks goes from 79 g/l to 79.5 for the smaller ones – a difference of 0.5 g/l compared to 0.8 g/l for the isothermal. The conclusion is that a better temperature profile helps to reduce the impact of bigger tanks. Like for the isothermal comparison, with shorter time the difference would be bigger.

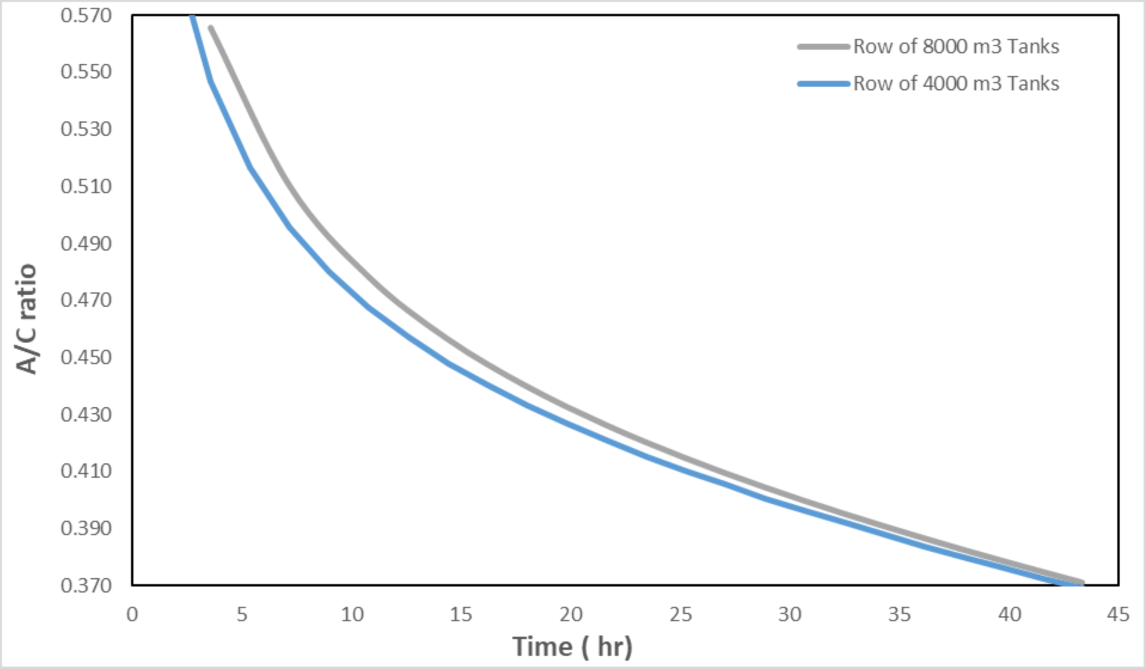


Figure 4. Effect of the Tank Size on De-supersaturation Curve for Steep Temperature Profile.

Although this steep profile happens to be not too far from an optimum profile, there are many possible temperature profile strategies but the most common is to maximise productivity while maintaining an acceptable occluded soda content. The determination of the optimum temperature profile is difficult to calculate as the second derivative with temperature of the precipitation rate with other properties related to temperature (like Occluded soda for instance) is needed. However, this also illustrates how shallow the optimum is, meaning that (apart from the first few front tanks) it is not too critical to be exactly on the optimum temperature for every tank to achieve near optimum productivity.

4. Comparison of Effect of Number of Cooling Steps in a Precipitation Circuit

This series of comparison was done to illustrate the last point discussed in the previous section; the optimum temperature is relatively broad in range particularly from the middle of the circuit towards the end.

To do the comparison only one type of tank was used (the middle size) and the profile was varied in the following way: the base case the temperature was changed linearly in the same amount (half a degree) until the final temperature of 62.5. The two others were starting the same way until the 4th tank and then in the second scenario, the temperature was changed every two tanks. Finally, for the last scenario, the temperature was changed every four tanks, while reaching the same finishing temperature in all cases. The difference between the temperature profile in each is shown graphically in figure 5.

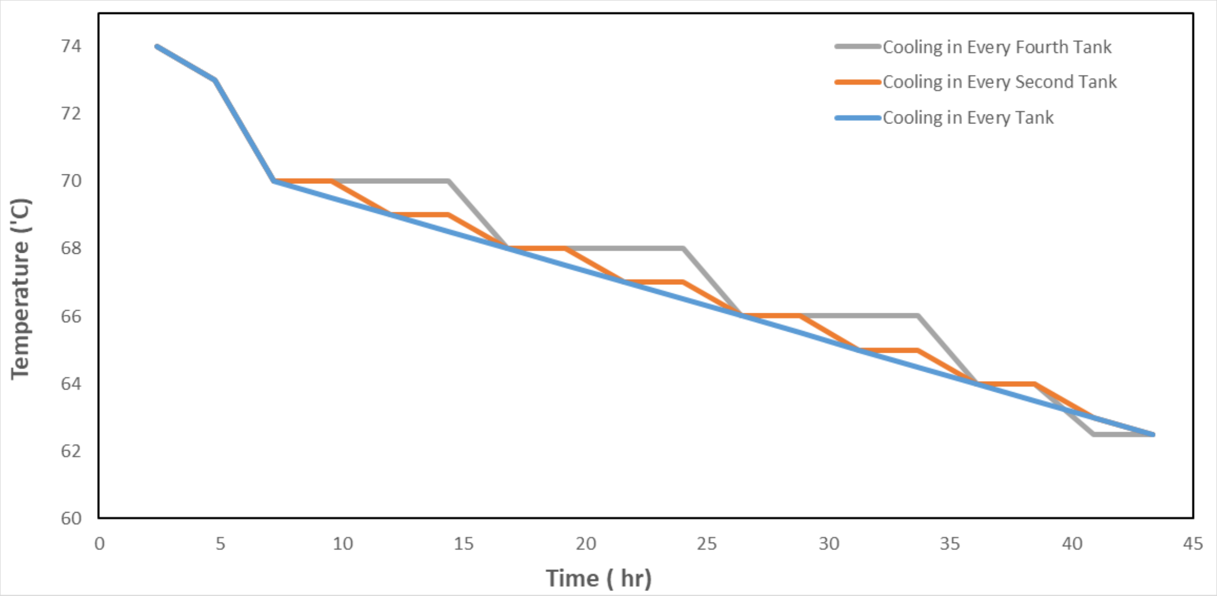


Figure 5. Comparison of the Three Temperature Profiles used for this Study.

Figure 6 shows the de-supersaturation curve for the three scenarios, and it is particularly noticeable that the difference is rather small. The lower ratio is the one where every tank is changed followed by the one where changes occur every two tanks and lastly the one with less cooling stages. The productivity is respectively of 77.9, 77.6 and 77.4 g/l which is probably smaller than what may be expected considering the extra capital costs needed to achieve the first flowsheet. This is again a confirmation that it is not required to be exactly on the optimum temperature for every tank, as long as the overall profile is the same.

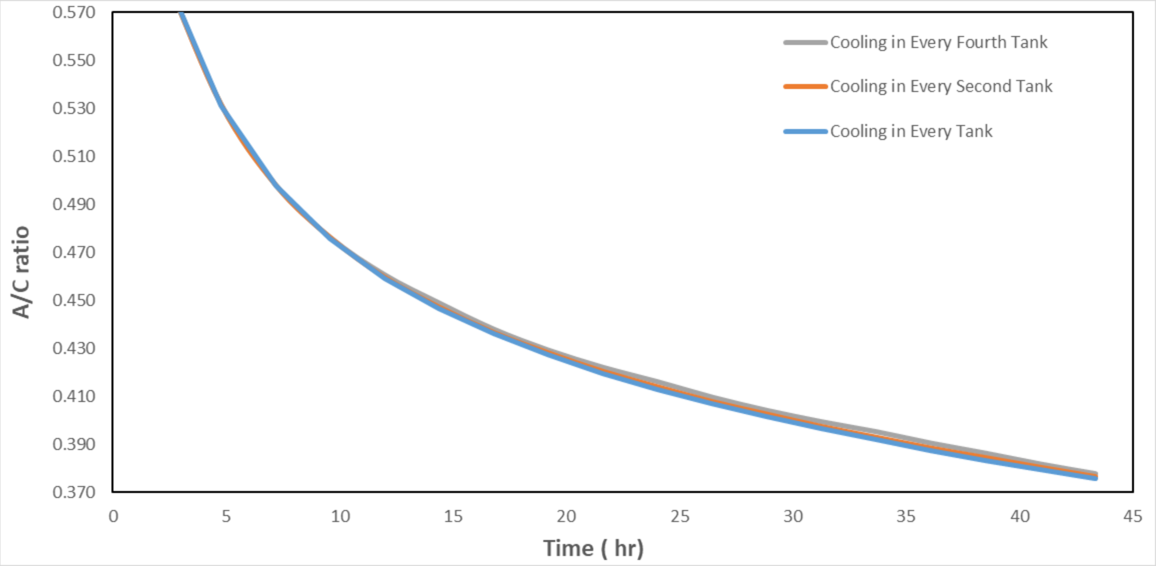


Figure 6. De-Supersaturation Curve for the Three Temperature Profile with Same Finishing Temperature.

5. Effect of Slurry By-pass on Productivity Losses

Often as a refinery is reaching nominal production there is strong incentives to try to achieve higher production by many ways, one of them being higher liquor flow through the plant. In the precipitation area, this translate as a lower residence time but overall higher production. In precipitation there is also the potential for higher flow to cause some slurry bypass on the top of the precipitator. While it can become visually quite noticeable then, it is much harder to quantify exactly the amount of slurry flow that is by passing the precipitator and going directly to the launder towards the next tank without reacting. The quantification of the bypass is best done using some type of chemical or radioactive tracer.

To simulate this type of behavior, a portion of the slurry (depending of the % bypass desired) was sent directly toward the exist of the tank and the remaining (most of the flow) was reacted and then mixed with the flow that was bypassed. It is understood that this is a simplification of the real behavior, as there is some intermixing going on before they are mixed at the end but should be accurate enough for the objective of this study.

The flowsheet used for this comparison of the cooling profile, consists of set of 18 tanks of 5330 m3, with the simpler cooling profile, the one which has fewer cooling stages (last one). The comparison case is done with the same amount of 25% of by-pass for every tank. In reality this is rarely the case, as the by-pass tend to be more pronounced in the first few tanks due to higher scaling in those.

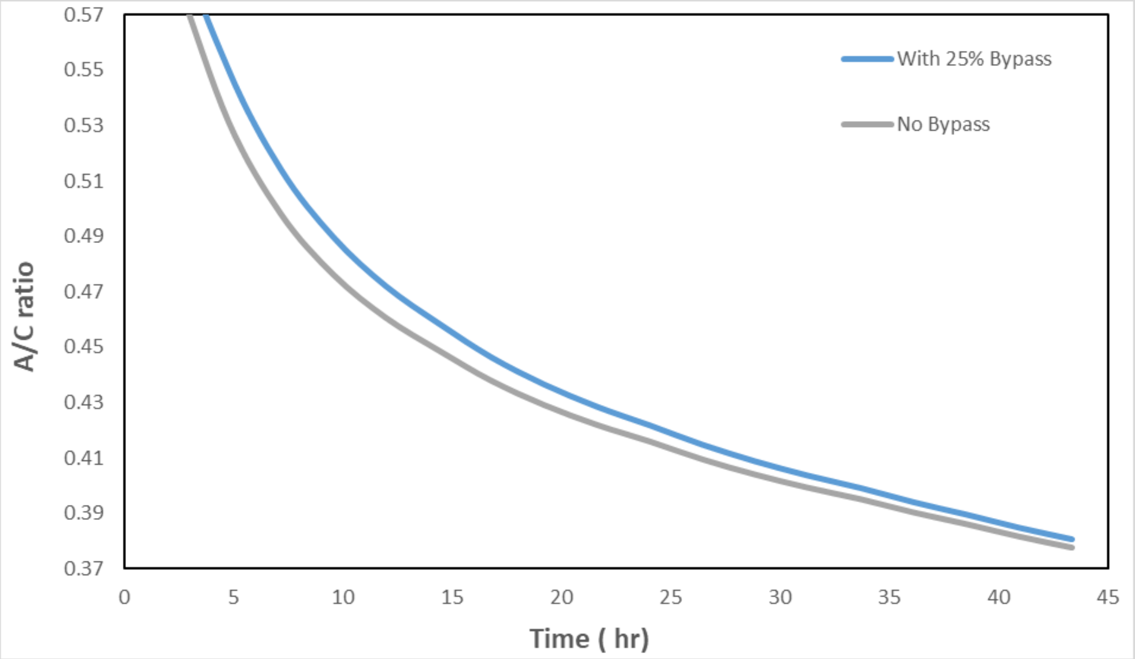


Figure 7. De-supersaturation Curves for the scenario with and without 25% bypass.

The results in the figure 7 also show that the effect is not as strong as could perhaps have been expected considering that a quarter of the slurry is not participating in the reaction. However, the difference in productivity is not negligible, dropping from 77.4 to 76.6 g/l, or a bit less than one g/l of productivity loss. The reason is that the slurry that doesn't bypass the precipitator gets a longer residence time than in the base case before being mixed with the 'unreacted slurry'.

Like for the other factors studied, the difference starts large but gets much smaller before the end of the circuit. So, we could assume that if the bypass is mostly present in the first few tanks, that the productivity loss is even less important.

6. Conclusion

A series of comparisons aimed at identifying the importance of several key factors for production in the precipitation area were performed using a spreadsheet simulation tool. The comparisons showed that many of the general assumptions of what influence productivity do not necessarily play as important a role as initially thought.

The role of the tank size and the arrangement in continuous, batch or in parallel is important and could potentially lead to important productivity gains if applied appropriately; particularly for older refineries which are considering converting to continuous while leaving some of the precipitators operating in batch mode. Using a spreadsheet tool like the one demonstrated here, should be seen as a first step. For a better and full analysis of all scenarios, more complex tool like SysCAD or Aspen would be advisable.

7. References

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