

## Improving the Alkali Recovery Efficiency of Red Mud Sedimentation System

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<https://doi.org/10.71659/icsoba2025-aa022>

### Abstract

The principle of soda recovery in a clarification and red mud washing system has been studied, and the traditional settling process has been systematically modified. A new type of high-efficiency settler has been developed, which can significantly improve the settling efficiency and increase the soluble soda recovery from red mud. A DSP (DeSilication Product) soda recovery process has been added to the red mud washing system to substitute and recover DSP soda from red mud by adding lime. Multi-scenario simulations of varying the red mud washing stage, at which the DSP soda recovery process is implemented, have been performed using SysCAD simulation software to identify the configuration with the lowest soda losses. These simulations including the laboratory tests have shown that a reduction of the DSP soda losses by more than 53.8 % and a reduction of the soluble soda losses by about 40 % can be achieved with the modified clarification and red mud washing system. This new type of clarification and red mud washing system can significantly reduce the soda consumption and provide important guidance to alumina plants.

**Keywords:** Red mud, Soluble soda recovery, High-efficiency settler, DSP soda recovery, Process simulation.

### 1. Introduction

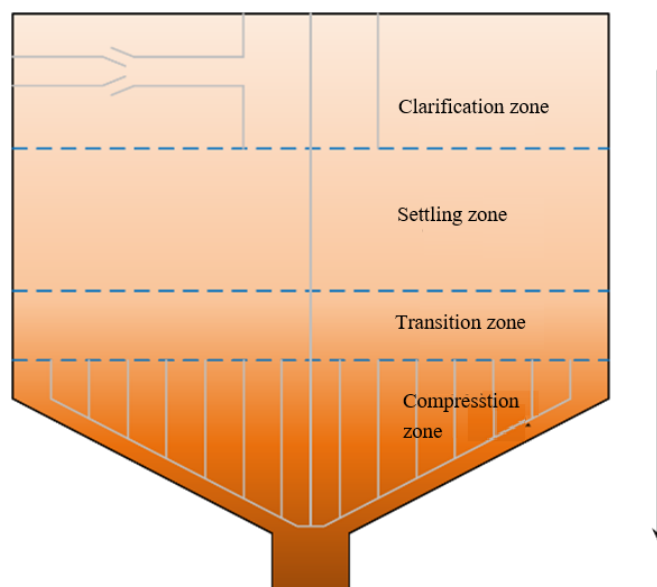
Clarification and red mud washing is a key process in alumina production, and settlers are the most commonly used equipment for red mud solid-liquid separation in modern alumina refineries. The diluted digested slurry enters the clarifiers, where, under the effect of a certain amount of flocculant, the solids sink rapidly by gravity, and the overflow with low turbidity goes to the downstream process, while the compacted underflow slurry goes through several counter-current washing stages to minimize soluble soda losses with the discharged red mud.

Red mud soda losses mainly include DSP soda losses (mainly sodium aluminium silicate) and soluble soda losses. DSP soda losses mainly depend on the bauxite composition and the digestion process. Soluble soda losses are mainly affected by the red mud washing water flow, the number of washing stages and the individual washing efficiencies. Based on the composition and character of a given bauxite, the most suitable process parameters are selected to optimize operating costs. The DSP soda losses and red mud wash water flow are a result of this economic optimization. The soluble soda losses can be reduced either by increasing the number of washing stages and/or improving the red mud washing efficiency. To do the latter one, a possible pathway is to improve the performance of the settler. DSP soda losses can be reduced via a DSP soda recovery process which can displace soda from red mud into the liquor. The economics of the inputs and outputs of the DSP soda recovery process should be evaluated, though.

## 2. Study and Application of a New Type High-Efficiency Settler

Alumina refineries primarily utilize flat-bottom and conical settlers. Conical settlers are commonly used in greenfield and brownfield alumina refinery projects for the significant advantages they present, which are a higher settling efficiency and a smaller footprint. If clarifiers and washers have the same diameter, due to the relatively difficult settling conditions in clarification, typically two settlers are put in parallel to receive diluted digestion slurry, and the rest of the settlers operate in series as washers, with the settling performances getting gradually better after each stage. Typically, four to six washing stages are necessary to achieve the target soluble soda losses.

Red mud decantation in settlers is divided into four zones, as shown in Figure 1: the clarification zone, the settling zone, the transition zone and the compression zone. When the settler is operating at a steady state, the feed mass flow equals the discharge mass flow, the interface height of each zone remains unchanged, and red mud is continuously decanting in the settler. The red mud slurry enters the settling zone from the bottom of the feed well and starts gravity settling. Red mud particles in the settling zone bear less resistance, and the settling speed is high. Red mud particles in the transition zone are subject to increased resistance, and the settling speed is gradually reduced. Red mud particles in the compression zone are piled up layer by layer, gravity does no longer play a dominant role, and active settling switches to passive compression.



**Figure 1. Red mud solid distribution in the settler.**

Furthermore, the settling character of red mud from different bauxites varies greatly. In alumina refineries, increasing the flocculant flow normally allows to achieve higher red mud settling performances, including treating capacity and washing efficiency, but the effect is limited. Developing high-efficiency red mud settling technology and equipment that is capable to achieve higher compaction rates allows for an increase in the unit area's solids throughput capacity and underflow solids contents.

## 2.1 Laboratory Experiments

Static experiments (volumetric cylinder experiments, Figure 2) and small-scale continuous dynamic experiments (Figure 3) have been performed to experiment the effects of the slurry dilution ratio and the flocculant dosage on the settling velocity, the clarity of the upper liquor and the solids content of the compacted mud. The experiment results are shown in Figure 4.

Different flocculants have been used for the settling experiments. YH-01 and YH-03 were confirmed as the most suitable flocculants, and the selected flocculants have been used for further testing to identify the optimum solids content of diluted slurry. The settling velocity varies with the solids content, and considering the settling velocity and solids throughput capacity, the best range for solids content of diluted slurry is 60–90 g/L.

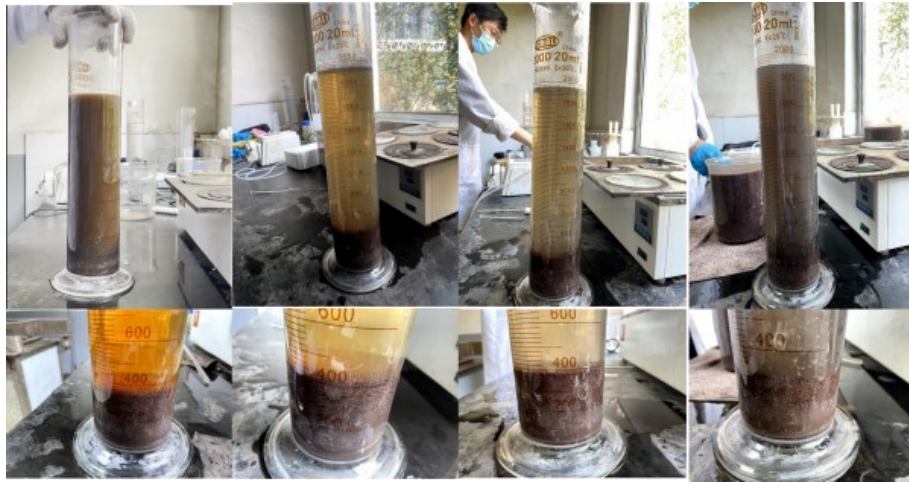


Figure 2. Static settling experiments.



Figure 3. Small-scale continuous dynamic settling experiments.

The results from the static experiments have been applied in dynamic experiments. The underflow solids content and the required compaction time have been determined based on the dynamic experiments, with the overflow suspended solids content below 500 mg/L and the underflow solid content reaching 600 g/L or above.

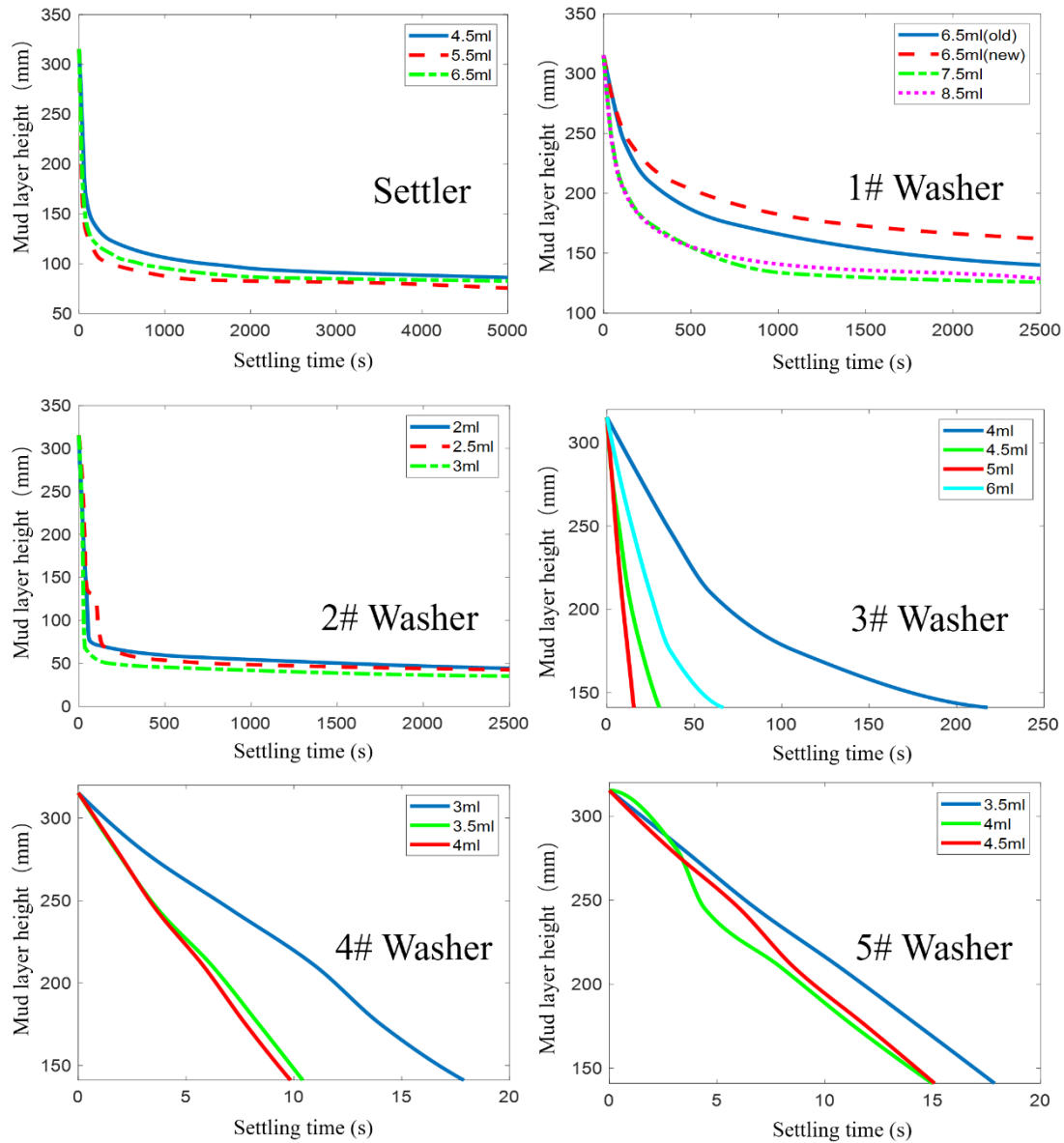


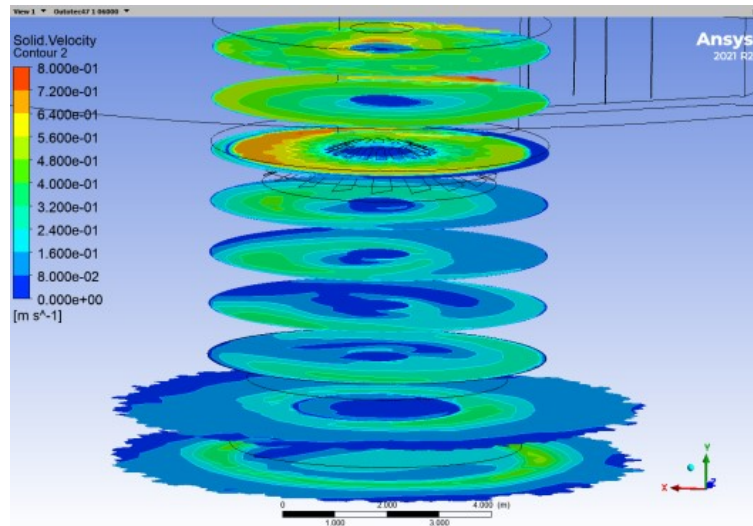
Figure 4. Experimental results for clarifier and washers.

## 2.2 Numerical Simulation Analysis

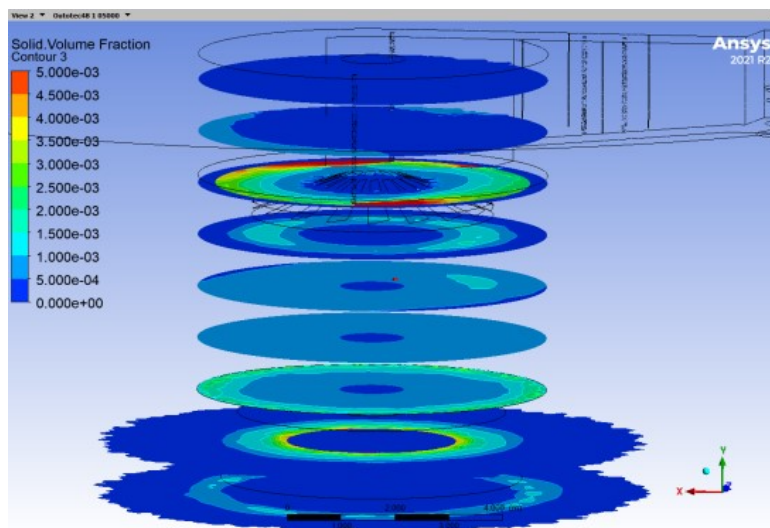
The red mud settling process is a typical solid-liquid two-phase flow and transport process. There are many factors affecting the solid-liquid flows in a settler, such as mass diffusion, heat transfer and other physicochemical processes. The computational fluid domain in this study mainly contains red mud particles and sodium aluminate solution, which is a typical solid-liquid two-phase flow [1]. In order to describe it with a suitable numerical computational model, it is necessary to make a reasonable simplification of the settler and its transport process. Therefore,

the rake and top slurry level difference for example are not included in the simulation. With this reasonably simplified model, it will be easier to obtain definitive and reliable results.

The simulation process for the three-phase flow solid-liquid separation in a settler has been carried out on a computational platform. The Eulerian-Mixture numerical simulation method [2] for three-phase flow, Realizable  $k - \epsilon$  dual-range turbulence model has been used [3]. Some simulate flows are shown in Figures 5 and 6.



**Figure 5. Particle trajectory, velocity field of different cross sections (m/s).**



**Figure 6. Particle volume fraction in different cross sections.**

CFD numerical simulation was studied through computational fluid dynamics, combined with the theory of settling and static experimental results, compared the flow field character of the settler in refinery production. The character of the settler flow field, which enables a full effectiveness of the flocculant, was studied in ref. [4]. The flow field and structure form of the settler, which can bring out the full benefit of a flocculant, was determined in ref. [5].

According to the numerical simulation results, a flow velocity below 1 m/s is beneficial for the formation of flocs.

### 2.3 Industrial Experiments

Through theoretical research, static experiments, numerical simulation analysis, dynamic experiments, the main factors affecting the operating parameters of the settler (solids throughput capacity, overflow turbidity, underflow solids content) have been systematically studied. High efficiency settling technology and equipment have been developed. The feeding device of the settler has been redesigned to ensure sufficient "maturation" time for the flocculant and a good mixture with the red mud slurry. As a result, better red mud flocs are formed, which accelerates the red mud settling rate and improves the compaction performance. The capacity and underflow solids content of the new settler are significantly improved.

The new high-efficiency settler has been installed in the clarification stage of one alumina refinery (Figure 7). After one year's operation, good performance has been achieved, the solids throughput capacity of the settler has been greatly improved. One single settler can now treat the mud flow that requires two traditional settlers. The flocculant dosage has slightly increased. The operating data is shown in Table 1.



Figure 7. New high-efficiency settler installation on site.

Table 1. Results of industrial application.

	Underflow solids content	Mud layer height	Solids throughput capacity	Flocculant dosage
Unit	g/L	m	t/m <sup>2</sup> .h	g/t mud
Traditional settler	650	~2	0.24	30
New high-efficiency settler	645	~2	0.46	33

## 2.4 Red Mud DSP Soda Recovery Technology

The clarification and red mud washing system generally recovers only the soluble soda. If the DSP soda in red mud can be recovered, the consumption of raw material soda can be further reduced.

Many kinds of red mud DSP soda recovery techniques have been studied, including methods using lime, carbonation, inorganic chloride and sulphate salts, calcification-carbonation, etc. The lime-based is the most common DSP soda recovery method applied in alumina refineries. Lime or lime milk is added to red mud slurry and reacts with the DSP, where calcium ions partly replace sodium ions, the sodium ions going into solution as a way to recover DSP soda. Daoxing Sun [6] studied the DSP soda recovery from red mud via lime addition. With red mud particles size less than 180  $\mu\text{m}$ , a CaO dosage from 5 to 8 % based on the mass of red mud, a temperature of 80–90  $^{\circ}\text{C}$ , and a residence time of 2 h, the total soda mass fraction in the treated mud was less than 1.0 %. Guozhen Wang et al. [7] studied DSP soda recovery from red mud with a calcium oxide water bath method. When the addition of calcium oxide in Bayer red mud is 5 %, the recoverable soda content is 60 % higher than without calcium oxide. The recovery efficiency was at its highest when applied after the third washing stage (close to 3/4 of the total amount of recovered soda). Xiu-fang Zheng et al. [8] investigated adding lime to recover DSP soda from red mud produced by low-temperature Bayer process. The experiment showed that the optimal process conditions were: temperature set to 70–90  $^{\circ}\text{C}$ , calcium-sodium ratio of 3, liquid-solid ratio of 3, residence time 4–7 h. The red mud DSP soda recovery efficiency could reach more than 80 %, and the sodium oxide content in red mud after treatment was less than 1 % [9].

Different red mud requires different DSP soda recovery process parameters to obtain the most economical performance. This paper presents the DSP soda recovery trials carried out in an alumina refinery in Shanxi and determines the suitable conditions according to the experimental results. The most important factors affecting the performance of red mud DSP soda recovery are temperature, lime dosage and residence time. Since the operating temperature in red mud washers is basically above 90  $^{\circ}\text{C}$ , which should satisfy the ideal DSP soda recovery process requirements, the experiments in this paper focus on the lime dosage and the residence time.

The refinery treats domestic diasporic and imported gibbsitic bauxite, the red mud used for DSP soda recovery is generated from gibbsitic bauxite and the reacting agent for DSP soda recovery is lime. The chemical composition of red mud and lime are shown in Table 2 and Table 3.

**Table 2. Chemical composition of the red mud.**

Composition	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>	TiO <sub>2</sub>	Na <sub>2</sub> O	CaO
Content %	4.52	58.15	9.28	4.76	3.03	0.69

**Table 3. Composition of the lime powder.**

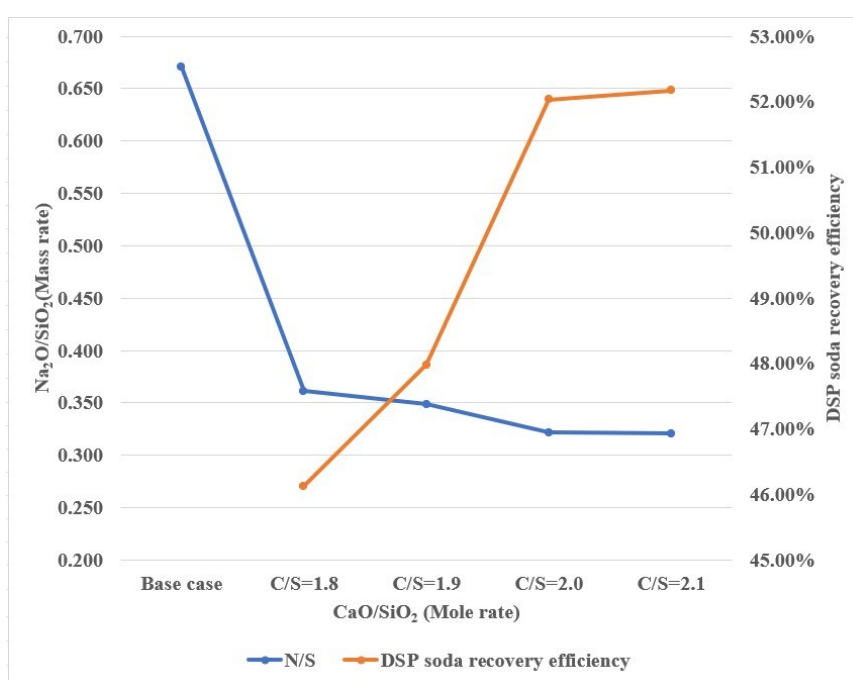
Composition	CaO(Total)	CaO(Effective)	CO <sub>2</sub>
Content %	90.26	85.45	2–3

## 2.5 The Effect of Lime Dosage on DSP Soda Recovery Efficiency

Lime powder was added according to the SiO<sub>2</sub> content in red mud, in terms of CaO/SiO<sub>2</sub> mole ratio = 1.8, 1.9, 2.0, 2.1, and the residence time was 2 hours. The results for DSP soda recovery are shown in Table 4 and Figure 8.

**Table 4. Effect of different lime dosages on DSP soda recovery efficiency.**

CaO/SiO <sub>2</sub> defined	Composition (%)							DSP soda recovery efficiency
	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	CaO	CaO/SiO <sub>2</sub> (mole ratio)	Na <sub>2</sub> O/SiO <sub>2</sub> (Mass ratio)	%
Base case	9.28	4.52	58.15	3.03	0.69	0.153	0.670	-
1.8	8.19	3.96	50.64	1.43	7.14	1.803	0.361	46.13 %
1.9	8.21	3.9	51.08	1.36	7.39	1.895	0.349	47.98 %
2.0	8.49	3.95	50.15	1.27	7.92	2.005	0.322	52.04 %
2.1	8.55	3.93	50.36	1.26	8.24	2.097	0.321	52.17 %



**Figure 8. Effect of lime dosage on DSP soda recovery.**  
 Note: N/S represents Na<sub>2</sub>O/SiO<sub>2</sub>, C/S represents CaO/SiO<sub>2</sub>

From Table 4 and Figure 8, it can be seen that within the range C/S=1.8–2.0, with the increase of calcium dosing, the N/S value of red mud decreases significantly, indicating a fast increase of the DSP soda recovery efficiency within this range, while the N/S value hardly changes within C/S = 2.0–2.1, indicating almost no change in DSP soda recovery efficiency. Considering that adding lime will cause alumina losses from the process, the recommended C/S value is 2.0–2.1, at which the DSP soda recovery efficiency can reach more than 52 %.

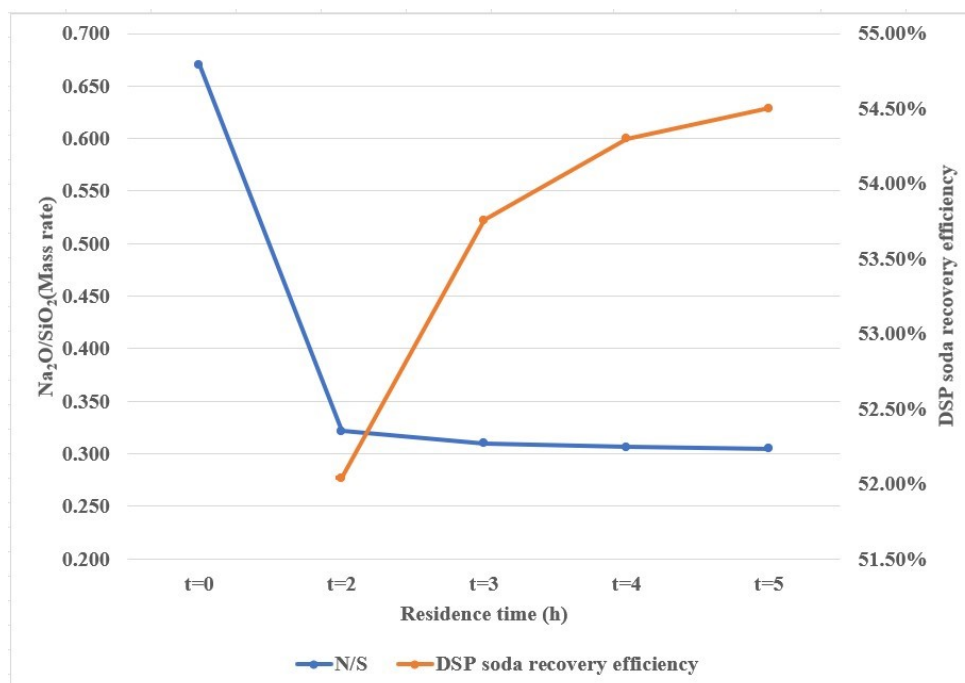
## 2.6 The Effect of Residence Time on DSP Soda Recovery Efficiency

According to the chemical reaction kinetics, the residence time affects the progress of the DSP soda recovery reaction. Too short time leads to insufficient reaction progress, while too long time requires more equipment to be installed and generates more operating costs, and the reaction kinetics decreases with time. Maintaining C/S at 2.0, DSP soda recovery efficiencies have been

compared for the residence times 2h, 3h, 4h, 5h and 6h. The experimental results are shown in Table 5 and Figure 9.

**Table 5. Effect of residence time on DSP soda recovery efficiency.**

Reaction time	Composition (%)							DSP soda recovery efficiency
	Al <sub>2</sub> O <sub>3</sub>	SiO <sub>2</sub>	Fe <sub>2</sub> O <sub>3</sub>	Na <sub>2</sub> O	CaO	CaO/SiO <sub>2</sub> (mole ratio)	Na <sub>2</sub> O/SiO <sub>2</sub> (Mass ratio)	%
Base case	9.28	4.52	58.15	3.03	0.69	0.150	0.670	-
2	8.49	3.95	50.15	1.27	7.92	2.005	0.322	52.04
3	8.45	3.90	50.30	1.21	7.89	2.023	0.310	53.76
4	8.39	3.85	50.85	1.19	7.75	2.013	0.308	54.02
5	8.38	3.89	50.76	1.19	7.80	2.005	0.305	54.50



**Figure 9. Effect of residence time on DSP soda recovery.**  
**Note: N/S represents Na<sub>2</sub>O/SiO<sub>2</sub>.**

From Table 5 and Figure 9, it can be seen that when C/S = 2.0, the DSP soda recovery efficiency still increases significantly between 2h and 3h. Extending the residence time to 5h, the benefit for DSP soda recovery efficiency continues to increase but the increase rate obviously slows down. It is hence recommended that the residence time should not be less than 3h, and if the conditions allow, it can be extended to 5h, where the DSP soda recovery rate can reach 54.5 %.

### 3. Simulation of Different Configurations for DSP Soda Recovery Implementation

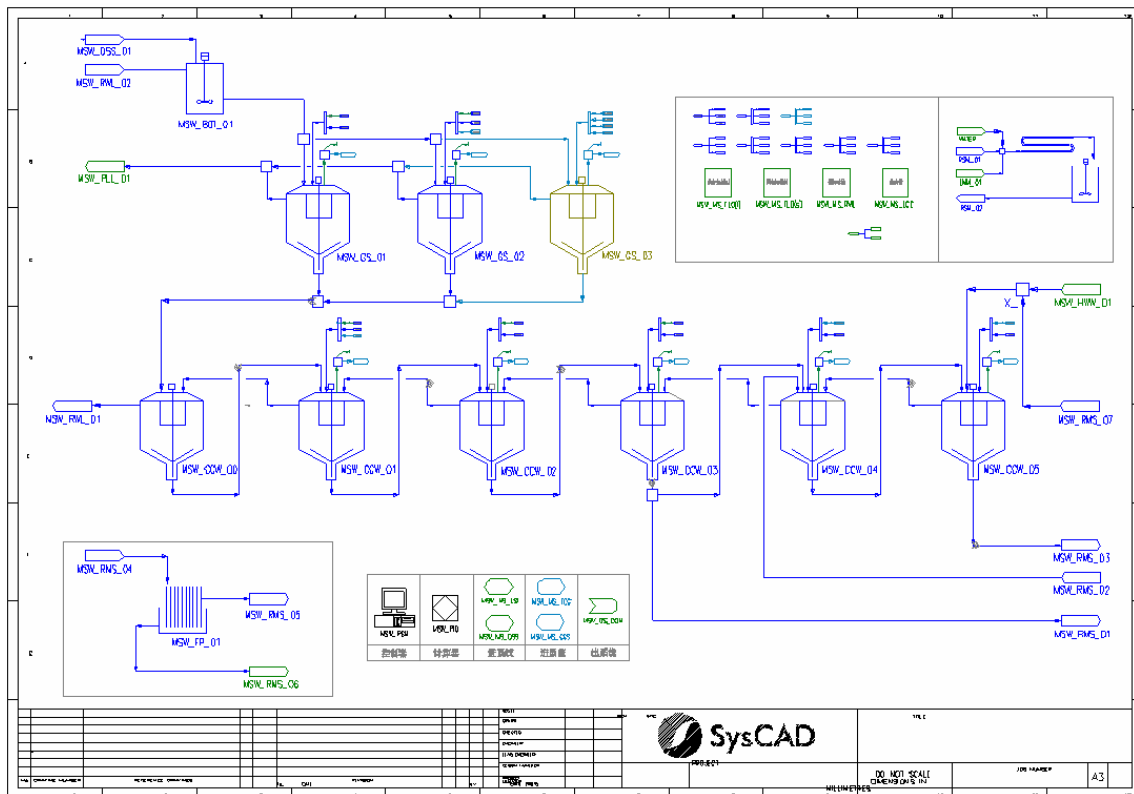
Through the study above, several cases have been simulated in the aim of improving the clarification and red mud washing system and recovering some lost soda compared to the traditional configuration. The two traditional settlers that are used for clarification can be replaced by a new high-efficiency settler, and the third settler, which was used as a common spare, can be

used as a washer, hence reducing the soluble soda losses by adding another washing stage [10]. For the same feed flow as a traditional settler, the new high-efficiency settler allows the underflow solids content of clarifiers to be increased, which reduces the amount of soda contained in the liquor of clarifier underflow slurry transferred to the first washer. This allows to improve the washing efficiency, hence more soluble soda can be recovered. In addition, by the introduction of the DSP soda recovery process, further soda can be recovered from the red mud solids as well.

In order to evaluate the effect of different configurations on the overall soda recovery, several cases were simulated using SysCAD process simulation software (Figure 10). The simulated cases are listed in Table 6.

**Table 6. Simulated Cases.**

No	Description
Case 01	Base case with two clarifiers, four washers, red mud filter-pressed
Case 02	One clarifier, five washers, red mud filter-pressed
Case 03	One clarifier, five washers, the underflow from 3# washer sent to DSP soda recovery and back to 4# washer, red mud filter-pressed
Case 04	One clarifier, five washers, the underflow from 4# washer sent to DSP soda recovery and back to 5# washer, red mud filter-pressed



**Figure 10. Mathematical modelling of clarification and red mud washing system.**

The basic input data for the simulations is shown in Table 7, the results are shown in Table 8.

From the simulation results in Table 8, provided that other conditions remain the same, Case 02 with one more washing stage reduces the soluble soda losses significantly compared to Case 01, the soda concentration in the last washer underflow having dropped from 14.19 g/L to 8.44 g/L, which is a reduction rate of 40.5 %.

**Table 7. Simulation basic input data.**

Items	Value	Unit
Solid content of diluted digestion slurry	80	g/L
Red mud output rate	126	t/h
Moisture of filter-pressed red mud cake	32	%

**Table 8. Model simulation results.**

	Number of washing stages	Soda concentration in the last washer	Red Mud Na <sub>2</sub> O/SiO <sub>2</sub>	DSP soda losses	Soluble soda losses	Total red mud soda losses with red mud
Unit	-	g/L	-	kg Na <sub>2</sub> O/t-Al <sub>2</sub> O <sub>3</sub>		
Case 01	4	14.19	0.67	32.404	4.791	37.195
Case 02	5	8.44	0.67	32.404	2.884	35.288
Case 03	5	11.53	0.31	14.996	4.288	19.284
Case 04	5	12.85	0.31	14.996	4.760	19.757

Case 03 and Case 04 are based on Case 02 but featured with the red mud DSP soda recovery process. The soda incorporated in red mud DSP partly enters into the liquor, which increases the soda concentration in the liquor, hence affecting the red mud washing efficiency.

In order to further recover the leached soda, it is usually necessary to wash the red mud slurry after DSP soda recovery. The purpose of the simulation of the different cases is to compare the DSP soda recovery implementation at different washing stages. Case 03 supposes the underflow of 3# washer going to DSP soda recovery and then back to 4# washer, so that there can be two washing stages before discharge to red mud stockyard. Case 04 supposes the underflow of 4# washer going to DSP soda recovery and then back to 5# washer, so that there can be one washing stage before discharge to red mud stockyard.

According to the simulation results, Case 03 has lower total red mud soda losses than Case 04, which means better soda recovery efficiency. In Case 03, the total red mud soda losses are reduced by 17.91 kg Na<sub>2</sub>O per tonne of alumina, which is a reduction rate of about 48 %.

#### 4. Application in Production

The new high-efficiency settling technology has been applied in a domestic alumina plant, which was equipped with eight deep cone settlers in a single line: two of them being used exclusively as clarifiers, one of them used as a common spare settler and five of them used exclusively as washers. The structure of the deep cone settlers used exclusively as clarifiers has been upgraded, realizing that one single settler can meet the whole red mud solids throughput requirement, therefore allowing to add one more washing stage, and enhancing efficiency of the red mud DSP soda recovery process implemented in the washing system (Figure 11).



**Figure 11. Upgraded clarifiers and washers.**

According to the feedback from the refinery, the total soda consumption has been reduced by about 30 %. The soda losses before and after implementing the new settlers and the DSP soda recovery process are shown in Table 9.

**Table 9. Soda Losses Before and After Modification (kg Na<sub>2</sub>O/t Al<sub>2</sub>O<sub>3</sub>).**

	Date	DSP	Soluble	Product	Others	Total
Before	2024-05	162.52	2.46	3.56	4.65	173.19
	2024-06	150.22	2.54	3.72	5.22	161.7
	2024-07	142.98	2.6	3.24	6.54	155.36
	2024-08	144.56	2.52	3.58	5.58	156.24
	Average	150.07	2.53	3.53	5.50	161.62
After	2024-10	101.78	4.63	3,74	5.84	112.25
DSP soda loss reduction, %		32.19	Total soda loss reduction, %			30.55

The DSP soda losses have decreased significantly by ~32 % after implementation of the process, though this reduction is less than what was observed under laboratory conditions (~48 %). This is because lime addition also leads to some alumina loss, and use of lime and steam is optimized relative to the costs of soda, alumina, lime, steam and electricity needed for lime slaking, in order to maximize economic profit.

Table 9 also shows that the soluble soda losses have increased. This is because the soda recovered from DSP is transferred from solid phase to liquor, while the flow of hot wash water is still the same, resulting in lower washing efficiency and higher soluble soda content in the residual liquor after red mud press filtration.

## 5. Conclusion

By improving the structure of the settler, at similar flocculant consumption, the solids throughput capacity has been significantly improved. For alumina refineries with traditional settlers, it is possible to merge two clarifiers into one single clarifier. The spare settler can then be used as a washer, and the additional washing stage can reduce soluble soda losses by about 40.5 %.

The use of lime milk is currently one of the main technologies for red mud DSP soda recovery in alumina refineries. Through experiments on red mud generated from gibbsitic bauxite with the aim to select the optimum reaction conditions, it is recommended to target a C/S value = 2.0–2.1, a residence time of not less than 3h, so as to achieve a DSP soda recovery efficiency above 53.7 %.

The clarification and red mud washing process has been digitally modelled using simulation software, and multi-scenario simulation has been performed. With improved high-efficiency settlers, an additional washing stage can be obtained, and, in combination with the DSP soda recovery process, the total red mud soda losses can be reduced by about 48 %.

The new high-efficiency settlers and DSP soda recovery process has been applied in some refineries, the total soda consumption has been reduced by about 30 %, which is less than the modelled result. Lime addition should be optimized relative to the costs of soda, alumina, lime, steam and electricity to maximize economic profit.

## 6. Acknowledgements

The authors would like to acknowledge the contribution of Xiaoqiang Xie, Yingzi Guo, Shengren Sun and many other colleagues.

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