

Innovations in Process Water Treatment for Enhanced Reuse in Alumina Refining

Santanu Dey¹ and Chiradip Roy²

1. Section Head - Red Area Operations

2. Section Head - Red Mud Management

Hindalco Industries, Belagavi, India

Corresponding author: santanu.dey@adityabirla.com

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Abstract

Alumina refineries are water-intensive, with significant water usage across multiple stages of the refining process. Consequently, water becomes an indispensable resource, driving a growing emphasis on sustainable water management practices essential for corporate responsibility and environmental stewardship. Hindalco is firmly committed to Environmental, Social, and Governance (ESG) principles, setting bold sustainability targets to drive progress.

Water scarcity presents a significant challenge for Hindalco Belagavi Plant, a 100 % specialty alumina and hydrate manufacturing facility located in a water-stressed region with no river water sources. The entire water supply for both the city and industrial operations is sourced from the Hidkal reservoir, which relies solely on monsoonal rains. In the specialty alumina and hydrate business, product quality is paramount, and the manufacturing process is highly complex, requiring precise control over various product grades. The use of high-quality water is crucial in this process, and any situation involving water scarcity or poor water quality can have a detrimental impact on the business.

To maintain a consistent, high-quality water supply for specialty alumina production and become water-reliant, the unit implemented the reuse of treated process effluent water as a key sustainability initiative. However, increasing the reuse of treated water led to significant issues, including high Total Suspended Solids (TSS), strong pungent odours, and a greenish tint, primarily due to caustic soda presence and algal growth. Traditional treatment approaches, such as acid neutralization and hypochlorite dosing, failed to resolve these challenges, instead exacerbating TDS levels and complicating operations. As a result, relying on treated process water became a challenge for sustaining plant operations. Moreover, the corporation has sharply reduced freshwater supply due to declining precipitation rates, a direct impact of climate change, intensifying water scarcity. To address this, an in-house study evaluated alternative treatment strategies through process innovation, including various flocculants, coagulants, and chemical aids. Trials initially did not yield desired results, necessitating process optimization through controlled dosage and treatment sequencing. This led to a breakthrough in eliminating colour and odour, while providing 100 % discontinuation of hypochlorite. The adoption of a coagulant-flocculant system significantly improved turbidity and clarity, enhancing treated water usability.

For the first time ever in the alumina industry, Hindalco Belagavi conducted detailed technical trials to improve treated process water quality, reducing freshwater intake and enabling sustained, self-reliant operations. These improvements offer a scalable, cost-effective approach to optimizing water treatment in specialty alumina refining, providing a replicable model for industries in water-scarce regions.

Keywords: ESG, Sustainability, Water reuse, Water-reliant, Innovation.

1. Introduction

Water is a critical resource in the industrial sector, playing an indispensable role in numerous production processes. In the context of alumina refineries, its importance is magnified due to its involvement in virtually every stage of the refining operation. Alumina, the key intermediate derived from bauxite ore through the Bayer process, is the foundational raw material for aluminium production. The Bayer process is inherently water-intensive, encompassing operations such as bauxite washing, digestion, clarification, precipitation, and calcination. Beyond these core processes, water is also essential for auxiliary operations, including cooling systems, dust suppression, and effluent management.

On the other hand, the increase in population and decrease in available water potential has a significant impact not only on water usage or withdrawal level, but also on security of the world. The reduction in the level of withdrawal means an increase in water scarcity, and this on the other round mean a rise in security tension. The other very related issue is deterioration of water in chemical quality after use [1]. Therefore, if the wastewater generated after withdrawal cannot be reused by implementing treatment techniques, it will go to the remaining water body through running ways and affect the chemical constituent of freshwater which again affect usage security [1]. The world is facing enormous challenges in meeting rising demands for clean water as the available supplies of freshwater are decreasing due to rapid population growth, urbanization, rapid industrialization, global climate change, and more stringent health-based water quality standards [2].

At Hindalco's Belagavi Plant, a 100 % specialty alumina and hydrate manufacturing facility, water assumes a particularly critical role. Located in a water-stressed region of Karnataka, the plant faces unique operational challenges due to its complete reliance on the Hidkal reservoir for water supply in absence of any river for water withdrawal. This reservoir, fed solely by monsoonal rains, also supports the city's municipal water needs, making efficient and sustainable water use a shared priority.

In the specialty alumina and hydrate business, where product quality and consistency are paramount, the need for high-purity water is even more pronounced. The manufacturing process is highly specialized, requiring tight control over a wide range of product grades to meet diverse end-use specifications. Any disruption in water availability or degradation in water quality poses a direct risk to operational continuity, product integrity, and overall business performance. To reduce freshwater consumption and enhance resource efficiency, the plant has implemented several conservation measures. One of the most impactful initiatives has been the recycling of treated process effluent for reuse in various process applications. This is facilitated through an on-site Effluent Treatment Plant (ETP), which treats the effluent to a quality suitable for internal reuse. Initially, this initiative resulted in substantial savings in freshwater usage and contributed significantly to the plant's sustainability goals.

However, over time, changes in climatic conditions began to impact the quality of the treated effluent. Seasonal variations and prolonged dry spells led to increased algal growth, greenish colouration, a pungent odour, and elevated levels of suspended solids in the recycled water. These changes rendered the treated water unsuitable for continued use in sensitive process operations, undermining the effectiveness of the recycling initiative and posing a significant risk to water conservation efforts. This paper presents a detailed analysis of the challenges faced in maintaining effluent water quality under changing environmental conditions and explores the advanced treatment strategies adopted by the Hindalco Belagavi Plant to restore and sustain the usability of recycled water in its critical manufacturing processes.

2. Effluent Treatment Process

The process effluent generated at the plant is predominantly alkaline and inorganic in nature. Initially, it is directed to an equalization pond designated as RMP #3, which also receives surface runoff from the red mud storage area. From this point, the effluent is fed to the Effluent Treatment Plant (ETP) for systematic treatment. The first stage involves acid dosing to neutralize the pH, followed by a hypochlorite (hypo) treatment aimed at controlling algal growth in the water. Subsequently, a flocculating agent is added to facilitate the aggregation and settling of suspended solids within the ClariTube settler unit. The clarified overflow from the settler is then reused within the plant's process operations as treated water as shown in Figure 1.

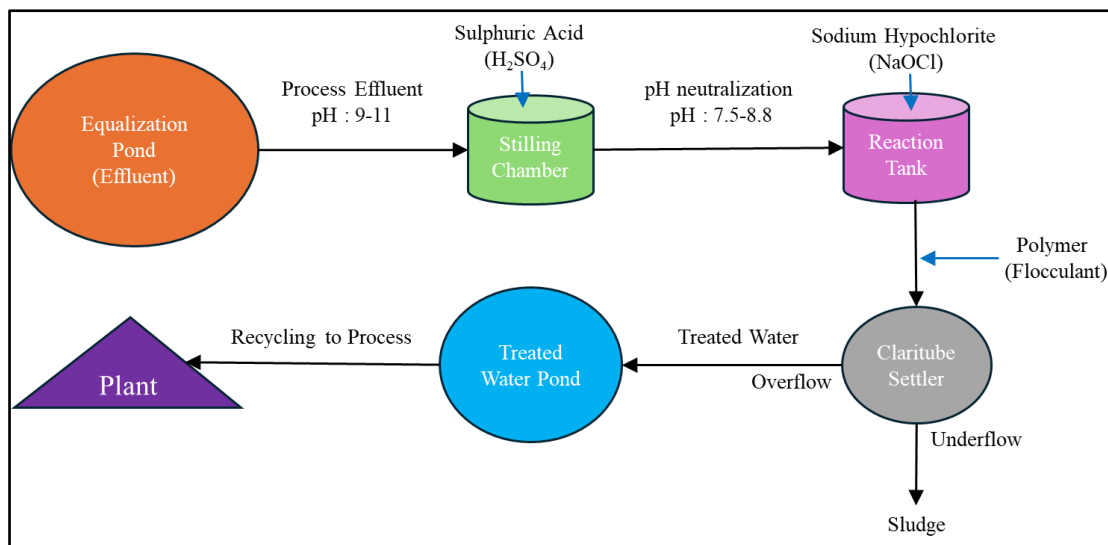


Figure 1. Effluent treatment process and treated water recycling.

This integrated approach to effluent treatment and reuse enables the facility to maintain a zero liquid discharge (ZLD) status, supporting the dual objectives of minimizing freshwater consumption and achieving environmental compliance through zero effluent discharge.

3. Sustainability Commitment

In the current global context, industrial advancement must go hand in hand with sustainable development. As the impacts of climate change and resource scarcity become increasingly evident, industries around the world are recognizing the need to integrate sustainability into the core of their operations. This alignment is essential to ensure that economic progress does not compromise environmental integrity or deplete critical natural resources.

As a leading player in the global metals industry, with operations spanning the aluminium and copper value chains across 13 countries, Hindalco Industries places sustainability at the forefront of its strategic agenda. The company has embraced a comprehensive Environment, Social, and Governance (ESG) framework, with a strong emphasis on environmental responsibility. Key pillars of Hindalco's environmental strategy include:

- ✓ Circular Economy and Recycled Materials: Advancing the use of recycled inputs and adopting circular economy principles to effectively manage industrial by-products such as red mud, fly ash, and single-use plastics.

- ✓ Decarbonization and Waste Minimization: Committing to net carbon neutrality and a zero waste-to-landfill target by 2050 through innovation, process optimization, and waste valorisation initiatives.
- ✓ Water and Biodiversity Stewardship: Pursuing water positivity at mining sites and ensuring no net loss of biodiversity by mid-century, aligning operations with ecological preservation goals.
- ✓ Freshwater Efficiency: Aiming to reduce specific freshwater consumption by 20 % by 2025, relative to the FY 2018–19 baseline, through improved water recycling, recovery, and process redesign.
- ✓ Zero Liquid Discharge (ZLD): Striving for 100 % ZLD implementation across all manufacturing units by 2025, reinforcing a closed-loop approach to water use and discharge management.

Water stewardship is a key focus area for Hindalco, reflecting the company's recognition of water as a vital shared resource and a cornerstone for long-term business resilience. These strategic goals underscore Hindalco's long-term vision of embedding environmental sustainability across its value chain, while contributing meaningfully to global climate and resource conservation efforts.

4. Challenges

Water management at the Belagavi Alumina Plant is conducted through a structured and prioritized approach based on the criticality and nature of end-use applications, ranging from process requirements and critical equipment cooling to domestic consumption. A comprehensive water mapping exercise has been carried out across the facility to categorize and allocate water use accordingly.

The plant's total water demand is met through a combination of freshwater sourced from the Hidkal reservoir and treated effluent water from the Effluent Treatment Plant (ETP). ETP treated water is utilized for most of the plant operations, thereby significantly reducing dependence on freshwater resources. However, for niche applications that require low Total Dissolved Solids (TDS) and high-quality water, freshwater is specifically allocated. These niche applications include critical processes such as hydrate washing, boiler make-up, calciner seal water, squeezing operations of Red Mud Filters etc. Freshwater is also exclusively used to meet domestic and drinking water requirements, ensuring compliance with health and safety standards. This dual-source strategy supports the plant's broader objectives of optimizing water usage, enhancing sustainability, and freshwater conservation goals.

4.1 Freshwater Availability

The Belagavi region is classified as a water-stressed zone, primarily due to the absence of perennial river systems in the vicinity. The entire water demand of the city and surrounding industrial establishments, including the alumina refinery, is met by a single source, the Hidkal reservoir which is exclusively rain-fed. In recent years, the region has experienced a consistent decline in monsoonal rainfall patterns, attributed largely to the broader impacts of climate change. This has led to increasing uncertainty and vulnerability in water availability.

There have been instances in the past when the supply of freshwater to the alumina refinery was either severely curtailed or completely halted due to acute water scarcity or disruptions in the municipal water distribution network. The plant's freshwater requirement ranges between 2.3 and

2.6 million litres per day (MLD), which is currently fulfilled by the City Corporation (Hidkal reservoir). However, maintaining a consistent supply at this level remains a persistent challenge, given the competing demand from domestic users and the city's priority water allocation commitments. Any further increase in freshwater intake by the plant is unlikely to be sustainable, as it would place additional stress on an already limited resource. Even ensuring the current supply volume on a reliable, year-round basis is becoming increasingly difficult. This underscores the critical need for effective water management strategies, alternative sourcing, and enhanced recycling measures to ensure the continued operation of the refinery without compromising regional water security.

4.2 Deterioration of Treated Water Quality

The plant's process effluent, along with runoff from the red mud storage area, is routed to an equalization pond (RMP #3) with a storage capacity of 600 000 m³. Over time, due to stagnant conditions and environmental exposure, the water in the pond developed extensive algal growth, resulting in a greenish hue and a strong, unpleasant odour. To mitigate algal proliferation, sodium hypochlorite was routinely dosed; however, this approach led to a substantial increase in the Total Dissolved Solids (TDS) in the treated water, thereby limiting its suitability for reuse in sensitive process applications.

The deteriorated water quality with its discoloration, odour, and elevated suspended solids rendered it unsuitable for process use. The suspended particulates led to operational challenges, including deposition in pump glands, which caused frequent pump failures. Additionally, the quality concerns prompted resistance from shop floor personnel, who were reluctant to use the recycled water for routine operations.

Given the chronic water stress in the Belagavi region and the plant's reliance on efficient water reuse to reduce freshwater intake, addressing these water quality issues became a critical operational priority. Improving the usability of treated water was essential not only for sustaining process reliability but also for advancing the plant's broader water conservation and zero liquid discharge objectives. Increasing the utilization of treated water within the plant is essential for reducing dependence on freshwater; therefore, maintaining high-quality standards of treated water is critical for the sustainable operation of the Belagavi Alumina Plant.

5. Chemical Trials and Process Optimization

In Effluent Treatment Plant (ETP), a significant challenge was the progressive deterioration of the quality of the feed effluent. Over time, the effluent exhibited a greenish coloration, algae formation, a pungent odour, and elevated levels of suspended solids. These changes rendered the treated water unsuitable for process use, both due to its visual and olfactory characteristics and the presence of solid particles. This deterioration led to operational difficulties, especially affecting mechanical seal pumps and other equipment that rely on treated water for seal cooling. The poor water quality contributed to frequent failures of mechanical seals of pumps, reducing their operational lifespan and increasing maintenance requirements.

Therefore, the treated water had to be replaced with again freshwater for seal cooling applications during the Q1 and Q2 of FY25. This led to a marked increase in freshwater consumption, rising by 25 - 30 cum/ h. The increased demand not only elevated the overall freshwater usage but also negatively impacted the unit's specific freshwater consumption. In FY24, the unit had achieved a benchmark specific freshwater consumption of 2.11 t/t. However, at the beginning of FY25, this performance metric was adversely affected by the decline in the quality of ETP-treated water. However, the overall setback in freshwater performance was partially offset by reductions in

freshwater consumption in other areas, such as drinking and domestic use, both within the plant and the colony.

5.1 Screening and Establishment

The quality of treated water from the Effluent Treatment Plant (ETP) has been a significant concern, as it directly influences the high consumption of freshwater in the plant's process operations. Therefore, enhancing the treatment efficacy beyond the existing methodologies has become imperative. The conventional approach involving acid and hypochlorite dosing, in combination with claritube settler polymer, was found to be insufficient in producing treated water that meets the required standards of being colourless, odourless, and free from suspended solids i.e., the qualities essential for sustained process reuse.

To address this challenge, chemical trials were initiated in collaboration with several water treatment solution providers. These trials aimed to identify a suitable coagulant-flocculant chemistry capable of achieving higher water clarity with minimal odour. Jar tests were conducted on-site to evaluate the performance of various chemical formulations. In total, 5-6 water solution providers with prior experience in treating effluent from alumina refineries were engaged for the study. A series of experiments were carried out, and some combinations demonstrated promising improvements in water clarity, as shown in Figure 2.



Figure 2. Jar test with ETP feed and treated water.

Despite these improvements, the trials did not fully meet the desired water quality objectives. The treated water continued to exhibit a pungent odour and a greenish tint, rendering it suboptimal for continuous process usage. Additionally, the cost associated with the flocculant-coagulant treatment combinations was found to be significantly high at around 4 370 USD/month (3.85 Lakh INR/month). This posed concerns about the economic feasibility of adopting such treatments on a sustained basis.

In response to the stringent requirements for improved effluent water quality, a specially formulated chemical aid, referred to as a biocide, has been introduced into the treatment process. A biocide in effluent water treatment is a chemical agent used to control or eliminate biological contaminants such as algae, bacteria, fungi, and biofilms that negatively affect water quality. In the treatment process, biocides help mitigate issues related to algal growth, which is a common cause of turbidity and greenish coloration in water, particularly in systems exposed to sunlight or

with long retention times. By disrupting the cellular structures or metabolic functions of algae and microbes, biocides reduce both the biological load and the pigments released by these organisms, thereby improving water clarity and colour. Additionally, they play a crucial role in odour control by limiting the microbial activity responsible for generating foul-smelling compounds like hydrogen sulphide and ammonia.

With the introduction of biocide, the quality of treated water improved significantly, resulting in clear, colourless, and odourless water free from suspended particles as shown in Figure 3.



Figure 3. Biocide-treated water.

This treated water proved to be highly suitable for plant processes. The implementation was completed by the end of Q3, and from December 2025 onwards, this chemical aid has been brought into continuous operation to realize the anticipated benefits.

5.2 Benefits

During the jar tests, it was observed that the biocide performed effectively when applied after acid treatment, thereby eliminating the need for the hazardous chlorinated chemical, sodium hypochlorite (NaOCl). From both safety and operational standpoints, the complete removal of hypochlorite use represents a significant advantage in addition to the improvement in treated water quality from the Effluent Treatment Plant (ETP). With the introduction of biocide treatment, the turbidity of treated water was drastically reduced from 200 NTU (very high and indicates poor water clarity with a heavy presence of suspended particles) to just 11.2 NTU, resulting in significantly clearer, suspended particle-free water suitable for process reuse. This marks a substantial improvement in water quality and treatment efficiency.

The elimination of sodium hypochlorite not only reduces safety risks but also results in considerable cost savings. Furthermore, based on the successful application in the ETP, the use of biocide was extended to the cooling tower water treatment system. Previously, a separate chemical aid was used to control algal growth in the cooling towers, which was not only costly but also less effective. With the adoption of biocide, the quality of cooling tower water has also improved, allowing for the discontinuation of the earlier chemical treatment.

Thus, the introduction of biocide has successfully replaced two major chemicals in the plant’s water treatment processes, one in the ETP and the other in the cooling towers, bringing both performance and economic benefits.

The introduction of the biocide chemical aid has delivered the key benefits summarised below:

1. **Clear, colourless, odourless, and suspended particle-free treated water** made suitable for plant use, thereby improving water efficiency and reducing freshwater consumption by maximizing the reuse of treated water in the process.
2. **Complete elimination of hazardous chemicals** such as sodium hypochlorite (Hypo) and the existing cooling tower chemical aid, significantly reducing the risks associated with handling hazardous substances.
3. **Net monetary savings of 37.5 kUSD/y** (33 Lakh INR /annum), achieved through the elimination of Hypo and cooling tower chemicals, after accounting for the cost of the biocide chemical aid.

6. Results and Conclusion

With the adoption of biocide, the overall efficiency of effluent treatment improved significantly, delivering superior water quality suitable for recycling and reuse in plant processes. Once the treatment was established and operational parameters were optimized, the quantity of recycled treated water not only returned to previous levels but was further maximized and extended to additional applications, resulting in a substantial reduction in freshwater consumption. Moreover, this significant breakthrough was achieved without incurring any substantial CAPEX or OPEX.

This advancement led to a significant milestone in FY25, with the alumina plant achieving its lowest ever specific freshwater consumption at 1.94 t freshwater / t alumina hydrate, beating last year’s record of 2.11 t/t by 8 %. This achievement reflects a remarkable transformation in water efficiency, with specific freshwater consumption reduced by approximately 55 % compared to the baseline year FY19, when it stood at 4.27 t/t; a testament to the plant’s commitment to sustainable and resource-efficient operations, as illustrated in Figure 4.

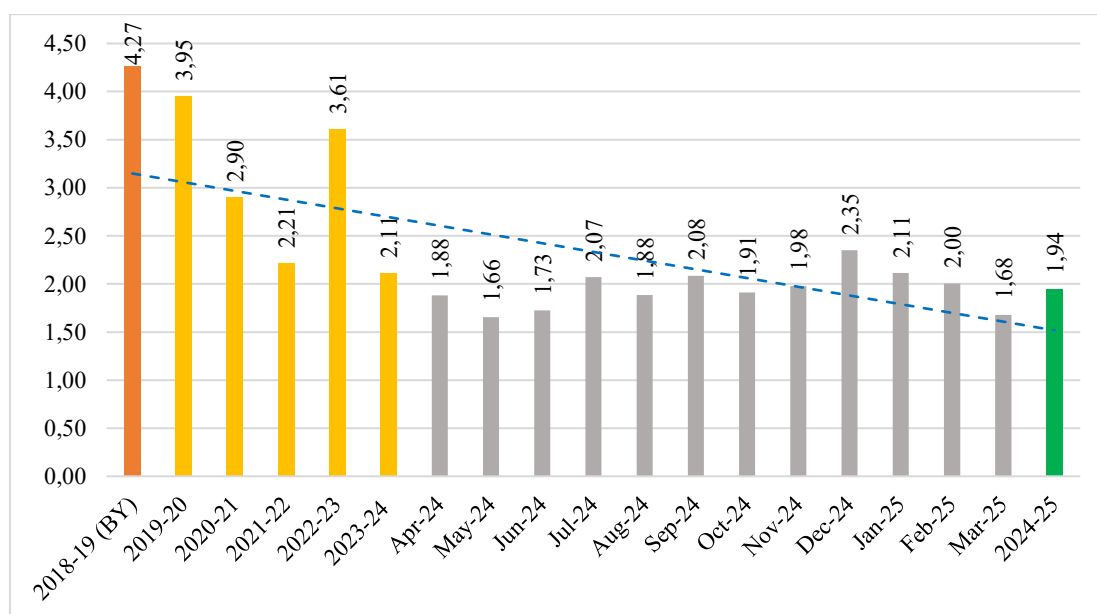


Figure 4. Specific freshwater consumption, tonne freshwater per tonne Al₂O₃·3H₂O.

In summary, Hindalco continues to set a benchmark in sustainable industrial practices, with a strong focus on responsible and forward-looking water management. At the Belagavi unit, a circular water strategy built on the pillars of reuse, recovery, and innovation is actively driving the journey toward water positivity. A key highlight of this approach is the successful implementation of advanced chemical trials aimed at significantly improving the quality of treated effluent water. This proactive and science-driven initiative underscores Hindalco's commitment to expediting innovative solutions that support increased process reuse, reduce dependency on freshwater, and enhance overall operational resilience. By prioritizing such transformative actions, Hindalco positions itself as a leader in sustainability, water stewardship, and circular economy principles; reflecting its role as a socially responsible organization dedicated to safeguarding vital environmental resources for future generations.

7. References

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