Comparative Analysis of Seawater- and Calcium-Based Desulphurization of Aluminium Cell Fumes

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Abstract

In recent years, influenced by factors such as raw material, fuel, and transportation costs, the deployment of aluminium smelter projects at coastal ports has become a prevailing trend in the industry. This paper takes a large-scale newly built aluminium smelter project abroad as a case study to conduct an in-depth comparative analysis of seawater desulphurization and calcium-based desulphurization (limestone-gypsum process) for pot fume. The research results indicate that both technologies are technically feasible in meeting ultra-low emission requirements. However, seawater desulphurization offers a simpler process, reduced equipment maintenance workload, and operating costs that are 12 % lower than those of calcium-based desulphurization. Given the specific project conditions (coastal location, suitable seawater alkalinity, favourable dispersion conditions, and moderate distance for seawater intake and discharge), the seawater desulphurization system has clear advantages. It avoids issues related to solid by-products and complex wastewater treatment, offers better environmental compatibility, and not only effectively achieves ultra-low flue gas emissions but also aligns with the aluminium industry's goals for clean production and sustainable development.

Keywords: Aluminium electrolysis cell fume, Seawater desulphurization, Calcium-based desulphurization.

1. Introduction

The fume produced during aluminium electrolysis (hereinafter referred to as "pot fume") mainly contains dust, fluorides, and the gaseous pollutant sulphur dioxide (SO_2). Among these, SO_2, due to its large total emissions, has become a key target of environmental control. The SO_2 in pot fume primarily originates from sulphur content in prebaked anodes [1]. Under the high-temperature environment (~960 °C) of electrolysis cells, the sulphur in anode carbon blocks is oxidized to generate SO_2. It is noteworthy that in recent years, influenced by raw material availability and cost, the use of medium- to high-sulphur petroleum coke (typically containing 2–3 % sulphur, sometimes as high as 5 %) in prebaked anode production has increased [2], directly leading to a significant rise in SO_2 concentrations in pot fume, thus placing higher demands on end-treatment technologies.

Wet desulphurization technology, due to its high removal efficiency and proven reliability, dominates the field of pot fume treatment in China (with an application rate of approximately 74 %) [3]. Major wet desulphurization technologies include the calcium-based process (limestone-gypsum method), seawater process, and ammonia process. The calcium-based method is mature and widely used [4], but its system is complex and generates by-product gypsum and wastewater requiring treatment; in contrast, the seawater method makes full use of the natural alkalinity (mainly containing HCO_3^-, CO_3^{2-} etc.) and buffering capacity of seawater as the absorbent [5]. However, its application is significantly limited by geographic conditions, making it suitable only for coastal aluminium plants with convenient seawater intake and discharge.

With the implementation of domestic capacity "ceiling" policies for electrolytic aluminium, and increasing constraints on resources, energy, and the environment, Chinese aluminium smelters are accelerating capacity relocation to regions such as Southeast Asia and the Middle East that offer advantages in resources, energy, and port access. Against this backdrop, considering the logistics costs of raw material imports and product exports, as well as energy supply, building large-scale electrolytic aluminium bases in coastal port areas has become an irreversible industry trend. For such coastal projects, utilizing abundant seawater resources for pot fume desulphurization becomes a highly attractive option. However, the actual performance of seawater desulphurization is influenced by several key factors: seawater alkalinity (which directly affects absorption capacity), marine dispersion conditions (impacting compliance and ecological assessment), discharge water quality requirements (especially pollutant limits for heavy metals, Chemical Oxygen Demand or COD, etc.), and the engineering complexity and investment of the seawater intake and discharge system (transport distance, lift, anti-corrosion requirements), among others. Therefore, for newly constructed coastal aluminium smelter projects, this paper provides a scientific and objective comparative analysis of seawater and the mature calcium-based desulphurization technologies, evaluating their technical adaptability, economic viability, and environmental benefits, offering important practical guidance for project decision-making and green development in the industry.

2. Overview of Desulphurization Schemes

2.1 Seawater Desulphurization

Seawater desulphurization [6-10] utilizes the inherent alkalinity and strong acid-base buffering capacity of natural seawater to absorb SO_2 from pot fume. The basic chemical reactions are as follows:

$$\mathrm{SO_{2\,(g)}} + \mathrm{H_2O} + \mathrm{CO_3^{2-}} \rightarrow \mathrm{HCO_3^-} + \mathrm{HSO_3^-} \tag{1}$$

$$\mathrm{HSO_3^-} + \frac{1}{2}\mathrm{O_2} \rightarrow \mathrm{SO_4^{2-}} + H^+ \quad \text{(oxidation by forced aeration required)} \tag{2}$$

The absorption process causes a significant decrease in seawater pH (usually around 3). The treated acidic seawater requires forced aeration (injection of large amounts of air) to fully oxidize the unstable bisulphite (HSO_3^-) to stable sulphate (SO_4^{2-}). Subsequently, the oxidized seawater is usually mixed with a certain amount of fresh seawater for dilution, ensuring that the pH, temperature, and other water quality indicators (such as COD and heavy metal content) meet local strict discharge standards before being released back into the ocean. The inherent salts in seawater (mainly Na^+, Cl^-, Mg^{2+}, etc.) are the primary dissolved solids (TDS), and their concentration remains largely unchanged before and after treatment, despite the anion composition shifts (decrease in HCO_3^-/CO_3^{2-}, increase in SO_4^{2-}).

The system mainly includes the flue gas system, absorption system, seawater recovery system, and the water intake and discharge system. The typical process flow is shown in Figure 1.

5. References

1. Zhuxian Qiu, *Prebaked Cell Aluminium Smelting* (3rd Edition) [M], Metallurgical Industry Press, 2005 (in Chinese).
2. Yongjian Yuan, Lili Huang. Brief Analysis of Pot fume Desulphurization Technologies for Electrolysis Cells [J], *Light Metals*, 2019(7): 33–36, 45 (in Chinese).
3. Shanshu Lao and Zhijie Zhao, Selection of Desulphurization Technology for pot fume [J], *Light Metals*, 2023(7): 54–57 (in Chinese).
4. Zongbing Liu, Comparative Study on Desulphurization Technology Schemes for Pot Fume [J], *China Science & Technology Overview*, 2024(6): 94–96 (in Chinese).
5. Hongjun Lv and Xunhai Wu, Application and Development of Seawater Desulphurization Technology [J], *Energy Conservation and Environmental Protection*, 2005(4) (in Chinese).
6. Jun Xue et al., Research and Application of Seawater Pot fume Desulphurization Technology [J], *Electric Power Science and Environmental Protection*, 2010, 26(1): 36–38 (in Chinese).
7. Dong Yang et al., *Seawater Pot fume Desulphurization Technology and Demonstration Report for Large-Scale Coal-Fired Power Plants* [R], 2011 (in Chinese).
8. Lifeng Li and Shushen Zhang, Comparative Study on Seawater and Limestone/Lime-Gypsum Desulphurization Schemes in Thermal Power Plants [J], *Chemical Equipment Technology*, 2006(4): 60–62 (in Chinese).
9. Yingying Zhao et al., Research Progress on Integration of Seawater Decalcification and Pot fume Carbonation Desulphurization [J], *Chemical Industry and Engineering Progress*, 2020, 39(11): 4315–4329 (in Chinese).
10. Hui Lv and Fengchun Lan, Application Research on Seawater Flue Gas Desulphurization Process in Domestic Thermal Power Plants [J], *Jilin Electric Power*, 2007, 35(4): 23–26, 30 (in Chinese).
11. Tianbao Lv, Industrial Desulphurization and Comprehensive Utilization Technology [M], *National Defense Industry Press*, 2011 (in Chinese).