Fresh Alumina Unloading and Conveying for Large-Scale Aluminium Electrolysis Projects

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Abstract

Driven by the "Dual Carbon" policy and the high-quality development of the aluminium industry, the selection of bulk material conveying solutions is crucial to the economic and environmental performance of aluminium electrolytic projects. This paper focuses on the unloading, storage, and conveying of fresh alumina in large-scale aluminium electrolytic projects. By comparing and analysing key indicators such as conveying capacity, construction investment, operating costs, and alumina attrition rate, a technical solution centred on bulk unloading, storage in spiral-rimmed steel silos, and hyper-dense phase conveying or belt conveying is proposed. Taking into account the impact of alumina on electrolytic production, comprehensive economic benefits and labour productivity, this solution has obvious technical and economic advantages over traditional solutions and has broad prospects for industry promotion.

Keywords: Electrolytic aluminium project, Bulk unloading, Steel silo storage, Hyper-dense phase conveying, Belt conveying.

1. Introduction

Under the guidance of the "dual carbon" strategy, electrolytic aluminium, as an important pillar industry of the national economy, is undergoing a profound transformation and upgrading towards low carbon and intelligence. At present, China's electrolytic aluminium industry is showing a trend of regional cluster layout and intelligent upgrading of technical equipment, with the core goal of focusing on energy conservation, carbon reduction, cost reduction and efficiency improvement. Alumina is the main raw material for electrolytic aluminium production, and the choice of its transportation scheme directly affects production indicators, economic benefits and environmental benefits. This puts higher demands on the quality control of alumina—not only must it meet the strict requirements of the electrolytic process on particle size distribution and specific surface area [1], but it must also ensure its physical stability during unloading, transportation and storage.

Research shows that the physical properties of alumina (such as particle size and morphology) significantly affect its dissolution rate and current efficiency in the electrolytic cell, while the stability of the particle morphology is related to the adsorption efficiency of pollutants such as hydrogen fluoride in the purification system [2]. However, the design of alumina conveying system faces many technical challenges, especially when balancing different transportation modes (road/rail) and conveying processes (such as hyper-dense phase pneumatic conveying, belt conveying [3]), it is necessary to take into account low attrition rate, high environmental protection and operation economy.

This paper takes a large-scale electrolytic aluminium project as a case study and focuses on the unloading, storage and conveying scheme of market-purchased alumina. By combining theoretical calculation with engineering practice, the bagged and bulk transportation modes are compared and analysed, and the comprehensive performance of core process systems such as hyper-dense phase conveying and belt conveying is evaluated, and finally an optimized solution with both economic and environmental benefits is formed. The research results can provide important technical references for similar large-scale engineering projects and help the green development of the electrolytic aluminium industry.

2. Brief Description of the Main Systems

2.1 Packaging System

The packaging method of alumina has evolved from "disposable packaging bags" to "recycling bag packaging" and then to "bulk de-packaging". At present, efficient logistics modes such as bulk shipping by car or train and container transportation have become the mainstream [4]. "Bulk-to-packaging" not only eliminates packaging, lifting, stacking, and unpacking, significantly improving logistics efficiency, but also effectively reduces loading and unloading costs and labour costs (the cost per tonne of alumina can be reduced by approximately 20 yuan). It also addresses the problem of packaging bag consumption and alumina dust generation at the source.

As a result, "bulk-to-packaging" has become the preferred mode of alumina transportation for large-scale aluminium smelters, offering significant operating cost advantages and environmental benefits, marking a new era of green and efficient alumina transportation.

2.2 Storage Solutions

Bagged alumina is typically stored in warehouses or silos, while bulk alumina primarily relies on large-scale storage silos. Traditional large-scale alumina storage silos primarily include concrete silos and welded steel silos. Concrete silos are expensive and have a long construction period, while welded steel silos have issues such as thick walls, high steel consumption, high construction costs, and the tendency for misalignment, limiting their application.

Drawing on the successful experience of spiral rolled steel plate silos in the building materials industry, it was introduced into the field of alumina storage, and technical optimization was carried out based on the material properties of alumina (such as fluidity and repose angle) [5]. This type of silo uses a spiral rolled edge interlocking structure, forming continuous spiral reinforcement ribs on the outside of the cylinder, which has both structural connection and overall reinforcement functions, significantly improving the strength and rigidity of the silo body, while reducing the steel structure engineering volume by about 30 %. This technology effectively solves the problems of small effective storage capacity, high investment, complex construction, and long construction period in traditional alumina storage silos, and has good technical applicability and economic benefits.

2.3 Transportation Solution

Traditional alumina transportation mostly uses dilute phase pneumatic conveying technology, but due to its severe wear, high alumina attrition rate, high energy consumption, and limited transportation capacity, it is difficult to meet the needs of modern large-scale electrolytic aluminium smelters [6]. At present, the mainstream conveying methods applicable to large-scale electrolytic aluminium projects are hyper-dense phase conveying [7, 8] and belt conveying [9]. Hyper-dense phase pneumatic conveying uses fans to supply air to drive pneumatic chutes (or sending tanks), so that powdered materials are fluidized and moved forward at a low speed. Its characteristics are high solid-gas ratio (generally > 100), low conveying speed, low alumina attrition rate, fully enclosed system, relatively low energy consumption and high degree of automation. Belt conveying: using conveyor belts as load-bearing components, it is particularly suitable for long-distance and large-volume transportation scenarios. Among them, air cushion belt conveyors replace traditional roller supports by forming an air film, significantly reducing operating friction resistance, and have the advantages of low energy consumption, large conveying capacity and stable operation.

3. Comparison of Conveying Systems

3.1 Project Introduction

The research object of this paper is a newly built large-scale electrolytic aluminium project in China with an annual output of 500 000 tonnes of primary aluminium. The project's main raw materials are alumina and anode carbon blocks, while auxiliary materials include aluminium fluoride and cryolite. The intermediate product is liquid aluminium, and the final product is a 25 kg remelted aluminium ingot.

The project utilizes NEUI600kA high productivity aluminium electrolytic cells and their associated process equipment. The main project includes the potrooms, cast house and anode plant. Auxiliary projects include a cell relining centre, a molten aluminium crucible-cleaning workshop, a comprehensive maintenance workshop, and a quality inspection and testing centre. Utility works include power supply and rectification system, an air compressor station, water supply and drainage systems, and a natural gas supply system.

The potline has 312 NEUI600kA cells, divided into two potrooms. The fresh alumina storage and transportation system primarily consists of a discharge station, two alumina storage silos with a capacity of 35 000 tonnes each, and a conveying system. Hyper-dense phase conveying or belt conveying can be used as conveying method, depending on the material properties, distance, capacity requirements, and operational efficiency. In the comparison in Table 1, hyper-dense phase system is recommended in this situation.

3.2 Transportation Option Comparison

Based on the project's large-scale requirements and preliminary demonstration, bulk transportation and unloading were selected, and spiral-rimmed steel silos were selected for the alumina storage silos. A technical and economic comparison of two conveying system options, hyper-dense phase conveying and belt conveying, is currently underway.

3.2.1 Hyper-dense phase Conveying

This option provides for a single unloading station, located adjacent to a roadway near two 35-kt alumina silos (located in the electrolytic purification area). The unloading station is equipped with one dump truck stations and one car dumper station, each with a capacity of four trucks, for a total unloading capacity of 240 t/h.

To prevent alumina eccentricity and increase silo capacity, the silos are equipped with a multi-point feed system and a bottom fluidization and discharge system.

The hyper-dense phase conveying system has a conveying capacity of 240 t/h, an average daily alumina consumption of approximately 2 630 tonnes, an effective daily operating time of approximately 11 hours, and an annual operating period of 365 days. The hyper-dense phase conveying system can be installed underground or overhead.

3.2.2 Belt Conveyor

A single unloading station is also provided, located near the alumina silo, close to the road.

The unloading station is equipped with two dump truck stations and one car dumper station. Each station has an unloading capacity of four trucks per hour, increasing the system's total unloading capacity to 350 t/h.

The air-cushion belt conveyor system has a designed conveying capacity of 350 t/h. The project's average daily alumina consumption remains at 2 630 tonnes, while the system's effective daily operating time is reduced to approximately 7.5 hours, resulting in 350 annual operating days.

The belt conveyor can be arranged in either an underground corridor or an overhead trestle.

3.2.3 Key Technical and Economic Comparisons

Table 1 gives the comparison.

A detailed comparison and analysis of four configuration options: hyper-dense phase conveying (underground/overhead) and belt conveying (underground/overhead) reveals the following:

The belt conveyor option offers high conveying capacity, short daily operating time, and eases equipment maintenance and overhaul; the hyper-dense phase chute has no moving parts and requires virtually no maintenance. The hyper-dense phase conveying option facilitates continuous and stable material supply and maximizes annual operating days.

The construction cost of the hyper-dense phase scheme is slightly higher than or equal to that of the belt conveyor scheme. The difference is mainly due to the chute laying method (underground is usually higher cost than overhead) and the supporting civil engineering. The equipment purchase and installation cost of the belt conveyor scheme is significantly higher than that of the hyper-dense phase scheme, mainly due to the cost of the conveyor itself and the supporting equipment. The total investment is the lowest for the hyper-dense phase underground chute scheme, and the highest for the belt underground scheme. The power (electricity) cost of the belt conveyor scheme is lower than that of the hyper-dense phase scheme, which reflects the advantage of low friction resistance of the air cushion belt. The equipment maintenance cost of the belt conveyor scheme is higher than that of the hyper-dense phase scheme, which is directly related to its higher equipment investment.

4. Conclusions

This paper systematically analyses and proposes optimization solutions for the unloading, storage and transportation of fresh alumina in large-scale electrolytic aluminium projects, and draws the following conclusions:

1) The "bulk de-packaging" transportation method of alumina can significantly reduce packaging and loading and unloading costs, improve transportation and unloading efficiency, and is the preferred technical route for alumina logistics in large-scale electrolytic aluminium plants, which has effectively promoted the implementation of the new green transportation model.

2) The spiral hem steel silo storage solution optimized for the characteristics of alumina materials effectively overcomes the shortcomings of traditional storage silos (concrete silos, welded steel silos) in terms of effective capacity, investment cost, and construction complexity, and has significant technological advantages and economic rationality.

3) Both hyper-dense phase conveying and belt conveying are new generation high-efficiency conveying technologies suitable for large-scale electrolytic aluminium projects. Hyper-dense phase conveying has advantages in system sealing, alumina attrition rate control, and automation level; belt conveying (especially air cushion belt type) has outstanding performance in conveying capacity and operating efficiency. The selection of specific solutions should be based on the actual needs of the project (such as conveying distance, terrain height difference), site conditions, and comprehensive economic indicators.

Table 1. Key technical and economic comparisons.

Project	**Unit**	**Hyper-dense phase Conveying**		**Belt Conveying**		**Remarks**
		Under-ground Chute	**Overhead Chute**	**Under-ground Belt**	**Overhead Belt**	
Technical Parameters						
Primary Aluminium Production Capacity	kt/a	500	500	500	500	
Alumina Consumption	t/d	2630	2630	2630	2630	
Unloading and Conveying Capacity	t/h	240	240	350	350	
Effective Operating Time	h/d	11.0	11.0	7.5	7.5	
Labor Requirements	People	4	4	4	4	
Construction Investment	Million RMB	39.30	40.30	41.10	40.50	
Construction Project	Million RMB	3190	3290	3170	3130	
Equipment Purchase and Installation	Million RMB	7.40	7.40	9.40	9.20	
Operating Costs	Million RMB/a	2.92	2.97	302	298	
Power (Electricity)	1000 RMB/a	25.2	25.2	21	21	Electricity: 0.35 RMB/kWh
Wages and Benefits	1000 RMB/a	600	600	600	600	150,000 RMB/year per capita
Equipment Maintenance	1000 RMB/a	180	180	230	220	Calculated at 3% of the equipment price
Depreciation	Million RMB/a	1.89	1.94	1.98	1.95	

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