

Research Article

Application of Long-distance Conveying and Curved Rail Ship Loading System for Fly Ash

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Abstract

For coastal and riverside thermal power plants with convenient water transportation resources, waterborne shipment has become an effective and economical approach to enhance the resource utilization of fly ash. However, conventional transportation and ship loading systems are often confronted with prominent challenges, including limited conveying distance, frequent pipe blockage over long distances, severe pipe wear, poor adaptability to multiple vessel types, high dust emission, material spillage, and fuel-related pollution. To address these engineering problems, this paper presents an integrated system that combines double-pipe dense-phase pneumatic conveying and curved rail ship loading technology, based on a practical project of a 2×660 MW coal-fired power plant in Southeast Asia. The system adopts a two-stage closed pneumatic conveying process to realize stable long-distance transportation of fly ash from dust collectors to intermediate silos and then to wharf buffer tanks; meanwhile, the curved rail ship loader is adopted to achieve full-hold distribution, high efficiency, and environmental protection during ship loading operations. Engineering application results show that the integrated system features stable operation, high automation level, low energy consumption, and excellent environmental performance, which effectively eliminates dust and spillage and establishes a dual-channel utilization mode of waterborne shipment combined with land transportation. The system provides a reliable, economical, and replicable solution for fly ash disposal in coastal and riverside thermal power plants, and can also serve as a valuable reference for long-distance conveying and environment-friendly ship loading of granular and powdery materials in other related industries.

Keywords

Thermal Power Plant, Fly Ash, Resource Utilization, Double-pipe, Dense-phase Pneumatic Conveying, Curved Rail, Environmentally Friendly Ship Loading, Long-distance Conveying

1. Introduction

Under the dual background of carbon peaking and carbon neutrality policy and solid waste resource management, the harmless disposal and resource comprehensive utilization of fly ash in coal-fired power plants have become regular work in the power industry. As a major by-product of coal-fired power gen-

eration, fly ash can be used as high-quality raw materials in cement production, subgrade filling, new building materials manufacturing and other fields after collection and drying treatment, with prominent economic value of resource utilization.

Large-scale thermal power plants located along rivers and

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coasts naturally enjoy superior waterway transportation conditions. Compared with short-distance road transportation and railway trunk transportation, bulk ship transportation has the advantages of large carrying capacity, low unit freight and suitability for large-scale outward transportation of bulk materials, which has become the optimal transportation mode for fly ash sales of coastal power plants.

However, the supporting system for fly ash waterway transportation still has many technical shortcomings at this stage. Conventional single-pipe pneumatic conveying is prone to powder settlement, pipeline blockage and rapid pipe wall wear under the working condition of kilometer-level long-distance transportation. Traditional fixed and linear ship loading equipment has a limited operating coverage range, failing to meet the shared operation demands of special closed fly ash ships and open barges. The open ship loading process causes serious unorganized dust emission, which fails to meet the environmental protection control standards in port areas.

With the bypass air supplement disturbance structure, double-pipe dense-phase pneumatic conveying realizes low-speed dense-phase continuous conveying, which is perfectly adapted to the working condition of long-distance powder conveying. Centering on the curved rotary traveling structure, curved rail ship loading equipment features compact layout, wide rotary coverage and strong adaptability to multiple ship types. Combined with an overseas coastal power plant project, this paper expounds the overall framework, equipment configuration, core principle, type selection comparison and operation optimization measures of the integrated conveying and ship loading system, and analyzes the operation effect and comprehensive benefits, so as to provide practical basis for the design, transformation and operation maintenance of solid waste conveying systems for similar coastal thermal power projects.

2. Project Overview and Overall System Scheme

2.1. Project Construction Conditions

The research is based on a newly built coastal coal-fired power plant in Southeast Asia, equipped with 2 sets of 660 MW supercritical coal-fired generating units. The boiler adopts solid slag discharge design, matched with high-efficiency electrostatic precipitators to ensure the stable collection of dry fly ash. The plant is adjacent to the offshore sea area, and production coal is transported to the special coal unloading wharf of the plant by large ocean-going cargo ships. Combined with the fly ash sales plan, a 3000 DWT special fly ash operation berth is constructed adjacent to the coal wharf, independently equipped with conveying pipelines, buffer ash storage facilities and special ship loading equipment to realize professional and closed ship loading operation of fly ash.

2.2. Overall Technological Process

The fly ash treatment of the whole plant adopts the overall process route of graded collection, two-stage conveying and dual-path distribution.

The first stage is the in-plant collection and conveying link. The dry fly ash collected from the ash hoppers of denitrification facilities, economizers and electrostatic precipitators of the boiler is pressurized and conveyed to the centrally arranged steel intermediate ash silo in the plant via bin pumps for centralized buffer storage.

The second stage is the long-distance distribution and conveying link. A shunt conveying module is arranged at the bottom of the intermediate ash silo. One path of materials is transported over a long distance to the buffer ash tank in the wharf area, directly connected to ship loading equipment for sea export; the other path is transported to the reinforced concrete terminal ash silo outside the plant for storage, and then exported by bulk trucks for land transportation.

In the wharf operation link, fly ash in the buffer ash tank is sent into the curved rail ship loader in a closed manner. After dust removal and purification, quantitative feeding, air chute conveying and telescopic chute discharging, fully closed ship loading operation is completed, and finally transported to downstream resource utilization enterprises by bulk carriers.

The whole process realizes a flexible disposal mode dominated by waterway transportation and supplemented by land transportation, ensuring the stable consumption of fly ash in the power plant throughout the year.

2.3. Main Structures and Equipment Parameters

Three steel flat-bottom intermediate ash silos are arranged in the plant, with an effective volume of 620 m³ for each silo to meet the buffer demand of daily ash discharge of the generating units. Three reinforced concrete terminal ash silos are laid out in the ash yard outside the plant, with an effective volume of 800 m³ for each silo, featuring large-scale long-term storage capacity.

The wharf is supporting a 3000-ton special berth, with closed ash conveying pipelines laid along the approach bridge. The core equipment of the wharf is equipped with one curved rail ship loader with a rated capacity of 150 t/h.

Actual conveying line mileage: the total length of the primary in-plant conveying pipeline is 400 m; the conveying distance of the secondary pipeline to the wharf is 1500 m; the conveying distance of the secondary pipeline to the terminal ash silo in the ash yard reaches 2100 m, belonging to a typical ultra-long-distance powder conveying working condition.

2.4. Adaptable Ship Type Parameters

The project outward transportation ships include two categories: professional closed fly ash carriers and ordinary inland

open barges, covering mainstream ship types of 1000 DWT ~ 3000 DWT. The professional fly ash carrier is built with built-in pressure storage tanks and gasification unloading devices, equipped with standardized feeding interfaces; open barges have no closed cabin, requiring ship loading equipment to

have a wide-range swinging material distribution capacity to ensure uniform loading in the whole cabin. The core dimension parameters of each designed ship type are shown in Table 1.

Table 1. Main Dimensions of Designed Ship Types for Fly Ash Berth.

Designed Ship Type	Length/m	Breadth/m	Depth/m	Load Draft/m
3000 DWT Special Fly Ash Ship	93	15	7.2	5.9
3000 DWT Open Barge	80	16	5.5	4.0
1000 DWT Special Fly Ash Ship	75	12.5	4.7	3.8

3. Design of Double-pipe Dense-phase Pneumatic Conveying System

3.1. System Working Principle

Double-pipe pneumatic conveying belongs to the technical system of positive pressure dense-phase conveying, with the core innovation adopting a composite pipeline structure of main pipe for material conveying + auxiliary pipe for air supplement. An auxiliary air pipe is added above the main conveying pipeline, with pressure relief injection openings arranged at fixed intervals along the auxiliary pipe and equipped with throttling flow limiting components.

During actual operation, compressed air drives materials to move forward steadily at a low speed. When powder deposition occurs in low-lying sections and long straight sections of the pipeline, the conveying air flow automatically diverts into the upper auxiliary pipe, forming local high-speed air flow through the injection opening to disturb, break up and push the deposited ash layer, prompting the deposited powder to re-mix into the conveying air flow. [12].

Relying on the continuous dynamic air supplement and disturbance mechanism, it avoids the risk of pipeline blockage in long-distance transportation from the structural level, maintains a dense-phase, low-speed and stable conveying state in the whole process, and adapts to the working scenarios of long-distance and large-capacity continuous operation [3].

3.2. Core Performance Advantages of the System

Compared with traditional dilute-phase pneumatic conveying and single-pipe positive pressure conveying modes, the double-pipe conveying technology selected in this project has prominent advantages [9]:

3.2.1. High Ash-air Ratio and Low Energy Consumption

The dense-phase conveying mode has a higher ash-air ratio, with large material conveying capacity per unit gas volume, less compressed air consumption and significantly reduced overall operation energy consumption [11].

3.2.2. Low Flow Velocity and Low Pipeline Wear

The overall conveying flow velocity is controlled in the low-speed range of 2~7 m/s, which greatly reduces the scouring and wear of powder on the pipe wall. The service life of ordinary carbon steel straight pipes can stably reach more than 10 years, reducing equipment replacement and operation and maintenance costs. [13].

3.2.3. Strong Operational Stability and Anti-blocking Performance

The system features strong operation fault tolerance; it can start and stop at any time and run intermittently. No pipe cleaning operation is required for restart after shutdown without caking and blockage.

3.2.4. Flexible Equipment Configuration and Operation Combination

It supports flexible equipment combination and allows parallel or series operation of single and multiple bin pumps. The operating groups can be flexibly adjusted according to the unit load and actual ash discharge volume.

3.2.5. High Degree of Automation and Convenient Operation

The system achieves high automation integration and supports three control modes: local operation, remote manual and automatic program control, with convenient operation and

maintenance [10].

3.3. Project Equipment Configuration and Operation Mode

The two-stage conveying system of the project is independently designed and controlled separately. The output parameters are comprehensively determined combined with unit ash discharge and ship loading scale.

3.3.1. Primary Collection and Conveying System

Each 660 MW unit is matched with an independent double-pipe conveying device, covering all dust removal ash hoppers, denitrification and economizer ash sources. Three ash conveying pipelines are arranged for each unit, conveying dust with different thickness from different electric fields of the electrostatic precipitator in zones. Pipeline switching valves are set at the same time to flexibly adjust the feeding distribution of different ash silos. The designed output of a single furnace is 38.5 t/h to meet the ash discharge demand under full load of the unit.

3.3.2. Secondary Long-distance Conveying System

Two branch conveying systems are arranged under the intermediate ash silo. The designed output of the conveying system towards the wharf is 3×50 t/h to meet the continuous operation demand of the ship loader; the designed output of the conveying system to the terminal ash silo of the ash yard is 3×30 t/h to ensure emergency storage and land outward transportation supply.

Three independent closed ash conveying pipelines are laid on the approach bridge, which can serve as standby for each other to improve system fault tolerance.

The whole pneumatic conveying system optimizes pipe diameter and air supply pressure through accurate hydraulic resistance calculation, with balanced pressure distribution of long-distance pipelines, closed and leak-free in the whole process, meeting the requirements of 24-hour three-shift continuous and stable operation.

4. Curved Rail Environmental-friendly Ship Loading System

4.1. Selection and Comparison of Mainstream Ship Loading Equipment

Combined with the current situation of narrow berth, mixed ship types and strict environmental protection requirements of the project, a comprehensive comparative analysis is carried out on the current mainstream bulk material ship loading equipment [5].

4.1.1. Fixed Ship Loader

It features simple equipment structure, low manufacturing

and civil engineering investment, and low foundation construction difficulty. However, the operating range is only limited to the rotary arc area of the cantilever with limited coverage. It cannot realize full-hold material distribution for open barges, requiring frequent ship movement to cooperate with operation, which seriously restricts ship loading efficiency, and is mostly suitable for small terminals with single ship type operation [1].

4.1.2. Mobile Ship Loader

The walking mechanism relying on the track expands the operating range without frequent ship movement. However, the overall self-weight of the equipment is large, requiring strict bearing capacity and structural strength of the wharf foundation, resulting in a substantial increase in wharf civil engineering reconstruction and construction cost; meanwhile, the cantilever length is limited, with insufficient overall adaptability.

4.1.3. Linear Swing Ship Loader

It is suitable for large-scale continuous ship loading of bulk cargo such as coal and ore, with high operation efficiency and low operation energy consumption. However, it needs to lay hundreds of meters of linear tracks, occupying large wharf shoreline space, with high cost of tracks and supporting foundations, and is not suitable for small special fly ash berths [4].

4.1.4. Curved Rail Ship Loader

The rear part of the equipment adopts a fixed hinge support, and the front walking mechanism rotates along the curved track with a fan-shaped full coverage operating area. The overall layout is compact, occupying small wharf area, with less reconstruction of hydraulic structures; flexible rotation angle [2], adaptable to ship berthing deviation, compatible with ship loading operation of various ship types, short installation cycle and reasonable comprehensive cost.

Considering site conditions, ship type adaptability, environmental protection requirements and investment cost comprehensively, the curved rail ship loading scheme is finally adopted in the project [6, 14].

4.2. Equipment Composition and Key Technical Parameters

The rated processing capacity of the ship loader in this project is 150 t/h, with a maximum peak output of 180 t/h, matched with a 400 m³ large buffer silo to stably match the incoming material rhythm of the upstream long-distance pneumatic conveying.

The core components include closed buffer silo, bag dust removal system, quantitative feeding device, main and auxiliary jib air chute, curved walking rotary mechanism, large-stroke telescopic chute, compressed air system, integrated electric control system and complete set of safety protection

devices.

Core design parameters: the rotation radius of the main cantilever is 8 m, and that of the auxiliary cantilever is 19.5 m; the clear height at the bottom of the equipment is not less than 7 m; the whole machine is designed according to the coastal strong wind environment, with a designed wind resistance speed of no less than 55 m/s, meeting long-term operation under severe offshore meteorological conditions.

4.3. Closed Ship Loading Operation Process

Fly ash is sent into the wharf buffer silo via long-distance pneumatic pipelines. A bag dust removal device is integrated on the top of the silo, and the dusty gas generated during feeding is discharged at low altitude after being filtered and reaching the standard. An air-lock discharging device is arranged at the bottom of the buffer silo to prevent air backflow and dust overflow. [15].

Materials are evenly conveyed to the air chute through the quantitative feeding device, smoothly transported to the equipment head through the primary and secondary jib chutes, and directly discharged into the cabin through the vertically telescopic closed chute. The dust raised inside the cabin is collected uniformly through the chute dust collection device, purified by the terminal dust removal equipment and then discharged. The whole process adopts closed conveying and segmented dust removal to restrain dust diffusion from the source and completely solve the dust pollution problem of traditional ship loading operation [7].

4.4. Special Design Optimization Measures

4.4.1. Multi-ship Type Adaptation Optimization

By adjusting the curved rotation angle, optimizing the combined length of the jib and increasing the stroke of the telescopic chute, it fully covers various fly ash ships of 1000~3000 DWT, realizing uniform material distribution in the whole cabin for deck barges, hatch barges and closed fly ash ships without manual adjustment of ship position.

4.4.2. Water Level Adaptation Optimization

Combined with the characteristics of coastal tidal water level changes, the telescopic adjustment range of the chute is expanded. The equipment clear height meets the two-way operation requirements of empty ships at high water level and fully loaded ships at low water level. The maximum falling depth of the chute can reach the bottom of the cabin, adapting to the operation conditions of deep cabin barges.

4.4.3. Safety and Wind Protection Optimization

Aiming at the coastal strong wind and typhoon-prone environment, it is equipped with wind speed monitor, track wheel clamp, mechanical anchoring device, windproof cable and other protective facilities, synchronously set with travel limit,

overload protection, material level interlock and other automatic control protection functions to ensure the safe docking and stable operation of equipment under extreme weather.

5. System Operation Characteristics and Comprehensive Benefits

5.1. Core Operation Characteristics of the System

5.1.1. Strong Stability of Long-distance Conveying

The double-pipe air supplement disturbance structure completely solves the pipeline blockage problem of 2100 m ultra-long-distance conveying, with low equipment failure rate and small daily operation and maintenance workload, suitable for the operation and maintenance conditions of overseas projects.

5.1.2. Efficient and Flexible Ship Loading Operation

The curved rotary structure has a wide material distribution range, flexible start-stop adjustment of equipment, real-time adjustment of blanking volume according to ship loading rhythm, strong continuous operation capacity, and the overall ship loading efficiency is increased by more than 30% compared with traditional equipment.

5.1.3. Outstanding Green Environmental Protection Performance

The whole link of conveying, storage and ship loading adopts closed design with multi-point negative pressure dust removal. The problems of unorganized dust emission and material scattering are fully controlled, effectively protecting the ecological environment of the port area.

5.1.4. Diversified Resource Utilization Mode

Waterway export combined with land emergency transportation double guarantee the fly ash consumption channels, avoiding external risks such as market fluctuation and waterway suspension, realizing stable resource utilization of solid waste [8].

5.2. Economic and Social Benefits

Economically, relying on low-cost waterway transportation mode, the long-distance outward transportation cost of fly ash is greatly reduced; the high automation level of the system reduces the allocation of on-site operators; low equipment wear and long service life lower the whole life cycle operation and maintenance investment, creating additional resource utilization benefits for the power plant.

Environmentally, it avoids land occupation and dust pollution caused by open stacking and open transportation of fly ash, conforming to port environmental protection control

standards; reduces the investment of fuel transportation vehicles, lowering exhaust gas and fuel pollution, and helping enterprises achieve green and low-carbon production.

Socially, it stably supplies high-quality raw materials for downstream building materials enterprises, improves the regional circular economy industrial chain, and provides a mature and replicable technical scheme for the same type of overseas thermal power projects.

6. Conclusion

Combined with the engineering example of overseas coastal thermal power plant, this paper systematically introduces the design idea, equipment selection and practical application effect of the combined system of double-pipe long-distance pneumatic conveying and curved rail environmental-friendly ship loading.

The double-pipe dense-phase pneumatic conveying technology breaks the traditional limitation of powder conveying distance, and can stably realize two-kilometer-level long-distance closed conveying with the advantages of low wear, low energy consumption and high reliability, which is the preferred technology for long-distance ash conveying of coastal power plants. The curved rail ship loading equipment features compact layout, wide ship type adaptability and excellent environmental protection performance, which can perfectly adapt to the narrow operating space of special fly ash berths.

The integrated whole system opens up a complete chain of fly ash collection, long-distance conveying, environmental-friendly ship loading and multi-channel export, with stable operation and convenient management and prominent benefits. It not only meets the requirements of compliant disposal of solid waste in thermal power enterprises, but also improves the economic benefits of resource utilization. The system is not only applicable to the reconstruction and new projects of coal-fired power plants along rivers and coasts, but also can be popularized and applied to the port conveying and ship loading scenarios of various industrial powder materials such as mineral powder and lime powder, with extensive engineering promotion value.

Abbreviations

MW	Mega Watt
DWT	Dead Weight Tonnage
PLC	Programmable Logic Controller

Author Contributions

Huang Shuzhen: Conceptualization, Writing – original draft, Writing – review & editing

Conflicts of Interest

The author declares no conflicts of interest.

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