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Research on Optimization of Construction Management Mode and Multi-Professional Collaborative Operation of Sludge Incineration Project Based on BIM Technology

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SUMMARY: *This paper combines BIM visualization technology with the construction requirements of sludge incineration project design drawings to construct the various components of the sludge incineration treatment system and the BIM model of the sludge incineration system. The collision detection function of BIM technology is used to assist in reviewing construction design drawings, thereby reducing errors and conflict risks during the construction process. Additionally, the BIM model of the sludge incineration system is used to statistically analyze and calculate the data of each component, thereby estimating the engineering volume required for the construction of the sludge treatment system. By integrating the BIM intelligent management platform and referencing established standards, multi-disciplinary collaborative design is conducted for system units such as the sludge reception and storage system and the drying system within the process. Based on the actual expansion requirements of the sludge treatment plant, the construction and operational results of the sludge incineration project supported by BIM technology are calculated. The system trial operation results of the sludge incineration project meet construction requirements, and the continuous operation results of the disposal process also meet standards. No faults occurred during the entire continuous operation period, achieving efficient and stable operation of the project. The daily average processing capacity for sludge with 80% moisture content reaches 873.4 tons, while the daily average production of dried sludge is 186.3 tons, both meeting the design requirements for stable processing capacity and annual cumulative operation time.*

KEYWORDS: *BIM visualization; sludge incineration system; intelligent management platform; collaborative operations*

1 Introduction

As China's urbanization process accelerates, the rate of urban wastewater treatment has been increasing year by year, and the production of sludge from urban wastewater treatment plants has also surged significantly [1, 2]. Untreated sludge entering the environment directly causes secondary pollution to water bodies and the atmosphere, not only reducing the effective treatment capacity of wastewater treatment systems but also posing a serious threat to the ecological environment and human activities [3-6]. Currently, the primary methods for sludge disposal are landfilling, composting for agricultural use, and incineration [7]. Landfilling of sludge results in significant waste of land resources, and leachate generated during transportation and at landfills can easily cause secondary pollution to the environment [8, 9]. When sludge is composted or used to produce composite microbial fertilizers, heavy metals and

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harmful substances in the sludge cannot be effectively removed, leading to the accumulation of heavy metal ions in soil and plants, thereby restricting land use [10-12]. Dried sludge can generate 16.65–20.93 MJ/t of thermal energy, making it a low-calorific fuel, and the ash residue from incineration does not cause secondary pollution [13, 14]. Therefore, sludge incineration is currently the most effective method for the harmless and reduced disposal of sludge [15].

Sludge has fine particles, low density, high moisture content, and is difficult to dewater. It also has a high organic matter content, making it prone to decomposition and odor [16, 17]. Municipal wastewater also contains hospital drainage and industrial wastewater, and sludge often contains harmful substances such as parasite eggs, bacteria, and heavy metals [18, 19]. However, sludge also contains plant nutrients such as nitrogen, phosphorus, and potassium, which can be used as fertilizer. The dried sludge has a calorific value and can burn [20, 21]. It has the potential to be used as a fuel source [22]. The Building Information Modeling (BIM) approach, which can be described as a holistic technology-driven process that covers the entire lifecycle of buildings, from conception to deconstruction, can be instrumental in promoting sludge burning projects, particularly through optimizing the construction management model and fostering cross-disciplinary cooperation [23-25]. Through BIM technology, all parties involved can comprehensively simulate and optimize design schemes and construction processes in a virtual environment, significantly enhancing the control capabilities of all participating units over project layout, improving the efficiency of interdisciplinary construction team collaboration, and thereby enhancing engineering quality and efficiency [26-29]. Additionally, the parametric models encompassing all disciplines that are created also lay the foundation for the subsequent operation and maintenance of wastewater treatment plant equipment and pipelines [30].

This paper analyzes sludge drying and incineration technology based on the principles of sludge incineration and the existing developments in sludge incineration technology. It is primarily divided into four sections: the sludge pretreatment system, the incineration system, the waste heat boiler, and the flue gas purification system. The paper proposes the use of Building Information Modeling (BIM) technology to analyze the project construction management process of the BIM intelligent collaborative management platform. A BIM model of the sludge incineration system is constructed, utilizing the BIM model to assist in reviewing design drawings. BIM visualization technology is employed to simulate the sludge incineration construction process, and plug-in modules for various parameters of sludge incineration are developed to form an actual application scheme for sludge incineration construction quality management based on BIM technology. Combining the example, the actual operational results of the sludge treatment plant under this scheme are analyzed.

2 Key factors in the development of sludge incineration technology

Sludge incineration principle: Sludge incineration technology primarily involves the complete combustion of organic matter in sludge under specific temperature and oxygen conditions, converting volatile substances (such as sugars, fats, and proteins) in the sludge into corresponding gaseous substances, such as carbon, oxygen, hydrogen, and nitrogen, which are further converted into CO_2, H_2O, N_2, etc., along with various physical changes. The chemical reactions involving mass transfer and heat transfer are relatively complex, primarily involving processes such as evaporation, volatilization, decomposition, and redox reactions [31].

Since the mass fraction of oxygen in air is approximately 23%, the theoretical air consumption is 4.35 times the calculated oxygen consumption value. To ensure the completion of the sludge incineration reaction, an excess air ratio of over 50% is required. Sludge incineration technology requires the treatment of furnace slag (ash) and flue gas. The furnace slag primarily consists of inorganic minerals that do not participate in the physical and chemical reactions during sludge incineration, but it also contains a small amount of unburned residual organic matter (combustible material). The furnace slag has advantages such as being non-corrosive, odorless, and free of pathogenic bacteria, and it does not pose a hazard to the natural environment. However, during sludge incineration, some heavy metal ions in the sludge are difficult to participate in chemical reactions and remain in the residue without volatilizing. These heavy metals are an important source of environmental pollution.

Additionally, the flue gas emitted from the furnace contains a widespread solid particle known as fly ash. This not only contains minerals from the sludge but may also contain chemicals used in flue gas treatment processes (such as lime powder and lime slurry used in dry or semi-dry acid gas purification processes). These solid particles can leach out toxic waste with excessive toxicity. The organic substances they contain are mostly heat-resistant, chemically degraded toxic and harmful substances. Furthermore, the dioxins produced by the gas-phase re-synthesis of these organic substances have strong toxicity and are easily adsorbed onto solid particles (fly ash). Therefore, the safe disposal of solid particles (fly ash) must be given high priority. Surveys indicate that the flue gas contains harmless substances such as N_2, O_2, CO_2, H_2O etc., as well as conventional pollutants including suspended particulate matter, NO_X, HCI, SO and CO among others. Additionally, it contains trace amounts of toxic pollutants, including heavy metals (lead, cadmium, chromium, tungsten, mercury, etc.) and organic compounds (polychlorinated dibenzofurans, polychlorinated biphenyls, polychlorinated dibenzodioxins, etc.). Therefore, the flue gas generated by sludge incineration is a pollutant that requires further purification in sludge incineration technology, and flue gas treatment is an essential component of sludge incineration technology.

2.1 Sludge incineration technology

Sludge thermal treatment mainly involves the incineration of sludge alone or in combination with other materials.

2.1.1 Sludge incineration alone

Based on the type of pretreatment process, sludge incineration can be categorized into direct incineration, semi-dry incineration, and fully dry incineration. After conventional mechanical dewatering, the moisture content of sludge is approximately 80%, which remains relatively high. The low calorific value of sludge typically makes it difficult to meet requirements, necessitating the addition of auxiliary fuel during direct incineration. Therefore, reducing the moisture content of sludge to below 50% through drying or advanced dewatering technologies is a prerequisite for implementing subsequent disposal and utilization methods such as standalone incineration or co-incineration.

The commonly used semi-dry incineration process for sludge involves further drying and dewatering of mechanically dewatered sludge with a moisture content of around 80% using an external heat source, reducing the moisture content to 30%–40%, followed by incineration in an incinerator. The process flow is shown in Figure 1. The sludge full-drying incineration process is similar to semi-drying incineration, but the sludge is dried more thoroughly, reducing the moisture content to less than 10%.

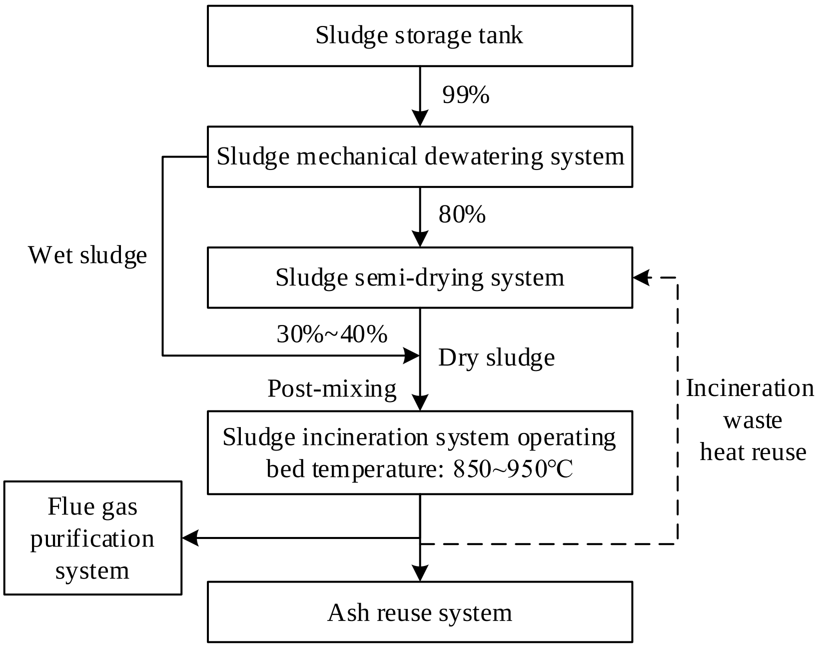

Figure 1: Simple process of sludge semi-dry incineration process

2.1.2 Sludge co-incineration

Some of the typical sludge co-incineration processes are cement kiln co-incineration, coal-fired power plant co-incineration and waste-to-energy plant co-incineration.

The cement kiln co-incineration ash has a direct use as cement clinker and the flue gas waste heat is applied to dry sludge. The given process has a number of technical and economic benefits, and attracted wide attention in the field of environmental protection, as well as in the cement industry.

Co-incineration in coal-fired thermal power plants consists of combining dry sludge with coal and directly conveying the mixture to the boiler to be burned. On top of solving the problem of disposing of sludge, this method will help thermal power plants in saving the boiler fuel and lowering the cost of power generation. But with increasing the level of sludge co-incineration, the melting temperature of ashes of the mixed fuel slowly drops, and compounds are susceptible to sintering. Sludge co-incineration ratio also limits the wear on heat transfer surfaces and flue gas velocity, normally restricted to under 5%.

Co-incineration of waste and sludge at waste-to-energy power plants involves the co-incineration of sludge and waste. It has less effects on boilers and its running cost is lower than when co-incinerated in cement kilns and coal-fired thermal power plants. Nonetheless, there is high variability in waste composition and therefore temperature control in incineration is difficult and incineration ash may be used as hazardous solid waste, preventing the use of sludge incineration ash as a resource.

2.2 Analysis of examples of sludge drying and incineration technology

2.2.1 Sludge pretreatment system

Prior to incineration, mechanical dewatering is applied to minimize the moisture content and the volume of the sludge mixture. The procedure raises the calorific value of the sludge, improving the self-sufficiency and the financial effectiveness of the incineration process.

Usually, sludge that has been mechanically dewatered only cannot be used to achieve selfsustainable combustion. Such equipment may be applied to dry the material more thoroughly prior to incineration in the case. It further decreases the mass of sludge and elevates its calorific power. When the dewatering process in the dryer is completed, the sludge is transported by the screw conveyor to the distributor. The most popular types of drying machines nowadays are disc dryers, thin-layer dryers, paddle dryers and low-temperature air-cooled dryers, each with their own peculiarities. Thin-layer dryers also have the advantages of less time spent in the equipment, simple handling of processes and maintenance as well as having a lesser footprint. Taking into consideration the particularities of the current project, it is proposed to use thin-layer dryer.

2.2.2 Incineration system

Fluidized bed incinerators are commonly applied in treating sewage sludge but may also be applied in treating other types of industrial sludge. They have been extensively implemented in the sludge treatment sector overseas because of their excellent performance. The project has been developed on the basis of real conditions with consideration of the process needs of the drying and incineration system and incorporation of existing sludge incineration equipment arrangements in places like Shanghai, Beijing and Chengdu. Engineering design involved choosing a fluidized bed incinerator.

The fluidized bed incinerators generally work at fairly low fluidization velocities, around 0.6-2 m/s, which causes insignificant wear of the heat transfer surfaces due to flue gas in the combustion chamber. The use of such a low fluidization velocity to burn sludge allows burning it effectively and completely without causing wear.

2.2.3 Waste Heat Boiler

The hot flue gas (about 870ºC) leaving the fluidized bed furnace enters into the waste heat boiler via the flue gas passage in the inner lining wall at its upper end, where it exchanges heat with boiler water at 104ºC. In order to avoid condensation corrosion of the boiler and to preserve the subsequent equipment including the electrostatic precipitator, the outlet temperature of the waste heat boiler is regulated within 180 - 200ºC and the produced saturated steam is used in the system. Waste heat boiler uses a single-drum natural circulation water tube boiler design that has a vertical radiation furnace chamber and a horizontal convection flue layout. The flue gas temperature is lowered to 180-200 o C after heat exchange involving the evaporator and economizer prior to leaving the boiler and entering the next flue gas purification system.

2.2.4 Flue gas purification system

The furnace exhaust of the waste heat boiler has large quantities of fly ash and acidic gases which require the installation of dust removal equipment and acid removal equipment. Flue gas purification plant of this project consists of two stage dust removal system i.e. electrostatic precipitator and baghouse filter and two stage wet scrubber to remove acids.

For dust particles with larger diameters (>0.1 μm), the dust removal efficiency of the electrostatic precipitator can reach over 99%. The dust and boiler ash are collected in ash silos and either treated as general waste or reused as construction materials for road projects.

3 Sludge incineration project engineering operation practices and evaluation

3.1 Building Information Modeling (BIM)

Building Information Modeling (BIM) is an extremely clever three-dimensional design of a building that is commonly utilized by all the stakeholders engaged in construction projects. The essence of its value is the possibility to join the data flows, workflows and the distribution of resources at all the stages of the building lifespan, and provide a complete and precise digital image of the engineering object [32, 33].

The fully developed BIM model acts as a medium of transfer of data, processes and resources at every stage of a building project life-cycle offering an intricate depiction of engineering project in a digital form. The model has broad applications in the day-to-day activities of all project participants to create, manage and share engineering information dynamically and efficiently during the full lifecycle of the project. In particular, BIM has the following remarkable features:

(1) Comprehensive and detailed information
(2) Interconnectivity of information
(3) Consistency and continuity of information

The application of BIM technology in current engineering general contracting management practices is notably reflected in its three core advantages:

(1) Visualization benefit: The use of three-dimensional models is an advantage of BIM technology over conventional two-dimensional drawings as it can visualize the design intent and information about components more efficiently, thus, improving the degree of visualization control at the construction site. In particular, when there are many design modifications, this overcomes the shortcomings of two-dimensional drawings regarding searching, verification, and comprehension. Construction personnel find BIM models straightforward to understand with a simple glance as they simplify the complicated construction information, which minimizes errors that results in the misinterpretation of information.

(2) High Coordination: General contractors need to manage multiple participating parties and facilitate communication and collaboration among them. Project managers use BIM models as a communication platform to quickly convey design intent and change information, reducing the human, material, and time costs associated with traditional communication methods. The model is dynamically updated, enabling real-time alignment between construction and design.

(3) Simulability: The simulability of BIM technology is not only applicable to the demonstration of process details but also to construction management needs. Project managers can pre-simulate the construction process, including site layout, construction environment, and workflow, to identify and resolve potential issues in advance, such as conflicts between mechanical and electrical pipelines or scheduling conflicts. This simulation for construction management can even be extended to the project bidding stage to validate the reasonableness of schedules and costs, providing decision-making basis for general contractors in bidding or tendering.

3.2 Project Construction Management Based on BIM Intelligent Collaborative Management Platform

(1) Application of BIM Technology in Deepening Construction Technology Management

On the one hand, the application of BIM technology makes it possible to visualize the construction process. On the other hand, the application of BIM technology can help managers achieve real-time updates and collaborative management of construction technology. BIM technology supports multiple entities to collaborate on the same platform, updating and sharing information in real time.

(2) Application of BIM Technology in Labor Management

In terms of quality management, the application of BIM technology assists managers in achieving digital approval processes, such as using laser scanners and other on-site data collection devices to measure the height of sludge awaiting incineration, recording the incineration process and quality inspection results using BIM software, and comparing the measured data with BIM model parameters to ensure that the construction quality of the sludge incineration project meets design specifications and energy-saving standards.

3.3 Application of BIM Technology in Quality Management of Sludge Incineration System Construction

3.3.1 Building a BIM model of the sludge incineration system

The construction of a 3D virtual model serves as the foundation and prerequisite for applying BIM technology in the quality management of a sludge treatment system at a water plant, and it is also the key to realizing all the functions of BIM technology.

Compared to traditional two-dimensional design drawings, three-dimensional BIM virtual models can dynamically display the construction process of the wastewater treatment plant's sludge incineration system in real-time throughout its entire lifecycle. When constructing the BIM model for the wastewater treatment plant's sludge incineration system, the starting point coordinates for the group project must first be determined to ensure that each individual structural model is aligned within the same coordinate system during model integration.

Next, the specific scope of creation for the BIM model of the sludge incineration system at the water treatment plant must be defined. Within the BIM software, each component of the sludge incineration system is constructed in accordance with the dimensions and proportions specified in the design drawings. These components include, but are not limited to, water supply and drainage pipelines, sludge concentration tanks, and electrical distribution management rooms. The specific modeling processes for each professional model are illustrated in Figure 2.

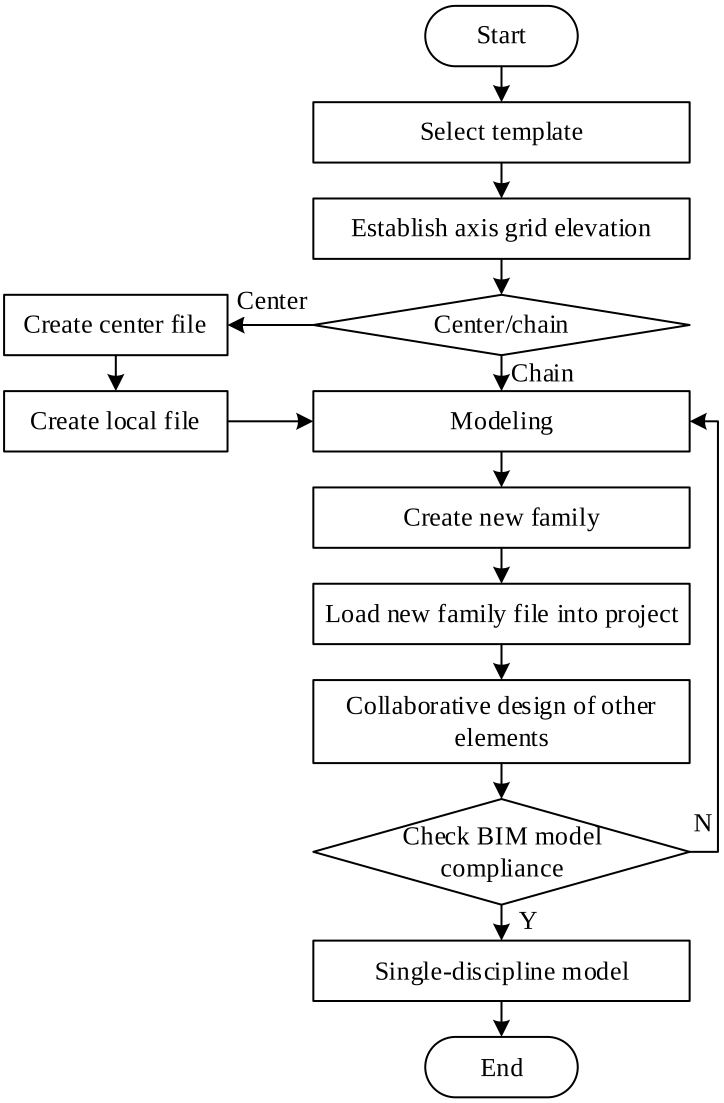

Figure 2: The construction process of the BIM model of sludge processing system

3.3.2 BIM model-assisted design drawing review

The review of construction design drawings is one of the key quality management tasks during the construction preparation phase of the sludge treatment system at this water treatment plant. Utilizing the collision detection functionality of BIM technology to assist in the review of construction design drawings enables more visual and intuitive identification of issues in the design drawings, allowing for resolution prior to construction to ensure the quality of subsequent construction work.

During the collision detection process of various professional models, this paper needs to set some rules to define whether there are collision risks between models. Here, this paper mainly sets the calculation of spatial distance and angle parameters, with the expression shown as follows:

$$D=\sqrt{(x_1-x_2)^2+(y_1-y_2)^2+(z_1-z_2)^2} \tag{1}$$

$$\delta = \arccos\left(\frac{U_1 \cdot U_2}{|U_1| \cdot |U_2|}\right) \tag{2}$$

In the equation, D represents the minimum distance between collision detection points on different components in the BIM model of the sludge treatment system of the water plant. During the collision detection process, the software automatically traverses the detection points on the BIM model across all professional models and calculates D. This value is compared with the collision threshold to determine whether a collision exists. (x_1, y_1, z_1) and (x_2, y_2, z_2) represent the coordinates of collision detection points on two different components in the BIM model. δ represents the angle between different components in the BIM model of the water treatment plant sludge treatment system. In collision detection, angle calculation can help identify components that collide due to angle issues, such as intersecting pipes or beams. U_1 and U_2 represent the vectors at the collision check points on two different components in the BIM model. $|U_1|$ and $|U_2|$ respectively represent the magnitudes of vectors U_1 and U_2.

After setting the relevant parameters according to Equations (1) and (2), click Run Detection, and Navisworks will automatically calculate and detect collision points between individual professional models, thereby completing the collision detection. Based on the collision detection results, identify and locate issues in the construction design drawings of the wastewater treatment plant sludge treatment system.

3.3.3 Construction visualization simulation to assist technical briefing

Generally speaking, in the construction quality management of the sludge treatment system at this water plant, it is essential to strictly control the rationality of the construction processes for each work procedure to avoid adverse effects on the overall construction quality. Therefore, whether the on-site construction technical briefing is adequately conducted is a key aspect of construction quality management.

First, using the BIM model of the wastewater treatment plant's sludge treatment system, statistical analysis and calculations are performed on the data of each component to estimate the engineering volume of the construction project for the sludge treatment system. The specific estimation formula is as follows:

$$Q_0 = Q_1 + Q_2 + Q_3 \tag{3}$$

Among them:

$$Q_1 = \sum_{i=1}^{n} V_i \times G_i \tag{4}$$

$$Q_2 = \sum_{j=1}^{n} L_j \times R_j \times H_j \times g_j \tag{5}$$

In the formula, Q_0 represents the total engineering volume of the construction of the sludge incineration treatment system at the water plant. Q_1 represents the engineering volume of structures such as sludge ponds. Q_2 represents the engineering volume of pipelines such as water supply and drainage. Q_3 represents the engineering volume of equipment installation, which is primarily determined based on the actual number of equipment units during construction. V_i represents the volume of the i th structure, and G_i represents the unit weight of the materials for the i th structure. n represents the number of structures in the wastewater treatment plant sludge incineration system, L_j represents the length of the j th type of pipeline, R_j represents the outer diameter of the j th type of pipeline, and H_j represents the wall thickness of the j th type of pipeline. g_j represents the unit weight of the material for the j th type of pipe. m represents the types of pipes used in the construction of the wastewater treatment plant sludge incineration system. Using the above formula, the engineering volume of the wastewater treatment plant sludge incineration system can be automatically estimated. This method of estimating engineering volume using a BIM model can avoid the risks associated with manual calculation errors.

Then, the construction company develops a feasible construction schedule based on factors such as the construction timeline requirements for the water treatment plant sludge incineration treatment system. This construction schedule is imported into the BIM model, and the construction status of each professional model is color-coded to visually demonstrate the construction schedule, thereby achieving virtual construction of the water treatment plant sludge incineration treatment system construction process.

Finally, resources and construction processes are configured for specific construction phases within the BIM model to simulate various scenarios and conditions during the construction process of the wastewater treatment plant's sludge incineration system. During the simulation, construction process issues are promptly identified, and corrective actions are taken for specific construction phases that may delay the construction schedule. This provides optimized solutions for the actual construction of the wastewater treatment plant's sludge incineration system, ensuring construction quality.

3.3.4 Development of a parametric oxidation ditch plug-in

The plugin interface is designed using a combination of lists and pagination. Each subpage uses form controls such as input fields, selection boxes, text boxes, and buttons.

Each plugin interface has its own corresponding callback function in the background. The callback function continuously monitors the operating system's message queue, retrieves valid operations from the message queue, and stores the parameters entered by the designer through the interface in memory. Simultaneously, it performs data storage, calculation, and extraction in the background, awaiting subsequent calls from the model generation module.

(1) Sludge Calculation Interface

Sludge Return Concentration: The coefficient r for the sludge index SVI (unit: m^3/d) is typically set to 1-2, so:

$$X_r = \frac{10^6 \times r}{SVI} mg/L \tag{6}$$

Sludge return ratio R: Mixed sludge concentration X (unit: $\mathrm{mg/L}$) is taken as 2500~4000, then:

$$R = \frac{X}{X_r - X} \tag{7}$$

(2) Aerobic zone effective volume calculation interface

Design flow rate Q (unit: m^3/d), sludge production rate coefficient Y (unit: $\mathrm{kgMLSS}/\mathrm{kgBOD}_5$) taken as 0.3~0.6, inlet BOD_5 concentration S_0 (unit: $\mathrm{mg/L}$), outlet BOD_5 concentration S_e (unit: $\mathrm{mg/L}$), total coefficient F is set to 1.5–3, and nitrifying bacteria specific growth rate $\mu = d^{-1}$. Then: The design sludge age $\theta_{c0} = F\frac{1}{\mu}d$, and the effective volume of the aerobic zone is:

$$V_1 = \frac{Q\left(S_0 - S_e\right)\theta_{c0}Y}{X}\mathrm{m}^3 \tag{8}$$

(3) Calculation interface for effective volume of anoxic zone

Total incoming Kjeldahl nitrogen concentration N_0 (unit: $\mathrm{mg/L}$), Total nitrogen concentration in effluent N_e (unit: $\mathrm{mg/L}$), denitrification rate K_{dc} (unit: $\mathrm{kg\ NO_3\text{-}N/(kg\ MLSS\cdot d)}$), and the proportion of MLVSS in MLSS y ranging from 0 to 1, then the effective volume of the anoxic zone is:

$$V_2 = \frac{0.001Q\left(N_0 - N_e\right) - 0.12\Delta X_V}{K_{dc}X} \tag{9}$$

Among them:

$$\Delta X_V = yY\frac{Q\left(S_0 - S_e\right)}{1000}\mathrm{kg\ MLVSS/d} \tag{10}$$

(4) Planar dimension calculation interface

A total of groups are set, with each group consisting of cells (4, 6, 8), effective water depth h (unit: m) . Recommended range: 3.5–4.5, excess height h_1 (unit: m), channel width B (unit: m), pool wall thickness A (unit: m), pool centerline length:

$$\begin{aligned} L = {} & \pi\left(\frac{B}{2} + \frac{A}{2}\right) \times (N+1) + \frac{2\pi\left(2B + \frac{3A}{2} - \frac{B}{2}\right)}{4} \times 2 \\ & + L_{\text{Straight section}} \times (N+1) + (2A + 2B) \end{aligned} \tag{11}$$

$$L = \frac{V_1 + V_2}{B \times h} \tag{12}$$

Combining (11) and (12) yields $L_{\text{Straight section}}$, and at this point, all the necessary parameters have been obtained to construct a complete model.

Verification:

Hydraulic retention time:

$$t = \frac{V_1 + V_2}{Q} \times 24 = h \tag{13}$$

BOD_5 sludge load:

$$L_s = \frac{Q\left(S_0 - S_e\right)}{\left(V_1 + V_2\right)X} \times 24\text{kg BOD}_5 / (\text{kg MLSS} \cdot d) \tag{14}$$

3.4 Case Study

3.4.1 Project Overview

The current treatment capacity of a certain wastewater treatment plant is 2.3 × 10^4 m^3/d. The effluent quality complies with the Class B standards of the Pollutant Discharge Standards for Urban Wastewater Treatment Plants. The secondary treatment unit uses a CASS biological reactor, with a designed sludge concentration of 3.5 g/L.

Currently, the plant's treatment capacity is already at full capacity, and the effluent water quality does not meet local environmental protection requirements. Taking into account the above two factors, the plant has implemented an upgrading and expansion project. The near-term treatment capacity of the project is 3.0 × 10^4 m^3/d, and the long-term treatment capacity is 3.6 × 10^4 m^3/d. The primary indicators in the effluent comply with Class IV water standards in the Surface Water Environmental Quality Standards, where $\rho(TN) \le 15mg / L$.

The influent and effluent water quality of the wastewater treatment plant is shown in Table 1.

Table 1: The sewage treatment plant is in and water quality

Water quality index	$\rho(COD)$	$\rho(BOD_5)$	$\rho(SS)$	$\rho(NH_3 - N)$	$\rho(TN)$	$\rho(TP)$
Water inflow	300	200	250	40	60	5
Current discharge	80	30	30	10(20)	30	1.5
Design target	40	8	15	1.4	16	0.2

3.4.2 System Unit Trial Operation Results

(1) Wet Sludge Reception and Transportation System

The wet sludge reception system involves a large number of devices, which poses certain challenges to its smooth operation. However, during the trial operation and commissioning process, the system demonstrated good stability and continuity. The entire process unit can be started or stopped at any time and operated for extended periods. The system's capacity to receive and transport sludge fully meets the original design specifications, providing strong support for the continuous operation of the entire production line.

The equipment involved in the wet sludge receiving system and its specific operational status are shown in Table 2.

The process system flow is smooth, and the receiving-transfer pathways are functioning normally. The process equipment operates stably and can be started/stopped at any time and run for extended periods.

Table 2: Wet sludge receiving system equipment operation

Device name	Specification/model	Device number	Quantity	Running condition
Receiving warehouse slide	PDSL7528	L105A/B	3	(1) The process of the process is smooth, and the receiving and transit path is normal. (2) Process equipment stable operation. (3) The storage warehouse maintains the medium load operation, and the storage material level is 8~10m.
Double screw discharging machine	SHS3015SH	L105A/B/C/D	4	
Wet sludge transfer pump	KOS1587	P105A/B/C/D	5	
Accept warehouse hydraulic station	HA142E-SP	H105A/B	4	
Device name	Specification/model	Device number	Quantity	
Storage rack	PDSF8000	L106A/B	3	
Feed single screw conveyer	SHS5261SE	L108A/B/C/D	6	
Storage hydraulic station 1	HA52CI	H101A	1	
Storage hydraulic station 2	HA26CE	H106A	1	
Feed double screw conveyer	THS336HCB	L105A	1	
Incinerator sludge transfer pump	KOS1250	P107A	1	
Drying machine sludge transfer pump	NM090SF04S21V/Z	P106A/B/C	1	

(2) Sludge drying system

The heat source required for the sludge drying system can be divided into two types. One type is the waste heat generated by the boiler used in the system, which is utilized in the form of steam. The other type is the comprehensive utilization of waste heat steam from the Gaoqiao Power Plant.

The specific operational status of the supply equipment is shown in Table 3. During the trial operation and commissioning process, the steam supply was stable, with pressure maintained between 0.67 and 0.81 MPa. Once the sludge enters the dryer, the water content is continuously evaporated through the combined effects of specially designed paddle stirring and external heating. Meanwhile, to accelerate the evaporation of water vapor, the dryer maintains a low pressure state (-64 to 160 Pa), and the temperature of the carrier gas inside the dryer remains constant, indicating normal system operation. The trial operation results show that the drying system can achieve a stable processing capacity of 2.1 to 3.5 t/h.

Table 3: Drying system equipment operation

Device name	Device number	Quantity	Running condition
Drying machine	C205A/B/C	4	(1) Ensure the negative pressure of the drying machine system.-64~160pa. (2) Safe steam supply. (3) The measured sludge is continuously sent to the dryer. 2.1-3.5t/h. (4) Ensure the temperature of the drying machine.
Gas washing tower	E203A/B/C	4	
Air blower	J202A/B/C	3	
Condensate pump	P205A	3	
Tap water booster pump	P206A	2	
Belt conveyor	P207A	1	

(3) Sludge incineration system

The incineration system equipment and specific operating conditions are shown in Table 4.

The dried sludge is transported vertically by a horizontal belt conveyor and chain bucket elevator to a semi-dry sludge storage silo, then weighed by a metering device with a discharge screw at the bottom of the silo and sent to the incinerator for incineration. The combustion temperature of the incinerator can be stably maintained between 850 and 950°C. Under these conditions, the sludge is burned thoroughly, and the high-temperature flue gas (approximately 830–910°C) produced after complete combustion enters the waste heat recovery equipment. The results of the trial operation and commissioning demonstrate that the entire system can achieve continuous and stable operation, ensuring a processing capacity of 6 t/h, fully meeting the system's design capacity.

Table 4: Incineration system equipment and specific operation

Device name	Device number	Quantity	Running condition
Auxiliary burner	B406A	5	(1) Ensure the stable supply of wet sludge, about 6t/h. (2) Ensure the burning furnace stable combustion and maintenance. (3) Start burner fan: 180 m^3/min. Pressure: 10Kpa, Run normal. (4) fan: 10000~15000 m^3/h, Running normal.
Initiating burner	/	2	
Start burner fan	J401	3	
Fan	J403A	1	
Other auxiliary equipment	/	/	

The temperature curve of incinerator A during the evaluation period is shown in Figure 3. It can be seen that during the evaluation period, the temperature of incinerator A remained mainly around 900°C. The lowest temperature recorded for this incinerator during the evaluation period was 200°C.

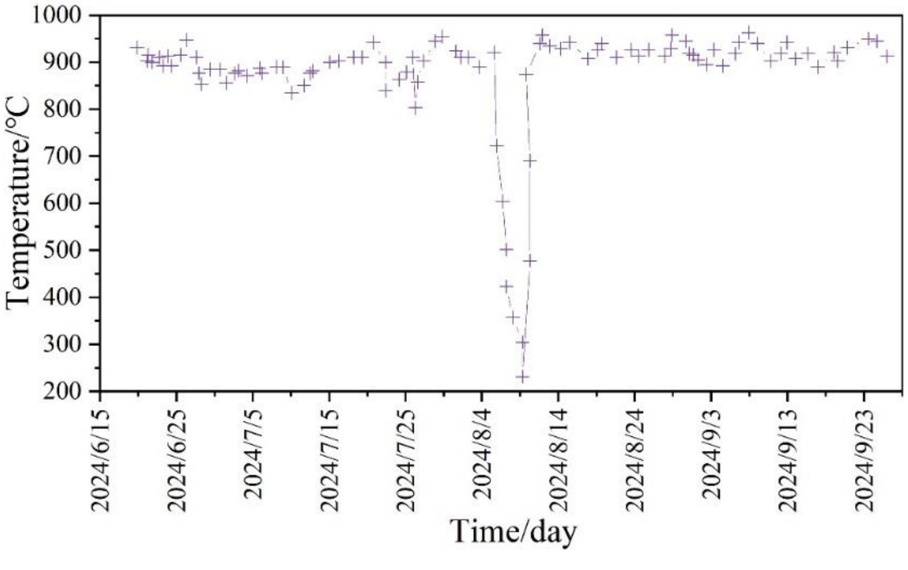

Figure 3: The temperature curve of the incinerator in the assessment period

3.4.3 Handling and disposal of continuous operation results of engineering projects

After completing the commissioning and testing of the process units, the entire treatment and disposal project underwent a 90-day continuous trial operation, with the operational results shown in Figure 4.

No faults occurred during the entire continuous operation period, achieving efficient and stable operation of the project. The daily average processing capacity for sludge with 80% moisture content reached 873.4 tons, while the daily average production of dried sludge was 186.3 tons. Both figures met the design requirements for stable processing capacity, annual cumulative operating time, total planned shutdown time for annual maintenance, maximum single shutdown time for annual maintenance, and total potential shutdown time due to faults. This further confirmed the reliability and stability of the treatment and disposal project in terms of process technology.

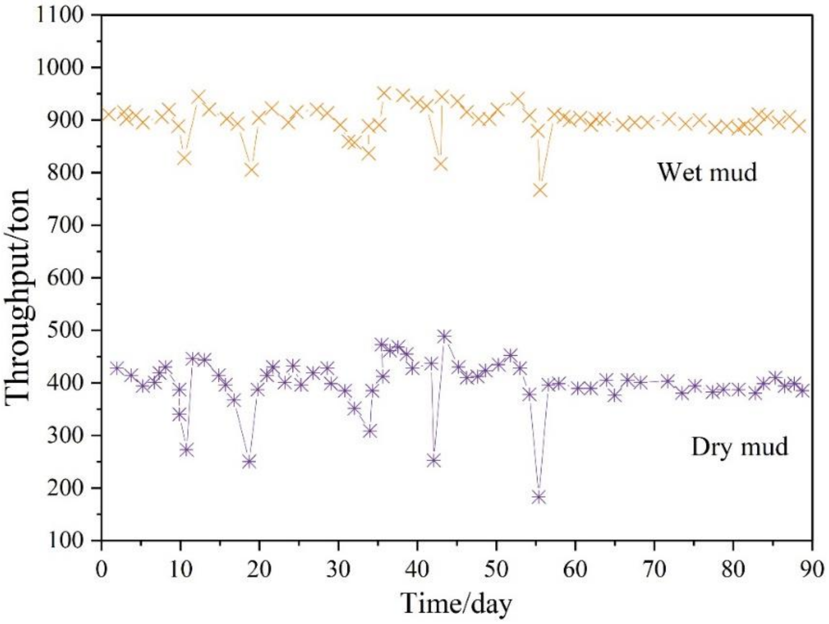

Figure 4: The sludge is dry and the disposal of the disposal project is continuously

The results of construction management and treatment capacity for the sludge incineration project supported by BIM technology are shown in Table 5.

During stable operation: With a guaranteed supply of sludge, the daily treatment capacity was achieved on 80 days within three months. The cumulative operating time during the three-month operation period exceeded 1,890 hours. The cumulative downtime due to malfunctions during the three-month operation period was less than 5 hours.

Table 5: The results of the management of construction management

Parameter	Unit	Demand	Actual value	Results
Stable throughput	Tds/d	≥182	164	Qualify
Each production line annual operation time	h	≥7800	8695	Qualify
Each continuous running time per line	h	≥2200	2240	Qualify
Each production line is planned for the total stop time of the furnace	h	≥800	200	Qualify
Each production line is planned for the longest time of stopping	h	≥500	50	Qualify
Each line of production can be stopped at a time of annual failure	h	≥380	0	Qualify

3.4.4 Water quality after renovation

The actual operational status of the wastewater treatment plant from June 2024 to December 2024 is shown in Table 6.

It can be seen that: the effluent $\rho(COD)$ ranged from 0.98 to 20.13 mg/L, with an average value of 9.35 mg/L. The effluent $\rho(BOD_5)$ ranged from 3.02 to 4.56 mg/L, with an average value of 3.32 mg/L. The effluent $\rho(TN)$ ranged from 0.18 to 14.47 mg/L, with an average value of 7.24 mg/L. The effluent $\rho(NH_3-N)$ ranged from 0.01 to 1.26 mg/L, with an average value of 0.22 mg/L. The effluent $\rho(TP)$ ranged from 0.08 to 0.41 mg/L, with an average value of 0.19 mg/L. The effluent $\rho(SS)$ ranged from 2 to 4 mg/L, with an average value of 2.8 mg/L. It can be seen that after the implementation of the upgrading and expansion project, all effluent testing indicators met the design requirements.

Table 6: The actual operation of the sewage treatment plant in June 2024

Date	Detection index	$\rho(COD)$	$\rho(BOD_5)$	$\rho(TN)$	$\rho(NH_3-N)$	$\rho(TP)$	$\rho(SS)$
202406	Mean	13.42	4.56	8.97	0.08	0.21	3
	Min	6.51	-	3.01	0.04	0.13	-
	Max	20.13	-	14.26	0.12	0.40	-
202407	Mean	10.96	3.51	8.22	0.03	0.26	4
	Min	4.14	-	4.74	0.01	0.12	-
	Max	18.07	-	12.95	0.26	0.36	-
202408	Mean	7.85	3.83	3.12	0.03	0.21	3
	Min	1.63	-	1.45	0.02	0.25	-
	Max	15.69	-	5.69	0.12	0.31	-
202409	Mean	11.04	3.74	7.84	0.08	0.29	3
	Min	6.26	-	2.63	0.02	0.24	-
	Max	16.89	-	5.91	1.26	0.41	-
202410	Mean	8.01	3.10	9.11	0.05	0.23	2
	Min	1.86	-	2.98	0.04	0.14	-
	Max	19.03	-	14.47	0.21	0.31	-
202411	Mean	7.64	3.02	5.26	0.04	0.15	3
	Min	2.78	-	0.18	0.03	0.08	-
	Max	15.01	-	8.14	0.18	0.23	-
202412	Mean	9.33	3.65	3.77	0.06	0.06	3
	Min	0.98	-	0.52	0.03	0.17	-
	Max	18.12	-	8.01	0.50	0.22	-

3.4.5 Evaluation of system operating costs

Based on the actual conditions of the trial operation of the project, this paper also calculated the unit cost of treating sludge using the incineration drying process. The detailed calculation results are shown in Table 7.

The direct costs of sludge treatment during the operation of this project mainly include electricity, steam, tap water, recycled water, sewage discharge, etc., based on their usage during operation and current market prices. The final calculation shows that the cost of treating each ton of dry sludge is 938.7 yuan, and the cost of treating each ton of sludge with an 80% moisture content is approximately 188 yuan. The cost of treating sludge using the incineration drying process has certain cost advantages compared to other treatment and disposal methods, while fully achieving the reduction, harmless disposal, and resource utilization of sludge.

Table 7: Detailed calculation results

Direct running cost		Annual cost/10,000 yuan	Yuan/ton dry sludge	Tonnage sludge consumption	Unit	Cost of consumption t/yuan
1.1	Electric power	912.25	235.26	325.36	kWh/Tds	0.812
1.2	Steam	913.01	246.91	1.21	t/tDS	213
1.3	Running water	25	6.24	1.54	t/tDS	7
1.4	Medium water	263	60.15	113.6	t/tDS	0.6
1.5	Sewage discharge	947.01	235.65	135.96	t/tDS	1.9
1.6	Light diesel	56.32	26.57	4.5	kg/tDS	8000
1.7	Sand	0	0.00	0	t/tDS	600
1.8	Activated carbon	7.09	1.52	0.6	kg/tDS	6000
1.9	NaOH(solid)	300	75.63	21.63	kg/tDS	3600
1.10	Ca(OH)2	101	23.64	0.15	kg/tDS	320
1.11	Other agents	0	0.15	0.03	kg/tDS	7000
1.12	General fly ash disposal	81	20.33	0.55	t/tDS	60
1.13	Hazardous waste treatment	34	6.65	0.012	t/tDS	1890
Total cost			938.7	Yuan/ tDS	/	/
			188	Yuan/ t@80% Moisture content	/	/

4 Conclusion

This paper takes an actual sludge treatment project as an example, integrating the BIM technology management platform with the construction management and operation of a sludge incineration project. It makes the sludge incineration disposal scheme optimal and identifies the treatment process of the sludge incineration project and computes the final economic advantages.

The following conclusions are drawn:

(1) The wet sludge reception system operates smoothly, with stable process equipment, enabling flexible start/stop functionality and prolonged operation. The system implements interlocking control, enhancing automation levels. System operation meets design capacity.

(2) During trial operation, the sludge drying system achieves a stable processing capacity of 2.1-3.5 t/h.

(3) During the trial operation of the incineration system equipment, the combustion temperature of the incinerator is maintained at a stable range of 850–950°C. Under these conditions, sludge combustion is thorough. The entire system can achieve continuous and stable operation, ensuring a processing capacity of 6 t/h, fully meeting the system's design capacity.

(4) During continuous operation of the treatment and disposal project, no faults occurred throughout the entire continuous operation period. The daily average processing of sludge with 80% moisture content reached 873.4 t, while producing an average daily quantity of 186.3 t of dried sludge.

(5) After the expansion of the sludge treatment plant, all discharge water quality parameters meet the design requirements.

(6) After the renovation of the sludge treatment plant, the cost per ton of dry sludge is 938.7 yuan, and the cost per ton of sludge with an 80% moisture content is approximately 188 yuan. This sludge incineration treatment scheme offers certain cost advantages and achieves sludge reduction, harmless disposal, and resource utilization.

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