APPLICATION RESEARCH AND DISCUSSION ON GREEN LOW-CARBON TECHNOLOGY IN FIBER CEMENT BOARD FACTORY

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ABSTRACT

Traditional fiber cement board production enterprises are facing a series of issues related to high material consumption, high energy consumption, and waste emissions, which are crucial for production cost control and sustainable development. Wuhan Building Material Industry Design & Research Institute Co., Ltd.(referred to as: Sinoma-Wuhan) in the in-depth exploration and practice of technical research and development projects, effectively solved the practical pain points and difficulties of fiber cement board production enterprises by adopting technologies such as solid waste recycling, waste steam recovery, and oil-water separation treatment, achieving a successful transformation of production cost reduction, resource and energy savings, and environmentally friendly production methods. This provides more experience and reference for the fiber cement board production industry to adapt to global development trends and pursue green low-carbon production.

KEYWORDS:

Comprehensive solid waste utilization; Waste steam heat recovery; Wastewater treatment and recycling; Intelligent microgrid system

INTRODUCTION

In the third decade of the 21st century, the world is facing unprecedented environmental challenges. Climate change, resource depletion, and environmental pollution have become critical issues affecting sustainable human development. As one of the major sources of global carbon emissions, the construction industry and its related building materials production sector are at a crossroads of transformation. Against this backdrop, fiber cement board, as a new type of green building material, not only demonstrates excellent environmental performance during its use phase but also it focuses on low-carbon and energy-efficient production processes as key directions for industry innovation [1].

The development of fiber cement board production technology can be traced back to the "Hatschek process" at the end of the 19th century [2]. After more than a century of evolution, modern fiber cement board has become a building material that combines multiple advantages such as environmental friendliness, light weight, high strength, and durability. However, traditional fiber cement board production processes still face issues such as high energy consumption, low resource utilization efficiency, and significant environmental impact. With the increasing global emphasis on carbon neutrality goals and the environmental protection requirements for the building materials industry by governments worldwide continually rising, fiber cement board manufacturers urgently need to innovate and upgrade comprehensively in aspects of production processes, energy utilization, and waste management.

This paper will use a modern, low-carbon, energy-efficient fiber cement board factory as an example to comprehensively explore how to achieve low-carbon and high-efficiency fiber cement board production processes through technologies in four aspects: **comprehensive solid waste utilization technology, waste steam heat recovery and cascade utilization technology from autoclaves, production wastewater treatment and recyling technology, and intelligent microgrid system.**

1. BREAKTHROUGHS AND APPLICATIONS IN COMPREHENSIVE SOLID WASTE UTILIZATION TECHNOLOGY

1.1 Utilization of Industrial By-products

Flue gas desulfurization (FGD) gypsum and fly ash, two major industrial by-products are commonly used to replace a portion of cement in the production of fiber cement boards [3].

The $CaSO_4 \cdot 2H_2O$ in FGD gypsum and the SiO_2 and Al_2O_3 in fly ash, driven by the hydration of cement, form C-S-H and C-A-H gels and $Ca(OH)_2$. The reaction process is shown in equations 1~2:

$$2CaO \cdot SiO_2 + nH_2O \rightarrow xCaO \cdot SiO_2 \cdot yH_2O + (2-x)Ca(OH)_2 \quad (1)$$

$$2(3CaO \cdot Al_2O_3) + 27H_2O \rightarrow 4CaO \cdot Al_2O_3 \cdot 19H_2O + 2CaO \cdot Al_2O_3 \cdot 8H_2O \quad (2)$$

During the hydration process, desulfurized gypsum can react with tricalcium aluminate to form ettringite, providing a certain degree of promotion for the early strength of fiber cement boards. The reaction process is shown in equations 3~4:

$$3C_3A + 3(CaSO_4 \cdot 2H_2O) + 26H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O \quad (3)$$

$$C_3A + 3(CaSO_4 \cdot 2H_2O) + 2Ca(OH)_2 + 24H_2O \rightarrow 3CaO \cdot Al_2O_3 \cdot 3CaSO_4 \cdot 32H_2O \quad (4)$$

Therefore, theoretically, by providing appropriate curing conditions that enable the aforementioned reactions of FGD gypsum and fly ash, it is possible to produce new carbon-reducing fiber cement boards with excellent performance. To explore suitable curing conditions, the Sinoma-Wuhan Technology Center conducted experimental research and pilot-scale verification. In this study, the cement used is Huaxin P.O 42.5 cement. The pulp utilized is Jinxing pulp with a freeness of 29±1 ^{0}SR and a wet weight of 14g. The quartz sand has a SiO_2 content of ≥95%, with less than 5% retained on a 200-mesh sieve. The board formation method employs vacuum filtration.

Table 1 shows the preparation formulas and product performance results of fiber cement boards under the same curing condition. When the FGD gypsum content increased to 45% and the fly ash content increased to 25%, there was a significant improvement in the dry flexural strength of the fiber cement board. Therefore, the 9th group formulation was selected as the optimal alternative formulation for industrial curing and molding condition studies (see Figure 1). This phenomenon can be attributed to the ternary cementitious system involving cement, flue gas desulfurization (FGD) gypsum, and fly ash. In this system, the C-S-H gel and ettringite crystals, formed during the early and later stages of hydration respectively, fill the skeletal structure created by dihydrate gypsum. This process optimizes the pore structure, thereby enhancing the strength of the material.

Table 1 – Preparation formula and product properties of fiber cement board (180℃, 8h)

Series	Preparation formula						Product properties	
	Cement	Quartz sand	FGD gypsum	Fly ash	Booster	Paper pulp	Density (g/cm³)	Dry flexural strength(MPa)
1	20	23	30	20	2	7	1.37	10.2
2	20	23	30	20	3	7	1.32	9.8
3	20	23	30	20	4	7	1.31	10.5
4	15	23	40	10	2	7	1.24	9.5
5	15	23	40	10	3	7	1.24	9.8
6	15	23	40	10	4	7	1.34	12.5
7	12	23	45	25	2	7	1.32	10.5
8	12	23	45	25	3	7	1.31	11.3
9	12	23	45	25	4	7	1.33	12.8

Fiber cement boards were prepared using the 9th group formulation from Table 1 under both autoclave and atmospheric pressure curing conditions. The autoclaved curing environment is provided by a laboratory-scale autoclave, while the atmospheric pressure curing environment is maintained using a cement curing cabinet.

The results in Figure 1 show that under the autoclave curing condition, the highest flexural strength of the board was achieved at 180°C for 6 hours. Interestingly, the flexural strength of the fiber cement board cured under atmospheric pressure at 80°C for 24 hours was even higher than that under the autoclave curing condition. This is due to the formation of more ettringite under atmospheric pressure curing at 80°C, providing higher early strength.

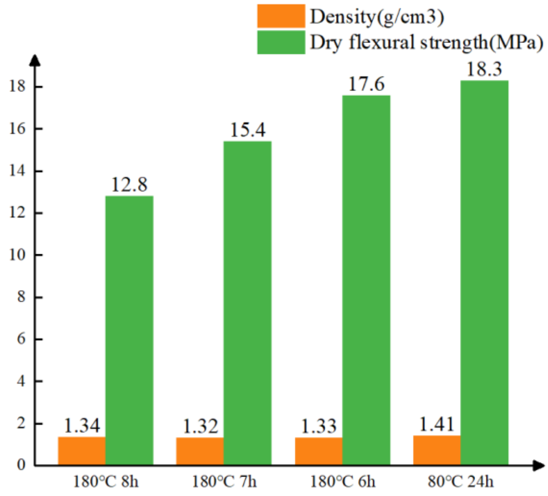

Figure 1 – Comparison of curing condition of fiber cement board

Other performance tests were also conducted. All performance tests are conducted in accordance with the Chinese standard *GB/T7019-2014*. The results indicate that the curing condition of 80°C for 24 hours under atmospheric pressure yielded superior dry flexural strength, impact resistance, and freeze-thaw cycle resistance for the board blanks (see Table 2).

Table 2 – Comparison of curing condition of fiber cement board

<table>
<tr><th colspan="2">Properties</th><th>Standard requirements</th><th>180°C、6h</th><th>80°C24h</th></tr>
<tr><td colspan="2">Apparent density (g/cm³)</td><td>Not less than the value specified in the manufacturer's documentation</td><td>1.5</td><td>1.5</td></tr>
<tr><td colspan="2">Saturated flexural strength (MPa)</td><td>R3≥12
R4≥16</td><td>16.0</td><td>17.6</td></tr>
<tr><td colspan="2">Impact-resistance strength (kJ/m²)</td><td>C3≥1.8</td><td>2.3</td><td>2.9</td></tr>
<tr><td colspan="2">Water absorption rate(%)</td><td>Class A≤30
Class B≤45</td><td>26</td><td>25</td></tr>
<tr><td colspan="2">Wet expansion rate(%)</td><td>0.25</td><td>0.1</td><td>0.1</td></tr>
<tr><td rowspan="2">Frost-resistance test</td><td>Frost-resistance</td><td>Class A 100 times Class B 25 times freeze-thaw cycle without rupture and stratification</td><td>100 freeze-thaw cycles without rupture and stratification</td><td>100 freeze-thaw cycles without rupture and stratification</td></tr>
<tr><td>Flexural strength ratio</td><td>≥70%</td><td>78%</td><td>90%</td></tr>
</table>

1.2 Recycling of Production Waste

The main waste from fiber cement board factories consists of crushed waste boards and sanding powder from the sanding process. These materials have the same main components as fiber cement boards and can theoretically be fully recycled as raw materials for fiber cement board production. This method helps reduce the consumption of all primary production materials on the factory production line, lower the product cost, and enhance the process carbon reduction capability of fiber cement board factories [4].

Table 3 – Preparation formula of fiber cement board

Series	Quartz sand	Cement	Waste boards	Paper pulp	Wollastonite	Total
1	54	38	0	7	1	100
2	36	36	20	7	1	100
3	18	30	40	7	1	100
4	0	32	60	7	1	100

To explore the rational utilization rate of waste boards, the laboratory used waste boards to replace part of the cement and quartz sand in preparing low-carbon fiber cement boards. The experimental formulations are shown in Table 3, with waste board content ranging from 0 to 60%.

Table 4 presents the performance test results of boards prepared using the experimental formulations from Table 3. As can be seen, when the waste board content was 20%, the board performance did not decrease, and the flexural strength even improved. Subsequently, as the waste board content increased, although the wet expansion rate and water absorption rate of the boards increased to varying degrees, and the dry and saturated flexural strengths continued to decrease, the various performance indicators of each group of fiber cement boards still met the requirements for Class A boards with strength grade R2. This indicates that by adjusting the replacement rate of cement and quartz sand with waste boards during production, fiber cement boards with qualified performance can be prepared.

Table 4 – Influence of different content of sanding powder on physical properties of fiber cement board

Series	Apparent density (g/cm^3)	Porosity(%)	Water absorption rate(%)	Wet expansion rate(%)	Dry flexural strength(MPa)	Saturated flexural strength (MPa)
1	1.39	37	27	0.09	13.4	10.1
2	1.39	37	27	0.09	13.9	11.1
3	1.37	37	27	0.12	12.8	9.9
4	1.20	50	42	0.10	11.6	9.1

1.3 New Material Carbon Fixation Technology

The preparation of novel carbon sequestration materials utilizes waste residues emitted by high carbon-emitting enterprises themselves. These materials can also consume flue gas (rich in CO_2) from high carbon-emitting enterprises, thereby reducing the carbon emissions from factory production and decreasing the consumption of high-carbon energy sources[5].

The application principle of new carbon-fixing materials is that carbon dioxide dissolves in water to form carbonic acid, which then reacts with partially hydrated calcium hydroxide to form calcium carbonate, The reaction process is shown in equations 5~7:

$$CO_2 + H_2O \rightarrow H_2CO_3 \quad (5)$$

$$H_2CO_3 \rightarrow HCO_3^- + H^+ \quad (6)$$

$$H_2CO_3 + Ca(OH)_2 \rightarrow CaCO_3 + 2H_2O \quad (7)$$

When calcium silicate minerals are present in the raw materials, calcium silicate reacts with carbon dioxide in the presence of water, ultimately producing calcium carbonate. The main product of the mineralization reaction, calcium carbonate, has good stability. The internal product layer of the material is dense, forming a certain strength and improving the dimensional stability of the material. The reaction process is shown in equations 8~9:

$$3CaO\cdot SiO_2 + (3-x)CO_2 + yH_2O \rightarrow xCaO\cdot SiO_2\cdot yH_2O + (3-x)CaCO_3 \quad (8)$$

$$2CaO\cdot SiO_2 + (2-x)\,CO_2 + yH_2O \rightarrow xCaO\cdot SiO_2\cdot yH_2O + (2-x)CaCO_3 \quad (9)$$

Based on the above theoretical foundation, the laboratory used the prepared new carbon-fixing material (CSM) to design production formulations for trial production and industrial production verification of fiber cement boards, as exemplified in Table 5.

Table 5 – Carbon sequestration fiber cement board formula

Series	WISCO steel slag	Flyash	FGD gypsum	Cement	Carbide slag	CSM	Paper pulp	Total
1	66	23	4	/	/	/	7	100
2	65	8	4	16	/	/	7	100
3	65	8	4	8	8	/	7	100
4	65	8	4	4	12	/	7	100
5	93	/	/	/	/	/	7	100
6	47	/	/	/	/	46	7	100
7	65	/	/	/	/	28	7	100
8	84	/	/	/	/	9	7	100

The basic properties of the resulting carbon-fixed fiber cement boards were all qualified, with the saturated flexural strength of the boards reaching R2 grade and the impact resistance reaching C4 grade.

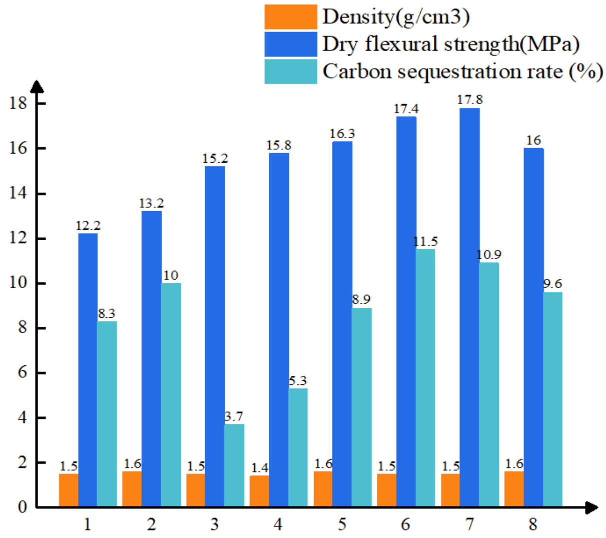

Figure 2 – Comparison of carbon sequestration rate of fiber cement board

As shown in Figure 2, under room temperature conditions, a carbon fixation rate of 12% can be achieved when the CO_2 concentration in the reaction environment is ≥65%. Calculating based on the production of 6mm standard boards, each square meter of carbon-fixed fiber cement board is estimated to reduce CO_2 emissions by 0.624kg.

2. WASTE STEAM HEAT RECOVERY AND CASCADE UTILIZATION TECHNOLOGY FROM AUTOCLAVES

The autoclave waste heat recovery technology can be effectively applied to multiple heat demand processes in fiber cement board production lines, such as pre-curing chamber, post-autoclave insulation chamber, and preheating of boiler feed water. The implementation of this technology not only significantly reduces the natural gas consumption in the factory's heating process but also effectively mitigates the white smoke and odor problems caused by direct discharge of exhaust steam from autoclaves. This method has multiple advantages, mainly reflected in achieving cascade utilization of waste heat, promoting energy conservation and carbon reduction, improving the factory environment, while also bringing considerable economic and environmental benefits [6].

The waste steam heat recovery and utilization system from autoclaves is shown in Figure 3.Combined with actual projects, this technology is applied to waste heat recovery from 6 Ø2m×32m autoclaves. The exhaust steam with a pressure of 0.5MPa after the first steam release from the autoclave enters the waste steam heat recovery condensing device through the exhaust steam distributor and exhaust pipe. It exchanges heat with the circulating cooling water at about 70°C from the cold water tank. The waste steam enters the shell side of the heat exchanger, while the circulating cooling water flows through the tube side. After heat exchange, the shell-side waste steam is condensed into condensate water with an outlet temperature of about 90°C and atmospheric pressure, which enters the condensate discharge pipe network and is reused as process water in the factory area. The tube-side circulating hot water temperature is heated from 70°C to about 90°C and enters the heat storage tank for temporary storage. According to the production line process requirements, the boiler feed water is first heated from ambient temperature to about 65°C through the supply and return water heating network, which can effectively reduce the natural gas consumption of the gas boiler. The remaining unconsumed heat continuously and stably provides heat for the pre-curing chamber, maintaining a constant temperature of about 60°C in the chamber throughout the day. The hot water at about 70°C after heat exchange enters the cold (make-up) water tank through the return water network for system circulation and reuse.The waste steam heat recovery and utilization system from autoclaves is shown in Figure 3.

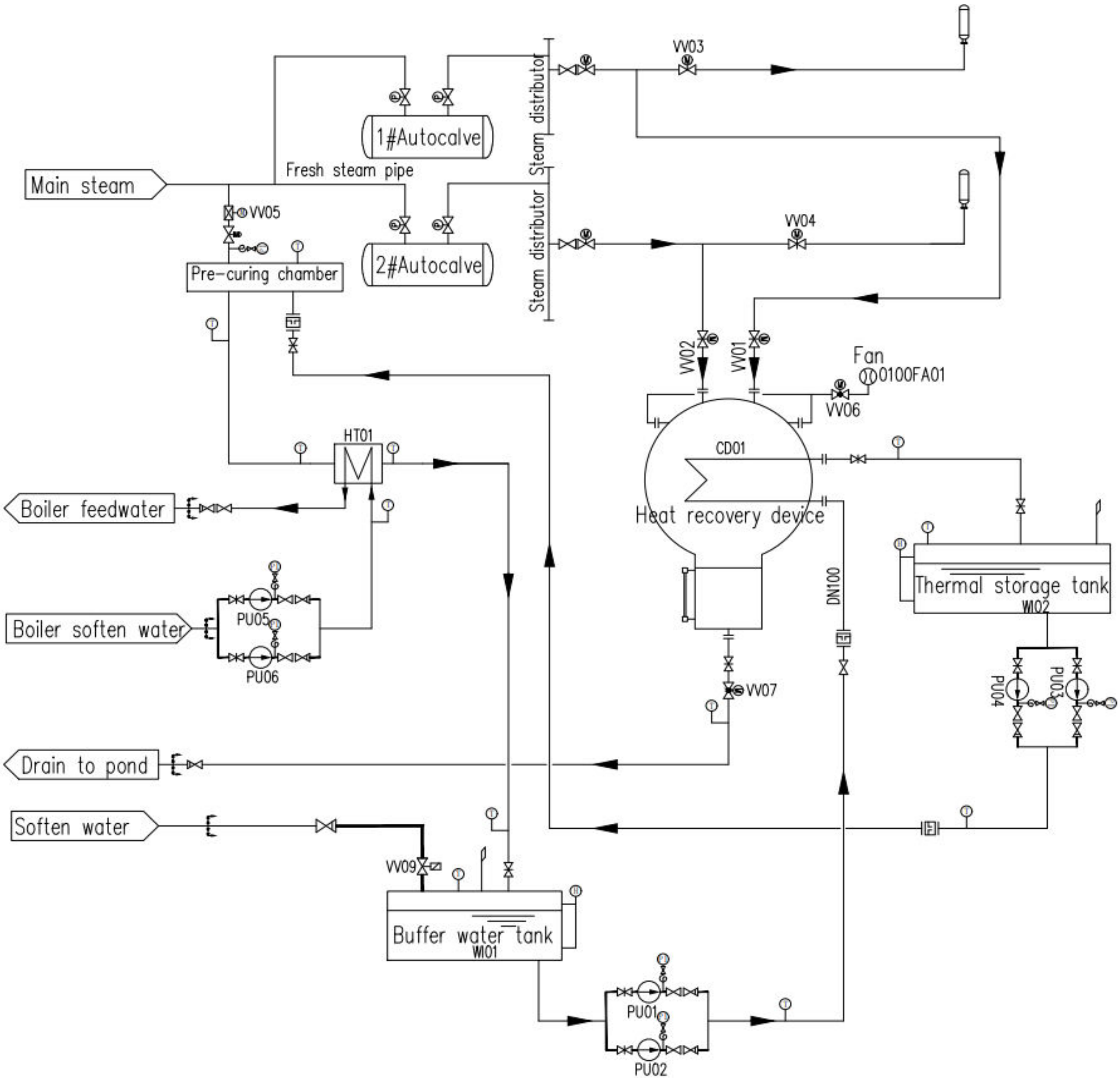

Figure 3 – PLC Control System for Waste Heat Utilization of Autoclave Exhaust Steam

As shown in Table 6, after the exhaust steam from 6 autoclaves is recovered and utilized through the waste heat recovery system, the annual natural gas savings can reach 163,800 Nm^3, reducing carbon dioxide emissions by 309.5 tons per year.

Table 6 – Cascaded Utilization of Waste Heat Recovery from Autoclave Exhaust Steam

Item	Unit	After 6 autoclaves and steam distribution	Remark
		0.5MPa	Exhaust steam pressure of autoclaves
Daily heat recovery from steam distribution of autoclaves	kWh	4200	Daily exhaust from 6 autoclaves; Steam distribution to ~0.5MPa
Daily waste heat recovery from autoclave exhaust steam	kWh	5460	Daily exhaust from 6 autoclaves; Steam distribution to ~0.5MPa
Daily water consumption of boiler	t	45	
Temperature of softened water	℃	20	
Heating temperature of boiler feed water	℃	65	
Daily heat absorption for heating boiler feed water	kWh	2362	
Daily natural gas savings for boiler	m^3	236.2	1Nm^3 natural gas equivalent to 10kWh heat
Heat load absorption of pre-curing chamber	kW	150	200kW in winter, 100kW in summer
Daily heat absorption of pre-curing chamber	kWh	3098	24h
Daily natural gas savings for pre-curing chamber	m^3	309.8	1Nm^3 natural gas equivalent to 10kWh heat
Daily natural gas savings	Nm^3	546	24h
Annual natural gas savings	Nm^3	163800	300 days of operation
Annual reduction in carbon dioxide emissions	Tons/ year	309.5	1Nm^3 reduces 1.89kg CO_2 emissions

By adopting this refined waste heat utilization scheme, the factory can significantly improve energy utilization efficiency, achieving synergistic optimization of economic and environmental benefits. This technological innovation not only complies with the energy-saving and emission-reduction requirements of modern industrial production but also provides a valuable reference example for energy optimization in similar processes.

3. PRODUCTION WASTEWATER TREATMENT AND RECYCLING TECHNOLOGY

3.1 Characteristics of Production Wastewater in the Fiber Cement Board Industry

The main production wastewater from fiber cement board production lines includes oil-containing wastewater from presses and condensate from autoclaves. This production wastewater has complex components, containing large amounts of petroleum, wood fibers, inorganic salt particles, suspended solids, etc. It has high pollutant concentrations and poor sensory properties, with the main pollution indicators being petroleum, total hardness, and suspended solids.

The wastewater test indicators from fiber cement board production exceed national discharge standards by several times or even dozens of times [7]. Such wastewater, if discharged directly without treatment, will impact the ecological environment. If directly reused, due to the large amount of emulsified oil in the recycled water, the long-term cumulative effect will cause the concentration of emulsified oil and other suspended solids (SS) in the recycled water to become increasingly higher, affecting the lifespan of felts and product quality.

3.2 Oil-containing Wastewater Treatment Technical Solution

Based on the water quality characteristics of oil-containing water from presses and autoclave cooling water in fiber cement board production, and the requirements for water reuse, it is considered to mix and treat the press water and autoclave cooling water together [8]. The advantage of mixed treatment is that the relatively better quality autoclave cooling water can be used to dilute the oil-containing wastewater from presses, effectively improving the operating conditions of the treatment process equipment. This method effectively enhances the operational stability of the equipment while simplifying the treatment process.

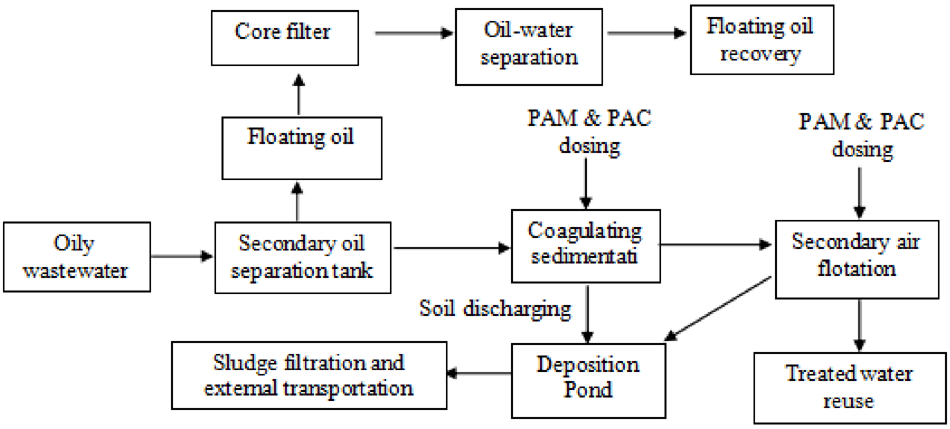

Figure 4 - wastewater treatment process flow diagram

As shown in Figure 4, This process first removes surface oil from the wastewater through a two-stage oil separation tank. The effluent enters a coagulation sedimentation tank, where PAC and PAM are added for coagulation and sedimentation to remove petroleum, suspended solids, and part of the COD from the water. It then undergoes secondary air flotation to further remove petroleum, suspended solids, and COD. The effluent water quality has a petroleum content of less than 10 mg/L, thoroughly resolving the impact of recycled water on product quality, achieving complete closed-loop treatment and recycling of oil-containing wastewater from presses and autoclave condensate. The comparison of treatment effects is shown in Figure 5.

Figure 5 – Comparison before and after production wastewater treatment

The above wastewater samples were sent to a laboratory for testing of petroleum and suspended solids content. The test results are shown in Table 7. From the table, it can be seen that the content of petroleum and suspended solids in the treated wastewater has significantly decreased, indicating that this wastewater treatment process can effectively remove petroleum and suspended solids from the wastewater. The treated production wastewater can be reused for production water. Calculations estimate that 57,600 tons of water resources can be saved annually, reducing wastewater discharge by 72,000 tons.

Table 7 – Test Results of Wastewater Samples Before and After Treatment

Sample No.	Sample source	Sample status Of floating oil	Test Items	Test result mg/L
1	Inlet water (sewage raw water)	amounts	petroleum	20.6
	Inlet water (sewage raw water)	amounts	Suspension	34
2	Outlet water（After treatment）	trace amounts	petroleum	3.21
	Outlet water（After treatment）	trace amounts	Suspension	22

4. INTELLIGENT MICROGRID SYSTEM

An intelligent microgrid system is a small, controllable power system that can autonomously manage power supply and demand, typically including generation, storage, and load equipment. It can not only operate independently of traditional large-scale power grids but also connect with them when needed, offering high flexibility. Applying intelligent microgrid systems in fiber cement board production lines can significantly improve energy utilization efficiency, reduce production costs, and decrease carbon emissions, helping enterprises achieve green transformation. The following are specific practical applications of intelligent microgrid systems in fiber cement board production lines and their energy-saving effects.

4.1 Distributed Photovoltaic Power Generation System

Installing large-scale photovoltaic power generation systems on the roofs of fiber cement board production plants can fully utilize idle space, achieving on-site production and consumption of clean energy.

Figure 6 – Distributed Photovoltaic Power Generation System Installed on Plant Roof

Research data shows [9] that a fiber cement board production line plant is about 10,000 m^2, and installing a 1mW photovoltaic power generation system on its roof can generate about 1 million kWh of electricity annually, meeting at least 15% of the production line's electricity demand.

4.2 Energy Storage System

Large-capacity lithium battery energy storage systems can effectively solve the intermittency problem of photovoltaic power generation, achieve peak shaving and valley filling, and optimize the electricity consumption structure. Based on production line design experience calculations, configuring a 0.5mW/2mWh energy storage system in a fiber cement board production line can convert peak-valley electricity price differences into economic benefits, saving substantial electricity cost annually. Additionally, the energy storage system can provide emergency backup power, improving the power supply reliability of the production line.

4.3 Intelligent Load Management

The load management function of the intelligent microgrid system can achieve intelligent scheduling and optimized operation of electrical equipment at various stages of the production line. During periods of high electricity prices, the intelligent load management system can appropriately reduce the operating power of energy-intensive equipment (such as ball mills, mixers, etc.) and shift some production tasks to off-peak price periods. Practice has shown that this intelligent load management can help fiber cement board production lines save 1-3% in electricity costs.

4.4 Electric Forklift Charging Pile System

Electric forklifts have advantages over traditional internal combustion forklifts, such as no exhaust emissions, higher energy utilization efficiency, convenient and quick charging, and energy cost savings. Replacing internal combustion forklifts with electric forklifts in fiber cement board production lines and integrating charging pile systems into the intelligent microgrid system can not only reduce pollution emissions in the plant area but also achieve flexible adjustment of electricity load. Data shows [10] that replacing two traditional internal combustion forklifts with electric forklifts can reduce fuel consumption by about 35 tons annually, equivalent to reducing CO_2 emissions by about 92 tons (1L diesel emits 2.3kg CO_2).

Figure 7 – Charging Station System (Electric Forklifts and Employee Electric Vehicles)

In summary, Table 8 shows the estimated annual electricity savings for a single fiber cement board production line. From the table, it can be seen that after applying the intelligent microgrid system to a single fiber cement board production line, it is estimated that about 1.06-1.2 million kWh of comprehensive energy can be saved annually, reducing CO_2 emissions by about 1,100 tons (consuming 1 kWh emits 0.997kg CO_2).

Table 8 – Estimated Annual Electricity Savings for a Single Fiber Cement Board Production Line

No.	Item	Approximate Electricity Savings (mWh)
1	Photovoltaic Power Generation	1
2	Intelligent Load Management	0.06~0.2
Total		1.06-1.2

CONCLUSION

The implementation of **comprehensive solid waste utilization technology, waste steam heat recovery and cascade utilization technology from autoclaves, production wastewater treatment and recyling technology, and intelligent microgrid system** can create a low-energy, environmentally friendly green and low-carbon fiber cement board production line factory. This not only significantly reduces energy consumption and carbon emissions but also achieves efficient resource recycling, demonstrating the building materials industry's determination to pursue sustainable development.

(1) In terms of solid waste utilization technology, desulfurization gypsum and fly ash can be used as raw materials to replace quartz sand, with addition rates reaching 45% and 25% respectively. Moreover, during production, adjusting the replacement rate of waste boards for cement and quartz sand can produce fiber cement boards that meet performance standards. Additionally, using new carbon fixation materials (CSM) to produce 6mm standard boards, it is estimated that each square meter of carbon-fixing fiber cement board can reduce CO_2 emissions by 0.624kg.

(2) Regarding steam autoclave exhaust heat recovery and cascade utilization technology, through the adoption of refined waste heat utilization schemes, factories can significantly improve energy utilization efficiency. After the exhaust steam from six autoclaves passes through the waste heat recovery and utilization system, the annual natural gas savings can reach 163,800 Nm^3, reducing annual carbon dioxide emissions by 309.5 tons.

(3) In terms of production wastewater treatment and recycling technology, by combining and treating press water and autoclave cooling water, it is estimated that 57,600 tons of water resources can be saved annually, reducing wastewater discharge by 72,000 tons.

(4) Regarding intelligent microgrid system technology, after applying the intelligent microgrid system to a single fiber cement board production line, it is estimated that comprehensive energy savings of about 1.06-1.20 million kWh can be achieved annually, reducing CO2 emissions by approximately 1,100 tons.

Through systematic integration and optimization, the factory significantly enhances its environmental performance while ensuring product quality, setting a new benchmark for the industry. This green and low-carbon practice not only brings economic benefits to enterprises but also provides a replicable example for the ecological transformation of the building materials industry.

REFERENCES

1. Cheng Qian. 2020. “Discussion on the development of fiber cement board/calcium silicate board products”. Concrete World (08) 48-54.

2. Shen Rongxi. 1997. “The development trend of non-asbestos fiber cement board”. New Building Materials 24(7):23-25.

3. Gu Xiaowei, Zhang Yannian, Zhang Weifeng, et al. 2022. “Research status and prospect of high-value building materials utilization of bulk industrial solid waste”. Metal Mine 51(1):12.

4. Zheng Xincong. 1997. “On the use of industrial waste residue - calcium carbide mud and self-discharge sanding powder waste in the plant to produce calcium silica board”. Fujian Building Materials (002):000

5. Liu Zhichao, Wang Fazhou, Hu Shuguang. 2023. “Research progress on carbon-fixing cementitious materials”. Journal of the Chinese Ceramic Society 51(5):1234-1245.

6. Wang Fuping, Wu Qingjie, Wang Jianqiang. 2011. “Application of autoclave waste heat recovery technology”. China Special Equipment Safety 27(7):3.

7. Wang Ping, Feng Ming. 2012. “Discussion on environmental protection emission of production line of fiber cement board and calcium silicate board”. Concrete and Cement Products (9):3.

8. Zeng Xianwen. 2003. “Governance of the "three wastes" of hardboard production”. Building Materials Industry Information 000(003):39-39.

9. Zhang Yi. 2016. “Application of smart microgrid in building electrical system”. Engineering Technology (Abstract Edition) 000(006):00078-00078.

10. Yan Qin, Yu Guoxiang. 2024. “A review of microgrids for integrated photovoltaic storage, charging and construction stations”. Journal of Electric Power Science and Technology (1).