Technical Analysis of Producing Refractory Materials by Calcining Magnesite and Coal Gangue in an Intelligent Three-Ring Kiln

The intelligent three-ring kiln, developed by Shandong Hening Shun Kiln Industry Co., Ltd., demonstrates industry-leading technical advantages in the innovative application of calcining key refractory raw materials—magnesite and coal gangue. Facing the industry's predicament of traditional kilns with low capacity, high energy consumption, severe pollution, and low automation, the intelligent three-ring kiln, as a new type of digital kiln integrating high efficiency, energy conservation, intelligent control, and environmental protection, provides a revolutionary solution for the technological upgrading of the refractory materials industry.

In the production of light-burned magnesia, the kiln achieves the goal of large-scale production through its unique structural design, waste heat recovery system, and innovative measures such as the intelligent application of robots. The product's loss on ignition is below 1%, significantly reducing energy consumption and labor costs. In the high-value utilization of coal gangue, the core technology of the intelligent three-ring kiln is "activation roasting." Through precise temperature control and calcination processes, the activity of the silicon-aluminum components in the coal gangue is efficiently stimulated, achieving a utilization rate of over 95%. This lays the foundation for the subsequent extraction of high-purity alumina, nano-silica sol, and other high-end refractory raw materials, realizing the "eat-clean" style of high-value utilization of industrial solid waste.

The core technical principles, process flow, specific practices in the application of calcining two different materials, and the economic and social benefits of the intelligent three-ring kiln fully demonstrate its technological advancement. Facts show that the intelligent three-ring kiln is not only a simple replacement for traditional kilns but also a key piece of equipment for promoting the transformation of the refractory materials industry towards "new quality productive forces" and achieving green, low-carbon, and

intelligent development. It has broad market promotion prospects and significant industrial demonstration significance.

1. Introduction

1.1. Industry Background and Challenges

Refractory materials are indispensable basic materials for high-temperature industries, and their performance directly affects the development of downstream industries such as steel, non-ferrous metals, building materials, and chemicals. Magnesite and coal gangue are important raw materials for producing magnesia-based and alumino-silicate refractory materials. However, for a long time, the calcination and processing of these raw materials have faced severe challenges.

Currently, in the concentrated industrial cluster of magnesia-based refractory materials in Liaoning, the thousands of vertical kilns for light-burned magnesia powder are all traditional, old-style earthen kilns. They suffer from numerous drawbacks such as simple production processes, low output, high energy consumption, poor working environments, high labor intensity, and very low levels of mechanization and automation. They are completely unsuited to the current strict national requirements for energy conservation and environmental protection. This extensive production method not only leads to the waste of valuable mineral resources but also puts enormous pressure on the ecological environment.

Similarly, coal gangue, as the main solid waste from the coal mining process, not only occupies land but can also cause spontaneous combustion, polluting water sources and the atmosphere. How to transform coal gangue from an "industrial burden" into a high-value resource is an important issue in the field of comprehensive solid waste utilization.

1.2. Technical Breakthrough of the Intelligent Three-Ring Kiln

Technology companies, represented by Shandong Hening Shun Kiln Industry Co., Ltd., are committed to developing new and efficient kiln technologies. Their HNS series intelligent three-ring kiln is a new type of digital intelligent kiln with a novel structure, low energy consumption, large output, intelligent digital control, simple operation, and is energy-saving and environmentally friendly. It represents the advanced technology in the domestic calcination industry today.

The emergence of this kiln has completely changed the backward equipment situation of traditional earthen kilns for magnesia-based refractory materials. Through technological innovation, it achieves the goal of "'eating up' the raw materials completely, increasing profit margins, and increasing corporate income." The intelligent three-ring kiln technical solution provided by Shandong Hening Shun Kiln Industry Co., Ltd. is comprehensively and detailedly elaborated from two core application scenarios: **light-burned magnesia powder production** and **high-value utilization of coal gangue**, covering its technical principles, process characteristics, application effectiveness, and its profound impact on the refractory materials industry.

2. Core Technology Analysis of the Intelligent Three-Ring Kiln

The superior performance of the intelligent three-ring kiln stems from its systematic innovations in structure, thermal engineering, and control. It abandons the crude design of traditional kilns and incorporates refined heat management and a highly intelligent operational philosophy.

2.1. Overall Design and Process Characteristics

The core process of the intelligent three-ring kiln lies in the calcination method that combines **parallel co-current firing with counter-current roasting**. The main body of the kiln is divided into three parts vertically from top to bottom: a **preheating zone, a firing zone, and a cooling zone**. The material moves slowly downwards in the kiln, while the hot gas stream forms a complex circulation path within the kiln, ensuring that the thermal requirements of different stages are precisely met.

Structural Composition: The upper part of the kiln body is a cylindrical preheating zone, the middle part is a rectangular box-shaped firing zone, and the lower part is an elliptical column-shaped clinker storage and cooling zone. Taking the HNS-5300S model as an example, its effective height reaches 66 meters, and the maximum inner diameter of the cylinder is 11.4 meters. This design not only optimizes the movement trajectory of the material within the kiln but also provides space for the enhancement of each functional area.

Thermal Principle: This calcination method effectively solves the drawback of traditional reverberatory earthen kilns, which can only calcine large lumps of material. It can uniformly heat various particle sizes of ore ranging from 25mm to 200mm and extend their calcination time, ensuring complete decomposition of the ore and stabilizing the crystal phase content of the final product (such as periclase).

2.2. Key Technical Innovations

The leading position of the intelligent three-ring kiln is reflected in the following key innovative designs:

2.2.1. Addition of a Smoldering Decomposition Heat Exchange Device in the Cooling Zone

This is a major technical highlight of the kiln. A tubular heat exchange device is installed in the cooling zone at the lower part of the kiln body. A hot air fan extracts the residual heat from the clinker to form high-temperature hot air. This hot air is then used as secondary combustion air for the burners in the lower part of the firing zone, achieving efficient waste heat recovery. More importantly, the light-burned magnesia powder stays in this area for **24-36 hours** before being discharged from the kiln, achieving a special process effect of "**smoldering and homogenization**." In this process, the incompletely decomposed magnesium carbonate ($MgCO_3$) in the material continues to decompose, thus ensuring that the loss on ignition of the final product is stably reduced to **below 1%**, fundamentally improving product quality. At the same time, a high-pressure blower at the

bottom of the kiln forces in dry cooling air (or low-temperature nitrogen) to cool the heat exchange pipes, preventing cold air from directly impacting the firing zone and ensuring the continuous and stable operation of the kiln.

2.2.2. Energy-Saving Insulation Design of the Kiln Wall

The kiln wall adopts a refined multi-layer masonry structure, consisting of a **working lining, an insulation layer, and a load-bearing layer** from the inside out. According to the different working temperatures of the preheating, firing, and cooling zones, refractory and insulation materials of different materials and thicknesses are used accordingly. This effectively controls the heat loss from the kiln to the outside, significantly improves the overall thermal efficiency of the kiln, and results in outstanding energy-saving and consumption-reduction effects.

2.2.3. Optimization and Expansion of Kiln Volume

To maximize thermal energy utilization and production efficiency, the kiln has been optimized in the vertical space:

Top Hopper and Preheater: The top of the kiln is designed as a large hopper that also functions as a preheater, capable of storing a day's worth of material for the kiln. This greatly increases the material loading capacity, allowing the waste heat from the kiln's exhaust gas to be fully utilized to preheat the ore before it enters the kiln, thereby increasing the kiln's utilization factor and reducing the energy consumption per unit of product.

Expanded Bottom Cooling Zone: The storage capacity of the cooling zone at the bottom of the kiln has been expanded by **11 times** compared to traditional designs. The huge storage space not only extends the cooling and "smoldering" time of the material but also greatly expands the heat exchange area, thereby increasing the waste heat utilization factor and further reducing the energy consumption per unit of product.

2.2.4. New Hot Gas Burners and Combustion System

The firing zone of the kiln is equipped with two rows of new high-speed gas burners that use hot air for combustion. One set of combustion air comes from the hot air recovered from the cooling section, and the other set comes from an independent hot air stove. The gas is fully mixed with the high-temperature combustion air when entering the kiln, promoting complete combustion and ensuring that the flame has sufficient length and penetration. This design fully embodies the long-flame combustion characteristics of hot gas, allowing the material to be uniformly wrapped and calcined by the flame, effectively reducing the occurrence of "under-burning" and laying a solid foundation for the qualification rate of semi-finished products in subsequent processes (such as briquetting).

2.2.5. Intelligent Robotic Discharging Device

This is the core of achieving the kiln's intelligence and automation. The traditional manual discharging method is dusty, has severe heat loss, is labor-intensive, and has low efficiency. The robotic discharging system adopted by the intelligent three-ring kiln completely changes this situation:

Sealed and Eco-friendly Production: The discharging area adopts a forced sealing and insulation device, achieving sealed discharging and eliminating dust from the source, reducing heat loss from the kiln, and improving the operating environment.

24-Hour Continuous Operation: The discharging robot equipped with an intelligent rocker arm can operate in a 24-hour cycle, with both sides operating simultaneously, resulting in extremely high efficiency.

Intelligent and Precise Operation: When the robot is working, its front-end high-temperature resistant protective cover will accurately dock with the kiln's poking port and activate a sealing air curtain to form positive pressure protection, preventing cold air from intruding. The robot senses the calcination state of the material through far-infrared and embedded temperature measurement devices, and adjusts the up-down and left-right swing, poking force, and direction of the poking drill rod at any time to ensure that the

discharged finished material meets the calcination standard, maximizing the control of product quality.

Massive Efficiency Improvement: Preliminary calculations show that compared to manual discharging, intelligent robotic discharging can increase output by **three to five times or more**, while saving **80%** of labor.

2.2.6. High Automation and Digital Control

The entire kiln system adopts digital intelligent control, achieving full-process automation from proportioning and feeding to discharging. Key parts of the kiln (such as exhaust, preheating, heating, and cooling zones) are densely installed with various sensors for temperature, pressure, flow, and oxygen content, achieving timely and accurate "four measurements." All data is transmitted to the central control room in real time, and the system automatically adjusts, ultimately achieving the "four modernizations" management goal of "**precise material calcination, digital product quality, safe personnel and equipment, and a clean site environment**."

3. Application in Light-Burned Magnesia (LBM) Production

Light-burned magnesia (CCM), or caustic calcined magnesia, is the basic raw material for producing high-purity magnesia, medium-grade magnesia, magnesia cementitious materials, and other refractory products. The application of the intelligent three-ring kiln in LBM production is a subversive upgrade of the traditional process.

3.1. Project Background and Goals

This application is based on the technological upgrading and transformation project of old earthen kilns of a group in Liaoning. The group decided to dismantle 12 old kilns and build a new HNS-5300S intelligent three-ring kiln with a daily output of 380 tons on the original site, aiming to **replace environmental indicators, save land, save energy, reduce operating workers, and improve production efficiency and product quality**.

3.2. Production Process Flow

Raw Material Preparation: Magnesite lumps are graded by particle size, usually into three specifications: 25-50mm, 50-100mm, and 100-200mm. It is recommended to roast them separately in the kiln to achieve the best results. Crushed ore smaller than 25mm can be used for other purposes.

Feeding: After precise proportioning by an automatic proportioning system, the ore is transported to the top of the kiln by a "feeding cart" and then uniformly added to the preheater through a distributor.

Calcination: The material passes through the preheating, firing, and cooling zones in sequence within the kiln. In the firing zone, the material stays at a high temperature (usually 700-1000°C) for 6-8 hours to ensure the complete decomposition of $MgCO_3$ into MgO and CO_2.

Discharging: The calcined light-burned magnesia powder is pushed into the smoldering layer by the intelligent robot. After sufficient homogenization and cooling, it is discharged by a screw conveyor at the bottom of the kiln.

Finished Product: The temperature of the discharged light-burned magnesia powder is about **ambient temperature + 65°C**. It can be directly transported to the silo or briquetting workshop via a belt conveyor in a fully enclosed process, ensuring a clean environment.

3.3. Technical Advantages and Product Quality

The advantages of using the intelligent three-ring kiln to produce light-burned magnesia are comprehensive:

Huge Output Increase: The daily output of a single kiln can reach **380 tons ±7%**, which is **more than ten times** higher than that of traditional earthen kilns.

Excellent Product Quality: Thanks to uniform heating, long calcination time, and the "smoldering and homogenization" effect of the cooling zone, the product quality is comparable to that of international advanced kiln types such as suspension kilns, fluidized bed kilns, sleeve kilns, and Maerz kilns. Its **residual loss on ignition (caustic burn) can be stably maintained below 1%**, fundamentally solving the problem of unstable product quality in traditional earthen kilns.

High Added Value: High-quality light-burned magnesia powder has excellent sintering activity and a high briquetting rate, making it an ideal raw material for preparing high-purity magnesia and medium-grade magnesia, significantly increasing the product's profit margin.

Significant Comprehensive Benefits: Compared with kiln types such as Maerz, the intelligent three-ring kiln, while ensuring high quality, has the characteristics of a **high investment-to-performance ratio, small footprint, and high capacity**, with outstanding comprehensive economic benefits.

4. Application in High-Value Utilization of Coal Gangue

If the application in light-burned magnesia production is about "improving quality and increasing efficiency," then the application in coal gangue treatment is a model of "turning waste into treasure." The role of the intelligent three-ring kiln here is not just a calcination furnace, but a **chemical reaction activator**.

4.1. Project Background and Innovative Concept

This application is based on the project of Shandong Hening Shun Kiln Industry to build a plant in Inner Mongolia to process 1 million tons of coal gangue annually to produce alumina and silica sol. Its core concept is to completely abandon the traditional path of using coal gangue as a low-grade fuel or filler and adopt **independent intellectual property rights of intelligent three-ring kiln calcination technology,**

combined with a hydrochloric acid high-efficiency leaching process system, to carry out "**eat-clean**" style full-component high-value utilization of coal gangue.

4.2. The Core Process of "Activation Roasting"

The main chemical components of coal gangue are Al_2O_3 and SiO_2, mostly existing in stable crystalline forms such as kaolinite, which has extremely low reactivity for direct acid leaching. The key role of the intelligent three-ring kiln here is to perform "**activation roasting**."

Under precisely controlled temperature and atmosphere in the kiln, the kaolinite ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$) in the coal gangue undergoes a dehydroxylation reaction, its crystal lattice structure is destroyed, and it is transformed into amorphous, highly chemically active metakaolin ($Al_2O_3 \cdot 2SiO_2$). This step is the "dragon head" of the entire process chain. Through activation roasting, **>95% high-efficiency utilization of the silicon-aluminum components in coal gangue** can be achieved.

4.3. Full Industry Chain Process Flow

With activation roasting as the starting point, a complete new material industry chain is formed:

Raw Material Pre-treatment: Lump coal gangue (30 - 300mm) enters the intelligent three-ring kiln after precise selection.

Activation Roasting: Activation treatment is carried out in a φ6.2×56m intelligent three-ring kiln to obtain calcined clinker.

Secondary Processing: The clinker is processed into fine powder through crushing, screening, secondary selection, and a grinding system.

Acid Leaching and Desilication: The powder enters a hydrochloric acid cascade leaching system. Due to its high activity, the alumina is leached out by hydrochloric acid to form an aluminum chloride solution.

Solid-Liquid Separation: After separation, an aluminum-containing liquid and insoluble silica residue are obtained.

Product Preparation:

Aluminum Line: The aluminum liquid undergoes processes such as aluminum powder reduction and precipitation to finally produce **aluminum hydroxide products** (annual output of 320,000 tons, Al_2O_3 ≥65%, meeting metallurgical grade standards).

Silicon Line: The silica residue undergoes steps such as alkali dissolution for silicon extraction and nano-colloid stabilization to produce **silica sol powder products** (annual output of 450,000 tons, particle size 30±5nm, specific surface area >500m²/g, with excellent technical indicators).

Waste Residue Utilization: The final residue is used to prepare **low-carbon cement clinker** (annual output of 80,000 tons), achieving zero solid waste discharge.

4.4. Profound Significance for the Refractory Industry

This application model has strategic significance for the refractory industry. It opens up a new path for producing high-end refractory raw materials that does not rely on high-grade natural minerals (such as bauxite).

Provides High-Quality Synthetic Raw Materials: The high-purity aluminum hydroxide and high-activity silica sol produced by the project are ideal for synthesizing advanced synthetic refractory raw materials such as mullite ($3Al_2O_3 \cdot 2SiO_2$) and cordierite. These synthetic materials have characteristics such as high purity, stable composition, and excellent high-temperature performance.

Reduces Raw Material Costs and Foreign Dependence: Starting from low-cost industrial solid waste coal gangue to produce products that can replace or even surpass

natural mineral raw materials helps to reduce our country's refractory industry's dependence on high-quality resources such as bauxite and ensures the security of the industrial chain.

Promotes Green and Circular Development: This model perfectly fits the "dual carbon" goals and the concept of a circular economy, combining solid waste treatment with new material manufacturing, with extremely significant social and environmental benefits. The project consumes 1 million tons of coal gangue annually, which can reduce CO_2 emissions by 850,000 tons and save 280,000 tons of standard coal.

5. Comprehensive Comparative Analysis and Market Prospects

5.1. Comparative Advantages over Various Kilns

Compared to traditional earthen kilns: The intelligent three-ring kiln has achieved a "qualitative leap" in output, quality, energy consumption, environmental protection, and automation, representing a complete replacement and upgrade.

Compared to other advanced kilns (suspension kilns, Maerz kilns, etc.): While ensuring comparable product quality, the intelligent three-ring kiln highlights comprehensive advantages such as **good product quality (especially high briquetting rate), excellent sintering properties of high-purity pellets, high investment-to-performance ratio, small footprint, and high capacity**, providing investors with a more economical choice.

5.2. Market Positioning and Prospects

The market positioning of the intelligent three-ring kiln is for enterprises with high requirements for product quality, environmental standards, and production efficiency, aiming to solve industry pain points and promote industrial upgrading.

In the field of magnesia materials: With the increasing demand for high-quality refractory materials from downstream industries, the market for high-quality, low-cost

light-burned magnesia powder is broad. The intelligent three-ring kiln is the ideal equipment for producing such products.

In the field of solid waste utilization: The success of the "activation roasting" technology for coal gangue has opened up a new and huge potential market for this kiln. Its technological demonstration effect is significant, and the capacity of a single project to dispose of coal gangue can be expanded to 20 million tons per year, which is expected to be widely promoted in the domestic field of high-value utilization of solid waste.

Industrial Chain Extension Value: The high-end silica sol produced by the project can be used in cutting-edge industries such as semiconductors and artificial intelligence robotics; the aluminum hydroxide can be used for local development of electrolytic aluminum; and the low-carbon cement is in line with the green trend of the future construction industry. This powerful industrial chain extension capability makes it not just a piece of equipment, but a core technology that can spawn a 7-billion-level industrial cluster.

With its high technical barriers, low raw material costs, and strong product competitiveness, projects using the intelligent three-ring kiln are expected to quickly occupy the high-end market and become the technological leader in the industry.

6. Conclusion

The intelligent three-ring kiln developed by Shandong Hening Shun Kiln Industry Co., Ltd., through a series of profound technological innovations, has successfully solved the multiple long-standing problems of energy consumption, environmental protection, efficiency, and quality in the traditional calcination industry.

Technological Advancement: The kiln integrates innovative thermal design, efficient waste heat recovery, a revolutionary robotic discharging system, and comprehensive digital intelligent control, representing the cutting-edge level in the current industrial kiln field.

Breadth and Depth of Application: In the production of light-burned magnesia, it has achieved "quality and efficiency improvement" and modernization transformation of a traditional industry; in the treatment of coal gangue, it has created a new paradigm for the resource utilization of solid waste through the key step of "activation roasting," turning an environmental burden into a source of high-value new materials.

Economic and Social Value: Whether from the perspective of reducing production costs and increasing corporate profits, or from the perspective of consuming industrial solid waste, reducing carbon emissions, and promoting a circular economy, the intelligent three-ring kiln has shown huge economic and social benefits.

In summary, the intelligent three-ring kiln is not only a high-performance piece of industrial equipment but also a powerful technological engine for practicing the concept of "new quality productive forces" and promoting the high-quality, sustainable development of the refractory materials and related industries. Its successful application in the calcination of magnesite and coal gangue fully proves its technological maturity, reliability, and broad promotion value, which is worthy of in-depth demonstration and active implementation in the industry.