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

The innovative application of the intelligent three-ring kiln, developed by Shandong Hening Shun Kiln Industry Co., Ltd., in the calcination of key refractory raw materials—magnesite and coal gangue—demonstrates industry-leading technical advantages. Facing the industry's predicament of low capacity, high energy consumption, severe pollution, and low automation in traditional kilns, the intelligent three-ring kiln, as a new type of digital kiln integrating high efficiency, energy saving, 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 large-scale production goals through innovative measures such as its unique structural design, waste heat recovery system, and intelligent application of robots. The product's loss on ignition is less than 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 lies in "activation roasting." Through precise temperature control and calcination processes, the activity of the silicon and aluminum components in the coal gangue is efficiently stimulated, with a utilization rate exceeding 95%. This lays the foundation for the subsequent extraction of high-end refractory raw materials like high-purity alumina and nano-silica sol, achieving a "complete utilization" style of high-value use of industrial solid waste.

The core technical principles, process flow, specific practices in the calcination of two different materials, and the economic and social benefits of the intelligent three-ring kiln fully demonstrate its technological advancement. It is evident that the intelligent three-ring kiln is not just a simple replacement for traditional kilns but a key piece of equipment driving the refractory industry's transformation towards "new quality productive forces" and achieving green, low-carbon, and intelligent development. It has broad market prospects and significant industrial demonstration value.

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, the calcination processing of these raw materials has long faced severe challenges.

Currently, the industrial cluster for magnesia-based refractory materials in Liaoning has thousands of vertical kilns for light-burned magnesia powder, all of which are traditional, old-style earthen kilns. They suffer from numerous drawbacks, including simple production processes, low output, high energy consumption, poor working environments, high labor intensity, and very low levels of mechanization and automation. These have become completely incompatible with the country's strict requirements for energy conservation and environmental protection. This extensive production method not only leads to the waste of valuable mineral resources but also places enormous pressure on the ecological environment.

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

1.2. The Technological Breakthrough of the Intelligent Three-Ring Kiln

Technology companies, represented by Shandong Hening Shun Kiln Industry Co., Ltd., are dedicated 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 state of equipment in the traditional earthen kilns for magnesia-based refractory materials. Through technological innovation, it aims to "completely utilize the raw materials, enhance profit margins, and increase corporate income." The intelligent three-ring kiln technology solution provided by Shandong Ning Shun Kiln Industry Co., Ltd. is comprehensively and detailedly elaborated from two core application scenarios: **the production of light-burned magnesia powder** and **the high-value utilization of coal gangue**, covering its technical principles, process characteristics, application effectiveness, and profound impact on the refractory materials industry.

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

The outstanding performance of the intelligent three-ring kiln stems from its systematic innovations in structure, thermal engineering, and control. It abandons the extensive design of traditional kilns and incorporates concepts of refined heat management and highly intelligent operation.

2.1. Overall Design and Process Characteristics

The core process of the intelligent three-ring kiln lies in the calcination method that combines **cocurrent direct firing with countercurrent roasting**. The main body of the kiln is divided vertically from top to bottom into three zones: **a preheating zone, a firing zone, and a cooling zone**. The material moves slowly downwards inside the kiln, while the hot gas flow 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 is a rectangular box-shaped firing zone, and the lower part is an

elliptical cylindrical 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 inside 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 blocks of material. It can uniformly heat various particle sizes of ore ranging from 25mm to 200mm and extend their calcination time, ensuring the complete decomposition of the ore and stabilizing the crystal phase content of the final product (such as periclase).

2.2. Key Technological 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 technological highlight of the kiln. A tubular heat exchange device is installed in the cooling zone at the lower part of the kiln body. A heat extraction fan draws out 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 exiting the kiln, achieving a special process effect of **"smoldering and homogenization."** During this process, any incompletely decomposed magnesium carbonate ($MgCO_3$) in the material continues to decompose, 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 forces dry cooling air (or low-temperature nitrogen) into the bottom of the kiln 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 and Insulating 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 operating temperatures of the preheating, firing, and cooling zones, refractory and insulating 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 effects.

2.2.3. Optimization and Expansion of Kiln Volume

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

Top Hopper as a 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. 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.

Expansion of the 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, using hot air for combustion support. One set of combustion air comes from the hot air recovered from the cooling section, and the other comes from an independent hot blast stove. The gas is fully mixed with the high-temperature combustion air upon 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. This effectively reduces the occurrence of "under-burning" and lays 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, causes severe heat loss, has high labor intensity, and is inefficient. The robotic discharging system used in the intelligent three-ring kiln completely changes this situation:

Sealed and Environmentally Friendly Production: The discharging area uses a forced sealing and insulation device, achieving sealed discharging. This eliminates dust from the source, reduces heat loss from the kiln, and improves the operating environment.

24-Hour Continuous Operation: The discharging robot, equipped with an intelligent rocker arm drill, 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 protective cover will precisely engage with the kiln's poking port and activate a sealing air curtain, forming positive pressure protection to prevent cold air from intruding. The robot senses the calcination state of the material through far-infrared and embedded temperature measurement devices, and adjusts the swing, impact force, and

direction of the poking drill rod at any time to ensure that the discharged finished material meets the calcination standards, maximizing product quality control.

Huge Efficiency Improvement: According to preliminary calculations, 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 automation from proportioning and feeding to discharging. Key parts of the kiln (such as flue gas 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-izations" management goal: **"precision in material calcination, digitalization of product quality, safety of personnel and equipment, and cleanliness of the site environment."**

3. Application in Light-Burned Magnesia Production

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

3.1. Project Background and Objectives

This application is based on the technological upgrade and renovation 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. The aims were to replace environmental indicators, save land, conserve

energy, reduce the number of operators, and improve production efficiency and product quality.

3.2. Production Process Flow

Raw Material Preparation: The magnesite lumps are graded by particle size, typically 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 batching system, the ore is transported to the top of the kiln by a "feeding cart" and then uniformly added into the preheater through a distributor.

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

Discharging: The calcined light-burned magnesia powder is poked into the smoldering layer by the intelligent robot. After sufficient homogenization and cooling, it is discharged from the bottom of the kiln by a screw cone rotary discharger.

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 conveyor belt, with the entire process being enclosed and the environment clean.

3.3. Technical Advantages and Product Quality

The application of the intelligent three-ring kiln for producing light-burned magnesia offers comprehensive advantages:

Massive Increase in Output: 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 homogenization" effect in the cooling zone, the product quality is comparable to that of internationally advanced kiln types such as suspension furnaces, fluidized bed furnaces, sleeve kilns, and Maerz kilns. Its **residual loss on ignition can be stably maintained below 1%**, fundamentally solving the problem of unstable product quality in traditional earthen kilns.

High Added Value: The 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 and medium-grade magnesia, significantly increasing the product's profit margin.

Significant Comprehensive Benefits: Compared with kiln types like the Maerz kiln, the intelligent three-ring kiln, while ensuring high quality, has the characteristics of a high investment-to-performance ratio, small footprint, and high capacity, resulting in 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 efficiency," then its application in coal gangue treatment is a model of "turning waste into treasure." Here, the intelligent three-ring kiln acts not just as a calcination furnace, but as a **chemical reaction activator**.

4.1. Project Background and Innovative Concept

This application is based on a project proposed by Shandong Hening Shun Kiln Industry to build a facility in Inner Mongolia for processing 1 million tons of coal gangue annually to produce alumina and silica sol. The core concept is to completely abandon

the traditional path of using coal gangue as a low-grade fuel or filler. Instead, it adopts **proprietary intelligent three-ring kiln calcination technology combined with a high-efficiency hydrochloric acid leaching process system** to achieve a "complete utilization" style of high-value, full-component use 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 like kaolinite, which have 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 inside 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 transforms into amorphous, highly chemically active metakaolin ($Al_2O_3 \cdot 2SiO_2$). This step is the head of the entire process chain. Through activation roasting, **over 95% efficient utilization of the silicon and aluminum components in the coal gangue** can be achieved.

4.3. Full Industrial Chain Process Flow

Starting with activation roasting, a complete new material industrial chain is formed:

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

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

Secondary Treatment: The clinker is processed into fine powder through crushing, screening, secondary selection, and grinding systems.

Acid Leaching and Desilication: The powder enters a hydrochloric acid graded leaching system. Due to its high activity, the alumina in it is leached 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 like 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 is processed through steps like alkali dissolution for silicon extraction and nano-colloidal 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 Materials Industry

This application model has strategic significance for the refractory materials 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).

Providing High-Quality Synthetic Raw Materials: The high-purity aluminum hydroxide and high-activity silica sol produced by the project are ideal choices for synthesizing advanced synthetic refractory raw materials like mullite ($3Al_2O_3 \cdot 2SiO_2$) and

cordierite. These synthetic materials are characterized by high purity, stable composition, and excellent high-temperature performance.

Reducing Raw Material Costs and Foreign Dependence: Starting with low-cost industrial solid waste (coal gangue) to produce products that can replace or even surpass those from natural mineral raw materials helps to reduce China's refractory industry's dependence on resources like high-quality bauxite, ensuring the security of the industrial chain.

Promoting Green and Circular Development: This model perfectly aligns with the "dual carbon" goals and the concept of a circular economy. It combines solid waste treatment with new material manufacturing, resulting in 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 achieves a "qualitative leap" in terms of output, quality, energy consumption, environmental protection, and automation, representing a complete replacement and upgrade.

Compared to Other Advanced Kilns (Suspension Furnaces, 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 briquettes, high investment-to-performance ratio, small footprint, and high capacity**. This provides 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 vast. The intelligent three-ring kiln is the ideal equipment for producing such products.

In the Field of Solid Waste Utilization: The success of the coal gangue "activation roasting" technology 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, with the potential for large-scale promotion in the field of high-value utilization of solid waste in China.

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 aligns with the future green trend of the construction industry. This powerful industrial chain extension capability makes it not just a piece of equipment, but a core technology capable of spawning 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 capture the high-end market and become technological leaders 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 long-standing multiple 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 disruptive robotic discharging system, and comprehensive digital intelligent control, representing the cutting edge in the field of industrial kilns today.

Breadth and Depth of Application: In the production of light-burned magnesia, it has achieved the "quality and efficiency improvement" and modernization of a traditional industry. In the treatment of coal gangue, through the key step of "activation roasting," it has created a new paradigm for the resource utilization of solid waste, 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 angle of consuming industrial solid waste, reducing carbon emissions, and promoting the development of a circular economy, the intelligent three-ring kiln demonstrates enormous 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 the maturity, reliability, and broad promotional value of its technology, making it worthy of in-depth demonstration and active implementation within the industry.