White Paper on Intelligent Three-Ring Kiln Activation Calcination Technology ——A Disruptive Solution Empowering the Calcination of Lumpy Materials and High-Value Utilization of Industrial Solid Waste

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Against the backdrop of global "dual carbon" goals and circular economy strategies, the resource-oriented and high-value utilization of bulk industrial solid waste has become a core indicator for measuring industrial sustainable development capabilities. However, traditional calcination processes, when dealing with lumpy, low-grade, and complex solid wastes, generally face four core pain points: high energy consumption, heavy pollution, low added value of products, and unstable quality. This not only causes a huge waste of valuable resources but has also become a "siege" constraining the green transformation of related industries.

Shandong Hening Shun Kiln Industry Co., Ltd., building on its deep expertise in high-value utilization technology for solid waste, has developed a large-scale patented equipment with independent intellectual property rights—the Intelligent Three-Ring Kiln. It deeply integrates thermodynamic reconstruction, activation calcination of lumpy materials, ultra-low emissions, intelligent control, and high-value conversion technologies, forming a complete series of industrial solutions. Through its disruptive technological system, it transforms "environmental liabilities" that are difficult to utilize in traditional processes (such as coal gangue, low-grade magnesite, and hazardous aluminum dross) into "strategic resources" for producing high-end new materials.

The core advantages of this technology are:

Quality Leap: Through the original **Three-Zone Gradient Activation** and a "smoldering homogenization" technique lasting up to 24-36 hours, it achieves uniform and deep activation of large lumpy materials ranging from 3 to 30 centimeters for the first time. The product's loss on ignition is stably below 1%, and core indicators like activity far exceed those of traditional processes, comparable to top international kiln types.

Energy Efficiency Leap: A **Four-Stage Waste Heat Closed-Loop Circulation** system increases comprehensive thermal efficiency to over 78%, far exceeding the sub-50% level of traditional kilns. The energy cost per ton of product is significantly reduced by more than 40%, and it can be equipped with waste heat power generation to achieve energy self-sufficiency.

Intelligent Upgrade: The fusion of **AI Digital Twin** and **Intelligent Robots** replaces over 80% of manual operations, boosting production efficiency to 3-5 times that of traditional kilns and leading the industry towards unmanned smart factories.

Environmental Breakthrough: An integrated pollution control solution achieves **ultra-low emissions of SO_2 and dust** and stable solidification of heavy metals. Environmental indicators are comprehensively superior to national standards, providing a benchmark contribution to the construction of "waste-free cities".

Value Reshaping: It has successfully transformed coal gangue into alumina and silica nano-grade new materials and low-carbon cement; converted low-grade magnesite into battery-grade magnesium carbonate, increasing its added value by 10 times; and completely detoxified hazardous aluminum dross while recovering high-purity alumina and cryolite, turning an environmental disposal project into a high-return, high-quality industry.

These breakthrough achievements have collectively built an economic model with outstanding comprehensive benefits for the Intelligent Three-Ring Kiln project, achieving

investment payback periods as short as a few months and providing a "Chinese solution" for the global high-temperature calcination industry that is economical, environmentally friendly, and disruptive.

Introduction: A Profound Industrial Revolution

China's and the world's industrial systems are at a historic crossroads. On one hand, the "carbon peak and carbon neutrality" strategy is reshaping the industrial landscape with unprecedented force, bringing the high-energy-consumption, high-emission traditional development model to an end. On the other hand, the increasing depletion of high-quality mineral resources and supply chain security issues compel us to turn our attention to the vast stocks of long-neglected industrial solid waste.

However, on the path to solid waste resource utilization, simple, patchwork technical improvements have proven inadequate. The industry urgently needs a disruptive technological revolution, a fundamental solution that can systematically address the multiple contradictions of quality, energy consumption, environmental protection, and efficiency. The Intelligent Three-Ring Kiln activation calcination technology is the "technical detonation point" of this revolution. It is not an improvement on traditional processes but a profound, systematic paradigm innovation.

1. The "Siege" of Traditional Calcination Processes and the Pains of an Era

Before the advent of the Intelligent Three-Ring Kiln, the field of bulk solid waste calcination was long dominated by traditional kilns (such as rotary kilns and reverberatory furnaces). While these pieces of equipment supported past industrialization, they also accumulated unavoidable structural contradictions, forming a "siege" that constrains industrial upgrading.

1.1 The Pain of Quality: Uneven Heating, Difficult to Control Quality

The heating method of traditional kilns for lumpy materials is simple and crude, with slow and uneven heat transfer from the outside in, which easily leads to the phenomenon of being "burnt on the outside, raw on the inside". The exterior of the material is over-burned due to excessive temperature, forming inactive, inert crystals, while the interior is under-burned due to insufficient temperature, resulting in incomplete reactions. This directly leads to low activity, high impurities, and large quality fluctuations in the final product. For example, light-burned magnesia powder produced in traditional earthen kilns typically has an activity of only 60-75% and a loss on ignition as high as 3-8%, making it difficult to meet the stringent requirements of downstream high-end applications for high-purity, high-activity, and high-stability raw materials. This low-end, homogenized product can only be trapped in a quagmire of low-price competition, causing a huge waste of valuable resources.

1.2 The Pain of Energy Consumption: Open-Loop Circulation, Massive Heat Loss

Traditional kilns mostly use open-loop thermal systems, where flue gas at several hundred degrees Celsius carries a large amount of heat and is directly discharged into the atmosphere, resulting in astonishing heat loss. Their comprehensive thermal efficiency is generally below 50%, indicating extremely low energy utilization. This not only drives up production costs but also becomes a heavy economic burden for enterprises amidst high energy prices and dual controls on energy consumption. Taking coal gangue calcination as an example, the cost per ton in a traditional kiln is over 200 RMB, while the standard coal consumption per ton of calcined magnesite is 205 kg.

1.3 The Pain of Environmental Protection: High Pollution, Difficult to Manage

Traditional calcination is a typical "high-energy-consumption, high-pollution" process. The production process is accompanied by large amounts of sulfur dioxide (usually above 100mg/m³) and unorganized dust emissions (usually above 30mg/m³), significantly impacting the regional atmospheric environment. With the unprecedented strengthening of national ecological civilization construction, increasingly stringent environmental

standards have transformed from "soft constraints" of the past into "hard thresholds" that determine a company's survival. High environmental investment and operating costs further weaken the profitability and market competitiveness of traditional enterprises.

1.4 The Pain of Efficiency: Reliant on Manual Labor, Rife with Risks

The operation of traditional kilns, from feeding, fire-watching, and temperature adjustment to discharging, is highly dependent on manual experience and physical labor, with a very low degree of automation. This not only leads to low production efficiency and high labor intensity but, more importantly, the working environment with high temperatures, dust, and gas poses serious safety hazards, which is incompatible with modern, human-centric industrial production concepts.

2. Integrated Solution—In-depth Analysis of the Intelligent Three-Ring Kiln Technology System

The Intelligent Three-Ring Kiln fundamentally resolves the four major pain points mentioned above through a systematic reconstruction and integrated innovation of the various elements of the calcination process.

2.1 Thermodynamic Reconstruction: The Precise "Scalpel" of Tiered Temperature Zones

The Intelligent Three-Ring Kiln subverts the traditional "one-pot" heating model by creating a unique, vertically arranged **tiered three-zone programmed calcination process**. This acts like a precise "scalpel" for the material's physical and chemical transformation process.

Preheating Zone (400–600°C): Located in the upper part of the kiln, it uses the waste heat from high-temperature flue gas recovered from subsequent processes to provide stable and gentle preheating and dehydration for the newly fed cold lumpy materials. This process effectively prevents physical cracking of the materials due to

sudden temperature increases, ensuring a raw material utilization rate of over 95% and stable operation of the production line.

Decomposition Zone (650–850°C): This zone is the key preparatory stage for the activation reaction. Through precise temperature control, lumpy materials (such as $MgCO_3$ in magnesite or kaolinite in coal gangue) are deeply decomposed and transformed into intermediate products with high reactivity. Another major breakthrough in this process is that the high-concentration CO_2 generated from decomposition (e.g., CO_2 concentration can reach over 85% during magnesite decomposition) is enriched in this zone, creating excellent conditions for subsequent low-cost, high-purity carbon capture and utilization (CCU).

Activation Zone (900–1100°C): This is the core zone that determines the final activity of the product. The Intelligent Three-Ring Kiln uses **fine temperature difference control of ±15°C** to reconstruct the mineral lattice, effectively inhibiting the formation of inert crystals (like mullite and cristobalite) that tend to form at high temperatures and significantly reduce material activity. This ensures that the content of highly active amorphous substances in the product is stably above 95% (taking coal gangue as an example), or the product activity exceeds 95% (taking light-burned magnesia powder as an example).

2.2 A Leap in Lumpy Material Activation: "Simplification from the Source" and "Smoldering Homogenization"

This is the hallmark capability that distinguishes the Intelligent Three-Ring Kiln from all traditional powder calcination processes.

Direct Firing of Lumpy Materials: It can directly process large lumpy materials with sizes ranging from 3 to 30 centimeters. This innovation greatly simplifies high-energy-consumption pre-treatment processes like crushing and grinding from the outset and eliminates common problems in powder calcination such as adhesion and wall

accretion, significantly improving production efficiency and the comprehensive utilization rate of raw materials.

"Smoldering Homogenization" Technology: To completely solve the "burnt on the outside, raw on the inside" problem of lumpy materials, the Intelligent Three-Ring Kiln innovatively features a **slow-cooling homogenization section at the bottom of the kiln lasting 24 to 36 hours**. Much like "steaming rice," the hot-calcined materials undergo slow and thorough internal heat transfer and residual reactions in this zone using their own residual heat, ensuring that the material is uniformly activated from surface to core. This unique technology enables the final product's **loss on ignition to be stably controlled below 1%**, far superior to the 3-8% level of traditional processes, fundamentally guaranteeing high uniformity and stability of product quality.

2.3 Closed-Loop Energy System: Forging Ultimate Energy Efficiency

The Intelligent Three-Ring Kiln has taken energy saving and consumption reduction to the extreme. Its innovative **Four-Stage Waste Heat Closed-Loop Circulation System** achieves a comprehensive thermal efficiency as high as 78% (and can reach over 85% with oxygen-enriched combustion), far surpassing the sub-50% level of traditional kilns.

First and Second Stage Recovery: High-temperature flue gas (900-1100°C) from the outer ring is not discharged but is directly used within the kiln to preheat the lumpy materials in the middle ring and the upper preheating zone.

Third Stage Recovery: The low-temperature waste gas (about 350°C) from the inner ring is directed to a waste heat boiler to drive a steam turbine for power generation, which can be equipped with 3.2 MW to 7.8 MW generator sets.

Fourth Stage Recovery: The final exhaust gas temperature is below 130°C, maximizing heat energy utilization.

2.4 Intelligent Control Center: AI Digital Twin and Robotic Operation

The Intelligent Three-Ring Kiln deeply integrates artificial intelligence and industrial automation technology, achieving "four modernizations" in its management goals: precision in material calcination, digitalization of product quality, safety of personnel and equipment, and cleanliness of the site environment.

AI Digital Twin: The system can monitor and optimize over 2,000 process parameters in real-time. Based on data models, it can dynamically adjust calcination parameters in response to fluctuations in raw material composition and predict product activity (with an accuracy of ≥95%) and loss on ignition in advance, enabling predictive maintenance and optimal control.

Intelligent Robotic Discharging: The bottom of the kiln is equipped with intelligent robots fitted with infrared sensors, capable of continuous operation 24/7 in a fully sealed environment. The robots can accurately identify the calcination state of the lumpy materials and adaptively adjust the discharging force, which not only eliminates dust leakage and heat loss but also replaces over 80% of manual operations, increasing the processing efficiency of lumpy materials to 3-5 times that of traditional kilns.

2.5 Integrated Pollution Control: Achieving Ultra-Low and Net-Zero Emissions

From its initial design, the Intelligent Three-Ring Kiln incorporates a full-process pollution control system, shifting from end-of-pipe treatment to process control to ensure all pollutant emission indicators are significantly better than national standards, even reaching "net-zero emission" levels.

Source Desulfurization and Solidification: Through wet activation desulfurization technology, the SO_2 emission concentration is kept below 35mg/m³ (national standard is 100mg/m³). In the high-temperature section of 1250–1350°C, heavy metals from the raw materials are effectively encapsulated and solidified into a stable vitreous body, reducing the leaching toxicity of the final product by 99%.

Ultra-Low Dust Emissions: A dual-stage system of "electrostatic precipitator + nano-fiber bag filter" is used to control dust emission concentration to within 8mg/m³, far below the national standard of 30mg/m³.

3. Paradigms of Industrial Application—Value Reshaping by "Turning Waste into Treasure"

The outstanding technical advantages of the Intelligent Three-Ring Kiln have been translated into astonishing economic and social benefits in multiple fields. The following are three typical application cases.

3.1 Case 1: "Solid Waste Mining" of Coal Gangue—Opening a New Materials Supply Chain

Value Restructuring: Redefines coal gangue, long considered an environmental burden, as a valuable "silicon-aluminum symbiotic mineral resource". It is "eaten clean" through an "Intelligent Three-Ring Kiln activation roasting - hydrochloric acid graded leaching - fractional purification" process.

High-End Product Matrix:

Nano-grade α-Alumina: Purity >99.5%, primary crystal size ≤1μm, a key raw material for strategic industries like advanced ceramics, lithium battery separators, and semiconductor polishing, capable of replacing imports.

Nano-grade Silica Sol: Controllable particle size (10-50nm), high purity and stability, used in high-tech fields such as precision casting, specialty coatings, electronic polishing slurries (CMP), and catalyst carriers, breaking foreign technology monopolies.

LC3 Low-Carbon Cement: Using activated coal gangue as the core active component, it can replace up to 50% of cement clinker, reducing carbon

emissions from cement production by 40% while improving concrete durability, providing a perfect solution for the green transformation of the cement industry.

Investment Return: A project processing 1 million tons of coal gangue annually to produce high-end nano-materials has a total investment estimate of 1.976 billion RMB, with an expected annual net profit of 5.124 billion RMB and a post-tax dynamic investment payback period of about 1 year and 5 months. Another project with a total investment of 595 million RMB has an annual net profit of 1.181 billion RMB, with a **static investment payback period of only 6.0 months**.

3.2 Case 2: "Upgrading Inferior Ores" of Magnesite—Reshaping the Industrial Ecology of "China's Magnesia Capital"

Quality Improvement: Completely changes the situation of resource waste and severe pollution in the "China's Magnesia Capital" region. The resulting high-activity light-burned magnesia powder has an

activity >95% with stable and reliable quality, comparable to top international suspension and fluidized bed furnaces, making it a high-quality raw material for producing high-end synthetic refractories like fused magnesia and magnesia-alumina spinel.

"Eat Clean" Value Chain: Constructs a triple-cycle of "intelligent calcination → gas recovery → solid waste regeneration," increasing mineral resource utilization to 99%.

By-products: Captured high-purity CO_2 can be sold as food-grade/industrial-grade products.

Solid Waste Regeneration: Calcination dust can be used to prepare magnesium hydroxide flame retardants; low-grade tailings can be used to prepare **battery-grade high-purity $MgCO_3$ micropowder**, increasing its added value by 10 times (from about 1,200 RMB/ton to 12,000 RMB/ton).

Investment Return: A project with an annual output of 100,000 tons of light-burned magnesia powder and by-products has a **static investment payback period (including construction) of only 1.4 years**, demonstrating unparalleled profitability and risk resistance.

3.3 Case 3: "Complete Detoxification" of Hazardous Aluminum Dross—Conquering a Global Environmental Challenge

Core Process: Provides a perfect solution for the global environmental challenge of high-fluorine aluminum dross. Through a "calcium-based fluorine fixation + activation calcination" process at high temperatures of 1250-1350°C, >98% of harmful fluorine elements are solidified into the stable crystalline phase of fluorite (CaF_2), completely eradicating its environmental risks.

Total Resource Recovery: While achieving detoxification, it purifies and produces **α-Al_2O_3 ultrafine powder with a content >95%**. It also captures the trace amounts of gaseous fluorine in the tail gas, converting it into

high-purity cryolite that can be directly returned to the aluminum electrolysis process, achieving "zero waste discharge".

Investment Return: This project boasts a **gross profit margin as high as 77.05%** and a **pure static investment payback period of only 8 to 9 months**, transforming an environmental disposal project into a high-quality industrial project with high investment value and commercial explosive potential.

4. Strategic Value and Business Model Innovation

The value of the Intelligent Three-Ring Kiln extends far beyond the technical and financial levels; it represents a completely new industrial development philosophy and business model.

4.1 Reshaping the View of Resources: From "Consumption" to "Circulation"

This technology redefines industrial solid waste, long seen as an environmental burden and low-value liability, as a high-value "urban mine" and "strategic resource". It propels the industrial model from a "resource-consuming" type dependent on high-grade minerals to a "resource-circulating" type that activates existing solid waste stocks, providing a new paradigm for ensuring national resource security.

4.2 Disrupting the Economic Model: The Realization of "Triple Benefits"

The Intelligent Three-Ring Kiln project breaks the traditional industrial model of relying on single-product profits and builds a more robust and diversified **"Triple-Benefit"** economic model.

Product Profits: Obtains core revenue by producing a diversified, high-value-added product portfolio.

Environmental Benefits/Government Subsidies: As a comprehensive utilization and environmental protection project for bulk solid waste, it can receive national and local financial subsidies and tax incentives (such as a 50% VAT refund upon collection and a "three-year exemption, three-year half-rate" income tax holiday).

Carbon Benefits: Through significant energy savings, emission reductions, and CO_2 capture and utilization, it can generate additional revenue in future carbon trading markets.

4.3 Building Technical Barriers and an Industrial Moat

The combination of the Intelligent Three-Ring Kiln and deep purification processes creates an extremely high technical barrier. It is not a single piece of equipment that can be easily replicated but a complex process system involving multiple fields such as thermal engineering, chemistry, materials science, automation, and AI, establishing a strong technological moat and market leadership position for early adopters.

Conclusion: Pioneering a New Industrial Paradigm of Green, High-Quality Development

The Intelligent Three-Ring Kiln and its activation calcination technology are not a simple patch or improvement on traditional industry but a profound, systematic paradigm innovation. Through an integrated technology system that combines **precise activation, ultimate energy efficiency, intelligent control, ultra-low emissions, and high-value conversion**, it systematically solves the five major pain points that have long plagued the industrial solid waste treatment field. It skillfully transforms environmental liabilities into core assets and high-value products that solve industry crises, pointing the way to a technically advanced, commercially viable, and green, high-quality development path for traditional high-energy-consuming industries facing existential tests.

This is not just the application of a technology, but a new industrial paradigm based on the "eat clean" principle for solid waste, driven by intelligent manufacturing as its operational engine, and defined by low-carbon, refined output as its value proposition. Its successful promotion and application will undoubtedly accelerate the green transformation of the industrial sector in China and around the world, providing an outstanding Chinese solution and industrial model for achieving carbon neutrality goals.