Journal of World Architecture, 2026, Volume 10, Issue 2
http://ojs.bbwpublisher.com/index.php/JWA
Online ISSN: 2208-3499
Print ISSN 2208-3480

Preliminary Study on Design Theory and Practice of Coking and Refractory Specialties

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Abstract: This paper takes the 73-year technological development of MCC Coking & Refractories Engineering Technology Co., Ltd. (abbreviated as MCC Coking & Refractories) as the research object. As a leading enterprise in the field of coking and refractory engineering technology, MCC Coking & Refractories has undergone a 73-year development journey since its establishment in 1953. The evolution of its design theories and practices reflects the complete trajectory of China's coking industry from technology introduction and independent innovation to global expansion. The paper systematically reviews the historical development and practical achievements of its professional design theories in coking and refractories. The study reveals that MCC Coking & Refractories' design theories have gone through four stages: initial absorption of imported technologies, independent exploration during the growth phase, technological breakthroughs in the maturity phase, and green intelligent transformation during the transition phase. These stages have formed unique technical characteristics centered on furnace structure innovation, based on refractory material research and development, and aimed at energy conservation and emission reduction. Through an in-depth analysis of this historical process, the paper elucidates the internal logic of its design theory evolution, summarizes its implications for the development of the coking industry, and aims to provide references for engineering technology history research and future industry development.

Keywords: MCC coking & refractories; Coking design; Refractory materials; Design theory

Online publication: May 12, 2026

1. Introduction

The coking industry is a pillar industry in metallurgy and chemical engineering, exerting significant influence on national economic development. China, as the world's production and consumption center for coke, accounts for over 68% of global annual coke output. Behind this massive industrial system, the technical accumulation and theoretical innovation of engineering design units play a crucial supporting role. MCC Coking & Refractories, as the sole member of the "national metallurgical construction team" in China's coking, refractory materials, and lime sectors, has seen its 73-year development journey deeply integrated with the modernization process of China's coking industry. Currently, systematic research on this important engineering technology institution remains insufficient in academic circles. Existing literature predominantly focuses on the introduction of specific technological achievements, lacking historical reviews and academic analyses from the perspectives of design theory and professional practice.

2. Incubation and exploration phase: From technology introduction to independent design

2.1. Technical accumulation and technology introduction in the reconstruction of Ansteel

The initial stage of MCC Coking & Refining coincided with the critical phase of laying the foundation for the new China industrial system. The Ansteel Ferrous Metallurgy Design Company, established in 1953, was initially tasked with assisting Soviet experts in the reconstruction and development of Ansteel. During this period, the design team primarily relied on Soviet technical documentation and design specifications, gradually establishing a professional system for coking plant design through the process of assimilation and absorption [1].

Notably, technology introduction during this period was not merely about imitation and replication. Through collaboration with Soviet experts, Chinese technical personnel gradually mastered the fundamental methods of coking process design, including core aspects such as coal yard layout, coke oven configuration selection, and gas purification processes. This "learning by doing" approach to knowledge accumulation laid the groundwork for talent development and technological reserves for subsequent independent innovation.

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2.2. The emergence of type 58 coke oven and its design theory innovation

The year 1958 became a significant turning point in the history of coking design in China. Building on the completion of large-scale design projects such as the Ansteel Chemical Plant, Benxi Iron and Steel Coking Plant, and Wuhan Iron and Steel Coking Plant, MCC Coking & Refractories successfully innovated the design of China's Type 58 coke oven. The birth of this furnace model had dual significance: from a technical perspective, it propelled China's coking technology into the ranks of world leaders; from an industrial perspective, it marked China's capability to independently design large-scale coke ovens.

The design theoretical breakthrough of the Type 58 coke oven is reflected in multiple aspects. In terms of furnace structure, China's technical personnel adapted and improved the Soviet furnace model based on domestic coal quality characteristics and refractory material conditions. Regarding heating systems, they explored combustion control parameters suitable for China's operational conditions. The coke oven was first built and put into operation at Beijing Coking Plant, making significant contributions to celebrating the 10th anniversary of the founding of New China and addressing the gas supply issue for the Great Hall of the People. This case vividly demonstrates that engineering design not only holds technical value but also bears the mission of serving national strategies [3].

2.3. Design practices and theoretical reflections during the "three-line construction" period

In 1964, in response to the CPC Central Committee's call for the' Third Front Construction,' technical personnel from MCC Coking & Refractories headed to the Panxi Plateau to undertake the design of the Pangang Coking Project under extremely challenging conditions.

The Panzhihua Steel Group coke oven was originally designed for a 25-year service life, yet it operated for an impressive 39 years before being decommissioned in 2009, earning the title of "Red Flag Coke Oven." This remarkable longevity stands as the ultimate testament to the effectiveness of its original design principles. Throughout its nearly four-decade operational history, the facility underwent multiple major overhauls and technological upgrades. Its structural design intentionally incorporated ample space for future modifications, showcasing the engineers' visionary engineering expertise and strategic foresight.

The practical experience accumulated during this period, particularly the understanding of coke oven long-term operational patterns, provided valuable feedback data for subsequent design theories.

The hardworking spirit of Northwest China embodied by Jiao Nairen, 'using three stones to support a pot and setting up tents in mountain hollows', has also become a vital component of the cultural traditions within engineering and technical teams.

3. Autonomous construction of technological systems during growth and maturity phases

3.1. Technological leap and design theory enhancement in Baosteel engineering construction

Reform and opening-up ushered in a new phase of development for MCC Coking & Refractories. As a landmark project of China's modern steel industry, the Baosteel project provided MCC Coking & Refractories with a historic opportunity to benchmark against international advanced levels. MCC Coking & Refractories was fully involved in the construction of the Baosteel coking project, a process characterized by distinct "introduction-digestion-transcendence" features.

The first phase of Baosteel's coking project was entirely imported from Japan, while the second phase required performance standards matching or exceeding those of the first phase. The third phase, however, was entirely independently planned and designed by MCC Coking & Refining. When Baosteel's second-phase coking project commenced operations in 1991, its domestic production rate exceeded 90%, with the coke oven section achieving a remarkable 100% localization rate, the highest among all major projects in the second-phase development.

Compared with the first phase, the localized design has cumulatively saved the country over $300 million in foreign exchange. In 2001, the Baosteel Phase III Coking Project won the National Design Gold Award. This achievement marks that China's coking design theory has gained the capability to compete with international advanced levels.

3.2. Formation of large-scale coke oven design theory

In the 1990s, large-scale coke oven design became a global trend in coking technology development. Building on Baosteel's expertise, MCC Coke & Refractories gradually established a systematic theory for large-scale coke oven design. The core components of this theory include: the matching relationship between carbonization chamber height and width, heating uniformity control mechanisms, and thermodynamic stability analysis methods for furnace structures.

The large-scale development of coke ovens is not merely an enlargement in size, but also involves a reevaluation of fundamental issues such as heat transfer laws, combustion control, and structural mechanics. Through theoretical analysis, numerical simulation, and engineering validation, the design team of MCC Coke & Refractories gradually mastered the design principles for large coke ovens. By the late 1990s, China had acquired the capability to independently design 6-meter-class coke ovens, laying the theoretical foundation for subsequent breakthroughs in 7-meter and 7.65-meter-class coke ovens.

3.3. Institutional reform and theoretical inheritance in design

In 1998, with the reform of national institutions, MCC Coking and Refractories was placed under the direct administration of China Metallurgical Construction Group. In August 1999, it was renamed China Metallurgical Construction Group Anshan Coking and Refractories Materials Design and Research Institute. In October 2004, the company's first chairman, Mr. Yu Zhendong, restructured the company into MCC Coking and Refractories Engineering Technology Co., Ltd., with Ms. Tan Ping as its first general manager. The institutional reforms during this period had a profound impact on the inheritance and development of design theories.

After restructuring, MCC Coking & Refining has evolved from a standalone design institute into an international engineering company with EPC capabilities. This transformation necessitates expanding design theory beyond technical specifications to encompass the entire lifecycle dimensions of procurement, construction, and operation. Designers must not only evaluate technical feasibility but also coordinate multiple factors including cost control, schedule management, and risk mitigation. The transition to a "design-construction + operational services" model has opened new avenues for enriching and advancing design theory.

4. Breakthrough and leadership phase: Independent innovation and international leadership

4.1. Theoretical breakthroughs in National 863 program's clean and efficient coking technology

Entering the 21st century, facing mounting environmental pressures and intense international competition, MCC Coking & Refining launched a new round of technological breakthroughs. In 2008, MCC Coking & Refining took the lead in collaborating with Beijing University of Science and Technology and Angang Steel to apply for a National 863 Program key project under the theme "Development of Ultra-Large Capacity Top Charging Coke Oven Technology and Equipment" with the Ministry of Science and Technology. The project was officially approved in December 2009, marking the beginning of a technology innovation model featuring deep integration of industry, academia, and research.

The hallmark of innovation during this phase was a significant enhancement in theoretical depth. The research team not only addressed engineering design challenges but also delved into the fundamental mechanisms of coke oven heating technology and clean production technology. By establishing a NOx generation model for coke ovens, developing air cascade supply technology, and inventing an enclosed exhaust gas recirculation hole structure, they achieved source control of pollutant formation.

4.2. Systematization of large-scale coke oven design theory

The successful implementation of the 863 Program has propelled the systematic development of large-scale coke oven design theory at MCC Coking & Refining. The core components of this theoretical framework include as follows:

(1) Furnace type innovation theory: Building upon the 7-meter top-loading coke oven and 6.25-meter ramming coke oven, MCC Coking & Refining rapidly developed the 7.65-meter top-loading coke oven and 6.78-meter ramming coke oven. These furnace designs represent not mere scale-up but systematic optimizations based on in-depth understanding of heat transfer principles, combustion control, and structural mechanics;

(2) Combustion control theory: By implementing multi-node coupled regulation of heating technology, the longitudinal temperature difference of coke cake is maintained within $\leq$ 50°C, while the temperature coefficient of the coke oven's crosswise arrangement reaches $\geq$ 0.95. This achievement stems from precise simulation of airflow distribution within the combustion chamber and in-depth research on the regulation mechanism;

(3) Longevity design theory: Constructing a full-scale structural thermal-structural stability decomposition model for combustion chambers, and developing an integral mosaic large-biting coke oven combustion chamber structure, which increases the ultimate side load of furnace walls by over 10% and extends coke oven service life by more than 15 years.

In 2017, the project "Development and Application of Technology and Equipment for Ultra-large Capacity Top-loading Coke Ovens" won the only Special Prize in Metallurgical Science and Technology. In 2018, the project "Development and Application of Clean and Efficient Coking Technology and Equipment," with MCC Coking & Refractories as the first completing unit, won the National Science and Technology Progress First Prize, achieving a breakthrough in winning the National Science and Technology Progress First Prize for the first time for China Minmetals, MCC Group, and China Metallurgical Construction Industry.

4.3. Deep integration of dry quenching technology with energy conservation and emission reduction theory

Dry quenching technology serves as a critical component for achieving energy conservation and carbon reduction in coking processes. The large-scale serialized dry quenching technology independently developed by MCC Coking & Refining won the Second Prize of National Science and Technology Progress Award in 2009. The core theoretical innovation of this technology lies in the integrated design of coke cooling processes with waste heat recovery systems, enabling efficient cascaded energy utilization.

In theoretical research, MCC Coking & Refining has conducted in-depth studies on the thermodynamic principles of dry quenching coke technology, flow characteristics of circulating gases, and thermodynamic matching of boiler systems. By optimizing gas distribution devices and waste heat boiler parameters, the thermal recovery efficiency of dry quenching coke systems has been significantly enhanced. These project achievements have been applied to numerous domestic and international engineering projects, providing critical technical support for energy conservation and emission reduction in the coking industry.

4.4. Innovation and integration of flue gas treatment theories

Coke oven flue gas treatment remains a key challenge in coking environmental protection technologies. MCC Coke & Refining has achieved significant breakthroughs in flue gas desulfurization and denitrification, developing an activated carbon-based multi-pollutant synergistic control technology. The theoretical innovation of this technology lies in via studying the reaction mechanisms of activated carbon's high-efficiency denitrification and multi-pollutant synergistic control, researchers developed an adsorption reactor featuring zoned desulfurization-denitrification reactions and mobile layered activated carbon control. This approach has achieved industrial application results with denitrification efficiency exceeding 80%.

5. Transition and innovation phase: Green low-carbon and intelligent manufacturing

5.1. Theoretical transformation of design under dual carbon goals

The introduction of the "dual carbon" goals has posed new challenges and requirements for the coking industry. During this period, the design theories of MCC Coking & Refractories exhibited distinct characteristics of green transformation. From the perspective of integrated pollution and carbon reduction management, the R&D team systematically integrated multiple technologies including low-NOx combustion, efficient heat transfer, and waste heat recovery, establishing a theoretical framework for comprehensive optimization of coking processes.

In 2024, the "Development and Application of Synergistic Pollution Reduction and Carbon Mitigation Coking Technology" project led by MCC Coking & Refining achieved significant progress. The innovation lies in integrating source emission reduction, process control, and end-of-pipe treatment through unified design to achieve multi-objective optimization. The 65 coking projects implementing this technology can reduce NOx emissions by 40,000 tons annually, save 850 million yuan in gas costs, and cut CO2 emissions by 13.18 million tons.

5.2. Theoretical breakthrough in heat recovery technology for coke ovens

Heat recovery coke ovens represent another technical approach distinct from traditional chemical recovery coke ovens. MCC Coking & Refining has also achieved significant breakthroughs in this field. China's earliest heat recovery coke oven was designed by MCC Coking & Refining and put into operation in Houma, Shanxi in 2002. Over the following two decades, heat recovery coke ovens underwent four generations of design evolution and refinement.

In 2023, the fourth-generation JNHR4.2 clean horizontal tamping heat recovery coke oven independently developed by MCC Coking & Refractories was successfully commissioned at Henan Angang Zhoukou Iron & Steel Co., Ltd. The theoretical innovations of this fourth-generation heat recovery coke oven are reflected in multiple aspects: a full-process negative pressure operation design to eliminate unorganized emissions; optimized integration of furnace structure with advanced refractory materials; and synergistic improvements in coke oven mechanical automation coupled with cold-end control solutions.

The new-generation heat recovery coke oven has achieved an advanced level of controlling dry coal consumption at approximately 1.34 tons per ton of coke while generating over 1,000 kWh of electricity per ton of coke. Compared to traditional chemical recovery coke ovens, this technology significantly reduces carbon dioxide emissions under identical coke and power production conditions, making it a widely recognized environmentally friendly coke production process.

5.3. Digital evolution of intelligent manufacturing and design theory

In the field of coke oven heating control, intelligent heating control systems based on infrared temperature measurement, wireless sensor networks, and machine learning algorithms have been widely adopted. The system employs vertical fire channel automatic temperature measurement technology and dual-level regulation technology for rich gas main pipelines and branch pipelines, achieving a "main pipeline coarse adjustment + branch pipeline fine adjustment" two-tier control architecture. In a 5.5-meter ramming coke oven application, this system significantly improved furnace temperature stability and uniformity while reducing manual temperature measurement labor intensity. In the realm of coke oven mechanical automation, the fully automated ramming coke oven vehicle system enables one-touch full automation operations for coke pushers, coke interceptors, coal chargers, coke quenchers, and flue gas guide vehicles. The accompanying coke oven operation management system utilizes multi-dimensional dashboards and scenario analysis functions to achieve digital monitoring and management throughout the entire equipment operation process.

6. The intrinsic logic and historical implications of design theory evolution

6.1. Stage characteristics of technological paradigm evolution

Looking back at the 73-year development journey of MCC Coking & Refractories, the evolution of its coking and refractory professional design theories exhibits distinct phased characteristics as follows:

(1) The first stage was characterized by technology absorption and independent exploration, achieving a leap from technological dependence to autonomous design. The birth of the 58-type coke oven marked the initial formation of China's coking design technical paradigm;

(2) The second stage featured system construction and capability enhancement, with Baosteel projects enabling benchmarking and alignment with international advanced levels. Large-scale coke oven design theories gradually took shape, while refractory material design theories developed synergistically;

(3) The third stage was defined by independent innovation and international leadership, leveraging major scientific initiatives like the 863 Program to achieve systematic breakthroughs in clean and efficient coking technologies, earning the National Science and Technology Progress First Prize;

(4) The fourth stage was characterized by green transformation and intelligent upgrading, restructuring design theory systems toward dual-carbon goals and deeply integrating smart manufacturing technologies throughout coking design processes.

6.2. Core elements of design theory innovation

From the 58-type coke oven to the 7.65-meter top-loading coke oven, and from traditional ramming coke ovens to fourth-generation heat recovery coke ovens, furnace design has consistently served as the core vehicle for technological innovation. Each generation of furnace development has been accompanied by profound advancements in understanding heat transfer principles, combustion control, and structural mechanics. The evolution of coke oven technology has been deeply integrated with progress in refractory materials. The application of new materials such as high-conductivity silicon bricks, silica-based insulating bricks, and nanoscale thermal insulation coatings has provided the material foundation for performance enhancement. From reducing coking heat consumption to controlling NOx source generation, from waste heat recovery in dry quenching coke systems to coordinated multi-pollutant control using activated carbon, energy conservation and emission reduction objectives have consistently guided the direction of technological innovation.

6.3. Implications for the study of engineering technology history

The 73-year development journey of MCC Jiaonai has provided abundant case resources for the study of engineering technology history. Several universally significant insights can be distilled from this case: the cumulative and leapfrog nature of engineering technology knowledge. Advances in engineering technology manifest not only as incremental improvements in daily operations but also as breakthroughs at critical junctures. The success of the 863 Program demonstrates that organized industry-academia-research collaboration can effectively facilitate technological leaps; the interdependent relationship between design theory and engineering practice. Design theory originates from engineering practice and, in turn, guides it. Leveraging extensive empirical data accumulated from numerous engineering projects, MCC Jiaonai continuously refines its design theories, while these theoretical achievements are validated and refined in new projects. MCC Jiaonai's technological innovation is not an isolated corporate endeavor but is achieved through collaborative interactions with universities, research institutes, equipment manufacturers, and project owners. The formation and evolution of such a technological innovation ecosystem represent a crucial dimension for understanding the development of China's engineering technology.

7. Conclusion

The 73-year development journey of MCC Coking & Refractories is a microcosm of the modernization process of China's coking industry. MCC Coking & Refractories has always stood at the forefront of China's coking engineering technology development, leading industry technological progress through independent innovation. The design theory of MCC Coking & Refractories has undergone an evolutionary process from technology introduction and independent exploration to system construction and international leadership, forming a unique technical paradigm centered on furnace structure innovation, based on refractory material research and development, and guided by energy conservation and emission reduction goals. Facing the constraints of dual carbon targets, the wave of intelligent manufacturing, and the challenges of international competition, design theory innovation remains a long and arduous task. As long as independent innovation are adhered to, serve the national interests, and deepen the integration of industry, academia, and research, China's coking engineering technology will surely write new glorious chapters. MCC Coking & Refractories will undoubtedly contribute more wisdom and strength to the high-quality development of China's coking industry on the new journey of building a world-class enterprise.

Disclosure statement

The author declares no conflict of interest.

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