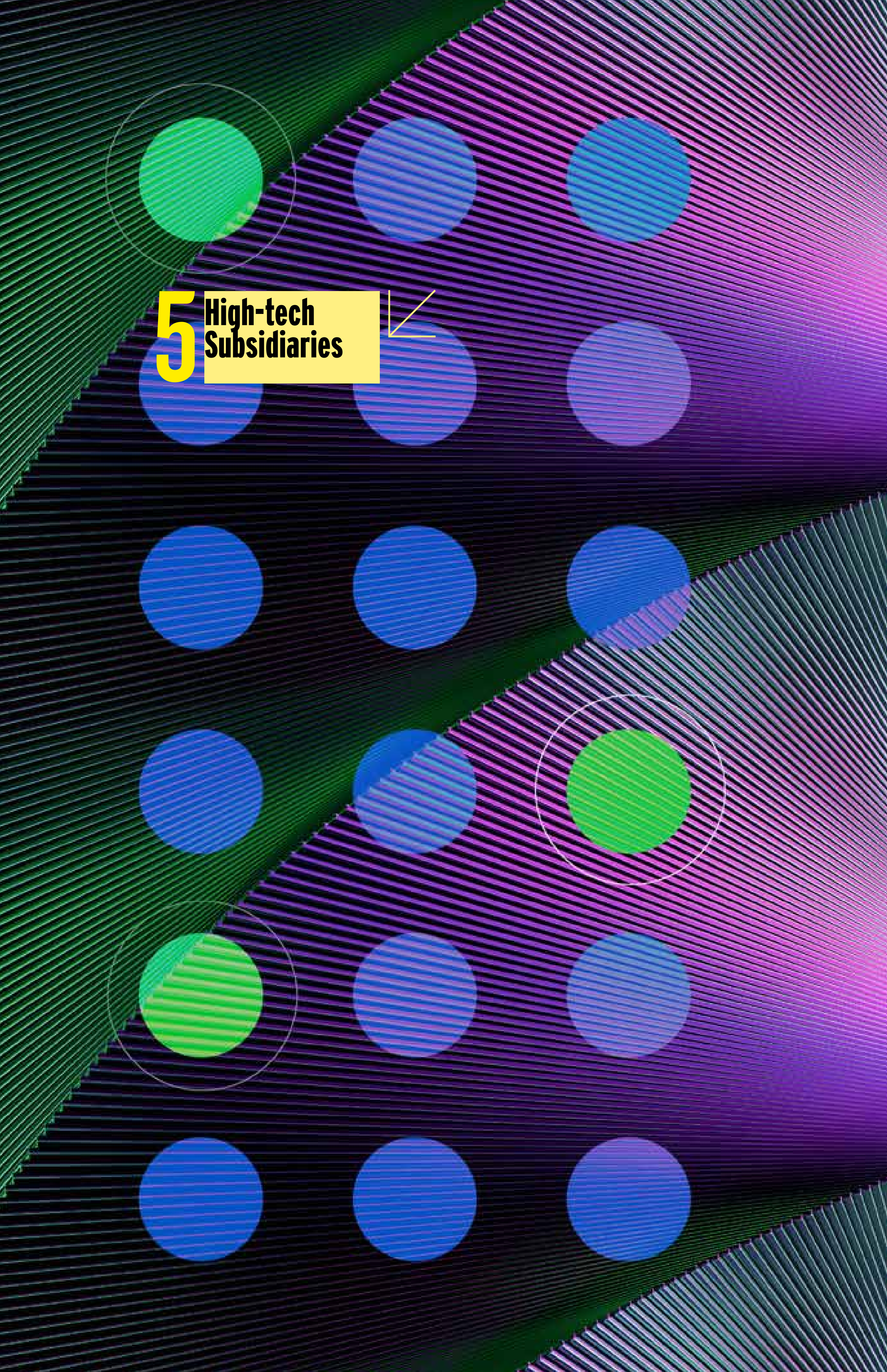
The Driving Force: Technological Innovation

HyCROF: Decarbonization of Blast Furnace

Achieve Clean Steel: China's 1st 1mpta Hydrogen-based Shaft Furnace

Innovative Prowess



IMPORTANT **DATA**

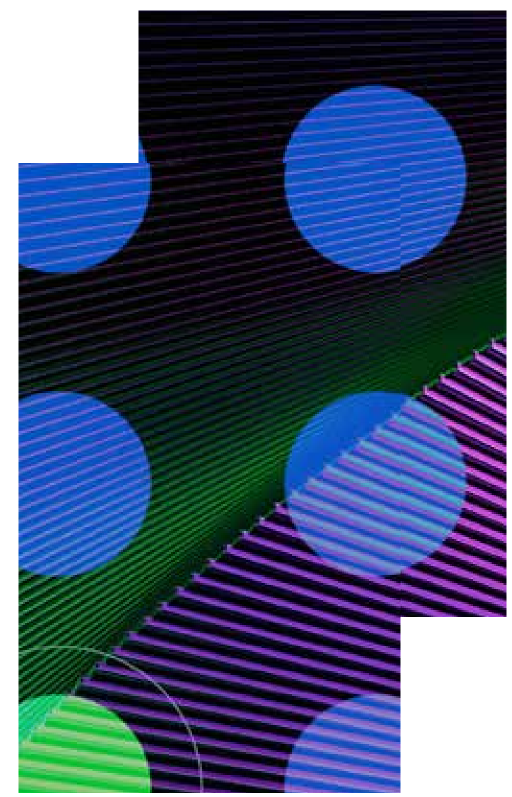
The "National Industrial Flue Gas Dust Removal Engineering Technology Research Center" under the Ministry of Science and Technology

Supporting company for the "National Environmental Protection and Industrial Flue Gas Control Engineering Technology Center" under the Ministry of Ecology and Environment

Jointly established the "National Engineering Research Center for Synergetic Control of Air Pollutants and Greenhouse Gases" under the National Development and Reform Commission with Tsinghua University and other units

The only academicians and experts research platform focuses on ultra-low emission technology in the iron and steel industry

The formal State Administration of Work Safety: the Analysis and Identification Laboratory of Occupational Hazards in Metal and Nonmetal Mines, the National Quality Inspection and Testing Center for Personal Protective Equipment, the Mine Dust Poison and Radiation Hazard Detection Technology Laboratory



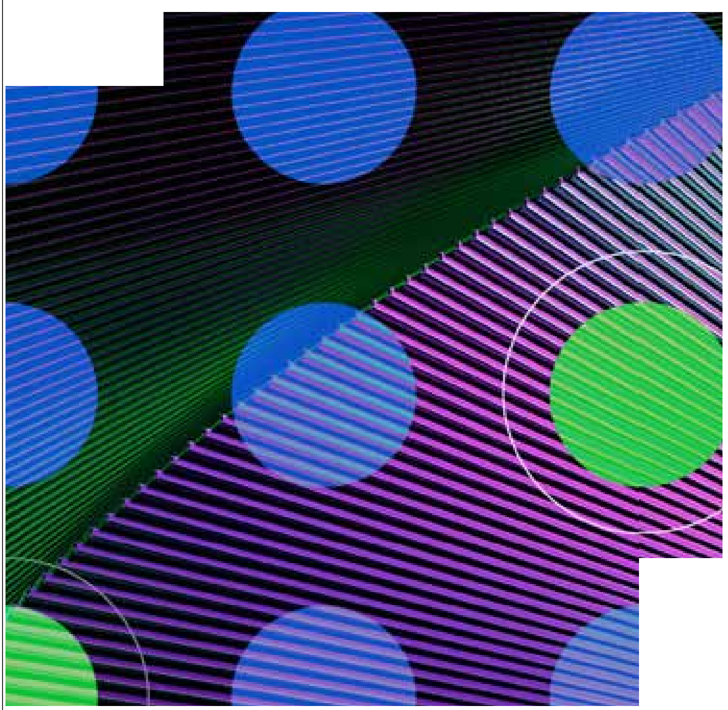
IMPORTANT DATA

Participated in 18 National R&D projects

Issued 2 safety regulations and 45 safety technical standards

Editor-in-chief / co-editor for 90 national standards

Holder of 348 valid patents



18x National R&D

90 National standards

2 Safety regulations

45 Safety technical standards

348 Valid patents

Complete qualifications

Fully qualified in a various of sectors and industries, including metallurgy, construction, communication towers, non-metallic minerals and raw material processing, and environmental engineering.

Grade A of engineering design in the metallurgical industry, construction industry (construction engineering), electronic communication, radio and television industry (communication tower), environmental engineering (solid waste treatment and disposal engineering), municipal industry (drainage engineering and environmental sanitation engineering), and environmental engineering (water pollution prevention and control engineering and air pollution prevention and control engineering)

Grade B of engineering design in the environmental engineering (physical pollution prevention and control engineering), municipal industry (water supply engineering), and fire protection facilities engineering

Grade A of engineering consulting in ecological construction and environmental engineering and municipal public works. Grade B of engineering consulting in metallurgical (including steel and non-ferrous metallurgy)

Grade I for professional contracting of environmental protection projects, **Grade II for professional contracting** of fire protection facility projects

Have qualifications for professional contracting of special projects (structural reinforcement)

Grade A of Hubei Province environmental pollution control (water pollution control and environmental restoration engineering)

Class I operation services of dust removal, desulfurization, and denitrification facilities (dust removal facilities, desulfurization facilities, and denitrification facilities); Class II operation services of pollution control facilities (industrial wastewater)

Work safety inspection and testing agency qualification certificate

Quality inspection agency for construction projects (main structure and steel structure inspection)

Safety evaluation agency qualification

Standardized work safety (Class II, including metal and non-metal mines, hazardous chemicals, and industry and trade industries)

Category I, technical service institution of occupational health

China Inspection Body & Laboratory Mandatory Approval (CMA) issued by the Certification & Accreditation Administration of China

Member of the expert committee of the "Steel Industry Low-carbon Work Promotion Committee" established by the China Iron and Steel Association

Member of the board of directors of the **Chinese Society for Metals**

Member of the board of directors of the **China Metallurgical Construction Association**

Member of the board of directors of the **China Chamber of Commerce for Import and Export of Machinery and Electronic Products**

Member of the board of directors of the **China International Contractors Association**

Member of the board of directors of the **China Engineering and Consulting Association**

Member of the board of directors of the **China Association of International Engineering Consultants**

Chair and secretary-general of the **Bag Filter Committee of China Association of Environmental Protection Industry**

Member of the board of directors of the **Chinese Society for Environmental Sciences**

Deputy Director of the **Air Cleaning Equipment Sub-committee of the Technical Committee for Environmental Protection and Standardization of Machinery Industry**

Industrial Dust Protection Committee of the China Occupational Safety and Health Association

MAJOR AWARDS

1 State Scientific & Technological Progress Award

First prize of the 2020 State Scientific and Technological Progress Award - Advanced Treatment Technology and Application of Industrial Flue Gas Multi-Pollutant Control by Sinosteel Tiancheng

Second prize of the 2020 State Scientific and Technological Progress Award - Technology and Application of Ultra-low Emission Control for Multiple Pollutants from Multiple Processes in the Iron and Steel Industry by Sinosteel Tiancheng

2 Engineering News-Record (ENR)

Since 2008, Sinosteel MECC has been listed on the ENR Top 250 International and Top 250 Global for 16 years and hit a new high in 2019, ranking 107.

3 National Quality Engineering Award

HBIS Group's 2x4.8mtpa Traveling Grate Iron Ore Pellet Project, which was contracted and constructed by Sinosteel on an EPC basis, won the 2022 /2023 National Quality Project Gold Award

The Gas Cleaning Project for the Relocation Project of Hebei Risun Coking, which was contracted and constructed by Sinosteel on an EPC basis, won the 2020/2021 National Quality Engineering Award.

The 3mpta Copper Ore Beneficiation Plant project of Cudeco in Australia, which was contracted and constructed on an EPC basis won the 2018/2019 National Quality Engineering Award.

The 2x600-MW Unit 2 of the Power Plant of ICDAS BIGA in Turkey, which was contracted and constructed on an EPC basis, won the 2016/2017 National Quality Engineering Award.

The 1.2mtpa MSPL Pelletizing Plant Project in India, which was contracted and constructed by on an EP basis, won the 2014 / 2015 National Quality Engineering Award

The 1.2mtpa MSPL Pelletizing Plant Project in India, which was contracted and constructed by on an EP basis, won the 2014/2015 National Quality Engineering Award

The No.4 Blast Furnace Project of ISDEMIR in Turkey, which was contracted & constructed on an EPC basis, won the 2012 /2013 National Quality Engineering Award.

The 950mm Hot-strip Rolling Strip Project of Tosyali Osmaniye steel mill in Turkey, which was contracted and constructed on an EP basis, won the 2011/2012 National Quality Engineering Silver Award.

4 Ministry of Ecology and Environment

2021 National Advanced Pollution Prevention & Control Technology Catalogue (air pollution prevention and control field) - Catalytic cracking regeneration flue gas bag filtering + wet desulfurization cleaning technology by Sinosteel Tiancheng;

First Prize of the 2019 Environmental Protection Science and Technology Awards —— Ultra-low emission control technology for multiple pollutants from multiple processes and its application by Sinosteel Tiancheng;

2018 National Advanced Pollution Prevention and Control Technology Catalogue (air pollution prevention & control field) - Pre-charged bag filter technology & catalytic cracking regeneration flue gas dedusting and desulfurization technology by Sinosteel Tiancheng;

5 Ministry of Industry and Information Technology

Catalogue of Major Environmental Protection Technology and Equipment Encouraged by the State (2020 Ed.) —— Pre-charged bag filter, coke oven flue gas multiple pollutants dry co-processing equipment, and catalytic cracking regeneration flue gas treatment equipment by Sinosteel Tiancheng

6 Ministry of Education

Special Prize of the 2019 Outstanding Achievements Award in Scientific Research of Colleges and Universities - Key technologies for an in-depth treatment of multiple pollutants in flue gas and their application in non-electrical industries by Sinosteel Tiancheng

7 National Development and Reform Commission

Green Technology Promotion Catalogue (2020) - Pre-charged bag filters for capturing fine particles in flue gas from kilns and furnaces to achieve an ultra-low emission developed by Sinosteel Tiancheng;

8 Metallurgical Science and Technology Award

Sinosteel MECC's self-developed "Equipment Set and Key Technologies for High-efficiency and High-precision Controlled Rolling of Double High- >>> speed bar" won the 2nd prize of the 2022 Metallurgical Science and Technology Award

Sinosteel MECC's self-developed "Integrated Development and Application of Core Technology for Large Belt-roaster Pellet" won the second prize of the 2018 Metallurgical Science and Technology Award

9 China Engineering and Consulting Association

Sinosteel MECC has been selected for the 2019 and 2020 List of Overseas Engineering Benchmarking Enterprises in the National Survey and Design Industry consecutively

10 China Association for Science & Technology

Top 10 Scientific and Technological Advances in China's Ecological Environment in 2019 — "Key Breakthroughs in Core Technology of Ultra-low Emission in China's Steel Industry" and "Collaborative Deep Treatment Technology for Multiple Pollutants in Industrial Flue Gas" by Sinosteel Tiancheng

11 China Association for Work Safety

The Second Prize of Scientific & Technological Progress Award in 2021 — research on the standardized management system for work safety in enterprises and the formulation and application of national standards conducted by Sinosteel SEPRI

12 World Metals

"Top 10 Technology Highlights of the Global Steel Industry in 2021" — the Hydrogen-enriched Carbon Recycling Blast Furnace Pilot Project constructed by Sinosteel MECC on an EPC basis for Bayi Iron & Steel Co., Ltd. and intelligent sintering control system developed independently by Sinosteel MECC

"Top 10 Technology Highlights of the Global Steel Industry in 2020" — the Twin High-Speed Bar Mill Project for Hunan Valin Group LY Steel Co., Ltd. constructed by Sinosteel MECC on an EP basis, which is also the first domestically manufactured twin high-speed bar mill

13 China Metallurgical News

"Green and Low-Carbon Technologies" on the 2021 Green List of Steel and Industrial Chain — the belt-roaster pellet technology, DRI technology, and long product rolling technology of Sinosteel MECC, and the technology of pre-charged bag filters for capturing fine particles in flue gas from kilns & furnaces to achieve an ultra-low emission of SinosteelTiancheng

Green Benchmarking Enterprises of the Steel Industry Chain in 2021 — Sinosteel MECC and Sinosteel Tiancheng

A FORWARD LOOKING TECHNIQUE OF LOW CARBON IRON MAKING

HyCROF OVERVIEW & HIGHLIGHTS

TECHNICAL RESEARCH & ACHIEVEMENTS

DIGITAL EMPOWERMENT

HyCROF

Hydrogen-enriched Carbonic oxide Recycling Oxygenate Furnace

On July 15, 2020

China Baowu established a testing platform for low-carbon metallurgy in Xinjiang Bayi Iron & Steel, conducting industrial experiments of low-carbon metallurgy with its original 430m³ blast furnace. Pioneering in Baowu's green low-carbon metallurgical technology, the experiment aimed to lower carbon emissions by 30% while greatly increase the utilization coefficient of smelting furnace.

In addition, China Baowu, upholding its political responsibility & historical mission of carbon peaking and carbon neutrality, was determined to contribute its own solutions to global green low-carbon iron-making. A closed-circuit injection of pure oxygen and blast furnace gas with carbon dioxide removed and coal injection for comprehensive smelting to reduce solid fuel consumption by 30%. Until today, 20% carbon emission reduced.

HyCROF, a forward-looking technique of low-carbon iron making, features safety, stability, smoothness, high efficiency, strong anti-fluctuation ability, low manufacturing cost, and good compatibility with traditional manufacturing processes.

On November 16, 2022

Chen Derong, Chairman of China Baowu, announced at the Global Low-Carbon Metallurgy Innovation Forum 2022 that China completed its first 430m³ low-carbon metallurgical blast furnace, which marked that Sinosteel MECC recognized the HyCROF process of Bayi Iron & Steel in a large-scale industrial production for the first time.

The process achieved a phased goal of reducing carbon emissions by 20%, which represented a major breakthrough in global low-carbon metallurgical technology and also the latest achievement in the engineering of the low-carbon metallurgy developed by Sinosteel MECC as an EPC contractor.

Thanks to aforementioned valuable experience, Sinosteel MECC will continue to facilitate the uograding and rebuilding of 2500m³ HyCROF so as to find out a green, low-carbon and highly efficient solution to blast furnaces decarbonization.

01

HyCROF OVERVIEW & HIGHLIGHTS

The conventional blast furnace enjoys an extremely high thermal efficiency (about 93.5%) but low carbon utilization efficiency (only 65.5%), and the remaining carbon was basically consumed by the furnace top gas. If the carbon in gas cannot be fully utilized, the traditional blast furnace will not be possible to reduce carbon emissions in large scale.

93.5%
High Thermal Efficiency

65.5%
Low Carbon Utilization

In order to recover and utilize the furnace top gas, the quality of furnace top gas must be improved to increase the content of effective components in it. Given the composition of gas from the traditional blast furnace, it is not an economical way to denitrify or decarbonize the top gas under the current technical conditions, which in turn may affect the recovery and utilization of the carbon in gas.

Full-oxygen smelting technology

However, HyCROF adopts a full-oxygen smelting technology to reduce the nitrogen content in the top gas, and uses CO_2 removal devices to improve the quality of the top gas. Then it heats the decarbonized gas to over 1200°C and injects it back into the blast furnace for maximizing the carbon utilization in the blast furnace.

In this process hydrogen-enriched gas can be injected into the decarbonized gas for smelting and further reduce CO_2 emissions during iron making.

As the executing unit for the engineering (EPC contractor), under the guidance of Baowu Central Authority Research Institute, Sinosteel MECC has made deep cooperation with Bayi Iron & Steel throughout the process research, design, core equipment R&D, summary of production and operation experience, development of standards for safety technology and other arrangements to form a package of technologies equipped with complete core technologies.

Reduce CO_2 emissions during iron making

Thanks to the theoretical and experimental verification, the basic principle of HyCROF has been verified and the engineering of this new process has been completed.

02

TECHNICAL RESEARCH & ACHIEVEMENTS

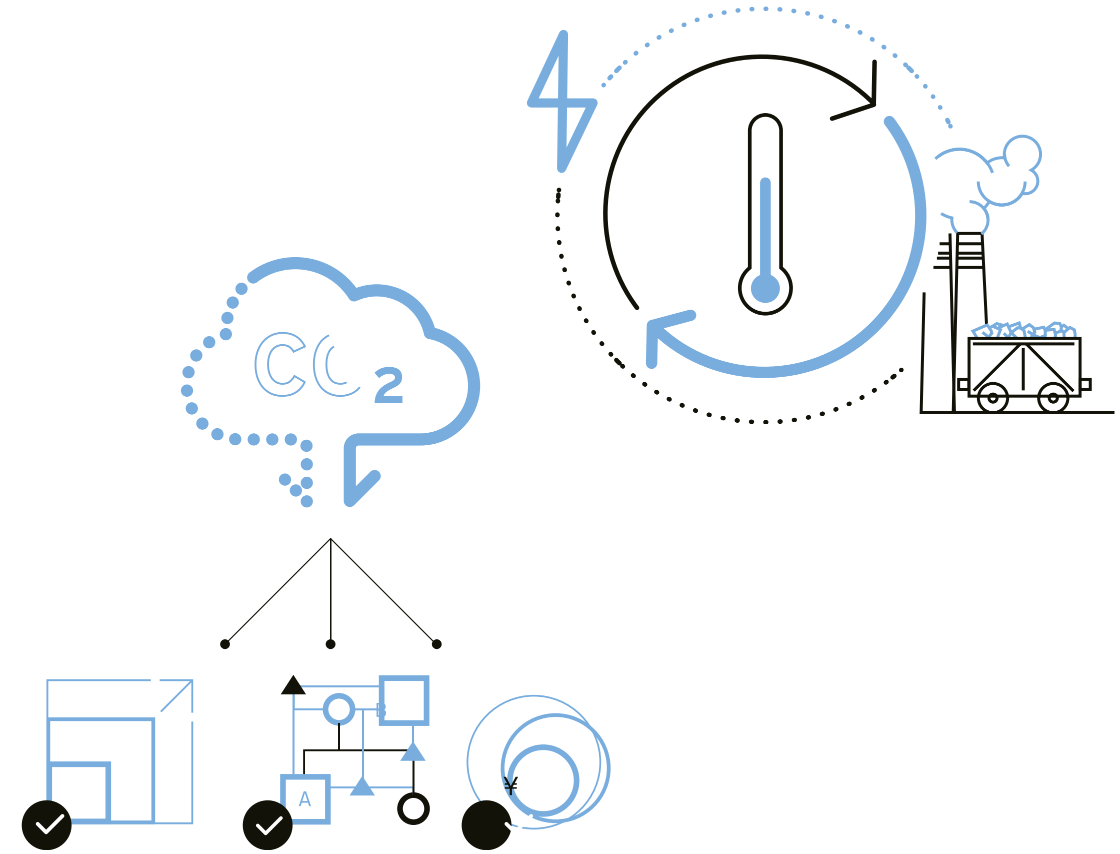
Thanks to the theoretical and experimental verification the basic principle of HyCROF has been preliminarily understood and the engineering of this new process has been completed. The process has been practiced with increasing smoothness in production with all steps perfectly aligned and the 2500m^3 HyCROF engineering design completed.

Heating highly reductive gas through regenerative stove

The top combustion hot blast stove has been developed to successfully heat the gas to above 1200°C, breaking through the technical barriers in safety concerns and carbon precipitation during the gas heating process. At the same time, gas electric heating and gas plasma heating devices have been installed to replace fossil fuel with electricity in heating and explore technologies for green-power iron making and maximized carbon reduction.

HyCROF and injection facilities have been developed to achieve the design of furnace type, furnace body, hot gas injection facilities, oxygen injection facilities and coal injection facilities under the new process, and eliminate the barriers in simultaneous injection of hot gas, oxygen, and pulverized coal.

The CO_2 removal devices compatible with HyCROF has been successfully developed to solve the outstanding problems of large scale, complex operating conditions, heavy investment and high costs of the CO_2 removal devices and lay a solid foundation for the commercial operation of HyCROF.

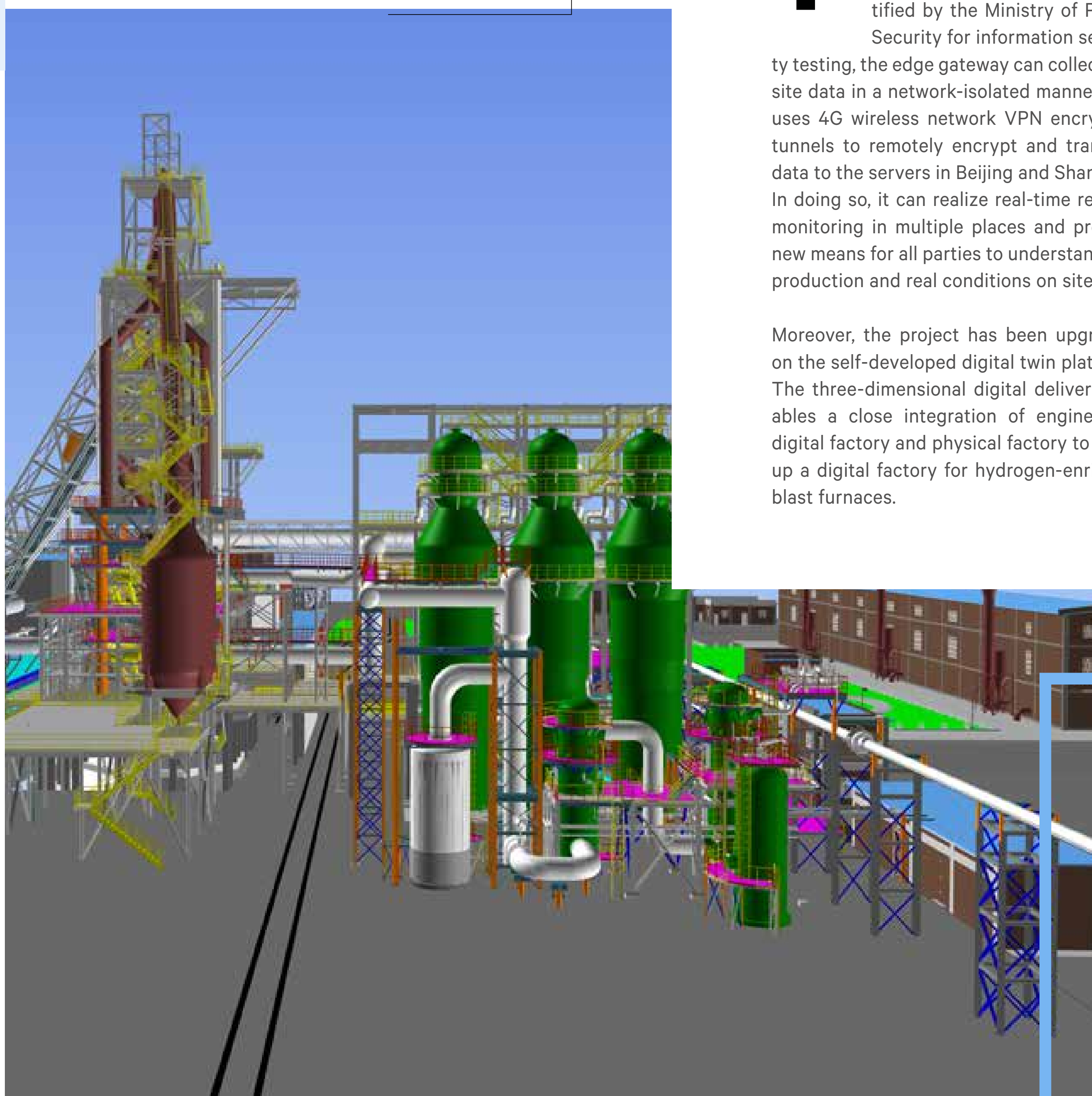


03

DIGITAL EMPOWERMENT

The project has not only realized the three-dimensional digital design, but also developed supporting control cockpit software featuring a human-computer interaction interface, multi-site collaborative monitoring and real-time detection and control to fully support the follow-up R&D of Bayi Iron & Steel.

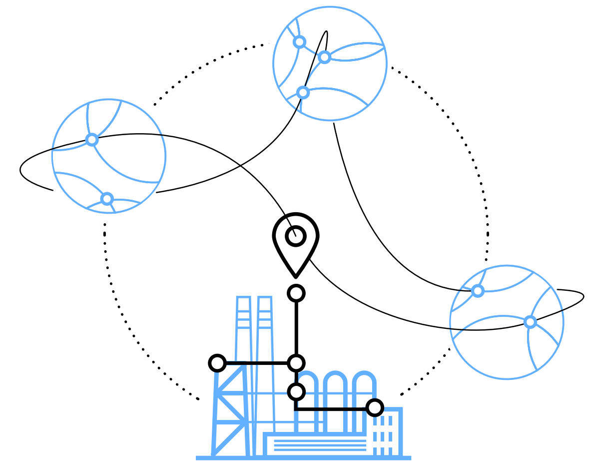
This project has also equipped with a set of Internet of Things (IoT) platform based on a real-time database and time series database. The platform is composed of application portal, console, platform management, tenant management, platform application, extended application and 3D digital twin application in a distributed, micro-service and multi-tenant architecture. The configuration of the IoT platform includes factory model, equipment object model, equipment management, data calculation, alarm triggering and message notification, monitoring operation and maintenance, and comparison and analysis of object model specification query.



Digitalization: upgraded on the self-developed digital twin platform

The operating platform also enjoys multi-site access. With network security products certified by the Ministry of Public Security for information security testing, the edge gateway can collect on-site data in a network-isolated manner and uses 4G wireless network VPN encrypted tunnels to remotely encrypt and transmit data to the servers in Beijing and Shanghai. In doing so, it can realize real-time remote monitoring in multiple places and provide new means for all parties to understand the production and real conditions on site.

Moreover, the project has been upgraded on the self-developed digital twin platform. The three-dimensional digital delivery enables a close integration of engineering digital factory and physical factory to build up a digital factory for hydrogen-enriched blast furnaces.



China Baowu began to scale up its HyCROF production **In November 2022,** and planned to duplicate the success of the third-phase engineering of HyCROF experiments in the significant upgrading and rebuilding of the three 2500m³ HyCROF in the charge of Sinosteel MECC. Based on the new process, it aims to build a demonstration project with gas self-circulation injection and supporting public auxiliary system. Research and development of high-temperature gas self-circulation injection has been conducted in full-oxygen smelting for low-carbon metallurgy development in large and medium-sized blast furnaces, so as to realize carbon reduction for the blast furnace system.

An important technical path for reducing carbon emissions by 30% in 2025.

It is an important technical path for "reducing carbon emissions by 30 percent in 2025" of China Baowu to transform the existing 2,500m³ traditional blast furnace into HyCROF and push forward its upgrade. Also, it is of great significance in leading the low-carbon transformation of the long-process blast furnaces in the global steel industry and providing practical green solutions for the decarbonization in the iron and steel industry.

A GIANT LEAP TOWARDS Steel Decarbonization

MAIN PROCESS
FLOW-GAS TREATMENT
FLOW OF PROJECT

D&M OF CORE
PROCESS EQUIPMENTS
"MADE IN CHINA"

DIGITALIZED
DESIGN SYSTEM
DEVELOPMENT

Hydrogen-based Shaft Furnace

Sinosteel MECC undertaking China's First 1mtpa Hydrogen-based Shaft Furnace

FEB/15/2022

Sinosteel MECC& Baosteel Zhanjiang inked a milestone deal for a 1mtpa-scale hydrogen-based shaft furnace project on February 15, 2022, marking the kickoff of this groundbreaking low-carbon project.

This project will enable Baosteel Zhanjiang to reduce its CO_2 emissions by over 500,000 tons when producing the same amount of hot metal compared to the traditional iron-making process, bringing it closer to becoming the world's most productive and environment-friendly quality carbon steel base. It will also create China's first 1mtpa-scale hydrogen-based shaft furnace — the first commercial DRI production line that integrates hydrogen and COG — helping China Baowu and the steel industry to reach their carbon reduction and "dual carbon" goals. This endeavor will pave the way for regional clean energy optimization and economic development.

When hydrogen is used to reduce iron oxide, the main products are metallic iron and water vapor. The tail gas after reduction has no adverse effect on the environment and can significantly reduce the environmental burden. Producing hydrogen with clean energy and reducing iron ore with hydrogen has the potential to achieve nearly zero carbon emission in the steelmaking process, which is one of the important paths to carbon neutrality in the steel industry. The one million-ton-level hydrogen-based shaft furnace project is designed to produce one million tons of direct reduced iron per year. The "DRI + Electric Furnace" steelmaking process reduces carbon dioxide emissions by 50-60% compared with the traditional "Blast Furnace + Converter" steelmaking process, which is one of the important paths to carbon neutrality in the steel industry.

Producing hydrogen with clean energy and reducing iron ore with hydrogen has the potential to achieve nearly zero carbon emission in the steelmaking process, which is one of the important paths to carbon neutrality in the steel industry.

DRI TECH

Sinosteel MECC, the first industrial engineering and technical service company to construct DRI projects has already built two of the world's largest DRI projects the Tosyali 2.5mpta DRI project in Algeria and the AQS (Qatar Steel Company) 2.5mtpa DRI project in Algeria, both of which are in operation now. It is also general contracting DRI project of the Mutun integrated steel in Bolivia and the second 2.5 million ton 2.5mtpa DRI project of Tosyali in Algeria.

Drawing on its wealth of experience in developing, engineering and practicing pioneering technologies for direct reduction of iron, Sinosteel MECC acted as the design unit for the 1 million-ton-level hydrogen-based shaft furnace project of Baosteel Zhanjiang Steel & Iron Carbon Neutral Demonstration Plant, successfully completing the feasibility study and preliminary design, and taking charge of process package and equipment introduction, development and supply of core process equipment and materials, development and supply of automation control system, commissioning and training services. The project adopted digital design and established equipment, civil engineering, steel structure, architecture, pipeline and electrical models for the entire plant. Through collaborative design of various specialties, a 3D visualization plant model was built. On December 23, 2022, the project witnessed the hoisting of the furnace shell, officially entering the equipment installation stage. The furnace shell is positioned at the lowest section of the cone end body, 7.2 meters high and 18 tons in weight.

Hydrogen-based shaft furnace

01

MAIN PROCESS FLOW-GAS TREATMENT FLOW OF PROJECT

The R&D and technical team of Sinosteel MECC shared many details with us, including the development of process layout, core equipment and materials as well as digital design, unveiling the mystery of China's first million-ton hydrogen-based shaft furnace.

Lu Pengcheng(left), Chairman of Sinosteel E&T and Tian Guobing(right), SVP of Obei

coke oven gas + hydrogen + natural gas

The raw material pellets are first placed onto a vertical belt conveyor, which carries them to the top of the reduction furnace. The pellets then travel through a chute, feed bin, and a series of valves and pipes, before entering the reduction shaft furnace. The pellets and reducing gas are charged from the top and middle of the furnace respectively, with the oxidized pellets falling by gravity and the reducing gas flowing oppositely from the bottom to the top, thereby reducing the iron oxide in the pellets to iron. The reduced gas is discharged from the exhaust port on the upper side of the furnace and enters the circulating gas loop. The lower conical structure of the furnace is a cooling zone, filled with natural gas, which cools the reduced materials down to below 80℃, before they are discharged from the shaft furnace to the CDRI treatment system.

The hydrogen-based shaft furnace utilizes coke oven gas, hydrogen, and natural gas as its makeup gas, with the ratio being freely adjustable. The coke oven gas from the COG compression system is first introduced into the cone section of the furnace, where contact cracking with high-temperature DRI reduces BTX and heavy hydrocarbon components. The gas exiting the cone section, is scrubbed and cooled, before entering the process gas loop. The gas at the bottom is injected preceding the process gas compressor, and then mixed with the recovered process gas.

A closed process gas loop

The natural gas and hydrogen used as the reducing agent are injected into the process gas loop at the outlet of the CO_2 collection device. The humidity of the mixed gas is adjusted through a humidifier, then heated to 950°C in a reheating furnace. Oxygen is injected into the high-temperature reducing gas pipeline in front of the shaft furnace for non-catalytic partial oxidation, thereby heating the reducing gas to the required temperature for reforming and reduction reactions within the furnace.

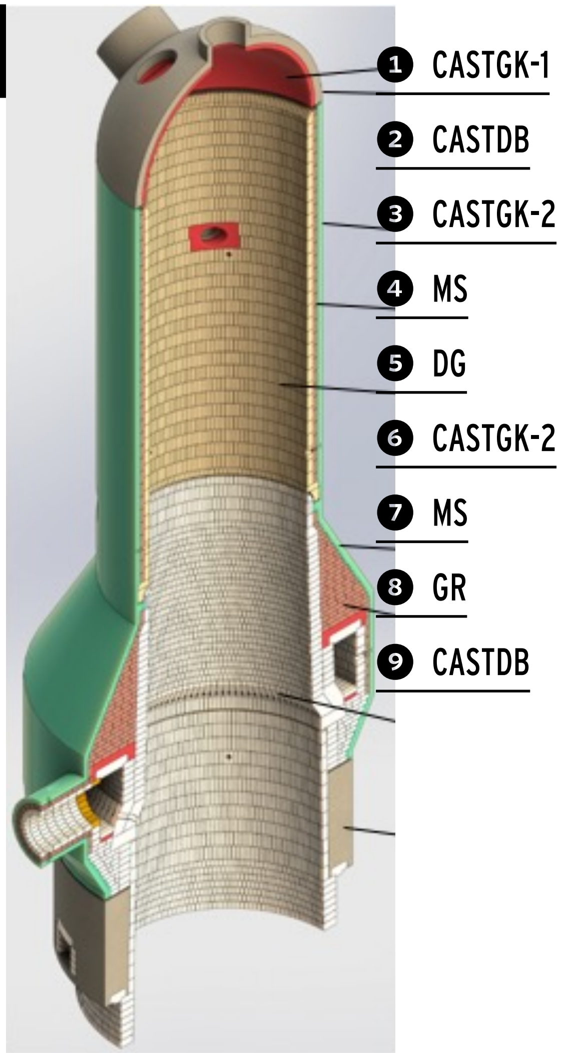
The hot reducing gas is evenly supplied into the reduction section of the shaft furnace, where it rises to come into full contact and reaction with the oxidized pellets. As soon as it is in contact with solid materials in the shaft furnace, methane initiates in-situ reforming. When leaving the shaft furnace, the top gas passes through a top gas heat exchanger to recover its heat for steam production, before being directed to the cooling and scrubbing systems. Here, the water produced during the reduction process is condensed and removed from the gas, and most of the dust in the gas is separated. Then, the gas is boosted by a process gas compressor and directed to an activated MDEA carbon dioxide collecting unit, where the CO_2 generated during the reduction is selectively removed. Finally, the process gas and the makeup gas mix and are delivered to the reheating furnace, thus establishing a closed process gas loop.

Hydrogen-based shaft furnace

02

DEVELOPMENT AND MANUFACTURING OF CORE PROCESS EQUIPMENT & MATERIAL

Notably, Sinosteel MECC team has independently designed and produced an active-MDEA-based CO_2 collecting system, its process package and amine liquid.



Sinosteel MECC has completed the over-all engineering of most of the core process equipment of the project, with the exception of the production process package, the reheating furnace, the top gas exchanger, and the high-pressure material valves which have been sourced from overseas.

From material systems to tower equipment and gas treatment internals like gas separators, quench towers, demisters and coolers, as well as other raw material and finished product processing equipment and water treatment equipment, including a wet ESP for cold DRI. Notably, they have independently designed and produced an active-MDEA-based CO_2 collecting system, its process package and amine liquid. Additionally, they they can provide tailor-made solutions to fit different application scenarios following simulation experiments with high hydrogen-ratio, high temperature and high pressure, gas-solid reaction simulation with Factsage, and corrosion resistance tests.

Hydrogen-based shaft furnace

03

DIGITALIZATION OF HYDROGEN-BASED SHAFT FURNACE

Digital design is applied to improve efficiency

The Sinosteel MECC team designed the process, equipment & pipelines

and pipelines of the project based on chemical engineering principles, while utilizing metallurgical engineering practices for the design of other disciplines, thereby creating a set of process, labor division, and drawing system for the integrated design of steel-chemical co-production. This helps to develop and accumulate expertise for the design of similar low-carbon metallurgy and steel-chemical co-production projects in the future.

Also, Sinosteel MECC makes digital delivery of the project possible, and a delivery platform will be established to ultimately form a digital twin of the project through collecting information and analyzing checks at various stages of the project construction.

TOP-DOWN DESIGN

Adopting a top-down forward 3D design, the design inputs are all from the process PID drawings.

DESIGN INTERFACE

The visualization design interface, coupled with periodic design reviews, effectively avoids field installation collisions.

POWERFUL DATABASE

With a powerful database support, it ensures the consistency between the drawing information and the database.

PREFABRICATION

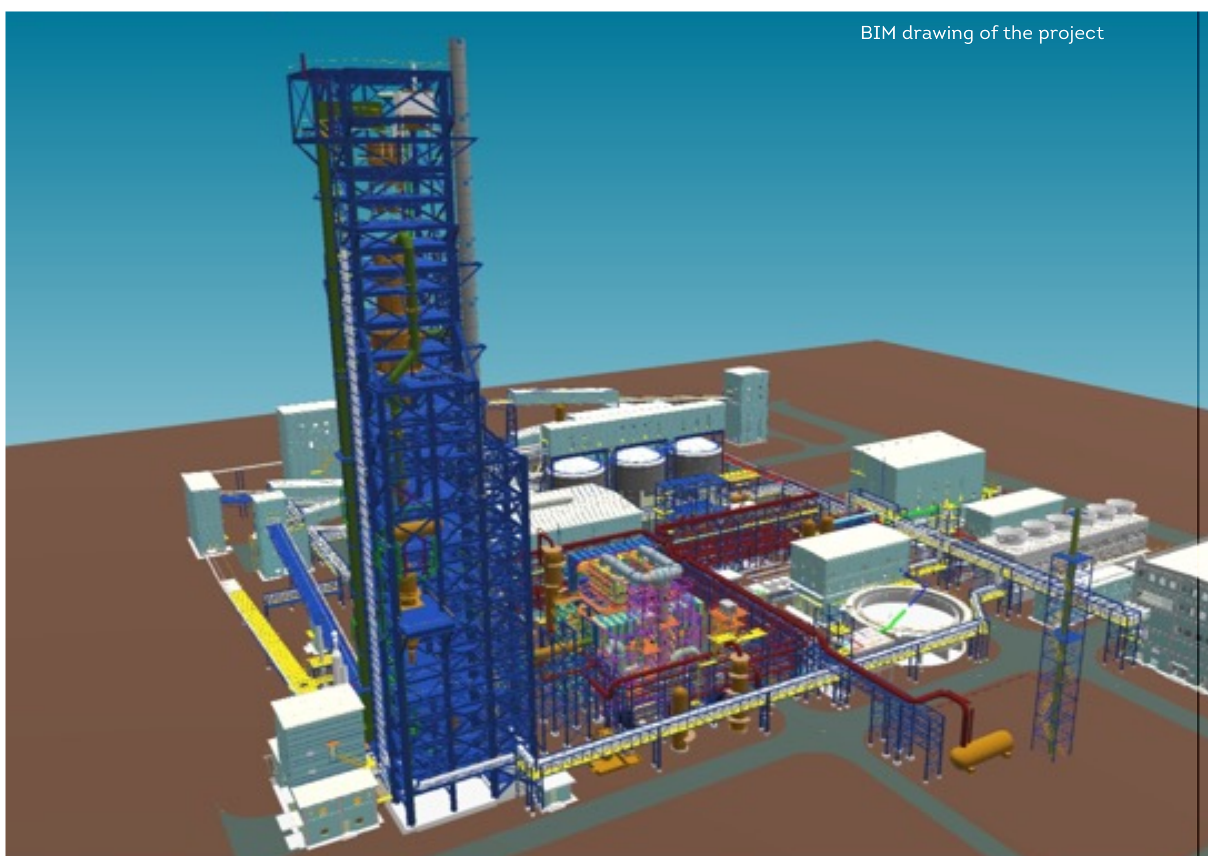
The prefabrication of pipes shortens the installation period on site and increases the construction efficiency.

SUPERVISION

Supported by efficient installation supervision, the installation personnel carry out the installation according to 3D models.

OUTPUT TOOLS

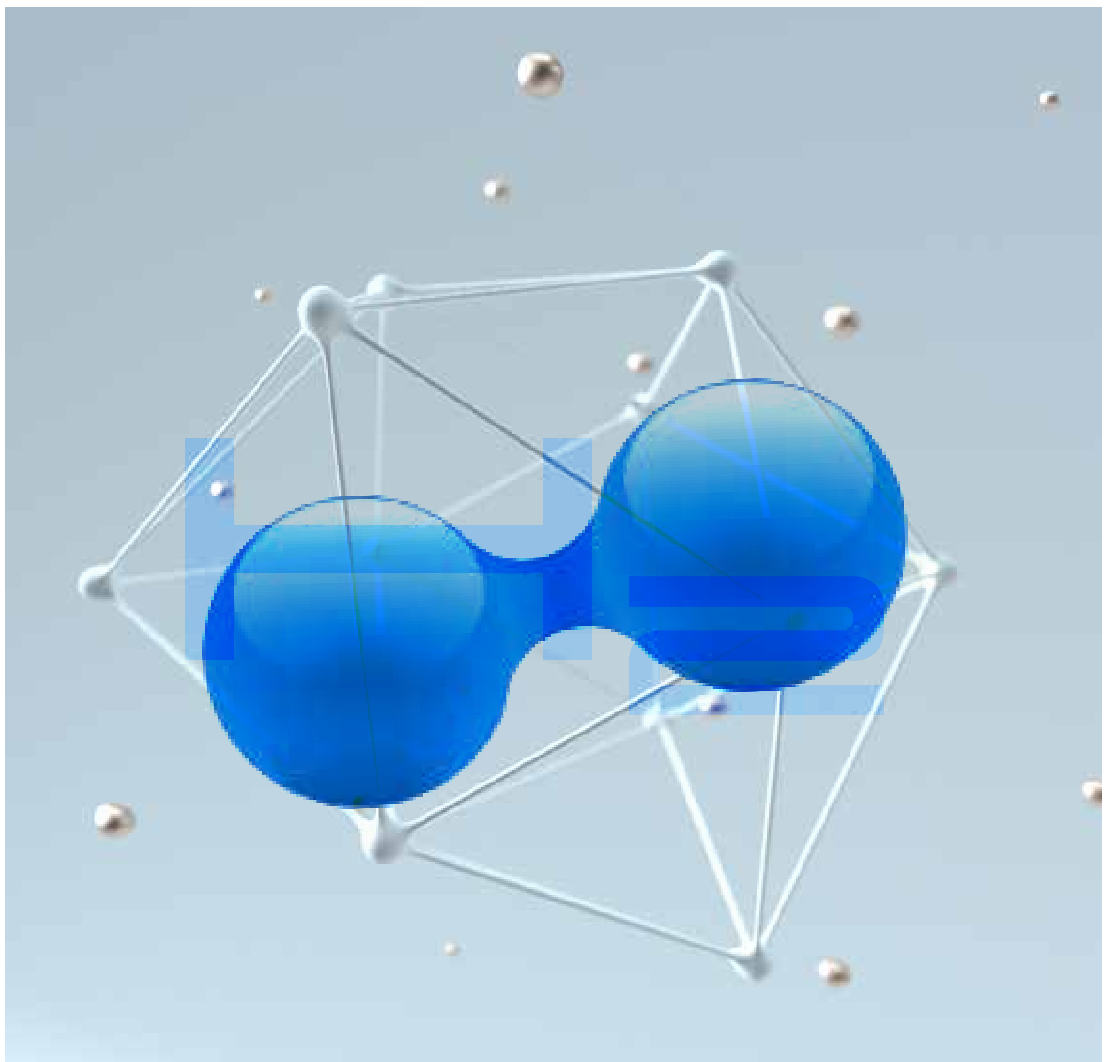
Batch output tools for isometric and plan drawings are used to improve work efficiency.



BIM drawing of the project

Hydrogen Energy: Sinosteel MECC Undertakes National Research Programs

Sinosteel MECC is dedicated to the R&D of clean, efficient and stable green hydrogen energy, and seeks coordinated hydrogen utilization in steel, chemical and energy industries. A ministerial key R&D program involving Sinosteel MECC, the Solid-state Hydrogen Storage System for Low and Medium-pressure Hydrogen Pipelines and Technological Application, was approved in December 2022.



Green Hydrogen Industry

Fudan University is leading the program, which consists of four sub-projects aimed at developing a very safe and large-capacity solid hydrogen storage system using low-cost high-density hydrogen storage materials. The system will integrate storage, regulating and connection functions for higher efficiency, well match the solid hydrogen storage system of medium and low-pressure hydrogen pipelines up with supply systems in chemical/metallurgical industries, and build a "Green Hydrogen Industry" verification platform, reducing carbon emissions.

Because of its long-term research and practice in the fields of hydrogen metallurgy and hydrogen energy, Sinosteel MECC was invited to undertake Project No.4 — Integration of Hydrogen Storage and Supply Systems and Intelligent Interconnected Control Technology Throughout Whole Process of Hydrogen Metallurgy. Sinosteel MECC aims to establish a platform to verify the hydrogen storage functions in typical hydrogen-based metallurgical production, and to well match the efficient storage of pipe-carried green hydrogen up with the hydrogen supply in given scenarios, in order to reduce carbon emissions. The study is of great importance. Sinosteel MECC has currently defined the research content and technical roadmap for the research, and incorporated digital and AI technologies:

Research on the effect on pellet reduction by replacing hydrogen-rich COG with pure hydrogen.

Develop hydrogen supply stability and residual gas recycling technology for the entire hydrogen-based metallurgy process with shaft furnaces.

Set up a system for solid hydrogen storage and supply suitable for hydrogen plasma metallurgy.

Develop a verification platform for the solid hydrogen storage and supply system that serves hydrogen-based metallurgy, powered by intelligent and safe interconnection technology.

Formulating risk monitoring strategies.

Conduct intelligent system diagnostic and maintenance to assure the steady functioning of the hydrogen storage and supply system.

Big data-driven real-time online analysis technology.

Grid monitoring technology and early warning strategies for hydrogen leakage in high-risk locations with complex conditions will be researched.

Create a decision-making model for hydrogen supply.

Development and application of an ultra-low NOx emission radiant tube burner

Sun Zhibin, Li Guojie, Wang Linjian, Shen Quan
(Baosteel Engineering & Technology Group Co., Ltd.)

Abstract: **Based on the analysis of the NOx generation mechanism of the burner and combined with the actual situation on the site, this paper determined to reduce NOx emission concentration in the way of flue gas ejection reflux, carried out grouping experiments of burners with different structures in the thermo-technical laboratory, and finally obtained a suitable burner and ejector structure; at the same time, the burner was applied to an annealing furnace in an iron and steel plant and achieved good results.**

Introduction

Common nitrogen oxides (NOx) include nitric oxide (NO, colorless), nitrogen dioxide (NO_2, reddish brown), nitrous oxide (N_2O), nitrogen pentoxide (N_2O_5), etc.[1] The NOx from the flue gas emission in industrial production usually refers to NO and NO_2, which will do great harm to the environment as one of the air pollutants: NOx is one of the main substances to form acid rain, a vital matter to form photochemical smog in the air, and an important factor to reduce ozone (O_3).

Therefore, China has intensified efforts to reduce NOx emissions in recent years, especially in the steel industry, a large carbon dioxide emitter where the generation of NOx mainly comes from the combustion of fossil fuel. Five Chinese ministries and commissions jointly launched the Opinions on Promoting the Implementation of Ultra-low Emissions in the Iron and Steel Industry. It stated that the ultra-low emission transformation of existing steel enterprises should be promoted, wherein the upper limit of NOx emission concentration for steel rolling industrial furnaces is 200mg/Nm^3 (equivalent to 8% O_2 concentration).

From the investigation and survey of the steel rolling heating furnaces in an iron and steel plant in China, we can see that many furnaces have a high temperature and a small combustion space. For the furnaces using coke oven gas as the fuel, the NOx concentration from flue gas emissions is high, which cannot satisfy the upper limit of 200mg/Nm^3 of NOx emission concentration. Therefore, technological transformation or equipment innovation is desperately needed to reduce the NOx emission concentration. Aiming at the above problems, we carried out a series of research and exploration on an ultra-low NOx emission burner and achieved good results.

1 NOx generation mechanism

NOx generated at a high temperature mainly exists in the form of NO (the concentration of NO accounts for about 95%). However, since NO is prone to chemically react with O_2 in the air to generate NO_2, NOx is generally stable in the air in the form of NO_2 under natural conditions. Therefore, how to reduce NOx generated at a high temperature is the focus of this research.

Studies showed that NOx is mainly divided into the following three types based on their generation paths in the combustion process of the burner of steel rolling heating furnaces: thermal NOx, fuel NOx, and prompt NOx[2].

1) Thermal NOx

Thermal NOx is mainly generated from the oxidation reaction of N_2 in the air with O_2 in the air at a high temperature during combustion and is mainly affected by the combustion temperature. Fig. 1.1 reflects the relationship between thermal NOx production and combustion temperature. It can be seen from the figure that when the temperature is lower than 1300°C, there is almost no thermal NOx production; as the combustion temperature raises to a certain degree, the generation rate of NOx grows exponentially.

At sufficiently high temperatures, the NOx production may account for 30% of the total NOx[3]. Therefore, we can take the following measures to reduce thermal NOx: reducing the combustion temperature or reducing the partial high-temperature zone; reducing the O_2 concentration in the high-temperature zone; shortening the duration of flue gas staying in the high-temperature zone.

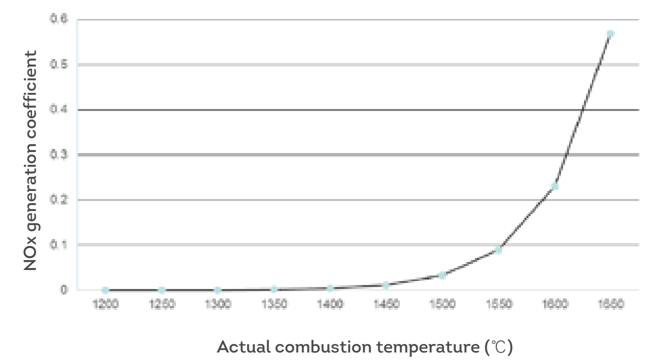


Fig. 1.1 Relationship graph between thermal NO_x production and actual combustion temperature

2) Prompt NOx

Prompt NOx is generated from the reaction between HCN and O_2 at an extremely rapid speed, wherein HCN is generated from the reaction between N_2 in the air and the carbon-hydrogen ionic group (e.g. CH). There is only a small amount of Prompt NOx produced during combustion, so it can be negligible.

3) Fuel NOx

Fuel NOx is generated from the oxidation reaction between the nitrogen compounds in the fuel (e.g. NH_3 and HCN in the coke oven gas) and O_2 in the air. The more nitrogen compounds contained in the fuel, the greater the NOx production. Also, the higher the flame combustion temperature, the greater the NOx production. Table 1.1 shows the comparison of nitrogen compounds content in gas fuels with different calorific values and fuel NOx production.

tb. 1.1 Comparison of nitrogen compounds content in gas fuels with different calorific values and fuel NOx production

Nitrogen compound composition Gas fuel	（4400kcal/Nm³） Coke oven gas (4400kcal/Nm³)	（2000kcal/Nm³） Mixed gas (2000kcal/Nm³)	(8500kcal/Nm³) Natural gas (8500kcal/Nm³)
HCN content in the fuel (mg/m³)	150	52.5	0
NH3 content in the fuel (mg/m³)	50	17.5	0
Fuel NO_x generated in the fuel (mg/m³ at 8% O_2)	48	35	0

2 Development of an ultra-low NOx emission radiant tube burner

2.1 Development background

Through our investigation of the silicon steel and cold-rolling annealing furnace of a domestic steel plant, we found that different fuels used would cause different theoretical combustion temperatures. Moreover, according to the aforesaid NOx generation mechanism, the above-mentioned factors may affect the NOx concentration due to the temperature difference of the processing furnaces used in production. Table 2.1 shows theoretical combustion temperatures at different furnace temperatures and with different fuels.

From the above data, we can see that the silicon steel high-temperature furnace with coke oven gas as its fuel has the largest effect on the NOx concentration. And it is true in actual cases. The silicon steel annealing furnace used in a domestic steel plant adopted a W-type radiant tube burner and used coke oven gas as its fuel. The furnace temperature was 950-1000°C, and the measured NOx emission scope from the exhaust gas of the annealing furnace was about 360-500mg/Nm³ (equivalent to 8% O_2 concentration). Therefore, it is necessary to develop an ultra-low NOx emission radiant tube burner for the silicon steel high-temperature annealing furnace.

tb. 2.1 Theoretical combustion temperature at different furnace temperatures and with different fuels

Typical heating furnace	Silicon steel high-temperature furnace	Cold-rolling annealing furnace	Cold-rolling annealing furnace
Fuel gas medium (fuel calorific value)	Coke oven gas (4400kcal/Nm³)	Mixed gas (2000kcal/Nm³)	Natural gas (8500kcal/Nm³)
Mean furnace temperature (°C)	950	840	840
Theoretical combustion temperature (°C)*	2225	1867	2155

* Theoretical combustion temperature herein refers to the temperature that the fuel can reach during combustion under adiabatic conditions in an enclosed space (related to the fuel calorific value and the furnace temperature).

2.2 Introduction to the development of burner

2.2.1 Determination of the technical route

At present, there are two main methods to reduce NOx at home and abroad: combustion control method and emission control method. For the combustion control method, the generation of NOx is controlled by reducing the partial high temperature of the flame and the concentration in the reaction with O_2 through air staging combustion, flue gas reflux and recirculation, and low-oxygen combustion during the combustion of the burner. For the emission control method, NOx produced in the flue gas is treated through adsorption and chemical reaction before emission to the environment.

Given the actual situation on the site and economic risk analysis, the flue gas DeNOx solution was excluded. As for the adsorption of catalyst, we conducted many experiments on a catalytic adsorption product from Japan, but the results were not satisfactory. Therefore, the development in this paper mainly focuses on the technical route of the combustion control method.

In the actual development, we used a silicon steel high-temperature annealing furnace with the highest furnace temperature of 980°C in an iron and steel plant as the basis and the Φ190mm radiant tube (see Fig. 2.1) and the coke oven gas fuel burner used by this unit as the conditions of use to develop an ultra-low NOx emission radiant tube burner using combustion control technology. Its core structure includes two parts: a burner nozzle and an ejector. Therefore, this research and development mainly focus on the development of a new burner nozzle based on the air staging technology, the development of an ejector based on the flue gas reflux technology, and the control of the low-oxygen combustion of the burner by combustion adjustment, which are detailed below.

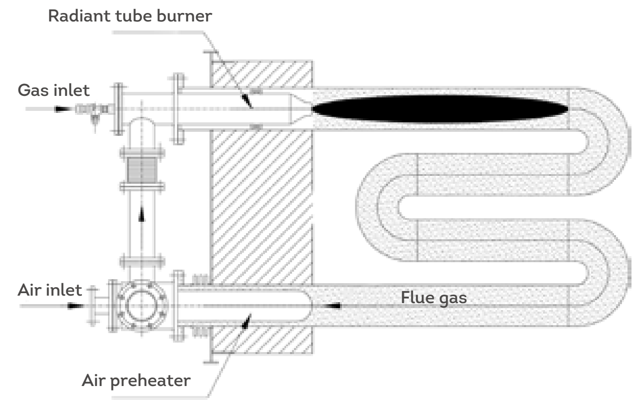
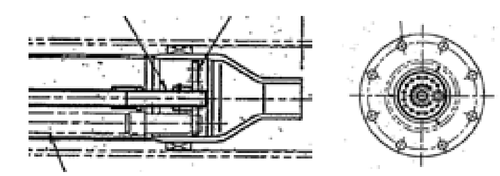
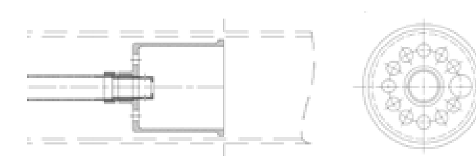
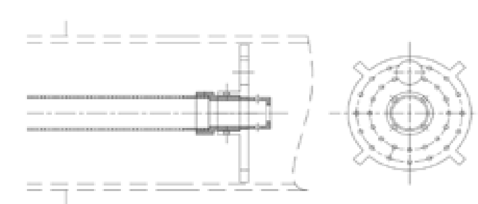


Fig.2.1 Installation diagram of the radiant tube, burner and heat exchanger

2.2.2 Development of the new burner nozzle

Since the two media, fuel gas and combustion air, are mixed at the burner nozzle and form flame through ignition by the ignition electrode or burner, the structure of the burner directly determines the combustion, including the flame length, burn-off rate, and the concentration of NOx produced in the flue gas composition. The burner nozzle using the air staging technology can not only effectively elongate the flame length and improve the temperature uniformity on the surface of the radiant tube, but also effectively reduce the high-temperature zones of the flame, thereby lowering the concentration of NOx produced in the flue gas composition. During the development, we compared the structures of three common burner nozzles, as shown in Table 2.2.

tb. 2.2 Comparison of structures of three common burner nozzles

Nozzle No.	Structure Comparison	Diagram of Nozzle Structure
1#Burner nozzle	The combustion air and fuel gas are forced to mix in the head combustion chamber, then combust concentratedly, and eject high-temperature flue gas.	
2#Burner nozzle	The combustion air is divided into primary air and secondary air, which are mixed with the fuel gas successively for combustion. The head flame shield can mix forcibly the primary air and fuel gas, thereby stabilizing the flame to a certain degree.	
3#Burner nozzle	The combustion air is divided into primary air and secondary air, which are mixed with the fuel gas successively for combustion. The multiple holes on the fire tray scatter the primary air to make it eject more evenly.	

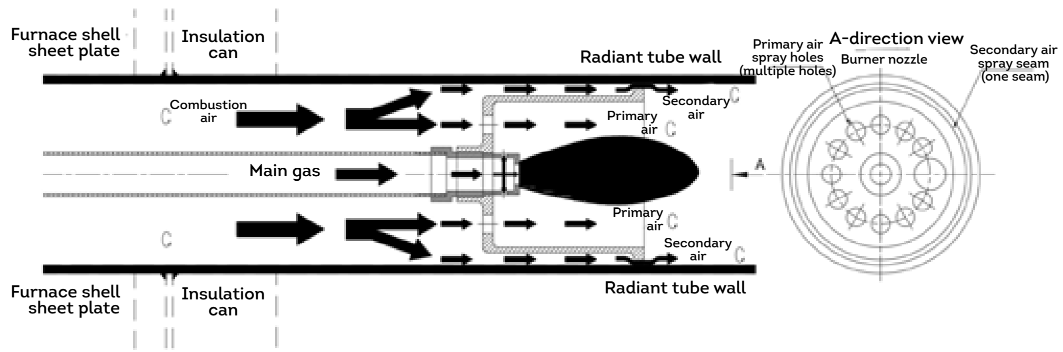


Fig.2.2 Schematic diagram of staged combustion of air

Making the coefficient of excess air in the primary combustion less than 1.0 can cause a lack of air in the primary combustion zone of the burner, thus reducing the combustion speed and temperature and effectively restraining the generation of thermal NOx. In addition, since the combustion of fuel in the primary combustion zone is incomplete, nitric oxides generated can be reduced by the CO produced, so that the production of fuel NOx can be effectively controlled.

In the secondary combustion, the remaining fuel continues to be mixed with the secondary air for combustion. At this time, there is an excess of air in the secondary combustion zone. However, the long mixing time of the fuel and secondary air results in a low flame temperature and slow combustion speed, so not much NOx is generated.

Through the experiment with different proportions between the primary and secondary air according to the above principle, several parameters were determined, such as the number of opening holes and size of holes of the fire tray in the primary air, and the clearance of the circular seam between the fire tray and the radiant tube. Finally, an optimal burner nozzle structure was determined.

2.2.3 Development of the ejector

Based on the laboratory findings, when a burner with air staging technology was used solely, the emission indicator of NOx produced in the flue gas was 200-300mg/Nm^3 (equivalent to 8% O_2 concentration), which could not ensure an up-to-standard indicator in actual production. Therefore, the flue gas reflux and recirculation technology need to be combined.

In the flue gas reflux and recirculation technology, some of the flue gas generated by combustion flows back to the combustion air through ejection or other ways and enters the circulation again along with the air. This can reduce not only the concentration of O_2 in the combustion air but also the combustion temperature of the flame, thereby effectively reducing NOx production.

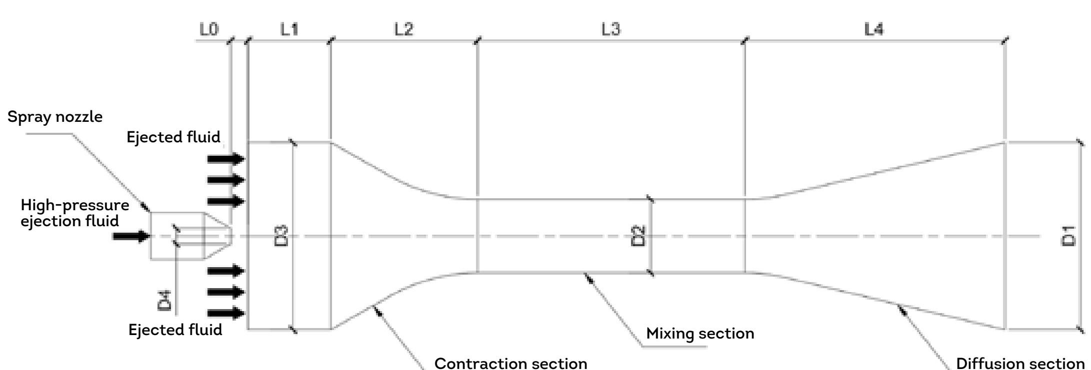


Fig.2.3 Structural schematic diagram of ejector

As the core equipment in the flue gas reflux and recirculation technology, the ejector adopts the principle of making two streams of fluid under different pressure mix with each other by using the turbulent diffusion effect of the jet[4]. Fig. 2.3 is the structural schematic dia Similarly, the ultra-low NOx emission burner in this development uses the ejector to eject and make some of the flue gas flow back by virtue of the ejection effect of the combustion air and then continue to participate in the combustion after mixing with the air. Furthermore, the ejector can improve the outlet pressure of the ejection fluid without the help of contraction by external forces and features a simple and reliable structure, no moving parts, and good tightness, which are also reasons for choosing the ejector as an accessory component of the burner.

How to determine the structural dimension of the ejector is the core of ejection design. From Fig. 2.3, we can see that the jet nozzle diameter (D4) and the distance between the jet nozzle and the ejector (L0) are also important in addition to the lengths (L1-L4) and diameters (D1-D3) of different functional sections of the ejector. During the actual development process of the ejection, grouping experiments were carried out on the structural dimension of the ejector, giving the ejector a high ejection ratio and maintaining its resistance loss within an acceptable range of the system.

2.3 Introduction to the experiment

After the structures of the burner nozzle and the ejector were determined, an overall hot-state experiment needs to be conducted on the ultra-low NOx emission radiant tube burner. Table 2.3 shows the basic conditions for the hot-state experiment. Fig. 2.4 shows the structure diagram and photo of the ultra-low NOx emission radiant tube burner in this development.

tb. 2.3 Basic conditions of burner hot-state experiment

Item	Parameter	Item	Parameter
Name of burner	Radiant tube burner	Type of combustion	Coke oven gas
Rated power	165-180kw	Lower calorific value of fuel	~17460kJ/Nm^3
Highest furnace temperature	980℃	Coefficient of excess air	1.05-1.15
Flame detection	Ion		

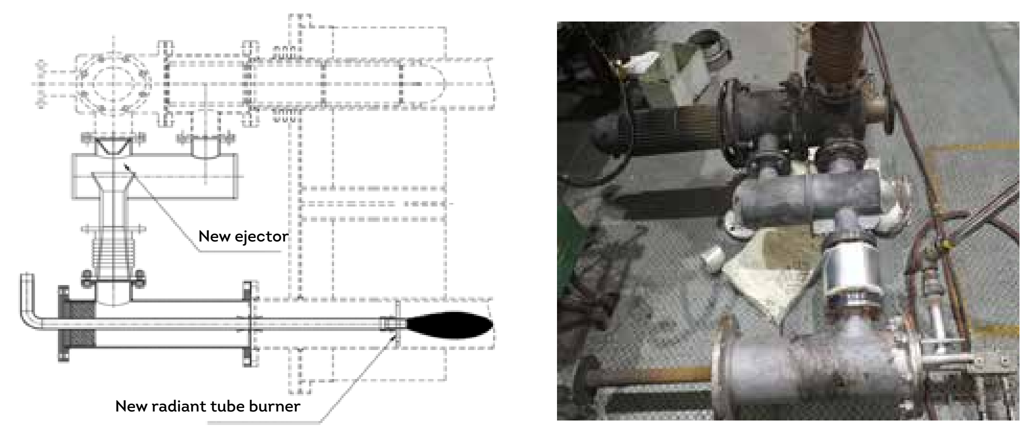


Fig.2.4 Structure diagram and photo of the new radiant tube burner and ejector

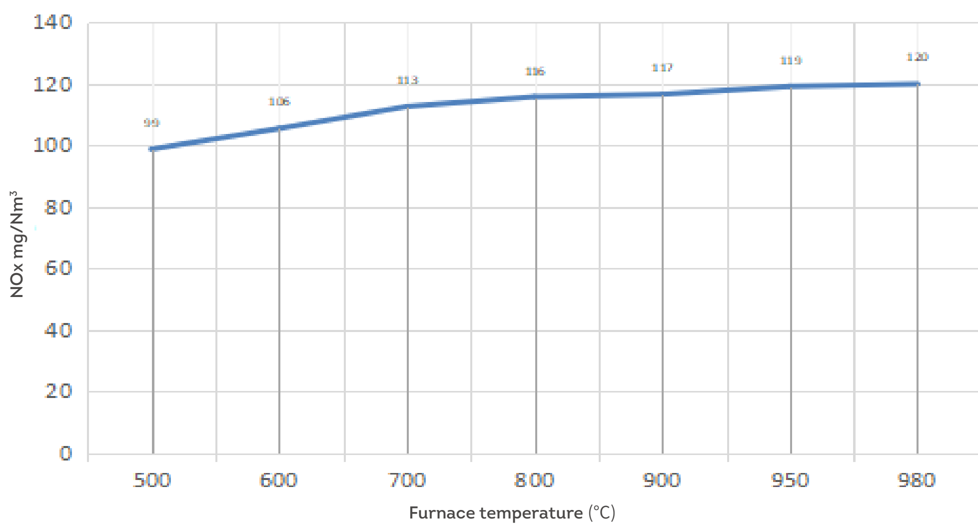


Fig.2.5 NOx concentration curve of the burner at different furnace temperatures

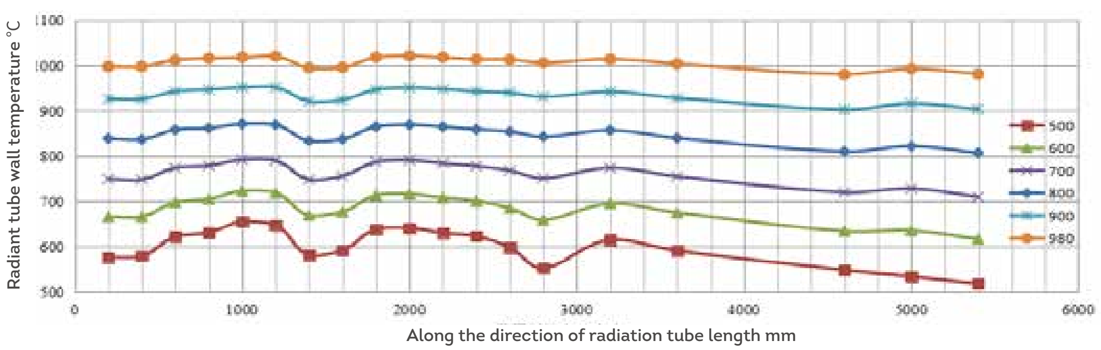


Fig.2.6 Surface temperature curves of the radiant tube at different furnace temperatures

The air and fuel gas P-V performance curve of the burner (i.e. different flow values (V) of the burner under different pressure (P)) was obtained through the hot-state experiment of the new ultra-low NOx emission radiant tube burner at a furnace temperature of 500-Fig. 2.5 NOx concentration curve of the burner at different furnace temperatures

As we can see from the experiment results, at the highest furnace temperature, the NOx emission concentration in the flue gas was only 120mg/Nm³ (equivalent to 8% O_2 concentration), far below the target of 200mg/Nm³.

Meanwhile, according to the thermocouple detection results laid on the surface of the radiant tube, the temperature difference on the surface of the radiant tube was lower than 40℃, which is beneficial to the service life extension of the radiant tube. The surface temperature curves of the radiant tube are shown in Fig. 2.6.

3 Application and effects of the new radiant tube burner

[redacted]

We applied the new ultra-low NOx emission radiant tube burner to the silicon steel annealing furnace in a domestic steel plant. All radiant tube burners and ignition burners were replaced and an ejection was newly installed. Only the air heat exchanger and radiant tube heat exchanger of the original unit were kept. Before the unit was formally put into production, we adjusted the cold-state air pressure and the hot-state gas pressure of the burner to ensure that the burner load in the same zone was the same. Then we adjusted O_2 in the flue gas composition of each burner to 2%-4% through the fuel gas valve to ensure that the burners operated under low-oxygen combustion.

Finally, when the highest furnace temperature was 980℃, the NOx concentration in the waste stack of the unit was detected to be 45ppm and the O_2 content was 9.57%, which was equivalent to 105mg/Nm³ under the national standard of 8% O_2 concentration. The development and application of this new ultra-low NOx emission radiant tube burner achieved good effects.

4 Conclusion

[redacted]

As China is implementing the latest environmental requirements, the steel-rolling heating furnaces in the iron and steel enterprises will have greater demands for NOx emission reduction. Though the development and application of the ultra-low NOx emission radiant tube burner achieved success, it is still an important topic in the future about how to use and promote the new burner and ultra-low NOx emission technology.

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Application of 3D imaging detection method based on TOF technology in steelmaking-continuous casting

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[redacted]

Abstract: **With the improvement and enhancement of industrial manufacturing technology and processing technology, traditional two-dimensional visual inspection tools have been unable to meet the development needs of modern industry. Intelligent equipment represented by three-dimensional imaging technology and perception system technology combined with robots or mechanical equipment is becoming the mainstream of the intelligenized and informationized development of the manufacturing industry. The production environment of the iron and steel industry scene is complex, and there are many dangerous sources, which pose a great threat to the personal safety of the operators. Therefore, the application of the detection system based on the continuous casting robot equipped with a TOF camera in steelmaking-continuous casting can improve the detection efficiency while being less susceptible to environmental interference, and to a certain extent replace the solution that only depends on the image for visual inspection.**

Introduction

[redacted]

Against the backdrop of economic globalization and industrial informatization, the iron and steel enterprises, which account for over 80% of the production capacity of the world's metallurgical industry, are also making efforts to transform from a traditional industry to digitalization, intelligentization, and modernization. Nevertheless, the continuous casting and steel pouring scene in the iron and steel enterprises, especially the steelmaking factories, features a heavy workload and high risk coefficient, making it one of the most difficult challenges for automation and intelligentization in the iron and steel industry; the continuous casting and steel pouring is in urgent need for a solution that can effectively improve labor productivity and lower manual operation risks.

In this context, iron and steel enterprises begin to utilize more and more intelligent robots to undertake heavy production work. In view of the high requirements for precision positioning by continuous casting and steel pouring, the intelligent robots for continuous casting and steel pouring generally require an additional set of depth sensors to provide assisted positioning and imaging detection functions. In general, the common intelligent robots for continuous casting and steel pouring adopt depth sensors based on the principle of binocular vision; however, the common problems of inaccurate positioning and low visual inspection quality in binocular vision have not been effectively solved. The three-dimensional imaging detection technology based on the principle of Time of Flight (TOF) can accurately locate and complete multiple types of on-site tasks in the special working scene of continuous casting and steel pouring, and is capable of working for 24 hours without compromising any performance, thereby achieving the goal of effectively stabilizing the production process and improving the product quality.

1 Conventional steelmaking process flow

[redacted]

The Chinese iron and steel enterprises mainly rely on two methods for steelmaking, i.e., the long-process converter steelmaking, which is from blast furnace to converter, and the short-process electric furnace steelmaking, which directly melts scrap into molten steel in the electric furnace[1]; currently, the electric furnace steelmaking production in China accounts for less than 10%, and the iron and steel enterprises still resort to the conventional “coking – sintering – ironmaking - continuous casting – rolling” long-process converter steelmaking process. The long-process steelmaking process specifically includes the following steps.

① Coking: After mixing and crushing the coking coal, it is delivered to the coke oven for dry distillation, during which hot coke, coarse coke oven gas, etc. are produced.

② Sintering: After mixing, granulation, etc. of fine ore, flux, coke breeze, etc., they are added to the sintering machine through a distribution system. The ignition furnace ignites the coke breeze, and the sintering reaction is completed by extracting air from the windmill. After crushing, cooling, and screening, the high-temperature sinter is sent to the blast furnace as the main raw material for smelting molten iron.

③ Ironmaking/Steelmaking: The iron ore, coke, flux, etc. are added to the blast furnace from the top, and then the high-temperature hot air is blasted into the blast nozzle below the blast furnace to produce molten iron and slag during the smelting.

④ Continuous casting: The molten iron is continuously injected into the crystallizer thro

The continuous casting production process is one of the core links in the entire process of steelmaking[3], whose main task is to adjust the composition and temperature of high-temperature molten steel, and cast it into steel billets that are consistent with the requirements with the help of a continuous casting machine[4]. It is worth noting that the transformation of molten steel from liquid to solid is not a simple physical form change process, but is accompanied by a large number of high-temperature chemical reaction processes, which will lead to such problems as high temperature, fast pace, and high noise. In a bid to provide continuous production, the modern continuous casting equipment is dominated by turntables or transverse trolleys, and the robots are relied on to complete the related work around the ladle turntable, such as the receiving position and casting position. However, the ladle operation with a full load of hot molten steel requires moving back and forth in the continuous casting area; even with the assistance of robots in positioning, the positioning precision will still be affected by the operating habits and levels of on-site operators, and errors are unavoidable. Further, the robots are also required to complete such operations as installing oil cylinders, installing corresponding oil and gas pipe signal

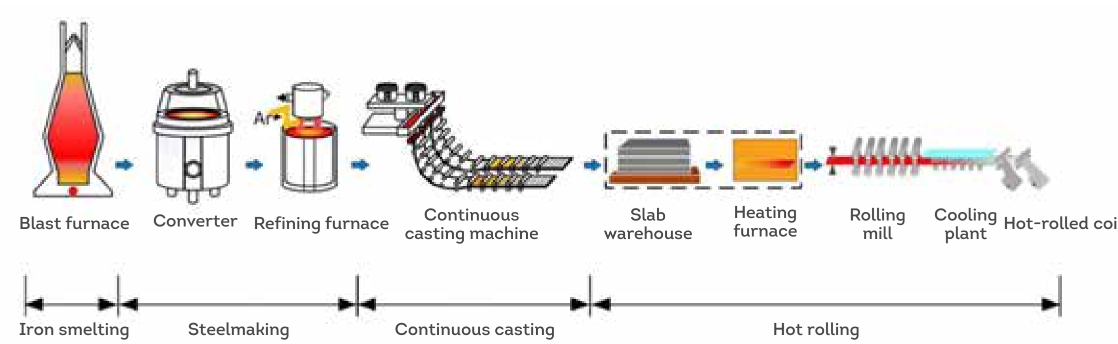

Fig.1 Long-process steelmaking process

line plugs, and installing long nozzles in the continuous casting and steel pouring area; the conventional binocular vision system has been difficult to ensure the accurate process control and cannot satisfy the requirements of continuous casting and steel pouring.

2 Principle of 3D imaging positioning technology

TOF (Time of flight) is literally translated as "flight time". Its ranging principle is to continuously deliver light pulses to a target, use a sensor to receive the light returned from an object and measure the distance between the target and the object by detecting the flight (round-trip) time of the light pulses. This technology is basically similar to the principle of a 3D laser sensor, except that the latter scans point by point, while the TOF camera simultaneously obtains the depth (distance) information of the entire image.

Compared to a conventional 2D camera, which is mainly based on binocular vision, the depth sensor with 3D imaging technology as the core presents fast detection and can effectively identify the defect types by saving the original image while conducting online real-time detection. These advantages empower the depth sensor to completely replace the conventional 2D camera and become one of the important means of continuous casting process detection.

The depth sensors are classified in Fig. 2.

The data information source of 3D imaging comes from the effective acquisition of 3D depth of field information. At present, the main 3D depth of field information acquisition methods are the Time of Flight (TOF) method, structured light method and binocular vision method, while 3D LiDAR imaging is rarely applied in the field of 3D imaging detection due to its high cost. It should be noted that the TOF method and structured light method are included in active measurement, while the binocular vision method is classified as passive measurement.

2.1 TOF method

The main measurement equipment for the TOF method is the TOF camera[6], a 3D camera for active ranging that emits continuous light pulses to a target scene, employs a sensor to receive light returned from an object, and relies on the TOF of the detected light pulses to obtain the distance of the target object, which can directly obtain the depth and grayscale of the object. Nonetheless, the resolution of an image obtained by the TOF camera, whose depth value is susceptible to noise interference, is far inferior to that of a 2D color image; moreover, the TOF camera is high in cost, which to some extent affects its large-scale application. To date, the TOF camera mainly has played a role in fields such as robots, agriculture, healthcare, and industrial automation.

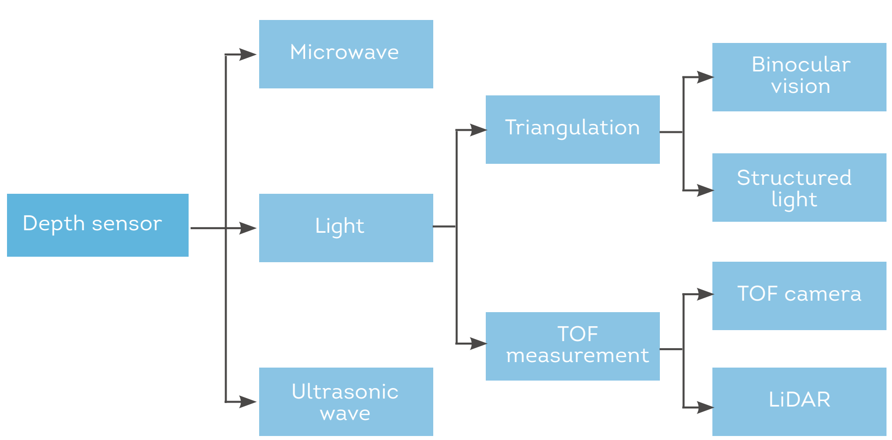

Fig.2 Depth sensor classification[5]

The working principle of TOF camera ranging is shown in Fig. 3.

2.2 Structured light method

The depth camera based on structured light technology consists of a camera and a projector[7]; with the help of the projector, structured light signals with eigenvalues are emitted to the surface of the measured object; the uneven surface of the measured object produces specific deformation corresponding to the structured light signals and reflects them to the camera; the camera collects and analyzes the reflected structured light signals. Structured light is a coded active projection light; due to the lack of depth information, it is vulnerable to strong light interference; it is more suitable for scenes with insufficient lighting conditions or even no light; so far, it has been mainly applied in games, medical treatment and other fields.

The basic principle of structured light ranging is shown in Fig. 4.

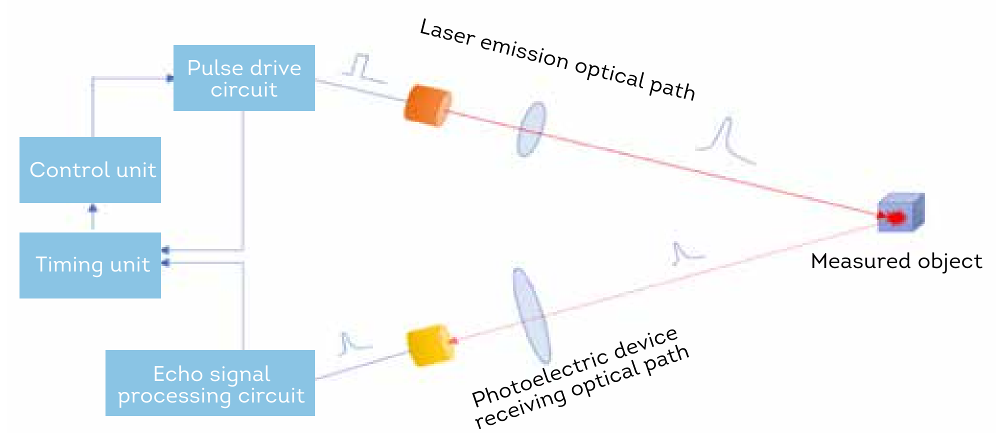

Fig.3 Fundamental diagram of TOF camera

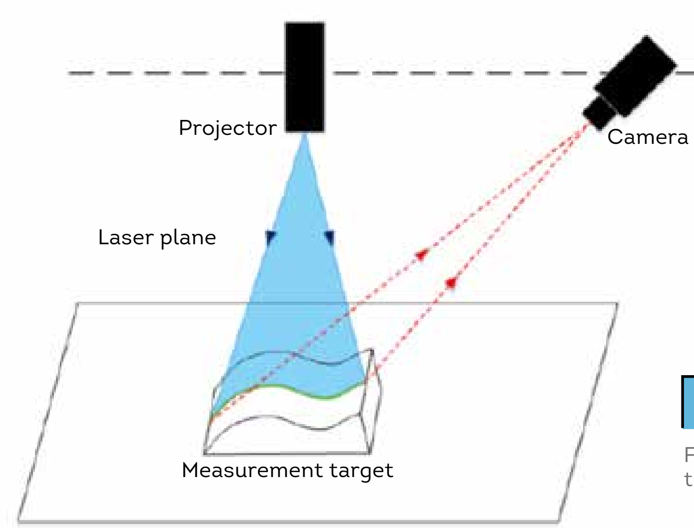

Fig.4 Fundamental diagram of structured light ranging

2.3 Binocular vision method

Binocular vision[8] utilizes the principle of binocular biomimetics, which mainly makes use of the principle of parallax to obtain the target information. Binocular vision consists of two cameras; under the premise of maintaining a certain length between the two cameras and the measured object, the two 2D images obtained from the two cameras can be integrated to restore the 3D information of the measured object, thereby achieving the three-dimensional reconstruction and determination of the position of the measured object. Binocular vision relies on passive light to measure an object, which is susceptible to external light interference; yet, the implementation cost of binocular vision is very low, and the common cameras can be used to present more intuitive images.

The basic principle of binocular vision ranging is shown in Fig. 5.

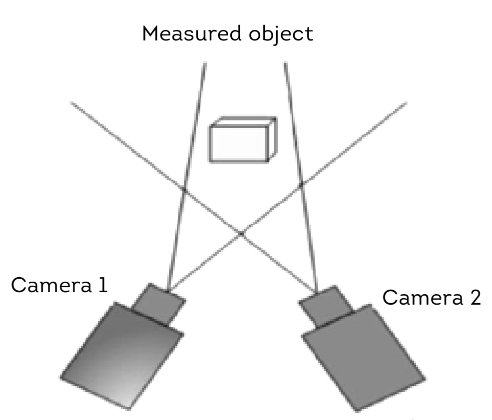

Fig.5 Fundamental diagram of binocular visual ranging

It is shown from the three main 3D imaging technologies that both structured light technology and binocular vision technology are leveraged to reconstruct the measured object in the field of visible light, which are vulnerable to strong light interference; hence, they cannot be effectively applied in the continuous casting and steel pouring scene under harsh production environment (high temperature, fast rhythm and high noise). The TOF camera based on the principle of the TOF method is basically not affected by visible light and temperature interference, and can be well applied in the continuous casting process, becoming a practical and operable new detection technology.

3 Application analysis of TOF camera in continuous casting process

In the complex steelmaking process, the continuous casting mainly covers the installation and replacement of long nozzle for ladle, oxygen burning for ladle, tundish temperature measurement, sampling, etc.; how to perform accurate positioning is the key to solving the current close cooperation between mechanical equipment and production process. Nowadays, the continuous casting process is mostly completed manually, with harsh professional environments, high-temperature baking, high labor intensity, and easy occurrence of molten steel splashing and spattering, which may cause personal scalds or burns. For example, the installation, alignment, lifting, replacement and other operations of the long nozzle for the ladle require the operators to operate the robotic arm to do the same; for temperature measurement/sampling of the tundish, it is necessary to manually install a probe and insert a temperature measurement/sampling gun into the molten steel for temperature measurement and sampling, and each furnace of steel shall be measured at least 5-6 times; the ladle replacement requires manual use of an oxygen gun to clean the cold steel inside the long nozzle.

The current solution is to install a set of tundish robot system on the pouring platform of the tundish; by replacing different tools, the robot and its related tools are used to complete the installation and replacement of the long nozzle, tundish temperature measurement, sampling, hydrogen determination, nozzle cleaning, etc., and the covering agent is added during the pouring process and after the ladle is replaced. The robot works at an interval of 2-3 minutes every 5 minutes on the steel pouring platform to replace the operator to complete all kinds of tasks, and the operators are kept away from dangerous operating positions during the production process.

The installation and removal functions of the long nozzle cannot provide precise positioning due to the lifting and rotation of the ladle turntable, which has been a long-standing and insurmountable problem for a long time. With the development of machine vision technology, the difficulty of ladle positioning has been overcome.

We can use the TOF technology to emit continuous infrared light pulses of specific wavelengths to a target, which are returned after encountering any object in the scene; then, the specific sensor receives the light signals transmitted by the object to be tested; the principle of calculating the TOF or phase difference of light to and from to obtain the depth information of the target object (distance, contour, 3D coordinates, etc.) has solved the problem of not being able to automatically and accurately locate and operate the target during the operation of the robotic arm, which makes it possible to work independently without manual intervention when using the robot to dismantle and install the long nozzle, and also gradually promotes the Flexible Manpower Line or even unmanned operation of the continuous casting and steel pouring area. Presently, the continuous casting machines of Baosteel, WISCO, SISG, Masteel, etc. have vigorously promoted robotic steel pouring technology.

Fig.6 Scene of casting steel in continuous casting

Upgrading from semi-automatic continuous casting with conventional manual or manual cooperation with robots to fully automated continuous casting with TOF intelligent sensors and robots is a trend in the development of continuous casting, where the latter is gradually becoming the standard configuration of continuous casting machines.

1. The combination of artificial intelligence technology and robot technology brings about the development of the fully automated steel pouring era

Today, the world's iron and steel industry is experiencing a wave of automated steel pouring and robot and intelligent sensor technology to replace manual labor; the iron and steel industries in Europe, the United States, Russia, and other countries have already taken the lead in replacing manual labor with robots due to operator shortages. Domestic iron and steel companies such as Shougang and Ansteel are also constantly experimenting with fully automated steel pouring technology, and Shagang has long planned to replace 1,000 to 1,500 positions with industrial robots in 3-5 years. As the world's largest iron and steel company, China Baowu shall also lead the trend of the times. The fundamental feature of automated steel pouring is unmanned operation. The combination of TOF intelligent sensors and robots makes a significant breakthrough, namely removing the influence of human factors throughout the entire production process, making the entire production process fully automated, standardized, and customized, which is conducive to maintaining the stability of equipment status and product quality. By collecting data related to equipment status and product quality, the relationship between the quality of cast billets and the equipment status can be further determined through big data analysis, which can lay a solid data foundation for improving product quality.

2. Improve the working environment of operators and reduce workload

The ladle-tundish-crystallizer area is a high-risk area with high temperature, high dust, high noise, and high radiation; with the retirement of the older generation of operators, the labor crisis may become more severe in the future. How to improve the working environment of operators has become a top priority. Currently, after the ladle arrives at the receiving position of the turntable, the operator needs to go to the platform of the receiving position of the ladle to install the argon blowing pipe and the board-sliding cylinder, and conduct the inching opening and closing test of the ladle sliding plate to confirm whether there is any leakage in the oil pipe. After the pouring is completed, the operator goes to the platform to remove the argon blowing pipe and board-sliding cylinder. The receiving position of the turntable is a high-temperature area, and there is also a risk of falling from high places. The operation in the tundish area is high-temperature and high-risk; during the temperature measurement, sampling, and burning of cold steel, it is prone to splashing and spattering of molten steel, which may cause personal scalds and burns; additionally, there is a risk of cold steel falling and injuring people during the operation when the ladle wall is attached to cold steel. A robot is used for operation, with the TOF intelligent sensor providing spatial coordinates and object distance, thereby completely replacing manual operations in high-risk areas, which not only reduces the workload of operators, but also greatly improves their personal safety.

3. Cut costs and improve efficiency

In the metallurgical industry, the overall economic benefit is low; the use of industrial robots combined with TOF intelligent sensors can replace conventional manual labor, improve labor productivity and reduce labor costs; the continuous rise in labor costs is weakening the international competitiveness of enterprises. Promoting the intelligentization, digitization, networking, and flexibility of the manufacturing industry not only enhances the efficiency of production tools, but also promotes the "replacement of labor by machines and manual control of machines" to increase labor productivity and improve the quality of workers.

Today, the major global steelmaking and continuous casting equipment designers and suppliers, including Primetals, Danieli, and Vesuvius, have developed their own intelligent robot equipment promotion plans that have been effectively implemented. Among them, Primetals completed the equipment tests on the installation of continuous casting nozzles, temperature measurement and slag addition in the tundish, and slag addition in the crystallizer on its continuous casting machines 3, 4 and 5 at the Linz Steel Plant in Austria.

Application analysis

With the TOF camera as the main detection means, the modulated light is utilized to illuminate the scene and measure the phase delay of the returned light reflected by the objects in the scene. After obtaining the phase delay, the distance is indirectly measured using orthogonal sampling technology; the depth value assisted positioning technology, and advanced image stabilization technology are used; its unique differential signal properties can effectively reduce the impact of background light, providing data jitter better than 1%. The TOF camera used in the perception system can also effectively eliminate the background light emitted by molten steel, reduce the impact of high-temperature molten steel, and accurately detect distance and locate at a fixed point, with a response time better than 90ms, thereby detecting the objects smaller than 0.2mm, which can completely replace the conventional visual detection system for continuous casting. The following Figs. 7 and 8 show the positioning and output grayscale image and point cloud image for the complex environment of iron and steel.

The depth map output by the TOF camera is represented as a grayscale image in 2D space, with each pixel corresponding to a distance value, where the higher the intensity, the closer the distance; if the light source is absorbed or no reflection signal is received, it is black.

On the basis of such a depth map, the 3D point cloud can be converted with the external parameter data of the camera. If you also have an RGB camera that can map the texture of the object surface to the point cloud voxels, then a lifelike 3D rendering model will come out, as shown below:

Currently, the use of intelligent robots equipped with TOF cameras to replace manual operations in the continuous casting area of steelmaking has become a trend, and the major steelmaking plants around the world have established relevant research and development and equipment projects. Data shows that intelligent robots equipped with TOF cameras can make positioning progress of less than 0.2mm, far exceeding the positioning precision of manual operations.

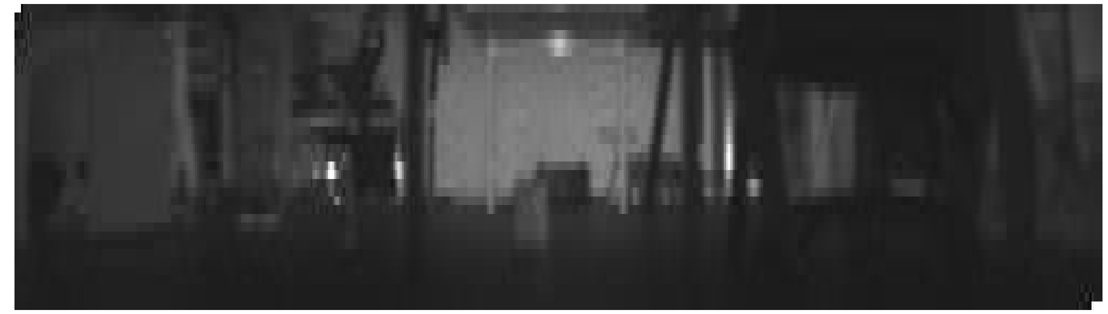

Fig.7 Grayscale image

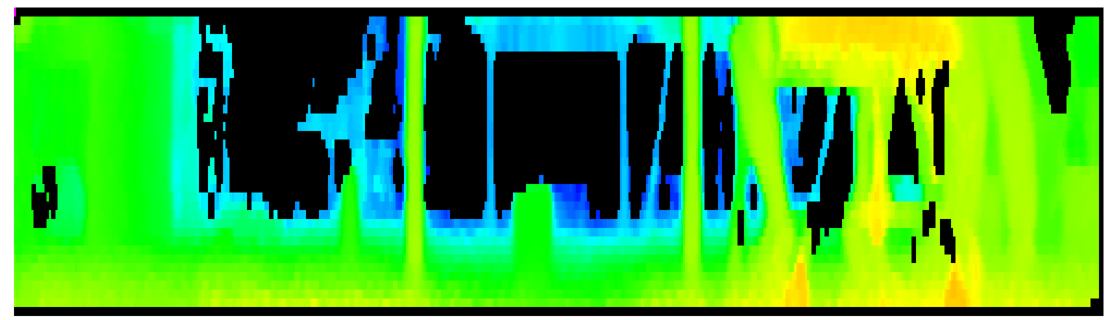

Fig.8 3D point cloud map

4 Conclusion

During the wave of national intelligent manufacturing in 2025, the iron and steel enterprises are confronted with significant transformation, with automation and unmanned production processes becoming an important part of it. Although intelligent robots have been increasingly applied in the iron and steel industry, higher technical requirements are also put forward for intelligent robots in environments of high temperature, high brightness, high dust, and strong electromagnetic radiation such as continuous casting and steel pouring. The continuous casting and steel pouring robot equipped with a TOF camera can effectively provide precise positioning and feature recognition of the measured object, while being less susceptible to environmental interference, which has greater prospects for application in the field of continuous casting and steel pouring. This paper introduces the application of intelligent robots equipped with TOF cameras in the continuous casting and steel pouring scene in the steel industry. Although this technology is intended to undergo large-scale promotion in the iron and steel enterprises and still presents such problems as a single application scene, it presents good foundations and prospects as an emerging technology for digital and unmanned production in the iron and steel enterprises.

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