Low-carbon and high-efficiency in the iron and steel industry

R & D and application on common problems

Preface

The global steel manufacturing center moved from UK to the United States at the beginning of the last century, to Japan and South Korea in the 1960s and 1970s, then to China at the beginning of this century. R&D of steel technology followed a similar path, and many steel enterprises in China have provided sufficient spaces for its progress. Following the economic restructuring of China, energy conservation and low-carbon economy have become the key points of the transformation and development of China's steel industry, promoting common technology R&D of the energy conservation and emission reduction in China’s iron and steel industry. In the past decade, China has developed a number of internationally leading common technologies for low-carbon and energy-efficient steel. With the green manufacturing as the research background, the low carbon and high energy efficiency as the technological goal, and the energy conservation and low carbon common technology problems in the steel industry as the research objects, this book shares the progress and achievements made in R&D, engineering and commercialization by individuals, teams and a group of like-minded people in China's iron and steel industry from their respective positions through theoretical analysis, numerical simulation, scientific experiments, engineering applications and commercial promotion.

Energy efficiency benchmarking of different steel enterprises is a headache in the industry, and the energy efficiency benchmarking of different divisions in the same process within an enterprise also varies greatly due to different production processes, equipment, technical parameters and products. It is difficult to compare the existing energy efficiency evaluation indicators with the process energy consumption values obtained by the reference system, and accordingly hard to quantify the process energy saving targets. Based on the theoretical minimum energies proposed by Professor R.J. Fruehan of Carnegie Mellon University, this book expands it into a three-layer and multi-level minimum energy consumption model, as theoretical minimum energy consumption, technological minimum energy consumption and actual production minimum energy consumption. Wherein, the theoretical minimum energy consumption is the energy consumption level calculated under the ideal raw material and ideal reactor, which is the boundary value of process energy consumption, and the goal of technology R&D; the technological minimum energy consumption is to compare the consumption conforming to “thermodynamics theory” under different technological conditions, and then compare the energy consumption level under different technical conditions after reaching the thermodynamic equilibrium state through the process; and the actual production minimum energy consumption refers to the energy consumption under specific physical and chemical reactions in the process and field operating conditions, which is the optimal operation target in the actual production process. The research is expected to provide quantitative tools for process energy consumption benchmarking through the introduction of three-layer minimum energy consumption.

Based on the energy consumption level of the steel industry and the development status quo of the energy-saving technology, this book, in accordance with the three-layer minimum energy consumption model of the process, quantitatively analyzes the potential improvement of process energy efficiency, and forms a number of R&D entry points in the process for solving the common technological problem. These include: 1) The technology of sensible heat recovery of coke oven crude gas. The technology has been studied internationally for decades, with projects implemented in Baoshan Base, Qingshan Base and Meishan Base of Baosteel. Baoshan Iron & Steel Co., Ltd. (Baosteel) and Shanghai Baosteel Energy Tech Co., Ltd. undertake national projects to carry out industrial experiments. Meanwhile, driven by the S&T Department of Baosteel, Baosteel has worked with Anhui University of Technology on the research of the coating technology of coke oven crude gas riser heat exchanger. The technology has made great breakthroughs in recent years, and commercial application has launched in a number of iron and steel enterprises. 2) The technology of sensible heat vertical cooling recovery of sinter. Seven years ago, Baosteel began to track the sinter sensible heat vertical cooling recovery technology, and explored the cooperated development of the technology with international companies. Knowing that the technology has been in operation in MCC BERIS Engineering & Research Co., Ltd. and Tianjin Tianfeng Iron & Steel Co., Ltd., the author paid a site visit and recommended the technology to Baosteel and China Iron and Steel Industry Association, and Baosteel decided to apply the technology in the 198m^2 sintering machine transformation of Meishan Base in an effort to facilitate the commercialization of the technology. Considering the immaturity and risks of the commercialization process of the technology, the leader of Baosteel specially arranged a supporting R&D project and the author was managing the project together with the field engineer responsible for the implementation of the technology. 3) The blast furnace slag (BFS) at 1450℃ - 1600℃ contains the energy more than 50kgce/t, and it is high grade waste heat. However, as the utilization of BFS requires rapid cooling, the mainstream industrial process is unable to recover its high grade waste heat yet. In response to this common industrial challenge, many different technological routes are outlined for the study of the sensible heat recovery of BFS in the world, including: the rotating disk dry granulation, for which domestic engineering companies have set up trial test-labs; the steel ball method, for which Germany has semi-industrial test unit; the technology of using its sensible heat and material characteristics to produce mineral wool by Japanese enterprises, which was introduced by certain domestic enterprises; the technology of using it to produce microcrystals; the study of using the sensible heat to produce cement; and the author also directed a doctoral student to explore the feasibility of using it to produce foaming building materials. 4) Sensible heat of converter fume is also an important waste heat resource in the whole process of ironmaking and steelmaking. The vaporizing cooling flue recovery is available in modern converter, but the temperature of the recovered fume is still as high as 800℃ - 1000℃; in addition, the gas recovery and utilization in converter fume requires to couple with different dusting technologies, making it a common challenging technology in the industry. This book shows the industrial test results of nearly 3,000 industrial trials of BOF, carried out in Baogang Group by people who are committed to the pure dry dedusting of converter fume to recover waste heat, Baosteel Engineering Technology Group Co., Ltd. has also carried out the integrated development of the technology, and the author has also discussed the feasibility of industrial application with them. 5) The author believes that, the intelligent and efficient hot links at the interfaces of ironmaking/steelmaking, steelming/casting and casting/rolling should be the mainstream direction of the energy efficiency improvement, especially by the ferrous flow temperature management. A few years ago, at Baosteel, the author initiated a collaborative tackling to this technology. In 2017 and 2018, with the leaders' support, the author organized nearly 100 people to carry out collaborative research and tackling in the four bases of Baoshan, Qingshan, Meishan and Dongshan. Baosteel carried out the R&D and tackling of the iron and steel interface intelligent and efficient hot link technology with the sub-project under the company-level large project, which generated the direct economic benefit of RMB 37 million in the project implementation year. This book highlights the progress of the project. According to preliminary estimation, the systematic application of the above entry points for the R&D of the process common technological challenges in steel and iron enterprises will improve the energy efficiency by 4%.

Based on the carbon emission status quo of the steel industry and the international research progress, this book also systematically analyzes the whole process energy-saving and low-carbon common technologies from the perspectives of collaborative energy efficiency improvement, system energy efficiency improvement, carbon dioxide capture and utilization, and sorts out a number of R&D entry points of common technological challenges. These include: 1) Waste heat driven blast furnace blast dehumidification technology. According to the late academician, Wu Zhonghua, the waste heat in situ utilization is relatively efficient. If the waste heat of BFS water is used for blast furnace blast dehumidifying, it may provide a new way for efficient utilization of waste heat of BFS water. Therefore, based on the theoretical basis and experimental platform of Shanghai University of Science and Technology in the field of air dehumidification, the dehumidification technology driven by waste heat is studied. The feasibility of this principle is verified from the established test bed. Tracing back to the history of blast furnace dehumidification technology, the time when Baosteel introduced this technology was just the shifting of Japan from the wet dehumidification to electric refrigeration dehumidification, Baosteel introduced electric refrigeration dehumidification, which became the mainstream of the industry; however, the technology of blast furnace dehumidification driven by waste heat should have its vitality in today when intelligent manufacturing technology has made great progress. 2) Waste heat steam is used for the micro powder technology for ironmaking slag and steelmaking slag. The steel mills have increasingly valued the waste heat recovery, the industry has been looking for and developing higher value steam waste heat utilization technology, and the author has been tracking the new technology breakthrough in this field. At an international conference in 2013, Pro. Chen, Southwest University of Science and Technology, introduced the technology of steam jet mill. The author discussed with him the feasibility of using the technology in processing ironmaking slag and steelmaking slag powder. Subsequently, our team colleagues used the experimental equipment of the University to carry out the micropowder processing experiment of steelmaking slag, and conducted the performance test of the processed micropowder, with a preliminary evaluation that the technology has considerable economic value and energy efficiency improvement value. 3) CO_2 Capture, Utilization and Storage (CCUS) technology. Both the European Ultra–low CO_2 Steelmaking (ULCOS) project and the Ultimate Reduction in Steelmaking Process by Innovative Technology for Cool Earth 50

(COURSE50) project in Japan involve steel CCUS. Five years ago, the author and the project team started the tracking and research in this field, and built a test bed in the enterprise to test the effect of blast furnace gas on the performance of different chemical absorbent. The project focused on how captured CO_2 can be used in steel production to form a technology roadmap for Baosteel, which is named as BAO- CCU by World Steel Association. 4) Iron and steel waste heat coupling biomass energy utilization and bio-char preparation technology. Internationally, there are very few one-megaton Carbon Capture and Storage (CCS) projects, and their sustainability has been a topic of concern in the industry. The use of bio-char in soils has gained international attention because of its carbon sink. Based on the calculation of 60% carbon content, 2% of a ton of bio-char escapes in the form of CO_2 in the soil, and the remaining 58% exists in the form of stable carbon, equivalent to 2.13 tons of CO_2 being sequestered. Bio-char can stay in the soil for hundreds or even thousands of years without escaping, this is like sequestering carbon in the soil, and the whole process is “carbon-negative”. After a large amount of previous research, the author put forward the use of waste heat from steel mills and idle metallurgical furnaces for metallurgical process biomass energy utilization and carbon sink technology development, and guided the doctoral students to carry out research. According to the research results, high-temperature process industry is coupled with biomass energy carbonization, forming million-ton-level carbon sink, which has strong economic and competitive advantages over traditional CCS. 5) Distributed energy technology in steel process. It is a new energy system architecture in steel enterprises with the fundamental characteristics of distributed energy. For the traditional centralized energy supply system of steel enterprises, it is not only a necessary development and supplement under the new situation, but also a systematic upgrade and reform. According to the internationally accepted definition, distributed energy is a kind of energy supply built on the client side, which is flexible and reliable. It maximizes resources and environmental benefits to determine the mode and capacity, and systematically integrates and optimizes users' diverse energy needs and resource allocation. It is a new energy system with demand response design and modular configuration, and the system optimization of multi-energy flow of centralized energy supply in steel industry from the four dimensions of source, network, load and storage. In the past decade, Baosteel has conducted research on a series of key scientific issues including the development of renewable energy suitable for the characteristics of the iron and steel industry, the deep utilization of waste energy in the iron and steel industry, the multi-energy flow production, supply and complementarity in the iron and steel industry, the distributed energy grid and the system optimization and improvement of source, network, load and storage, and has carried out project applications, with remarkable results.

The book consists of 13 chapters. Chapter I is the introduction, which focuses on the concept and the research status of steel energy efficiency, and puts forward relevant concepts on steel minimum energy consumption, outlines the background and history of the low-carbon steel industry, as well as the challenges and solutions for the low-carbon green development of steel industry at home and abroad, and the ongoing exploration in the field. Chapter II involves the common technology analysis of low carbon and high energy efficiency of steel industry, which summarizes a number of typical common technological challenges of steel low carbon and high energy efficiency based on the global carbon emission reduction and the current technology status of the steel industry. Chapter III proposes the three-layer conceptual model of limit energy consumption and explores the evaluation indicator system of steel energy efficiency based on the theoretical minimum model proposed by Professor R.J. Fruehan and the practical issues of steel energy management. Chapter IV - Chapter XIII describe the R&D and application practices of 10 typical common technological challenges in steel process.

The writing of this book was organized by Zhang Yongjie, the Chief Researcher of Baosteel, and co-edited by Chief Researcher Zhang Yongjie and Dr. Huang Jun from Inner Mongolia University of Science and Technology. The specific division of writing is: Chapters I and II were written by Comrade Dai Jian from the Department of Energy and Environmental Protection of Baowu Group; Chapter III was written by Dr. Li Haifeng from Northeastern University; Chapter IV was written by Dr. Bao Xiangjun from Anhui University of Technology, and Cao Xianchang, Chief Engineer of Shanghai Baosteel Energy Tech Co., Ltd. and Meng Xiaodong, Chairman of Jiangsu Longye Energy Saving Technology Co., Ltd. contributed to this Chapter; Chapter V was written by Dr. Sun Junjie from Meigang Technology Center of Baosteel Central Research Institute, and Dr. Dong Hui from Northeastern University contributed to this Chapter; Chapter VI was written by Dr. Huang Jun from Inner Mongolia University of Science and Technology, and Dr. Li Zhihui from North China University of Science and Technology and Professor Pan Yuhua from Liaoning University of Science and Technology contributed to this Chapter; Chapter VII was written by Dr. Zhang Liang from University of Shanghai for Science and Technology; Chapter VIII was written by Dr. Huang Jun from Inner Mongolia University of Science and Technology, and Zhao Shangwu and Ma Jianbo, who are dedicated to waste heat recovery by pure dry dedusting, contributed to this Chapter; Chapter IX was written by Professor Deng Anyuan from Northeastern University, and Dr. Hu Zhenwei from Northeastern University and Dr. Chen Guojun from the Institute of Energy and Environment of Baosteel Central Research Institute contributed to this chapter; Chapter X was co-written by Professor Chen Haiyan from Southwest University of Science and Technology and Dr. Wang Ruyi from Institute of Energy and Environment of Baosteel Central Research Institute; Chapter XI was written by Dr. Song Qingshi from Institute of Energy and Environment of Baosteel Central Research Institute; Chapter XII was written by Associate Professor Wu Wei and Dr. Zhang Lu from Northeastern University; Chapter XIII was written by Comrade Qian Feng from the Department of Energy and Environmental Protection of Baosteel.

In the compilation of this book, in addition to the aforementioned writers, the two editors of Zhang Yongjie and Huang Jun and all writers gradually formed the first draft in the process of technological exchange and cooperative development, and repeatedly discussed, revised and checked the first draft. Dr. Li Haifeng, Dr. Song Qingshi, Dr. Sun Junjie, Dr. Zhang Liang, Dr. Chen Guojun, etc. participated in the checking of the book, and Dr. Zhou Dianmin from the Department of Energy and Environmental Protection of Baosteel, Wang Senhui and Qi Tengfei, the PhD students from Northeastern University, and Wang Mingyue, who is about to join the Baosteel Central Research Institute, etc. put in a lot of efforts and sweat on writing and checking of some parts of this book. During the research and development of related projects, the author had the honor to participate in the research of the Carbon Capture, Utilization and Storage - Steel Industry Project of Peking University, and it was with the support of this project that this book was able to be compiled and published, which was included in the research results of the Carbon Capture, Utilization and Storage - Steel Industry Project of Peking University. The research involved in this book has also received strong support from many colleagues and leaders of Baosteel, Baowu Group, especially the Baosteel Central Research Institute, as well as peers in the steel industry. After completing the draft, a review meeting was held in Shanghai Baosteel, where Professor Cai Jiuju from Northeastern University, Professor Zou Zongshu from Northeastern University, Professor Zhang Yuzhu from North China University of Technology, Vice President Xie Guowei from Anshan Thermal Energy Research Institute of Sinosteel Group, Comrade Dai Jian from the Department of the Environment and Environment Protection of Baowu Group, Deputy Editor-in-Chief Zhang Dengke and Editor Xia Xiaoxue from Metallurgical Industry Press, etc. were invited to review the draft, who put forward many valuable suggestions. I would like to express my heartfelt thanks to them.

Baosteel and Baowu Group have always adhered to green development and corporate social responsibility, and invested a lot of resources in the research and development of low-carbon and energy-efficient common technologies for steel. Although some technologies have just entered the trial test and application improvement stage, and some are still in the R&D and improvement stage, the company has decided to support the publication of this book in consideration of the urgency of low-carbon and high energy efficiency transformation and development in the industry, expecting that the sharing of these technologies will play a positive role in promoting the green, low-carbon and high-quality transformation and development of steel industry.

The author has been devoted to the R&D of steel technology for more than 20 years, and focused on the R&D of low-carbon and high energy efficiency technology for steel for nearly 10 years. The author introduces some technologies involved by himself in this book, hoping to offer a few commonplace remarks to attract valuable opinions from others. Due to the knowledge limitation, there must be some mistakes and improper places in the book, the comments from experts and readers are highly appreciated. In particular, it needs to be noted that there are still a lot of technologies in the R&D process or the trial application stage, there must be a lot of technological details that still need to be discussed. It is possible that the theoretical views and technological directions of the book also need to be considered and discussed, and all your comments and advices are welcome.

Zhang Yongjie

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