THE ULTRA-LOW EMISSION TRANSFORMATION OF CHINA'S STEEL INDUSTRY AND ITS KEY TECHNIQUES

BY

DU LEI*, XU HAILUN, REN HAIXIA, YIN MING

SYNOPSIS:

As the country with the highest steel production capacity in the world, China launched an ultra-low emission transformation for its steel industry in 2019. Through various pollution control techniques and financial instruments, this transformation upgrades current pollution control measures to achieve the strictest emission standards in the world, reduces the emission of air pollutants significantly. At present, more than 462 domestic steel enterprises have completed the transformation or are implementing, which involves more than 681 mt/a of steel production capacity.

This paper briefly introduces the policy background together with key techniques such as dust removal, desulfurization and denitrification and fugitive emission control, demonstrates typical applications. As world's first ultra-low emission transformation for whole process of steel production, experiences and progresses in this field could provide reference for Southeast Asian steel enterprises.

Keywords: Ultra-low Emission, China's Steel Industry, Desulfurization, Denitrification, Fugitive Emission

*Engineer of Wuhan Iron & Steel Design & Research Institute (WISDRI)

Majored in environmental science and engineering, dedicated in environmental impact assessment for steel industry, specialized in air pollutants dispersion modelling.

Wuhan, Hubei province, China

Since 1996, China has become the country with the largest steel production capacity in the world. In 2021, China produced 1.03 billion tons of crude steel, which was more than 50% of world's steel output [1].

Dominated by long process flow which involves coking, sintering & pelletizing, blast furnace ironmaking and converter steelmaking, China's steel industry has been accused of high energy consuming and heavy environmental polluting. As the largest industrial emission source, the steel industry emitted 1.6 million tons of SO_2, 1.2 million tons of NO_x and 2.8 million tons of dust, which accounted for 7%, 10%, 20% of domestic emission in 2017 [2].

Since 2019, the Chinese government has introduced a series of policies to implement world's first ultra-low emission transformation of the whole process of steel industry, determined to significantly improve the air quality and promote the development of steel industry.

1.Before "Ultra-low"

Before 2019, the major emission standards which China's steel industry implemented were "Emission standard of air pollutants for sintering and pelletizing of iron and steel industry (GB 28662-2012)", "Discharge standard of pollutants for coking industry (GB16171-2012)", "Emission standard of air pollutants for iron smelt industry (GB 28663-2012)", "Emission standard of air pollutants for steel smelt industry (GB 28664-2012)", "Emission standard of air pollutants for steel rolling industry (GB 28665-2012)".

Here are brief comparisons of organized emission limits among major steel-producing countries [3][4].

Table 1.1 Comparison of national emission limits (mg/Nm^3) - Sintering and Pelletizing

	Austria	French	German	US	Vietnam existing	Vietnam new-built	China existing	China new-built	China special
PM	10	100	10	60	100	50	80	50	40
SO_2	350	300	500	90	500	500	600	200	180
NO_X	350	500	100	-	750	500	500	300	300
Dioxin (ng-TEQ)	0.1	-	0.4	-	0.5	0.1	1	0.5	0.5
Fluoride	3	-	-	-	10	10	6	4	4

Table 1.2 Comparison of national emission limits (mg/Nm^3) – Machine-coke oven chimney

	EU	Japan	India	Vietnam existing	Vietnam new-built	China existing	China new-built	China special
PM	-	-	50	100	50	50	30	15
SO_2	200~500	800	800	500	500	100	50	30
NO_X	350~500	123~820	500	750	500	800	500	150

Table 1.3 Comparison of national emission limits (mg/Nm^3) – Blast furnace ironmaking

	German	Japan	US existing	US new-built	UK	Vietnam existing	Vietnam new-built	China existing	China new-built	China special
PM (Cast house)	20	30	22.9	6.9	20	100	50	50	25	15
PM (Stove)	10	100	-	-	10	100	50	50	20	15
PM (Raw material)	20	20	18.32	11.45	20	100	50	50	25	10
SO_2 (Stove)	-	-	-	-	250	500	500	100	100	100
NO_X (Stove)	-	-	-	-	350	750	500	300	300	300

Table 1.4 Comparison of national emission limits (mg/Nm^3) – Converter steelmaking

	German existing	German new-built	Japan	US	Vietnam existing	Vietnam new-built	China existing	China new-built	China special
PM (Primary fuel gas)	50	20	-	22.9	100	50	100	50	50
PM (Secondary fuel gas)	20	20	-	11.9	100	50	50	20	15
PM-EAF	-	5	20	11.45	-	-	50	20	15
Dioxin (ng-TEQ)	0.5	0.5	0.5	0.5	0.5	0.1	1	0.5	0.5

Table 1.4 Comparison of national emission limits (mg/Nm^3) – Rolling

	German	Japan	Vietnam existing	Vietnam new-built	China existing	China new-built	China special
PM (rolling dedust)	20	20	100	50	30	20	15
PM (furnace for heat treatment)	-	-	100	50	30	20	15
SO_2 (furnace for heat treatment)	350	-	500	500	250	150	150
NO_X (furnace for heat treatment)	350	-	750	500	350	300	300

Basically, limits of China's standards are not so loose compared with other countries. According to the comparison, Chinese limits are notably stricter in SO_2 and NO_x controlling, but not as rigorous as EU counties and the US in dust controlling. However, the colossal product capacity of China's steel industry magnifies individual influence and impacts ambient air quality significantly. In 2017, the average $PM_{2.5}$ concentration of the top 20 domestic cities with highest steel production was 50μg/Nm^3, which exceed the national ambient air quality limits (35μg/Nm^3) and was 28% higher than national average [2].

Specially, the rapid development of China's economy has impelled some enterprises to ignore the importance of environmental protection. Some enterprises blindly cut down essential environmental protection expense, while the negative environmental externalities of such behavior were borne by everyone. This was unfair on law-abiding companies whose environmental expenditures doubled compared with irresponsible ones.

Such "Bad money drives out good" situation undermined not only the health of residents, but also the healthy development of China's steel industry. During the 13th Five-Year Plan period, a series of environmental policy initiatives have been introduced to cleanse the breathing air and to level the playing field for the market, called for a green turn of China's steel industry.

2.The target and content of ultra-low emission transformation

In 2019, Ministry of Ecology and Environment of the People's Republic of China (MEE) together with National Development and Reform Commission (NDRC), Ministry of Industry and Information Technology of the People's Republic of China (MIIT), Ministry of Finance of the People's Republic of China (MOF) and Ministry of Transport of the People's Republic of China (MOT) announced "On promoting the implementation of ultra-low emission in the steel industry", clarified the targets, the implementation progress and the specific content of the transformation.

The targets of the transformation are: a) All new-built steel enterprises shall approach ultra-low emission (ULE) level in principle; b) At least 60% of domestic product capability in key regions shall approach ULE level by the end of 2020; c) At least 80% of domestic product capability shall approach ULE level by the end of 2025, 100% in key regions.

The ULE requirements consist of four parts: organized emission controlling, fugitive emission controlling, clean shipping and monitoring.

2.1 Organized emission controlling

Table 2.1 lists the ULE limits of organized emission sources, while unspecified sources still follow the current legal standards.

Table 2.1 The Ultra-low emission limits of organized emission sources (mg/Nm^3)

Procedure	Facility	Reference oxygen content (%)	PM Limit	SO_2 Limit	NO_X Limit
Sintering & Pelletizing	Sintering machine head Shaft furnace pelletizing	16	10	35	50
	Grate kiln, Belt type pelletizing	18	10	35	50
	Sintering machine tail, others	-	10	-	-
Coking	Coke oven chimney	8	10	30	150
	coal loading and coke pushing	-	10	-	-
	Dry quenching	-	10	50	-
Ironmaking	Stove	-	10	50	200
	Cast house, Ore bin	-	10	-	-
Steelmaking	Pre-treatment, Secondary fuel gas of converter, EAF, Lime kiln, Dolomite kiln	-	10	-	-
Rolling	Furnace for heat treatment	8	10	50	200
Power plant	Gas boiler	3	5	35	50
	Coal boiler	6	10	35	50
	CCPP	15	5	35	50
	Oil boiler	3	10	35	50

Compared with foreign limits and national standards showed in Table 1.1 to 1.4, the ULE limits are much stricter in SO_2 and NO_X controlling, while the PM (particulate matter) limits are comparable to the most stringent ones.

2.2 Fugitive emission controlling

The ULE requires fully enhancement of fugitive emission controlling in material storage, transportation and production processes. The collection rate of exhaust gas shall be improved, facilities shall be sealed off or airtight to eliminate visible dust spills.

In storage procedure, lime, ashes and other powdery materials should be stored in silos or storage tanks. Ore, coal, coke, sinter, pellet, limestone, dolomite, ferroalloy, slag, desulfurized gypsum and other massive or sticky materials should be stored in sealed off silos or sheds. Dry slag storage procedure should adopt dust suppression measures such as water spraying.

Lime, ashes and other powdery materials should be transported in an enclosed manner by means of tubular belt conveyors, pneumatic conveying equipment and tank trucks. Ore, coal, coke, sinter, pellets, limestone, dolomite, ferroalloy, slag, desulfurized gypsum and other lumpy or viscous materials should be transported in tubular belt conveyors or other airtight manners. Enclosed carriages or tight thatch covers should be applied for inevitable vehicle transportation, and dust suppression measures such as humidification should be taken in loading and unloading processes. Conveying and blanking processes should be equipped with gas collecting hoods and dust removal facilities, dust suppression measures such as spraying should be adopted. Wheel and body washing facilities should be set up at the exit of the stockyard. Roads shall be hardened and kept clean.

Crushing, screening, mixing and other equipment in sintering, pelletizing, iron making, coking and other processes should be equipped with airtight covers and dust removal facilities. The gas-gathering capacities of sintering machine, annular cooler, pelletizing equipment, blast furnace charging, ore bin, cast house, mixer, steelmaking pretreatment, converter, EAF, refining furnace, lime kiln and dolomite kilns should be strengthened comprehensively, to eliminate visible dust or smoke. The blast furnace cast house platform should be enclosed or at least semi-enclosed, the iron ditch and slag ditch should be covered and sealed; the steelmaking workshop should be sealed off with a roof cover and be equipped with dust removal facilities. Gas collecting hood should be set up at the oven mouth of the coke oven machine to collect and treat the exhaust gas. The pressure equalization gas discharged at the top of blast furnace should be collected or purified. Scrap cutting should be carried out in enclosed space, with dust collecting and removal facilities. The coating unit in rolling process should be sealed off, and dust collection and treatment facilities should be set up.

2.3 Clean shipping

The ULE requires clean transportation (railway, water transport, pipeline or tubular belt conveyors) for at least 80% of the ore, coal, coke shipped in or out of steel enterprises. For those that cannot be conveyed by the above methods, vehicles that meet China VI emission standard should be adopted.

2.4 Monitoring

Steel enterprises should strengthen the construction of automatic monitoring facilities and connect them to administrative departments' network. In accordance with the requirements of the technical guidelines for self-monitoring, enterprises should prepare and carry out self-monitoring plan, disclose related information to the public truthfully.

Relative emission controlling facilities shall be equipped with automatic monitoring facilities as well as DCS system, which record the main parameters of the emission and operation. High definition video surveillance facilities shall be installed in stockyard, coke oven, sintering annular cooler, blast furnace ore bin, top of blast furnace and top of steelmaking workshop, etc.

2.5 Progress

According to the policy, the ULE is an encouragement rather than an enforcement. The original emission standards are still valid, while enterprises meet the ULE requirements could enjoy preferential policies on tax, finance, electricity price and environmental management in accordance with regulations.

In practice, not only state-owned enterprises but also private ones respond to the transformation positively. By the end of 2021, at least 462 domestic steel enterprises have completed the transformation or are implementing, which involved more than 681 mt/a of steel production capacity [5].

3.Key techniques to achieve ultra-low emission

To truly achieve ultra-low emission transformation, targeted source reduction techniques as well as terminal control techniques shall be applied in each step of steel production process.

3.1 Key source reduction techniques

3.1.1 Fine desulfurization techniques for BFG

Blast furnace gas (BFG) is an important by-product of ironmaking process and is widely used as fuel in almost every stage of steel production. It contains high concentration of organosulfur compounds like Carbonyl sulfide (COS) that cannot be effectively removed by traditional desulfurization techniques, making it difficult for emission sources like stove fuel gas to meet ULE limits ($SO_2 \leq 50mg/Nm^3$). Though implementing terminal desulfurization measures could temporally solve this problem, it cannot prevent the pipelines and equipment from being corroded by the impurities.

To radically reduce the COS contents of BFG, several fine desulfurization techniques have been developed which could be roughly divided into two categories based on their reaction mechanism: wet fuel desulfurization (WFD) techniques and dry fuel desulfurization (DFD) techniques. The WFD techniques such as Rectisol method, sulfolane method, alkanolamine method are relatively mature but the defects also obvious: the mass transfer efficiency is relatively low while the equipment is huge, and the desulfurization sewage (discard solution) needs to be treated to avoid associated pollution.

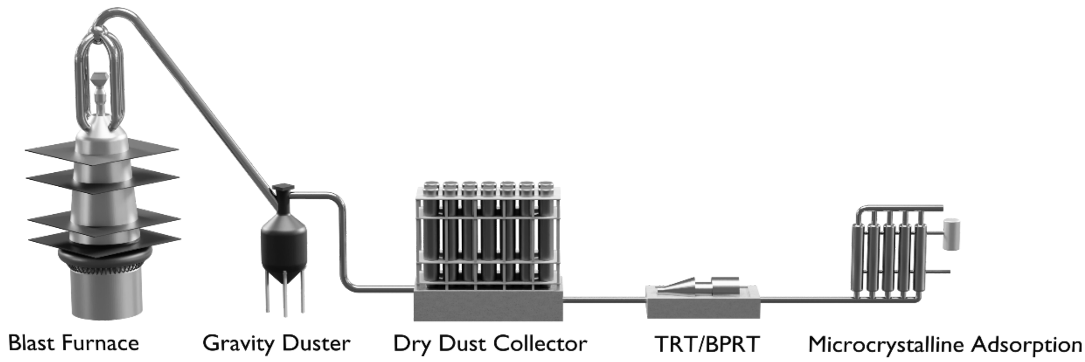

Figure 3.1-1 The schematic illustration of microcrystalline adsorption process

As a DFD technique, microcrystalline adsorption could avoid the sewage problem. The BFG is first subjected to dedusting process, followed by TRT/BPRT process, then microcrystalline selective adsorption process. When the adsorption is saturated, purified BFG is sent to pipeline while the adsorbents are heated to release desorbed gas with high concentrations of sulfides. Finally, the sulfides could be removed by desulfurization facilities of sintering machine which used the desorbed gas as fuel.

The pros and cons of microcrystalline adsorption technology are obvious. The full-solid-phase reaction is more environmentally friendly than WFDs, since no sewage would be generated. However, since the adsorption simply transfers sulfide rather than eliminating it, terminal desulfurization measures are still required. Furthermore, compared with WFD the investment as well as operational cost is much higher.

Catalytic hydrolysis conversion (CHC) provides another possibility for DFD. Instead of adsorbing COS directly, CHC process converts COS to inorganic sulfur (H_2S) t which could be removed by existing techniques. The CHC could be divided into low-temperature hydrolysis and medium-temperature hydrolysis depending on catalyst types. The low-temperature (20~80℃) hydrolysis conversion could be implemented after the TRT/BPRT process which would be friendlier to the facility while the conversion rate is not so high as medium-temperature hydrolysis [6].

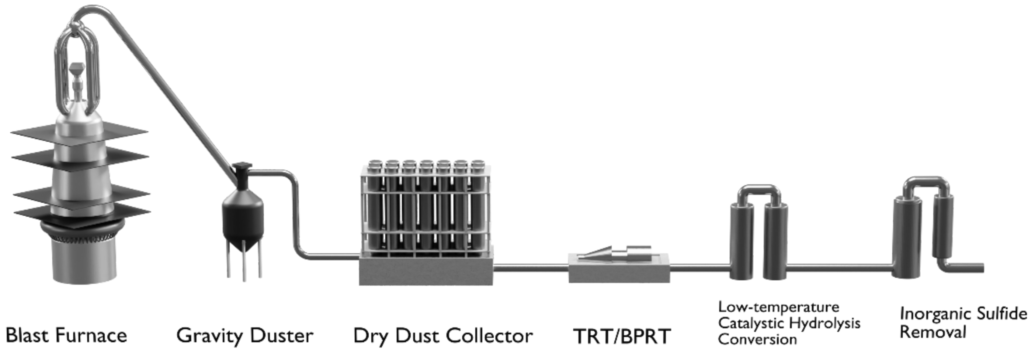

Figure 3.1-2 The schematic illustration of low-temperature catalytic hydrolysis conversion and inorganic sulfide removal process

3.1.2 Flue gas circulation technology of sintering machine

Sintering process is the main sector of SO_2 and NO_X emission in steel enterprises. To reduce the emission of air pollutants and save energy, the ultra-low emission policy encourages enterprises to implement the flue gas circulation technology to sintering machines.

The principle of this technology is to circulate part of the sintering flue gas to the airtight hood above the sintering machine and participate in the sintering process again. Through pyrolysis, the toxic components such as dioxins in the flue gas are reduced and SO_2 is enriched, thereby reducing the cost of flue gas desulfurization. At the same time, this method recovers the combustible substances and part of the sensible heat in the flue gas, reducing the fuel consumption of the sintering process.

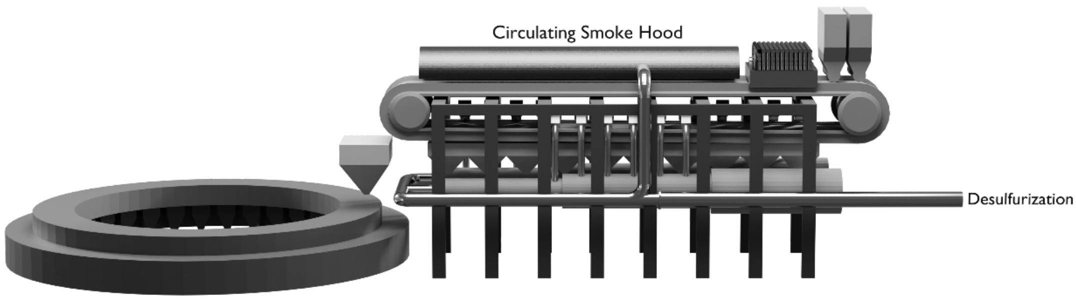

Figure 3.1-3 The schematic illustration of flue gas circulation technology of sintering machine

Typical flue gas circulation process includes Regional Flue Gas Recycling, Emission Optimized Sintering (EOS), Low Emission & Energy Optimized Sinter process (LEEP) and Environmental Process Optimized Sintering, etc. According to a research, a well-functioning flue gas circulation process could save up to 146 MJ for every ton of the product, reduce 35%~45% of dust emission, 20%~45% of NO_X emission, 60%~70% of dioxins emission and 25%~30% of SO_2 emission [7].

At present, several domestic iron and steel enterprises have implemented or prepared to implement this technology.

3.2 Key terminal control techniques

Terminal control technology is the ultimate guarantee for ultra-low emission, key techniques in dust elimination, desulfurization, denitrification and fugitive emission control are briefly introduced as follows.

3.2.1 Bag filter with membrane material

For traditional bag filter, the fine particles are captured by the dust layer formed on the surface of the cloth, the filter cloth itself acts only as a support structure. The accumulation of particulates on the dust layer increases the resistance and reduces dust removal efficiency, making it difficult for traditional bag filters to meet the ULE limit (10 mg/Nm^3) stably.

The new generation of bag filter with membrane material improves the performance of dust removal and significantly reduces the occurrence of blockages especially in wet condition. Such filter is coated by smooth and waterproof polymer membrane with small pore size which could effectively capture fine particulates without the help of dust layer. Compared with traditional bag filter, the membrane coated filter could reduce the resistance of airflow, save energy and run more stably.

At present, this technology has been widely used in the ultra-low emission transformation of China's steel industry. Numerous practical applications have proved that this technology can fully meet the ULE requirements and be widely applied to various processes.

3.2.2 Semidry and dry desulfurization processes

Wet desulfurization processes such as lime-gypsum and double-alkalic are the most mature desulfurization process at present. They are welcomed by many steel enterprises because of the low operational cost and 90~95% desulfurization efficiency [8]. However, wet desulfurization processes generate sewage which must be purified before discharged. Ca-based process such as lime-gypsum not only is prone to blockage but also causes “gypsum rain” which is disastrous for ambient environment and surrounding residents.

The circulating fluidized bed (CFB) is another widely applied desulfurization technique in ultra-low emission transformation. As a semidry process, CFB is less prone to fouling and blocking, while no desulfurization sewage would be generated.

A typical CFB system consist of an adsorbent preparation system, a desulfurization tower, a dust removal system, etc. Some CFB processes add a flue gas circulation system to improve stability. The strong turbulent state in the reactor can improve the contact efficiency between the absorbent and the flue gas, helping the CFB process achieve high desulfurization efficiency with a lower Ca/S ratio [9]. Furthermore, it also has the advantages of less land occupation and more environmentally friendly by-products.

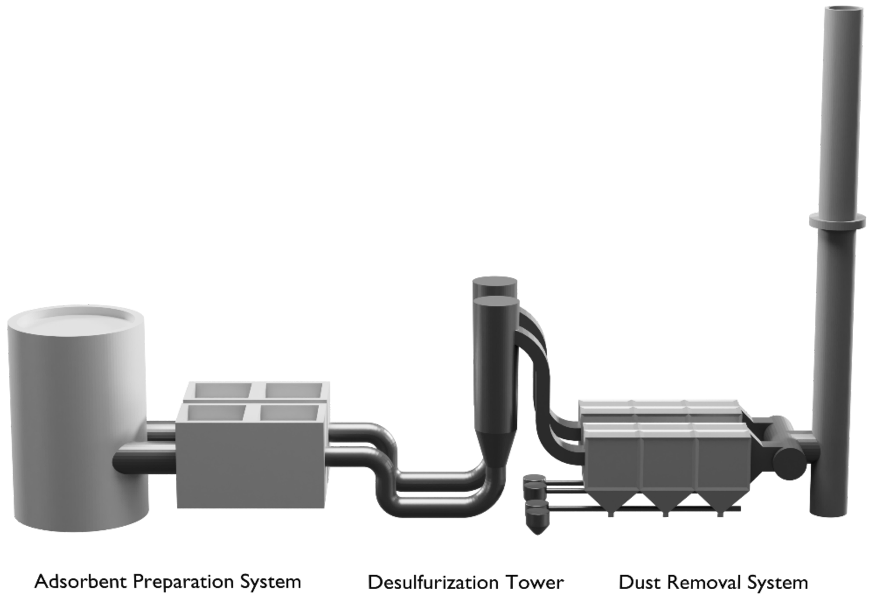

Figure 3.2-1 The schematic illustration of a typical CFB process

Sodium bicarbonate dry powder spray (SDS) is a Na-based dry desulfurization process, which could be applied in coking [10], sintering, power plant, etc. Unlike CFB, SDS use sodium bicarbonate as adsorbent which reacts better with SO_2, and is suitable for low SO_2 concentration fuel gas.

In SDS process, the sodium bicarbonate is stored in adsorbent silo and ground to fine powder before injected into the desulfurization reactor. The mixed exhaust gas from reactor will be filtered out through the dust removal system while the by-product (Na_2SO_4) could be collected and utilized. Though sodium bicarbonate is more expensive than Ca-based adsorbents, it could provide a more stable working condition than lime-gypsum, and the saleable by-product (Na_2SO_4) could deduct part of the costs.

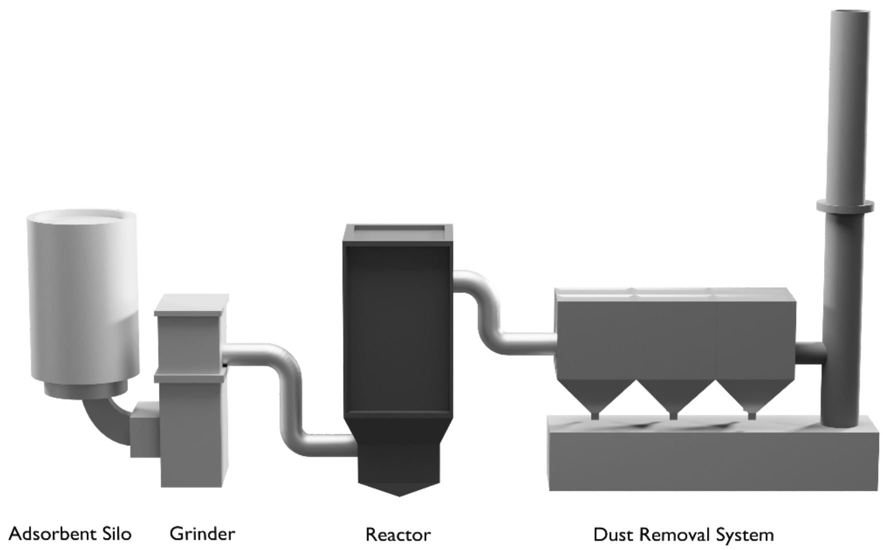

Figure 3.2-2 The schematic illustration of a typical SDS process

Activated coke desulfurization (ACD) is an advanced dry desulfurization process that can also meet the ULE requirement. Activated coke is a porous adsorbent whose high specific surface area is beneficial for improving the adsorption performance, and can be regenerated and recycled to reduce operational costs.

The desulfurization procedure of the ACD process is mainly realized in the reactor. The sulfur-containing gas pumped in is fully absorbed by the activated coke, and undergoes an oxidation reaction under certain conditions to achieve the conversion from SO_2 to SO_3 on the surface of the coke. The SO_3 as an intermediate product reacts with steam and generate the H_2SO_4 which stored in the pores of the coke. When saturated, the coke will be heated and release sulfide-rich gas (SO_2) in the regeneration reactor, completing its own regeneration [11].

Unlike CFB or SDS, the ACD process concentrates SO_2 rather than converting it, hence a following by-product recovery process for the sulfide-rich gas is required. The by-product recovery process such as acid production or sodium metabisulfite production may cause extra pollution if not properly disposed. Furthermore, the process is not selective, not only SO_2 but also other pollutants such as heavy metal and dioxins will be adsorbed, making the treatment of sulfide-rich gas tougher.

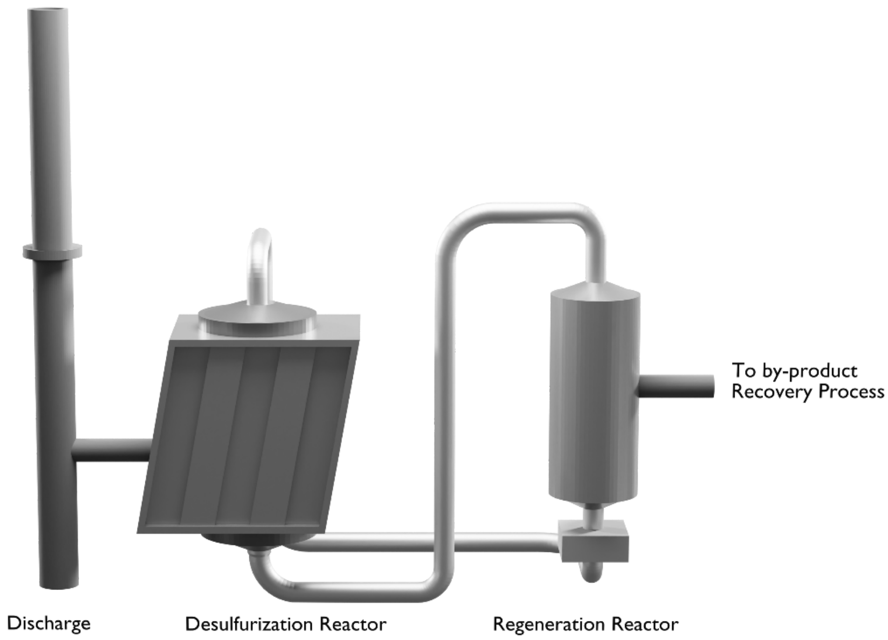

Figure 3.2-3 The schematic illustration of an ACD process

3.2.3 SCR denitrification process

Selective catalytic reduction (SCR) is the most widely applied denitrification technique in steel industry. It uses NH_3 to "selectively" reduce NO_X to nitrogen and water under catalysis condition, without reducing the oxygen. The SCR facility possesses the advantages of small land-occupation and stable de-NOx effect, is suitable for environmental protection transformation of enterprises since it can be connected to existing desulfurization devices.

A typical SCR facility consists of an ammonia system, a denitrification reactor, a heat exchanger, etc. In ammonia system the ammonia hydroxide (20%) is evaporated to ammonia and then injected into denitrification reactor, in which the ammonia reacts with NO_X at 280~420℃ and converts to N_2. In sintering process, the flue gas needs to be heated through the heat exchanger before denitrification to ensure catalysis performance if a wet desulfurization has been carried out before SCR and results in a decrease in temperature, [12].

Catalyst is the most crucial part of a denitrification reactor. The composition and structure of the catalyst will directly influence the efficiency and stability of the SCR system. At present, V_2O_5/TiO_2 is the mainstream catalyst which has the advantage of high SCR activity under low-temperature as well as high SO_2 resistance [13]. Other usual catalysts include noble metals (Ag, Sn), metal oxides (CeO_2, MnO_2, CuO_2, etc.), zeolite and carbon-based catalyst.

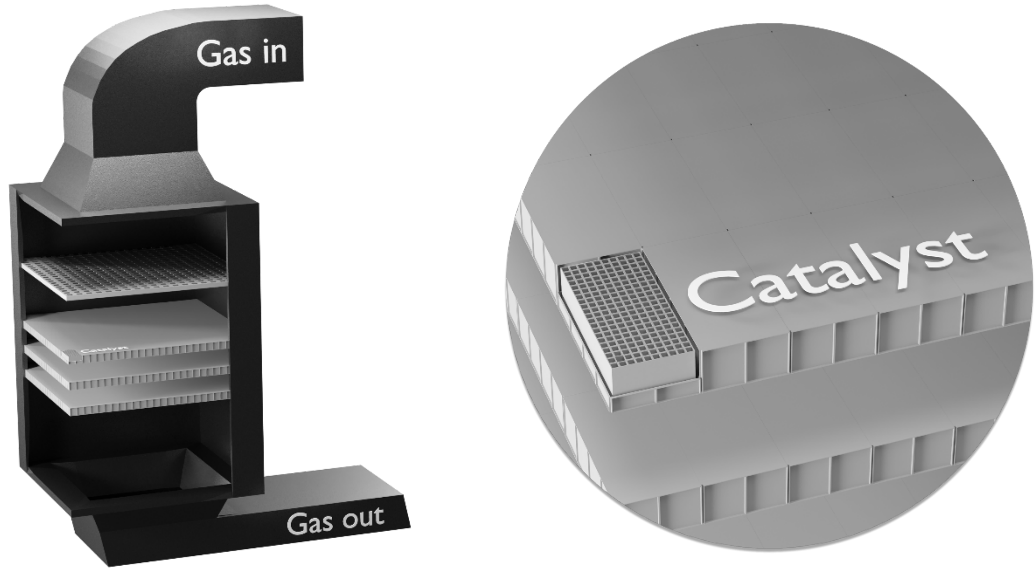

Figure 3.2-4 The schematic illustration of the structure of a typical SCR reactor

Compared with selective non-catalytic reduction (SNCR) process, a well-functioning SCR process could achieve 90% or higher de-NO_x efficiency at a lower temperature, ideal for the denitrification of coking and sintering procedures.

3.2.4 Fugitive emission control techniques for stockyard

Fugitive emissions are major but often overlooked emission sources for steel enterprises, which exist in almost every procedure of steel production. One of the most influential fugitive emission sources is the raw material stockyard. On average, steel enterprises with long process flow must convey 5 tons of raw materials, fuels and additives for per ton crude steel production, and a significant percentage of shipping, storage and transportation take place in stockyard. According to statistics, a stockyard with poor environmental protection facilities discharge 200-270 tons of dust for every million ton of materials it stores and conveys, 112 tons if equipped with wind-proof meshwork, harden surface, wheel washer, sealed off belt conveyors or dust collectors. [14] In windy weather, the PM concentration close to a poorly-sealed-off stockyard could be several times beyond statutory limit (1.0mg/Nm^3).

A usual solution for the fugitive dust spilling problem is sealing off the whole stockyard, which has been adopted by many steel enterprises. At present, the B-type, C-type, D-type and E-type are the frequently-used enclosed stockyard structures.

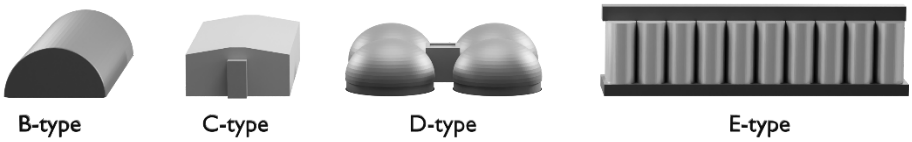

Figure 3.2-5 The schematic illustration of different types of enclosed stockyard

However, the environment and sanitation of indoor stockyards is unideal, especially for those that still require massive manual labor since traditional automatic controlling techniques are not smart enough to run a fully unmanned yard. Recently, a technology called intelligent stockyard provides a new solution for fundamentally improving the automation control capability of the stockyard.

The intelligent stockyard adopts digital twin technology to create a full digital entity of real stockyard. Through the advanced technology of artificial intelligence and machine learning, the digital twin establishes an "authentic" model in cyberspace which has a strong presence and could be updated in real time, supporting the decision-making of the corresponding physical entity in real world. Figure 3.2-6 shows an application of digital twin based intelligent stockyard technology in Jiangxi province.

Figure 3.2-6 An intelligent digital twin stockyard in Jiangxi province, China

As world's first intelligent digital twin stockyard, this platform applies several patented technologies, such as bulk material conveying path optimization technology, clean transfer and the wisdom "taking, making, depositing and checking" testing technology. The platform is driven by full-time-domain-accuracy, which is the world's first and the most complete refactoring and mapping of stockyard in steel enterprises. It can use efficient data collection technology to obtain massive point cloud data. Based on the original " diversified and multi-source" analysis technology, perform non-differentiated feature mapping on various types of data, match digital stockpile elements in real time, instruct the machine to stack and reclaim materials automatically depend on the production status of the stockyard.

Through the application of digital twin techniques, equipment can work together efficiently and prepare samples automatically since the stockyard data is connected. The whole process integration from management decision-making to production task formulation could be realized, as well as precise execution of specific instructions and real-time feedback. Through intelligent control, simulation and analysis optimization, the enterprise could minimize error and maximize efficiency, enjoy both economic and environmental benefits.

4.Conslusion

China is the first country in the world to propose and implement the whole-process ultra-low emission transformation of domestic steel industry. According to the reports, by the end of 2025 when the milestone of the ULE transformation is achieved, China's steel industry could reduce SO_2, NO_x and dust emission by 61%, 59%, 81%. During the transformation process, the industry has applied and explored several key source reductions as well as terminal pollution control techniques and has achieved expected results, which is meaningful for the development of global steel industry.

It is foreseeable that with the progress of China's economic restructuring, the manufacturing and infrastructure construction in Southeast Asia will usher in a new high-speed development in the future, driving the explosive growth of local iron and steel enterprises. According to the historical experience of China and other major steel-producing countries, with the development of the economy, the environmental protection requirements for the steel industry will become much stricter in the future.

We hope that the experience and lessons of the ultra-low emission transformation of China's steel industry can provide reference for our counterparts in Southeast Asia, and the key technologies introduced in this article may come in handy for upcoming projects.

References

[1] CHINA IRON & STEEL ASSOCIATION. 2021. 2021 annual report of China's iron and steel industry [OL]. lwzb.stats.gov.cn.

[2] He K B. 2019. Winning the defense of the blue sky needs to accelerate the ultra—low emission transformation of the steel industry. China Environ News.20l9—05.06

[3] Li X C. 2021. Key ultra-low emission technologies in the whole process of steel production [M]. China: Metallurgical Industry Press, 2021, 16-22.

[4] Quality standard on treated gas emissions, waste water of environmental process equipment, projects in the complex. Vietnam national standard, QCVN 51:2017/BTNMT.

[5] China iron & steel association. 2022. The progress of ultra-low emission transformation and evaluation and monitoring of iron and steel enterprises [OL]. lwzb.stats.gov.cn.

[6] Yang M. 2021. Research and application of fine desulfurization system of blast furnace gas in iron and steel enterprises [J]. Energy for metallurgical industry, 1001-1617 (2021) 01-0061-04.

[7] Fan X H. 2015. Research status of flue gas circulating sintering technology [C]. Proceedings of the 2015 National Sintering and Pelletizing Technology Exchange Annual Conference.

[8] The best available technology and emission reduction potential report for the air pollution control of iron and steel industry. The Environmental Impact Assessment Center of Ministry of Ecology and Environment of the People's Republic of China. 2017.

[9] Li H M. 2010. The analysis of circulating fluidized bed desulfurization for sintering machine flue gas [J]. China New Technologies and Products, 2010 (24)

[10] Chang Z T. 2019. Application of SDS+SCR process in desulfurization and denitrification of coke oven flue gas [J]. China Metallurgy, 2019,29(10):65-70

[11] Du Y N. 2020. Review of activated coke for dry desulfurization of flue gas [J]. Modern Chemical Industry, 0253-4320(2020)01-0063-05

[12] Zhang Y Z. 2020. Analysis on SCR Denitrification Process of Sintering Flue Gas [J]. Metallurgical Power, 1006-6764(2020)08-0087-03

[13] Chen C M. 2018. Review on the latest developments in modified vanadium-titanium-based SCR catalysts [J]. Chinese Journal of Catalysis 39 (2018) 1347-1365

[14] Technical Specification for application and issuance of pollutant permit iron and steel industry. Ministry of Ecology and Environment of the People's Republic of China. HJ846-2017.