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Current status and development trends of innovative blast furnace ironmaking technologies aimed to environmental harmony and operation intellectualization

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ABSTRACT

Blast furnace (BF) ironmaking is dominant for reducing pollution emission and energy consumption in iron and steel industry. Under the increasingly strict environmental pressure, some innovative technologies of BF ironmaking for environmental protection have been developed and applied in actual operating facilities. The current state of BF ironmaking in Europe, America, Japan, and China were briefly overviewed. Moreover, some innovative BF ironmaking technologies aiming at environmental harmony and operation intellectualization in the world, such as waste gas recycling sintering, BF operation with coke oven gas injection, ferro-coke, lime coating coke, BF visualization and intellectualization, were roundly summarized. Finally, some discussion on the technologies was carried out and the development trends of BF ironmaking were pointed out. The review could provide references and supports for the progress of environment-friendly technologies of BF ironmaking, thereby promoting their practical applications and achieving sustainable development of BF ironmaking, especially for Chinese ironmaking industry.

1. Introduction

Recently, environmental problems such as global warming and air pollution have become increasingly serious and attracted wide attention. The mitigation of CO_2 emission has become a hot issue for achieving low carbon living throughout the world (Paris Climate Conference in 2015). As one of the pillar industries for national economy and society, steel industry is responsible for reducing CO_2 emission, which accounts for 5%—7% of the total global CO_2 emission[1] and about 15% of the whole industrial CO_2 emission[2]. Meanwhile, blast furnace (BF)-converter process is dominant for steel production presently and in the future. Among this process, BF produces more than 94% of the total pig iron all over the world[3], whose energy consumption and CO_2 emission account for about 70% of the whole iron and steel enterprise[1,4]. The energy consumption is quite high and the pollution is much more severe considering raw materials processing, such as sintering, pelletizing, and coking. Therefore, energy conservation and pollution reduction in ironmaking system are remarkably significant for the sustainable development of iron and steel industry.

Under the increasingly strict environmental standards, some innovative technologies for reducing pollutants emission and saving energy in BF ironmaking were developed or applied in actual operated facilities with good results in many countries, such as Ultra Low CO_2 Steelmaking (ULCOS) Project[5], CO_2 Ultimate Reduction in Steelmaking process by innovative technology for cool Earth 50 (COURSE50) Project[6], Super-SINTER, lime coating coke, waste gas recycling sintering, magnesia pellet, ferro-coke, reactive coke agglomerate, co-injection of natural gas and coal, and BF visualization. In this paper, the current state of BF ironmaking in Europe, America, Japan, and China was briefly overviewed. Furthermore, some innovative BF ironmaking technologies aiming at environmental harmony and intellectualization were roundly summarized together with practical applications. Finally, some discussion on the technologies was carried out and the future development trends of BF ironmaking were indicated. This review could provide beneficial informa-

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tion for the investigation on environment-friendly technologies of BF ironmaking, and promote the progress and sustainable development of BF ironmaking, especially for Chinese ironmaking industry.

2. Environment-friendly and Intellectualization Technologies of BF in Europe

2.1. Overview of BF ironmaking

BF hot metal production was decreased from 103 Mt in 1980 to 80 Mt in 2014 for EU15 (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxemburg, Netherlands, Portugal, Spain, Sweden, UK) since the financial crisis in 2008 brought about a collapse to steel industry, as shown in Fig. 1[7]. Moreover, the number of BFs reduced from 92 in 1990 to 45 in 2013. However, the average production per furnace rose from 1.04 to 1.71 Mt of hot metal per year and the average volume of the furnace increased from 1630 to 2063 m^3[8]. Furthermore, the energy utilization efficiency of BF in Europe is quite high and the coke ratio is decreased to an average of about 330 kg per ton of hot metal (kg/t) in 2013. In some BFs, the coke ratio is reduced to 270 kg/t together with 230 kg/t coal injection. Additionally, almost all BFs were operated with coal injection and without oil and natural gas injection for economic reasons. The emission of CO_2 from BF is about 1570 kg/t in Europe[8], considered as the lowest emission in the world. Currently, the standards for the environmental protection in the industry are strict and the operations with high pollutant emissions like the steel industry have become a major issue in recent years.

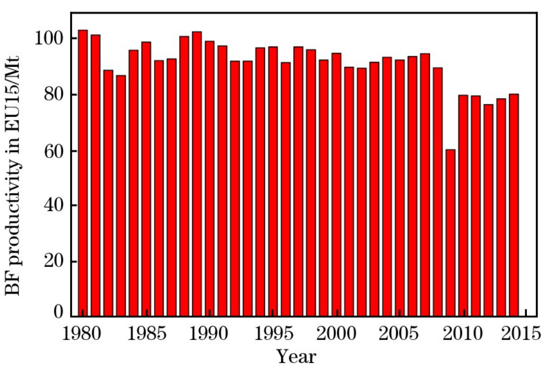

Fig. 1. Variation of hot metal production in EU15.

2.2. BF charging burdens

The iron-bearing burdens of BF in Europe mainly consist of sinter, pellet and lump ore. Recently, sinter charging ratio in mixed burdens was remarkably decreased while that of pellet was increased in terms of environmental protection. In 1990, the sinter charging ratio for many actual operating BFs was over 80% while the charging burdens tended to be shifted to a higher pellet ratio in 2013[9]. Furthermore, sinter plants were closed in Sweden and Finland, where BF charging burdens consisted of about 90% pellets and 10% briquettes of recycling waste materials. In Europe, sinter cannot be tradable and pellet as well as lump ore is almost provided by iron ore supplier. The only pellet plant is operated at IJmuiden works in Tata Steel[10].

Additionally, the sintering process is mainly used to treat recycling materials and waste materials such as iron-bearing dust, sludge, and fines material, which is why sintering process is still reserved in Europe under meeting the requirement of metallurgical performance and environmental protection. However, waste materials containing high Cl, high S, high Zn, high Pb, and high alkali are not permitted to recycle via sinter plants. In 2013, 29 sinter plants were commercially operated in EU15. The average suction area of sinter machine is about 288 m^2 and the largest suction area is up to 589 m^2. The highest productivity of sintering with 59.5 t/(m^2 · d) sinter was achieved[8].

2.3. Sintering waste gas cleaning and recycling technologies

In Europe, sinter plants have to adopt feasible and effective measures to meet the severe standards for environmental protection, especially for reducing discharging of dust, SO_2, NO_x, and dioxins. Almost all sinter plants employed waste gas cleaning technologies and waste gas recycling sintering technologies for governing the sintering waste gas[11]. MEEP (moving electrode type electrostatic precipitator) technology and waste gas dry cleaning technology were developed for cleaning sintering waste gas. Also, some waste gas recycling sintering technologies[12], such as LEEP (low emission and energy optimized sinter process) and EPOSINT (environmental process optimized sintering), were adopted to reduce exhaust gas emission.

Dust in sintering waste gas cannot be adsorbed by the traditional electrostatic precipitation technology since its resistance is more than the critical value. The moving electrode and rotating brush are used in MEEP technology to avoid partial blowback effect[13,14]. The operating principle of MEEP technology is shown in Fig. 2[15]. MEEP technology was developed and successfully applied at Eisenhüttenstadt sintering machine in ArcelorMittal[15]. In addition, milled lignite semi-coke, coke breeze or active coal used as adsorbent are injected into the off-gas line together with electronic magnetic filter bag or cloth bag units to reduce the emission of dioxins in sintering waste gas, which is currently state of the art technology for reducing dioxins emission, as shown in Fig. 3[15].