Recent Development of Energy-saving Technologies in Ironmaking Industry

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Abstract. Environmental protection and carbon emission reduction pressures are increasingly becoming a key factor affecting the sustainability of China's steel companies at this stage. The key to energy saving and emission reduction in the steel industry lies in the innovation of ironmaking technology. It is inevitable to innovate and improve the traditional blast furnace ironmaking process and further strengthen the development of new ironmaking processes. This paper briefly reviews the representative achievements of iron and steel energy saving and emission reduction and new ironmaking process development in recent years, such as blast furnace utilization of alternative fuel, oxygen blast furnace ironmaking process, HIsarna smelting reduction ironmaking technology, COURSE50 technology and RHF iron nugget technology. It is expected to provide reference for achievement of energy saving, emission reduction and sustainable development of China's steel industry.

1. Introduction

The iron and steel industry is the basic raw material production department of China's national economy. In 2017, China's crude steel output has reached 832 million tons, accounting for 49.2% of world steel production. As China is in the stage of accelerating industrialization and urbanization, the amount of steel consumption required for capital construction and manufacturing development will remain high for a long period of time. China has become the global center of metallurgical production and consumption. However, the steel industry takes a major responsibility for China's energy consumption and pollution emissions. The energy consumption of the steel industry accounts for 16% of China's total industrial energy consumption, while the energy consumption of the ironmaking process accounts for about 90% of the entire process of steel smelting. The key to achieving energy-saving and emission reduction in the steel industry lies in the innovation of ironmaking technology. There are two main ideas: on the one hand, the improvement of the existing ironmaking process; on the other hand, the development of a new ironmaking process. This article will focus on the above two aspects to discuss recent development of energy-saving technologies in worldwide ironmaking industry.

2. Technologies

2.1. Fuel replacement of blast furnace ironmaking process

In the process of blast furnace ironmaking, a large amount of coke and coal powder are consumed as reducing agents and energy sources. However, coal resources are non-renewable. The application of renewable energy materials in blast furnaces can not only alleviate the shortage of coal resources and
reduce pollutants and greenhouse gas emissions, but also develop an effective clean utilization way for hydrocarbon-containing solid waste resources.

Biomass energy has always been the main form of energy used by humans, accounting for about 10-14% of the world’s energy supply. The research and development of biomass energy to replace fossil energy for blast furnace production has become a hot spot for many scholars at home and abroad. Among them, many scholars of Japan, Brazil, Canada, Australia, Europe, the United States and China have studied a lot. Japan JFE Engineering Company found that it is completely feasible to prepare metallurgical coke by mixing the pressed biomass with coal; University of Science and Technology Beijing has studied the preparation and properties of biomass coke for ironmaking [1]. Kyushu University and the Aachen University conducted research on different wood powders in the blast furnace and found that their combustion behavior is no less than that of coal powder [2]. The Canadian National Energy Laboratory found that charcoal is a fuel suitable for direct injection in blast furnaces [3]. Brazil is the largest producer of charcoal in the world, with an average annual output of more than 2.3 million tons, and Brazil is also the country with the most biomass-charcoal applications in the ironmaking process. The charcoal injection ratio reached 100-150 kg/tHM in Brazil [4].

In addition to biomass, it is also feasible to inject waste plastics into blast furnaces. The H/C ratio of waste plastics is significantly larger than the equivalent amount of pulverized coal. The diffusion and reduction abilities of H\(_2\) are greater than CO. Therefore, replacing pulverized coal with waste plastics in the blast furnace ironmaking process is beneficial to increase productivity and reduce coke ratio. The low ash and sulfur content of the plastic can reduce the amount of lime in the blast furnace, and thus reduce the slag ratio and ironmaking cost of the blast furnace; the reaction rate of the waste plastic is much better than that of the pulverized coal. Some countries have relatively early conducted research on the injection of waste plastics into blast furnaces, and Germany and Japan have already achieved industrialization. Japan’s NKK has tried to inject chlorine-free waste plastic into blast furnaces since 1996, and the volume of test injection reached 200 kg/t. In 2000, the injection volume reached 90,000 tons. Schematic diagram of the waste plastic blast furnace injection technology is shown in Fig2. China is actually in the stage of theoretical research and feasibility demonstration about it [5-11]. Compared with direct incineration, the waste plastic blast furnace injection technology has the following advantages: theoretically, no dioxin is produced; the energy utilization efficiency is higher than that of other waste plastics treatment technologies, and the heat utilization ratio is as high as 80%; the practice of injecting waste plastics into blast furnaces has been proved that the treatment cost is only 60% of the incineration treatment method [12].
2.2. Oxygen blast furnace ironmaking technology

In 1970, Professor Wenzel and Gudenau of Germany proposed the concept of oxygen blast furnace ironmaking technology\cite{13}. The process has been improved on the basis of the existing blast furnace: the tuyere is blasted into normal temperature oxygen and a large amount of pulverized coal, and the top gas is circulated into the hearth. The process can not only improve production efficiency, but also provide high calorific value gas for external use, but also provides a possibility for carbon dioxide separation and capture to further reduce carbon emissions. However, this process has not been applied to industrial production. The main reason is that with the increase of oxygen enrichment rate and pulverized coal injection volume, the blast air volume and the physical heat brought in by the blast are reduced, which makes the furnace charge insufficiently heated\cite{14}, so that seriously affects the reduction process of ore and makes the coal-coke substitution ratio has decreased and the overall fuel ratio has increased significantly. To this end, many scholars in the metallurgical industry have carried out a lot of research work on oxygen blast furnaces\cite{15-17}, but they are all in the theoretical research stage. In 2007, some scholars conducted industrial tests on a blast furnace with a volume of 8.9m3, and found that the coke ratio can be reduced from 400-405 kg/tHM to 260-265kg/tHM, and carbon emissions can be saved by 24%.

2.3. HIsarna smelting reduction ironmaking technology

The HIsarna process originated from the previous Isarna process. Isarna is based on the melting pool technology, which makes coal preheat and partial pyrolysis in the reactor. HIsarna is a combination of Isarna technology developed by ULCOS and HIsmelt smelting technology owned by Rio Tinto, combining HIsmelt smelting technology with cyclone ore smelting and pre-reduction techniques\cite{19}. This cyclone technology originated from the cyclone (CCF) developed by the early British steel, Hoogovens and Ilva. The final reduction and coal gasification phase of the HIsarna process is basically a modified HIsmelt process, so the HIsarna process is based on an improved version of HIsmelt smelting technology\cite{20}.
Figure 4. Schematic diagram of the HIsarna process

The composition of molten iron in the HIsarna process is different from that of blast furnace molten iron. Since the slag oxidation degree of the HIsarna process is higher than that of the blast furnace slag, the reduction of SiO2 and P2O5 is reduced, and the content of Si, Mn, P and the like in the molten iron is very low, while the content of S is high. The content of FeO in this slag is about 5 to 6%. The HIsarna process produces liquid molten iron for use in BOF or EAF plants. In the current pilot plant operation, the calculated coal consumption is 750kg/t. If it is expanded to a commercial scale demonstration plant with an annual output of 100t molten iron, the converted coal consumption will be less than 600kg/t. In recent years, the pilot test of the HIsarna process is still going on, and it will take some time for the process to develop into industrial applications. Shandong Molong, a Chinese company, has improved the HIsarna process by combining rotary kiln pre-reduction and melting furnace separation. The indicators are as follows: the coal ratio is 950kg/t, and the oxygen content in blast is 36.7%. The productivity is 1876 tHM/d in the new process.

2.4. COURSE50 technology

The COURSE50 technology originated in Japan and was funded by the New Energy and Industrial Technology Development Organization (NEDO), a national project jointly researched by several Japanese steel companies and research institutions[21]. The project mainly includes[22]: blast furnace ironmaking technology to reduce CO2 emissions and blast furnace gas capture, separation and recovery. The project also takes into account the environmental protection requirements and economic benefits of energy conservation and emission reduction. The ultimate goal is to reduce CO2 emissions by 30% (10% reduction by hydrogen reduction ironmaking and 20% reduction of carbon dioxide by blast furnace gas separation). The main research content of this process is shown in Figure 5.

Figure 5. COURSE50 process

At present, Japan has carried out comparatively systematic research on COURSE50. First, the basic research related to the new ironmaking process was carried out by universities and steel companies, including iron ore hydrogen reduction, new coking processes, slag waste heat recovery, CO2 capture and separation, etc. Further, Nippon Steel & Sumitomo Metal Corporation[23] built a trial blast furnace in 2015 with a volume of 12m³. The furnace has three hearth vents and three shaft vents, a loading
system, an iron port with a tapping machine and a mud gun, an ore and coke bin, and a gas purification system. Two trial blast furnace operations were conducted in July 2016 and February 2017. The test results show that the direct reduction degree of carbon is reduced from 31% to 21%, and the direct reduction degree of hydrogen is increased from 3% to 10%.

2.5. Rotary hearth furnace iron nugget technology
In 1995, Kobe Steel discovered the phenomenon that slag and iron can be separated during high-temperature heating of carbon-containing pellets. The reduction temperature was 1350~1450°C, and the reaction time only spent about 10 minutes. The obtained product is granular iron nugget, of which the main components are Fe and C. The purity is higher than that of the blast furnace pig iron, which is called “Ironmaking Technology Mark 3” (ITmk3). After that, the research institutes in Japan, South Korea, Germany, and the United States carried out basic research on this new ironmaking process. While conducting basic laboratory research, Kobe Steel also carried out industrial research of ITmk3. In January 2010, finally, American Power Steel Company build a commercial plant with an annual output of 500,000 tons in Minnesota by this technology and put it into production (Mesabi Nugget). The product can be used as an electric furnace charge, a coolant for converter steelmaking and a high quality clean iron source for casting. The experiment shows that the tapping time can be shortened by 2 to 3 minutes and the productivity can be increased by 5 to 8%, when the proportion of the addition of the iron nugget is 15 to 20%. In 1997, Prof. Kong Lingtan of University of Science and Technology Beijing also discovered the phenomenon of formation of iron nugget in laboratory experiment, which was named as Coal Hot-Air Reduction Process (CHARP)[24]. The iron ore/carbon composite pellets are used as burden to improve the reduction of iron ore and the melting separation of slag and iron[25]. In March 2015, due to the steel prices’ decline in the whole world and weak demand of steel products, the Mesabi Nugget was forced to halt production. It has reached 32,000 tons/month this moment, which is close to the ideal capacity.

![Figure 6. RHF iron nugget process](image)

3. Conclusion
The energy saving and emission reduction are of great significance to China's industrial production process. And the key to energy saving and emission reduction of the steel industry lies in the iron making process. The direction of energy saving and emission reduction in the iron making process includes: (1) using renewable sources to enhance the function of the steel plants that serve the development of the city, and to promote the integration of the steel mill and the city; (2) oxygen blasting to create conditions for CO2 separation, capture and storage; (3) developing short-process ironmaking process and ironmaking process that can directly use powdery iron ore to reduce energy consumption and emissions in high-temperature processing during raw material preparation.
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