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# Sulfur Flow Analysis for New Generation Steel Manufacturing Process

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**Abstract**: Sulfur flow for new generation steel manufacturing process is analyzed by the method of material flow analysis, and measures for $SO_2$ emission reduction are put forward as assessment and target intervention of the results. The results of sulfur flow analysis indicate that 90% of sulfur comes from fuels. Sulfur finally discharges from the steel manufacturing route in various steps, and the main point is BF and BOF slag desulfurization. In sintering process, the sulfur is removed by gasification, and sintering process is the main source of $SO_2$ emission. The sulfur content of coke oven gas (COG) is an important factor affecting $SO_2$ emission. Therefore, $SO_2$ emission reduction should be started from the optimization and integration of steel manufacturing route, sulfur burden should be reduced through energy saving and consumption reduction, and the sulfur content of fuel should be controlled. At the same time, BF and BOF slag desulfurization should be optimized further and coke oven gas and sintering exhausted gas desulfurization should be adopted for $SO_2$ emission reduction and reuse of resource, to achieve harmonic coordination of economic, social, and environmental effects for sustainable development.

**Key words**: material flow analysis; sulfur flow analysis; steel industry; sustainable development; $SO_2$ emission

Steel industry is an energy-intensive industry. Integrated steel plants are dominating steel producers and BF-BOF steel occupies about 80%−85% of the total crude steel output in China. The energy consumption of the Chinese steel industry accounts for 10%−15% of the total energy consumption. In the energy structure of the Chinese steel industry, consumptions of coal and electricity account for 75% and 20% of the total energy consumption, respectively. The energy structure and low quality of coal actually result in serious pollution of $CO_2$, $SO_x$, and dust from the steel industry. $SO_2$ emission of the steel industry occupies about 14% of the industrial emission in China[1].

The resulting $SO_2$ emission and acid rain are one of the main global environmental issues, especially for developing countries. However, at the same time, $SO_2$ is an important resource for vitriol and fertilizer. According to the modern scientific environmental standpoint, which combines the principles of ecology, methods of clean production, and targets of sustainable development and recycling economy, reducing and recycling of $SO_2$ is an efficient way to restrain acid rain pollution.

Whether and how to combine emission control with recycling for $SO_2$ are important questions for study. In the following sections of the article, the source, pathway, chemical-physical transformation, and dissipation of sulfur for BF-BOF route will be analyzed by the method of material flow analysis. Based on this analysis, the possibility of and the approach to emission control and recycling of $SO_2$ as raw material of other industries will be researched.

## 1 Material Flow Analysis

### 1.1 What is material flow analysis?

Material flow analysis (MFA) is a systematic assessment of the flow and stock of materials within a system in given space and time. MFA is widely applied in the fields of industrial ecology, environmental management and protection, resource management, and waste management. It is also used as a basis for life-cycle assessment, eco-balance, environmental impact statements, etc[2].

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MFA links mining, production, consumption, and waste treatment of materials on the basis of the law of the conservation of matter. By balancing the inputs and outputs of a given system, the state and process of material flow are analyzed, described, and simulated, to understand sources, pathways, intermediate storage, and dissipation of material in the system for more reasonable designing, and control of materials with improved energy and resource utilizing efficiency in material circulation, and expected environment protection, resource conservation, and sustainable development[2-4].

## 1.2 Definition of system boundary

Crude steel is now predominantly produced by two routes: the BF-BOF route and EAF route, which will continue to be the mainstay of steel production for years to come. In 2005, the BOF steel output accounted for 65.4% and the EAF for 31.7% of the total world steel production. The rest, 2.9%, was produced by other processes[5].

The system studied in this article is BF-BOF route including coking, sintering, ironmaking, steelmaking, continuous casting, and hot rolling.

## 1.3 Procedure of sulfur flow analysis

Firstly, the theoretical analysis of sulfur flow in steel manufacturing rout is carried out at the process level, and then, according to the parameters of advanced domestic and foreign plants, including raw material conditions, equipment parameters, technique, operation level, and technico-economical indexes, new generation steel manufacturing process is reconstructed and its sulfur flow is studied and evaluated. Then, the approaches and measures to reduce $SO_2$ emission further and to recycle $SO_2$ are put forward as assessment and target intervention of the results.

## 1.4 Theoretical analysis of sulfur flow at process level

### *1.4.1 Coking*

In coking process, nearly 60%−70% of sulfur in coking coal is transferred to coke, and the rest enters into gas. In coke oven gas, nearly 95% of sulfur exists as $H_2S$ and the sulfur content is generally 5−8 g/m$^3$.

In wet coke quenching process, a comparative amount of $H_2S$ is produced owing to the reaction of water with red-hot coke; while in dry coke quenching process, an equivalent amount of $SO_2$ is produced because a little coke is burnt[6].

### *1.4.2 Sintering*

In sintering process, sulfides are decomposed and oxidized at different temperatures, and the sulfur in burden is redistributed along the vertical direction. Finally, $SO_2$ is emitted or further oxidized to $SO_3$. The desulfurization rate of the sintering process can be as high as 85%−95%.

In sintering process, gasified sulfur from combustion zone and/or preheating zone enters into the preheating zone and the over-wet zone as S, $SO_2$, and $SO_3$. The sulfur content of off-gas decreases gradually while the sulfur content of burden increases from top down, described by the change in the $SO_2$ content of exhausted gas from sintering machine (Fig. 1[7]).

### *1.4.3 Ironmaking*

Sulfur is circulated in BF. The charges react with ascending gas and absorb the majority of sulfur in gas. When entering into the high temperature zone, part of sulfur gasifies. The desulfuration by slag, as the main mode of desulfuration in BF, will occur during passage of molten iron hearth through slag. Sulfur is absorbed by slag in the whole zone over the tuyeres while sulfur is mainly gasified at the bottom of BF from the dropping zone to tuyeres. Generally, slag absorbs 85% of the total charged sulfur and less than 10% is dissolved in hot metal. Fig. 2 shows the distribution of sulfur among the charge, slag, metal, and off-gas[8].

### *1.4.4 BOF steelmaking*

In the BOF steelmaking process, desulfuration is mainly accomplished by slag-metal interface reactions. Only at the beginning of oxygen blowing, sulfur is gasified in the reaction zone, where only less than 10%−20% of sulfur is removed by gasification.

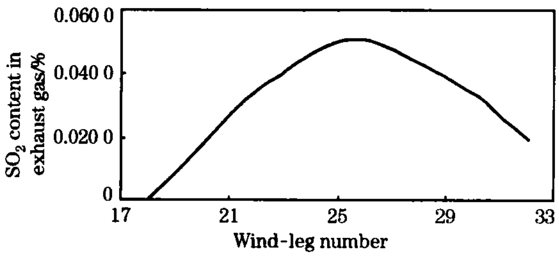


**Fig. 1 $SO_2$ distribution in sintering process**