Applied Thermal Engineering 136 (2018) 152–160

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Fluctuation characteristic of billet region gas consumption in reheating furnace based on energy apportionment model

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HIGHLIGHTS

- A system analysis method about fluctuation degree of BRGC is put forward.
- Strict production rhythm is conductive to reduce the fluctuation of BRGC.
- Hearth pressure and loading temperature have influence on the fluctuation of BRGC.
- The loading plan should be formulated according to the principle of unity.

ARTICLE INFO

Keywords:
Reheating furnace
BRGC
BRGCSD
Fluctuation degree

ABSTRACT

To master the fluctuation characteristic of billet gas consumption in different regions of reheating furnace, a system analysis method about fluctuation degree of billet region gas consumption (BRGC) is put forward in accordance with energy apportionment model. And this system analysis method mainly includes: (i) The space division of reheating furnace; (ii) The simplification of energy apportionment model in reheating furnace; (iii) The classification of billet samples; (iv) The establishment of BRGC standard deviation (BRGCSD) analysis model. A case study shows that (i) the BRGC fluctuates greatly in low temperature area, and fluctuates smoothly in high temperature area; (ii) The volatility degree of BRGC is intensified because of the lower loading temperature; (iii) It is very reasonable that the residence time of billets is controlled in (3,4] and (4,5] range, and the average fluctuation degree is about 0.01 and 0.012 respectively; (iv) The fluctuation of BRGC is amplified in some regions because of mixed charging. The analysis results show that some measures can reduce the fluctuation of BRGC, such as the stable operation of tiny positive pressure, the control of production rhythm, the improvement of billet loading temperature, the optimization of loading plan.

1. Introduction

The iron and steel industry, which has made great progress in steel output [1], product structure [2,3], energy saving [4,5], is an important pillar industry in national economic development [6,7]. With the rapid development of iron and steel industry, it is accompanied by mass energy consumption (Especially in China, as shown in Fig. 1). However, there is a sharp contradiction between high energy consumption and increasingly exhausted tradition energy source [8,9]. And then, the rapid growth of energy consumption has not only increased the cost of enterprise [10,11], but also increased emissions of the environment, such as CO_2 [12,13], NO_x [14,15], SO_2 [16,17], etc.

At present, there are two main production processes in iron and steel industry, namely the long flow production process (TLFPP) and the short flow production process (TSFPP). And TLFPP is a production process, which mainly includes sintering/pelletizing process, iron-making process, converter steelmaking process, continuous casting process, and steel rolling process. And then, TSFPP is a production process, which mainly includes EAF steelmaking process, continuous casting process, and steel rolling process. Whatever the case, steel rolling process is indispensable part of iron and steel enterprise. And the reheating furnace, whose energy consumption accounts for 15–20% of the total enterprise energy consumption and 70% of the energy consumption of steel rolling process [18,19], is very important thermal equipment. Therefore, the research on energy consumption of reheating furnace has always been one of the hot topics in the iron and steel

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https://doi.org/10.1016/j.applthermaleng.2018.03.007
Received 4 November 2017; Received in revised form 2 March 2018; Accepted 3 March 2018
Available online 05 March 2018
1359-4311/

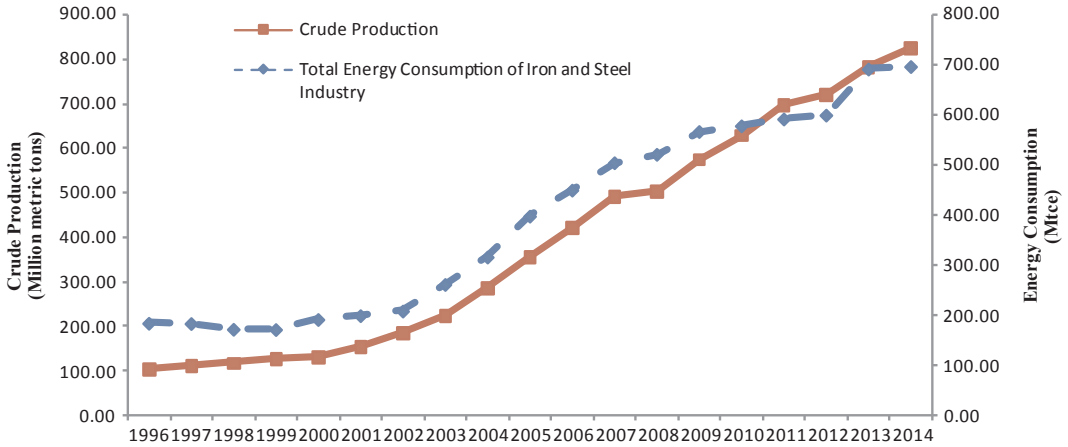

Fig. 1. The crude production and energy consumption of Chinese iron and steel enterprise over the years (Data Source: CHINA STATISTICAL YEARBOOK).

enterprises.

2. Literature review

The research on energy consumption of reheating furnace is mainly carried out in the following aspects.

2.1. The research on heat transfer model of steel billet

Heating transfer model of steel billet, which is able to achieve the calculation and prediction of billet temperature, can be established through heat transfer theory. And it also can improve the quality of steel billet heating (mainly including target temperature and heating uniformity of billet). And then, the temperature set-point of each heating section should be optimized in accordance with the analysis results of these heat transfer model in reheating furnace. And the application of heating transfer model can be divided into two types: on-line and off-line.

(1) The application of on-line

The reheating furnace's level 2 control system, which includes optimized the heat transfer model of steel billet, is a very important on-line temperature control system. And this control system includes the optimization heat transfer model of steel billet, which is established using the total heat absorption rate method. And then, the validity of the model is verified by the "black box" experimentation [20,21].

(2) The application of off-line

With the development of computer performance, Computational Fluid Dynamics (CFD) is widely used to solve the complex problem concerning heat transfer. And these analysis results provide foundation for establishment of reheating furnace temperature system. For example, a novel numerical approach was used to predict the gas phase combustion, heat transfer and transient heating characteristics of the billets in the furnace using CFD [22]. A modification to the energy transport equation was introduced through source terms in the billet region to convert the transient movements of the billets into a steady-state CFD simulation [23].

2.2. Production scheduling and optimization

Production scheduling, which can achieve energy conservation of reheating furnace, is optimized and implemented in accordance with the rolling scheduling. Therefore, a large number of optimization algorithms are used for reheating furnace scheduling. For example, Tang, LX etc. proposed improvement scatter search algorithm, which could determine the feed-in time and the residence time for each slab in order to reduce the unnecessary energy consumption reflected by minimizing the objective under consideration [24]. Suzuki, M. etc. put forward a modeling method that simultaneously optimizes both the permutation scheduling of slabs and the heat controlling of the furnace based on a hybrid model composed of a nonlinear advection equation [25]. And a two-stage method for solving hot rolling planning was proposed, then a simulated annealing, ant colony optimization and variable neighborhood tabu search algorithm was used for solving these two stage problem [26]. And then, other scholars also have important research results in production scheduling and optimization of reheating furnace [27–30].

2.3. Other energy-saving measures

Waste heat of flue gas and vaporization cooling system is about 50% of the energy consumption of reheating furnace [31]. And W.H. Chen etc. [32] has illustrated that near one-third heat of the system is contained in the flue gas, which is leaving from the furnaces. Therefore, if one is able to recover the energy from the hot flue gas sufficiently, a large amount of fuel can be saved. And this waste heat can be reused for preheating cold air, gas or billets [32–35]. Moreover, the application of blackbody technology can also effectively achieve the energy conservation of reheating furnace [36,37].

However, the whole reheating furnace is considered as the research object in above studies. And energy saving of reheating furnace could be achieved through optimization of temperature system, production scheduling and waste heat recovery etc. In actual production, billets are heated gradually through each space region of reheating furnace from loading to unloading position. Moreover, Biao Lu etc. [38] put forward the billet region energy consumption (BREC). And then, the BRECs are different when billets pass through the same region by calculation. However, the fluctuation characteristic of BREC has not been further discussed in this paper. One the one hand, the fluctuation characteristic of BREC is ubiquitous in reheating furnace; on the other hand, the fluctuation characteristic of BRGC has strong influence on the stability of reheating furnace production. Moreover, the stability of reheating furnace production is an important factor to ensure the heating quality of billet. That is, the higher the fluctuation characteristic of BREC, the lower the heating quality of billet. Therefore, the research on the fluctuation characteristic of BREC has very significant implications for improving the heating quality of billet. Moreover, gas is the most important form of energy in reheating furnace, and the fluctuation characteristic of BRGC is discussed in this paper. Consequently, the concept of BRGC is defined firstly. And then, BRGCSD analysis model, which can quantitatively describe the volatility degree of BRGC for various