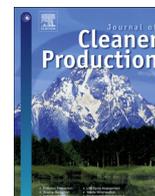




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Burdening proportion and new energy-saving technologies analysis and optimization for iron and steel production system

Xun Shen ^{a, b, c}, Lingen Chen ^{a, b, c, *}, Shaojun Xia ^{a, b, c}, Zhihui Xie ^{a, b, c}, Xiaoyong Qin ^{a, b, c}

^a Institute of Thermal Science and Power Engineering, Naval University of Engineering, Wuhan, 430033, PR China

^b Military Key Laboratory for Naval Ship Power Engineering, Naval University of Engineering, Wuhan, 430033, PR China

^c College of Power Engineering, Naval University of Engineering, Wuhan, 430033, PR China

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ABSTRACT

Taking the 1780 mm hot rolling strip production process as an example, an optimization model covering the sinter matching process to the steel rolling product output for iron and steel production system (ISPS) is established. Linear programming (LP) and nonlinear programming (NLP) methods and “e-p” analysis are applied. Energy consumption and CO₂ emission minimizations are taken as optimization objectives. Total 61 key constraints are considered. The optimal scenario of burdening proportions and operation parameters of blast furnace are obtained. After optimization, the comparable energy consumption per ton steel of ISPS decreases by 2.39% and the comprehensive one by 2.29% compared with the initial values, respectively. Moreover, on specific procedures and process levels, applications of new energy-saving technologies will have significant effects on system energy consumption. When these new energy-saving technologies are synthesizing adopted as the following combination: “hierarchical porous sintering, equivalent calorific value injection + sensible heat recovery of high temperature slags in blast furnace and converter + sensible heat recovery of high temperature converter gas”(without considering the oxygen blast furnace), the maximum energy conservation of 20.63 kgce per ton steel can be achieved, which can make the system energy consumption approximately decrease by 3.40%. When the combination above is applied to the proposed optimization model, the energy-saving effect can attain 5.69%.

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1. Introduction

The iron and steel industry has gone through a booming prosperity in the past few decades around the world. But it is facing some unprecedented challenges, including growing production demands, high quality ore-supply shortage and increasingly complex burden structure of blast furnace (BF), which will have detrimental effects on the energy conservation and CO₂ emission reduction for iron and steel production system (ISPS) (Helle et al., 2011; Lu et al., 2016). At the same time, “green iron and steel” concept is lodged in the public mind, which means higher requirements are put forward on the former two goals from current state (Kuramochi, 2016; Lin and Wang, 2015), environmental impacts (André et al., 2016; Morfeldta et al., 2015; Olmez et al., 2016) and practical measures (Pan et al., 2016a; Wang and Lin, 2016,

2017). The BF process is the key part connecting all the other processes within iron-making system, and the beginning of “thermal connecting” processes (Shen et al., 2016). Energy consumption of BF process accounts for more than 60% of that of ISPS (Chen et al., 2015; Qin et al., 2014). How to make a rational scenario of burden proportions and operation parameters is essential for the BF process (Wu et al., 2010; Zhang et al., 2012a), and has far-reaching effects on the other processes within iron-making system, basic oxygen furnace (BOF) process and secondary refining process, etc (Liu et al., 2016b; Shen et al., 2017; Wang, 2008). Thus, it has a dramatic effect on the energy consumption and CO₂ emission for ISPS. What is encouraging is that further researches on individual component, process module, functional subsystem and process system are being made with developments of mathematical modeling and industrial technologies (Gordon et al., 2015; Jiang et al., 2013a; Shen et al., 2016), including multi-objective optimization (Filippo et al., 2014; Liu et al., 2016d), system dynamics modeling (Kim et al., 2014; Long et al., 2016), application of planning theory (Ates, 2015; Sbihi et al., 2014), carbon capturing (Arasto et al., 2013; Duan et al., 2014) and utilization (Ghanbari et al., 2015;

* Corresponding author. Institute of Thermal Science and Power Engineering, Naval University of Engineering, Wuhan, 430033, PR China.

E-mail addresses: lgchenna@yahoo.com, lingenchen@hotmail.com (L. Chen).

Nomenclature

<i>b</i>	weight coefficient	<i>b</i>	blast
<i>E</i>	<i>e</i> energy consumption, kgce/t	<i>bf</i>	blast furnace process
<i>Em</i>	CO ₂ emission, kg/t	<i>bof</i>	basic oxygen furnace process
<i>G</i>	<i>g</i> the relative equation or objective function of mass and operating parameters	<i>cc</i>	continuous casting process
<i>m</i>	mass, kg or kg/t	<i>coal</i>	coal
<i>p</i>	process steel ratio or constraint	<i>cp</i>	coking process
<i>q</i>	unit energy consumption or CO ₂ emission for a certain material, kgce/t or kg/t	<i>gf</i>	the public auxiliary system
<i>R</i>	basicity	<i>hm</i>	hot metal
<i>T</i>	temperature, °C	<i>i, j, k</i>	components
<i>t</i>	time period	<i>kb</i>	comparable energy consumption per ton steel
<i>TFe</i>	sinter grade, %	<i>l, L</i>	lower and upper bounds
<i>V</i>	volume, m ³	<i>lp</i>	lump pretreating (process)
Greek letters		<i>lump</i>	lump ore
α	coefficient of CO ₂ emission to energy consumption	<i>pellet</i>	pellet ore
ω	component percentage or burdening coefficient, %	<i>pp</i>	pelleting process
Subscripts		<i>qt</i>	other factors
		<i>rp</i>	rolling process
		<i>sp</i>	sintering process
		<i>zh</i>	comprehensive energy consumption per ton steel

Liu and Gao, 2016), efficient heat recovery by chemical heat storage (Chen et al., 2017b; Hayashi et al., 2015; Zamengo et al., 2015) and thermoelectric system (Wang et al., 2014), etc. More potentials for energy conservation and CO₂ emission reduction in ISPS may be explored then.

1.1. Mathematical modeling covering individual component to process system

The feasibility of using mathematical modeling method to study the individual component, process module, functional subsystem and process system in ISPS has been verified by some researchers (Chen et al., 2014; Hocine et al., 2009; Xu and Lin, 2016; Zhang et al., 2011, 2014). Based on material flow and energy flow, many efforts have been made to establish optimization models for processes, subsystems and the whole process system by taking different optimization objectives. Sun et al. (2016) established a mathematical model on the basis of the “industrial metabolism” concept, analyzed the process energy flow by using genetic algorithm and recovery of secondary energy considering the present energy consumption status. They pointed out that there still exist a strong potential for energy conservation on an industrial level in China no matter whether a technological breakthrough or vast investment happens. Based on the driving relationship between the material and energy flows, Sun et al. (2010, 2013a) established a specific energy consumption model of a typical ISPS. The combination of energy consumption structure division, exergy flow analysis and statistical theory is used to obtain the values of theoretical minimum and additional energy consumption. The results indicated that the latter one accounted for nearly 2/3 of practical energy consumption, showing the huge potential of energy conservation. The dynamic programming method was also applied into the optimization for the recovery and utilization of the surplus gases in ISPS. Zhang et al. (2012a) made a deep research on the operation characteristics of ingredients and their effects on coke rate in BF process, and established a BP model to simulate their internal relations by taking the comprehensive coke ratio minimization as the objective. Based on the neural network model, the optimal structure of ingredients was found. While Liu et al. (2015a) performed a systematic analysis of ferrite flow characteristics in ISPS, Lu et al.

(2016) made a further study on the relationship between those characteristics and energy consumption, and established an energy-saving optimization model for iron and steel industry. Production processes with five different ferrite flow structures were calculated by using the actual data of a steel plant, and specific effects of sinter grade, amount of scrap recycling and lump usage on the systematic energy consumption were analyzed, respectively. The results showed that the optimization of iron-making subsystem was the key stage for the optimization of ISPS. Jiang et al. (2013b) established the thermodynamic models of the main processes and whole production system, and compared the theoretical and actual energy consumptions to obtain the energy-saving potential of each process. A new simulation platform was exploited based on the gPROMS software (Orestis et al., 2016), and used to explore energy-saving results of several technologies, the optimal operation parameters and the energy distribution strategies within main processes, etc. Under a series of assumptions and based on physical chemistry reactions, Fruehan et al. (2000) implemented a calculation of the theoretical minimum energy consumptions and the actual ones under certain conditions for the main processes in ISPS. Liu (2015); Liu et al., 2016e) took more practical factors and more objectives into account, and worked out the theoretical minimum energy consumptions, exergy losses and CO₂ emissions of main processes from the coking process to the rolling. Further research on the influence of related factors on the calculation results were also performed.

1.2. Applications of LP and NLP theories

Based on the LP and NLP theories, many studies have concentrated on single- and multi-objective optimization models of individual component, process module, functional subsystem and production system, which can present the optimal performances and effects of some major parameters by taking energy consumption, CO₂ emission, cost and exergy loss minimizations as the objectives. Larsson and Dahl (2003) first introduced the mixed integer linear programming (MILP) method into the modeling of ISPS, and conducted an integrated analyses and optimization of energy consumption and CO₂ emission within a demarcated production process boundary. The optimal operation parameters of processes

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