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Research Paper

Global sensitivity analysis and multi-objective optimization design of temperature field of sinter cooler based on energy value

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HIGHLIGHTS

- An efficient global sensitivity analysis of sinter cooler was performed.
- A sensitivity-based multi-objective optimization of sinter cooler was conducted.
- An accurate RBNN metamodel of sinter cooler was established and adopted.

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ABSTRACT

Sinter cooler, as sinter cooling process equipment, is used to cool the hot sinter to be lower than specified temperature. While the hot gas produced in sinter cooling process is usually recovered and utilized to reduce the energy consumption in recent years. In present study, a global sensitivity-based optimization design method synthesizing both the performances of sinter cooling and energy conservation of sinter cooler was proposed. Firstly, based on the Latin hypercube sampling technique and radial basis neural network approach, an accurate metamodel of the sinter cooler was established. Secondly, to select the significant operating parameters, a global sensitivity analysis was performed to evaluate exactly the sensibility of the indicator parameters with respect to operating parameters. In the analysis, a function decomposition method was firstly introduced into sinter cooler analysis to obtain the global sensitivity indices of operating parameters. Finally, based on the results of global sensitivity analysis, a multi-objective optimization was performed to achieve the optimal indicator parameters and obtain corresponding operating conditions using nondominated sorting genetic algorithm II (NSGA-II). At the end, a Pareto frontier as a group of non-dominated optimal solutions was suggested for engineers to be selected according to actual situation.

1. Introduction

Sintering is the process of agglomeration of fine particles and now it is one of the most important parts of modern steel production process [1]. The amount of energy consumption of sintering is up to 10–15% of total energy consumption in steelworks [2]. Meanwhile, 19–35% of the total sintering energy consumption translates sensible heat of high temperature gas in sinter cooling process [3]. Therefore, the study of waste heat recovery of sinter cooling process is significant for reducing energy consumption of sinter.

Some researchers studied it using numerical and experimental methods. As far as we know, a lot of researchers implemented experiments to study sinter cooling process and obtained useful conclusions. Zhang [4] studied the voidage distribution in an experimental industrial vertical tank which was produced to cool the hot sinter and recover waste heat. The influences of height, particle size, shape factor and tube to particle size ratios on the flow and temperature distributions were discussed. Zhao [5] studied the effects of particle size, materials height, air flow rate and inlet air temperature on sinter sensible heat extraction in an orthogonal experimental research. Feng [6,7] investigated the flow regimes and pressure characteristics using an experimental study. In the study, a modified Ergun's correlation was obtained to calculate the pressure drop of sinter layer. Tian [8–10] investigated the structural and thermo-physical properties of sinter ore and the wall effects on the pressure drop in a series of experiments. Due to the high cost and long period of experiment, numerical simulation which is convenient to be carried out has become another important way to study the sinter cooling process [11,12]. Some investigations on

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Nomenclature

d	average sinter size, m
v	inlet gas velocity, m/s
V_g	volume of gas, m^3
$T_{initial}$	initial sinter temperature, K
T_{inlet}	inlet gas temperature, K
FST	final sinter temperature, K
C_p^{out}, C_p^{in}	specific heat capacity, J/(kg K)
T_{avg}^{out}	average temperature of collected gas, K
T_{gas}	the temperature of collected waste gas, K
t_w	the length of time of waste heat recovery, s
φ	porosity
ρ^{out}, ρ^{in}	density, kg/m^3
E_x	exergy of waste heat recovery (EWHR), J
Q	amount of waste heat recovery, J
PleaseCheck	energy level of waste heat recovery
S_i	sensitivity indices of ith vector
V	variance
V_i	ith part of the variance
N_V	number of design variables
RE	relative error
$RMSE$	root mean square error
k	number of design sampling points
y_i	exact value of ith sampling point
y_i	approximation value of ith sampling point
SSE	sum of squared errors

the sinter cooling process using numerical simulations were conducted and reported. Caputo [13] presented a steady-state one-dimensional mathematical model to simulate the sinter cooling process. The recovery of waste heat was optimized on the basis of simulation results. Jang [14] presented a 3-D model to simulate the sinter cooling process, and the temperature distribution in sinter cooler was obtained. Leong [15] firstly introduced the model of porous media to get the temperature distribution in a sinter cooler, but the temperature difference between the sinter and gas was ignored in the model. Considering the temperature difference, Zhang [16] and Tian [17] presented a local non-equilibrium thermodynamics model in the simulated model to get the temperature distribution of cooler. In order to optimize the energy conservation of sinter cooler, Liu [3,18] presented the energy and exergy analysis of sinter cooling process using a two-dimensional unsteady mathematical model, and the energy and economic properties were optimized with evolutionary algorithm. Feng [19] presented the constructal optimization of sinter cooling process based on exergy output maximization to get the optimal constructal parameters of cross section of sinter cooler.

The above-mentioned analysises and optimizations are helpful for the design of sinter cooler. However, it should be pointed out that the influences of operating parameters on the performances of sinter cooler have not been well analyzed and compared quantificationally until now. In addition, the operating parameters of the above optimizations were selected on the basis of engineering experience. Some important operating parameters such as initial sinter temperature and inlet gas temperature were not considered in the optimization design. Therefore, it is very meaningful to develop a global sensitivity analysis method and optimization design considering synthetically the performances of sinter cooling and energy conservation for the sinter cooler.

In present paper, a global sensitivity analysis was performed to investigate quantificationally the influence of operating parameters on the indicator parameters by introducing a function decomposition method into sinter cooler analysis. Furthermore, based on the results of the global sensitivity analysis, a multi-objective optimization was performed to improve the performances of sinter cooler. The remainder of

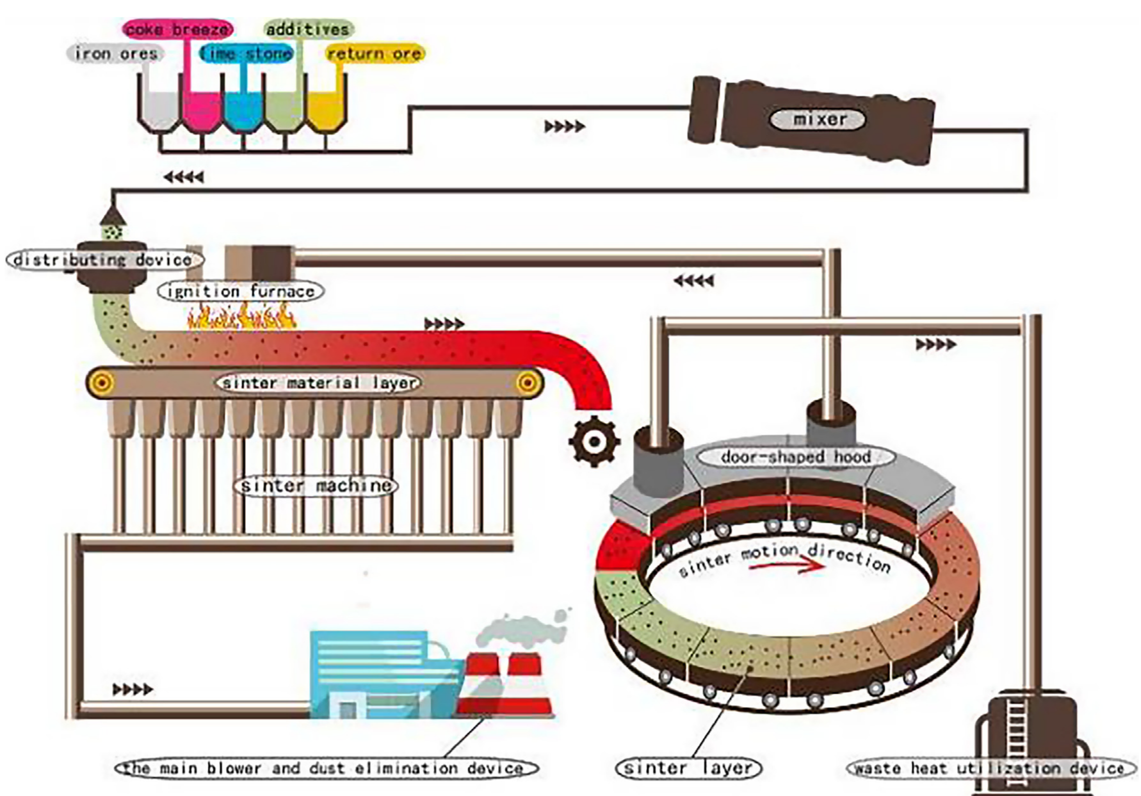

Fig. 1. A typical sintering process.