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Research paper

System dynamics analysis on characteristics of iron-flow in sintering process

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HIGHLIGHTS

- A system dynamics model for iron-flow in sintering process is built.
- Simulation result is accurate.
- Applicability of system dynamics to study of iron and steel production process is verified.

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ABSTRACT

A system dynamics model for iron-flow in sintering process is built at relatively macroscopic level using the methods of causal loop diagrams and stock-flow diagrams. The simulation results are accurate. The applicability of system dynamics to the study of steel manufacturing process, as well as the validity of the modeling and simulation are verified. The calculations show that the iron-flow of sinter increases rapidly in the initial period and then it tends to steady; the greater the returned iron-flow changes, the longer the time is required to reach steady state for the iron-flow of sinter, the loss iron-flow and the iron-stock in the sintering machine.

1. Introduction

The world's energy resources supply and utilization system is facing the dual pressures of demand growth and energy savings. Coordinating the relationship between energy resources and environment as well as achieving the economic and social sustainable development are hard tasks to be completed urgently. Iron and steel industry has a huge energy saving potential. According to conservative estimates, the production life of the world's iron mine available for use in planning is less than 120 years [1]. It is imperative to improve the utilization efficiency of iron resources. The study on iron-flow in steel manufacturing process is important to reduce the consumption of iron ore, to save energy and to decrease pollutant emissions. Sun et al. [2] used e–p method to analyze the variation rule and influencing factors of energy consumptions of large- and medium-scale iron and steel plants within different stages, which indicated that the key topic of the next 15 years' research on the energy conservation is the synergistic operation of material flow and energy flow. Zhang et al. [3] proposed a hybrid material and energy flow analysis approach at company level. With the new method, they analyzed the material based on energy flow routes and the transformation rules and developed an evaluation index to evaluate the specific energy consumption and direct carbon dioxide emissions. Lu [4] used the standard iron-flow diagram to analyze the life cycle (LC) of steel products. Cai et al. [5] introduced the recycling of materials on three different levels in the industrial system based on the iron-flow diagram. Du et al. [6] studied the influence of material flow in steel manufacturing process on atmosphere environmental load. Michaelis et al. [7,8] calculated the consumption of exergy associated with the UK iron and steel sector with the analysis method of material for the period from 1954 to 2019. However, steel manufacturing process has complicated iron-flow network. In order to achieve continuous or

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Nomenclature

A	iron-flow added from external environment (t/min)
AISC	Anshan Iron and Steel Cooperation
F	iron-flow of sinter (t/min)
f	productivity
I	iron-flow of input (t/min)
I_M	iron-stock of ironmaking (t)
M	iron ore consumption in the statistical period (t)
m	sampling number of times
N	total number of production cycles
O	iron-flow of output (t/min)
P	mass of iron element contained in sinter (t)
Q	mass of iron element contained in lost materials (t)
R	iron-flow of returned (t/min)
R_L	iron-stock of rolling (t)
r	iron-flow returned rate
S	mass of iron element contained in returned materials (t)
S_I	iron-stock of sintering (t)
S_M	iron-stock of steelmaking (t)
T_n	production time of the n-th cycle (min)
T_n^s	sampling interval of the n-th cycle(min)
T_{tot}	total time of the statistical period (min)
W	iron-flow of loss (t/min)
w	iron-flow loss rate

Greek symbol

τ	time (min)
ω	iron content of iron ore

Subscripts

IM	ironmaking
SI	sintering
SM	steelmaking
RL	rolling
1, 2, 3…, n	number of production cycles

quasi-continuous operation of the iron-flow and to improve the utilization efficiency of iron resource in the manufacturing process, it is essential to optimize the operation period and continuous degree of each process and improve the operational compactness. Therefore, it is necessary to analyze the dynamic characteristics of each iron-flow as well as to figure out the feedback relationship between the returned iron-flow and the main iron-flow at relatively macroscopic level.

System dynamics can be used effectively to study complex systems with the methods of macroscopic analysis and microscopic analysis, qualitative analysis and quantitative analysis [9]. Qudrat-Ullah and Seong [10], Chi et al. [11] applied system dynamics to study energy transport and conversion system. Swinerd and McNaught [12] proposed three basic types of hybrid agent-based system dynamics simulations to guide the nature and variety of hybrid simulation models. Wang et al. [13] built a system dynamics model to simulate and analyze the dynamics of water resource of Yulin city over time.

In this paper, a system dynamics model in which structural equation is shown in detail for iron-flow in sintering process is established. With the practical data of steel manufacturing processes, the accuracy of the model is verified and the dynamic characteristics of the iron-flow in sintering process are analyzed. The effects of returned iron-flow on the dynamic characteristics of iron-flow in sintering process are also studied. The results can provide some guidelines to recognize the dynamic characteristics of the iron-flow in sintering process, to improve the utilization efficiency of iron resource and to optimize the process operation.

2. System dynamics model of sintering process

2.1. Introduction of system dynamics

System dynamics is a cross-discipline that developed on the basis of feedback control theory, decision theory, simulation technology and computer application technology. The modeling process contains systematic reasoning. It is a process of learning, investigating and researching [9]. As shown in Fig 1, the system dynamics modeling process is consist of four steps: defining the problem, determining the structure, building the relationships and testing the model. Each step contains specific modeling tasks with the loop optimization ideas of assumptions, questioning, testing and refining through them.

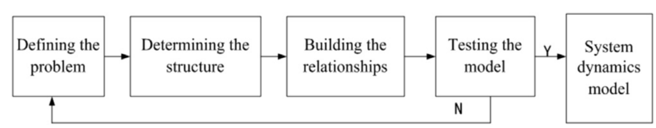

Fig. 1. Modeling steps based on system dynamics.

Causal loop diagrams and stock-flow diagrams are the basic components of a system dynamics model. Causal loop diagram contains a number of variables, which are connected by arrows with causal relationship (causal chain). It is an important tool to show the feedback structure of the system. Stock-flow diagram is a further description of the system based on causal relationship. It can not only clearly reflect the logical relationships among system elements, but also clear the cumulative effects and rate of change of each variable. This paper builds causal loop diagrams and stock-flow diagrams based on the software platform of Vensim [14].

2.2. Analysis of sintering process

In sintering process, iron ore with other accessories are put into the sintering machine. After a complex physical and chemical reaction, the sinter will be obtained. During the sintering process, some iron containing materials are lost. In today's precision production, most of the lost materials are recycled and some iron containing wastes from the downstream processes are reused in sintering process, too. The change of the amount of returned iron containing materials will affect the stability of production. Generally speaking, there are five kinds of iron-flows in sintering process. These are the iron-flow added from outside, the iron-flow returned from the downstream processes, the iron-flow returned of the unit, the iron-flow of the effective output and the iron-flow of loss. The iron-flow returned from the downstream processes and the iron-flow returned of the unit both have feedback effects on the other iron-flows. In Vensim simulator, the five kinds of iron-flows are all flow variables and the iron in the sintering machine is stock variable.

Sintering production process is shown in Fig 2 [15]. At a macro level, the iron-flow added from outside is iron ore, flux and fuel, etc. The iron-flow returned from ironmaking is blast furnace dust, etc. The iron-flow returned from steelmaking is converter slag, etc. The iron-flow returned from rolling is millscale, etc. The iron-flow