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Research Paper

Simulation of the transfer process in the blast furnace shaft with layered burden

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HIGHLIGHTS

- A desirable method is developed to simulate the layered furnace by *Fluent*.
- Influence of the layered burden treatment has been investigated.
- Validation of the layered burden treatment has also been performed.

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ABSTRACT

A symmetric, two dimensional, steady state burden distribution model is proposed to simulate the flow of gases and solids in a blast furnace. The charged material is treated as porous media with alternating coke and ore layers of different permeability. Their heat transfer processes coupled with fluid flowing and chemical reactions are predicted by *Fluent*. To investigate the influence of the layered burden treatment on the calculated in-furnace condition, a mixed burden model, in which the charging materials are assumed as mixed layer of coke and ore, has also been developed with the same boundary condition except for the burden properties. The results indicate that the layered burden treatment has great influence on the calculated temperature distribution as well as the gas pressure distribution. Validation of the layered burden treatment has also been performed. The gas temperature at the furnace top as well as the gas pressure at the furnace wall are in good agreement with the measured data in the operating blast furnace. Obviously, a mathematical model that takes the layered structure into consideration is necessary to simulate the temperature and chemical reactions of materials in the blast furnace.

1. Introduction

The blast furnace (BF) is a counter flow type of chemical reactor, where iron oxides are reduced into iron. In the blast furnace, coke and ore are charged at the top of the furnace. Hot air and enriched oxygen are blasted through the tuyeres, and hot blast gas which contains reducing gases such as CO and H_2 is generated from the combustion of coal and coke in the raceway. The hot gas heats up the charged material as it flows up to the packed bed. Iron ore is reduced and melt by the reducing gases. Molten pig iron and slag are discharged through the tap hole near the bottom of the furnace, while the gases exit from the top of the furnace [1]. The complexity of these processes makes it difficult to understand their exact physical and chemical natures, making modeling of a blast furnace a complicated endeavor. Since 1960s, many studies have attempted to characterize the internal state of a blast furnace with different techniques such as dissection studies [2], physical experimentation [3], and mathematical modeling [4]. Of these methods, numerical modeling has been proven to be quite promising for providing detailed information about fluid flow, heat and mass transfer, and the chemical reactions in the furnace.

During the past few decades a number of mathematical models of the blast furnace have been produced from 1D steady state models based on kinetics of 1D dynamic model and 2D model [5]. Kuwabara and Muchi [6] developed a 1D model that takes into a consideration the layered structure of the charged materials, revealing the effects of the layered structure on gas distribution. Yang and others [7–10] derived a 2D steady state model, which considers the four phases (lump solid, gas, liquid, and fine). Danloy et al. [11,12] presented a 2D model, which includes a charging distribution model. The distribution of the temperature, velocity, and the chemical composition was calculated based on the layered burden. Recently, a 3D steady state model was established and a home code was developed by Fu et al. [13], which considers the chemical reactions

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in the gas–solid–liquid–fine phases, as well as the phase changes based on the conservation equations. Moreover, a virtual blast furnace has been developed on an immersive system at the Purdue University Calumet's CIVS.

In the blast furnace, the charging pattern has great influence on burden permeability as well as gas flow distribution. However, most of the previous numerical simulations have assumed that the charged material is a mixed layer of coke and ore. To be sure, the influence of the burden distribution on in-furnace conditions has not been sufficiently investigated in the mixed model. Although some codes with the layered burden are programmed in FORTRAN [14,15] or C [16], they take a very long time to be developed and are difficult to be applied by more researchers since the extra work related to the finite volume method (FVM) programming must be added. Nowadays, the computational fluid dynamics software Fluent has been widely used in numerical simulation field due to its built-in solver strategy of FVM. However, it is not impossible for Fluent to solve more than one energy conservation equation within a single computational cell [17]. In this study, a user-defined function (UDF) is programmed and embedded in Fluent in order to enhance the standard features of the code without changing the computing framework of Fluent. In this way, gas energy conservation equation and solid energy conservation equation can be calculated simultaneously. Besides, UDF has tremendous superiority in developing the two-dimensional steady state model and reflecting the layered burden and chemical reactions of the blast furnace. We hope to obtain detailed information on the various processes in the blast furnace and optimize the processes in a more convenient way.

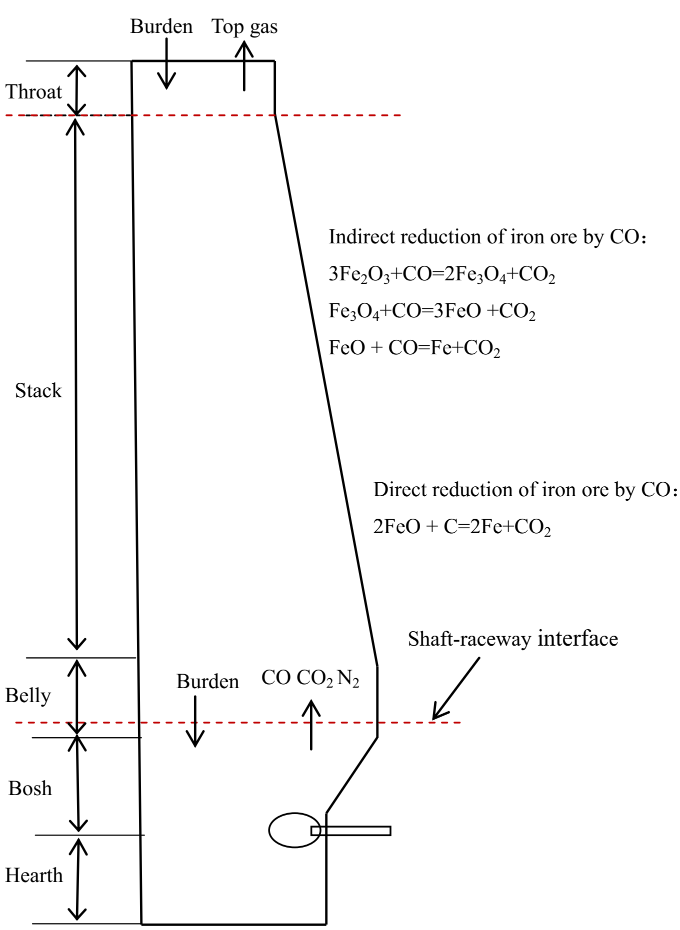

Fig. 1. Schematic of blast furnace.

Table 1
The operating parameter of the burden distribution.

Charging mode	Material	Weight of materials (t/p)
$O_{3\;3\;2\;2\;2\;2}^{35^\circ\;33^\circ\;31^\circ\;29^\circ\;27^\circ\;25^\circ}$	Ore	13.7
$C_{3\;3\;2\;1\;2\;3}^{36^\circ\;34^\circ\;31^\circ\;29^\circ\;27^\circ\;20^\circ}$	Coke	61.2

2. Computational model

2.1. The structure of the blast furnace

A blast furnace (BF) with inner volume of 2500 m^3 was simulated numerically. Since we assumed that the distribution of process variables is axially symmetric, we only considered half of the BF geometry in the simulation, allowing us to model the blast furnace in 2D. A schematic of a blast furnace is shown in Fig. 1: the corresponding computational domain is delineated by the dashed line. Generally, the whole computational domain was divided into 252,280 nonuniform computational cells in the Cartesian coordinates. Each computational cell is around 20 mm × 20 mm. The maximum equisize skew is 0.079.

2.2. Layered structure of coke and ore

Coke and ore charged in the blast furnace form alternating layers. The charging pattern obtained from an operating blast furnace is shown in Table 1. The corresponding burden structure was calculated in the previous studies [18,19] as shown in Fig. 2. Fig. 3 shows the ratio of the quantities of ore and coke (O/C). As for the mixed layer, the O/C is constant and shown by the dashed line. As for the layered material, the O/C is represented by the solid line and there is a small O/C at the central region where a preferential gas flow exists. The O/C increases along the radial direction and reaches its maximum value where r/R is 0.5–0.6, and decreases in the near-wall region.

Fig. 2. Burden (layered structure).