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Evaluation of Burden Descent Model for Burden Distribution in Blast Furnace

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Abstract: Mathematical models for burden descending process have been applied to obtain whole burden structures in blast furnace, whereas the accuracy of those burden descent models has not been sufficiently investigated. Special evaluation method based on timeline burden profiles was established to quantitatively evaluate the error between experimental and modeled burden structures. Four existing burden descent models were utilized to describe the burden structure of a 1/20 scaled warm blast furnace. Input modeling conditions including initial burden profile, descending volumes in each time interval, and normalized descending velocity distribution were determined via special image processing technology. Modeled burden structures were evaluated combined with the published experimental data. It is found that all the models caught the main profile of the burden structure. Furthermore, the improved nonuniform descent model (Model IV) shows the highest level of precision especially when burden descends with unstable velocity distribution tendency. Meanwhile, the traditional nonuniform descent model (Model III) may also be desirable to model the burden descending process when the burden descending velocity presents a linear tendency. Finally, the uniform descent model (Model I) might be the first option for roughly predicting burden structure.

Key words: blast furnace; burden distribution; mathematical model; burden descent model; evaluation

Blast furnace (BF) is a vertical reactor with the countercurrent flows between solids and gases for reducing iron oxides to iron. The efficiency of BF is dominated by the heat exchange between gas and charged materials, but essentially depends on the gas flow distribution[1]. Due to differences in permeability and density of the charged materials, the gas flow distribution is largely controlled by the burden distribution[2,3]. Besides, the control of radial ore/coke ratio distribution is significant in forming the gas passage and resultant gas permeability in the furnace operation[4,5]. Thus, many mathematical models have been established to simulate the burden distribution in BF[6-21]. Among those studies, the movement processes of the raw materials simplified in the mathematical model mainly include: discharging from the hopper, colliding on the chute, sliding along the chute with the driven force of gravity, centrifugal force, reaction force, friction force and Coriolis force, falling in the freeboard driven by gravity, buoyancy force and drag force, stocking on the previous burden to form a new burden profile, and descending to form the entire burden structure.

The mechanism of the burden descent sub-model is crucial for making accurate burden structure prediction since it is a direct reflection of the BF's internal condition. The continuous descending theory, assuming that the physical properties of the material remain uniform throughout the whole descending process, is made to develop analytical burden descent models based on empirical data[9]. Over the past few decades, continuous models have gained wide applications ranging from accurate prediction of the burden structure[9-12] to fast evaluation of the charging programs[13] in running industrial BF.

Nishio and Ariyama[14] derived the original analytical burden descent model in 1982. With the assumption of radial descending path and uniform de-

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scending speed, whole layer structures could be obtained from the top burden profile. Ichida et al.[15] investigated the influence of shaft expansion on burden descending path via a scaled cold model. The corresponding study divided the shaft region into two parts, the vertical descending region and the radial descending region. The latter was proved to be the only affected region through comparison of the measured particle stream lines in both regions. Besides, the operation condition of the BF strongly influenced burden descending velocity along the radius. With linearity assumption on the distribution of vertical descending velocity, the non-uniform descent model was proposed by Kajiwara et al.[16] according to the operating furnace measurement on Kokura BF No. 2. In addition, the distribution of vertical descending velocity can also be significantly affected by the charging pattern. Experiment data of the 1/20 scaled warm model built by Ichida et al.[17] showed that strong nonlinear descending velocity distribution might occur even under normal charging pattern. In recent years, with the development of measurement technology on top burden surface[18], radial descending velocity distribution of the top burden surface could be measured entirely and accurately by equipments such as laser scanner and multiradar. Burden descent models based on entire velocity distribution of the top layer have gained wide range of applications on burden structure prediction[19].

Due to the harsh in-furnace condition, it is difficult to measure burden profile of each layer below the top burden surface with traditional equipments. Validations of those burden descent models are mainly conducted on scaled cold models which neglected the chemical reactions[2,5,15]. However, the local solid consumption, i. e. ore reduction and coke gasification, plays a critical role in burden descending process. Accuracy of those burden descent models has not been sufficiently investigated. The objective of this study was to evaluate the suitability of the burden descent models and to analyze their accuracy through comparison with published experimental data of a scaled warm BF[17].

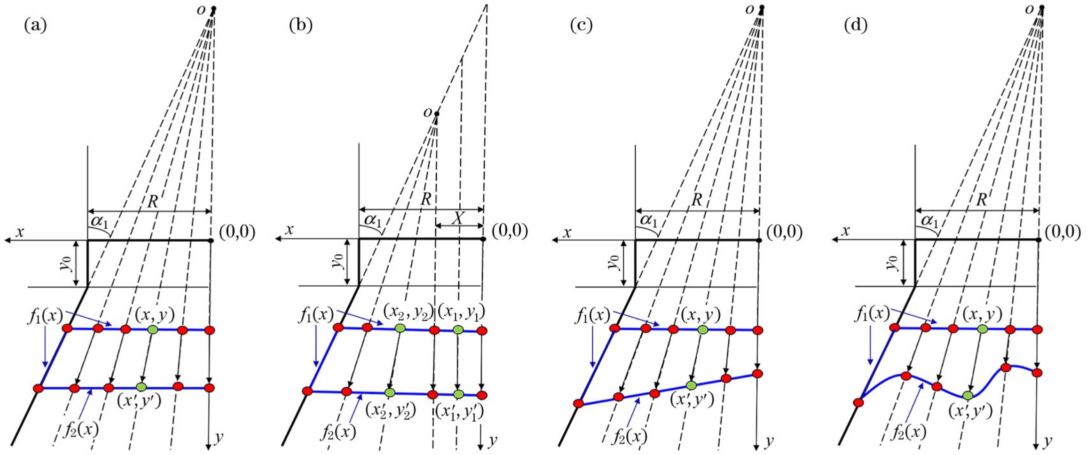
1 Burden Descent Models

The burden descent models, by which the burden layers are shifted downwards, are based on the assumption that the physical properties of the materials remain uniform throughout the whole descending process. The influence of the shaft expanding along the vertical direction has also been taken into account while the effects like mixed layer formation and gas flow are neglected.

The concepts of the four conventional burden descent models are shown in Fig. 1. In model I[14] (Fig. 1(a)), the burden descends along the lines radiating from the cone apex O located above the tapered wall. O is the intersection of the furnace centerline and the extension of the furnace shaft. The basic assumption of model I is that particles in the same level possess the identical vertical descending velocities which results in a uniform vertical advancement for these particles. In a blast furnace with throat radius R, throat height y_0 and shaft angle α_1, the movement of the particles from the point (x, y) to the point (x', y') in the stack region is formulated as Eq. (1).

$$\begin{cases} y' = [3V_d/(\pi\tan^2\alpha_1) + (y - y_0 + \\ \quad R/\tan\alpha_1)^3]^{1/3} + y_0 - R/\tan\alpha_1 \\ x' = x(y' - y_0 + R/\tan\alpha_1)/(y - y_0 + \\ \quad R/\tan\alpha_1) \end{cases} \tag{1}$$

where, V_d is the descending volume enclosed by the



(a) Model I; (b) Model II; (c) Model III; (d) Model IV.

Fig. 1 Illustration of different burden descent models