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Investigation on interface resistance between alternating layers in the upper of blast furnace

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A R T I C L E I N F O

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A B S T R A C T

In order to mitigate CO_2 emissions from steel industry, decreasing coke rate by establishing oxygen blast furnace ironmaking process is a favorable way. Yet every improvement in productivity is fundamentally related to better flow distribution of gas across a particle bed and hence total pressure drop in granular zone is a leading parameter affected by interfacial resistance between alternating layers of coke and metallic burden. In this work, the existence and change rule of interface resistance with different parameters such as flow rate, interface numbers, layer thickness are confirmed. A new pore-throat equation proposed by J.S. Wu and B.M. Yu [30] is imported to study pressure drop of gas flow through stock column in blast furnace and compared with well-known Ergun's equation. Furthermore, the relationships between interface resistance and physical parameters involved in this study is explored and combined with this new pore-throat equation to be a new modified equation. Meanwhile, its adaptability is verified for various conditions. On the basis of modified equation, interfacial porosity with flow rate is discussed and linked to microphenomenon of previous work and achievement of other researchers.

1. Introduction

In recent years, the importance of minimizing carbon dioxide emissions in the steel industry has emerged as a critical concern in slowing the rate of global warming [1]. Some joint projects have been proposed to develop technologies against high energy consumption as well as tremendous greenhouse gas emission in steel plants [2], such as Ultra-low CO_2 Steelmaking (ULCOS) in Europe [3]. To achieve this purpose, low coke ratio operation has been a preferable way [4]. Since oxygen blast furnace has been proposed by Wenzel [5], the studies of aiming to this object have been done so much. And L. Hooey et al. [6] has also forecasted oxygen blast furnace ironmaking technology is one of new ironmaking processes to achieve large-scale application possibly. Because the conception based on oxygen blast furnace is able to bring several profits for intensifying gas reduction, [7] decreasing coke rate [8,9], promoting productivity [10] and greatly decreasing CO_2 emissions [11].

Yet any improvement in blast furnace productivity under a given set of operating conditions is fundamentally related to better flow distribution of gas across a particle moving bed in blast furnace [12]. Extensive scholars have researched the gas flow and burden distribution in blast furnace. For example, M. Shimizu and A. Yamaguchi [13] have reported dynamics of burden Materials and gas Flow in the blast furnace. J. Juan and M. Javier et al. [14] have studied the mutual influence between gas flow and burden distribution in the upper part of a blast furnace by employing a simplified mathematical model to estimate burden distribution and a gas flow model. K. Yang, S. Choi et al. [15] have investigated numerical modeling of reaction and flow characteristics in a blast furnace with consideration of layered burden. Many others also have focused on these aspects though mathematical model, numerical simulation or physical model [16–24]. However, few particularity aspects of burden distribution are involved, like layered burden structure above fusion zone in blast furnace. It comprises of alternate layers or metallic burden and coke separated by a so-called mixed or 'interface' layer as shown in Fig. 1 [25].

Furnas [26] has developed a useful approach for tackling this case by assuming the interface layer as consisting of an intimate mixture of coke and ore. In blast furnace burdens this factor will be important for many layers and hence many interfaces. The increase in pressure drop due to these interfaces has been researched by H. J. Schultz and O. Abel [27] under laboratory conditions. N. Standish and I.D. Williams [28] have conducted laboratory scale experiments in order to investigate the structure and flow resistance of coke-ore interface. On above these basics, M. Guha and S. Nag et al. [25] have also studied effect of interface resistance on gas flow in a scaled down blast furnace model.

Yet the above widely employed resistance equation for flow through porous media was proposed by Ergun [29] in 1952. This equation is called Ergun equation:

$$-\frac{\Delta P}{\Delta L}=\frac{150\mu(1-\varepsilon)^2\nu_s}{\varepsilon^3 D_p^2}+\frac{1.75\rho(1-\varepsilon)\nu_s^2}{\varepsilon^3 D_p} \quad (1)$$

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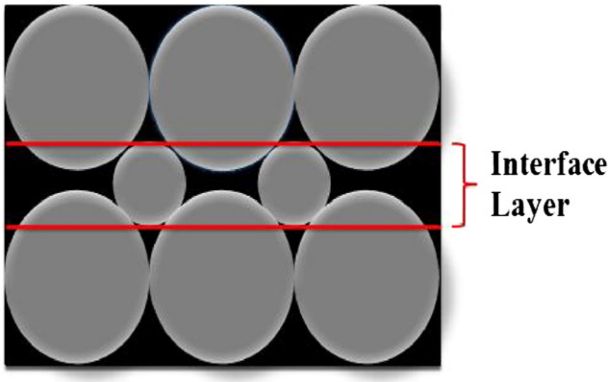

Fig. 1. Schematic of interface layer [25].

Where, $\Delta P/\Delta L$ is the pressure drop per unit height of the packed bed; μ, ρ and v_s are the viscosity, density and velocity of the gas; ε, D_P are the porosity and mean particle diameter of the granular medium.

Furthermore, J.S. Wu and B.M. Yu [30] have developed a new modified resistance equation of flow through porous media, namely fractal resistance equation, based on the fractal characters of porous media, on the pore-throat model for capillary and Ergun equation:

$$\frac{\Delta P}{L}=\frac{\Delta P_1}{L}+\frac{\Delta P_2}{L}=\frac{72\mu\tau(1-\varepsilon)^2 v_s}{D_p^2\varepsilon^3}+\frac{3\tau(1-\varepsilon)\rho v_s^2\left(\frac{3}{2}+\frac{1}{\beta^4}+\frac{5}{2\beta^2}\right)}{4D_p\varepsilon^3} \quad (2)$$

Where τ,β are the tortuosity and pore-throat rate, both of which is function of porosity.

From the above brief review, it is seen that few researches has been carried out to analyze the influence of interface resistance on gas distribution between two successive layers of different material. Meanwhile, the applications of the Eq. (2) in some fields have been found except the total stock column in blast furnace of ironmaking process. In addition, few have focused for the certain relationships between interfacial resistance and different parameters which were combined with Eq. (2) for understanding overall pressure drop.

Therefore, it is of great necessity to understand the situation of applying Eq. (2) to study pressure drop of gas flow through stock column. Also it is expected that, by correcting equation, in-depth knowledge of the permeability of stock column can be acquired to improve our understanding of its behaviors.

2. Experimental

The influence of alternate layers of different materials on the blast furnace shaft permeability has been simulated using cold model rig as shown in Fig. 2. The experimental setup consists of three dimensional a set of plexiglas segments type model that can be added or removed and thus easily adapted for various simulation conditions. The model is 490 mm in depth and has a width of 240 mm.

N_2 is used as the gas flowing through the packed bed of materials inside the model from the bottom. As the gas road is opened, N_2 flows into the only inlet through pressure regulator valve and rotameter that has been provided to measure and control the gas flow rate and enters through the single tuyere inside the model. The whole appliance is divided into two parts where one is experimental subject measuring pressure drop which gas streams through the packaged bed causes, the other is gas distribution device, into which the glass balls are filled for making gas distributed uniformly. In the central unit, gas distribution plates are used to distribute gas from bottom again. Pressure drop in the packaged bed is measured by a U-tube manometer. Distance from the tuyere to the two measuring points is chosen to maintain vertical parallel streaming through the packaged bed. Model is manually filled each time by putting glass balls regularly and dumping mung beans slowly from the top and experiments are conducted with static bed.

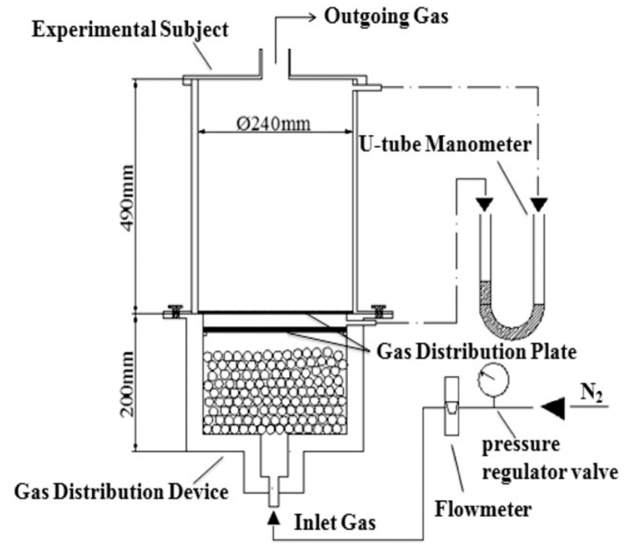

Fig. 2. Schematic of cold model. A. One interface B. Two interfaces. C. Three interfaces D. Four interfaces.

For investigating the influence of interface resistance on pressure drop only, some factors is excluded such as blast furnace shaft geometrical shape, furnace burden shape and uneven gas distribution. It is ensured during experiments that the gas flow remains constant through tuyere. Mung bean of ~4 mm which is considered to nearly spherical in shape and glass balls of ~20 mm used in this study are selected by simulating the actual burden particle size ratio in the blast furnace, say around 1:5. The both shape factor is considered to 1. The existence of interfacial resistance and the effect of interface numbers, flow rate and layer thickness on the pressure drop in different cases are examined. Study of interface resistance started with single-interface in which the cold model is filled with glass balls till 190 mm and the layer of mung beans is dumped to 380 mm. After that interface numbers are gradually increasing ranging from one to four and the stack height is always supposed to 380 mm as shown in the Fig. 3, in A and B of which the sketch map of different layer thickness is respectively shown in Fig. 4. In addition, the flowrates in cold model experiment is supposed to 5 m^3/h–25 m^3/h. (Reynolds number under the blast furnace conditions 600 < Re < 800). In this work, the following effects can be expected:

(1) Confirmation of existence of interfacial resistance resulted from interface layer
(2) Investigation of the influence of interface numbers, flow rate and layer thickness on pressure drop
(3) Relation between interface resistance and different parameters is deduced and compared with other relation from literature.
(4) Research of local interface porosity with flow rate

3. Results and discussion

3.1. Existence of the interfacial resistance

The experimental pressure drop per unit and the theoretical value during to Eqs. (1) and (2) in Fig. 3 obtained are plotted and shown in Fig. 5 for the reference case and in Fig. 6 for different interface numbers, respectively.

It is shown from the graph that there exists the differential between experimental value and theoretical value which is considered to possibly be caused by interface resistance that may have certain