Note

Particle Size Segregation in the Falling Stream of Burden Materials

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1. Introduction

Burden distribution (distribution of burden material along furnace radius), is used as an important parameter to control blast furnace operation. ‘Bell-less Top’ charging systems provide higher flexibility in burden distribution control over other type of charging systems. The rotating and tilting motion of the material distributing chute makes it possible to distribute a given amount of burden material at any desired radius inside the blast furnace.1,4) For a bell-less top charging system, knowledge of trajectories and size segregation provides basic information for the control of burden distribution.1) A trajectory is one of the characteristic which is due to a wide velocity distribution within the stream during burden motion on the chute.1,2) Another characteristic is extreme size segregation, which exists in the stream. This is attributed to the percolation of small particles into the spaces between large ones which happens as the particles flow on the chute.1,5)

The burden consisting of materials of various sizes when sheared in the presence of a gravitational field during burden layer movement on rotating chute of bell-less top charging system, the particles are segregated according to their size. The smaller particles fall to the bottom and the larger ones drift to the top of the sheared layer. As a result, the burden materials in the falling stream segregate according to their size. Segregation plays a major role in determining the fate of any burden distribution scheme since it affects permeability distribution inside blast furnace and hence productivity and stability of the process.

Therefore, enormous experimental data along with practical experience on bell-less top charging system are required to determine the parameters for optimum burden distribution control for a particular blast furnace.

During the relining process of one of the blast furnaces (working volume of 595 m³, throat diameter 5 m) in Tata Steel, the erstwhile charging system was replaced with bell-less top charging device to improve the furnace performance. Results of trajectory measurements in bell-less top and prediction of mass fraction distribution were discussed by Nag et al.6) In the present work, estimation of size segregation in the falling stream of burden materials (iron ore, coke, and sinter) has been attempted.

2. Experimental

The experimental setup comprised of the actual bell-less top charging system and its related mechanical and hydraulic accessories was installed outside the furnace on a raised platform. Below this platform, throat of the furnace was constructed with brickwork, 5 m in diameter. Details of the experimental setup have been mentioned elsewhere.6)

For size segregation measurements in the falling trajectory, a half cut pipe with 24 compartments as shown in schematic drawing (Fig. 1) was used at stock line level (1.6 m from chute tip) supported at both end with the brick wall (furnace throat). The falling stream while discharged from chute tip at different angles were collected in different compartments (Fig. 1) and analyzed for different size fractions, their weights and cumulative weights, in laboratory.

3. Results and Discussions

It has already been established as part of this study6) that the distribution of material along the radial direction is almost symmetrical about the central axis of furnace. With samples collected from each compartments, mass of different size fraction of materials were analysed.

Figure 2(a) shows the mass fraction distribution of different size ranges of coke in the feed. Figure 2(b) shows the relative mass fraction (with respect to mass in the feed) of different size ranges collected at different radial locations (dimensionless) for two chute angles of 30° and 45°. The radial locations correspond to distance of centres of the collection boxes measured from the furnace centre. Every discrete points represents the arithmetic sum of mass fractions collected on left-hand and right-hand positions, for a particular radius. The mass distribution of particles at different radial locations were substantially different from that in the feed. Irrespective of chute angles, materials segregating into two distinct particle size groups can be observed in Fig. 2(b). Relative mass fraction of the smaller particles (<30 mm) were highest (>0.3) at locations closest to the centre corresponding to inner part of the falling trajectory, whereas, bigger sized particles (>50 mm) tend to segregate towards outer part of the stream falling closer to the wall. The intermediate sizes distribute across the spread of the stream. It can also be observed from Fig. 2(b) that the highest mass fraction of the largest particles (+100 mm fraction) is slightly behind the outermost part of the stream. This can be attributed to presence of largest particles in very smaller quantity compared to the next size range. The resultant force imbalance on the next smaller size range lead to their shift towards outermost part of the stream.

For quantifying size segregation in the falling stream, the weighted average diameter was used and is calculated as per the following equation:

\[
\text{Weighted average diameter} = \frac{\sum m_j d_j}{\sum m_j} \quad \ldots \ldots (1)
\]
Where, \( m_i \) = mass of a particular size fraction \((j)\) in compartment no. \( i \), kg.
\( d_{j} \) = mean diameter of the particular size fraction \((j)\), mm.

Figure 3 shows the mean size of coke particles (as calculated in Eq. (1)) along radial locations for three different chute angles. Average particle size increases from furnace centre to wall indicating size segregation in the falling stream. At higher chute angles, location of largest mean size also shifts towards the wall corresponding to outer part of the stream indicating higher degree of segregation.

Figure 4(a) shows the mass fraction distribution of different size ranges of ore in the feed. Figure 4(b) shows the relative mass fraction of different size ranges of ore at different radial locations for two chute angles of \(23^\circ\) and \(46^\circ\). As observed for coke, smaller sized particles (<15 mm) tend to percolate down closer to the chute surface and falls closer to the inner stream resulting in highest mass fraction (~0.25) closer to centre. Larger particles (>15 mm) during travel on chute, drifts up to top surface and remains closer to outer stream and falls near the furnace wall. Due to higher density of ore, the spread of falling stream of material is less compared to coke and as a result the two size group peaks are closely placed than that observed for coke. With increase in chute angle, the particles spend more time on the chute which further promotes segregation of smaller sized particles with higher peak values (~0.28) near centre as observed in Fig. 4(b) for \(46^\circ\). Trend for mean size of ore samples along different radial locations is shown in Fig. 5. It is similar to that of coke, suggesting segregation of larger sized particles towards the outer part of the falling stream.

The mass fraction distribution of different size ranges of sinter in feed is shown in Fig. 6(a). Relative mass fraction of different size ranges of sinter at different radial locations for two chute angles of \(30^\circ\) and \(46^\circ\) has been shown in Fig. 6(b). Unlike ore, sinter feed contained higher amounts of intermediate and smaller particle size ranges and very small amounts of larger particles (lump size range).
quantity of larger particles. Particle size segregation in falling stream was observed to be least at 30°. Particles (<10 mm size) segregates closer to centre of the blast furnace and largest particles (>30 mm) accumulates closer to the furnace wall and the bulk of intermediate size falls at intermediate zone. At higher angles, smaller particles segregates towards inner stream but bulk of the intermediate size segregates and distributes itself across the falling stream. Figure 7 shows the mean size distribution of sinter. Due to the characteristic particle size distribution of sinter feed, the largest mean size for sinter is less than ore. The segregation of larger sized particles present in very small quantity are nearly complete. At higher chute angles (41° and above), with higher amount of intermediate particle size fractions distributing itself across the falling stream, sinter mean size reaches to a plateau (~9–10 mm) in the intermediate distance followed by higher mean size at the wall.

4. Conclusion

Size segregation behavior of ore, sinter and coke were studied in actual bell-less top set up. It was found for all the three types of burden materials, there is a tendency of size segregation into two or three size fractions. Larger size particles have a distinct tendency to segregate towards the outer part of the stream and the smaller size particles segregates towards inner part of the stream whereas the intermediate size distributes itself across the falling stream. This tendency of size segregation in falling stream of burden appears to be enhanced at higher chute angles. The particle size distribution in feed burden material affects the segregation behavior to a large extent.

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