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"Improved burden distribution in blast furnace by using mathematical simulation of material charging."

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ABSTRACT
The establishment of effective burden distribution is a highly recommended to maintain the stable operation of the blast furnace. It is difficult to directly measure the burden distribution for an operating blast furnace. Charging directly affects the burden distribution of a blast furnace, which determines the gas distribution in the shaft of the furnace. Adjusting the charging can improve the distribution of the gas flow, increase the gas utilizationefficiency of the furnace, reduce energy consumption, and prolong the life of the blast furnace.Blast furnace operator is struggling to analyze and assesse the burden distribution. Through this project pursued that the new way of predicting and adjusting the burden distribution by using mathematical simulation of material trajectory of BLT by using newton's law and validated through physical trajectory test by using chalk line probe. This project will be helpful to Blast furnace operator to achieve desired burden distribution by adjusting charging pattern.
The aim of the project is to improve the knowledge on Blast furnace bell less top charging system and burden distribution. The self-reliant and self-learning approach for blast furnace operators.
KEYWORDS:*Burden trajectory in blast furnace, BLT material trajectory, Blast furnace charging trajectory, Blast furnace burden distribution*

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1.INTRODUCTION

A blast furnace is a tall, large gas solid counter current bed reactor which employs coking coal to reduce iron from its oxide ore state to produce liquid hot metal. The raw materials (iron bearing, coke and flux) consist of particles that are multi-sized and have varied characteristics (density, shape, size, surface roughness etc). After detachment from the rotating chute, the particles impact the stock surface, roll, disintegrate and may even percolate (if small in size) through the particle bed. The raw materials are charged from top of the furnace and hot air (possibly oxygen enriched) is blasted through tuyeres near the bottom. The oxygen in the blast reacts with coke in the lower part of the process and produces a hot gas that on its ascent heats reduces and melts the descending ores.

The distribution of raw material burden at the stock level of a blast furnace is crucial for its smooth operation. It determines to a great extent the gas flow and its radial distribution and hence the reduction and smelting of the charged materials and thereby influences the output, fuel rate, metal quality and campaign life of the furnace. Control of gas distribution can mainly be achieved by adjusting the ratio of ore and coke and the particle size along the radius of the furnace. This work presents an approach, where a burden distribution model is used to evolve charging programs yielding a desired distribution of ore and coke along the furnace radius. Hence we developed a mathematical model for predicting the gas flow distribution along the radius of the blast furnace. This model has been produced to control and maintain the blast furnace in the best possible condition.

If the central gas flow is too high, there is a too small gas flow along the wall for heating, reduction and melting of the ore burden and consequently the root of the melting zone comes close to the tuyeres. In this situation the reductant rate will be high and there is a high chance of tuyere damage. If the center gas flow is (partially) blocked, a relatively large part of the gas escapes along the wall and is cooled down. The result is the part of the gas is cooled down low in the furnace and reduction reactions slow down. In this situation the central gas flow is small and heat losses are high. So optimization of central gas flow is required to operate the furnace smoothly. In order to achieve this requirement our burden distribution model will be helpful to predict the best possible option for central gas flow.

Many studies have used mathematical models to study the charging system of the blast furnace. Yoshimasa et al. [1] developed a simulation model for the burden distribution of blast furnace charging and studied the trajectory of the raw material, burden descent, and mixing layer, providing important information for the subsequent model development. Pohang Iron and Steel Company proposed a radial distribution function of the burden and applied it in an actual blast furnace to study the distribution characteristics of the burden and to improve the distribution of the gas flow [2]. Krishman et al. [3] developed a mathematical model for the optimization of bell-less charging, and the calculation results were consistent with the actual data. Saxén and Hinnelä [4] developed a bell-less burden distribution model on the basis radar measurement, and the dependence between the layer thickness and charging variables was modeled by neural networks [5]. Nag [6] proposed a mathematical model of the bell-less top to calculate the trajectory of the burden in charging. Park et al. [7] analyzed the blast furnace charging system by developing a burden descent model and a gas flow model, and compared the results with those from a 1/12-scaled model experiment. Samik et al. [8] proposed a general target methodology to estimate the stock profile in the blast furnace, where the burden distribution is based on experiments in different scaled models of a blast furnace with various materials. Shi et al. [9] proposed a new model of stock line profile formation in which equations were developed for the inner and the outer repose angles by considering the influence of the burden's vertical and horizontal flow.

The above mathematical models were developed based on some assumptions and different operating conditions. Therefore, it is quite difficult to apply them to get accurate results of the burden layer for other furnaces. From the above literature and statement, there are no publication presenting a mathematical model applicable to all the blast furnace bell less top system (especially smaller blast furnaces 350 to 700 cubic meter). This paper is concentrating the simplifying the mathematical model, model test and modifying the model to evaluate accurate burden trajectory of blast furnace bell less top system.

1.1 Blast Furnace Bell-less top charging system

The Bell- less. Top Charging System which is **a continuous system for charging raw material into a blast furnace for iron making**. The valve casing comprising material gate, lower sealing valve and distribution chute assembly is an important unit of the system.

The movement of the material during charging from a bell-less top charging system is schematically shown in **Figure 1**. Raw materials are charged from the hopper placed on top and the lower material gate controls its discharge. The opening of the lower material gate causes the material to fall down on the rotating chute. The chute, which rotates about the central axis of the furnace, uniformly distributes the material circumferentially on the stock line. The full length of the chute is denoted by L. The radial distance travelled by chute away from the reference axis is called the effective chute length (l).

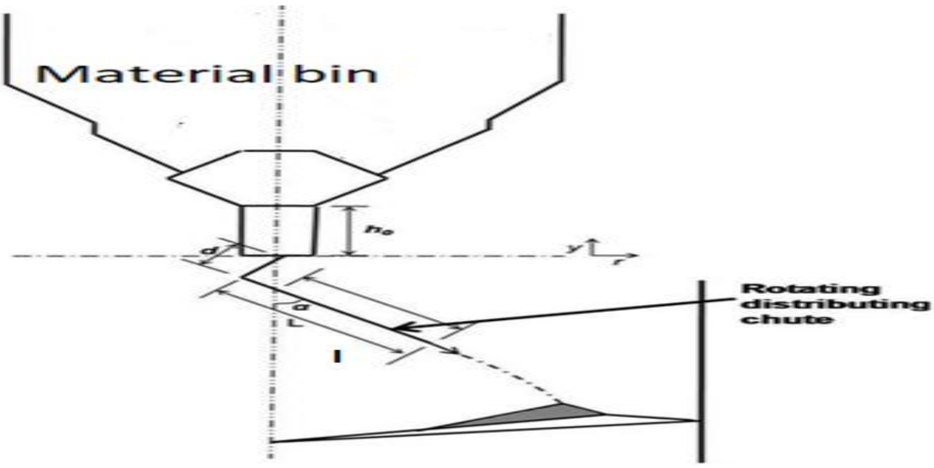


Fig-1 and 2: Schematic of Bell-less top charging system, where d, h_0, l, L are the dimensions of the system, α is the chute angle, and CL: Central line.

2.MATHEMATICAL SIMULATION MODEL DEVELOPMENT

The movement of the material during charging from bell-less top charging system is shown schematically in Fig.2. Raw materials are charged from the hopper placed on top, and its discharge is controlled by the lower material gate. Opening of the lower material gate causes the material to fall vertically downward and land on the rotating chute. The chute, which rotates about the central axis of the furnace, distributes the material circumferentially on the stock line. The material may not necessarily travel the entire chute length; the actual distance that the particle travels along the chute is called effective chute length.

Mathematical Approach

Three distinct zones can be identified along the path of material movement.

1. Material decent from charging bucket (hopper) to rotating chute

2.Material movement in the rotating chute

3.Material fall from chute tip to stock (burden) level.

Descent of material from discharge hopper: The particle falls from the Lower material gate opening freely under the influence of gravity and hits the surface of the rotating chute. Height of free fall depends on the geometry of the charging system and the chute inclination angle. So, the component of initial velocity of the particle, along the chute axis, immediately after striking the chute surface, can be given as

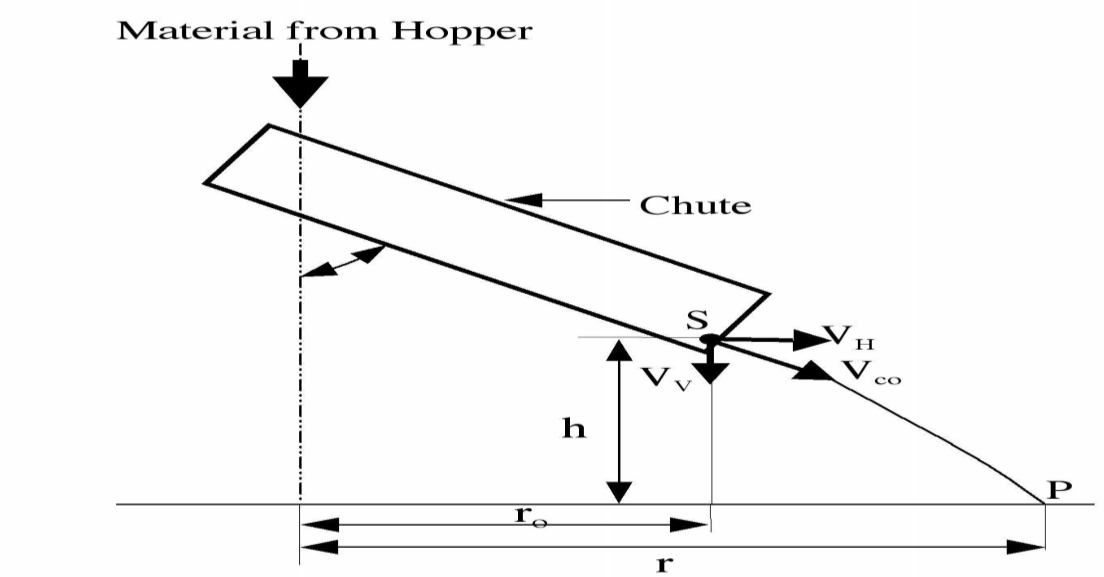
$vci = k\ 2ghf \sin\alpha$

Initial velocity of the material=Coefficient of friction*2*gravitational force*free fall height/Sine ꭤ (chute angle)

Coefficient friction for coke 0.5 and for oxides 0.9

Free fall height (hf): Height between the Lower material gate and chute impact point.

Figer-3: Flight height from chute tip



According to Newton's second law, the velocity VCo of particles leaving the chute end can becalculated and it is decomposed into the horizontal velocity Vh, vertical velocity Vv

1. Effective chute length l: actual chute length utilization for given chute angle.
2. Free fall height hf: Material falling height from LMG to chute impact point for given angle.
3. Initial velocity Vci: The velocity of material at chute tip (impact area).
4. Final velocity VCo: The velocity of material at chute end.
5. Flight height h: The height of chute zero to stock line
6. Horizontal velocity Vh: The Horizontal velocity of material at chute end (chute zero).
7. Vertical velocity Vv: The vertical velocity of material at chute end (chute Zero).
8. Material flight duration t: time (duration) of material fall from chute zero to stock line.
9. r0: Distance from furnace center to chute zero at stock line
10. r1: Distance from furnace center to material fall at stock line.
11. K: coefficient of friction
12. ὠ: Angular velocity of chute
13. t:time required to travel chute zero to stock line in sec
14. h: effective flight height (height from chute tip to stock line)
15. ꭤ: Chute angle

Final velocity of material

$$Vco=\sqrt{\dot{\omega}^2 * sin\alpha * sin\alpha + k * cos\alpha * l^2 + 2g * cos\alpha - k * sin\alpha + Vci * cos\alpha}$$

Horizontal velocity of material

Vh=Vco*sinꭤ

Vertical velocity of material

Vv=Vco*cos ꭤ

Time required to travel chute zero to stock line

$$t=\frac{\sqrt{Vv^2+2gh}-Vv}{g}$$

After leaving the chute end, the burden moves with the velocity of Vco in the throat until it falls onto the burden surface. In the movement, burden particles are subjected to gravitational force, buoyancy force, and the drag force of gas. The influence of the latter two forces on the movement of the burden is very small and is ignored.

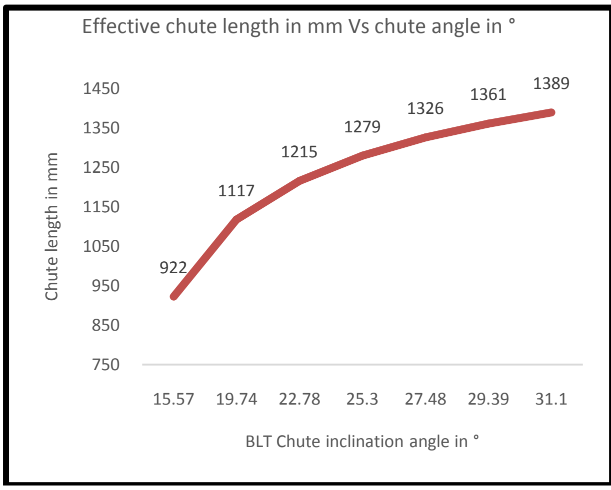
Distance of material fall (point P) from center of furnace axis (refer figure:3)

r1=Vh*t

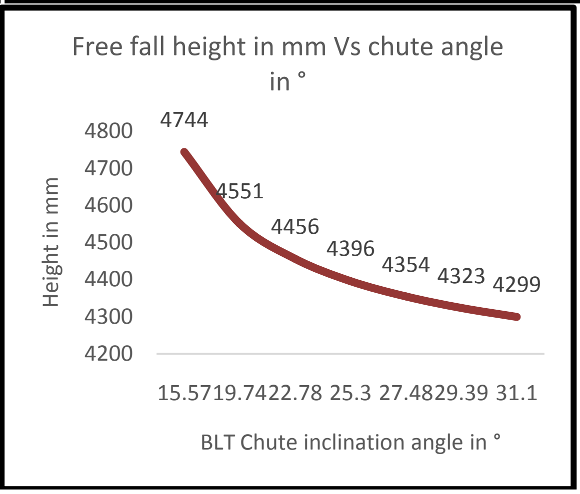
P=r0+r1

1. r0:Distance from furnace center to chute zero at stock line
2. r1:Distance from furnace center to material fall at stock line.
3. P: distance of material falls from furnace center axis

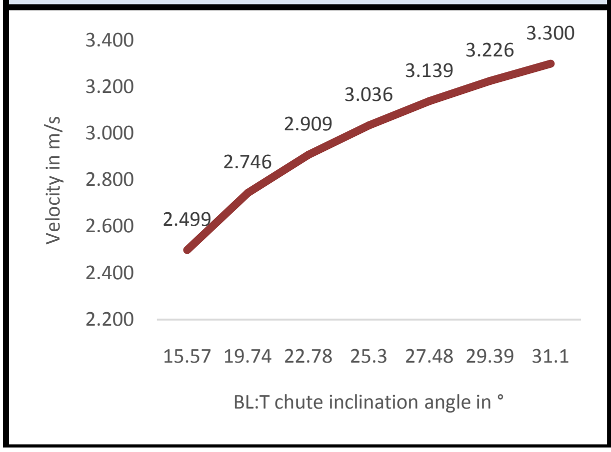
Graph-1: Actual (effective)l chute length utilization for given chute angle



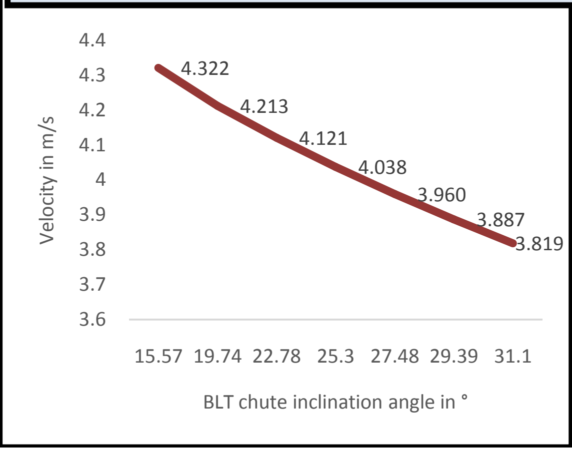
Graph-2 Material falling height from LMG to chute impact point for given angle.



Graph-3: The velocity of material at chute tip (impact area).

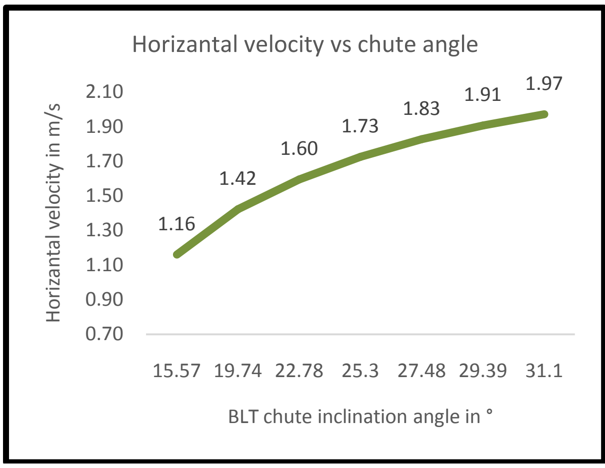


Graph-4: The velocity of material at chute end (chute zero).



Graph-5: The Horizontal velocity of material at chute end (chute zero).

Graph-6: The vertical velocity of material at chute end (chute Zero).



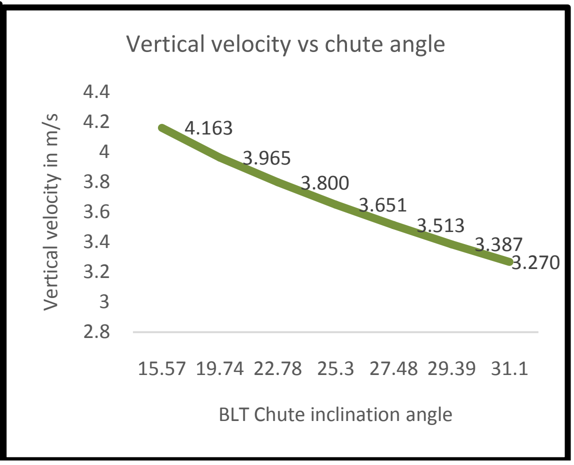


Fig:4 Final Trajectory width in mm (Material fall in stock line from furnacecenteraxis)

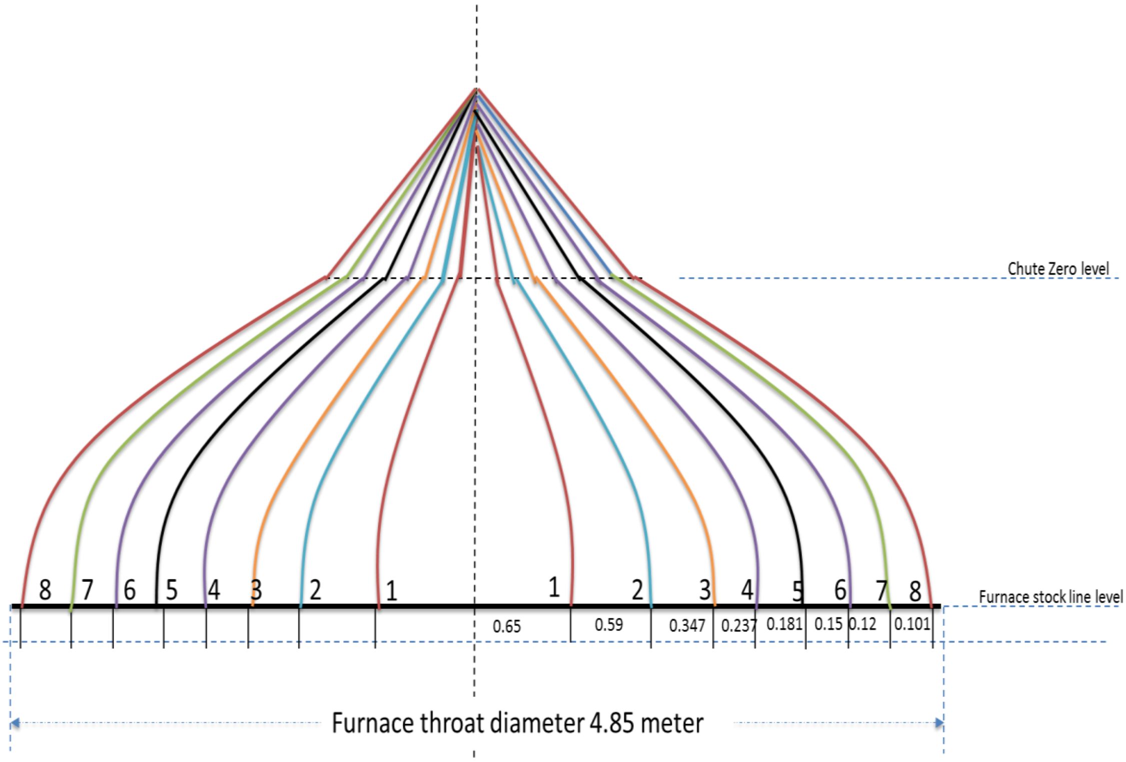


Table:1 Final Trajectory width in mm (Material fall in stock line from furnace center)

Ring No	1	2	3	4	5	6	7	8
Angle	7.57	15.57	19.74	22.78	25.30	27.48	29.39	31.10
Distance from furnace center in m	0.65	1.241	1.588	1.823	2.004	2.150	2.270	2.3710

Blast Furnace BLT Trajectory mathematical simulation

Ring No	Chute Angle (α)	Dumping level in m	Chute rotation speed in r/se	Final Trajectory width in furnace radius in mm
1	7.57	1.4	0.1562	650
2	15.57	1.4	0.1562	1241
3	19.74	1.4	0.1562	1588
4	22.35	1.4	0.1562	1791
5	25.3	1.4	0.1562	2004
6	27.48	1.4	0.1562	2150
7	29.39	1.4	0.1562	2270
8	31.1	1.4	0.1562	2371
Enter in gray shaded cells only				Calculated value don't enter

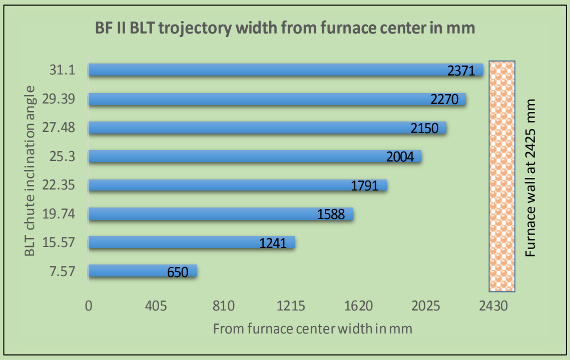


Figure-4:BLT trajectory model developed in excel format, by entering required chute angle, dumping level and rotation speed, the model enables to show the final trajectory width (material fall in stock line from furnace center) in mm. As calculation is inbuilt in the excel sheet:

3.MODEL VALIDATION

Model validation done through physical trajectory test by using chalk line probe. The hallow trajectory pipe length was of 4.2 m, outer diameter 60 mm, inner diameter 52 mm, and the thickness of 4 mm as shown in fig.5. The trajectory pipe was inserted from above burden probe slot and a locking system was arranged for holding the pipe as shown in the figure 5. The trajectory pipe was painted with liquid chalk and dried up so that after the coke or ore charge the impressions made by the materials will be clearly visible.

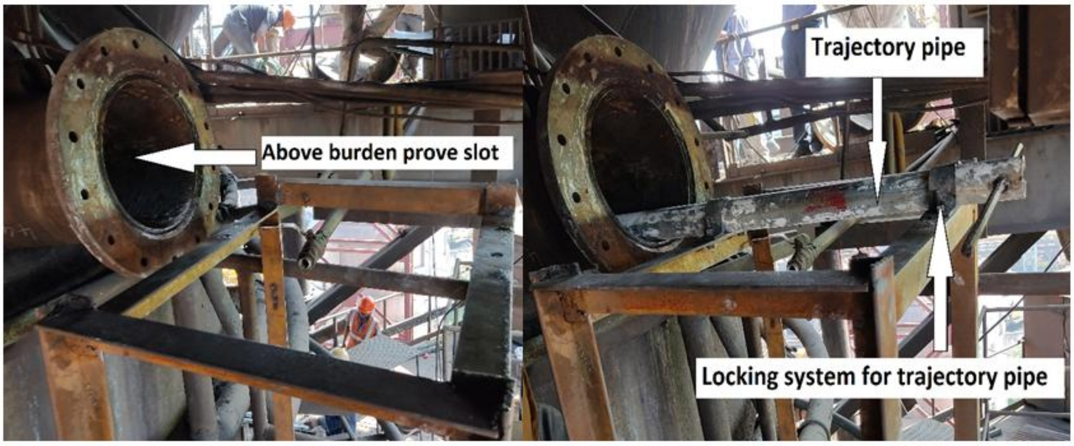


Figure-5: Chalk line probe fixing

3.1. Physical trajectory test

The trajectory test was conducted during charging to measure the material bandwidth in theselected ring. The pipe was inserted before the charging of material and was taken out once the charging is over. The impression made by the charged materials on the pipe was measured. There are 10 rings and the exercise was repeated twice in each ring – once for oxides batch and the other for coke batch.

The schematic diagram (figure-6) of the trajectory pipe after charging the material and the hatched region shows the material bandwidth falling from the rotating chute. The length B (measured from the furnace center) represents the outer line of the material band, and the inner line is represented by length A (measured from the furnace center). The difference of B and A represents the bandwidth of the charged material.

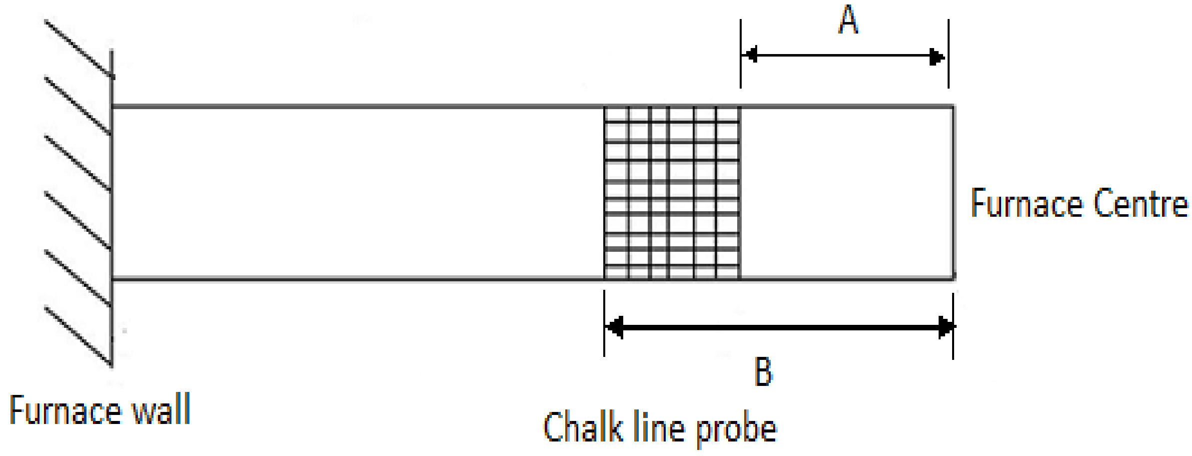


Figure-6: Trajectory pipe measurement

Trajectory measurement data Table-2:

Blast Furnace#2 Trajectory test																			
S.N.	Date	Coke	Oxide		Distribution Ring no. /Chute angle, degree										Radius		Band width	Average band width	Remarks
		ton	ton	Ring	1	2	3	4	5	6	7	8	9	10	A, m	B, m	B-A , m	, m	
				As per SCADA	7.57	15.57	19.74	22.78	25.30	27.48	29.39	31.10	33.10	35.20					
				Field Angle	10.50	16.50	19.50	21.50	23.50	25.20	26.50	28.00	29.50	31.00					
1	11-Sep	2.65			1										0.00	0.74	0.74	0.70	
2	11-Sep	2.65				2									0.47	1.00	0.53		
3	11-Sep	2.65					3								0.56	1.10	0.54		
4	11-Sep	2.65						4							0.61	1.23	0.62		
5	11-Sep	2.65							5						0.73	1.40	0.67		
6	11-Sep	5.30								6					0.74	1.40	0.66		
7	11-Sep	5.30									7				0.80	1.60	0.80		
8	11-Sep	5.30										8			0.90	1.70	0.80		
9	11-Sep	5.30											9		1.00	1.70	0.70		Material Dumping is on wall @ 2.0 m Level
10	11-Sep	5.30												10	1.00	1.90	0.90		Material Dumping is on wall in normal dumping level
11	12-Sep		8.44		1										0.00	1.02	1.02	0.91	
12	13-Sep		8.44			2									0.45	1.40	0.95		
13	14-Sep		8.44				3								0.60	1.45	0.85		
14	15-Sep		7.05					4							0.60	1.55	0.95		
15	16-Sep		7.05						5						0.60	1.60	1.00		
16	17-Sep		7.05							6					0.80	1.60	0.80		
17	18-Sep		7.05								7				0.84	1.70	0.86		
18	19-Sep		7.05									8			0.87	1.70	0.83		

4.RESULT AND DISCUSSION

The mathematical model can predict the influence of chute inclination angle on the radial landing position(s) of coke and oxides on a given stock level. Comparing the theoretical mathematical simulation of BLT trajectory data with physical trajectory test data, the data exhibits exact matching each other. The experimentally observed landing positions of coke and oxide as a function of chute inclination angle, with the theoretical predictions.

The distance of the mid position of the stream trajectory from the center line is considered as the stream distance. From the data it is evident that the predicted results show good agreement with the actual observation.

The result obtained from the mathematical simulation is very helpful to improve burden distribution in the blast furnace. Before this project coke was not dumbed in 8^{th} ring and highest dumping angle at 8^{th} ring was 29 degrees. After this Mathematical simulation development and validation coke is dumping in 8^{th} ring and highest dumping angle is increased to 32.1 degree based on the model. Subsequently 1 to 8^{th} ring dumping angle are altered based on the model

After this modification significant improvement is observed in burden distribution which result reduction in furnace abnormalities, improvement instable furnace process, significant improvement in PCI rate, improvement in gas utilization and productivity.

The numerical values of the (K) coefficients of friction and restitution were not known. In the mathematical simulation hypothetical values in the range of 0.1 - 0.9 to simulate the burden trajectory. In the actual furnace, chute inclination angles in the range of higher chute tilting level were operationally critical since the burden tended to strike the wall at higher angles. In view of the operational importance, burden trajectories at higher tilting angle were measured with maximum care during in furnace trials.

5. CONCLUSION

The below mentioned conclusion can be made with regards to scope and applicability of Mathematical simulation of material trajectory of BLT of Blast furnace

- ❖ The mathematical simulation of material trajectory model is well validated physical trajectory test data and found exact matching with the model.
- ❖ This model can be used for determining the trajectory of coke and oxides for any inclination angle, over the entire range of operating stock levels.
- ❖ The mathematical simulation approach appears promising in its ability to predict the flow phenomena of granular burden materials in the blast furnace chute.

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