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"Blast Furnace process optimization for sustainable Iron making".

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ABSTRACT:

A stable and efficient operation of the ironmaking blast furnace is prerequisite to reduce the greenhouse gas emission. JSW Steel, Salem have been proposed many projects to reduce greenhouse gas emission, for example Higher O2 enrichment, H2 gas injection, Waste plastic injection, Natural gas and use of biomass reductant. Additionally, the operation stability and efficiency have a large influence on gas utilization and the rate of reductants and emissions, which are all important and mutually interdependent factors. This study leveraged advanced statistical tools, mathematical models, and technical research to assess the blast furnace process and detect anomalies. Subsequent to this analysis, a series of optimization measures were implemented, driven by the study's insights. These actions targeted blast furnace process enhancement, leading to heightened production rates, reduced fuel consumption, and diminished greenhouse gas emissions. This work epitomizes the commitment to harmonizing iron production efficiency with environmental sustainability.

Keywords: Blast furnace abnormalities, Burden distribution, BF raw material, Greenhouse gas emission

I. INTRODUCTION

The blast furnace (BF) is still the main industrial process for the production of iron for steelmaking. It is a countercurrent three-phase (gas–solid-liquid) system with complex heat, mass, and momentum transfer as well as chemical reactions showing considerable spatial variation. The process accounts for more than 90% of the global hot metal production, and this ironmaking–steelmaking route contributes 6–8% of the global anthropogenic greenhouse gas emissions. As a reduction of CO2 emissions from industrial processes is an urgent topic today, some new solutions have been proposed for the blast furnace, for example, highly oxygen-enriched or hydrogen-rich operation of the furnace and use of biomass as a reductant. Additionally, the operation stability and efficiency have a large influence on gas utilization and the rate of reductants and emissions, which are all important and mutually interdependent factors. To achieve stable and efficient operation, four main control schemes are commonly employed: burden distribution control, thermal control, slag forming control, and blast parameter control. Burden distribution control, achieved through the use of a bell-less charging system, manipulates the initial radial distribution of burden materials in the blast furnace.

The specific focus of this research is on JSW Steel Salem BF-2, JSW Steel Ltd, Salem is 1.15 MTPA integrated special alloy steel plant located in Salem Tamilnadu India, with two mini Blast Furnaces (BFs) with useful volume of 402 m³ and 640 m³. This research concerned to Blast Furnace-2 which has a useful volume of 640 m3. JSW Salem Blast furnace burden consist of 60% agglomerated burden (Sinter) and 40% of Iron Ore lumps, occasionally pellet will be used in the burden. Blast volume 90000 $Nm^3/hour$ including 5% oxygen enrichment and 2 tons of steam injection. In Blast Furnace -2 the deviations in BF-2 process parameters starting from December 2022 resulted in a production loss of approximately 250 MT/Day, increased fuel rate by 10 kg/thm and also impacted the other techno-economical parameters. An extensive examination of blast furnace input, process, and output parameters was conducted to optimize the furnace operation. Production loss primarily stems from process abnormalities such as channeling, self-slipping, and liquid drainage issues. Despite employing conventional countermeasures, these challenges persisted, necessitating a more innovative approach to process optimization.

The central purpose of this project is to comprehensively address operational challenges within Blast Furnace-2 at JSW Steel Salem and consequently optimize its performance. The project aims to tackle the persistent issues of production loss attributed to process anomalies like channeling, self-slipping, and liquid drainage. By delving into various blast furnace parameters and employing advanced methodologies, the project seeks to not only identify the underlying causes of these deviations but also develop effective and innovative solutions to rectify them. The ultimate goal is to enhance the stability, efficiency, and overall productivity of the blast furnace, thereby contributing to sustainable ironmaking practices and aligning with the company's operational and environmental objectives.

2. LITERATURE REVIEW

Literature survey conducted to study the reasons and remedies for JSW Salem Blast Furnace-2 production loss and frequent abnormality,

1.Article: "Technological Innovations for Reducing CO2 Emissions in Blast Furnace Ironmaking" (Authors: Wang, Z., et al., 2020) This article discusses various technological innovations and strategies aimed at reducing CO2 emissions in blast furnace ironmaking. It provides insights into the use of alternative reductants, such as hydrogen and biomass, and explores the challenges and opportunities associated with implementing these innovations.

2.Article: "Improving Blast Furnace Performance through Operational Control" (Authors: Guo, L., et al., 2018) The article focuses on operational control strategies for improving blast furnace performance. It discusses the importance of burden distribution control, thermal control, slag forming control, and blast control, as mentioned in the main article, and provides detailed insights into their implementation and impact on operational efficiency.

3.Article: "Impact of Oxygen Enrichment on Blast Furnace Performance and CO2 Emissions" (Authors: Zhang, Y., et al., 2019) This article investigates the impact of oxygen enrichment in blast furnace operations on performance and CO2 emissions. It provides a comprehensive analysis of the effects of different oxygen enrichment levels on productivity, energy consumption, and CO2 emissions, offering valuable information for optimizing blast furnace operations.

4.Article: "Utilization of Biomass as a Renewable Reductant in Blast Furnace Ironmaking" (Authors: Wu, Q., et al., 2019) Focusing on the use of biomass as a renewable reductant in blast furnace ironmaking, this article explores the feasibility and potential benefits of incorporating biomass into the ironmaking process. It discusses the challenges and opportunities associated with biomass utilization, including its impact on reducing carbon intensity and promoting sustainability.

These articles, along with other relevant literature, provide valuable insights and research findings on optimizing blast furnace operations for sustainable iron production. They offer a deeper understanding blast furnace process optimization and control schemes;

Based on the literature survey, several measures were implemented to address certain issues related to the JSW Salem Blast Furnace-2. The specific details are as follows:

1. Raft Optimization: The raft in the Blast Furnace refers to the layer of coke and burden materials that support the weight of the materials above it. In this case, an optimization process was undertaken to improve the raft performance. The raft optimization aimed to reduce from 2220°C to 2180. The raceway adiabatic flame temperature (raft) reduced to improve the burden descent and gas flow dynamics within the furnace.
2. Top Pressure Optimization: Top pressure control is an essential parameter in Blast Furnace operation. It helps regulate the flow of gas and materials within the furnace. To optimize the top pressure, adjustments and refinements were made to the control mechanisms. This optimization process involved fine-tuning the pressure levels to ensure optimal conditions for the chemical reactions and heat transfer within the furnace.
3. Burden Distribution Adjustment: The burden in the Blast Furnace refers to the mixture of raw materials, such as pellets, iron ore lump (IOL), and sinter, which is fed into the furnace. Based on the raw material usage (pellets, IOL, and sinter), the burden distribution was adjusted. This adjustment involved modifying lower material gate (LMG) opening proportions or arrangement different ring selection of the raw materials to enhance their efficiency and improve the overall performance of the furnace.

Despite implementing these measures, JSW Salem Blast Furnace-2 problem was not resolved. It's unclear what specific problem or issue to be encountered or whether additional measures were required. Further research or analysis is required to identify and address the underlying cause of the problem.

3.METHODOLOGY

The research design for this study on enhancing blast furnace performance through permeability index monitoring at JSW Steel Salem BF-2 incorporates several key elements to investigate the relationship between blast furnace operation parameters, the permeability index, and overall furnace performance. The following points outline the research design:

1. Objective:
   - The primary objective of the research is to analyze the impact of fluctuations in the permeability index on the performance of JSW Steel Salem BF-2 blast furnace.
   - The aim is to identify abnormalities in the furnace early on and develop strategies to mitigate production losses and optimize techno-economical parameters.
2. Case Study Approach:
   - The research employs a case study approach, focusing specifically on JSW Steel Salem BF-2.
   - By selecting a single blast furnace, it allows for in-depth analysis of the furnace's unique characteristics, operational parameters, and performance metrics.

3. Data Collection:
   - Comprehensive data collection is conducted, including historical operational data, process parameter measurements, and production records.
   - Data is collected for a specific period starting from December 2022 when deviations in process parameters were first observed, leading to production losses.
4. Blast Furnace Operation Parameters:
   - Various blast furnace operation parameters are considered, Blast furnace input parameter, process parameter and output parameter. Including the coke-to-ore ratio, wall pressures and temperatures, flame temperature, top gas pressure, temperature and composition, hot blast pressure and temperature, and the level of hot liquid metal and slag in the bottom of the furnace.
   - These parameters are continuously monitored and recorded to assess their impact on the production loss and furnace performance.
5. Statistical Analysis:

- Statistical analysis techniques are employed to analyze the collected data and establish correlations between the permeability index, blast furnace operation parameters, and production losses.
- Advanced statistical methods, such as hypothesis testing, regression analysis or time series analysis and Design of experiment, may be used to identify patterns, trends, and causal relationships.

6. Technical research:

- Technical research and study are employed to analyze the significant causes, identifying the root cause and to develop the solution.
- Process modeling and mathematical modelling are used.

7. Interpretation and Recommendations:

- The research findings are interpreted to gain insights into the deviations in the process and their implications for the blast furnace's performance.
- Based on the analysis, recommendations and strategies are developed to optimize blast furnace operation, improve energy efficiency, and mitigate production losses.

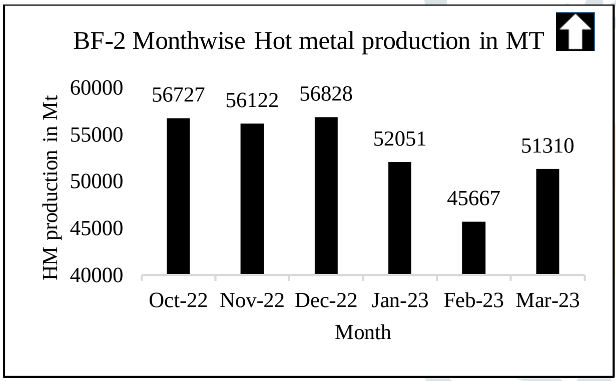
8. Validation:

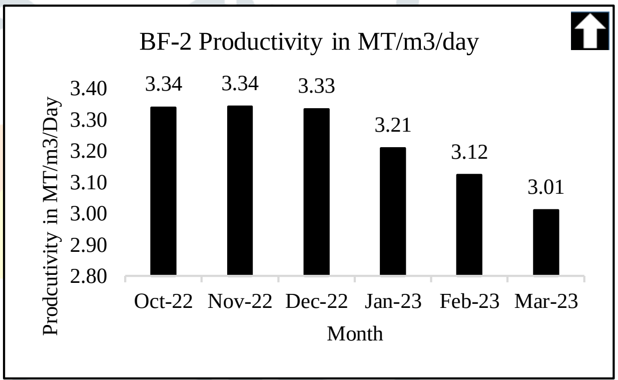
- The research design may include validation of the findings through comparative analysis with historical data or by conducting controlled experiments.
- This validation process ensures the reliability and accuracy of the research outcomes.

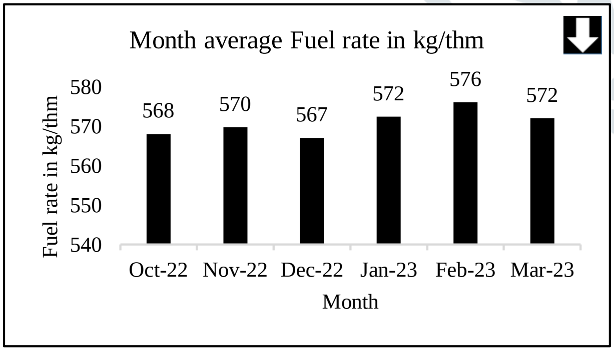
The research design outlined above provides a systematic and structured approach to investigate the impact of production loss on the performance of JSW Steel Salem BF-2. By considering various blast furnace operation parameters and employing statistical analysis techniques and technical research, the study aims to provide valuable insights and recommendations for optimizing blast furnace performance and minimizing production losses.

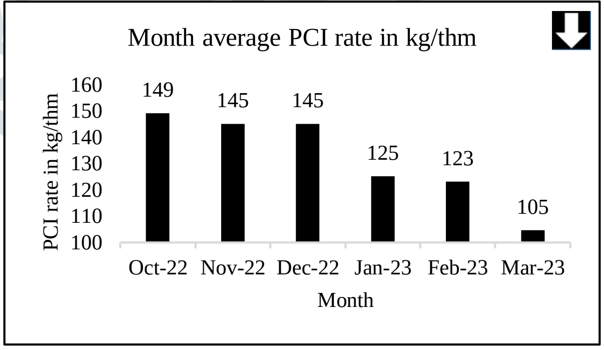
3.1 JSW SALEM BF-2 CASE STUDY:

In JSW Salem BF-2 hot metal production reduced by 250 MT/day and Fuel rate increased significantly due to the frequent abnormality in the process, such as variation in permeability index and frequent self-slipping in the furnace.





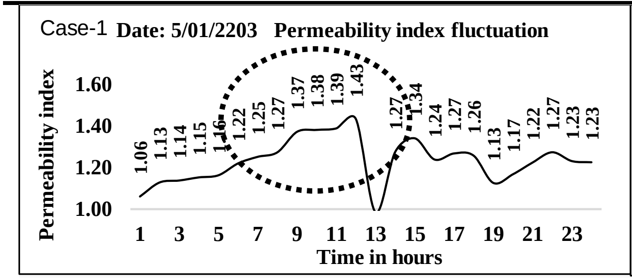


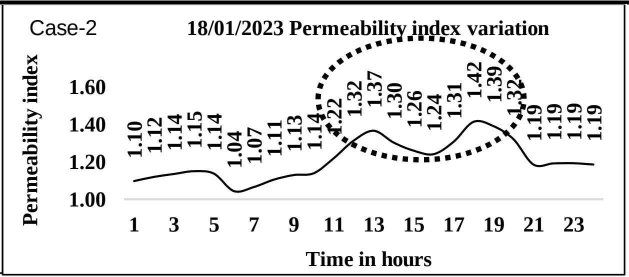


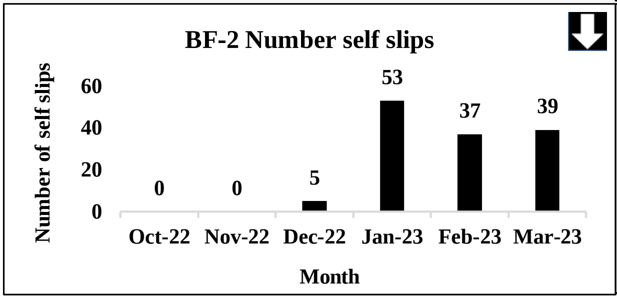
The blast furnace's monthly hot metal production experienced a significant reduction of 13%, dropping from an average of 56,944 metric tons to 49,676 metric tons. Additionally, productivity declined by 13%, going from an average of 3.52 metric tons per cubic meter per day to 3.09 metric tons per cubic meter per day. As a result of these decreases, the production cost of hot metal increased.

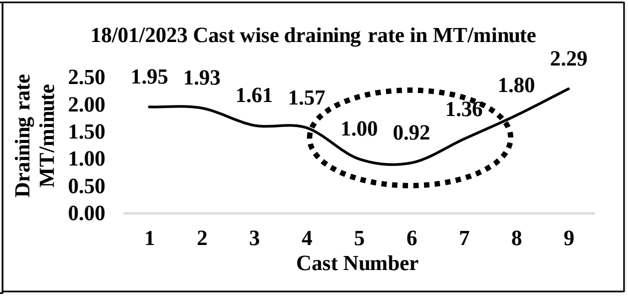
3.2 Background of the problem.

From December 2023, the blast furnace production process was running smoothly, with hot metal production consistently ranging from 1900 to 1950 metric tons per day. However, starting from the first week of January 2023, the production gradually decreased to as low as 1700 metric tons per day. The primary indicators of the problem were fluctuations in permeability and subsequent self-slipping of the furnace, leading to disturbances in the process. In an attempt to normalize the process, traditional actions were taken, including reducing blast volume, increasing coke charging, adjusting burden distribution, fine-tuning the ore/coke ratio, and raising the fuel rate. Despite implementing these measures, the persistent problems of permeability fluctuation and self-slipping continued to arise in the blast furnace operation.









3.3 Designing the study:

To analyze the current problem, all the input, process, and output parameters of the blast furnace are collected and verified using advanced statistical tools. This implies that a comprehensive data collection process has been carried out to gather relevant information related to the blast furnace operations. The collected data is then subjected to analysis using statistical tools to examine the relationship between different parameters and identify any potential issues or patterns. This approach allows for a systematic evaluation of the blast furnace's performance and helps in pinpointing areas that require attention or improvement.

During the data collection phase, a total of 46 variables related to the Blast furnace were collected from January 2022 to March 2023. These variables were analyzed using advanced statistical tools such as regression analysis, hypothesis testing, management and statistical tools, along with technical research. Through this analysis, five significant causes were identified.

The analysis of the Blast furnace input parameter, process parameter and output parameter data using advanced statistical tools and technical research has led to the identification of five significant causes related to the problem at hand. The lower material gate opening percentage, burden distribution time, manganese content in hot metal, burden distribution pattern, and fines input to the furnace were found to have a significant correlation with the issue.

These findings provide valuable insights for further investigation and potential solutions. By addressing these key factors, it is possible to make informed decisions and take appropriate actions to improve the performance and efficiency of the Blast furnace.

The five significant causes identified through detailed statistical and research analysis are as follows:

1.Lower material gate (LMG) opening percentage.

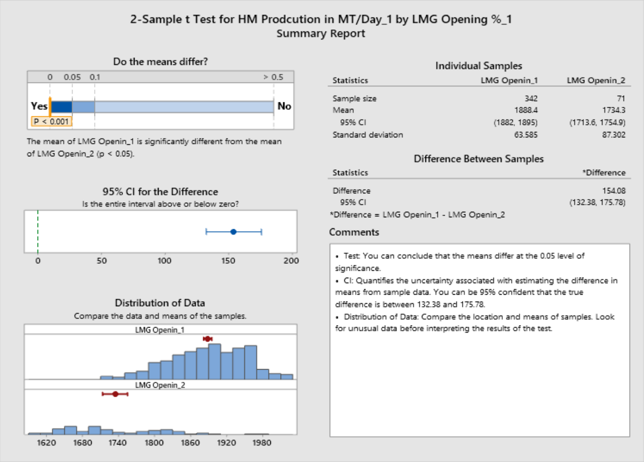
In the preliminary data analysis, it is found that, LMG opening % maintained in two options. In that 1st option is LMG opening 50 to 65% and 2nd option is 66 to 80 %.

Sample size-2 (Sample-1: Hot metal production during LMG 50 to 65% and Sample-2: hot metal production during LMG 66 to 80 % opening.

Cause: LMG opening % is discrete data.

Response: Hot metal production is continuous data.

Data normality and equal variance is observed normal hence 2 sample T test conducted to define the mean hot metal production difference for both the LMG options.



2-Sample t Test for HM Prodcution in MT/Day_1 by LMG Opening %_1
Summary Report

Do the means differ?

The mean of LMG Openin_1 is significantly different from the mean of LMG Openin_2 (p < 0.05).

95% CI for the Difference
Is the entire interval above or below zero?

Distribution of Data
Compare the data and means of the samples.

Individual Samples

Statistics	LMG Openin_1	LMG Openin_2
Sample size	342	71
Mean	1888.4	1734.3
95% CI	(1882, 1895)	(1713.6, 1754.9)
Standard deviation	63.585	87.302

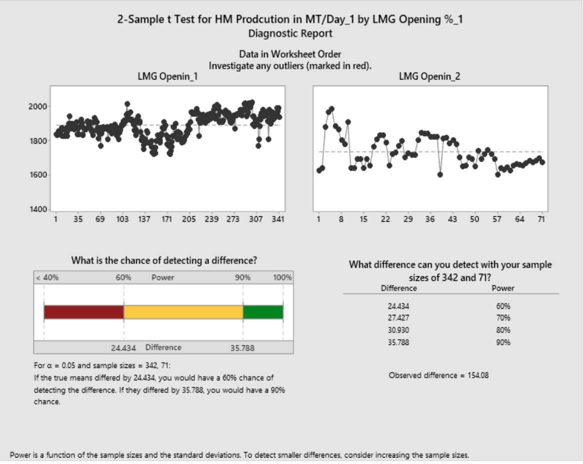
Difference Between Samples

Statistics	*Difference
Difference	154.08
95% CI	(132.38, 175.78)

*Difference = LMG Openin_1 - LMG Openin_2

Comments

- Test: You can conclude that the means differ at the 0.05 level of significance.
- CI: Quantifies the uncertainty associated with estimating the difference in means from sample data. You can be 95% confident that the true difference is between 132.38 and 175.78.
- Distribution of Data: Compare the location and means of samples. Look for unusual data before interpreting the results of the test.



2-Sample t Test for HM Prodcution in MT/Day_1 by LMG Opening %_1
Diagnostic Report

Data in Worksheet Order
Investigate any outliers (marked in red).

What is the chance of detecting a difference?

For α = 0.05 and sample sizes = 342, 71:
If the true means differed by 24.434, you would have a 60% chance of detecting the difference. If they differed by 35.788, you would have a 90% chance.

What difference can you detect with your sample sizes of 342 and 71?

Difference	Power
24.434	60%
27.427	70%
30.930	80%
35.788	90%

Observed difference = 154.08

Power is a function of the sample sizes and the standard deviations. To detect smaller differences, consider increasing the sample sizes.

Sample 1: Hot metal prodcution at LMG 50-65% opening
Sample 2: Hot metal prodcution at LMG 66-80% opening
H_o = LMG opening % is not contributed for HM production.
H_a = LMG opening % is contributed for hot metal production

Since probability value of analysis found that, the P=<0.05, which indicates the LMG opening % is contributed for hot metal production.
Hence it is taken as significant cause for hot metal production deviation.

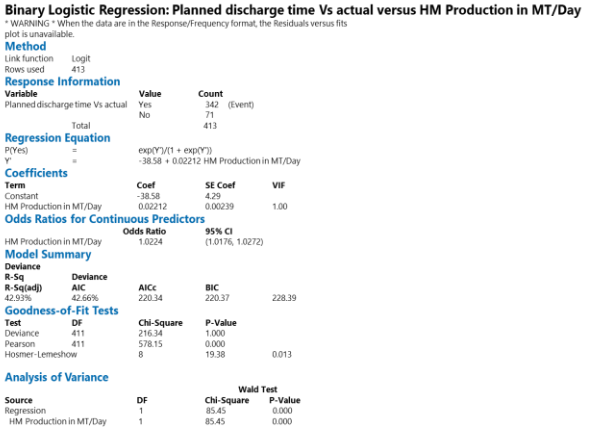
2. The burden discharge duration.

In the preliminary data analysis, it is found that, planned burden distribution duration (time) is matching with actual burden distribution time and sometime it is not matching, hence we taken binary data, that is matching is YES and non-matching is NO. In that 1st option Planned and actual time is matching and 2nd option is planned and actual time is not matching.

Cause: Burden distribution time is matching with planned time or not matching. (Yes or No binary response)

Response: Hot metal production is continuous data.

Hence Binary logistic regression conducted to define the hot metal production correlation in the with burden discharge time.



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Binary Logistic Regression: Planned discharge time Vs actual versus HM Production in MT/Day
* WARNING * When the data are in the Response/Frequency format, the Residuals versus fits
plot is unavailable.
Method
Link function      Logit
Rows used          413
Response Information
Variable                       Value       Count
Planned discharge time Vs actual  Yes        342   (Event)
                               No          71
           Total                           413
Regression Equation
P(Yes)        =            exp(Y')/(1 + exp(Y'))
Y'            =            -38.58 + 0.02212 HM Production in MT/Day
Coefficients
Term                       Coef        SE Coef       VIF
Constant                   -38.58      4.29
HM Production in MT/Day    0.02212     0.00239       1.00
Odds Ratios for Continuous Predictors
                        Odds Ratio     95% CI
HM Production in MT/Day    1.0224      (1.0176, 1.0272)
Model Summary
Deviance
R-Sq          Deviance
R-Sq(adj)     AIC          AICc         BIC
42.93%        42.66%       220.34       220.37        228.39
Goodness-of-Fit Tests
Test          DF           Chi-Square   P-Value
Deviance      411          216.34       1.000
Pearson       411          578.15       0.000
Hosmer-Lemeshow            8            19.38         0.013

Analysis of Variance
                                            Wald Test
Source                     DF          Chi-Square    P-Value
Regression                 1           85.45         0.000
 HM Production in MT/Day   1           85.45         0.000
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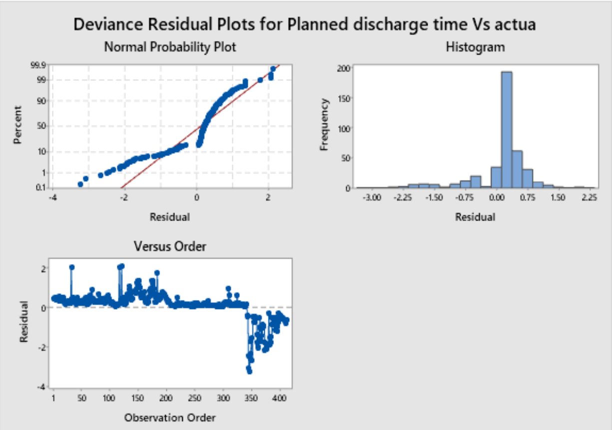


The goodness-of-fit tests are all lower than the significance level of 0.05, which indicates that there enough evidence to conclude that the model does not fit the data.

The R^2 value indicates that the model explains approximately 42.93% of the deviance in the response.

H_o = Discharge time is not contributed for HM production.

H_a = Discharge time is contributed for hot metal production

Since probability value of analysis found that, the P=<0.05, which indicates the burden distribution duration is contributed for hot metal production.

Hence it is taken as significant cause for hot metal production deviation.

3.Manganese content in Hot metal.

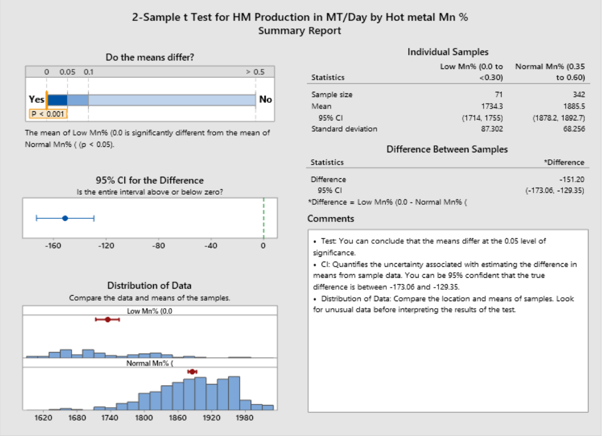
In the preliminary data analysis, it is found that, Manganese content in the Hot metal varied from 0.05 to 0.65 and data are segregated based on Mn input. In that 1st option is Hot metal Mn% 0.35 to 0.60% and 2nd option is 0.05 to 0.34 %.

Sample size-2 (Sample-1: Hot metal production during HM Mn% 0.35 to 0.60% and Sample-2: hot metal production during HM Mn% 0.05 to 0.34%.

Cause: Low HM Mn% and High Normal Mn% is Discrete data

Response: Hot metal production is continuous data.

Data normality and equal variance is observed normal, hence 2 sample T test conducted to define the mean hot metal production difference for both the level of hot metal Mn%.



2-Sample t Test for HM Production in MT/Day by Hot metal Mn %
Summary Report

Do the means differ?

The mean of Low Mn% (0.0 is significantly different from the mean of Normal Mn% ((p < 0.05).

Individual Samples

Statistics	Low Mn% (0.0 to <0.30)	Normal Mn% (0.35 to 0.60)
Sample size	71	342
Mean	1734.3	1885.5
95% CI	(1714, 1755)	(1878.2, 1892.7)
Standard deviation	87.302	68.256

Difference Between Samples

Statistics	*Difference
Difference	-151.20
95% CI	(-173.06, -129.35)

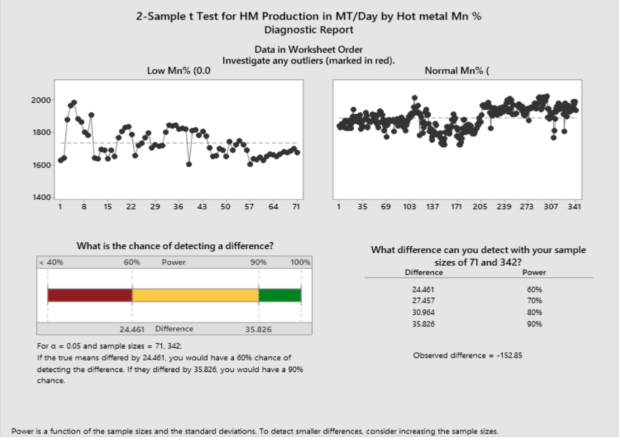
*Difference = Low Mn% (0.0 - Normal Mn% (

95% CI for the Difference
Is the entire interval above or below zero?

Comments

- Test: You can conclude that the means differ at the 0.05 level of significance.
- CI: Quantifies the uncertainty associated with estimating the difference in means from sample data. You can be 95% confident that the true difference is between -173.06 and -129.35.
- Distribution of Data: Compare the location and means of samples. Look for unusual data before interpreting the results of the test.

Distribution of Data
Compare the data and means of the samples.



2-Sample t Test for HM Production in MT/Day by Hot metal Mn %
Diagnostic Report

Data in Worksheet Order
Investigate any outliers (marked in red).

What is the chance of detecting a difference?

For α = 0.05 and sample sizes = 71, 342:
If the true means differed by 24.461, you would have a 60% chance of detecting the difference. If they differed by 35.826, you would have a 90% chance.

What difference can you detect with your sample sizes of 71 and 342?

Difference	Power
24.461	60%
27.457	70%
30.964	80%
35.826	90%

Observed difference = -152.85

Power is a function of the sample sizes and the standard deviations. To detect smaller differences, consider increasing the sample sizes.

Sample 1: Hot metal prodcution at Normal HM Mn%
Sample 2: Hot metal prodcution at Low HM Mn%

H_o = Hot metal Mn% is not contributed for HM production.

H_a = Hot metal Mn % is contributed for hot metal production

Since probability value of analysis found that, the P=<0.05, which indicates the Hot metal Mn % is contributed for hot metal production.

Hence it is taken as significant cause for hot metal production deviation.

Low manganese percentage in hot metal or low manganese oxide (MnO) input to the Blast furnace can have adverse effects on furnace operations, leading to deadman choking and thermal instability in the furnace hearth. Insufficient MnO input can also contribute to hearth build-up (Reduces the effective volume of Blast furnace hearth).

4. Burden distribution pattern.

In the preliminary data analysis, it is found that 4 different burden distribution pattern are used, which is named as Pattern A, B, C and D so sample size is 4.

Cause is discrete data and response in continuous data.

Since data is not normal and not having equal variance, hence Kruskal-wallis test conducted to find the hot metal production median difference among the different burden distribution pattern.

Burden distribution pattern																
BLT Distribution pattern	Ore BLT Pattern								Coke BLT Pattern							
	Ring1	Ring2	Ring3	Ring4	Ring5	Ring6	Ring7	Ring8	Ring1	Ring2	Ring3	Ring4	Ring5	Ring6	Ring7	Ring8
Pattern A	0	0	0	2	2	3	3	0	1	0	0	1	1	1	2	2
Pattern B	0	0	0	2	3	3	2	0	1	0	0	1	1	1	1	3
Pattern C	0	0	1	2	2	2	3	0	1	0	0	1	1	1	1	4
pattern D	0	0	1	2	2	3	1	0	1	0	0	1	1	1	2	2

Kruskal-Wallis Test: HM Production in MT/Day versus Burden distribution pattern

Since data is not normal, and not having equal variance

Descriptive Statistics

Burden distribution pattern	N	Median	Mean Rank	Z-Value
Pattern A	115	1870.74	207.3	0.03
Pattern B	197	1905.34	237.3	4.93
Pattern C	54	1923.10	231.5	1.62
Pattern D	47	1702.37	51.1	-9.51
Overall	413		207.0	

Test

Null hypothesis	H_0: All medians are equal
Alternative hypothesis	H_1: At least one median is different

Method	DF	H-Value	P-Value
Not adjusted for ties	3	95.12	0.000
Adjusted for ties	3	95.12	0.000

Sample 1: Hot metal prodcution at pattern A
Sample 2: Hot metal prodcution at pattern B
Sample 3: Hot metal production at pattern C
Sample 4: Hot metal prodcution at pattern D

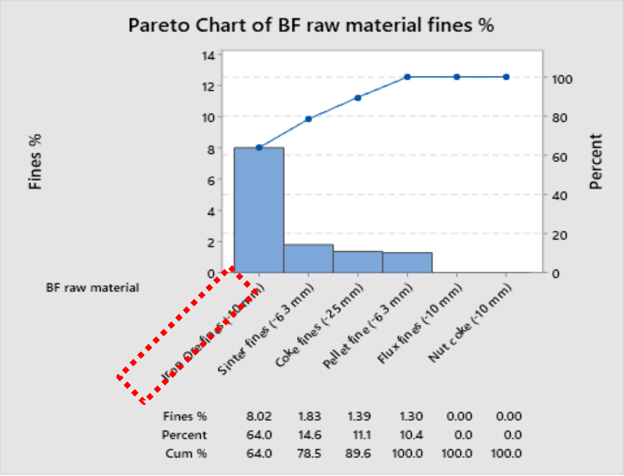
H_o = Burden distribution pattern is not contributed for HM production.

Since probability value of analysis found that, the P=<0.05, which indicates the burden distribution is contributed for hot metal production.

Hence it is taken as significant cause for hot metal production deviation.

H_a = Burden distribution pattern is contributed for Hot metal production

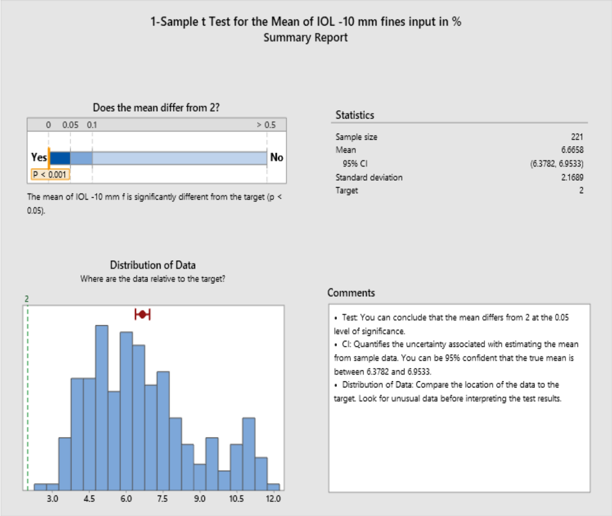
5. Fines input to the furnace.



In pareto chart it observed that Iron Ore Fines % is higher (-10 mm size fines ~8%).

Benchmarked target for Iron Ore Fines input is should be <2 %.

Based on the available data
Sample Size is -1 (Iron ore fine %)
Data is continuous data
Data normality checked and found normal
Hence we conducted the 1-sample T test to find out the means differential between the iron ore fines % and bench marked mean value of iron ore fines.



1-Sample t Test for the Mean of IOL -10 mm fines input in %
Summary Report

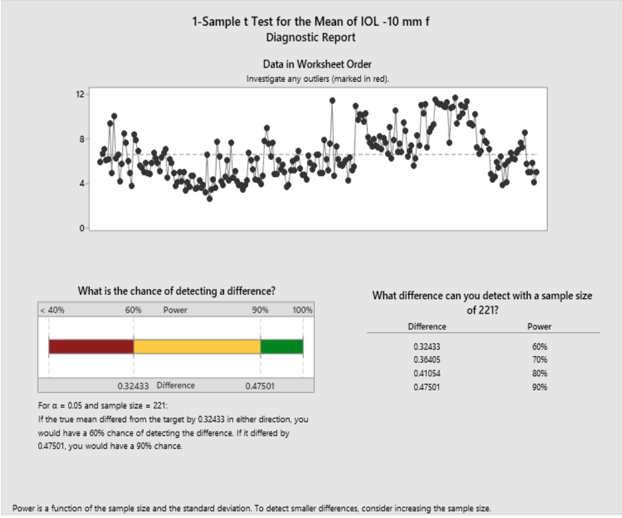
The mean of IOL -10 mm f is significantly different from the target (p < 0.05).

Statistics

Sample size	221
Mean	6.6658
95% CI	(6.3782, 6.9533)
Standard deviation	2.1689
Target	2

Comments

- Test: You can conclude that the mean differs from 2 at the 0.05 level of significance.
- CI: Quantifies the uncertainty associated with estimating the mean from sample data. You can be 95% confident that the true mean is between 6.3782 and 6.9533.
- Distribution of Data: Compare the location of the data to the target. Look for unusual data before interpreting the test results.



1-Sample t Test for the Mean of IOL -10 mm f
Diagnostic Report

For α = 0.05 and sample size = 221:
If the true mean differed from the target by 0.32433 in either direction, you would have a 60% chance of detecting the difference. If it differed by 0.47501, you would have a 90% chance.

What difference can you detect with a sample size of 221?

Difference	Power
0.32433	60%
0.36405	70%
0.41054	80%
0.47501	90%

Power is a function of the sample size and the standard deviation. To detect smaller differences, consider increasing the sample size.

Sample 1: Iron Ore fines input %
Sample 2: Bench marked target of Iron Ore fines %
H_o = Iron ore fines % is not differe from the Bench marking iron ore fines %
H_a = Iron Ore fines % significantly differe from the bench markined iron ore fines %

Since probability value of analysis found that, the P=<0.05, which indicates the iron ore fines input is higher than the bench marked mean.
Hence it is taken as significant cause for hot metal production deviation.

3.4 Designing the solution:

The causes for hot metal production loss are analyzed statically and technical research and found that 5 significant causes and validated through advanced statistic tools and technical research. Various technical study is conducted to optimize the causes to increase the hot metal production in Blast furnace.

1.Lower material gate (LMG) opening percentage.

The lower material gate (LMG) opening percentage, which is directly impact the flow rate of burden material during charging in the blast furnace and it is important parameter for effective burden distribution, is a significant factor identified during the analysis of the Blast furnace data. This parameter refers to the extent to which the LMG is opened, allowing the burden material to flow into the furnace. The LMG opening percentage plays a crucial role in controlling the rate at which the burden materials, such as iron ore, coke, and fluxes, are introduced into the furnace. By adjusting the LMG opening percentage, operators can regulate the flow rate and ensure the optimal distribution of burden materials within the Blast furnace. The analysis highlights the importance of monitoring and optimizing this parameter to maintain stable and efficient furnace operation.

LMG opening % conditions are analyzed, appropriate data are collected to find out the root causes for higher variable LMG operation. During the analysis it is found that three type of LMG are using in the Blast furnace which has different opening profile and the opening area. Whenever new type of LMG in operation, the operator change LMG opening % based on the furnace gas flow profile which has relation with other process variables. The practice of LMG opening based on the gas flow profile is not valid since gas flow profile is having correlation between other variables. This practice can change the burden distribution (flow rate of the burden) and causes the abnormality in the process which turns production loss.

The main root cause of the variability in LMG (Lower material gate) opening percentage is attributed to the diverse types of LMG usage and their varied operating parameters. Currently, operators lack knowledge about the specific flow rates associated with different types of LMG, leading them to rely on furnace parameters for controlling the LMG opening percentage. To enhance the process and optimize the LMG opening percentage, a plan has been devised to develop individual flow rate models for each type of LMG based on the geometry of their opening gates.

Development solution-2: LMG flow rate model.

To derive flow rate curve Johnson equation are used.

Equation-1: $\dot{m} = \rho_b * A * \sqrt{\frac{B*g}{2*(1-m)*\tan\theta}}$

Equation: Johanson equation (discharge rate through outlet for coarse particles)

$\dot{m}$ discharge rate in kg/s

θ angle of hopper in deg

ρ_b bulk density in kg/m3

g is the acceleration of gravity 9.81 ms-2

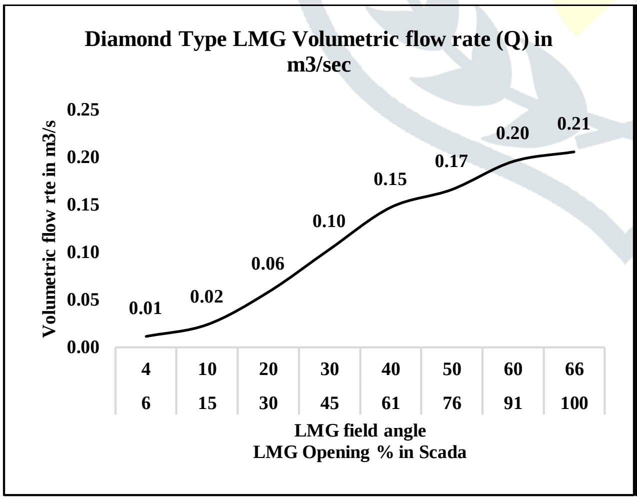
Parameter	Conical hopper	Wedge hopper
B	D, diameter of outlet	W
A	Pi*D^2/4	WL
m	1	0

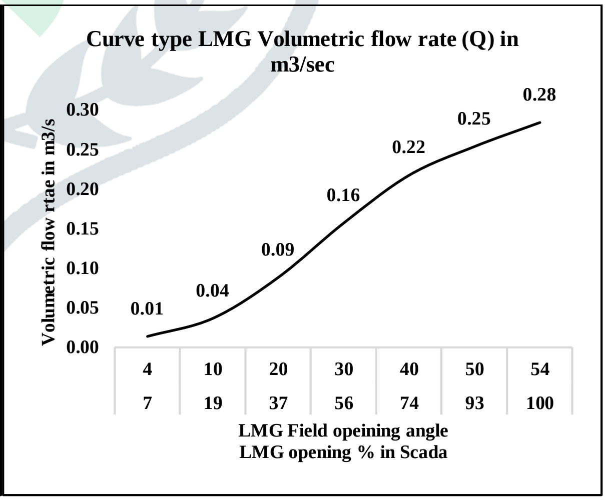
Lower Material Gate-1: Diamond type opening

LMG opening %	Field Opening angle °	Width in mm	Height in mm	Diamond type Area in m2	coke density in Kg/m3	IBM density in kg/m3	Gravitational force in m/s	Coke flow rate in kg/s	Volumetric flow rate of coke in m3/sec	IBM density*area	IBM flow rate in kg/s	Volumetric flow rate of IBM in m3/sec
6	4	150	220	0.017	600	2000	9.81	**7**	**0.01**	33	**23**	**0.01**
15	10	200	300	0.03	600	2000	9.81	**14**	**0.02**	60	**48**	**0.02**
30	20	310	380	0.059	600	2000	9.81	**35**	**0.06**	118	**116**	**0.06**
45	30	400	460	0.092	600	2000	9.81	**62**	**0.1**	184	**206**	**0.1**
61	40	480	500	0.12	600	2000	9.81	**88**	**0.15**	240	**295**	**0.15**
76	50	520	500	0.13	600	2000	9.81	**100**	**0.17**	260	**332**	**0.17**
91	60	580	500	0.145	600	2000	9.81	**117**	**0.2**	290	**391**	**0.2**
100	66	600	500	0.15	600	2000	9.81	**124**	**0.21**	300	**412**	**0.21**

Lower material gate -2: Curve type opening

LMG opening % (SCADA)	Field Opening angle °	Width in mm	Height in mm	Diamond type Area in m2	coke density in Kg/m3	IBM density in kg/m3	Gravitational force in m/s	Coke flow rate in kg/s	Volumetric flow rate of coke in m3/sec	IBM density*area	IBM flow rate in kg/s	Volumetric flow rate of IBM in m3/sec
7	4	100	300	0.024	600	2000	9.81	8	0.01	47	26	0.01
19	10	170	370	0.049	600	2000	9.81	22	0.04	99	72	0.04
37	20	270	450	0.095	600	2000	9.81	53	0.09	191	176	0.09
56	30	370	500	0.145	600	2000	9.81	94	0.16	291	313	0.16
74	40	460	500	0.181	600	2000	9.81	130	0.22	361	434	0.22
93	50	510	500	0.2	600	2000	9.81	152	0.25	401	507	0.25
100	54	550	500	0.216	600	2000	9.81	170	0.28	432	568	0.28





mathematical flow rate model for burden flow has been successfully developed and thoroughly validated using real-world practical data. This model allows for the derivation of a flow rate curve, which serves as a reliable representation of the material flow rate through the system. By utilizing this flow rate curve, adjustments to the LMG opening percentage are made to optimize the burden distribution. With the flow rate curve as a reference, adjustments to the LMG opening angle or percentage can be precisely determined and implemented. This optimization process ensures a constant and controlled material flow rate, leading to improved burden distribution within the system. As a result, the overall efficiency and performance of the process are enhanced. Furthermore, the developed model allows for the creation of flow rate curves for different types of LMGs. This means that each LMG can be optimized based on its specific flow characteristics, contributing to a more tailored and efficient operation.

In conclusion, the utilization of the flow rate model and curve-based adjustments to the LMG opening percentage provide a robust methodology to optimize burden distribution and enhance the overall process performance, leading to improved productivity and product quality

2. The burden discharge duration.

The burden distribution duration also referred to as the burden distribution time, is another significant factor identified in the analysis of Blast furnace data. This parameter represents the time taken for the burden materials to be discharged and distributed within the furnace. It encompasses the process of evenly spreading the burden materials, including iron ore, coke, and fluxes, across the furnace stack. The burden distribution time is crucial for achieving a uniform distribution of materials, which is essential for maintaining optimal furnace performance and product quality. By analyzing this parameter, operators can assess the efficiency of burden distribution and make adjustments as necessary to ensure proper utilization of the furnace's capacity and resources.

The burden distribution duration is analyzed and appropriate data are collected to find out the root causes for not matching the planned and actual distribution time. Based on the data actual time is not matched with planned discharge time. Actual discharge time depend on the material weight, material type and material flow rate. Burden distribution time should be matched with planned distribution time to maintain accuracy in burden distribution. Planned and actual discharge time is not matching due to operational practice of LMG opening based on furnace gas flow profile and above burden probe temperature which have the relation with other parameter.

Development of solution2:

Planned burden discharge time is a sum of required time of given BLT pattern which depend on Bell less top design, BLT distributor speed and given rotation in rings.
Planned discharge time= time required for one rotation *total number of rotation in BLT pattern.

Actual burden discharge time is duration of material discharge start and end of material discharge. As to attain effective required burden distribution actual discharge time to be matched with planned discharge time.

Planned discharge time is calculated based on the BLT chute rotation encoder and display shown in the SCADA and actual material discharge time is derived from Radar signal or by acoustic sensor of the burden tank. Actual and planned discharge time real time data are displayed in the SCADA.

BLT DISCHARGE MONITORING

IRON ORE (LAST DISCHARGE)

LMG POSITION (%) 60.60
TOTAL DISCHARGE TIME (S) 54.31
TOTAL AS RESPONSE TIME (S) 55.78

BURDEN TANK LEVEL

RING	START %	END %	SECS	COUNT
RING 10	0.00	0.00	0.00	0
RING 9	0.00	0.00	0.00	0
RING 8	0.00	66.13	0.00	0
RING 7	66.13	61.39	15.83	2
RING 6	61.39	44.15	13.72	2
RING 5	44.15	23.33	14.20	2
RING 4	23.33	0.00	10.15	2
RING 3	0.00	0.00	0.00	0
RING 2	0.00	0.00	0.00	0
RING 1	0.00	0.00	0.00	0

COKE (LAST DISCHARGE)

LMG POSITION (%) 61.59
TOTAL DISCHARGE TIME (S) 54.38
TOTAL AS RESPONSE TIME (S) 53.04

RING	START %	END %	SECS	COUNT
RING 10	0.00	0.00	0.00	0
RING 9	0.00	48.71	0.00	0
RING 8	48.71	42.75	15.72	2
RING 7	42.75	35.47	6.73	1
RING 6	35.47	27.81	7.18	1
RING 5	27.81	20.19	7.13	1
RING 4	20.19	12.44	7.35	1
RING 3	12.44	5.67	5.02	1
RING 2	5.67	3E-3	4.38	1
RING 1	3E-3	3E-3	0.00	0

After the implementation of the actions now operator monitor the actual and planned discharge time and based on that LMG opening to be adjusted. Furthermore, improvement Lower material gate auto correction logic is developed and implemented to optimize the Blast furnace process.

3.Manganese content in Hot metal.

Low manganese percentage in hot metal or low manganese oxide (MnO) input to the Blast furnace can have adverse effects on furnace operations, leading to deadman choking and thermal instability in the furnace hearth. Insufficient MnO input can also contribute to hearth build-up (Reduces the effective volume of Blast furnace hearth)

Development of solution3:

Analysis of consumption of **Mn**-containing materials in blast furnace burden composition shows that manganese in provides complex effect on condition of Deadman coke in the hearth, as well as on properties of hot metal and slag. In accordance with studies, the addition of **Mn**-containing materials to the mixture of sinter with pellets in an amount of 5–20% of weight of iron-bearing materials in charge helps to decrease the melting points of primary slag on 10-30°C, shifting up cohesive zone in BF, on average, by 0.1–0.3 m, and begin liquid phases filtration begin through Deadman coke earlier. The highest gradient of manganese concentration in hot metal is observed not in the melt filtration zone, but deeper, just above tap hole level. Consequently, the most intensive reduction of manganese compounds in hearth of BF is carried out not in the drip slag drainage mode, but in the layer of coke flooded with slag. It is in this layer, and especially in its more heated part, located under raceways, where is the highest basicity of slag and the lowest gradient of silicon content change in hot metal are observed. Moreover, the active reduction of manganese occurs not only hot metal droplets pass through the slag, but also at the interface between slag and metal. Consequently, the use of Mn-containing materials expands the possibilities of carbon gasification in the lower part of hearth where is experiencing a deficiency of bound oxygen for reaction with crashed particles of coke.

$$MnO + C = Mn + CO - 288.29\ MJ,$$

The use of Mn-containing materials in the blast furnace burden great for complex washing of Deadman coke due to properties of manganese oxides. At the same time, the melting point mobility of primary slag decreases, the mobility of intermediate slags is improved, carbon debris is oxidized due to the reduction of (MnO) by solid carbon, the mobility and desulfurization capacity of the final blast furnace slag is also improving. Manganese oxides reduce the viscosity of intermediate slags and reduce the melting point of the mixture of iron bearing part of burden, while their reduction by furnace gas occurs only to Mn monoxide. When (MnO) enters the lower high temperature zone of BF, part of manganese is reducing, helping to accelerate the renewal of Deadman coke and stabilize the thermal state of smelting process. Such a two-stages Mn reduction also allows to improve the quality of hot metal

Therefore, Mn % Hot metal to be maintained to 0.30 to 0.45%, however for some days (15 to 20 days) can be operated with <0.30%. based on the study procedure is updated to maintain Hot metal manganese to 0.30 to 0.45% by increasing the MnO input. MnO input from agglomerated iron bearing burden or iron ore, in some cases the Mn Ore can be used to increase the hot metal Mn%.

4. Burden distribution pattern.

The burden distribution process is an important and efficient measure to maintain the stable operation of the blast furnace. An accurate burden distribution model will reveal the impact on the internal furnace state and help to optimize the blast furnace production index. Burden distribution pattern in Blast furnace play important role in Blast furnace process and production, which deals with raw material distribution inside the furnace with help of top charging equipment (Bell less top charging system).

The burden distribution in a blast furnace is ensures uniform gas flow and temperature distribution, enabling consistent chemical reactions and heat transfer rates. Additionally, it facilitates optimal reduction of iron ore and minimizes coke consumption, leading to higher productivity and reduced costs. A well-distributed burden prevents furnace wall damage, operational issues, and improves energy efficiency while maintaining consistent product quality. Advanced control systems are employed to continuously monitor and adjust the burden distribution during operation, ensuring the furnace operates at its highest efficiency while maintaining safety and product quality.

The intensive technical research and data analysis aimed to determine the optimum blast furnace burden distribution for JSW Salem's specific operating conditions. The study incorporated practical data from JSW Salem blast furnace and other blast furnaces to ensure a comprehensive analysis. Through meticulous examination, the research yielded some of the best coke distribution patterns and IBM (Iron Bearing Material) distribution patterns, tailored specifically for JSW Salem's blast furnace operations.:

BLT Distribution pattern	**Selected BLT Pattern**							
	Ring-1	**Ring-2**	**Ring-3**	**Ring-4**	**Ring-5**	**Ring-6**	**Ring-7**	**Ring-8**
Coke Pattern A	1	0	0	1	1	1	2	2
Coke Pattern B	2	0	0	1	1	1	1	2
Coke Pattern C	1	0	0	1	1	1	1	3
Coke Pattern D	1	0	0	1	1	1	1	4
IBM Pattern A	0	0	0	2	3	3	1	0
IBM Pattern B	0	0	1	2	2	2	1	0
IBM Pattern C	0	0	0	2	2	2	2	0
IBM Pattern C	0	0	1	2	2	3	1	0

The research carefully analyzed coke and IBM distribution patterns for blast furnace operations at JSW Salem. The goal was to enhance burden distribution. To achieve this, a design of experiment (DOE) study is planned. This study aims to optimize the burden distribution by refining the coke BLT pattern and IBM BLT pattern.

Design of experiment (DOE):

RESPONSE ANALYSIS TABLE (RAT)

DEPARTMENT: BLAST FURNACE# 2

Sl.No	Response	Is there a spec?	If so, what is the spec?	What is the basis of spec?	Is it being monitored and how?	What is the actual?	Is there an actual or potential difference?	Action plan
1	Hot metal Production	Yes	>1900	Past performance	Yes, SCADA and log book	1780	Yes	Do CAT analysis

CAUSE ANALYSIS TABLE (CAT)

RESPONSE: Frequency occurrence of irregularities

Sl.No	Causes	Is there a spec?	If so, what is the spec?	What is the basis of spec?	Is it being monitored and how?	What is the actual?	Is there an actual or potential difference?	Action plan
1	Coke BLT Pattern	No	-	-	Yes, SCADA	Coke Pattern A	-	Trial to be taken
2	IBM BLT pattern	No	-	-	Yes, SCADA	IBM pattern D	-	Trial to be taken

General Factorial Regression: Hot Metal production in MT/day versus Blocks, Coke BLT pattern, IBM BLT pattern

Factor Information

Factor	Levels	Values
Coke BLT pattern	4	Coke pattern A, Coke pattern B, Coke pattern C, Coke pattern D
IBM BLT pattern	4	IBM pattern A, IBM pattern B, IBM pattern C, IBM pattern D

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	18	132232	7346	3.95	0.000
Blocks	3	14476	4825	2.59	0.064
Linear	6	76480	12747	6.85	0.000
Coke BLT pattern	3	22622	7541	4.05	0.012
IBM BLT pattern	3	53858	17953	9.65	0.000
2-Way Interactions	9	41276	4586	2.46	0.022
Coke BLT pattern*IBM BLT pattern	9	41276	4586	2.46	0.022
Error	45	83742	1861		
Total	63	215974			

a). In the Analysis of Variance table, the p-values for the linear terms A and B and interaction term A*B are significant Since P value is < 0.05.

b). The R^2 value shows that the model explains 61.23 % of the variance in strength, which indicates that the model fits the data extremely well.

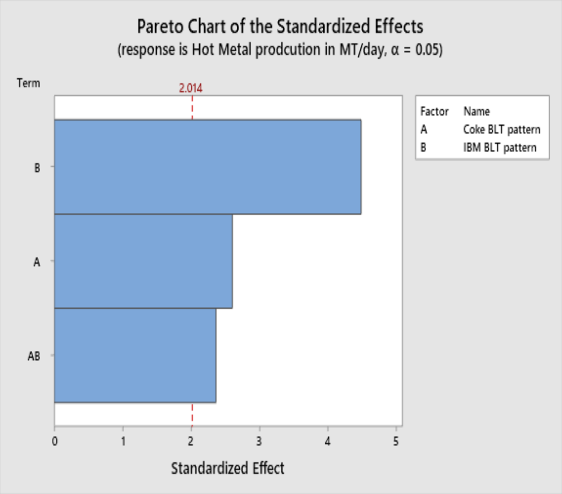
Model Summary

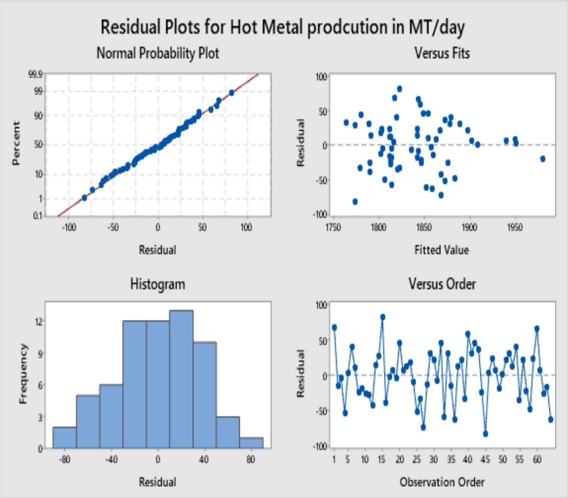
S	R-sq	R-sq(adj)	R-sq(pred)
43.1386	61.23%	45.72%	21.57%

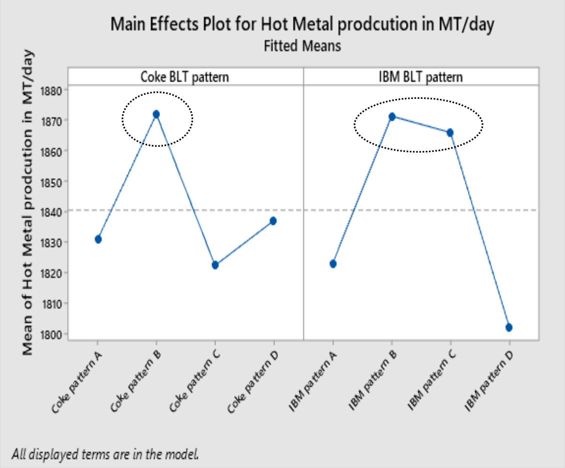
Coefficients

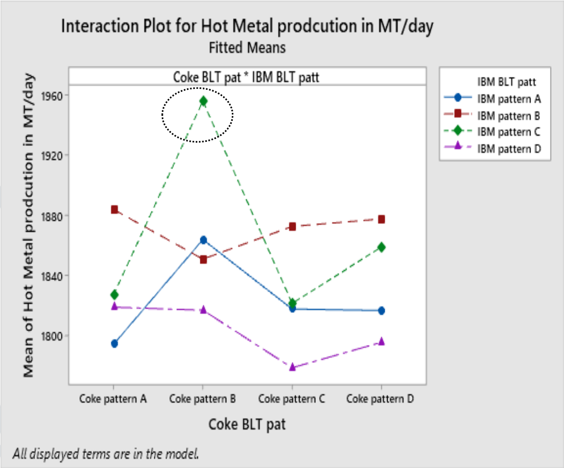
Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	1840.45	5.39	341.31	0.000	
Blocks					
1	-5.20	9.34	-0.56	0.580	1.50
2	24.98	9.34	2.68	0.010	1.50
3	-15.27	9.34	-1.63	0.109	1.50
Coke BLT pattern					
Coke pattern A	-9.64	9.34	-1.03	0.307	1.50
Coke pattern B	31.30	9.34	3.35	0.002	1.50
Coke pattern C	-18.14	9.34	-1.94	0.058	1.50
IBM BLT pattern					
IBM pattern A	-17.52	9.34	-1.88	0.067	1.50
IBM pattern B	30.67	9.34	3.28	0.002	1.50
IBM pattern C	25.30	9.34	2.71	0.010	1.50
Coke BLT pattern*IBM BLT pattern					
Coke pattern A IBM pattern A	-19.3	16.2	-1.19	0.239	2.25
Coke pattern A IBM pattern B	22.3	16.2	1.38	0.176	2.25
Coke pattern A IBM pattern C	-29.1	16.2	-1.80	0.079	2.25
Coke pattern B IBM pattern A	9.5	16.2	0.59	0.559	2.25
Coke pattern B IBM pattern B	-51.7	16.2	-3.19	0.003	2.25
Coke pattern B IBM pattern C	59.0	16.2	3.64	0.001	2.25
Coke pattern C IBM pattern A	12.7	16.2	0.79	0.436	2.25
Coke pattern C IBM pattern B	19.5	16.2	1.21	0.234	2.25
Coke pattern C IBM pattern C	-26.4	16.2	-1.63	0.110	2.25

Most of the VIFs are small <5, which indicates that the terms in the model have no multi co linearity.





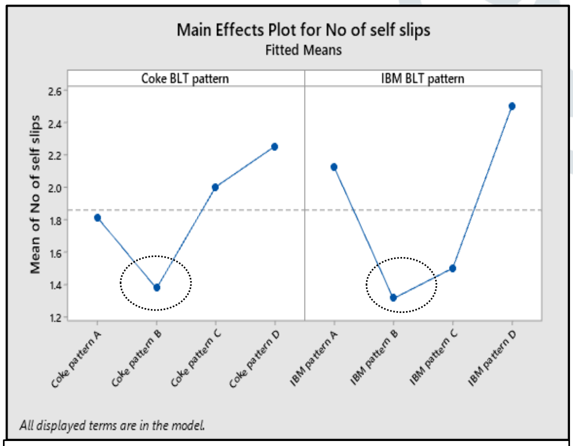


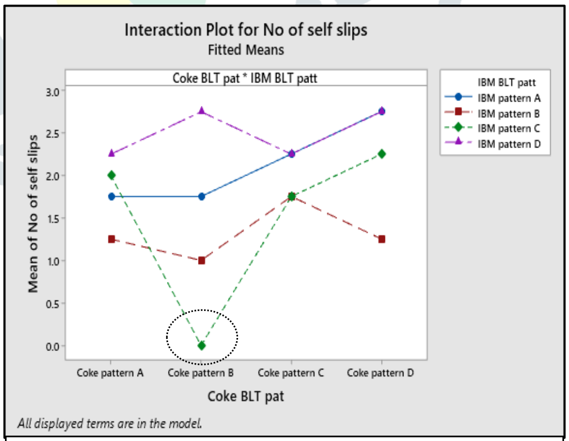


The Main Effect plot shows that Coke BLT pattern B and IBM BLT pattern B and C result in higher hot metal production, exceeding 1900 MT/day.

The interaction plot shows that Coke BLT pattern B and IBM BLT pattern C result in higher hot metal production, exceeding 1950 MT/day.

General Factorial Regression: No of self-slips in No/day versus Blocks, Coke BLT pattern, IBM BLT pattern also conducted to check the abnormality of the furnace vs burden distribution





The Main Effect plot shows that Coke BLT pattern B and IBM BLT pattern B and C result lower self-slips

The interaction plot shows that Coke BLT pattern B and IBM BLT pattern C result in higher hot metal production, exceeding 1950 MT/day.

The Design of Experiment (DOE) determined the best burden distribution combination (Coke and IBM distribution) by prioritizing increased hot metal production and reduced furnace abnormalities (self-slips).

Design of Experiments

Factor code	Factors	UOM	L1	L2	L3	L4
A	Centre coke	Pattern	Coke pattern A	**Coke pattern B**	Coke pattern C	Coke pattern D
B	Periphery coke	Pattern	IBM Pattern A	IBM Pattern B	**IBM Pattern C**	IBM Pattern D

The Design of Experiment identified Coke BLT pattern B and IBM BLT pattern C as the optimal combination for enhancing burden distribution, leading to improved hot metal production and decreased irregularities (self-slips) within the blast furnace. It is recommended to adopt this pattern for better operational outcomes.

5. Fines input to the furnace.

The input of raw material small particles, also known as fines, into a blast furnace can cause several issues and challenges in the ironmaking process. Fines can block the passages between the larger coke and ore particles, reducing the permeability of the blast furnace burden. This can hinder the flow of reducing gases (such as carbon monoxide) and impede the efficient reduction of iron ore, leading to lower production rates and increased fuel consumption. The fines may not make optimal contact with the reducing gases due to their small size and irregular shape. As a result, the fines might not fully participate in the reduction reactions, leading to reduced iron yield and a decrease in furnace efficiency. In order to compensate for the decreased permeability and maintain the desired production rates, operators may need to increase the amount of coke used in the blast furnace. This can lead to higher operational costs and environmental impacts.

The analysis of the ironmaking process reveals that the presence of fines, which are fine particles of raw material, poses significant challenges within the blast furnace operations. These fines, notably iron ore fines, comprise approximately 80% of the total fines introduced into the furnace. This insight was gained through a comprehensive study that involved data collection from the raw material yard, transportation processes, and stock house screening activities. The investigation found that the average receipt of iron ore fines measuring less than 10 mm in size from the supplier accounts for roughly 30% of the total fines input. However, a substantial reduction occurs during the screening process within the blast furnace stock house, resulting in only 8-10% of these fines eventually being introduced into the furnace. This diminished fraction still contributes significantly to the overall fines load on the Blast Furnace.

Following a benchmarked analysis that recommends limiting the introduction of -10 mm iron ore fines to less than 2%, a strategic approach was devised to curtail the fines' entry into the blast furnace. The initial strategy centered on fine-tuning the screening parameters, aiming to decrease the fines input. Through this endeavor, the screening rate was optimized by reducing it from 25 kg/second to 15 kg/second. However, the anticipated significant reduction in fines input was not achieved as expected. Subsequent attempts to further minimize the screening rate were hindered due to potential adverse effects on overall process efficiency and operational timeline. Regrettably, this impasse in screening rate reduction has resulted in a contingency situation where additional reduction becomes unfeasible, making it necessary to reevaluate the approach for fines load management.

To address the contradiction posed by the challenge of fines in the blast furnace, an inventive problem-solving approach employing TRIZ principles is being implemented. This methodology entails identifying innovative solutions by leveraging a set of strategic principles specifically designed for complex engineering problems. By systematically applying TRIZ principles, the aim is to devise creative and effective strategies that reconcile the conflicting goals of minimizing fines' impact on furnace efficiency while maintaining overall operational effectiveness. Through this approach, unconventional solutions can be explored, leading to breakthrough insights and enabling the optimization of the fines management process within the blast furnace operations.

TRIZ (INVENTIVE PROBLEM SOLVING TOOLS)

TRIZ, known as the Theory of Inventive Problem Solving, is a comprehensive methodology designed to unlock innovative solutions for engineering and technical challenges. It equips problem solvers with a range of principles and techniques that foster creative problem-solving. Within TRIZ, specific engineering problems are transformed into more abstract TRIZ general problems, enabling a broader perspective on the issues at hand. These general problems are then addressed using a set of TRIZ principles that guide inventive solutions, transcending conventional approaches. The resultant TRIZ general solution offers a high-level strategy for resolving the identified challenge. Finally, this general solution is refined and adapted to the specifics of the problem, ultimately yielding a tailored, specific solution designed to achieve the desired output. This structured process showcases how TRIZ navigates from specific issues to innovative resolutions through a series of transformative steps.

Sl.No	**Specific problem**	**TRIZ General Problem**	
		Improving parameter	**Worsening parameter**

1	Higher fines input in the furnace	Ease of operation	Loss of time

Improving Parameter		**Worsening Parameter**		**Contradiction matrix**
P.No	**Parameter**	**P.No**	**Parameter**	**General Solutions**
13	Ease of operation	25	Loss of time	**10**

Contradiction matrix yield is Principle Number-10

TRIZ Principle Number-10: Preliminary action which states that ***Perform, before it is needed, the required change of an object (either fully or partially).***

Applying TRIZ Principle Number 10, "Preliminary Action," entails executing necessary changes on an object in advance, whether wholly or partially, before the actual requirement arises. With this principle in mind, a strategic approach is being developed to address the challenges posed by fines in the blast furnace. The plan involves implementing preliminary screening actions on the raw materials even before they enter the blast furnace stock house. By preemptively processing the materials, these preliminary actions aim to modify the fines' characteristics, ensuring that they align more effectively with the furnace's operational requirements.

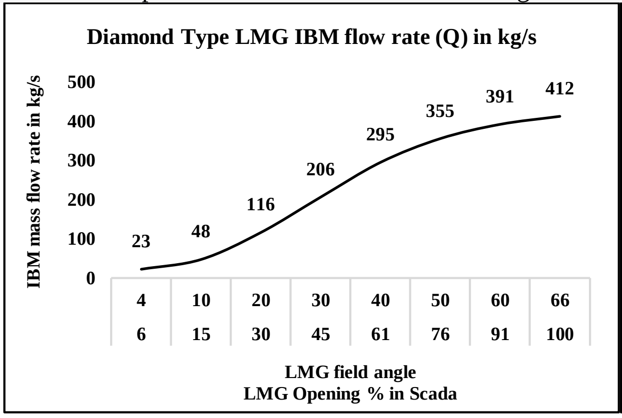
Sl.No	TRIZ General Solution	Specific solution
1	*TRIZ principle No-10:* "Preliminary Action," entails executing necessary changes on an object in advance, whether wholly or partially,	Prescreening of Iron ore before charging into the Blast furnace stock house.

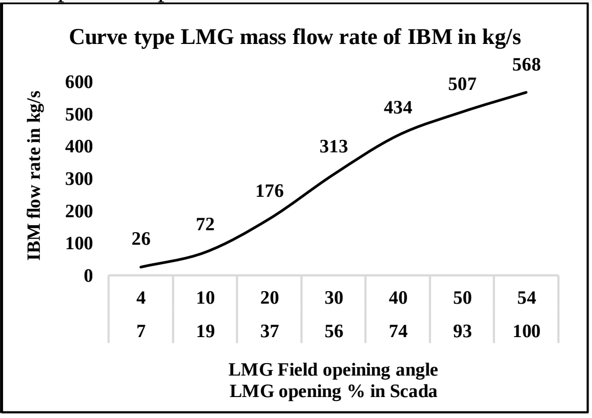
By leveraging the insights of TRIZ Principle Number 10, "Preliminary Action," a solution has been conceived to tackle the challenge of fines within the blast furnace context. The solution entails conducting a prescreening process on the iron ore prior to its introduction into the blast furnace stock house. This prescreening step occurs upstream, allowing for the separation of fines before they reach the furnace environment. Consequently, the fines that would have otherwise entered the blast furnace are effectively minimized through this preemptive screening process. This innovation aligns with the TRIZ principle by proactively initiating changes before the actual need arises. By executing this strategic alteration in the workflow, the overall fines input into the blast furnace is significantly reduced. The result is an optimized process that maintains furnace efficiency and increased hot metal production.

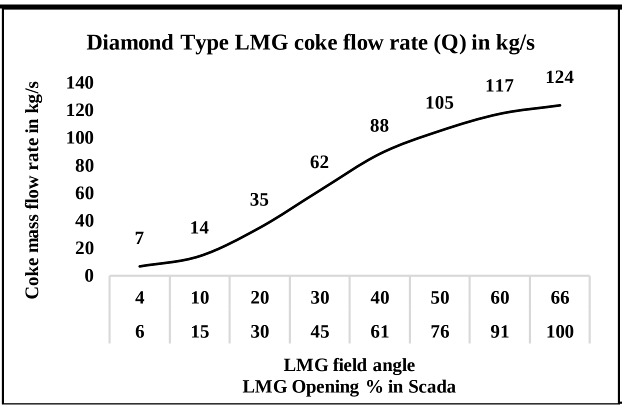
4.RESULT AND DISCUSSION

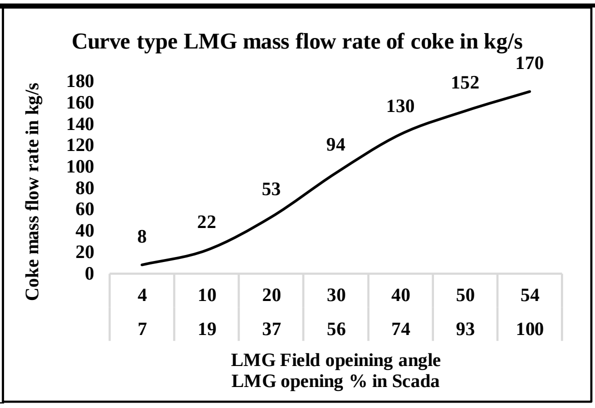
The result of this case study demonstrates the application of advanced statistical analysis, technical research, and problem-solving methodologies to identify and address challenges within the blast furnace operations at JSW Salem. Through a systematic approach, five significant causes impacting hot metal production and furnace efficiency were identified

1. It was observed that the LMG opening percentage significantly influenced hot metal production. The analysis revealed that the practice of adjusting LMG opening based on gas flow profile was not valid, leading to abnormality in the process. To address this, a flow rate model was developed to optimize LMG opening percentages based on the geometry of different LMG types. This led to a more controlled material flow rate and improved burden distribution, ultimately enhancing furnace efficiency. New technological gadgets such as radar level measurement system and acoustic sensor installation in burden tank helped to real time monitoring of the discharge time and also further improvement LMG auto correction logic also developed to improve the burden distribution in the blast furnace.

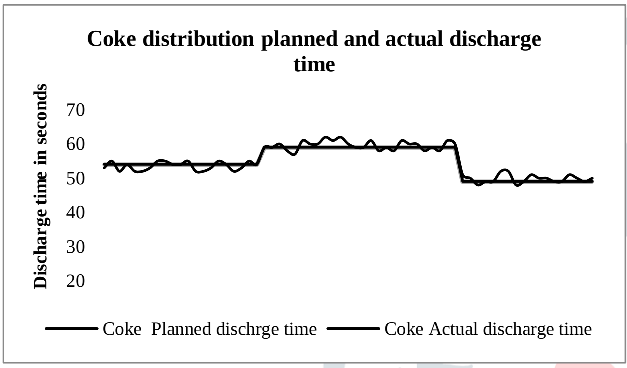


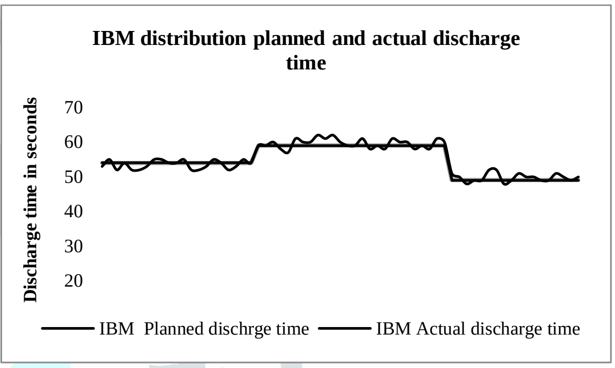




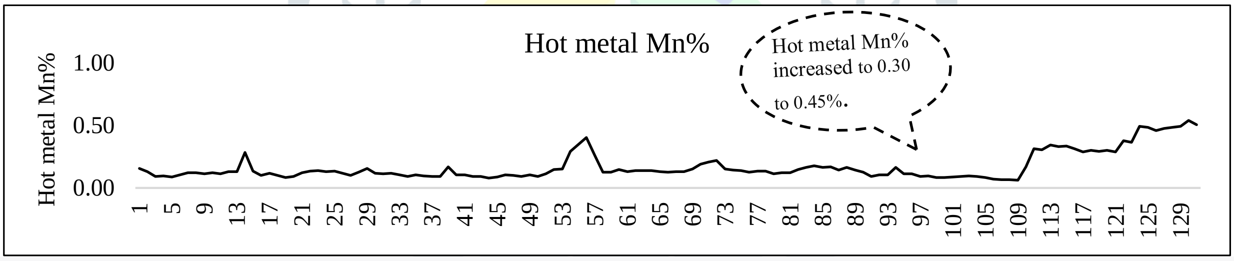


2.The burden distribution time or duration had a considerable impact on hot metal production. A logistic regression analysis highlighted the correlation between burden distribution time and hot metal production. By optimizing the burden discharge time through real-time monitoring and adjustments, the efficiency of the process was improved, leading to reduced irregularities. To achieve effective burden distribution, the planned discharge time should be actual discharge time of the burden.





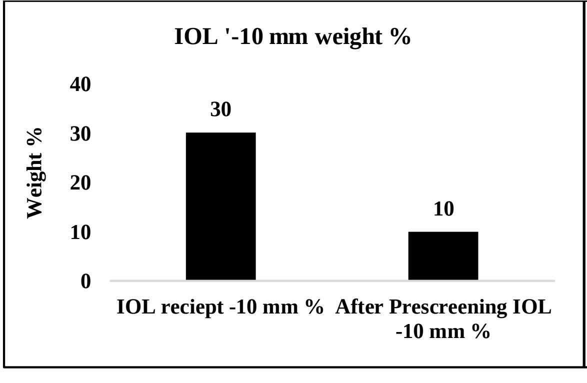
3.The manganese content in hot metal was identified as a significant factor affecting furnace performance. Low manganese percentage in hot metal or insufficient manganese oxide input could lead to deadman choking and thermal instability. To address this, the hot metal manganese content was maintained within the optimal range of 0.30 to 0.45% through adjusting the manganese oxide input.

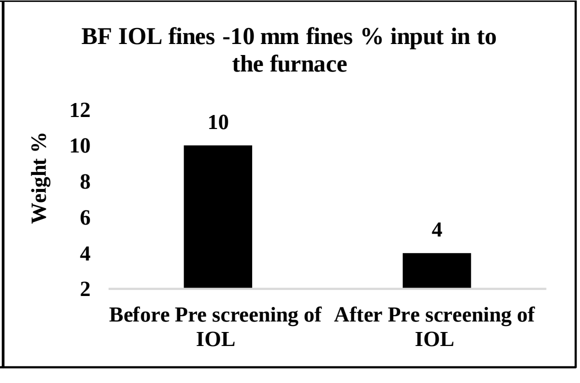


4.The distribution pattern of coke and iron-bearing materials (IBM) within the furnace played a crucial role in furnace efficiency. By conducting a Design of Experiment (DOE) study, an optimal combination of coke and IBM distribution patterns was identified to enhance burden distribution and to reduce furnace abnormalities.

BLT Distribution pattern	Selected BLT Pattern							
	Ring-1	Ring-2	Ring-3	Ring-4	Ring-5	Ring-6	Ring-7	Ring-8
Coke Pattern B	2	0	0	1	1	1	1	2
IBM Pattern C	0	0	0	2	2	2	2	0

5. The presence of fines, or small particles of raw material, posed challenges to furnace efficiency by reducing permeability and hindering gas flow. To address this, a TRIZ-based approach was adopted, involving preliminary screening of iron ore before introduction to the blast furnace stock house. This proactive measure reduced fines input and optimized furnace performance.





In the prescreening iron ore fines % reduced to 10% from 30% of receipt of iron ore fines, after prescreening iron ore charged to Blast Furnace Stock house bunker. In stock house again iron ore screening is takes place before charging into the blast furnace which helped to reduce the overall -10mm iron fines input to furnace to <4%. Further to reduce the fines input to bench marked value of <2% it is decided to all iron ore to be prescreened before charging the Blast Furnace stock house.

Initially, the prescreening of iron ore fines underwent a significant improvement, reducing the fines percentage from 30% to 10% upon receipt. These prescreened iron ore were then directed to the Blast Furnace Stock house bunker for further processing. Within the stock house, another round of iron ore screening occurred prior to the actual charging into the blast furnace. This meticulous screening process proved effective in further minimizing the presence of fines, specifically -10 mm iron ore fines to below 4%. To achieve an even more ambitious target of reducing fines input to the benchmarked value of less than 2%, a strategic decision was made. This decision mandated that all incoming iron ore be prescreened before being charged into the Blast Furnace stock house. This multi-step approach underscored the commitment to enhancing furnace efficiency by rigorously controlling and reducing the fines content, thereby optimizing overall operations and hot metal production.

The comprehensive implementation of these solutions has successfully optimized the blast furnace process, leading to several positive outcomes. These include increased hot metal production by 250 metric tons per day, aligning with the monthly business plan target. Productivity also saw an improvement from 3.33 to 3.51 metric tons per cubic meter per day. Additionally, there was a reduction in fuel consumption, with the fuel rate dropping from over 570 kg per ton of hot metal (thm) to under 560 kg per thm. The Pulverized Coal Injection (PCI) rate also rose to over 145 kg per thm, contributing to enhanced performance. Notably, the number of self-slips was reduced to under 5, indicating improved operational stability. Furthermore, specific greenhouse gas (GHG) emissions decreased by 5%. signaling progress towards environmental sustainability and sustainable Iron making.

5.CONCLUSION

In conclusion, the successful implementation of a comprehensive set of strategies and solutions aimed at optimizing the blast furnace operations at JSW Steel, Salem, has yielded remarkable results. Through meticulous technical analysis, innovative problem-solving methodologies, and the integration of advanced statistical tools, the challenges and limitations faced by the blast furnace process were systematically identified and effectively addressed. This endeavor stands as a testament to the power of combining theoretical insights with practical applications in the pursuit of enhanced operational efficiency and environmental sustainability.

The project's outcomes are indeed significant and multifaceted. The increase in hot metal production by 250 metric tons per day, in alignment with the monthly business plan target, reflects a substantial achievement that contributes directly to the company's bottom line. Moreover, the improvement in productivity from 3.33 to 3.51 metric tons per cubic meter per day indicates a heightened efficiency in resource utilization, showcasing the positive impact of the optimized blast furnace process.

The reduction in fuel consumption, witnessed by the decrease from over 570 kg per ton of hot metal (thm) to under 560 kg per thm, underscores the project's commitment to sustainable practices. This reduction not only translates to cost savings but also signifies a reduction in the overall carbon footprint associated with ironmaking. The concurrent rise in Pulverized Coal Injection (PCI) rate to over 145 kg per thm further demonstrates a balanced approach in utilizing alternative and environmentally friendly inputs.

Perhaps equally significant is the improvement in operational stability, exemplified by the reduction of self-slips to under 5. This indicator points to enhanced consistency and control within the blast furnace operations, a critical factor in ensuring reliable and sustainable production processes. Furthermore, the reduction of specific greenhouse gas (GHG) emissions by 5% is a step in the right direction towards environmental responsibility and aligns with global efforts to mitigate climate change.

In essence, this project showcases the intricate interplay between technical expertise, data-driven decision-making, and a deep commitment to operational excellence. By identifying and addressing key factors impacting blast furnace efficiency and stability, JSW Steel, Salem, has not only optimized its production processes but has also demonstrated its dedication to minimizing its environmental impact. The amalgamation of innovative strategies and collaborative efforts has set a benchmark for sustainable ironmaking practices, providing inspiration for the broader industry to embrace similar transformative initiatives.

As industries continue to grapple with the challenges of reducing greenhouse gas emissions and enhancing operational efficiency, the success story of JSW Steel, Salem, serves as a beacon of hope and a blueprint for progress. Through unwavering dedication, strategic thinking, and the relentless pursuit of excellence, this project offers a model for integrating economic growth, environmental stewardship, and technological innovation – a model that can lead the way towards a greener, more sustainable future.

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