International Journal of Engineering and Advanced Technology (IJEAT)
ISSN: 2249-8958 (Online), Volume-10 Issue-3, February 2021

Real-Time Lime-Storage Tracking Model in Steel-Making Plant

Vipul Kumar Tiwari, Kumar Gaurav, Umesh Kumar Singh, Jose Martin Korath, Manish Kumar Singh

Abstract: ***In Tata Steel Ltd.- India, the calcined lime produced in the Merz-kiln is stored in the respective bins for its further use in steel making at LD shops. The quality of lime controls the quality of steel, refractory life and productivity. It also helps in removing the impurities during the steel-making process. Longer and inefficient storage of calcined lime results into degradation of the lime quality due to air slaking and fines generation. To optimize the storage time, a model has been developed which tracks the live charging, storage and discharging of lime at each respective bin. The model further gives recommendations in the form of preferences for charging and discharging of the bins. Python has been used as a tool for the model development. By the integration of level 1 and level 2 automation, it has become easier to achieve this aim by using data from sensor devices. Level 1 sensors have been installed in each respective bin to get the information about the level of materials inside the bin. Further this crucial data is stored in level 2 automation system to use it in the model. Model's result shows the live tracking of calcined-lime stored in the bins. It generates a logical layer of material inside the bin and provides the age (storage time in hours) of each layer. Based on the age of layers, model gives the preferences for charging and discharging of the bins. Eventually It provides a decision-making platform to the plant user based on preferences for better lime-storage management. The system developed also contains a HMI (Human-machine interface) where user can visualize the live tracking and preferences for each bin given by the model. The system also captures the action taken by the user based on model's preferences. Ultimately, it optimizes the storage time and controls the lime quality inside the bin. Eventually, it also controls the degradation of lime quality due to long storage. The model has been validated quantitatively with the real-time data of processing plant captured by the level 1 sensors. The result shows that model is able to track the level of material inside the bin, age of each layer and its storage duration. The result also shows the name of preferred bins to be charged/discharged to optimize the storage duration. As per requirements, the calcined lime stored in the bins is drawn to use it in the steel-making process.***

Keywords: ***Automation, Bin-tracking-system, Industry4.0, Quality-control,***

I. INTRODUCTION

Manuscript received on January 17, 2021.
Revised Manuscript received on January 23, 2021.
Manuscript published on February 28, 2021.
* Correspondence Author
Vipul Kumar Tiwari*, Technologist, Automation Division, Tata Steel, Jamshedpur, 831001, India E-mail: vipul.tiwari1@tatasteel.com
Kumar Gaurav, Technologist, Automation Division, Tata Steel, Jamshedpur, 831001, India E-mail: kumar.gaurav6@ tatasteel.com
Umesh Kumar Singh, Principal Technologist, Automation Division, Tata Steel, Jamshedpur, 831001, India E-mail: umesh.singh1@tatasteel.com
Jose Martin Korath, Chief (ISMM), Automation Division, Tata Steel, Jamshedpur, 831001, India E-mail: jose.korath@tatasteel.com
Manish Kumar Singh, Chief (One IT), Automation Division, Tata Steel, Jamshedpur, 831001, India E-mail: manishk.singh@tatasteel.com

40-45% of calcined-lime produced in the word is used in steel manufacturing industry globally [1].

The steel making process uses calcined lime as basic flux [2]. It removes impurities present in hot-metal during steel-making process [3]. Therefore, calcined-lime of good quality is must to produce the good quality of steel [1]. A good quality lime has also an impact on the refractory life and productivity in steel-making [1]. Lime is produced from lime stone having at least 50% calcium carbonate and various impurities [4]. Quality of the calcined-lime mainly measured in terms of the availability of calcium oxide (CaO%) contained by it as shown in Fig. 1. It is produced in Merz-kiln during a chemical reaction by burning of limestone ($CaCO_3$) as shown in (1) [5]. In Tata Steel, Ltd-India, calcined lime is moved through conveyor belts after the production and stored in a storage bin from top as shown in Fig. 2. Based on the demand at the steel-making shop, lime is discharged from the bottom of the bin and it is dispatched for steel production as shown in Fig. 2.

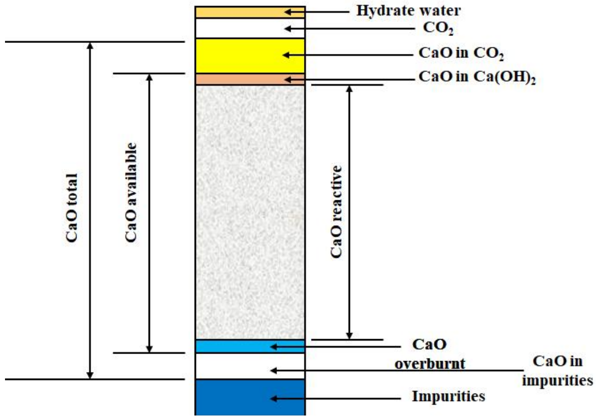


Fig. 1. Lime composition.
(Manocha, Sanjeev, and François Ponchon, "Management of Lime in Steel," *Metals*, 2018)

$$CaCO_3 \xrightarrow{\text{In presence of heat}} CaO + CO_2 \qquad (1)$$

These bins (Storage capacity of 120 tons in Tata Steel) can store the same or different amount of the calcined-lime based on rate production of calcined-lime. The filling and drawing process of calcined-lime at the respective bins may be continuous or discrete according to its demand. The filling and drawing process along with duration of storage play a very crucial role in effecting the calcined-lime's quality. Longer storage duration makes the calcined-lime to be in contact with moisture for longer time. As a result, the quality of calcined-lime deteriorates due to "air-slaking" phenomenon [6]. Air slaking is a chemical process where calcium oxide (CaO) converts into calcium hydroxide ($Ca(OH)_2$) [6].

Eventually, CaO% content in calcined lime becomes lower and calcined-lime becomes less reactive. At the end, it will lower the quality of steel when used in steel-making process.

The inefficient charging (loading) and discharging (unloading) of bins leads to the generation of lime fines from the calcined-lime due to the fine breakage of calcined-lime stones [7]. Eventually, the quality of calcined-lime gets degraded with time during storage. Hence, storage of calcined lime before using it into steel-making becomes a challenging task for producing quality steel.

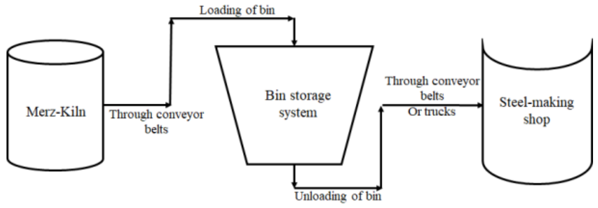


Fig. 2. Calcined-lime flow diagram at Tata-Steel.

The vital information (data) about the amount of lime stored, rate of storage, storage-duration and rate of drawing are very crucial for decision making to handle the calcined-lime appropriately. The access to information (data) has been possible with the development of industry 4.0 in the steel-making and lime production plants [8]. It has resulted into the integration of automated devices like sensors with physical process [9]. This facility has enabled the industry to fetch information (data) about physical process from PLC [10] and store it into the data-base systems for the analysis. Automation of welding process and issue related to steel products has described in a study [11]. Another study regarding automation in steel rolling has been presented to improve the rolling of small batches [12].

In Tata Steel, the bins, where calcined-lime is stored, have been facilitated with the similar automated technology. To serve the purpose of data gathering, level 1 automation system has been developed in the plant. The sensor devices have been installed physically into the respective bins to fetch the bin-level data during the charging and discharging of the bins. In addition to this, a level 2 automation system has been developed to store the data into usable format. Therefore, we have plethora of data available for the analysis about the physical process of charging and discharging and storage of calcined-lime inside the bins.

As far as the tracking of bin-level during charging-storage-discharging process is concerned, there are no studies available. This study aims to track the bin-level with a goal to optimize the storage time for controlling the degradation of lime quality. A model has been developed using python as a tool to achieve the goal. The model takes live data from physical process of charging-discharging of the bin and analyses it. It tracks the level of calcined-lime stored in the bin during its charging-storage-discharging process. Eventually, it provides the status about the storage of the bins (in terms of bin level), i.e. fraction of bin's storage capacity filled or empty. Moreover, the model also provides the preferred recommendation for charging and discharging of the bins based on storage time status. A HMI (Human-machine-interface) has been developed to display the result of model. Based on the model's recommendation, user decides that which bin has to be charged/discharged first. The model has been quantitively validated with the plant data fetched from the physical process of bin-storage system. The results extracted from the model contains live tracking of bin-level, storage duration of the calcined-lime. It also shows the recommended list of bins to be charged/discharged on preference for achieving optimum storage time.

II. METHODOLOGY

The developed model gives a decision-making platform to the user for charging and discharging of the bins on preference basis. User can also be able to track the live charging/discharging of the bin so that over-time storage of lime is avoided. This model has application in lime plants and steel-making plants where users have to optimize the calcined-lime's storage time to prevent the degradation of lime quality.

A. *Model Flow Diagram*

The below Fig. 3 shows the flow diagram of the overall steps taken for developing the model.

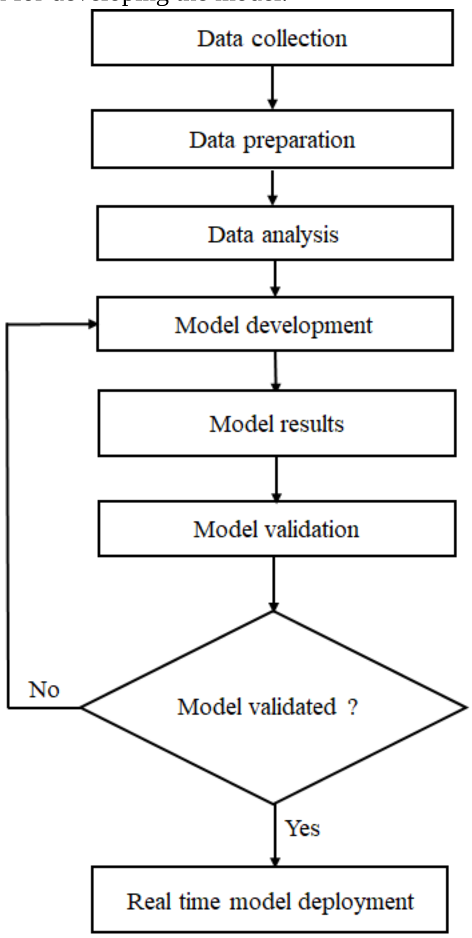


Fig. 3. Model flow diagram.

B. *Data Collection*

As listed in Table 1, Out of the15 bins available (each having capacity of 120 ton)

Retrieval Number: 100.1/ijeat.C21770210321
DOI:10.35940/ijeat.C2177.0210321
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication

in the lime plant at Tata Steel plant, Bin1 and Bin2 are on focus in this study. The same analysis has been done for the rest of the bins.

The data regarding charging and discharging of the respective bins is collected from the physical process using sensor devices (level#1 automation system). Fig. 4 shows the data collection from level#1 to level#2 automation system. The data collected at level#1 using sensor devices is captured in IBA server through PLC devices. It is further sent and stored at 10 seconds frequency in the plant's database (level#2 system of automation) as shown in Fig. 4. From the data-base, data of 4 months period is collected and used in the model for development purpose.

Table-I: List of bin name used in this study

Actual name of the bins	Alias name of the bins
BIN_LVL_PC4_BIN1	Bin1
BIN_LVL_PC4_BIN2	Bin2

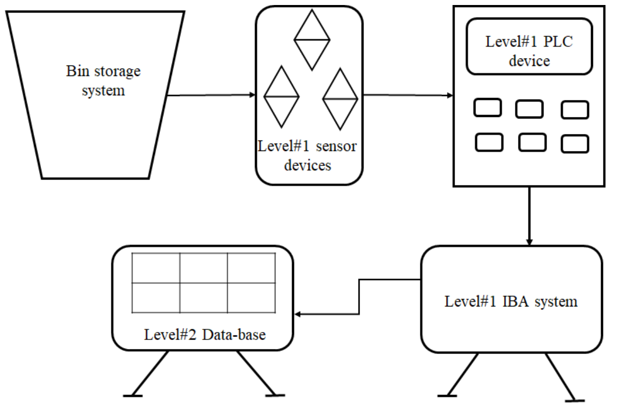


Fig. 4. Data flow diagram in automation system.

C. Data Preparation

Before going for data analysis, the collected data has been made free from any missing and undesired values. Python as a tool has been used to do the cleaning of data. This cleaning of the data is very crucial to remove the undesired fluctuation in data due to sensor's sensitivity.

D. Data Analysis

At this stage, the raw data has been presented in graphical format to figure out the trend inside the data. This helps to understand the charging and discharging trends of the bins. The trend charts for BIN1 and BIN2 have been presented in Fig. 5(a) and Fig. 5(b) respectively.

Fig. 5(a) and Fig. 5(b) shows the bin-level variation of PC4_BIN1 and PC4_BIN2 with their storage time. In other words, these line-graphs show the variation of percentage of calcined-lime available (material level) in the respective bin with time. The up and down trends show the filling of lime into the bin and drawing of lime from the bin respectively. The portion of graph which is almost horizontal (or little variation) shows that there is no material coming in/out from the bin. This whole trend creates different logical layers of lime-material being stored into the bins.

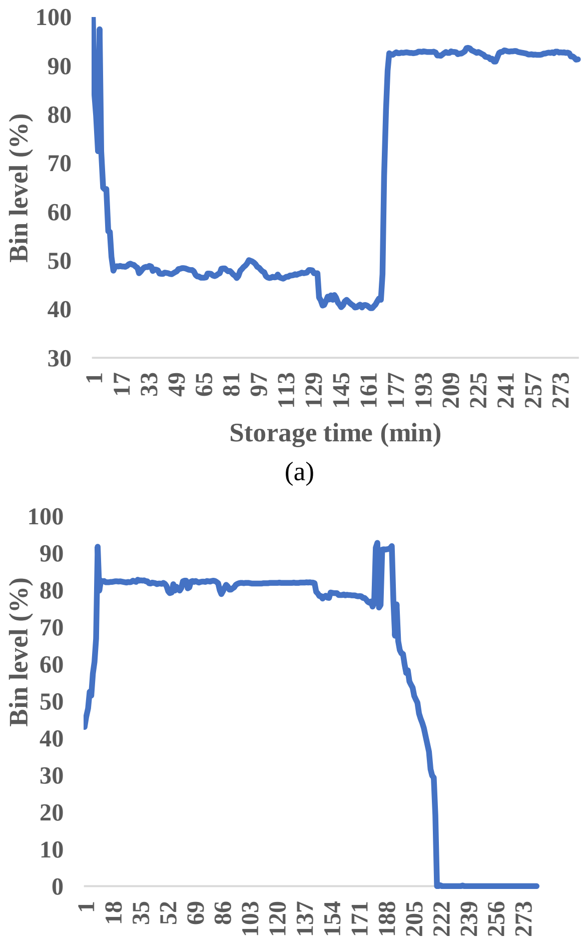


Fig. 5. Bin level variation for (a) PC4_BIN1 and (b) PC4_BIN2.

E. Model Development

Python as a tool has been used to develop the model for this work. Model takes real time plant data for BIN1 and BIN2 from the data-base and then starts processing the results. Hence, the developed model has been integrated with data-base inside level 2 automation system to work in the real-time scenario. Moreover, a HMI (Human-machine-interface) has also been developed to display the model results where user can take action (preferable charging/discharging of bins) as suggested by model.

(a) Assumptions

- Any fluctuations in data due to over sensitivity of sensors is not considered.
- The shape of the bin has been considered cylindrical.

(b) Model development steps

The model has been developed in three stages such as logical layer formation, logical layer tracking and bin preference calculation. These steps have been developed separately in python language and then integrated into the model. Finally, the model has been validated with real-time plant data.

Retrieval Number: 100.1/ijeat.C21770210321
DOI:10.35940/ijeat.C2177.0210321
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication

(b1) Logical layer formation

As it is shown the Fig. 5 under data analysis section that the level of calcined lime stored inside the bins vary with time. This material amount is captured in terms of percentage fraction of total bin's height (H). During charging of bin, material layer is formed inside the bin as shown in Fig. 6. The layer deforms when bin is discharged. The layer formation of material (h_m) inside the bins can vary from bin's bottom-level to top-level. This results into various logical layers (h_l) formation of lime-material during its storage-time (t_s) inside the bins. If the bin is not full, some of its portion can remain empty (h_e). Fig. 6 shows a diagram of bin's height, logical-layer formed during material storage inside the bin.

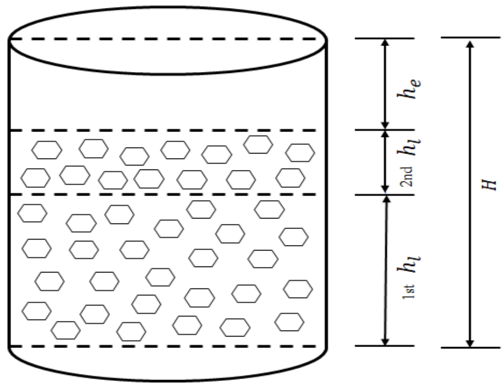


Fig. 6. Layer formation inside the bin.

Below equations describe the condition to form a logical layer based on the percentage variation in material's layer with time. Equation (2) gives the difference between final level of material-layer and initial level of material-layer for any duration of time (Δt). Equation (4) describes the formation of logical layer based on (2) and (3) as shown below:

$$(\Delta h)_{\Delta t} = \left(h_f - h_i\right)_{\Delta t} \tag{2}$$

$$(h_r)_{\Delta t} = \frac{(\Delta h)_{\Delta t}}{H} \tag{3}$$

$$(h_l)_{\Delta t} = \begin{cases} (\Delta h)_{\Delta t} & \text{if } (h_r)_{\Delta t} \geq 0.04 \\ 0 & \text{if } (h_r)_{\Delta t} < 0.04 \end{cases} \tag{4}$$

Here, h_i, h_f and H are initial level of material-layer, final level of material-layer and total height of the bin respectively. Δt denotes the time interval for which material-layer is tracked during bin filling or drawing process. It is noted that the value of Δt as been taken as 0-15 min.

(b2) Logical layer tracking

The logical layer formed by the model for lime-material inside bin is tracked based on the values of h_i and h_f. This tracking gives corresponding layer's thickness Δh during any time interval Δt as explained in (2) earlier.

(b3) Bin preference

It is very crucial to know which bin should be preferred to be charged (loaded with material) or discharged (unloaded) with the lime material for optimizing the storage time. Therefore, it minimises the degradation of lime quality. This aim is fulfilled by logical layer tracking of material layer along with its storage time inside the bin. Eventually, model calculated the preferred bin to charged and discharged.

(b3.1) Bin charging preference

It gives the preference of bin out of BIN1 and BIN2, which should be charged (loaded) first. The preference is decided based on the value of h_e as described in (5).

$$(h_e)_{\triangle t} = \left(H - \sum_{i=1}^{i=n} h_{l_i}\right)_{\triangle t} \tag{5}$$

Here, h_e, H and h_l denotes the empty portion of the bin from top, total height of the bin and thickness of logical layer (material layer). The term i and Δt denote the number of logical layer (of lime material) formed and timer interval of storage (of lime material) respectively. The bin which has larger values of h_e is preferred to be charged (loaded) at first.

(b3.2) Bin discharging preference

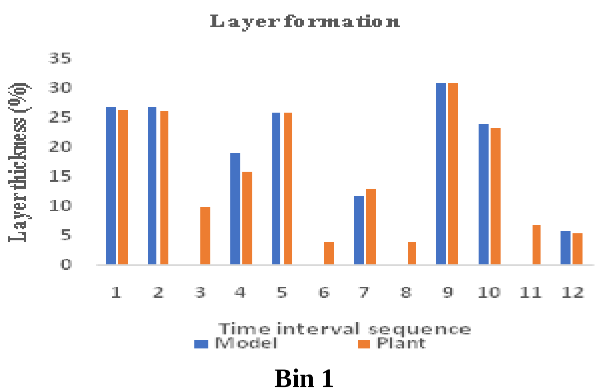
It gives the preference of bin out of BIN1 and BIN2, from which lime material should be discharged (unloaded) first. It is calculated based on storage time after the formation of final level of material layer (h_f) corresponding to the first logical layer (h_{l_1}). It gives the age (layer storage time in terms of hour) of the lime material contained inside the layer. Eventually, the bin with layer containing lime material with maximum age is discharged (unloaded) first.

III. RESULTS AND VALIDATIONS

This section includes the results obtained by the real-time model for BIN1 and BIN2. The results have been presented in three sub-sections as logical layer formation, material layer tracking and bin preference. Logical layer formation and material layer tracking have been validated with real-time plant data. Bin preference given by the model is based on the information about layers inside the bin.

A. Logical layer formation

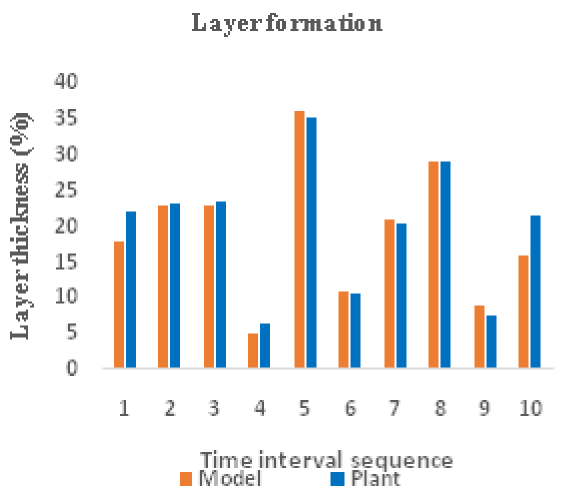
Fig. 7 shows the logical layer formation for bin 1 and 2 with respect to time interval sequence. It is clear that when the layer thickness is 4% or above then a layer has been formed. This represents the number of material-layer formed inside the bins at different time intervals. This result shows the comparative validation study of logical layer formation between model and real-time plant data. The acceptable absolute error of 0.82 and 1.5 has been found between model result and real-time plant result for bin 1 and bin 2 respectively.



Bin 1

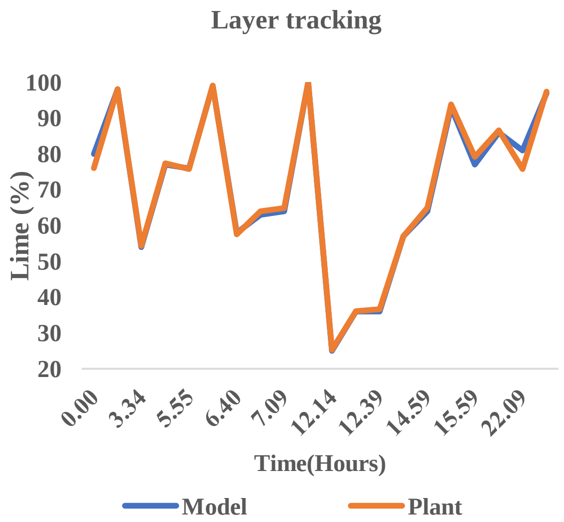
Retrieval Number: 100.1/ijeat.C21770210321
DOI:10.35940/ijeat.C2177.0210321
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication



Bin 2

Fig. 7. Formation of logical layer with time intervals.

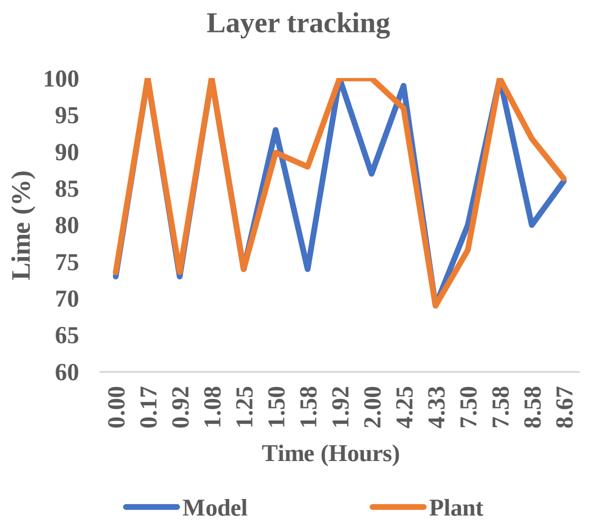


Bin 2

Fig. 8. Material layer tracking with time.

B. Material layer tracking

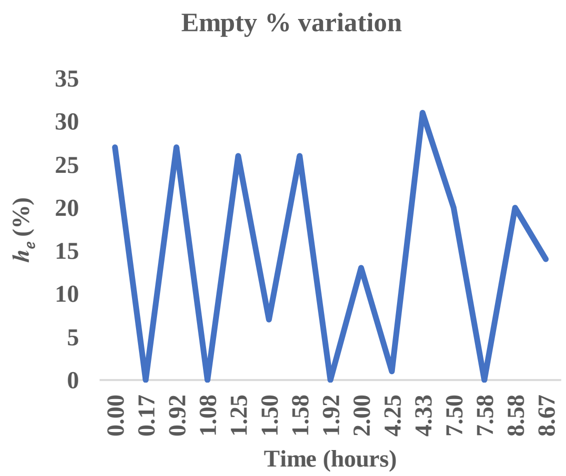
Fig. 8 shows the variation of material layer with time for bin 1 and bin 2. The variation has been plotted for the time when bin was loaded or unloaded. The increasing trend shows the loading (filling of lime) of the bin while decreasing trend shows unloading (drawing of lime) of the bin. This eventually provides the information about percentage of calcined lime available inside the bin at a time. This plot shows the comparative validation of lime percentage between model and real-time plant data. It is noted that there is good match between the results of model and real-time plant data, however, average absolute error of 3.3 and 0.9 has been found between the two for bin 1 and bin 2 respectively.



Bin 1

C. Bin charging preference

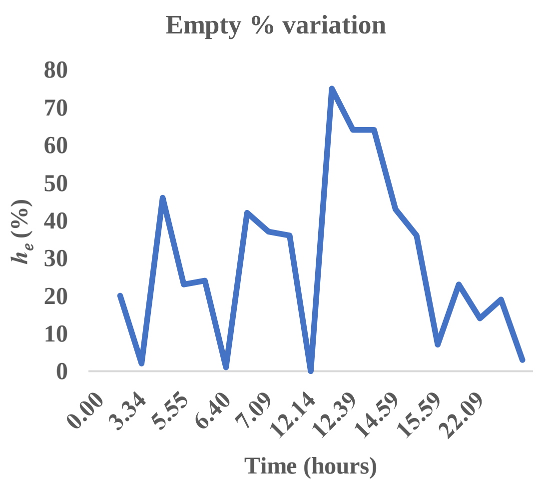
Based on thickness of material layer, presented previously, preference of bin is decided for loading the bin. Fig. 9 shows the percentage portion of the bin which is empty with respect to time. At any time, the bin with highest percentage of empty portion (h_e) has been given the first preference for loading with lime. Below Fig. 9 shows that BIN 1 should be filled first because it has larger empty portion value (h_e) as compared to BIN 2 at the start (t = 0). This decision is very crucial for the effective and optimised storage of lime inside the bin. This eventually reduces the air-slaking inside the bin. Hence, quality of calcined lime is maintained at the desired level.



Bin 1

Retrieval Number: 100.1/ijeat.C21770210321
DOI:10.35940/ijeat.C2177.0210321
Journal Website: www.ijeat.org

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication



Bin 2

Fig. 9. Variation of empty portion of bin with time.

D. Bin discharging preference

Fig.10 shows the preference of bin from which the lime should be drawn at first. It is based on the age of first layer formed inside the respective bins. Bar graph represents the age of first layer until its removal from the bin. It is quite clear that bin 1 has higher age of first layer with respect to bin 2. Hence, bin 1 must be unloaded first.

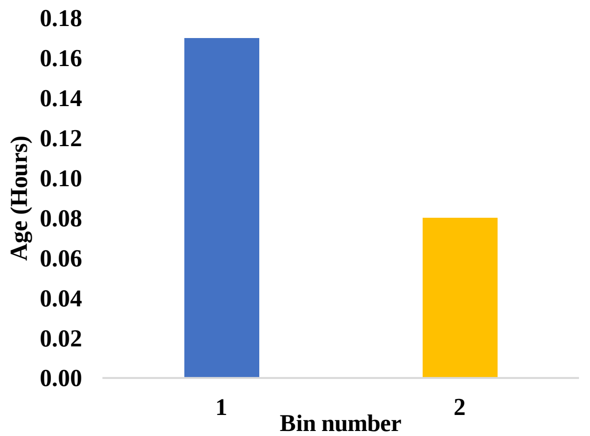
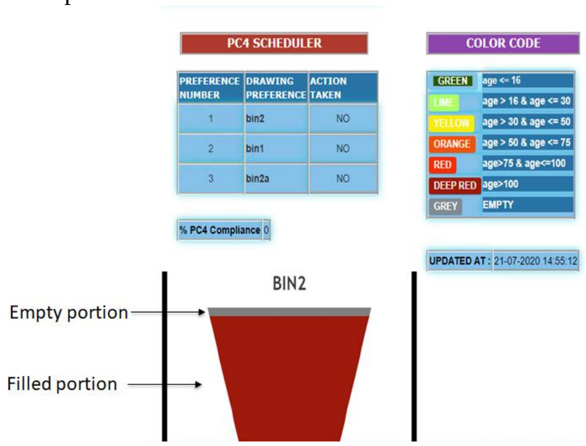


Fig. 10. Age of first layer for bin 1 and bin 2.

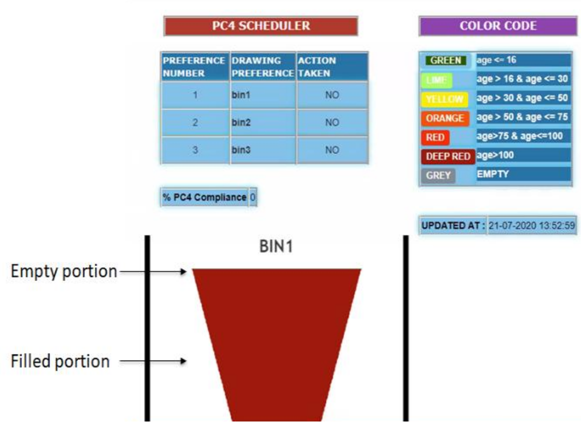
IV. DEVELOPMENT OF HUMAN MACHINE INTERFACE

The above validated model has been deployed in the lime plant at Tata Steel for its use in real-time by the operator as human-machine interface. It gives the platform to the operator to know the live lime-material layer formation, live layer tracking, age of material layer and preference of the bins for loading/unloading. It finally helps the operator to decide which bin should be loaded or unloaded first with calcine lime to optimise the storage time. The human-machine interface (HMI), developed and deployed for filling and drawing of bins, has been shown for demonstration in Fig. 11. Here, the action taken by operator based on the preference given by model is also captured. It is clearly demonstrated in Fig. 11 that bin 2 has been given the first preference to be charged (filled with lime) as it has larger empty portion. On the other hand, bin 1 has been given the first preference to be discharged based on the age (storage time) of layers.

Overall, this model provides a complete solution for bin management in lime plant at Tata Steel. It gives end-to-end layer tracking of calcined lime filled or drawing at the bin station and a decision-making platform for the same. This eventually optimise the storage time of calcined lime inside the respective bins.



(a) Bin charging preference



(b) Bin discharging preference

Fig. 11. Human-machine interface of the model.

V. REAL-TIME INTEGRATION

Finally, the model is integrated with level 2 automation system in real time inside the plant It tracks the charging and discharging of lime material inside the bin. It gives the information about lime-material layer formation (logical layer), layer tracking and bin charging/discharging preference based on age of layers. The model is validated with real time data of the lime plant in Tata Steel (India, Jamshedpur). Moreover, a HMI (Human-machine-interface) has also been developed to make it useful for the user at the plant.

VI. CONCLUSIONS

(1) The model provides an automation system in the plant for controlling the degradation of lime quality inside the bin.

(2) The model is also an advancement in manual practice related to calcined-lime storage management system, which is completely removed and became automated.

(3) Model provides information about the formation of logical layer of calcined lime stored inside the bins when layer thickness is more than 4% with an acceptable absolute error of 3.3 and 0.9 for bin1 and bin 2 respectively.
(4) Logical layers help in distinguishing the lime filled inside bins at different time interval.
(5) Calcined lime charged or discharged at the bin station has been tracked to calculate the variation of material percentage inside the bin. It eventually helps in calculating the material's layer formation inside the bin.
(6) The first layer formed inside the bin and its variation with time combine to conclude the preference of bin to be loaded or unloaded.
(7) Results shows that bin 2 is preferred over bin 1 and bin 1 is preferred over Bin 2 for the charging and discharging respectively.
(8) In past, the operator at plant used to physically visit each bin to check the level of material inside the bin. Development of this model and human-machine interface provides a decision-making platform to the operator to know which bin should be charged (loaded with lime) or discharged (unloaded) first.

ACKNOWLEGEMENT

The authors are highly grateful to the International Journal of Engineering and Advanced Technology for supporting this research work.

REFERENCES

1. Manocha, Sanjeev, and François Ponchon, "Management of Lime in Steel," *Metals*, vol. 8, no. 9, 2018, p. 686., doi:10.3390/met8090686, 2018.
2. Karl-Heinz, "Influence of lime and synthetic lime products on steel production," Journal of the south African institute of mining and metallurgy, 1972.
3. C. J. Lewis & B. B. Crocker, "The Lime Industry's Problem of Airborne Dust," Journal of the Air Pollution Control Association, 19:1, 31-39, DOI: 10.1080/00022470.1969.10466454, 1969
4. Schrama, F. N. H., Beunder, E. M., van den Berg, B., Yang, Y., & Boom, R, "Sulphur removal in ironmaking and oxygen steelmaking," Ironmaking & Steelmaking: processes, products and applications, 44(5), 333-343. https://doi.org/10.1080/03019233.2017.1303914, 2017.
5. Eric L Crump, "Lime Production: Industry Profile," U.S. Environmental Protection Agency. Project Number – 7647-001-020, 2000.
6. M. Hassibi, "Factors Affecting the Quality of Quicklime (CaO)", Chemco systems, L.P., 2002.
7. United State Environmental Protection Agency, "Lime handling systems,"1984.
8. Thoben, K., Wiesner, S., & Wuest, T., "Industrie 4.0 and Smart Manufacturing – A Review of Research Issues and Application Examples," *International Journal of Automation Technology*, *11*(1), 4-16. doi:10.20965/ijat.2017p0004, 2017
9. Hagemoen, S. (n.d.), "An expert system application for lime kiln automation". Conference Record of 1993 Annual Pulp and Paper Industry Technical Conference. doi:10.1109/papcon.1993.255821.
10. Gino Brittante et al., "Automation of multiple kiln plant". World cement, 1997.
11. McPherson, N. A., "Welding automation in shipbuilding and influence of materials," Ironmaking & Steelmaking, 39(7),483–486. https://doi.org/10.1179/0301923312z.000000000130, 2012.
12. Lundberg, "Rock drill steel rolling in fully automatic bar mill," Ironmaking & Steelmaking, 26(2), 99–110. https://doi.org/10.1179/030192399676979, 1999.

AUTHORS PROFILE

Vipul Kumar Tiwari, Technologist, Automation Division, Tata Steel, Jamshedpur, 831001, India E-mail: vipul.tiwari1@tatasteel.com
Mob: 9262691920

Kumar Gaurav, Technologist, Automation Division, Tata Steel, Jamshedpur, 831001, India E-mail: kumar.gaurav6@ tatasteel.com

Umesh Kumar Singh, Principal Technologist, Automation Division, Tata Steel, Jamshedpur, 831001, India E-mail: umesh.singh1@tatasteel.com

Jose Martin Korath, Chief (ISMM), Automation Division, Tata Steel, Jamshedpur, 831001, India
E-mail: jose.korath@tatasteel.com

Manish Kumar Singh, Chief (One IT), Automation Division, Tata Steel, Jamshedpur, 831001, India E-mail: manishk.singh@tatasteel.com

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication