



In order to take care of this issue, modern day Sinter Plants are equipped with mathematical model based raw mix optimization systems with closed loop controls. The purpose of these types of model is to generate a raw mix composition with the objective to achieve automatically the assigned target values of total Fe (iron) content, sinter basicity, coke breeze addition, silica content etc. Now-a-day a hybrid of mathematical model based raw mix optimization systems with expert systems are implemented with closed loop control.

Generally, two types of calculation methods are used in these types of models. One method is known as “Backward Calculation”. Here the system calculates the set points of raw material to achieve the desired chemical composition of sinter. The optimization of raw mix is done to achieve various targets like desired total Fe content, desired basicity, desired SiO<sub>2</sub> & MgO in output sinter etc. or combination of all these set-points. The objective of this model is to keep the sinter quality as consistent as possible and optimizes the material costs.

Another type of calculation method, known as “Forward Calculation” does the opposite of what is mentioned previously. It takes the input of the chemical composition of the raw materials and then calculates the chemical composition of the output sinter. This type of model takes the charge mix ratio from Level-1 system directly from raw mix bunkers and based on the material ratio calculates the chemical composition of the sinter. A combination of both the models is employed in tandem to control the output sinter quality in majority of sinter plants.

### III. ORE BED DISTRIBUTION MODEL

This type of models creates a 3-dimensional graphics of the ore bed in computer. It takes into account the bulk density of the raw materials, angle of repose etc. along with the volume of raw mix per stacking step to generate the figure in computer. The real time bed distribution model is generated based on the real time data from Level-1 devices like nature of the material, position of the charging weigh feeders, feed rate and quantity of materials.

### IV. MODEL BASED OPTIMIZATION OF SINTER MIX PERMEABILITY

The permeability of sinter bed is an important factor that determines the productivity of sinter machine. In sintering process, the top layer of sinter bed is ignited with burners. The flame front descends down the sinter bed under application of suction until the entire mass of material has been converted into a porous but physically strong block of sinter. This agglomerate is then crushed, screened and then fed directly to the blast furnace.

Thus, the productivity largely depends upon i) the suction under grate and ii) the permeability of charge mix. Generally moisture is added to sinter mix to facilitate the process. If the moisture content is high, it significantly reduces the permeability of sinter mix where the water blocks the inter-particle space of the sinter mix.

Too low moisture also results in significant drop of permeability because iron ore fines blocks the air passage between the spaces between the large particles. Generally permeability – moisture graphs are parabolic in nature, passing through a maximum at the point where the moisture is optimum. It was found during various laboratory experiments and literature that 1 % deviation of moisture from optimum, leads to 10% drop in sinter productivity. Hence precise control of water addition is very important to achieve higher productivity.

Previously, determining optimum moisture of sinter mix was totally based on the operator’s perception, which varies from operator to operator. More over the control of water flow was also done manually which makes the process more tedious and needs constant monitoring because the nature of charge itself varies constantly.

Considering above problems and the importance of optimum permeability in sinter making, a mathematical model based automatic permeability optimization system by online dynamic moisture control was developed by Research & Development Centre of Iron & Steel (RDCIS), the corporate research wing of SAIL and implemented at various steel plants of SAIL. Taking various signals from Level-I systems like feed rate, bunker weight, % moisture, water flow rate etc. as input, the mathematical model calculates the permeability of green charge mix and based on the estimated permeability value and the water being added, the working point on the parabolic relation of permeability and moisture is estimated.

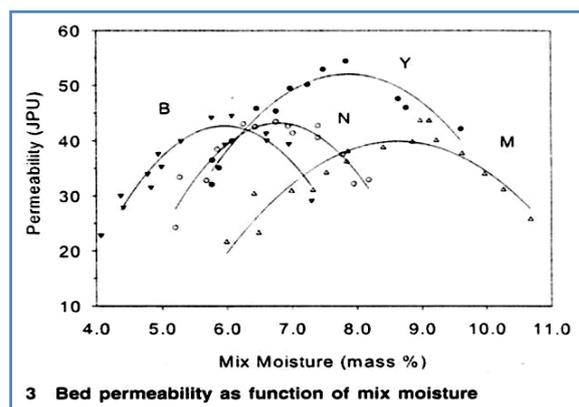


Fig. 2: Bed permeability as a function of raw mix moisture <sup>[2]</sup>

The existing permeability is estimated in charged raw mix bunker by considering the flow rate of compressed air which is coming through a pipe into the charging hopper and the back pressure developed due to hindrance posted by the raw material mixture to the air flow inside the hopper. The flow rate and back pressure of air are measured by flow and pressure transmitters installed in the air line. Height of the charge mix in the bunker and the average area are calculated using the load cell signal at regular intervals. The Programmable Logic Controllers collect those data from these transmitters and sent it to the mathematical model based permeability control system resident in PC. Taking those various signals as input, the mathematical model calculates the permeability of green

charge mix and based on the estimated permeability value and the water being added, the working point on the parabolic relation of permeability and moisture is estimated.

#### A. Working of Mathematical Model

Bed permeability is generally predicted mathematically with the following widely popular Equation no. 1 [2]

$$JPU = \frac{F}{A} \left( \frac{L}{\Delta P} \right)^{0.6} \quad \text{Eq. 1}$$

Where F=air flow rate (m<sup>3</sup>/ min), A=cross sectional area of the bed (m<sup>2</sup>), L=height of the bed (mm) and ΔP=pressure drop across the bed (mm H<sub>2</sub>O).

But considering the frequent variations in raw material quality and highly dynamic surrounding conditions, the real challenge is to determine the exact position of bed permeability in permeability-charge mix moisture curve. In mathematical model calculates the relative permeability at regular intervals and is compared with previous permeability value to determine the optimum moisture level. For example, the model first increases the water flow and then finds out whether permeability value of a given sinter mix has shown an improvement or not. If the permeability improves further, the model will keep on increasing the water flow at every iteration, until any further increase results in decrease in permeability value of that sinter mix. This is how the optimum permeability is achieved by the intelligent model. The model gives the set-point of the water flow rate and the system controls accordingly to maintain the permeability of sinter mix in the maximum point at real-time.

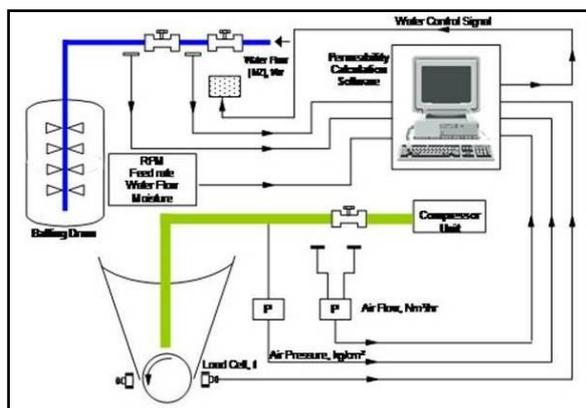


Fig. 3 : General arrangement of intelligent permeability measurement and water control system [3]

With any variation in raw material, the model again compares the new permeability values with old and repeats the same exercise to attain the new optimum point. This enables the system to take corrective actions dynamically based on real-time conditions which was earlier impossible to be done manually [4].

Now-a-day, ANN based data driven models are also used to determining the correct water flow set-points to achieve the optimum permeability. Moreover recently hybrid models, which are amalgamation of black box models like

ANN etc. and traditional mathematical models are used for getting better results.

### V. MODEL BASED BURN-THROUGH-POINT PREDICTION

The Burn-through-point is a very important parameter of sintering process. It's the point in the sinter strand along the length of sinter palette where the total sintering process is complete. This point is determined by measuring the temperature of flue gas, which is maximum at the burn-through-point. It signifies that at this point the whole raw material is converted to sinter. The faster burn-through-point is achieved, the higher will be the productivity.

Now-a-day mathematical models are increasingly used to determine the burn-through-point based on the input raw materials. These models considers the input parameters, permeability of sinter bed, waste gas data etc. to predict the burn-through-point in real-time. The controllers with the help of model prediction take corrective action and control the machine speed accordingly to get higher productivity.

Artificial Neural Networks are very popular modelling tool for predicting the BTP. Many new models are increasingly using ANN for predicting the BTP for particular sinter machine. But there are some problems associated with such type of techniques like during training process, there exist the problems of local minima, slow convergence, and that the network is difficult to determine the number of hidden layer and so on. These shortcomings at times limit the application of such techniques. It has been observed that Statistical Learning Theory (SLT) is a possible solution to this problem The Bayesian theory have found wider acceptance and can deal with inaccurate or incomplete knowledge and redundant information .The Bayesian theory can use the sample information and prior knowledge, and simplify forecasting model, optimization parameters etc. to predict the BTP of the sinter in the highly dynamic scenario.

### VI. MODEL FOR SINTER PROCESS

The objective of sinter machine operator is to position the BTP close to end of the strand. If the sintering is complete much before the end of strand, and then due to suction, there is a chance that the hot sinter gets cooled due to passage of ambient air through the sinter bed. So, in such cases, the operators generally increase the machine speed so that the BTP falls at the end of the strand.

Again, if the machine speed is too fast, there is a chance that before the completion of sintering, the un-sintered sinter mix falls at the discharge end. In both ways, there is a significant reduction in productivity achieved. Hence, it is very important to model the sintering process to optimize the machine speed based on different parameters of sintering process like suction, line speed, water flow, raw material composition etc. [5]

Now-a-day modeling has helped significantly in simulating various processes associated with sintering processes. These types of models employ traditional

mathematical relations along with non-traditional tools like ANN, Genetic Algorithms, Statistical analysis etc. to visualize the sintering process and taking decision regarding machine speed, permeability etc. to increase productivity and enhancing quality of output sinter. These models predict the Burn-Through-Time (BTT) and accordingly control the machine speed with the help of PLCs. They are not only fast but take real-time decision which is impossible to think of in earlier sinter plants.

## VII. CONCLUSION

The sinter process control is now not based on perception of operators but on more scientific and accurate method. Moreover the calculation of permeability, BTP, BTT etc. and accordingly control of moisture, machine speed, suction etc. are a real-time and continuous process which minimizes the need of continuous monitoring by the operators. The system itself takes care of change in nature of charge mix (granulometry of sinter mix, % of return sinter etc.) and controls the various parameters accordingly to get the optimum productivity & quality. These types of systems are very much operator friendly with easily comprehensible GUI showing all the important parameters with excellent & informative trends on the screen with an equally fast PLC that enables the system to finely control various parameters in real-time. With better decision making & control, process of sintering becomes much efficient & faster resulting in higher productivity and lower consumption of coke breeze.

The intelligent mathematical model based control systems not only provide a better way of controlling the highly complex process but also control the system in a logical & scientific way. These intelligent systems make the process less dependent on the experience & expertise of the operator. The PLC based system ensures the control more accurate which results in highly productive, efficient & environment friendly sintering process.

## ACKNOWLEDGMENT

We gratefully acknowledge the valuable help and support received from various sinter plants of SAIL for their extensive help & sharing of information. The authors also like to thank the support from the management of Research and Development Centre for Iron and Steel (RDCIS).

## REFERENCES

- [1] [http://www.csc.com.tw/csc\\_e/pd/prs02.htm](http://www.csc.com.tw/csc_e/pd/prs02.htm)
- [2] "Effect of ore properties on sinter bed permeability and strength", by B. G. Ellis, C. E. Loo and D. Witchard: Ironmaking and Steelmaking, 2007, 34, 99-108.
- [3] "An Intelligent Permeability Optimization System at Sinter Plant of Rourkela Steel Plant", Ayan Goswami, V T Selvan, Sanjay Kumar, MK Singh & D Muralimohan [www.interscience.in/IJARME\\_Vol3Iss2/52-55.pdf](http://www.interscience.in/IJARME_Vol3Iss2/52-55.pdf)
- [4] "An automatic on-line sinter mix permeability control device for increasing the productivity of sinter machine in steel plants" Patent No. 199446 (7th July 2006).
- [5] "Latest generation sinter process optimization system", Thomas Kronberger, Martin Schaler and Christoph Schöneegger, [www.intechopen.com/download/pdf/33160](http://www.intechopen.com/download/pdf/33160)