Iron Making and Steel Making
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Module – 05
Lecture – 24
Modeling of Blast Furnace

In this lecture, I will talk about the Modelling of Blast Furnace briefly.

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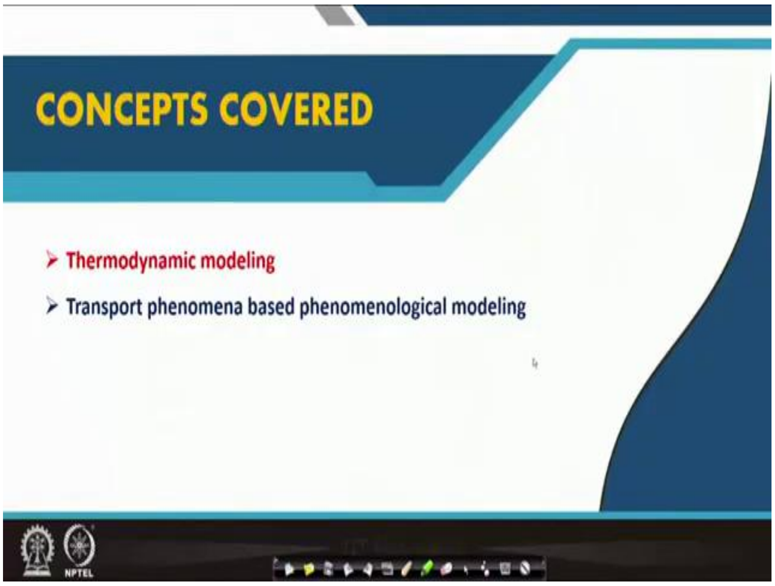

Two types of model exists: the thermodynamic modelling and the transport phenomena based phenomenological modelling. Some of the modelling studies have been done already; and I will cite some of these.

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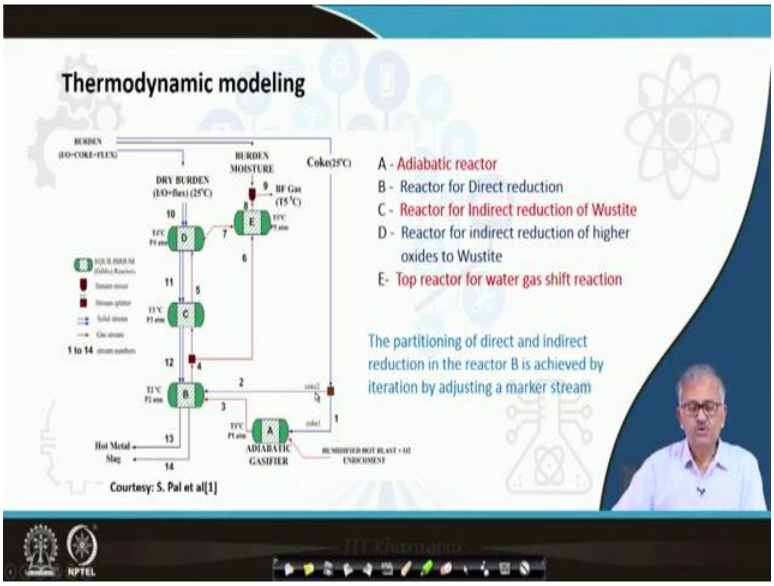

First, let us talk about the thermodynamic modelling. Here the reactor is assumed in thermodynamic equilibrium and then some thermodynamic database like Factsage may be applied to calculate the final temperature, pressure and the phase constituents at equilibrium. So, basically thermodynamic model can capture the saturation level of the products and it does not consider about the kinetics of the process like how the phases evolves with time or interaction between the phases; and whether the phases will attain thermal or chemical equilibrium or not during the process; it does not consider all this things.

In order to make thermodynamic model more realistic thermodynamic model usually divides the whole reactor into several smaller units in series, which are assumed to be in thermodynamic equilibrium; and subsequently all smaller thermodynamic reactors are connected through solid/gas/liquid streams from adjacent reactors. Sometimes some splitting of stream, or bypass of stream is done to account for deviation from equilibrium. This is called the multi zone thermodynamic model. Now, I will give an example of multi zone thermodynamic model for the blast furnace. The blast furnace is considered as 5 equilibrium reactors connected through solid and gaseous streams (see Fig. 23.1).

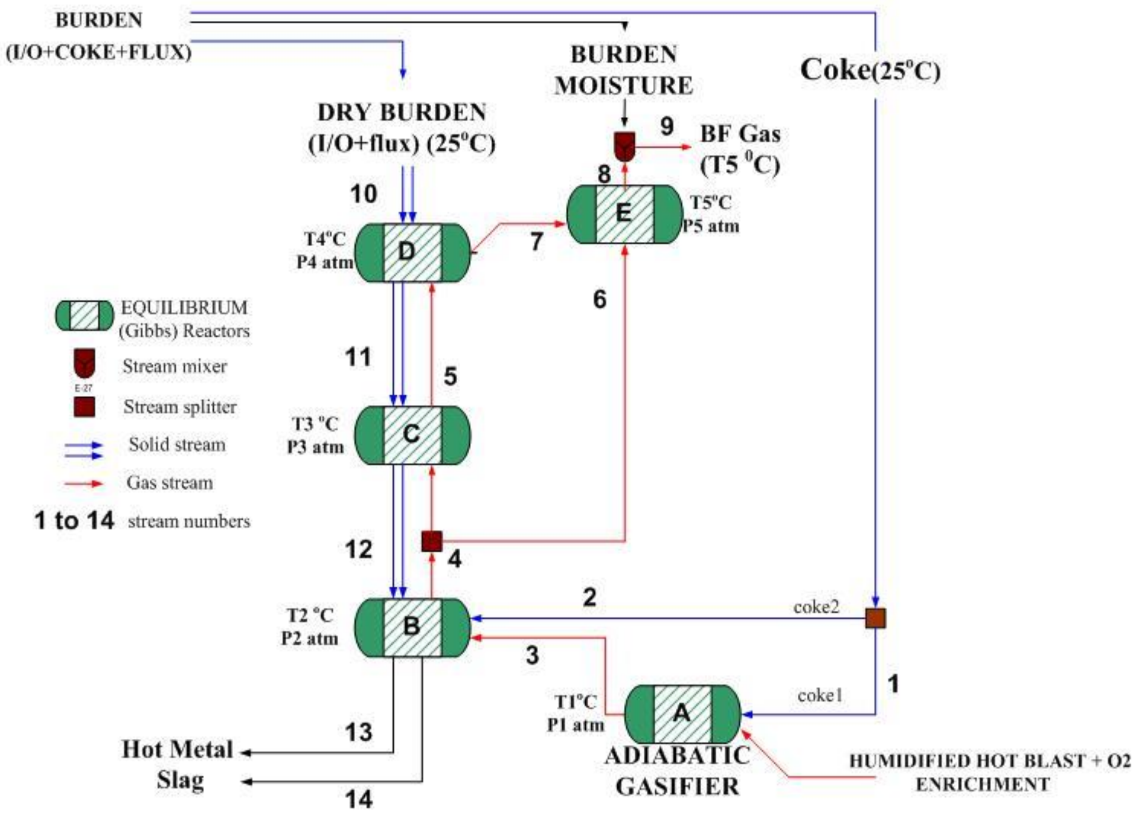

Figure 24.1: Pictorial representation of blast furnace as five equilibrium reactors connected through solid and gaseous streams[1]

Finally, you can predict the final product compositions like hot metal composition, slag composition, exit gas composition, coke rate.

Now, first let us discuss the five thermodynamic reactors. Reactor "A" represents an adiabatic gassifier. A part of the coke (coke 1) enters to the gasifier at 25°C and equilibriated with humidified and oxygen enriched air blast. The product gas $H_2/CO/N_2$ (equations 24.1 to 24.2) leaves at temperature, and pressure of T_1°C and P_1 atm, respectively and enters the reactor B (direct reduction reactor).

$$C + \frac{1}{2}O_2 = CO \tag{24.1}$$

$$H_2O + C = CO + H_2 \tag{24.2}$$

Rest of the coke (coke2) at 25^{o}C directly enters into the reactor B. Another solid stream that enters the reactor B is the solid output from reactor C at temperature T_3 ^{o}C (reactor for indirect reduction of wustite). The output from reactor C will constitute the fraction of wustite that remains to be reduced by direct reduction and ore gangue, and flux. The direct reductions in reactor B is represented by equations 24.3-24.5.

$$FeO + C = Fe + CO \tag{24.3}$$

$$SiO_2 + 2C = Si + 2CO \tag{24.4}$$

$$MnO + C = Mn + CO \tag{24.5}$$

$$P_2O_5 + 5C = 2P + 5CO \tag{24.6}$$

Also partitioning of impurities takes place between liquid slag and metal. The two output liquid streams from this reactor is liquid metal and liquid slag.

The gaseous output from reactor B (H_2/CO/N_2) at temperature and pressure T_2 ^{o}C and P_2 atm, respectively partially joins the Reactor C that also receives a solid stream of wustite, gangue and flux at temperature T_4 ^{o}C from reactor D (reduction reactor for higher oxides). In reactor C solid get preheated as well as wustite partially get reduced indirectly using the CO from reactor B. It may be noted here that all the reducing gas generated at the reactor B is not allowed to be equilibriated in reactor C, because in reality all CO/H_2 could not be utilized for indirect reduction of wustite due to kinetic limitation. To take care of this deviation from equilibrium, CO/H_2 generated in reactor B is partially allowed to by pass the reactor C and directly join the reactor E where the final exit gas composition is obtained by mixing gas from reactor D, bypass gas and the ore moisture. Besides solid preheating the major reaction in the reactor C is given by equation (24.7).

$$FeO + CO = Fe + CO_2$$

(24.7)

So output gas from C also contains CO_2. The output gas stream from reactor C ($CO/CO_2/N_2$) at T_3 ^oC joins the reactor D that also receive the solid stream that constitutes the dry burden containing hematite, ore gangue and flux at 25 ^oC. Here, solid get preheated to temperature T_4 ^oC and hematite reduced to Wustite via magnetite (equation 24.8-24.9).

$$3Fe_2O_3 + CO = 2Fe_3O_4 + CO_2$$

(24.8)

$$Fe_3O_4 + CO = 3FeO + CO_2$$

(24.9)

Ore moisture at 25 ^oC joins the reactor E along with bypass gas from reactor B at temperature and pressure T_2 ^oC and P_2 atm, respectively and the output $CO/CO_2/H_2/N_2$ from reactor D. The major reaction in this reactor is the water gas shift reaction, given by equation 24.10.

$$H_2O + CO = H_2 + CO_2$$

(24.10)

In this model we have used two splitter. One at coke partitioning between the gasifier (A) and the direct reduction reactor (B) and the second is partial bypassing of gas from reactor B to reactor E directly. The second splitting is done based on plant data called the shaft efficiency, which is defined as the ratio of fraction of (CO_2 + H_2O) in the gas mixture excluding nitrogen, in the actual plant practice to that of equilibrium value. It is found to be 70%. The former coke spiting is done based on some solid stream marker. Here it is decided based on moles of metallic iron obtained from reactor B. Amount of coke in reactor B (Coke 2) is decided when the metallic iron produced in reactor B equals to the total iron input through hematite, or twice the moles of Fe_2O_3 charged.

So, this is a simple thermodynamic model and it can be further be complicated, but it is based on the work of the Soumavo Pal and archived as M Tech thesis at IIT, Kharagpur[1].

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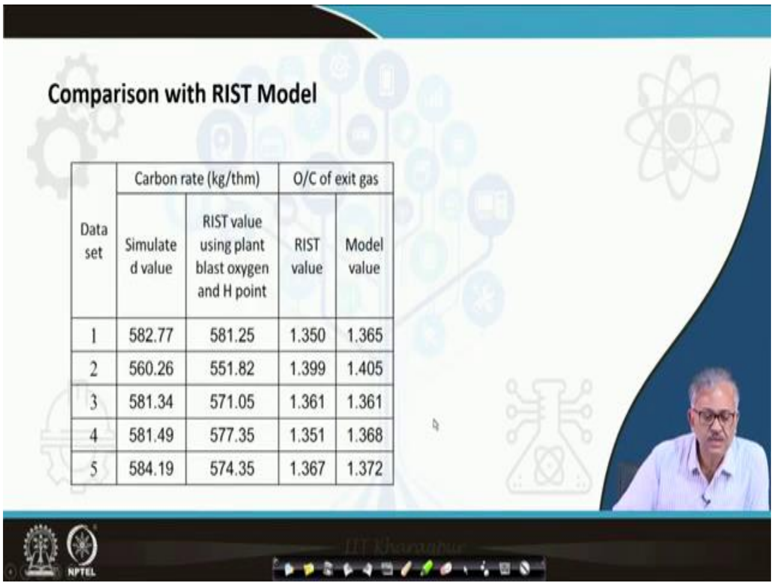

Table 24.1 shows the comparison of the calculated value of coke rate and exit gas composition with those estimated through RIST model using plant data, namely the blast oxygen and heat demand. A close match is observed.

Table 24.1 Comparison between calculated values and the estimated value using RIST model based on plant data.

Data set	Carbon rate (kg/thm)		O/C of exit gas	
	Simulated value	RIST value using plant blast oxygen and H point	RIST value	Model value
1	582.77	581.25	1.350	1.365
2	560.26	551.82	1.399	1.405
3	581.34	571.05	1.361	1.361
4	581.49	577.35	1.351	1.368
5	584.19	574.35	1.367	1.372

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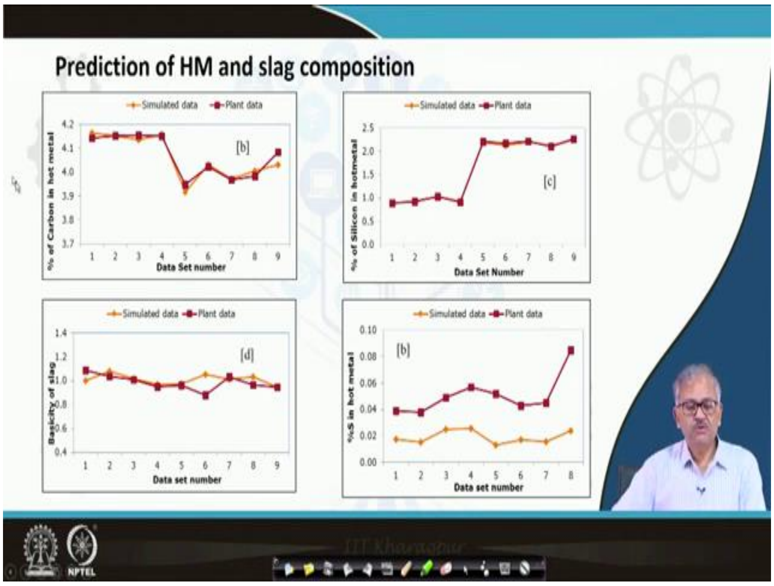

Fig. 24.1 to 24.3 show the comparison of model predicted metal and slag composition to that of plant data. Percentage of carbon and silicon in hot metal is compared with plant data in Figure 24.1 and Figure 24.2, respectively and a close match are observed. Similarly slag basicity is compared in Figure 24.3 and there also good match is observed.

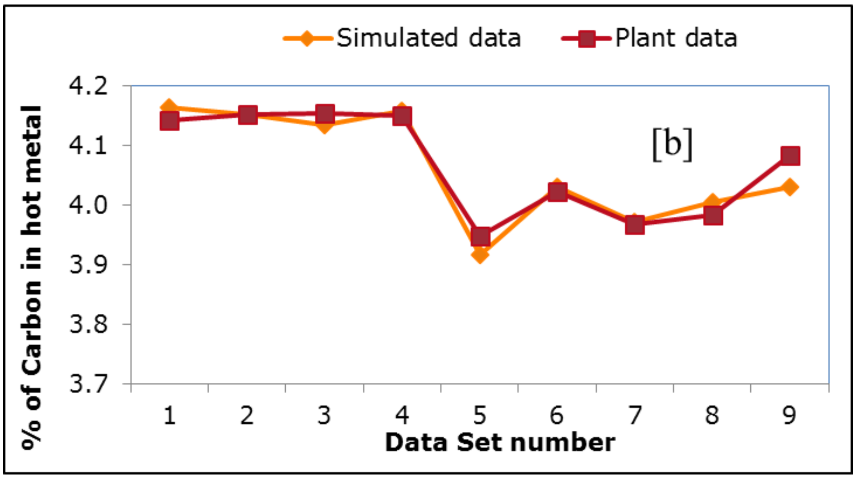

Figure 24.1: Comparison of %C in hot metal with several plant data

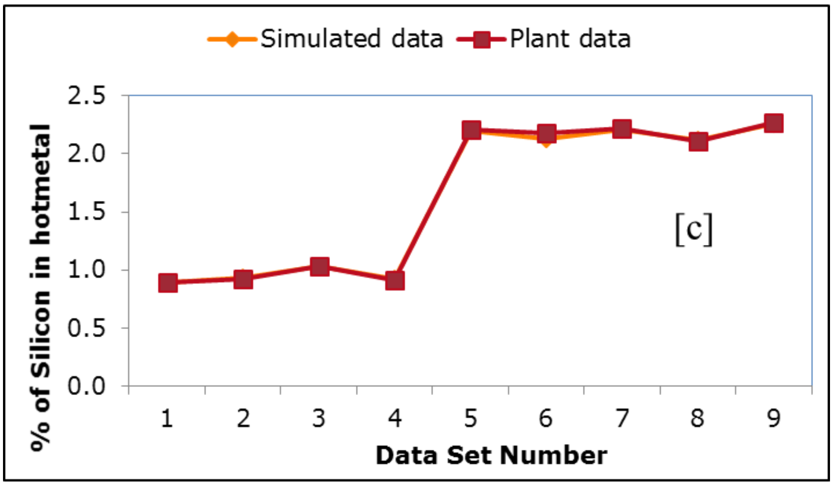

Figure 24.2: Comparison of %Si in hot metal with several plant data

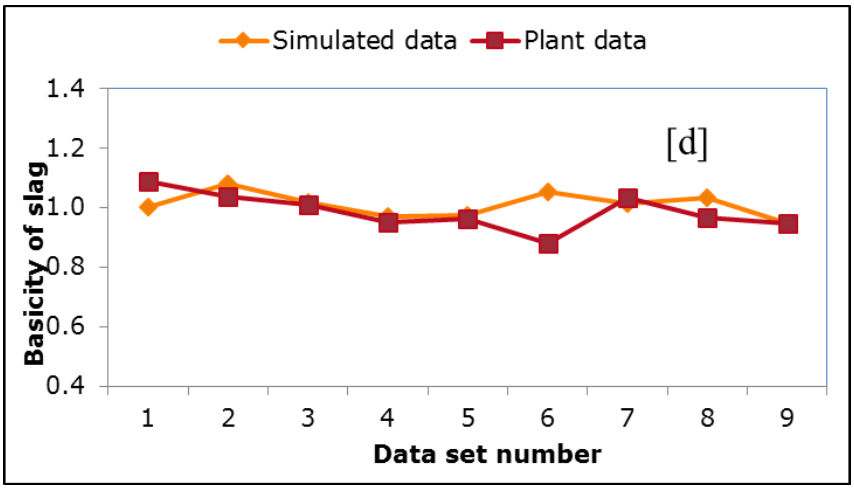

Figure 24.3: Comparison of basicity of slag with several plant data

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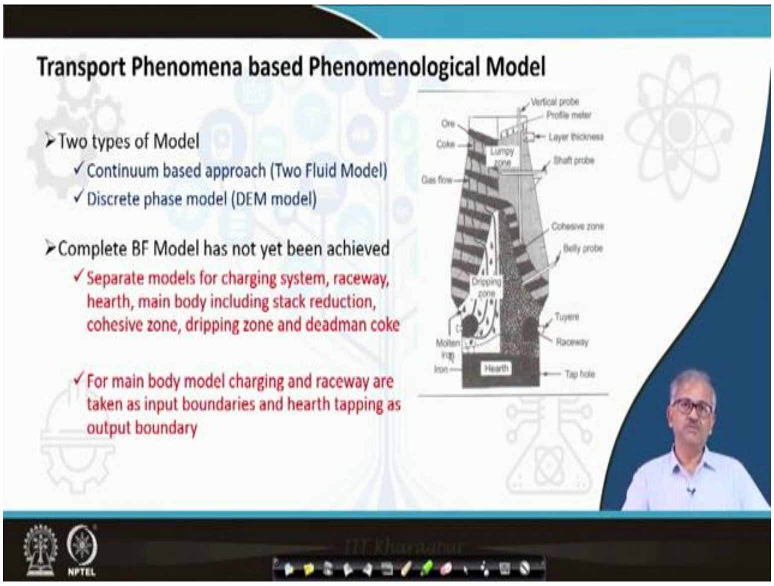
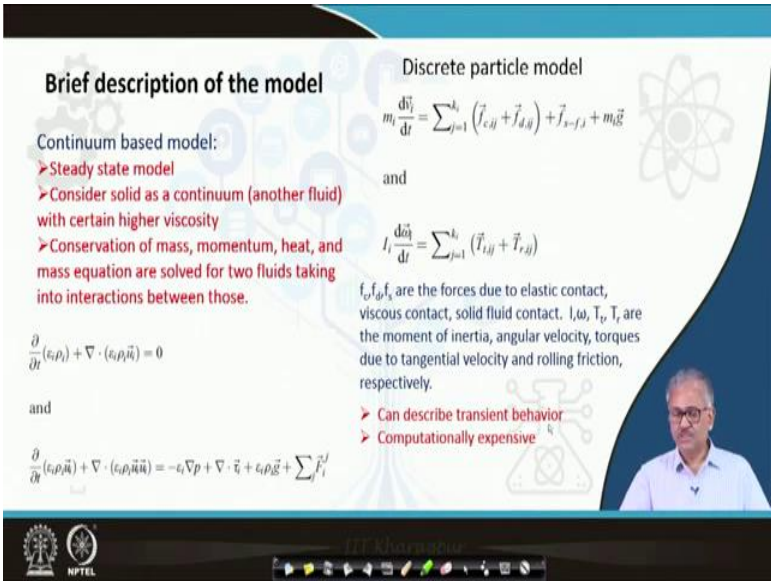


Now, let us discuss some transport phenomena based models. There are two types of models. One is continuum based approach and another is discrete phase model. In case of continuum model all solid phases namely coke, iron ore, flux are considered as a one continuum phase and it is treated as a pseudo-single fluid with a higher viscosity. The gas phase may be considered as another fluid. It will form a two fluid model. There can be three fluid model too if coke is treated as another separate fluid.

In discrete phase model each individual particles are treated as single entity and their locus are traced during the simulation; and their mutual interaction are taken into consideration in the model. Discrete Element Method (DEM) in commercial software, Fluent, is usually used to simulate discrete phase model.

Various zones of blast furnace have also been modelled separately. For example, race way, hearth and charging system, main body of blast furnace have been modelled separately. Main body modelling includes the granular zone, cohesive zone, dripping zone. For main body modelling, stock profile, gas inlet are used as inputs. (Refer Slide Time: 18:32)



Continuum based model are steady state model and consider solid as a fluid of higher viscosity; and. conservation equations for momentum, heat and mass for two or three fluids are solved considering interaction between them.

In discrete phase model, momentum balance is done on each and every particles separately. Force balance on the particles can be defined by Newton's second law of motion. Such model exhibits transit behaviour but computationally expensive. Because force balance is done on each particle; and then if there are billions of particles, it becomes computationally very expensive .

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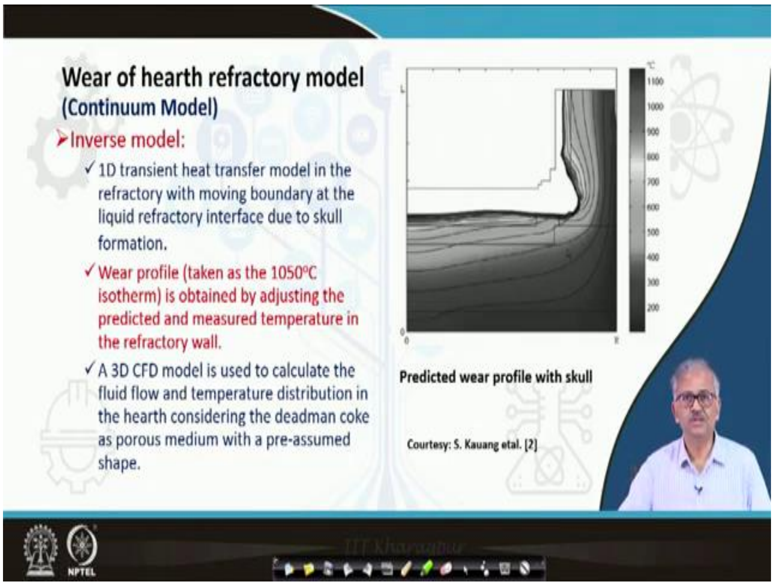

And, now I will just give some examples. Model for wear of refractory hearth. It can be solved by CFD model in the hearth including the refractory brick. Temperatures are recorded at different depths of the refractory wall and finally the wear lining on the surface of the refractory is estimated by matching the model predicted temperature in the brick lining with the experimentally measured temperature using thermocouples. This is called the inverse modelling because we calculate the input conditions by matching the output attributes from experiments and model. The solid liquid interface at the refractory is identified by the 1050ºC isotherm that is the solidus of the Fe-C system. However this interface actually represent the skull liquid interface rather than the refractory liquid interface. But since the thermal conductivity of skull is much lower compared to carbon refractory, isotherms are likely to be finer in the skull than those in carbon brick. Such transition helps to identify the exact surface contour on the refractory (see Figure 24.4).

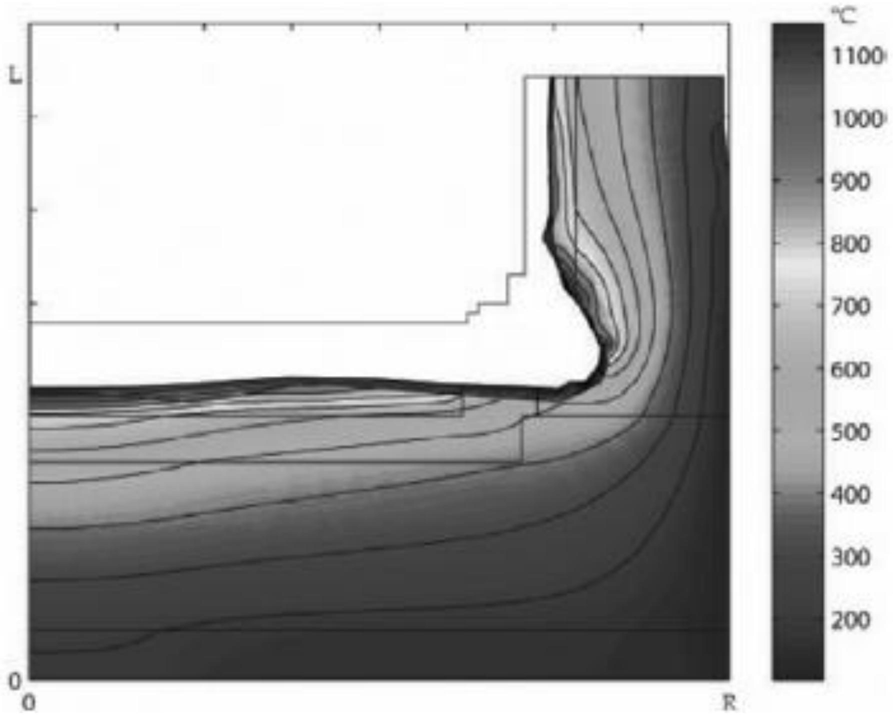

Figure 24.4 Predicted wear profile with skull [2]

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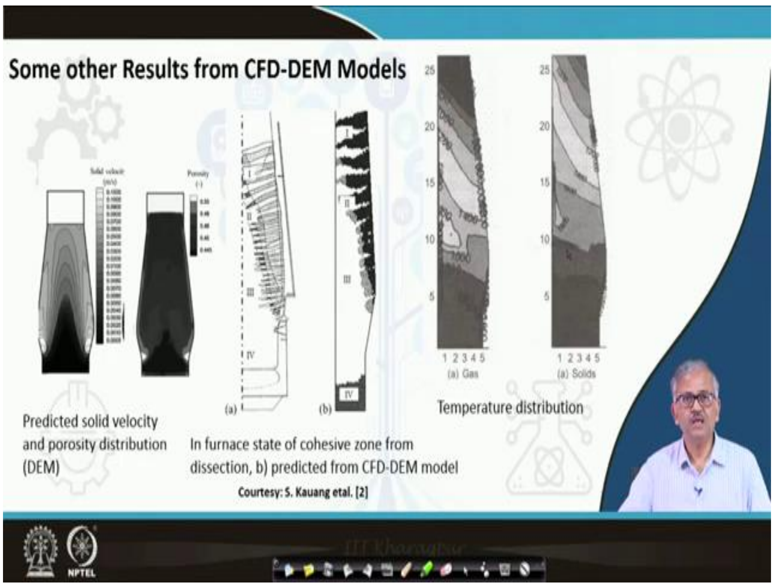

Figure 24.5 shows the predicted temperature profiles for gas and solid obtained from the continuum model. Figure 24.6 shows the predicted solid velocity generated by the discrete element model (DEM). Figure 24.5 show the experimentally estimated cohesive zone vis a vis predicted by the discrete phase model.

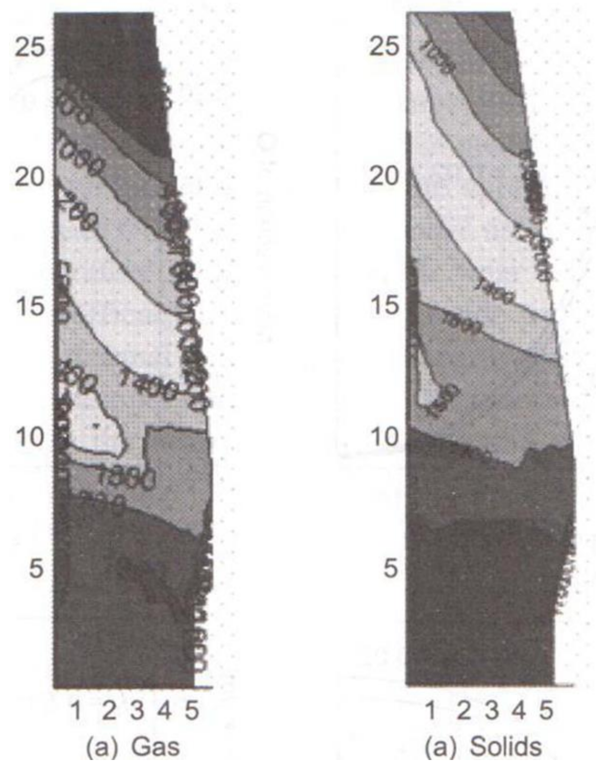

Figure 24.5: Temperature distribution of gas and solid predicted by continuum model[2]

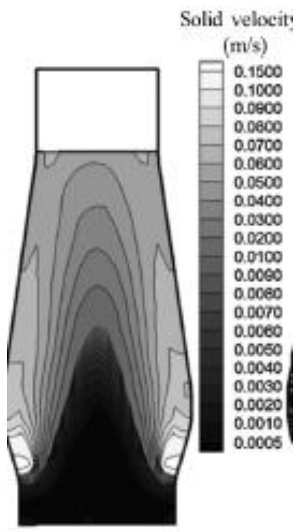

Figure 24.6 Predicted solid velocity profile by DEM[2]

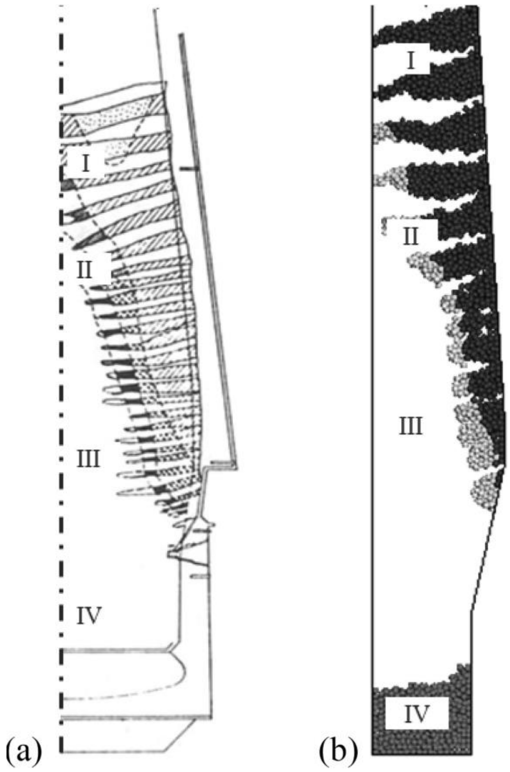

Figure 24.7: In furnace state of cohesive zone from dissection, b) predicted from CFD-DEM model[2]

The figure 24.7 (a) shows the dissection of cohesive zone by freezing laboratory scale blast furnace at LKAB, Sweden, by liquid nitrogen. Figure 27(b) shows the predicted cohesive zone, where the softened zone is indicated by white region.

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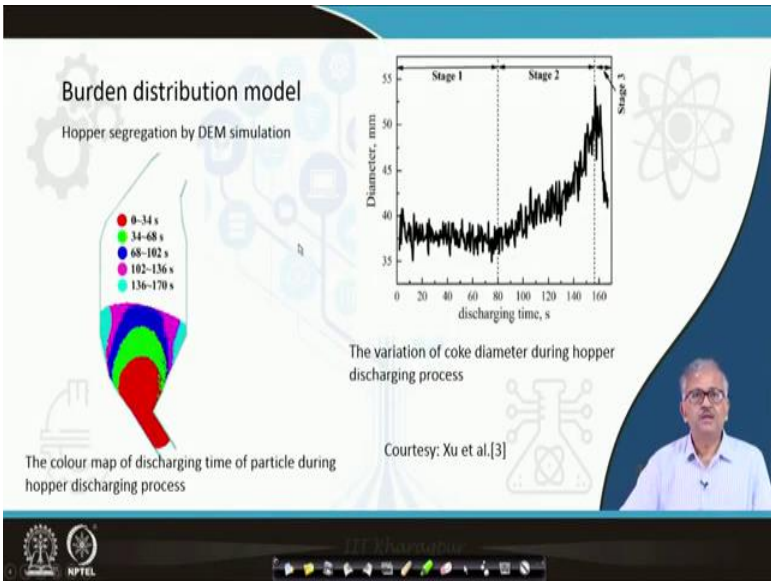

Figure 24.8 shows the colour map of discharging time during hopper discharge process in bell less top charging as predicted by DEM model. Since particles segregates in the hopper, particles will emerge with a size segregation. Figure 24.9 shows the variation of coke diameter during discharging. It shows smaller diameter particles will emerge during first 80 seconds (stage 1); and in the second stage (time from 80 secs to 160 secs) the size of the emitted particles will increase progressively from 40 mm to 55 mm. And finally at the 3rd stage, particle size progressively decreases with time again.

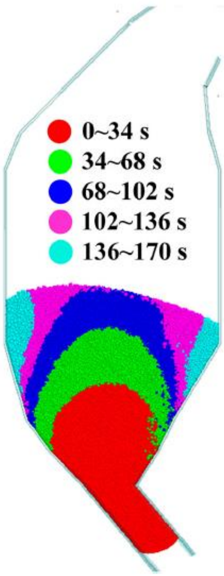

Figure 24.8: The colour map of discharging time of particle during hopper discharging process[3]

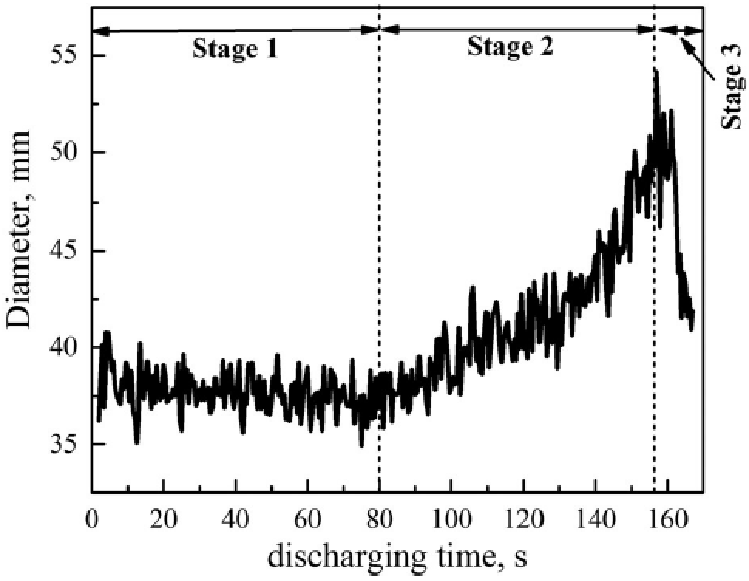

Figure 24.9: The variation of coke diameter during hopper discharging process[3]

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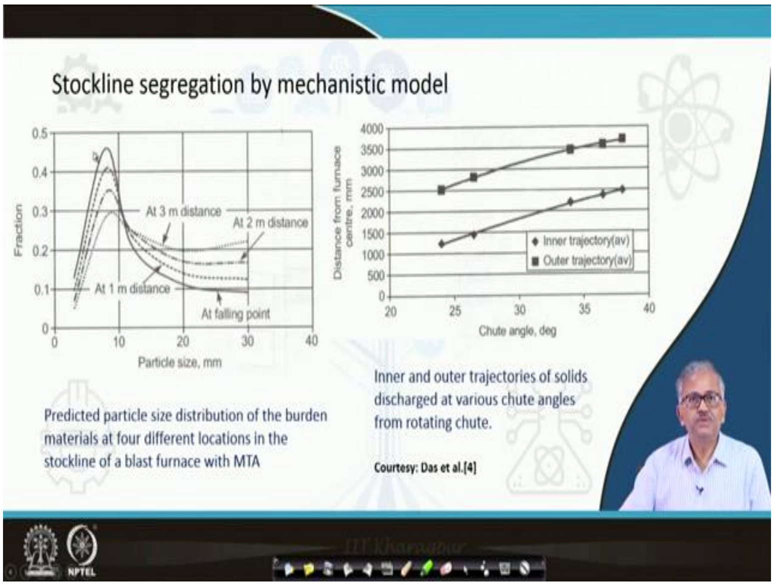

Figure 24.10 shows the predicted particle size distribution based on discrete phase model of the burden materials at four different locations in the stockline of a blast furnace with MTA

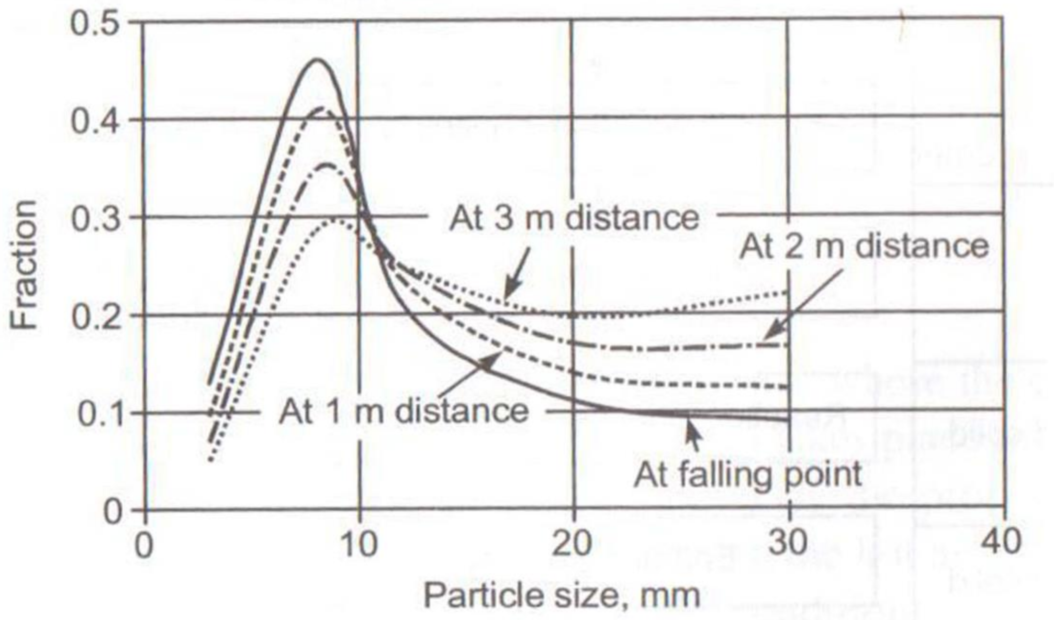

Figure 24.10: Predicted particle size distribution at four different location in the stockline from the falling point [4]

It is observed that at the point of fall fine fraction is maximum and fine fraction decreases progressively away from the point of fall.

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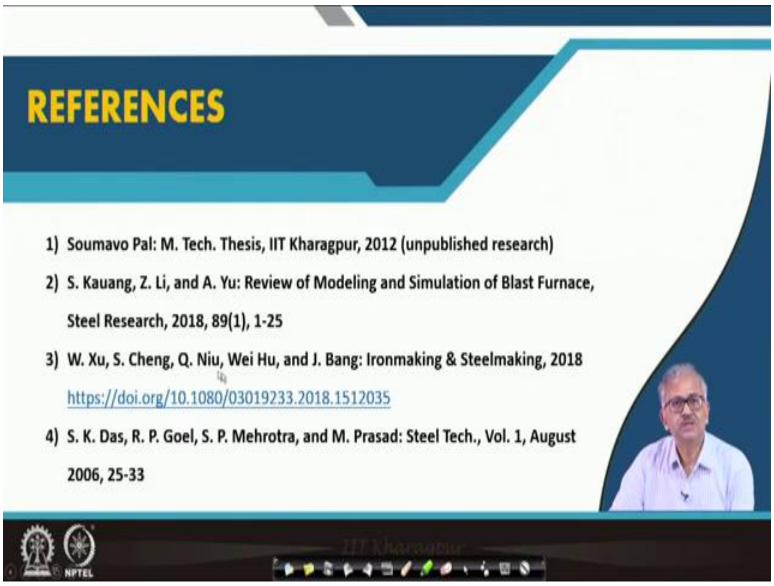

Reference list is attached above.

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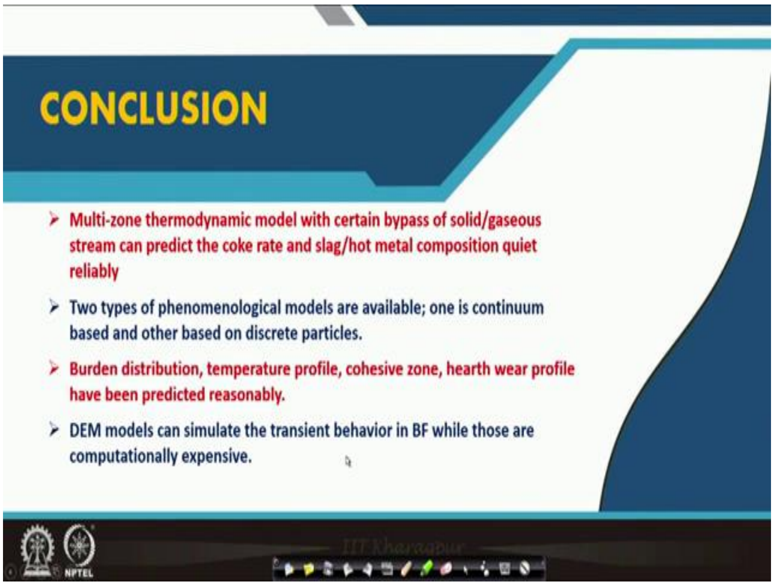

Conclusion: Multi-zone thermodynamic model with certain splitting of solid and gaseous stream can predict the coke rate as well as slag, and hot metal compositions quite reliably. Certain amount of gas bypass is done to account for deviation from thermodynamic condition.

Two types of phenomenological model are there: One is based on continuum, where discrete solid phases are also considered as a continuum; and such model may be based on two or three fluid system under steady state and conservation of heat, mass and momentum equations are solved for these continuum by taking into mutual interaction between these continuum.

The other type of model is discrete phase model where each individual particles are tracked using Newton’s second law of motion taking into account the interactions between those.

Some examples are demonstrated showing the applicability of these models.