Iron Making and Steel Making
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Module – 05
Lecture - 25
New Potential Technologies for Blast Furnace

In this lecture I will discuss about some of the new potential technologies for the Blast Furnace.

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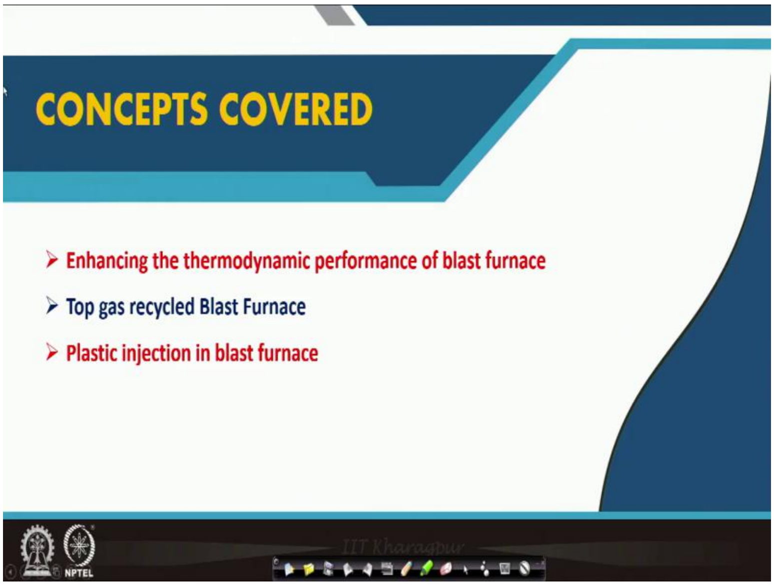

CONCEPTS COVERED

- Enhancing the thermodynamic performance of blast furnace
- Top gas recycled Blast Furnace
- Plastic injection in blast furnace

I will first discuss enhancement of thermodynamic performance of the blast furnace by lowering isothermal zone temperature, followed by two potential technologies like top gas recycling blast furnace (TGR-BF), and plastic injection in blast furnace.

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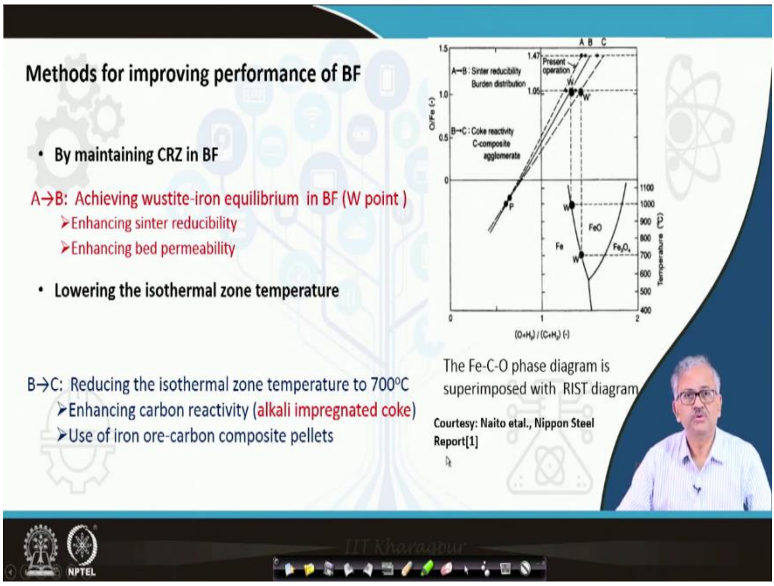

Methods for improving performance of BF

- **By maintaining CRZ in BF**

A→B: Achieving wustite-iron equilibrium in BF (W point)

➢Enhancing sinter reducibility

➢Enhancing bed permeability

- **Lowering the isothermal zone temperature**

B→C: Reducing the isothermal zone temperature to 700°C

➢Enhancing carbon reactivity (alkali impregnated coke)

➢Use of iron ore-carbon composite pellets

The Fe-C-O phase diagram is superimposed with RIST diagram

Courtesy: Naito etal., Nippon Steel Report[1]

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Figure 23.1 shows the Fe-C-O phase diagram superimposed with the RIST diagram. The x-axis represents the gas composition in terms of the ratio $(O+H_2)/(C+H_2)$; where the numerator represents the total oxygen atoms in the gas due to both carbon and hydrogen oxidation. Oxide of carbon can exists either as CO or CO_2 but oxide of hydrogen exists only as H_2O. So, oxygen in gas = oxygen from carbon oxidation ($nO = nCO+2nCO_2$)+ oxygen from hydrogen oxidation ($=nH_2$) = $O+H_2$. (dropping prefix, n, number of atoms/mole). Similarly, the denominator indicates total reductants in the gas = $nC+nH_2=C+H_2$. y-axis for Fe-C-O diagram represents temperature while y-axis of RIST diagram represent oxygen in the ore, in terms of atomic ratio O/Fe. Both the superimposed diagrams has the same x-axis, the gas composition.

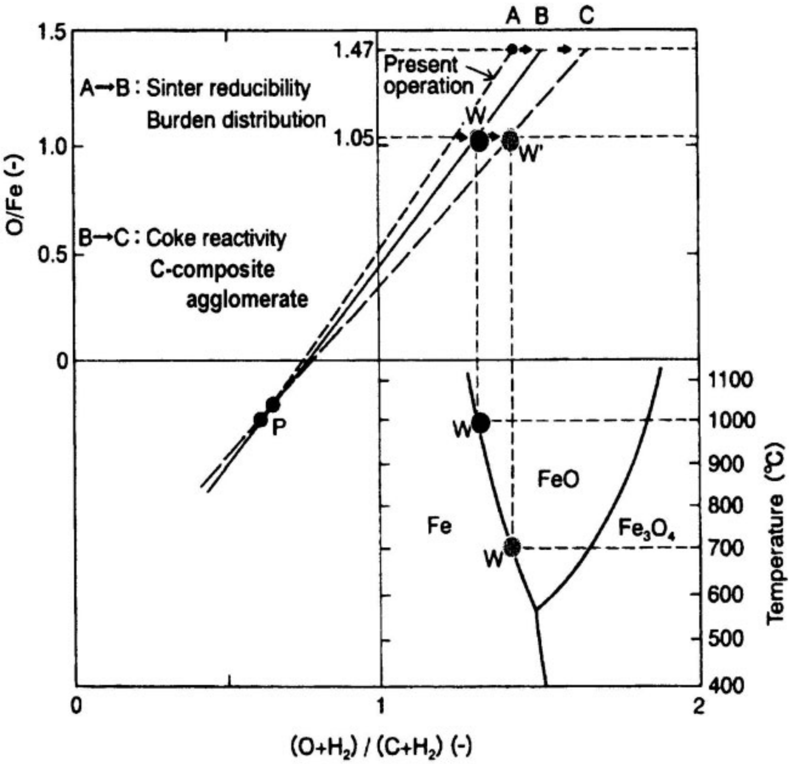

Figure 25.1: Fe-C-O phase stability diagram superimposed with RIST diagram[1]

In the Fe-C-O phase stability diagram, the right hand side arm represents the Wustite-iron (FeO-Fe) equilibrium and we see that with decrease in temperature, the equilibrium gas composition increases, meaning more oxygen in the gas, or reductant utilization is more. Such equilibrium gas compositions at two different temperatures, namely 1000^{o}C and 700^{o}C are indicated by W and $W^{/}$ points. These points are extra-plotted on the RIST diagram for the same gas composition. The minimum slop in RIST diagram is fixed by two points; one is thermal pinch point P (dictated by heat balance in the furnace) and other is chemical pinch point (W), represented by FeO-Fe equilibrium. We see that by reducing the temperature for FeO-Fe equilibrium, the W point is shifted to left in the RIST diagram, which will help to reduce the slope of the RIST line, lowering the carbon rate. It is to be noted that in conventional blast furnace the wustite-iron equilibrium is achieved in the upper part of the isothermal zone, called the chemical reserve zone. Isothermal zone is maintained between 800 to 1000^{o}C, or average at 900^{o}C. If this temperature is lowered to 700^{o}C (say), obviously we can find the gas utilization benefit. But how to lower it? In fact in isothermal zone endothermic carbon gasification and heat exchange from gas to solid comes to a dynamic equilibrium yielding a constant temperature zone in the middle of the furnace, called the isothermal zone. If coke reactivity is increased, the carbon gasification will be enhanced leading to more heat demand and it will be met by heat exchange from gas to solid. Consequently, both the temperature of the solid and gas will decrease resulting in a decrease of the isothermal zone temperature. Coke reactivity may be improved by impregnating coke with alkali metal like Ca, which catalyse the gasification reaction. Iron ore coal composite pellets could also be helpful; because of intimate contact between the iron ore and carbon particle, will enhance the ore reduction through in-situ carbon gasification. Fresh iron produced also gassify the carbon inside the pellet. As the W point shift to left and slope of the curve decreases; extrapolated curve also intersect the O/Fe line at 1.5 at higher values of oxygen to reductant ratio. In other words, exit gas composition will also shift from B to C, with higher oxygen in gas, indicating more utilization of gas. The point A on exit gas composition represents a case when the FeO-Fe equilibrium is not attained even in conventional blast furnace; as a result gas remains unutilized to a great extent, with lower oxygen to reductant ratio in the exit gas. Shifting of exit gas composition from A to B, indicates increase in gas utilization by attaining FeO-Fe equilibrium in conventional blast furnace; while shifting of exit gas composition from B to C indicates further increase in gas utilization by attaining FeO-Fe equilibrium at comparatively lower temperature than that usually happen in conventional blast furnace. Shifting from A to B might be achieved by increasing the sinter reactivity; while shifting from B to C may be achieved by using highly reactive coke or, iron ore coal composite pellets. Nippon Steel has tested such concept in a simulating cylindrical shaft furnace with gas injection facility. It was found that the isothermal zone temperature indeed decreased while utilizing highly reactive coke, or using composite pellet[1].

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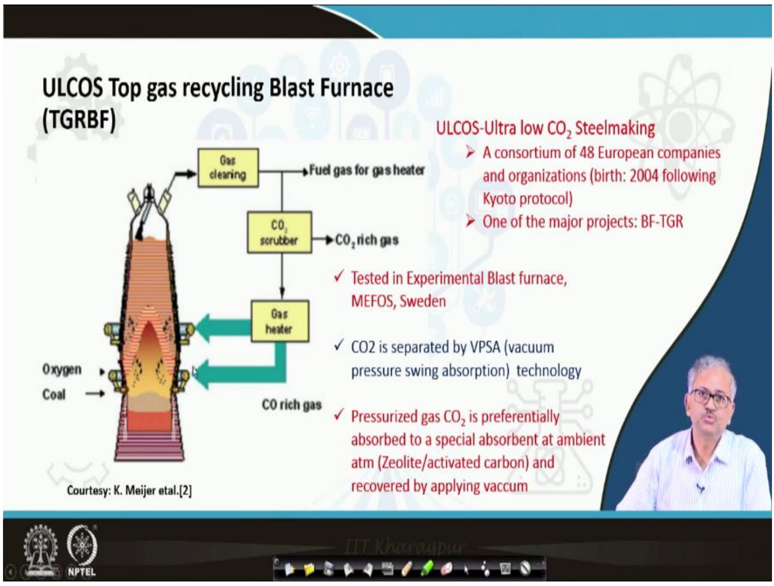

ULCOS Top gas recycling Blast Furnace (TGRBF)

ULCOS-Ultra low CO_2 Steelmaking

- A consortium of 48 European companies and organizations (birth: 2004 following Kyoto protocol)
- One of the major projects: BF-TGR

✓ Tested in Experimental Blast furnace, MEFOS, Sweden

✓ CO2 is separated by VPSA (vacuum pressure swing absorption) technology

✓ Pressurized gas CO_2 is preferentially absorbed to a special absorbent at ambient atm (Zeolite/activated carbon) and recovered by applying vaccum

Courtesy: K. Meijer etal.[2]

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Now, I will discuss about the top gas recycling blast furnace, which is an ULCOS project. ULCOS represents Ultra Low CO_2 steelmaking. It is a consortium of 48 European companies and organizations and it took birth on 2004 following the Kyoto protocol. Kyoto protocol represents the regulation on CO_2 emission that was framed in the climate summit that took place in Kyoto, Japan and came into action in 2005.

The major aim of TGR-BF is to reduce the CO_2 emission from blast furnace. The schematics of a top gas recycling blast furnace is shown if Figure 25.2.

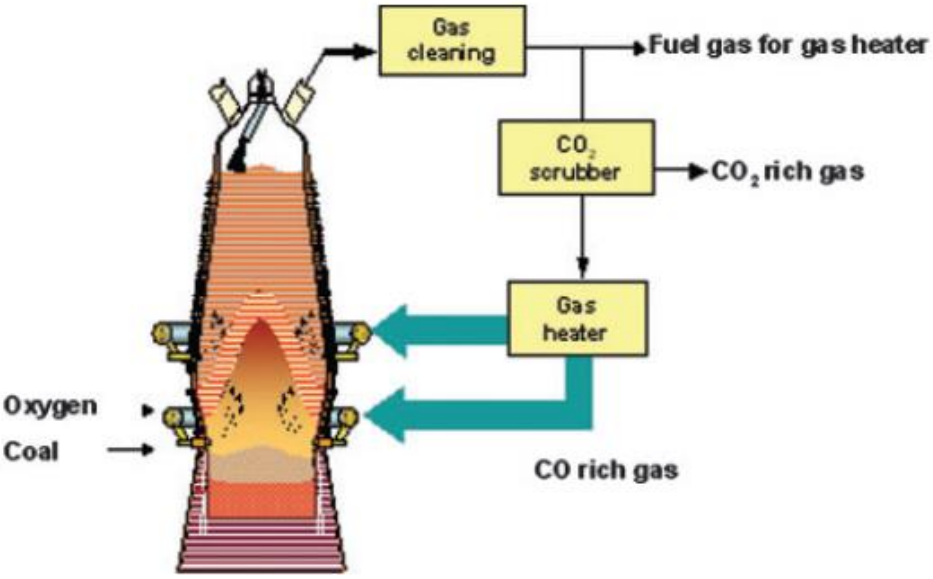

Figure 25.2 Schematics of Top gas recycling blast furnace (TGR-BF) [2]

In TGR-BF, a part of the cleaned exit gas is recycled back to the furnace after stripping CO_2 from the gas. In TGR-BF pure oxygen or highly oxygen enriched air blast is charged to reduce the dilution of top gas by nitrogen. So, stripping CO_2 become easier by VPSA (Vacuum Pressure Swing Absorption). In VPSA some solid absorbent like zeolite or activated carbon is used to absorb CO_2 preferentially at high pressure and subsequently CO_2 gas may be recovered under vacuum. This CO_2 gas goes for sequestration. The CO rich gas after preheating is directly fed into the furnace through tuyer at two locations; either through shaft tuyer or through conventional hearth tuyer, or both. It is to be noted reducing nitrogen from blast furnace gas reduces the heat capacity of the BF gas, which has to be entirely compensated through recycling of hot top gas. Therefore, pure oxygen injection was later replaced by preheated oxygen enriched air blast.

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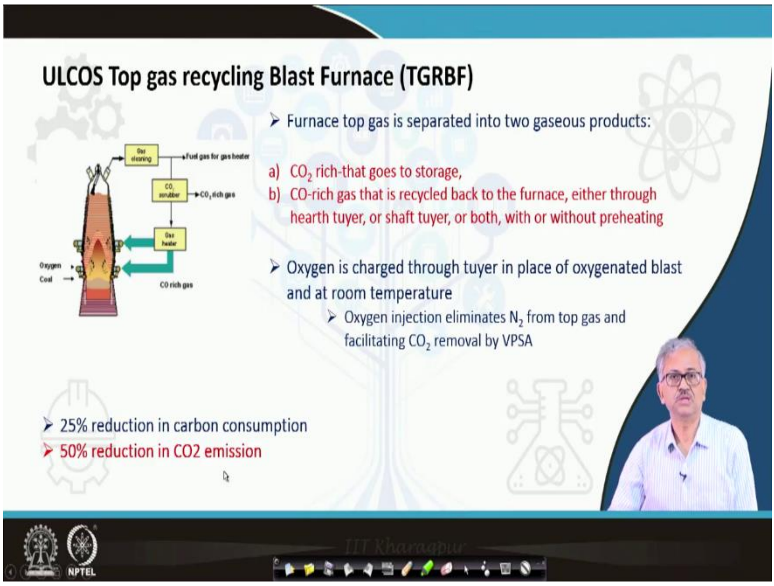

ULCOS Top gas recycling Blast Furnace (TGRBF)

- Furnace top gas is separated into two gaseous products:

a) CO_2 rich-that goes to storage,
b) CO-rich gas that is recycled back to the furnace, either through hearth tuyer, or shaft tuyer, or both, with or without preheating

- Oxygen is charged through tuyer in place of oxygenated blast and at room temperature
  - Oxygen injection eliminates N_2 from top gas and facilitating CO_2 removal by VPSA

- 25% reduction in carbon consumption
- 50% reduction in CO2 emission

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The idea here is to recycle the exit CO gas to reduce the carbon rate of the furnace. Such reduction of carbon rate combined with CO2 sequestration, also leads to reduction in significant CO_2 emission. Using this technique, it was found that carbon consumption can be reduced by 25% and CO_2 emission can be reduced by 50%.

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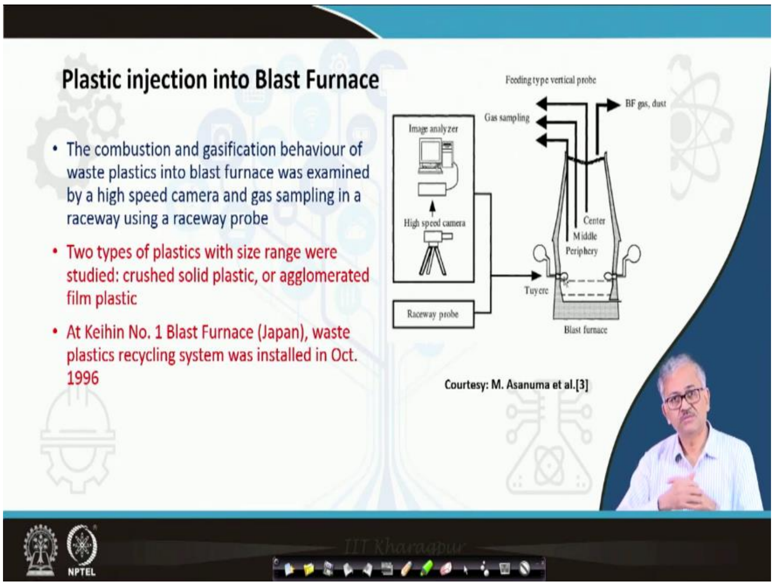


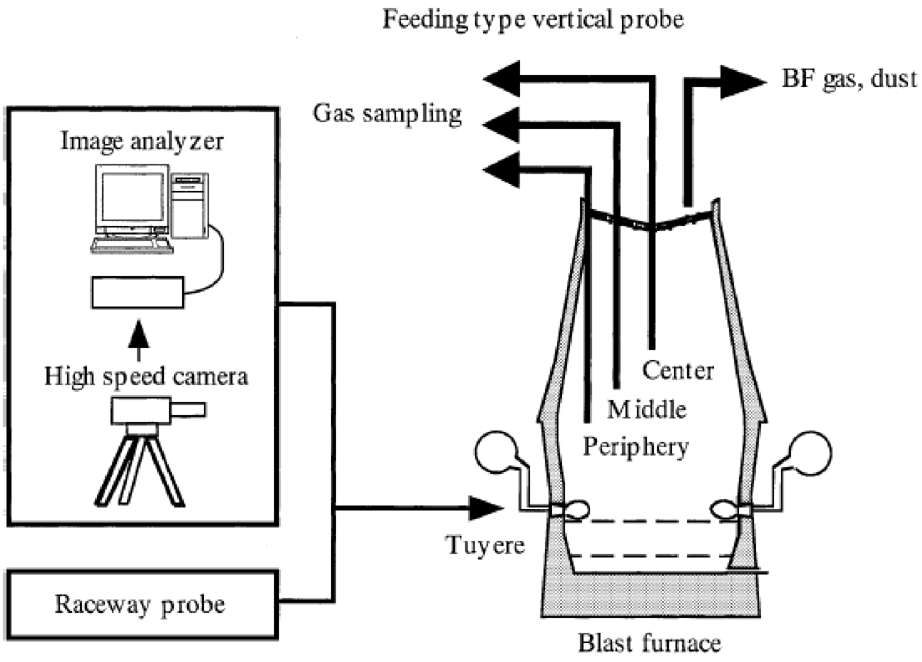
Plastic injection into Blast Furnace

- The combustion and gasification behaviour of waste plastics into blast furnace was examined by a high speed camera and gas sampling in a raceway using a raceway probe
- Two types of plastics with size range were studied: crushed solid plastic, or agglomerated film plastic
- At Keihin No. 1 Blast Furnace (Japan), waste plastics recycling system was installed in Oct. 1996

Courtesy: M. Asanuma et al.[3]

Now, another very important topic that is coming is the plastic injection in the blast furnace. The combustion and gasification behaviour of waste plastic in the blast furnace has been examined in a pilot blast furnace in Japan. Two types of plastic has been used; one is the agglomerated soft plastics and another is the solid crushed plastic. Hard plastic are crushed to different sizes and the filmy soft plastic like polythene bag is shredded and agglomerated. And, then subsequently those become suitable for charging into the blast furnace through tuyer.

First plastic injection was done in Keihin blast furnace, Japan in Oct, 1996. Before that plastic injection was tested in a pilot scale blast furnace, which was rigorously monitored through camera placed inside the tuyer. A high speed camera was installed inside tuyer to see the happenings in the raceway. They also did comprehensive sampling of exit gas and dust at different locations across the cross section of the blast furnace. They measured for the different lighter hydrocarbons like C1 to C4 hydrocarbon like methane, ethane, butane, as well as the tar. The experimental setup of pilot scale BF for investigation is shown in Figure 25.3.



25.3 Experimental setup for investigating plastic injection[3]

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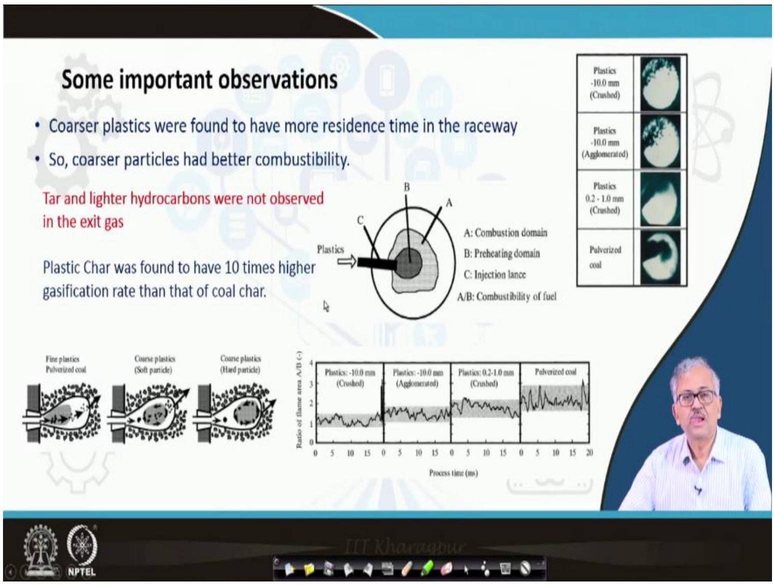

Some important observations

- Coarser plastics were found to have more residence time in the raceway
- So, coarser particles had better combustibility.

Tar and lighter hydrocarbons were not observed in the exit gas

Plastic Char was found to have 10 times higher gasification rate than that of coal char.

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Figure 25.4 shows the pathways for different types of plastics through the raceway. From Figure 25.4 it is seen that fine plastics, and pulverized coals easily escape the raceway; while coarser plastics follow a recirculatory path in the raceway. Coarser and harder plastics has the maximum residence time. Agglomerated plastics also found to decrepitate and generates fines. The combustibility of the particle is estimated by the ratio of combustion zone to preheating zone in the raceway, as pictorially shown in the Figure

25.5. Figure 25.6 depicts the variation of combustibility factor with time. It may be observed that big plastics (1 to 10 mm) both soft agglomerate plastics and crushed hard plastics have lower combustibility. Pulverized coal showed the maximum combustibility followed by hard crushed plastics in the intermediate size range: 0.2 to 1mm.

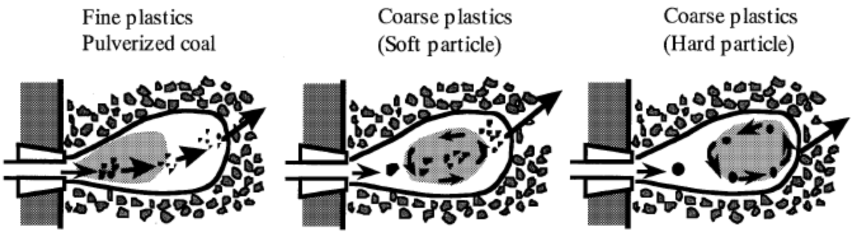


Figure 25.4 residence behaviour of particles in the preheating zone of raceway for different types of particles[3]

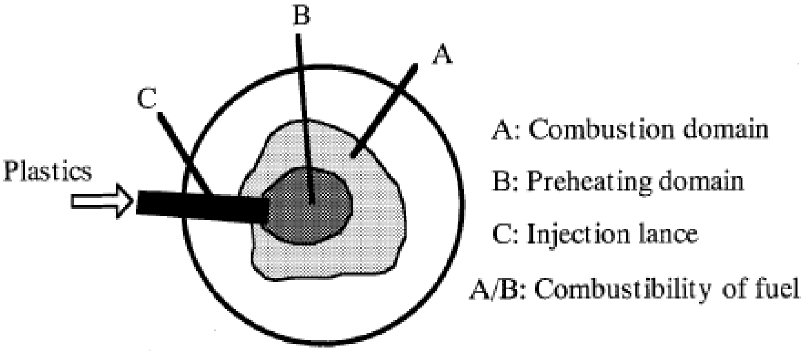
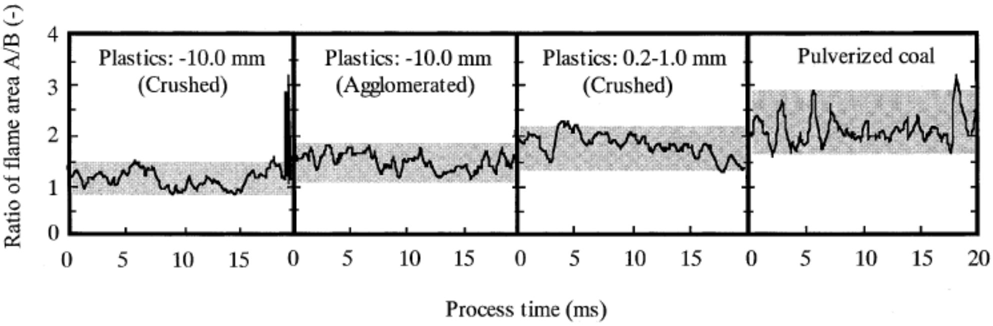


Figure 25.5 Pictorial representation for determining combustibility factor[3]



25.6 Combustibility as a function of time[3].

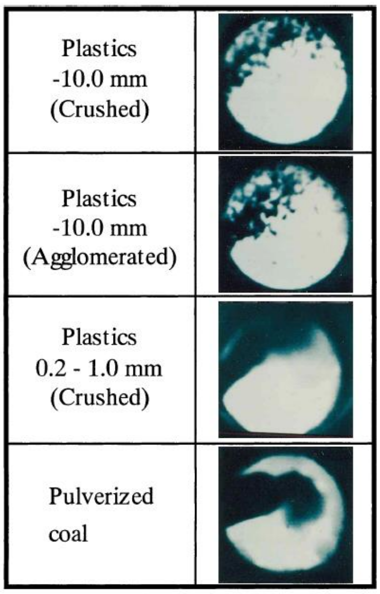


Figure 25.6 Combustion morphologies at surface for different plastics[3]

Surface combustion morphology of plastics and coal is shown in Figure 25.6. It is seen that pulverized coal and crushed plastics in the range 0.2 to 1 mm burns more uniformly; while the burning pattern is segregated in case of both crushed and agglomerated plastics of bigger size (1 to 10 mm). Plastics char has also been found to have 10 times higher gasification rate than coal char. Therefore, if some unburned plastic char emits the raceway and gets into the coke bed, those are likely to gassify rather than jamming the bed.

Interestingly, exit gas sampling could not traced and tar, or unburned lighter hydrocarbons in the exit gas; and the gas composition is found to be similar to that of blast furnace operated with PCI only.

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REFERENCES

1) M. Naito, A. Okamoto, K. Yamaguchi, T. Yamaguchi, Y. Inoue, Improvement of Blast Furnace Reaction Efficiency by Temperature Control of Thermal Reserve Zone, in: Nippon Steel 2006.

2) Koen Meijer, Mark Denys, Jean Lasar, Jean-Pierre Birat, Gunnar Still & Bernd Overmaat (2009) ULCOS: ultra-low CO2 steelmaking, Ironmaking & Steelmaking, 36:4, 249-251, DOI: 10.1179/174328109X439298

3) M. Asanuma, T. Ariyama, M. Sato, R. Murai, T. Nonaka, I Okochi, H. Tsukiji, and K. Nemoto: Development of waste plastic injection process in Blast Furnace, ISIJ, 2000, 244-251

List of reference is given in the slide above.

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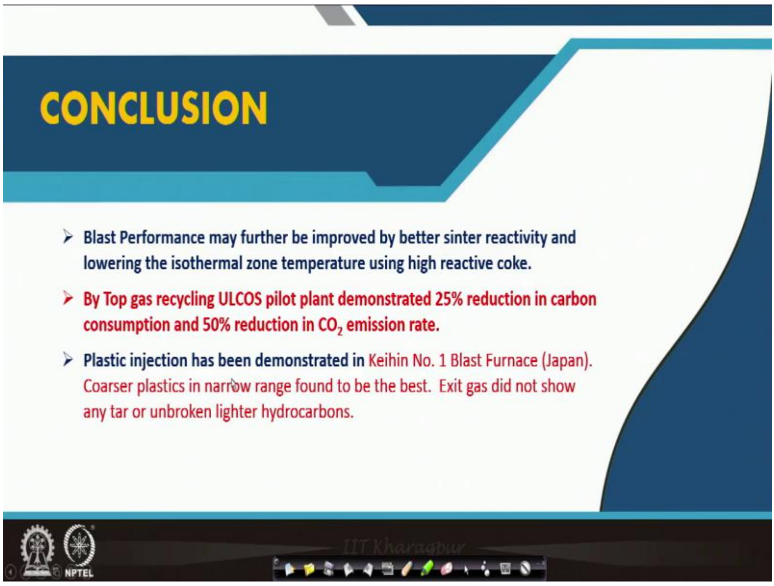

CONCLUSION

- Blast Performance may further be improved by better sinter reactivity and lowering the isothermal zone temperature using high reactive coke.
- By Top gas recycling ULCOS pilot plant demonstrated 25% reduction in carbon consumption and 50% reduction in CO_2 emission rate.
- Plastic injection has been demonstrated in Keihin No. 1 Blast Furnace (Japan). Coarser plastics in narrow range found to be the best. Exit gas did not show any tar or unbroken lighter hydrocarbons.

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Conclusions:

i) Blast furnace performance can be increased by attaining the FeO-Fe equilibrium in the upper part of the furnace. This can be achieved with high quality iron burden with higher reactivity and good bed permeability.

ii) The fuel efficiency may further be improved by lowering the temperature of isothermal zone, which can be achieved by using high reactive coke or using iron ore-coal composite pellet.

iii) Using top gas recycling blast furnace (TGR-BF), the CO_2 consumption in the blast furnace can be reduced by 50% and carbon consumption by 25%. In top gas recycling furnace, the top gas is partially recirculated into the furnace after stripping its CO_2, which is subsequently sequestrated.

iv) Plastic injection in the blast furnace has been proven to be safe without any tar accumulation. Gas efficiency is also found to be comparable to PCI based furnace. Combustibility of medium coarse (0.2 to 1mm) hard plastics is found to be higher. Soft plastics could be used after agglomeration. Fine plastics char are likely to escape the raceway and enter the coke bed; but it is likely to gassify there rather than jam the bed.