

Iron Making and Steel Making
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Module - 11
Lecture - 53
Coal Based DR Processes-Rotary Kiln Process

We will discuss about the Coal Based DR Process in this lecture.

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CONCEPTS COVERED

- Rotary Kiln processes
- RHF based processes

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Two coal based processes based on rotary kiln and Rotary Hearth Furnace will be discussed. (Refer Slide Time: 00:58)

Flow sheet of Rotary Kiln Process

- Coal acts both as reductant as well as heat producer
- Operates on Counter current principles
- Secondary air for post combustion of CO
- Waste gas cleaning system to reduce pollution
- Waste heat recovery through steam generation
- Kiln rotation refresh solid surfaces
- Rotation parameters and inclination of kiln should be adjusted to avoid fine segregation at wall

The slide includes a detailed flow sheet diagram of the rotary kiln process, showing the flow of high-temperature coal, limestone, and air through various stages including a cooling system, electrostatic precipitator, rotary kiln, rotary cooler, and screening. It also features a small inset video of Prof. Gour Gopal Roy pointing at the slide. Logos for IIT Kharagpur and NPTEL are visible at the bottom.

Figure 53.1 shows the flow sheet of Rotary Kiln Process. Iron ore and coal and limestone are charged from the inlet of rotary kiln furnace. Limestone is used to scrub the Sulphur from coal such that Sulphur in sponge iron remain low. Iron ore is added in the form of lump ore; sometimes iron ore pellets are also used.

Coal acts both as reductant as well as heat producer. Coal added from inlet is used for direct reduction of ore. Coal fines along with air is also added from discharge end as fuel to generate the heat for the process. Thus hot gas flows over the solid bed in a counter current direction.

Reduction takes place in a cylindrical reactor called the rotary kiln that is inclined to horizontal to a certain angle and rotate at certain rpm. The rotation renews the surface area of the ore as well as kiln surface to the hot furnace atmosphere, enhancing heat exchange and the kinetics of the process. Rotation and inclination of the reactor also helps in forward movement of the ore under gravity.

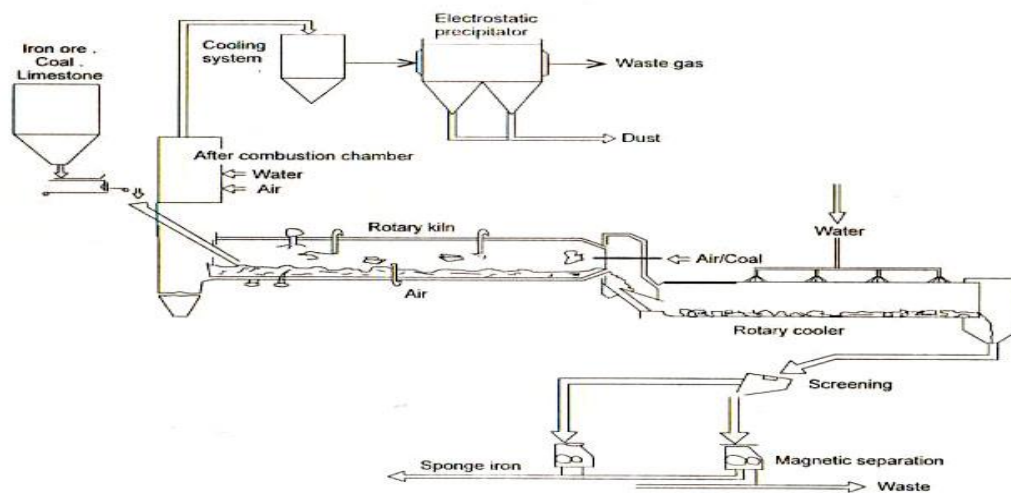


Figure 53.1: Flow sheet of Rotary Kiln

There also some ports on the circumference of the cylindrical reactor through which secondary air is injected for post combustion of CO for heat generation in the kiln in a controlled manner depending on the waste gas fuel value requirement for power generation outside. The DRI after emitting from discharge end is cooled a rotary cooler by indirect water quenching. Finally, DRI is crushed, sieved, and undergone magnetic separation before it is stored as sponge iron and gangue as solid waste.

Rotary kiln generates large amount of dust laden waste gas, which is required to be cleaned before it could be used for power generation and partially for preheating of raw materials. Gas cleaning is done through dry, wet scrubber, and finally electrostatic precipitator. Around 30 to 40 percent input heat energy is carried through the waste gas. Therefore utilization of the off gas is essential for process economics. Gas cleaning also make the process environmentally sustainable.

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Phenomena inside rotary kiln

- Secondary air
- Temperature 1050 - 1150°C
- Temperature 950 - 1050°C
- CO + ½ O₂ → CO₂
- Submerged air injection
- Charge
- Chemical reactions:
 - C + CO₂ → 2CO
 - Fe₂O₃ + CO → Fe₃O₄ + CO₂
 - Fe₃O₄ + CO → FeO + CO₂
 - FeO + CO → Fe + CO₂

Key points:

- Solid Charge constitutes only 15% of the total volume
- Gas temperature in the freeboard attained around 1100°C
- Temperature in the solid bed should not exceeds 1050°C to avoid ash fusion and accretion formation
- High reactivity of coal allows gasification reaction and restrict solid temperature beyond 1050°C
- Submerged controlled air injection to facilitate preheating and insitu CO generation in the solid bed

Figure 53.2 shows the cross sectional view of the kiln. It is seen that solid charge occupies a very small volume (15% of the total volume) leaving a large free board to accommodate large amount of dust laden gas.

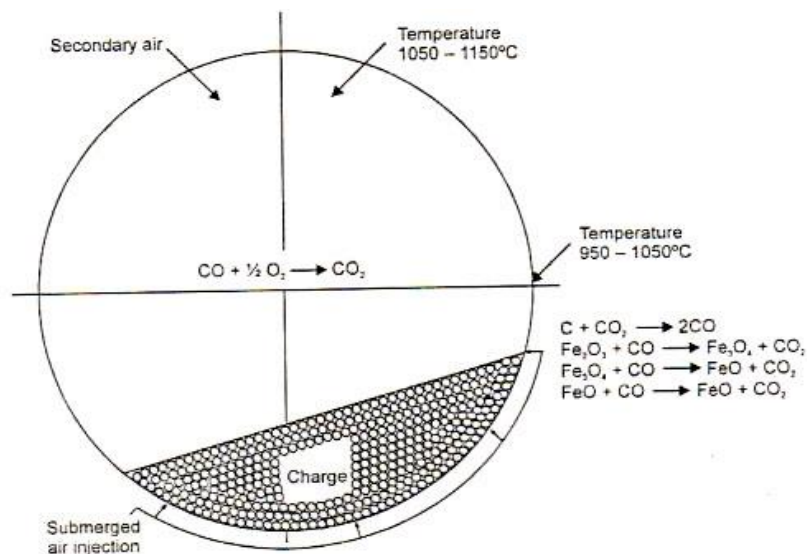
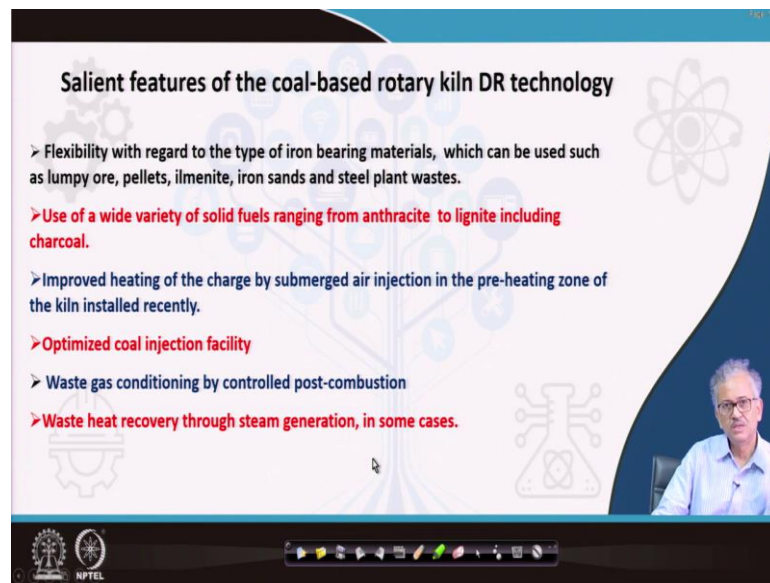


Figure 25.2: Cross sectional view of the rotary kiln

Gas temperature in the freeboard attained around 1100°C . Temperature in the solid bed should not exceed 1050°C to avoid ash fusion and accretion formation. High reactivity of coal allows gasification reaction and restrict solid temperature beyond 1050°C . Some provision are there for submerged controlled air injection to facilitate preheating of the solid bed.

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The slide is titled "Salient features of the coal-based rotary kiln DR technology". It lists six features in a bulleted format:

- > Flexibility with regard to the type of iron bearing materials, which can be used such as lumpy ore, pellets, ilmenite, iron sands and steel plant wastes.
- > Use of a wide variety of solid fuels ranging from anthracite to lignite including charcoal.
- > Improved heating of the charge by submerged air injection in the pre-heating zone of the kiln installed recently.
- > Optimized coal injection facility
- > Waste gas conditioning by controlled post-combustion
- > Waste heat recovery through steam generation, in some cases.

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Some salient features of rotary kiln process: (i) There is flexibility with regard to the type of iron bearing materials, which could be lump ore, pellets, ilmenite, iron sands and steel plant wastes.

(ii) Use of a wide variety of solid fuels ranging from anthracite to lignite including charcoal. Wide variety of solid fuels, starting from anthracite to the lignite coal could be utilized. Lignite is reactive and furnace could be operated at comparatively lower temperature but it has less fixed carbon that requires larger volume of coal. Therefore, low grade lignite could be blended with high grade coal and could be used. So, such kiln is equipped with optimized coal injection facility.

(iii) Waste gas conditioning by controlled post-combustion. It means depending on the fuel value required for power generation, the post combustion in the kiln may be controlled.

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Salient features of the coal-based rotary kiln DR technology contd..

- **Lurgi (Germany) SL/RN is the oldest and most widely applied Rotary Kiln based DR Process**
- Other processes are: Germany CODIR,
- **Canadian ACCAR (Allis Chalmers Controlled atmospheric Reduction; process also uses NG and oil in addition to coal),**
- Canadian DRC,
- **TDR(TISCO Direct Reduction; ensures proper reducing condition along the entire length of the kiln),**
- **Jindal Process (claims any inferior grade ore can be converted to sponge with 90% metallization).**

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(iv) SL/RN is the oldest and most widely applied Rotary Kiln based DR Process, developed by Lurgi (Germany). Important other processes are: Canadian Allis Chalmers Controlled atmospheric Reduction (ACCAR), which also uses NG and oil as fuel in addition to coal to control the furnace atmosphere. TDR (TISCO Direct Reduction), which ensures proper reducing condition along the entire length of the kiln. Jindal Process, claims any inferior grade ore can be converted to sponge with 90% metallization.

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Strengths of coal-based rotary kiln DR process

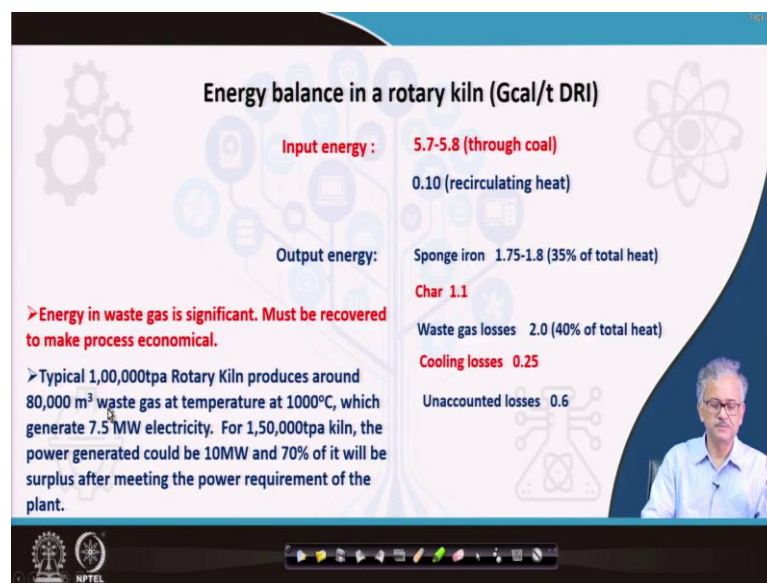
- **Efficient mixing of solid charge during simultaneous heating and reduction.**
- **Owing to large freeboard space above the solid charge (filling degree is never more than 15 %), kilns can tolerate presence of heavily dust-laden gases.**
- **In shaft furnaces, generation of dust can lead to choking and channeling of the reactor (ultimate disruption of the process).**
- **Rotary kilns serve dual purpose – efficient coal gassifier and ore reducer.**
- **They are commercially proven, rugged reactors, extensively used in the cement industry. Its low productivity per unit volume is more than compensated by its inherent versatility.**

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Now, I will talk about some of the strengths of the coal based rotary kiln DR process.

(i) Efficient mixing of solid charge during simultaneous heating and reduction. The kiln rotation renews the solid charge to furnace atmosphere enhancing the heat and mass transfer to solid. (ii) Due to large freeboard space above the solid charge (filling degree is never more than 15 %), kilns can tolerate with the presence of heavily dust-laden gases. In shaft furnaces, generation of dust can lead to choking and channeling of the reactor (ultimate disruption of the process). This make this process suitable for coal based process. (iii) Rotary kilns serve dual purpose – efficient coal gassifier and ore reducer. (iv) Finally, these reactors are commercially proven, rugged reactors, extensively used in the cement industry. Its low productivity per unit volume is more than compensated by its inherent versatility.

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Energy balance: Major input energy to rotary kiln is through coal (5.7 to 5.8 Gcal per ton of DRI produced). Heat input through solid preheating by waste gas only counts for 0.1 Gcal/ ton of iron produced.

Only 35% of the output energy is associated with sponge iron (1.75 to 1.8 Gcal/ton). And 40% of the output energy (2 Gcal/ton) passes through waste gas. Therefore, waste gas contains significant chemical heat in the form of CO, which could be burned for heat generation for raising steam and power generation to make the process economic. Typical

1,00,000 tpa rotary kiln produces around 80,000 m³ waste gas at temperature at 1000 °C, which could generate 7.5 MW electricity. For 1,50,000 tpa kiln, the power generated could be 10MW and 70% of it will be surplus after meeting the power requirement of the plant. Lot is heat is associated with the char produced (1.1 Gcal/ton) which could be recycled back as fuel.

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Drawbacks of rotary kiln DR process

- Productivity is low. Shaft furnaces have five times more output per unit volume.
- Large capacity DR plants have to incorporate multiple rotary kilns (maximum individual capacity 500 tpd).
- Gives rise to interference and complexity in large plants.
- Reactor rotates at 0.4-0.5 rpm making it difficult to incorporate process control and quality control systems.
- Length and diameter of the reactor and the fact that it has to be rotated make the engineering of rotary kilns fairly intensive.
- Rotary kiln DR processes exhibit low energy efficiency. Unless waste gas is used for electricity generation process can not be profitable.
- Unless dust laden waste gas is cleaned, it pollutes atmosphere and not sustainable

The slide includes a small video inset of a man in a white shirt and glasses in the bottom right corner. The background features a stylized atomic symbol and a gear icon. The NPTEL logo is visible in the bottom left corner.



Drawbacks of the rotary kiln process: (i) Productivity is low and shaft furnace have five times more output per unit volume compared to coal based process. Maximum capacity of a single rotary kiln hardly exceeds 500 tons per day and therefore, large capacity DR plant has to incorporate multiple rotary kiln units in series, which increases specific operating cost. This gives rise to interference and complexity in large plants. (ii) Due to rotation of the reactor, instrumentation of the reactor for process control becomes difficult. (iii) Most importantly, the waste gas has to be cleaned before it could be disposed to atmosphere. The waste gas contains lots of dust particles, toxic gases like SO_x, NO_x. The process will not be environmentally sustainable, unless the gas is cleaned. (iv) Accretion formation is another major problem in rotary kiln process. Kiln rotation promotes size segregation; fines try to align on the wall surface and the coarse on the free surface. Therefore, fines gets heat directly from hot wall and if the ash fusion point exceeds, it fuses and from accretion on the wall, which subsequently grows to large accretion and almost stop the solid movement through the furnace (Fig. 25.3).

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Accretion formation

- Repeated rotation results in size separation as the charge moves forward towards the discharge end.
- Coarse particles float to the top of the charge bed.
- Fines tend to segregate to the bottom, increasing the chances of adhering to the refractory lining.
- Ultimate result of size segregation is tendency towards ring formation.
- Reactive coal promotes endothermic carbon gasification reaction that restrict the temperature beyond 1050°C and restricts in attaining slag fusion temperature
- Rings consist of Al_2O_3 and SiO_2 from coal ash, CaO from the flux and FeO from sponge iron.

Photograph of accretion formation



NPTEL



Figure 25.3: Extensive accretion formation in rotary kiln

Accretion formation may be controlled by selecting raw material with high ash fusion point, optimum kiln rotation that produces minimum size segregation, and using high

reactive coal that can promote carbon gasification, which will not only promote reduction but also will restrict the solid temperature.

The lecture will be continued with another important coal based DR process based on Rotary Hearth Furnace in the next lecture.