CHAPTER 2

SPONGE IRON TECHNOLOGY
CHAPTER-II
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2.1 INTRODUCTION

Steel is the backbone of modern world. It can be produced from Sponge Iron, which looks like sponge under a microscope. The process of sponge iron making aims to remove oxygen from iron ore; when that occurs, the departing oxygen from the ore causes micro-pores in it. This makes the ore porous and lighter. The final products when observed under a microscope resembles a honey-comb like structure, looking spongy in texture and hence the name “Sponge Iron”.

The iron ores contain more than 27% of oxygen in oxide form. These oxygen particles occupy the space in the solid iron ore body in the compound form in the nature. During reduction in the solid state, only oxygen parts of the oxide ore are compounded with gaseous reductant and oxygen is removed from the ore making large number of micro-holes or cavities in the solid. This results in a sponge mass, known as sponge iron or Direct Reduced Iron (DRI). Due to solid state reduction, sponge iron retains all other impurities that are present in the original ore, but only weight is reduced proportionally due to removal of oxygen.

2.2 BIRTH OF SPONGE IRON

The recycling of scrap after Second World War was a great work done to find out the way to clear all war debris during 60’s. Lot of scarps was recycled due to contribution of Arc Furnace leading to recovery of steel. This process was widely accepted by all most all developing countries because the steel produced by recycling process found to be much cheaper than the steel produced by blast furnace process. As a result, the scrap vanished gradually causing threat to the Arc Furnace. To overcome this in USA during 70’s reduction of iron ore in solid state in small way was carried out in the same manner as Rutile was produced from Illuminate. Thus the birth of DRI/Sponge iron was brought into existence. The birth of sponge iron in India took place in 1984. At present, in India 145 operating units producing 10 MT Sponge iron per annum and another 190 units are in pipeline. The role of sponge iron is very vital due to increasing requirement of steel in our country.

2.3 RAW MATERIALS FOR SPONGE IRON

The principal raw materials for producing sponge iron by rotary kiln are (i) High grade iron ore (Haematite or Magnetite) (ii) Coal (iii) Lime Stone / Dolomite.
**Iron Ore:**

India has got 17.7 billion tons (BT) of iron ore of which 12.32 BT is Haematite (Fe₂O₃). Out of this 12.32 BT of Haematite, 14.3% contains > 65% iron, 43.7% has 62-65% iron and the rest 42% contains <62% iron.

Haematite ore is preferred over Magnetite because of its greater reducibility due to 5% more removal of oxygen. During reduction the hexagonal hematite changes its crystal structure to cubic magnetite and wustite (FeO). By this transformation the volume of solid expands to around 25% more resulting higher exposure of surface area for reduction. On the other hand during transformation of magnetite to Wustite the volume expansion is very less for which the reducibility is poor.

**Impurities:**

SiO₂, Al₂O₃, P, S, etc. are the major impurities available in sponge iron. The grade of sponge iron is varied due to presence of impurities in it. Better the grade of iron ore, less are impurities. The chemical composition of iron ore has the greater role in selection of ore for sponge iron making.

By reduction, oxygen present in the ore is removed and iron present as oxide is converted to metallic iron. More the oxygen present in the ore, more is the time of removal for getting desired metallization. The chemical analysis of Haematite ore of different grades is given in Table-9.

**Table-9**

<table>
<thead>
<tr>
<th>Iron Ore</th>
<th>No.</th>
<th>Fe%</th>
<th>SiO₂%</th>
<th>Al₂O₃</th>
<th>P%</th>
<th>LOI%</th>
<th>O₂%</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Haematite 1</td>
<td>65</td>
<td>2.74</td>
<td>2.28</td>
<td>0.031</td>
<td>1.80</td>
<td>27.94</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>-do-</td>
<td>66</td>
<td>2.30</td>
<td>1.89</td>
<td>0.028</td>
<td>1.20</td>
<td>28.38</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>-do-</td>
<td>67</td>
<td>1.78</td>
<td>1.38</td>
<td>0.030</td>
<td>0.80</td>
<td>28.81</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>-do-</td>
<td>68</td>
<td>1.05</td>
<td>0.88</td>
<td>0.028</td>
<td>0.60</td>
<td>29.24</td>
<td>0.20</td>
<td></td>
</tr>
<tr>
<td>-do-</td>
<td>69</td>
<td>0.59</td>
<td>0.21</td>
<td>0.029</td>
<td>0.04</td>
<td>29.67</td>
<td>0.20</td>
<td></td>
</tr>
</tbody>
</table>

LOI = Loss on ignition

**Gangue in Iron Ore:**

Many iron oxides ore are present as compounds with the gangue materials such as Silicates (FeO, SiO₂) Aluminates (nFeO, Al₂O₃), Carbonates (FeCO₃) hydrates (Fe(OH)₂) and more complex mixture of these. The presence of such compounds affects noticeably the rate of reduction.

During reduction reaction, gangue dissociates to:
\[
\begin{align*}
\text{FeCO}_3 &\rightarrow \text{FeO} + \text{CO}_2 \\
\text{Fe(OH)}_2 &\rightarrow \text{FeO} + \text{H}_2\text{O}
\end{align*}
\]

Since the above reactions are endothermic, temperature is lowered during decomposition. So, additional heat is required for these reactions. Therefore, less gangue in iron is preferred for sponge iron making. As per standard specification, gangue in sponge iron should not be more than 6% for 90% Metallization (Mz). The percentage of gangue in different grades of iron ore is indicated in Table-10.

**Table-10**

**GANGUE PERCENTAGE IN IRON ORE**

<table>
<thead>
<tr>
<th>Ore %</th>
<th>% Gangue in Ore ((\text{SiO}_2+\text{Al}_2\text{O}_3+\text{CaO}+\text{MgO}))</th>
<th>% Gangue reflects on Sponge Iron</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>65</td>
<td>5.02</td>
<td>7.14 (High)</td>
<td>Not suitable</td>
</tr>
<tr>
<td>66</td>
<td>4.19</td>
<td>5.94</td>
<td>Suitable</td>
</tr>
<tr>
<td>67</td>
<td>3.16</td>
<td>4.48</td>
<td>Suitable</td>
</tr>
<tr>
<td>68</td>
<td>1.93</td>
<td>2.75</td>
<td>Suitable</td>
</tr>
</tbody>
</table>

**Phosphorous in Iron Ores:**

Iron ore contains wide variation of phosphorous in the range of 0.030% to 0.035%; which also appear in the Sponge iron varying from 0.042% to 0.050%.

**Sulphur in Iron Ore:**

Sulphur is an additional impurity in sponge iron for which selection of iron ore having low sulphur is necessary. The iron ore in the Barbil sector of Orissa belt contains sulphur within the range of 0.006 to 0.02 (max.). The percentage of sulphur both in iron ore and sponge iron is given in Table-11.

**Table-11**

**PERCENTAGE OF SULPHUR IN ORE AND IN SPONGE IRON**

<table>
<thead>
<tr>
<th>S% in Ore</th>
<th>S% in Sponge Iron</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.006</td>
<td>0.008</td>
</tr>
<tr>
<td>0.009</td>
<td>0.013</td>
</tr>
<tr>
<td>0.015</td>
<td>0.021</td>
</tr>
<tr>
<td>0.02</td>
<td>0.028</td>
</tr>
</tbody>
</table>

The increase in % of ‘S’ in Sponge Iron is due to the fact that some amount of sulphur pick up takes place from sulphur in coal during reduction. It is always better to select ore having sulphur 0.015% (max) for sponge iron making.

**Size of the Ore for DRI:**

The rate of reduction of iron oxide depends on size of the particles. The time required for complete reduction of an ore particle is dependent on the longest path.
which an oxygen atom must travel to reach a gas solid interface. There is an inverse relationship between particle size and rate constant for the reaction.

From the experimental values it has been established that for very small size particle (<3mm), the rate of reduction is independent of size, for medium size particles (6 to 15mm) it is inversely proportional to diameter (d) of the particle and for very large size (> 20mm) it is inversely proportional to 2d. So, rate of reduction of oxide ore increases with decrease of ore size. The standard particle size for effective production of sponge iron is found to be 5 to 15 mm.

**Coal**

Coal may be defined as carbonized remains of vegetable matter and is to be considered as a rock forming unit of carbon and other gaseous matters and sulphur.

**Coal Varieties**

<table>
<thead>
<tr>
<th>Peat</th>
<th>Low-rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lignite</td>
<td></td>
</tr>
<tr>
<td>Bituminous</td>
<td>High-rank</td>
</tr>
<tr>
<td>Anthracite</td>
<td></td>
</tr>
</tbody>
</table>

The bituminous and anthracite coals are suitable for DRI process. Since reduction in rotary kiln is done by the direct contact of coal with the oxide ore in the solid state, it is necessary that the coal shall be totally non-coking in nature. Any coking tendency in coal may lead to agglomeration as well as material flow characteristic.

While selecting coal for DRI process, the following chemical compositions of coal are to be considered (i) Fixed Carbon (FC) (ii) Ash (iii) Volatile Matter (VM) (iv) Moisture.

- FC – 45% (min), VM – (28 – 32%)
- Ash – 25% (max), Moisture – 10% (max)

Ash is an impurity in coal. So it should be as low as possible. Higher the ash content, higher will be the operating temperature.

VM. is combination of CH₄, C₂H₆, and Tar etc. Low VM will not produce adequate heat for reduction.

**Lime Stone**

It is a composition of calcium carbonate and magnesium carbonate. It is used in the process for desulphurization. The sulphur is converted to SO₂, which combines
with moisture to form sulphurous acid. Since acidic gases are harmful, the desulphurization is made in the form of sulphites of calcium and magnesium.

\[
\begin{align*}
\text{CaO} + \text{SO}_2 & \rightarrow \text{CaSO}_3 \\
\text{MgO} + \text{SO}_2 & \rightarrow \text{MgSO}_3
\end{align*}
\]

2.4 QUALITY OF SPONGE IRON

The quality of Sponge iron is primarily ascertained by the percentage of metallization (\(M_z\)), which is the removal of oxygen from the ore. Metallization is the ratio of metallic iron (\(F_{eM}\)) to the total iron present in the final product (\(F_{eT}\)).

\[
M_z = \frac{F_{eM}}{F_{eT}} \times 100
\]

100% removal of oxygen from the ore is expensive, so 93% reduction is made to get 90% metallization. Hence commercial sponge iron holds some oxygen in FeO stage. In 65% Iron grade ore the total oxygen contains is 27.93%.

Materials Balance for Production of one Ton of Sponge Iron.

- 1.6 to 1.7 tons of iron ore having size 3-15mm.
- 1.6 tons of coal having size 4-20mm of high grade B/C or about 3 tons of low grade coal.

2.5 PROCESS OUTLINE

The process consists of the reduction of iron ore with solid carbonaceous material such as coal, lignite in a rotary kiln, which is heated to a temperature of 950-1000°C then cooled to 160°C temperature in the rotary cooler with indirect water-cooling system. The products are then screened and magnetically separated. Sponge iron being magnetic gets attracted and gets separated from the non-magnetic char.

The kiln can be divided process wise into two zones namely preheating zone and reduction zone. The material gets heated to the reduction temperature in the preheating zone. Upto 200°C the iron ore, coal, limestone and all the moisture are vaporized. Up to 800°C the iron ore gets roasted and any carbonates in it get calcinated. The limestone also gets calcinated and becomes active. The iron ore, which is in the form of hematite, gets reduced to magnetite (Fe\(_3\)O\(_4\)). After this the material enters to the reduction zone where the magnetite is reduced to wustite (FeO) and then to the metallic iron.
All the above reactions are possible only in the presence of CO. The generation of CO is by bounded reaction. \((C+CO_2 \rightarrow 2CO)\). The hot reduced material is then transferred to the rotary cooler via the transfer chute. The rotary cooler is 2-3 meters in diameter and 22 meters long. It is also inclined at 1.432 degree approximately and rotates at a step less variable speed of 0.3 – 1.2 rpm. An AC variable speed motor drives it. The water is sprayed on the top of the shell which cools the material. The material is cooled to 160°C and is discharged on the belt conveyor. The double pendulum valve acts as the seal for the prevention of the atmospheric air into the kiln cooler system.

The cooler discharge is then sent to the product separation house, where the material is screened to various size fractions and then fed to the magnetic separators which separate the magnetic sponge iron from the non-magnetic char.

**Reactions involved in the Process:**

1. \(C + O_2 \rightarrow CO_2\)
2. \(C + CO_2 \rightarrow 2CO\)
3. \(C + H_2O \rightarrow CO + H_2\)
4. \(3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2\)
5. \(Fe_2O_3 + CO \rightarrow 3FeO + CO_2\)
6. \(Fe_3O_4 + 3CO \rightarrow 2Fe + 3CO_2\)
7. \(FeO + CO \rightarrow Fe + CO_2\)
8. \(3Fe_2O_3 + H_2 \rightarrow 2Fe_3O_4 + H_2O\)
9. \(Fe_3O_4 + H_2 \rightarrow 3FeO + H_2O\)
10. \(FeO + H_2 \rightarrow Fe + H_2O\)

It takes about 7 hours for reductions of Iron Ore to Sponge Iron

### 2.6 PROBLEMS OF COAL BASED SPONGE IRON UNITS

- Non-availability of high grade iron ore and non-coking coal.
- Generation of large amount of ore fines (~ 35%) and coal dust (~ 30%) as waste.
- Generation of large amounts of fule dust and other wastes polluting air, watering and land considerably.
- Lack of adopting improved practices resulting in substantial energy loss and production of inferior sponge.
- Unsatisfactory pollution control measures and waste management.
PROCESS FLOW DIAGRAM

Raw material Ground Hopper (Iron Ore), Coal & Dolomite

Coal

Crushing

Oversize

Screening

Coal Bin

Iron Ore Bin

Setting up of Production of raw materials for Kiln feed

Proceed to rotary Kiln 1075 degree C. with control

Indirect cooling in rotary cooler with water supply

Screening of mixed end product Sponge Iron & Unburnt coal

S.I. Lumps + Char

Drum type magnetic Separator

S.I. Lump Bin

Char Bin

S.I. Lump + Dolo Char

Drum type magnetic Separator

S.I. Lump Bin

Dolo Char Bin

Fig.5
### ECONOMIC ANALYSIS FOR 1 TON OF SPONGE IRON IN A 100 TPD UNIT

<table>
<thead>
<tr>
<th>Inputs</th>
<th>Consumption</th>
<th>Rate (Rs.)</th>
<th>Cost (Rs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Iron ore</td>
<td>1.6 tons</td>
<td>3000-3400 / ton</td>
<td>4800 – 5400</td>
</tr>
<tr>
<td>Coal</td>
<td>1.5 tons</td>
<td>1800 – 2000 / ton</td>
<td>2700-3000</td>
</tr>
<tr>
<td>Dolomite</td>
<td>0.035 tons</td>
<td>300 / ton</td>
<td>10.5</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>3.5 Ltrs.</td>
<td>30/ Ltr.</td>
<td>105</td>
</tr>
<tr>
<td>Power</td>
<td>75 KW / hr.</td>
<td>4.5 – 5 KW / hr.</td>
<td>337.5 – 375 / hr</td>
</tr>
<tr>
<td>Consumables, operation and maintenance</td>
<td>-</td>
<td>-</td>
<td>100</td>
</tr>
<tr>
<td>Labour</td>
<td>About 75 – 100 persons employed</td>
<td>100 – 200 / persons employed</td>
<td>10000 – 20000 (max.)</td>
</tr>
<tr>
<td>Total production cost</td>
<td>-</td>
<td>-</td>
<td>Approx 8250 – 9350</td>
</tr>
<tr>
<td>Selling cost</td>
<td>-</td>
<td>-</td>
<td>Approx 12000-13000</td>
</tr>
<tr>
<td>Gross profit margin before tax</td>
<td>-</td>
<td>-</td>
<td>Approx 2500 – 4500</td>
</tr>
<tr>
<td>Annual profit margin before tax</td>
<td>-</td>
<td>-</td>
<td>8.25 – 14.85 crores.</td>
</tr>
</tbody>
</table>

Source: Green rating project, Centre for Science and Environment.

Fig. 6: A view of a Sponge Iron Plant
Fig. 7: View of Rotary Kiln of Sponge Iron Plant

Fig. 8: Nuggets of sponge iron