3. Production of Pig Iron and of Liquid Steel

3.1. Iron Ore and Scrap – Mines, Recycling

Steel is produced from iron ore and scrap. Iron ore is a mineral aggregate that can be converted economically into iron. The quality of the iron ore is mainly determined by its composition: high iron content and low sulphur and phosphorus contents are favorable. Iron ore can be found all over the world, but its iron content varies.

Steel scrap has been effectively collected for several decades and is recycled as a valuable raw material for steel production.

There are two main processes for producing steel: by means of a blast furnace (indirect reduction) in combination with a converter, or by means of an electric furnace. In the former process, iron ore is the main raw material. In an electric furnace, scrap iron is used and occasionally also sponge iron. Sponge iron is an intermediate product, which is produced from iron ore by means of direct reduction (DRI or directly reduced iron) and then further reduced and smelted in an electric furnace.

3.2. Raw Material Preparation: Coking Plant, Sinter Plant

Before being used in the blast furnace, iron ore, coke, fluxes and air are pre-treated to ensure that the blast furnace process proceeds optimally.

Coke is produced from coal. Coal is not suitable for direct use in a blast furnace since it contains too many harmful or useless constituents for the reductive smelting process. Moreover, coal is not strong enough to bear the blast furnace charge. The conversion from coal to coke takes place in the coking plant, in the coke ovens at a temperature of up to 1100 ˚C. Since no oxygen is present in these ovens, the coal does not burn. This process is called dry distillation. It liberates a large quantity of gas and smoke, which, after purification, yields coke oven gas and other valuable commodities such as tar, ammonia and benzene. When the coal has been converted into coke, the coke is removed from the oven and quenched by spraying with water. Then the coke is crushed and screened until its granule size is suitable for use in the blast furnace. To reduce coke usage in the blast furnace, pulverized coal is also used. This pulverized coal is injected via tuyeres into the smelting section.

The production capacity of the blast furnace is increased by first converting fine iron ore and additives into sinter rather than charging the ore as such directly to the blast furnace. Sintering is the agglomeration by heat of fine ores, fluxes and recuperated materials. The mixture is heated briefly in the sintering plant up to about 1400 ˚C. This makes the components agglomerate. The cake is then crushed and screened, after which it is ready to be charged into the blast furnace.

3.3. Blast Furnace

Blowing large amounts of air into the blast furnace maintains the process. The air is taken from outside and blown by ventilators to the hot blast stoves. There the air, also referred to as blast, is preheated to about 1200 ˚C. The main reason for pre-heating the air is to reduce coke consumption: the heat supplied by the hot air no longer has to be supplied by burning the fuel (coke). The pre-heated air is fed to the lower part of the blast furnace vie tuyeres that ensure an optimal air distribution inside the blast furnace.

The gases formed by the coke burning in front of the tuyeres rise. The space created by this combustion and the smelting of the raw materials is filled continuously by the charge moving downwards. Accordingly, there is movement in two opposite directions: the gas ascending and the charge descending. The reducing reaction, which removes the oxygen from the iron ore, takes place by the formation of carbon monoxide. We call this indirect reduction.

The carbon monoxide gas is formed in the lower part of the blast furnace and rises up inside the blast furnace. At the same time, the descending charge comes into contact with this reducing gas, as a result of which liquid pig iron is formed and collects in the bottom of the blast furnace. The pig iron is tapped from the blast furnace at regular intervals. Just above the tuyeres, the oxides that have not been reduced react with each other to form slag. The formation of a slag that flows properly through the furnace charge is vital for the removal of all unwanted elements from the pig iron. The slag consists of complex compounds of calcium, silicon and magnesium. The slag is tapped from the blast furnace together with the liquid pig iron. A skimmer separates the slag from the pig iron in the slag runner.

During the production of pig iron, a substantial amount of gas is formed within the blast furnace. The gas is collected at the top of the blast furnace and purified. It can be then supplied to a power plant where it serves as fuel for electricity generation.

3.4. Pig Iron Treatment

The pig iron from the blast furnace is taken to the steel plant in torpedo ladles. These are first of all desulphurised with calcium carbide, which is introduced into the pig iron bath via an injection lance. The calcium sulphide formed floats as a slag on the pig iron. The torpedo ladle is then emptied into the pig iron ladle. This ladle is taken to the slag removal station where the slag from the blast furnace and the desulphurization process is removed.

3.5. Converting Pig Iron to Liquid Steel

After the slag removal, the pig iron is poured into the converter or BOF vessel. Scrap is added. Pure oxygen is blown through a lance onto the metal bath to burn off the excess carbon and impurities. At the same time silicon, manganese, phosphorus and residual sulphur present in the pig iron are also burnt off. To allow the purification process to proceed optimally, an amount of lime is added to the bath and an inert gas is blown through the bottom of the ladle. The reaction with oxygen during blowing process produces heat. By the addition of scrap, the temperature of the bath is controlled at about 1560 ˚C after the blowing process. The pig iron becomes steel.

At the end of the blowing process in the converter, the composition of steel is always about the same. To obtain different steel grades, the chemical composition has to be adjusted.

Additives and alloying elements are added to the converter to obtain the desired steel grade. The steel is poured in such a way that the converter slag is removed separately.

3.6. Ladle Treatment

To obtain an even better steel quality, the steel ladle is taken to the ladle treatment station. Here the steel can be cooled by adding small bits of scrap, and alloying material can also be added. A stirring lance is introduced into the steel while an inert gas is blown through it. The ensuring agitation results in an improved homogeneity of temperature and steel composition. In addition, inclusions and impurities are brought to the surface so that the steel is optimally purified. By adding aluminum, the oxygen still present in the steel is bound: the steel has become aluminum-killed. This is necessary for continuous casting. The steel now has the required composition and temperature.

Special steel grades which require very low carbon content are treated in the vacuum degasser of the steel ladle treatment station. It is done by lowering two snorkels into the steel. The steel is then drawn up into the degassing vessel by vacuum. Owing to the low pressure, the oxygen is combined with the carbon in the steel. The resulting gas is drawn off. In this way, the carbon content of steel can be reduced to extremely low values.

3.7. Steel Casting

After the steel ladle treatment, the ladle is taken to the continuous casting unit. Liquid steel runs from the ladle into the pouring basin or tundish that divides the steel the strand casters. A strand caster consists of a casting mould that is cooled by water and a series of rolls. Spray heads in between the rolls apply cooling water to ensure a further solidification of the steel. The casting mould determines the dimensions of the strand cast. To prevent the solidifying steel from sticking to the wall of the mould, the latter is continuously oscillating.

After the tap hole of the ladle has been opened, pouring continues until the ladle is empty. Because the tundish has a considerable buffer capacity, it is easy to exchange the empty ladle for a full one without interrupting casting into the mould. That is why the process is called continuous casting.

The strands emerge from the installation in a solidified state onto a horizontal roller table. Subsequently they are cut to length. Then the slabs thus obtained are slit lengthwise according to the widths that have been ordered.

Usually the slabs are cooled and inspected carefully for casting defects. Surface faults are removed by scarfing and the slabs are then transported to the reheating furnaces. Slabs with a perfect surface can also be introduced into these furnaces while still hot. This is called hot charging.

3.8. Electric Furnace – Simplification

When using an electric furnace, the sintering plant, the coking plant, the blast furnace and the converter are no longer required.

The raw material for an electric furnace is scrap metal. The scrap is charged into the furnace and melted by electrical energy. This energy is supplied by an electric arc between the furnace charge and large graphite electrodes. The liquid steel is poured into the steel ladle and acquires the required composition by the addition of alloying elements in the steel ladle treatment station.

Most electric furnaces have a capacity of about 150 tons. The reactions in the furnace are comparable with those in the converter in the blast furnace process. Unwanted elements can be removed by oxidation. However, not all elements are amenable to this method of removal, which means that the selection of the scrap to be used is of crucial importance, since some alloy elements present in the scrap metal will be retained in the liquid steel. With modern furnaces, the process takes less than one hour.

Points to remember:

- Before being used in the blast furnace, iron ore, coke, fluxes and air are pre-treated to ensure that the blast furnace process proceeds optimally.
- Products that are used in the blast furnace:
    - Top: In through the charging system – Sinter, Coke, Additives
    - Bottom: In through the tuyeres – Hot air, Pulverized coal
- Products that are formed in the blast furnace:
    - Top: Out through the gas exhaust – Gas
    - Bottom: Out through the tap hole – Pig iron, Slag
- A better steel quality can be achieved in the ladle treatment station (e.g. vacuum degassing).
- Slabs emerging from the continuous casting machine are either transported to the reheating furnaces while still hot (hot charge) or stored for later cold charge (surface defects are removed by scarfing).

Glossary:

English	Czech
Blast furnace	Vysoká pec
Coke	Koks
Continuous casting	Kontilití
Direct reduced iron (DRI)	Železo po přímé redukci
Flux	Tavidlo
Hot charge	Teplá vsázka

Scarfing	Čištění plamenem
Sintering	Spékání, aglomerace
Skimmer	Odlučovač strusky
Slag	Struska
Slag runner	Struskový žlab
Sponge iron	Houbovité železo
Tuyere	Výfučna

skimmer – odlučovač strusky

slag runner – struskový žlab

slag heap – halda

charge – pecní vsázka