Steel-making processes

**Abstract:**
Steel is made by the Bessemer, Siemens Open Hearth, basic oxygen furnace, electric arc, electric high-frequency and crucible processes. In both the Acid Bessemer and Basic Bessemer (or Thomas) processes molten pig iron is refined by blowing air through it in an egg-shaped vessel, known as a converter, of 15-25 tonnes capacity. In the Siemens process, both acid and basic, the necessary heat for melting and working the charge is supplied by oil or gas.

Both the gas and air are preheated by regenerators, two on each side of the furnace, alternatively heated by the waste gases. The regenerators are chambers filled with checker brickwork, brick and space alternating. The high nitrogen content of Bessemer steel is a disadvantage for certain cold forming applications and continental works have, in recent years, developed modified processes in which oxygen replaces air.

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**Crucible and high-frequency methods**

The Huntsman crucible process has been superseded by the high frequency induction furnace in which the heat is generated in the metal itself by eddy currents induced by a magnetic field set up by an alternating current, which passes round water-cooled coils surrounding the crucible. The eddy currents increase with the square of the frequency, and an input current which alternates from 500 to 2000 hertz is necessary. As the frequency increases, the eddy currents tend to travel nearer and nearer the surface of a charge (i.e. shallow penetration). The heat developed in the charge depends on the cross-sectional area which carries current, and large furnaces use frequencies low enough to get adequate current penetration.

Automatic circulation of the melt in a vertical direction, due to eddy currents, promotes uniformity of analysis. Contamination by furnace gases is obviated and charges from 1 to 5 tonnes can be melted with resultant economy. Consequently, these electric furnaces are being used to produce high quality steels, such as ball bearing, stainless, magnet, die and tool steels.
Acid and basic steels

The remaining methods for making steel do so by removing impurities from pig iron or a mixture of pig iron and steel scrap. The impurities removed, however, depend on whether an acid (siliceous) or basic (limey) slag is used. An acid slag necessitates the use of an acid furnace lining (silica); a basic slag, a basic lining of magnesite or dolomite, with line in the charge. With an acid slag silicon, manganese and carbon only are removed by oxidation, consequently the raw material must not contain phosphorus and sulphur in amounts exceeding those permissible in the finished steel.

In the basic processes, silicon, manganese, carbon, phosphorus and sulphur can be removed from the charge, but normally the raw material contains low silicon and high phosphorus contents. To remove the phosphorus the bath of metal must be oxidised to a greater extent than in the corresponding acid process, and the final quality of the steel depends very largely on the degree of this oxidation, before deoxidisers-ferro-manganese, ferro-silicon, aluminium-remove the soluble iron oxide and form other insoluble oxides, which produce non-metallic inclusions if they are not removed from the melt:

\[ 2\text{Al} + 3\text{FeO} \text{ (soluble)} \leftrightarrow 3\text{Fe} + \text{Al}_2\text{O}_3 \text{ (solid)} \]

In the acid processes, deoxidation can take place in the furnaces, leaving a reasonable time for the inclusions to rise into the slag and so be removed before casting. Whereas in the basic furnaces, deoxidation is rarely carried out in the presence of the slag, otherwise phosphorus would return to the metal. Deoxidation of the metal frequently takes place in the ladle, leaving only a short time for the deoxidation products to be removed. For these reasons acid steel is considered better than basic for certain purposes, such as large forging ingots and ball bearing steel. The introduction of vacuum degassing hastened the decline of the acid processes.

Bessemer steel

In both the Acid Bessemer and Basic Bessemer (or Thomas) processes molten pig iron is
refined by blowing air through it in an egg-shaped vessel, known as a converter, of 15-25 tonnes capacity (Fig. 1). The oxidation of the impurities raises the charge to a suitable temperature; which is therefore dependent on the composition of the raw material for its heat: 2% silicon in the acid and 1,5-2% phosphorus in the basic process is normally necessary to supply the heat. The "blowing" of the charge, which causes an intense flame at the mouth of the converter, takes about 25 minutes and such a short interval makes exact control of the process a little difficult.

The Acid Bessemer suffered a decline in favour of the Acid Open Hearth steel process, mainly due to economic factors which in turn has been ousted by the basic electric arc furnace coupled with vacuum degassing.

The Basic Bessemer process is used a great deal on the Continent for making, from a very suitable pig iron, a cheap class of steel, e.g. ship plates, structural sections. For making steel castings a modification known as a Topenas converter is used, in which the air impinges on the surface of the metal from side tuyeres instead of from the bottom. The raw material is usually melted in a cupola and weighed amounts charged into the converter.

**Open-hearth processes**

In the Siemens process, both acid and basic, the necessary heat for melting and working the charge is supplied by oil or gas. But the gas and air are preheated by regenerators, two on each side of the furnace, alternatively heated by the waste gases. The regenerators are chambers filled with checker brickwork, brick and space alternating.

The furnaces have a saucer-like hearth, with a capacity which varies from 600 tonnes for fixed, to 200 tonnes for tilting furnaces (Fig. 1). The raw materials consist essentially of pig iron (cold or molten) and scrap, together with lime in the basic process. To promote the oxidation of the impurities iron ore is charged into the melt although increasing use is being made of oxygen lancing. The time for working a charge varies from about 6 to 14 hours, and control is therefore much easier than in the case of the Bessemer process.

The Basic Open Hearth process was used for the bulk of the cheaper grades of steel, but there is a growing tendency to replace the OH furnace by large arc furnaces using a single slag process especially for melting scrap and coupled with vacuum degassing in some cases.

**Electric arc process**

The heat required in this process is generated by electric arcs struck between carbon electrodes and the metal bath (Fig. 1). Usually, a charge of graded steel scrap is melted under an oxidising basic slag to remove the phosphorus. The impure slag is removed by tilting the furnace. A second limey slag is used to remove sulphur and to deoxidise the metal in the furnace. This results in a high degree of purification and high quality steel can be made, so long as gas absorption due to excessively high temperatures is avoided. This process is used extensively for making highly alloyed steel such as stainless, heat-resisting and high-speed steels.

Oxygen lancing is often used for removing carbon in the presence of chromium and enables scrap stainless steel to be used. The nitrogen content of steels made by the Bessemer and electric arc processes is about 0,01-0,25% compared with about 0,002-0,008% in open hearth steels.

**Oxygen processes**

The high nitrogen content of Bessemer steel is a disadvantage for certain cold forming applications and continental works have, in recent years, developed modified processes in
which oxygen replaces air. In Austria the LID process (Linz-Donawitz) converts low phosphorus pig iron into steel by top blowing with an oxygen lance using a basic lined vessel (Fig. 2b). To avoid excessive heat scrap or ore is added. High quality steel is produced with low hydrogen and nitrogen (0.002%). A further modification of the process is to add lime powder to the oxygen jet (OLP process) when higher phosphorus pig is used.

![Diagram](http://www.key-to-steel.com/ViewArticle.asp?ID=2)

**Figure 2.**

The *Kaldo* (Swedish) process uses top blowing with oxygen together with a basic lined rotating (30 rev/min) furnace to get efficient mixing (Fig. 2a). The use of oxygen allows the simultaneous removal of carbon and phosphorus from the (P, 1.85%) pig iron. Lime and ore are added. The *German Rotor* process uses a rotary furnace with two oxygen nozzles, one in the metal and one above it (Fig. 2c). The use of oxygen with steam (to reduce the temperature) in the traditional basic Bessemer process is also now widely used to produce low nitrogen steel. These new techniques produce steel with low percentages of N, S, P, which are quite competitive with open hearth quality.

Other processes which are developing are the Fuel-oxygen-scrap, FOS process, and spray steelmaking which consists in pouring iron through a ring, the periphery of which is provided with jets through which oxygen and fluxes are blown in such a way as to "atomise" the iron, the large surface to mass ratio provided in this way giving extremely rapid chemical refining and conversion to steel.

*Vacuum degassing* is also gaining ground for special alloys. Some 14 processes can be grouped as stream, ladle, mould and circulation (e.g. DH and RH) degassing methods, Fig. 3. The vacuum largely removes hydrogen, atmospheric and volatile impurities (Sn, Cu, Pb, Sb), reduces metal oxides by the C – O reaction and eliminates the oxides from normal deoxidisers and allows control of alloy composition to close limits. The clean metal produced is of a consistent high quality, with good properties in the transverse direction of rolled products. Bearing steels have greatly improved fatigue life and stainless steels can be made to lower carbon contents.
Vacuum melting and ESR. The aircraft designer has continually called for new alloy steels of greater uniformity and reproducibility of properties with lower oxygen and sulphur contents. Complex alloy steels have a greater tendency to macro-segregation, and considerable difficulty exists in minimising the non-metallic inclusions and in accurately controlling the analysis of reactive elements such as Ti, Al, B. This problem led to the use of three processes of melting.

(a) Vacuum induction melting within a tank for producing super alloys (Ni and Co base), in some cases for further remelting for investment casting. Pure materials are used and volatile tramp elements can be removed.

(b) Consumable electrode vacuum arc re-melting process (Fig. 4) originally used for titanium, was found to eliminate hydrogen, the A and V segregates and also the large silicate inclusions. This is due to the mode of solidification. The moving parts in aircraft engines are made by this process, due to the need for high strength cleanliness, uniformity of properties, toughness and freedom from hydrogen and tramp elements.

(c) Electroslag refining (ESR) This process, which is a larger form of the original welding process, re-melts a preformed electrode of alloy into a water-cooled crucible, utilising the electrical resistance heating in a molten slag pool for the heat source (Fig. 5). The layer of slag around the ingot maintains vertical unidirectional freezing from the base. Tramp elements are not removed and lead may be picked up from the slag.