June, 2014

ENERGY ECONOMY IN EXTRACTIVE METALLURGY

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Energy Economy in Extractive Metallurgy

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Fuel, heat, and electricity are costly items in metallurgical processes and should be used with great efficiency to decrease production costs. To this end, the recent trend in metallurgical plants is focused towards the following goals:

- Increased use of heat recovery systems
- Improved process design
- Increased use of oxygen instead of air
- Improved methods of operation
- Increased use of direct heating systems
- Attempts to economize energy in the aluminum industry
- Improved equipment design

Fuel
Air
Exhaust gas

A metallurgical operation without a waste heat recovery system is intolerable. Recovery of as much as possible of the heat generated during the reaction that would otherwise be wasted improves the heat economy of a reactor. An extensive heat recovery system is also undesirable because it becomes costly, involves extensive piping, and plant space. A compromise is usually made between the cost of the systems and the value of heat recovered.

Increased Use of Heat Recovery Systems

Heat recovery in pyrometallurgical processes is in most cases poor, and only a fraction is recovered from the hot exit gases leaving a reactor while the bulk of the heat in molten material is mostly wasted.

Direct heat recovery system

To improve energy economy, heat from an exhaust fluid is used for preheating the entering fluid. For example, exhaust hot gases from a furnace can be used to preheat the air and/or the fuel (gas or liquid) used in the furnace (Fig. 1). The exhaust gas can also be used to preheat the solid charge entering the furnace, e.g., scrap iron before being introduced into the electric furnace. This system is known as direct heat recovery because the quantity of heat leaving the reactor is directly returned in the same reactor in form of preheated material.

Equipment used are tube heat exchangers or regenerators. Heat exchangers (Fig. 2) can be metallic or ceramic. The metallic exchangers are characterized by a high heat transfer coefficient and low gas leakage, but the metal temperature should not be allowed to exceed 1000 °C even to avoid excessive working stresses and hot spots. They are usually operated at a preheated temperature of 500–600 °C. The ceramic heat exchangers on the other hand are capable of providing the highest preheated temperature (up to 900 °C) but suffer from gas leaks because of their porosity and the susceptibility of crack formation. Silicon carbide is a preferred material of construction for this type of heat exchanger.

Regenerators (Fig. 3) are large chambers containing refractory brick arranged to give a large contact surface with hot gases, usually constructed underground below furnaces. The brick alternatively absorbs heat from the hot gas and then transfers it to the ambient air. Switching of gas flow from one chamber to the other is carried out automatically.

Indirect heat recovery system

Heat recovery may also be indirect, e.g., hot gases from a furnace can be used to generate steam in a waste heat boiler (Fig. 4). In this equipment (Fig. 5) hot gases are used to heat water and generate high-pressure steam. It is an empty chamber lined with hundreds of tubes through which water in circulated. Steam generated in the steam drums is usually used to drive turbines and generate electricity for general service in the plant. Hot gases cannot be used directly in gas turbines to generate electricity because the dust particles in the gas will damage the turbine blades.
This type of equipment involves a cyclic operation. Regenerators are large chambers containing refractory brick arranged to give a large contact surface with hot gases. The brick alternatively absorbs heat from the hot gas and then transfers it to the ambient air. Switching of gas flow is carried out automatically.

**Flash tanks**

Heat recovery in pressure hydrometallurgical plants involves the installation of flash tanks (Fig. 6). Steam generated in the flash tank is used to preheat the slurry being introduced to the autoclave. The flash tank is simply a large empty vessel in which the hot slurry under pressure is introduced, so that pressure is released to permit filtration in the next step and at the same time steam is generated due to sudden expansion.

**Exhaust gases containing carbon monoxide**

Gases leaving a blast furnace are not at high temperature but have a high calorific value due to their CO content. The gases are first purified of their dust content then burned in stoves and the heat of combustion is used to heat fire brick chambers (Figs. 7 and 8). Once the stoves are hot, the blast furnace gas is switched over to another stove and air is introduced into the hot stove to take away the heat before entering the furnace.
In steelmaking, heat can also be recovered from the exhaust gases generated during converting pig iron into steel. A 200 ton steel converter batch contains about 8.4 tons of carbon which are oxidized during blowing to carbon monoxide. Gases leaving such converter were usually left to burn to CO₂ forming a long flame (Fig. 9). Introducing air-tight hoods prevents this combustion, and CO can now be cleaned of its dust content and directed to a gas holder, from which it can be used on demand as a fuel thus economizing the overall energy balance as well as improving working conditions (Fig. 10).

Coke production

Coal is used in metallurgy as a fuel but the major use is to make coke that is an essential component of the feed to iron blast furnaces. The present technology for its manufacture is based on heating coal in retorts in absence of air then quenching the product with a limited supply of water shower. This last step is highly polluting due to dust and toxic organic emissions (Fig. 11). It also consumes appreciable amounts of water. A new technology now used in Japan and at few plants in Korea,
Increased Use of Oxygen instead of Air

It has been realized that the cost of separating oxygen from the air is less than the cost of using large equipment utilizing air either in hydro- or in pyrometallurgy. Air contains only 21% oxygen and the rest is essentially nitrogen which plays no useful role in metallurgical processes. Furthermore, nitrogen must be heated in the reactor and then as much as possible of this heat must be recovered when it gets out of the reactor. Fig. 13 shows the reduction of the volume of the combustion gas with increasing oxygen content.

Increased Use of Direct Heating Systems

In the pyrometallurgical production of zinc, a milestone was achieved by switching over from the horizontal retort system to the vertical furnace. Because the reduction temperature of ZnO is higher than the boiling temperature of zinc, the metal is always recovered as vapor which has to be rapidly condensed to prevent its re-oxidation by CO₂ in the flue gases. Therefore, the initial concept in the reduction furnace was indirect heating to prevent the contact of CO₂ with zinc vapor (Fig. 17). However, this proved to be a very intensive energy consuming reactor. Direct heating in the Imperial Smelting Furnace with excess preheated coke and rapid cooling of the vapors with a spray of molten lead solved this problem (Fig. 18).

A similar innovation was introduced in the reduction of MgO by ferrosilicon. The retort furnace (Fig. 19) has been replaced by the Magnetherm Process (Fig. 20).
this new process the charge including fluxes is heated electrically by a direct contact of an electrode in the slag. The system is kept under vacuum, and the distilled magnesium is recovered in a receiver.

### Increased Use of Electric Energy

Heating ores or concentrates by using electric energy is more efficient than heating by burning a carbonaceous material. There is no flue gases to worry about recovering their sensible heat or remove their dust content. Also, in electric heating the conduction of heat by the immersed electrodes is more effective than by radiation from the roof as in a reverberatory furnace (Figs. 21-23). Further, when sulfides are melted in an electric furnace any SO₂ formed will be in a high concentration to justify its recovery. As a result many horizontal furnaces burning carbonaceous fuel for smelting copper concentrates have been transformed into electrically heated furnaces.

### Improved Equipment Design

In an attempt to continuously oxidize finely divided sulfide concentrates the multiple hearth furnace was invented towards the end of the 19th century. Many years later, it was discovered that if the intermediate hearths were removed, the productivity of the furnace increased (Fig. 24). This paradox is due to the fact that the rate of a solid-gas reaction on the hearth is low and most of the reaction takes place when the sulfide particles descend from one hearth to the next as it becomes completely surrounded by air. As a result, the flash oxidation reactor was introduced in the 1940's in which the sulfide concentrate was simply sprayed in a co-current flow with preheated air in an empty chamber (Fig. 25).

Parallel to these developments was the fluidized bed concept in which the finely divided sulfide particles were introduced counter-current to the air flow in such a way that they were kept in a suspended state in a certain region in the reactor like a boiling liquid (Fig. 26). The system proved to be a very effective reactor for oxidation of sulfides, and later, for numerous other reactions (exothermic as well as endothermic) because of the increased productivity and the more precise temperature control.
to permit decreasing the copper content in the slag. The Noranda Reactor has been commercialized, but after some modification. The reactor is operated only to get a high-grade matte instead of the metal to decrease the impurity level in the final product. The concept of one reactor with two regions, one oxidizing and the other reducing was applied to lead sulfide concentrate in the QSL Reactor (Fig. 29).

For nickel sulfide the situation was slightly different because of the high melting point of the metal, the insolubility of nickel oxide in the sulfide phase, and the solubility of metallic nickel in the sulfide thus the formation of the metal does not aid in favoring the converting reaction. It was possible to solve these problems only when a Top Blowing Rotating Converter was used (Fig. 30). This permitted the nickel oxide to be mixed thoroughly with the sulfide thus forming nickel instead of forming oxide and thus being lost in the slag. The top blowing with oxygen was also necessary to achieve the high temperature needed to keep the nickel molten.

**Improved Methods of Operation**

Many improvements took place in operating the iron blast furnace in the past few decades. These improvements apply to any vertical furnace and can be summarized as follows:

- A vertical furnace is usually susceptible to channelling, i.e., the ascending gases penetrate unequally through the bed due to the presence of channels. This causes inefficient operation because certain parts of the bed undergo reaction while others, where the gas does not penetrate, descend without reaction. The main reason of channelling is the uneven particle size of the charge. Agglomeration of the charge and sieving to a narrow size range results in preventing channelling. This has been demonstrated and applied in iron blast furnaces (Fig. 31).

- Increased air temperature decreases coke consumption, decreases air volume, and consequently decreases exit gas volume per ton of iron produced. It also increases the productivity of the furnace because the reactions are faster (Fig. 32).

- Operating the furnace at a slightly high pressure decreases coke consumption because the equilibrium reaction

  \[ \text{CO}_2 + \text{C} \rightleftharpoons 2\text{CO} \]

  is shifted to the left.
is favored to the left at high pressure, thus decreasing an unnecessary coke consumption and consequently increased productivity (Fig. 33).

The above improvements combined, decreased coke consumption by half in the past years (Fig. 34). A similar situation took place in the production of aluminum: improvements in cell operation like automatic adjustment of anode-cathode distance, additions to electrolyte to improve conductivity, decreasing heat losses due to better operation, resulted also in a 50% reduction in energy consumption (Fig. 35).

**Attempts to Economize Energy in the Aluminum Industry**

Aluminum production which comes next to iron in tonnage is an energy intensive process. The energy required to produce 1 ton of aluminum from ore is more than twice that required to produce 1 ton of copper and ten times that for 1 ton of steel. More than 75% of this energy is consumed in the reduction of Al₂O₃ to metal. The reasons for this high energy consumption are the following:

- High quality carbon anodes must be prepared, and these are consumed during the reduction of Al₂O₃ by the oxygen generated.
- The anode and cathode in the electrolytic cell must be maintained relatively far apart to permit CO and CO₂ formation and smooth escape. This represents a high voltage and consequently high energy.
- The frequent changing of the consumable carbon anodes is a labor intensive operation. The collection and processing of the effluent gases for environmental control is difficult and costly. Millions of dollars are being spent in these years to find a less energy intensive process than the present one. None of these,
The inert anode process. Theoretically, if an inert anode is used the energy of reduction of Al₂O₃ would be slightly higher than a consumable carbon anode. However, in the case of an inert anode, the anode-cathode distance would decrease. This factor alone results in an overall less energy. In addition, high quality carbon will not be needed, the labor intensive operation of consumable anode changing will be practically eliminated, and oxygen will be a valuable byproduct instead of CO₂ mixture. An inert anode must have high electronic conductance, should not react with oxygen or with the molten salt bath, and have adequate mechanical strength. The most promising materials that satisfy these conditions are metallic oxides, e.g., iron nickel oxide and tin oxide.

The composite anode process. In this process a stoichiometric amount of Al₂O₃ is mixed with carbon (85% Al₂O₃ and 15% C) then baked at 900°C to make an anode. The electrolyte is a NaCl-AICl₃ which may contain fluorides and operated at 700°C. The anode reaction is the same as in the Hall-Heroult Process, but the energy consumption is lower. The anode-cathode distance can be made narrower. However, the size of the anodes handled will be larger and their conductivity smaller than the conventional prebaked anodes.

The aluminum chloride process. In this process Al₂O₃ is first mixed with carbon and chlorinated to make AlCl₃ which is then dissolved in a molten bath of NaCl-AICl₃. Graphite is used as non-consumable electrodes. The electrolyte is decomposed on passing the current to produce aluminum and chlorine; the latter is needed for the chlorination step. The process could start with clay instead of bauxite which is an added advantage for countries not possessing bauxite deposits. The energy requirement is said to be low. However, there are still problems to be solved.

Suggested Reading

- F. Habashi, Textbook of Pyrometallurgy, Métallurgie Extractive Québec, Québec City, Canada 2002, 660 pages. Distributed by Laval University Bookstore » Zone], www.zone.ul.ca
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