FLASH FURNACE COPPER SMELTING

Japan Oil, Gas and Metals National Corporation
2. Brief history of flash furnace

Turning heat of oxidation of sulphides to full account, the flash furnace requires almost none or the far lesser amount of extrinsic fuels, compared with blast furnace, reverberatory furnace or electric furnace. The flash furnace process is classified into two types by the structure and the sort of gas applied; Outokumpu flash smelting process and INCO oxygen flash smelting process. Nowadays, the Outokumpu flash smelting process stays in the mainstream of flash smelting process that has a dominance among copper smelting processes worldwide. The first flash furnace was built at Harjavalta Smelter of Outokumpu Oy, Finland, in 1949.

In Japan, the first flash furnace for copper smelting was installed at Ashio Smelter of Furukawa Co., in April 1956, introducing the Outokumpu's technology. This furnace was the second to the Harjavalta in the world. Hitherto, many innovations were made in the flash furnace process, and as a consequence of which, the flash furnaces were further introduced into such smelters as Kosaka, Saganoseki, Toyo and Tamano. Today, the flash furnace produces about seventy percent of copper in Japan. Worldwide, twenty three copper smelting flash furnaces are in operation at twenty two smelters.

3. Résumé of flash furnace

The main metallurgical process for copper smelting is shown in Fig.1. Reaction formulas for each process can be written as follows;

[matte smelting process]

\[
2\text{CuFeS}_2 \rightarrow \text{Cu}_2\text{S} + \text{FeS} + \text{FeS}_2
\]

\[
\text{FeS}_2 + \text{O}_2 \rightarrow \text{FeS} + \text{SO}_2
\]

\[
2\text{FeS} + 3\text{O}_2 \rightarrow 2\text{FeO} + 2\text{SO}_2
\]

\[
2\text{FeO} + \text{SiO}_2 \rightarrow 2\text{FeO} \cdot \text{SiO}_2
\]

[converting process]

[slagging stage]

\[
2\text{FeS} + 3\text{O}_2 \rightarrow 2\text{FeO} + 2\text{SO}_2
\]

\[
x\text{FeO} + y\text{SiO}_2 \rightarrow x\text{FeO} \cdot y\text{SiO}_2
\]

[blister making stage]

\[
\text{Cu}_2\text{S} + \text{O}_2 \rightarrow \text{Cu}_{20} + \text{SO}_2
\]

\[
\text{Cu}_2\text{S} + 2\text{Cu}_2\text{O} \rightarrow 6\text{Cu} + \text{SO}_2
\]

[electrorefining]

[anode reaction]

\[
\text{Cu} \rightarrow \text{Cu}^{2+} + 2\text{e}^-
\]

[ cathode reaction]

\[
\text{Cu}^{2+} + 2\text{e}^- \rightarrow \text{Cu}
\]
Fig. 1. Main processes for extracting copper from sulphide ores.
A flash furnace process is one of the matte smelting processes which convert sulphide copper to matte. Notwithstanding its short application history, the flash furnace has become a mainstay of matte smelting due to its superior characteristics.

Fig.2 and Fig.3 show outlines of two flash furnace types schematically. Regarding an Outokumpu type flash furnace, desiccated copper concentrate is injected at the top of reaction shaft with a preheated air, or a preheated oxygen-enriched blast. On the other hand, in the case of an INCO type flash furnace, concentrate is blown in horizontally at both ends of furnace using pure oxygen instead of air. Off-gas is discharged from the central duct.

Furthermore, MI furnace (Fig.4) and Noranda furnace have come on the scene as a furnace of high productivity and a modern smelting process suited for the acid production due to its high SO\textsubscript{2} concentration of off-gas.
4. Technological features of flash furnace

In contrast with the iron metallurgy, the oxidation of sulphide minerals proceeds as an exothermic reaction. The heat thus generated within a furnace is utilized to some extent even in the case of blast furnaces. The flash furnace makes use of the heat of reaction to the utmost, and utilizes it to melt matte and slag. In order to achieve this, the Outokumpu type flash furnace applies a preheated air, or a preheated oxygen-enriched air, and the INCO type uses pure oxygen as an oxidant. As a consequence, the emission of combustion gas is suppressed due to the decrease of extrinsic fuels, and the amounts of heat and dust accompanied to off-gas are diminished due to the decrease of nitrogen intake. Besides, the efficiency of sulfuric acid production is raised as a result of elevated levels of sulphur dioxide concentration of the off-gas, thus achieving the highest levels of recovery and fixing of sulphur.

The flash furnace, however, has such a drawback as a difficulty with lowering the copper grade of slag, which necessitates the reprocessing of slag by slag cleaning furnace, or the application of a flash furnace fitted with söderberg type electrodes, that is "a flash furnace with furnace electrodes" to lower the copper content of slag.

5. Worldwide diffusion of the flash furnace process

Since the first flash furnace was installed at Harjavalta Smelter of Finland in 1949, thirty five Outokumpu type flash furnaces have been built worldwide before now. Except for nickel or pyrite processing furnaces and the ones ceased from operation, twenty three flash furnaces are in operation at the twenty two copper smelters (Saganoseki Smelter has two flash furnaces). Tab.1 and Fig.5 show whereabouts of these copper smelting flash furnaces in operation.

6. Improvements of flash furnace operation in Japan

Furukawa Co., Ltd. introduced to Ashio Mine the technology of the flash furnace which had come into first operation at Finland in 1949 and were in its infancy technically then, and commenced its operation in 1955. Hitherto, Furukawa Co., Ltd. has improved a drying process of concentrates, the structure of furnace, the cooling system of furnace, the structure of concentrate burner and the slag cleaning furnace, and proved that the flash furnace processing were optimal to the copper smelting in future.
Tab.1 List of flash furnaces in operation for copper smelting worldwide

<table>
<thead>
<tr>
<th>Key</th>
<th>Name, location</th>
<th>Company</th>
<th>Capacity (T/D)</th>
<th>Start-up</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Harjavalta, Finland</td>
<td>Outokumpu Oy</td>
<td>1,440</td>
<td>1949</td>
</tr>
<tr>
<td>2.</td>
<td>Baia Mare, Romania</td>
<td>Comb. Chimico Metalurg.</td>
<td>1,956</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Kosaka, Japan</td>
<td>Dowa Mining Co.Ltd.</td>
<td>1,200</td>
<td>1967</td>
</tr>
<tr>
<td>4.</td>
<td>Saganoseki, Japan</td>
<td>Nippon Mining Co.Ltd.</td>
<td>1,800</td>
<td>1970</td>
</tr>
<tr>
<td>5.</td>
<td>Toyo, Japan</td>
<td>Sumitomo Metal Mine Co.Ltd.</td>
<td>1,600</td>
<td>1971</td>
</tr>
<tr>
<td>6.</td>
<td>Ghatsila, India</td>
<td>Hinustan Copper Ltd.</td>
<td>1,971</td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Tamano, Japan</td>
<td>Hibi Kyodo Smelting</td>
<td>1,900</td>
<td>1972</td>
</tr>
<tr>
<td>8.</td>
<td>Hamburg, Germany</td>
<td>Norddeutsche Affinerie</td>
<td>1,900</td>
<td>1972</td>
</tr>
<tr>
<td>9.</td>
<td>Saganoseki, Japan</td>
<td>Nippon Mining Co.Ltd.</td>
<td>1,800</td>
<td>1973</td>
</tr>
<tr>
<td>10.</td>
<td>Khetri, India</td>
<td>Hinustan Copper Ltd.</td>
<td>1,974</td>
<td></td>
</tr>
<tr>
<td>11.</td>
<td>Saganoseki, Japan</td>
<td>Nippon Mining Co.Ltd.</td>
<td>1,800</td>
<td>1973</td>
</tr>
<tr>
<td>12.</td>
<td>Playas, USA</td>
<td>Phelps Dodge Corp.</td>
<td>2,200</td>
<td>1976</td>
</tr>
<tr>
<td>13.</td>
<td>Huelva, Spain</td>
<td>Rio Tinto Minera</td>
<td>1,300</td>
<td>1975</td>
</tr>
<tr>
<td>15.</td>
<td>Onsan, South Korea</td>
<td>Korea Mining &amp; Smelting</td>
<td>1,000</td>
<td>1979</td>
</tr>
<tr>
<td>16.</td>
<td>Norilsk, CIS</td>
<td>Norilskii G-M. Kombinat</td>
<td>1,981</td>
<td></td>
</tr>
<tr>
<td>17.</td>
<td>Camacari, Brazil</td>
<td>Caraiba Metals S.A.</td>
<td>1,982</td>
<td></td>
</tr>
<tr>
<td>18.</td>
<td>Isabel, Philippines</td>
<td>Pasar</td>
<td>1,800</td>
<td>1983</td>
</tr>
<tr>
<td>19.</td>
<td>Guixi, China</td>
<td>Jianxi Copper Corp.</td>
<td>1,250</td>
<td>1985</td>
</tr>
<tr>
<td>20.</td>
<td>El Tajo, Mexico</td>
<td>Mexicana de Cobre S.A.</td>
<td>2,500</td>
<td>1986</td>
</tr>
<tr>
<td>21.</td>
<td>Chuquicamata, Chile</td>
<td>Codelco-Chile</td>
<td>2,062</td>
<td>1988</td>
</tr>
<tr>
<td>22.</td>
<td>San Manuel, USA</td>
<td>Magma Copper Co.</td>
<td>2,700</td>
<td>1988</td>
</tr>
</tbody>
</table>

Fig.5 Location of Outokumpu type flash furnaces for copper smelting.
Key numbers refer to data in Table 1.
The then copper smelters in Japan were applying blast furnaces to copper matte smelting, but converted to the flash furnace to boost the copper production against the surging demand, in collaboration with Furukawa, Co., Ltd. On the occasion of its introduction, each firm made efforts to create a characteristic flash furnace by adjoining an original technology of its own, and rationalized its operation by applying the fuel conversion to cope with the "energy crisis" emerged afterwards. The outlines of each improvement are given as follows.

6.1 Kosaka Mine of Dowa Mining Co., Ltd.

The northern district of Akita Prefecture bears the most prominent black ore deposits in Japan, and the copper concentrates extracted from black ores contain the greater amount of impurities such as lead and zinc, in comparison with the ordinary copper concentrates. These elements are enriched in metallurgical dusts to multiply their amounts. At the commencement of operation, the whole dust from the flash furnace had been circulated to the flash furnace. In 1967, however, the dust was shifted to the treatment in a rotary furnace to separate into crude lead and copper matte, this being treated in a converter, for the circulation to dust to the flash furnace created dust troubles in the waste heat boiler. But the volume of copper matte increased due to the high copper content of flash furnace dust, to raise the loads in the pertinent converters. Then in 1975, a new plant for hydrometallurgical processing of dust was installed. This plant was to treat the converter dust and the other precipitates from sulfuric acid plant as well as the dust from the flash furnace, and to separate them into copper sulphide, lead sulphate and zinc hydroxide to facilitate the recovery of each metal. Its flow sheet is shown in Fig. 6.

Fig.6 Flow sheet of hydrometallurgical processing of dust at Kosaka Mine
It is stated that this process has enabled to complete the treatment of black ore in flash furnace which had been deemed very difficult then.

Afterwards, the hydrometallurgical plant was further improved to treat the lead concentrate from black ore simultaneously.

6.2 Saganoseki Smelter of Nippon Mining Co., Ltd.

In 1966, the Saganoseki Smelter had a copper concentrate processing capacity of 20,000 tons per month, applying the oxygen-smelting process by blast furnaces and converters. However, as the domestic copper demand was expected to increase rapidly and the availability of copper concentrates was promising, the need to increase its capacity to 40,000 tons per month emerged. As a consequence of consideration upon a suitable metallurgical method, the flash furnace was judged optimal, and it was decided to uplift its unit capacity from conventional 10,000 to 15,000 tons per month to 40,000 tons per month with a leap.

A waste heat boiler is one of the most important parts of flash furnace, in relation to the cooling of off-gas and acid manufacturing. It cools the temperature of off-gas from 1000°C at the uptake outlet to 350°C. In order to minimize the volume of off-gas as well as possible and build a more compacted boiler, a high temperature blast and an oxygen enrichment were adopted.

A large scale flash furnace with such characteristics came into operation at first time in the world in 1970, pioneering the installation of the large scale flash furnaces worldwide.

In 1982 the Saganoseki Smelter succeeded in stepping up the annual copper production capacity to 300,000 tons, without changing the production regime of two flash furnaces and six converters, by using the total 6,200 Nm³/h of oxygen combining the older plant with the new oxygen generator of 3,700 Nm³/h capacity. In this case, it is required to balance the capacity of flash furnaces with the one of converters. It had better to raise the copper grade of flash furnace matte in order to lessen the load of converters, and around 50% Cu has been regarded appropriate as a common sense in relation to the copper loss in the slag. However, as a new technology to raise the copper grade of matte to around 60% without encouraging copper loss in the slag, has been developed, it has become possible to increase production with an insignificant extension of the converter operation time. Besides in 1991, the Smelter succeeded to raise the annual copper production to 330,000 tons, owing to the enlargement of off-gas processing units and an improvement of converter operation.

(1) High temperature blast

Although the flash furnace can utilize the heat of oxidation of ore efficiently, the ordinary copper concentrate (Cu 25%, Fe 26%, S 28%) lacks the sufficient heat to make matte grade 50% Cu, and needs auxiliary fuels burnt in the furnace, which increase the volume of off-gas by corresponding amount of volume. As Fig.7 shows, the volume of off-gas can be reduced by 20% by raising the temperature of blast from 500°C to 1000°C. In order to obtain a 1000°C blast, a fuel oil fired, regenerative hot blast stove was installed.

(2) Oxygen enrichment

It is shown in Fig.7 that the volume of off-gas can be reduced also by raising the oxygen content of blast. As Saganoseki Smelter were already practicing the oxygen smelting process with an oxygen generator of 2,500 Nm³/h capacity, the oxygen was easily applied to oxygen enrichment for flash furnace blast.
Fig. 8 Automatic control system for operating the Toyo flash furnace.

Fig. 9 shows the stabilized performance of furnace operation that is controlled by such a computer control system.
6.3 Toyo Smelter of Sumitomo Metal Mine Co., Ltd.

Toyo Smelter, which came into operation in 1971, is the first copper smelter in the world that applied an online computer control system to flash furnace.

The mainstay of control system consists in matte grade control, slag grade control and molten mass temperature control. A matte grade control is exercised by the volume of blast to the concentrate charge. The volume of blast is automatically regulated to meet the desired value of grade, if the assay of matte is inputted. When the assays of iron and silica of slag are inputted, the amount of flux charge varies to meet the predetermined Fe/SiO₂ ratio. When the measured value of temperature of matte is inputted, the system sets the amount of fuel oil burnt in the shaft to keep the predetermined matte temperature and the volume of blast sufficient to sustain its combustion (Fig.8).

Besides, at the occasion of a renewal of the system in 1986, a system to automate the main instrumental manipulation which controls the charge stoppage to flash furnace and the reopening of operation as well as the ordinary operation, was additionally introduced.

Fig.9 Graphs showing improved control of: (a) slag composition, (b) matte composition, and (c) matte temperature when an automatic control system is used

![Fig.10 Structure of flash furnace with furnace electrodes](image)

![Fig.11 Change of power input to furnace electrodes and fuel substitution to carbonaceous materials](image)
6.4 Tamano Smelter of Hibi-Kyodo Smelting Co., Ltd.

Tamano Smelter, which started its operation in 1972 as a consortium of Mitsui Metal Mining Co., Ltd., Furukawa Co., Ltd. and Nittetsu Mining Co., Ltd., is applying a flash furnace with furnace electrodes system.

As shown in Fig.10, the structure of a flash furnace with furnace electrodes has an uptake with water-cooled jacket in order to lessen the dust trouble at the uptake of conventional flash furnaces and the dust trouble within the waste heat boiler by reducing the temperature of off-gas at the inlet of waste heat boiler. Applying this system, the settler portion of flash furnace is cooled by the back cooling from uptake and fallen solid dusts. As a countermeasure to this drawback, a system to heat the settler portion resistively by electrodes was applied to save a conventional slag cleaning furnace.

In 1982 they made a success in converting the water-cooled jacket of uptake into a boiler, and increased the hourly vapour recovery by $3 \sim 3.5$ tons.

As the fuel oil price rocketed after the oil crisis, a conversion to less expensive solid fuels started. As the consumption of carbonaceous materials increased, the circumstances within the furnace began to pose different aspects. By measuring the CO concentration within the settler to grip the circumstances, they found that the CO concentration could be controlled by adjusting the amount of carbonaceous materials, which lessened not only the copper loss to slag, but also the electricity for heating the settler. Besides, the complete stoppage of electric furnace ceased to influence the furnace operation since December in 1987. Fig.11 shows that transition.

6.5 Utilization of oxygen

Since Saganoseki smelter started the application of oxygen-enriched air to flash furnace for the first time in Japan in 1970, an oxygen enrichment is always on the scene on the occasion of studying a rationalization against an oil price surge. According to the paper of Mr. Fujii of Furukawa Co., Ltd., generally speaking, 4.27 kwh of electricity can be generated out of 1 litre of fuel oil, because the electricity generation efficiency stands around 35%. And, a low pressure, large scale air separation plant needs 0.55 kwh of electricity to generate 1 Nm$^3$ of oxygen. Therefore 7.7 Nm$^3$ of oxygen is obtained with 1 litre of fuel oil.

If this oxygen is applied to flash furnace instead of the ordinary air, the heat removed by the nitrogen in the off-gas (1300°C at the outlet of flash furnace) will be reduced by 12,800 kcal.

$$7.7 \times 0.79 \times 0.21 \times 0.34 \times 1300 = 12,800 \text{kcal}$$

On the other hand, as it is empirically known that the combustion of 1 litre of fuel oil in the flash furnace generates 5,500 kcal of effective heat, the route [fuel oil $\rightarrow$ electricity $\rightarrow$ oxygen] is 2.3 times more favorable to energy saving ($12,800 \div 5,500 = 2.3$).
The upper limit of oxygen usage is determined by the conditions in which the consumption of fuel oil in the reaction shaft becomes zero, and the overdose of oxygen creates a heat imbalance. The limit of oxygen usage varies with the components of treated ores.

The volume \((\text{Nm}^3)\) of oxygen required to oxidize one ton of ore, is called a air/ore ratio. Fig.12 shows the relationship between the concentration of oxygen and the fuel oil requirement in the shaft, at different levels of air/ore ratio. When an ordinary ore is treated, the limit of oxygen concentration appears to \(30 \sim 40\%\) at best.

The purpose of oxygen usage is not restricted solely to substitution of fuel oil. Another merit is a possibility to increase the ore throughput by a surplus in the off-gas processing capacity.

Although an enlargement of apparatuses after the converter of acid plant is needed due to the rise of the \(\text{SO}_2\) concentration of the off-gas, a merit of a possibility to increase the acid production without changing such installations as flash furnace, waste heat boiler, dust collecting apparatus and washing apparatus, is great. Notwithstanding, a balance must be taken with the processing capacities of subsequent converters and blister refining furnaces.

Each company has accomplished a production expansion without an enlargement of fundamental installations by adopting such improvements as a) capacity raising of flash furnace through the utilization of oxygen, b) load lessening of converter by upgrading of matte to 60% Cu.

Tab.2 shows how the blister copper producing capacities of flash furnaces in Japan in 1975 have been stepped up at the time of 1990, by the increase of oxygen concentration of blast.

6.6 Environmental countermeasures

Each company is making effort to protect environments by adopting the following measures.

① Adoption of double-contact converter

As the stabilized high concentration of \(\text{SO}_2\) is attained by the adoption of flash furnace, the adoption of double-contact process to sulfuric acid plant converter has become possible, which lowered the \(\text{SO} \downarrow 2 \downarrow\) concentration of exhaust gas of absorption tower to a great extent.

② Countermeasures against smoke spillage at tapping process

Collecting apparatus for the gas emitted on the occasions of tapping of matte and slag are accomplished, and gathered gas is washed in off-gas desulfurization apparatus jointly with the gas from double hood of converters.

③ Purification of slag flowing water

As the slag granulates finely while quenched, a filter is fitted to prevent carry-over of fines.

④ Disposal of waste acid

Waste acids originating from sulfuric acid plant are neutralized to produce gypsum etc.

⑤ Waste water disposal equipments

All the water liable to dissolve the heavy metals are gathered and poured out of the smelter after treated by the waste water disposal apparatus.

By applying the above-mentioned counter-measures, Japanese copper smelters have succeeded in achieving a most advanced pollution control to create one of the cleanest smelters in the world.
Table 2 Smelting capacity of Japanese flash furnaces and their oxygen concentration

<table>
<thead>
<tr>
<th>Year</th>
<th>Company</th>
<th>Smelter</th>
<th>Smelting capacity</th>
<th>Oxygen concentration</th>
<th>Smelting capacity</th>
<th>Oxygen concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1975</td>
<td>Dowa</td>
<td>Kosaka</td>
<td>5,000</td>
<td>21</td>
<td>8,000</td>
<td>38</td>
</tr>
<tr>
<td></td>
<td>Hibi-Kyodo</td>
<td>Tamano</td>
<td>7,500</td>
<td>21</td>
<td>17,500</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Sumitomo</td>
<td>Toyo</td>
<td>10,000</td>
<td>21</td>
<td>19,800</td>
<td>35</td>
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<td></td>
<td>Nippn M.</td>
<td>Saganoseki</td>
<td>24,000</td>
<td>23</td>
<td>32,000</td>
<td>26</td>
</tr>
<tr>
<td>1990</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</table>

7. References


6) Yasuda M. (1984) "Improvement of Overall Operation Efficiency at Saganoseki Smelter and Refinery" Jour. of M.M.I.J. 100, (1157) 555-60


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