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FLASH SMELTING PROCESS [1]

by

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Introduction

1. During the last few decades, copper pyrometallurgy has primarily developed within the bounds of the old, proven smelting methods. Larger reverberatory furnaces and converters have been built than before and their specific capacity increased. In the roasting of the concentrates fluosolid roasting is becoming more general in use. In some converters oxygen has already been used for a long time. Recently, however, the use of oxygen has also been tested in the reverberatory furnace.

2. Among the few new processes, only the flash smelting method developed by the Outokumpu Company is now, after 20 years from its adoption at Harjavalta, becoming established for the smelting of copper concentrates.

3. The following flash smelters of Outokumpu type are in operation at present:

- Finland: Outokumpu Co. - the Harjavalta copper smelter, capacity 500 t.p.d.

  Outokumpu Co. - the Harjavalta nickel smelter, capacity 250 t.p.d.

  Outokumpu Co. - the Kokkola pyrite smelter, capacity 1700 t.p.d.

- Japan: Furukawa Mining Co., Ltd. - the Ashio copper smelter, capacity 500 t.p.d.

  The Dowa Mining Co., Ltd. - the Kosaka smelter, capacity 840 t.p.d.

  Nippon Mining Co., Ltd. - the Saganoseki smelter, capacity 1500 t.p.d.

- Rumania: Combinatul Chimico Metallurgic "Gheorghe Georghiu Dej", the Baia Mare copper smelter

4. Under construction or design are the following smelters:

- Japan: Sumitomo Mining Co., Niihama, copper smelter

  Mitsui Mining and Smelting Co., Hibi, copper smelter

- Turkey: Karadeniz Bakir Isletmeleri A.S., Samsun, copper smelter

- India: Indian Copper Corporation Ltd., Ghatsila, copper smelter

  Hindustan Copper Ltd., Khetri, copper smelter

- West Germany: Norddeutsche Affinerie, Hamburg, copper smelter

- Botswana: Bamangwato Concessions Limited, Johannesburg, nickel smelter

- Australia: Peko-Wallsend Metals Limited, Mount Morgan, copper smelter

  Peko-Wallsend Metals Limited, Tennant Creek, copper smelter.

5. In addition to these Outokumpu type flash smelters, there is a flash smelter operated by the International Nickel Company at Copper Cliff which uses a process developed by the same company. This smelter uses oxygen enriched air to compensate for the heat deficit in the system. The oxidation of the concentrate takes place in the settler in a horizontal gas flow. So far, this smelting method has not been adopted elsewhere.

6. At present, two continuous smelting methods for copper concentrates are being developed: the Worcra and the Noranda processes. In both of these methods, metallic copper is produced from the concentrates in a single furnace unit. Neither of the processes has yet been realized on a full commercial scale.

Process Description

7. Flash smelting has been the subject of many articles, e.g. (1)/(2). Flash smelting is a continous process combining the three stages of the conventional copper smelting: roasting, smelting and part-converting, all of which are carried out in the same furnace unit, the flash smelting furnace. The heat generated by the exothermic oxidation reactions is thus utilized for smelting and only a small amount of additional fuel is needed. The flash smelting furnace (Fig. 1) consists of three sections: a reaction shaft, a settler and an uptake. The oxidation reactions and smelting are effected in the vertical reaction shaft. For this purpose, the dried, fine-grained concentrate, flux and flue dust are led into one or several concentrate burners on the top of the reaction shaft. The preheated air or oxygen enriched air is also led into the concentrate burner, the air and concentrate feed mix and form a suspension which is blown into the reaction shaft. The heat developed by the oxidation reactions and additional fuel raise the temperature so high that the reaction products are smelted. The following reactions take place in the furnace:

$$2\ CuFeS_2 \longrightarrow Cu_2S + 1/2\ S_2 + 2\ FeS$$

$$FeS_2 \longrightarrow FeS + 1/2\ S_2$$

$$1/2\ S_2 + O_2 \longrightarrow SO_2$$

$$2\ FeS + 3\ O_2 \longrightarrow 2\ FeO + 2\ SO_2$$

$$2\ FeO + SiO_2 \longrightarrow 2\ FeO - SiO_2 \quad \text{(mainly in the settler)}$$

$$3\ FeO + 1/2\ O_2 \longrightarrow Fe_3O_4$$

8. The above mentioned reactions utilize completely the oxygen of the process atmosphere. The matte is composed mainly of Cu_2S and unoxidized FeS, the used air-concentrate ratio determining to what extent the FeS is oxidized and consequently, the matte grade.

9. As the retention time of the concentrate-air suspension in the reaction shaft is only 2-3 seconds, it is very important that even in the upper part

of the shaft the suspension is as homogeneous as possible. In the case of the concentrate-air suspension being inhomogeneous, the oxidation reactions in that part of the shaft having an excess of air may proceed so far that a large part of iron is oxidized into magnetite, generating excess heat. The over-oxidation of iron also results in a high copper content of the slag. Correspondingly, in that part of the shaft having an air deficiency, the oxidation reactions do not generate heat sufficiently, which may result in solid concentrate formation in the settler. For these reasons, special attention has been paid to obtain a constant feed rate and an even distribution of concentrate.

10. Molten particles are separated from the gas stream in the settler part of the furnace. Matte drops pass through the slag layer to the bottom of the settler. Iron oxide and other slag-forming compounds collect in the slag layer, where the main part of the slag reactions occur.

11. According to the present practice, the grade of the matte produced in the furnace varies between 45 - 65 %, the matte being then treated further in conventional converters. The slag contains too much copper, 0,8 - 1,5 %, to be rejected, and therefore it is processed further in an electric furnace, separate oil-fired settler, or by flotation.

12. The furnace exhaust gases have an SO_2-content of 10 - 14 %. A part of the most fine-grained reaction products, in the form of molten or semi-molten particles, is carried out of the furnace in the gas stream, the amount totalling 6 - 7 % of the concentrate feed. If the concentrate contains volatile components, such as Pb, Zn, As, Bi, etc., the dust content in the outgoing gases increases correspondingly.

13. After the flash smelting furnace, the gases are first cooled to a temperature suitable for feeding to the electrostatic precipitator, where the dust is recovered. The clean gases are generally used for the production of sulphuric acid. Since the gases have such a high sulphur dioxide

content, the converter gases, which have a lower SO_2-content, can be mixed with them, the SO_2-content required for the sulphuric acid plant still being maintained.

14. Normally, the recovered flue dust is circulated back to the furnace feed. The volatile components in the concentrate, such as Pb, Zn, As and Bi, are concentrated into flue dust, from which they can be recovered by treating the dust separately, e. g. using a hydrometallurgical treatment.

Requirements for Raw Materials in Flash Smelting

15. The raw material to be used in flash smelting shall be fine-grained and entirely dry sulphide concentrate or ore. As the concentrates are, in general, obtained via flotation, their fineness normally meets the requirements. In the case of the raw material being coarse, it must be ground to a fineness of 50 % -200 mesh at least. The fluxing agent required in smelting can be coarser than the concentrate, a sufficient degree of fineness being 80%-14 mesh. Since most of the concentrates being transported to the smelter have a 5 - 15 % moisture content, they must be dried before smelting.

16. With regard to the composition of the concentrate, the flash smelting process is flexible and easily adjustable. Additional fuel and preheated air or oxygen enriched air is used to compensate for the heat deficit in the concentrate. It is, however, essential for the process that a feed is obtained, the composition of which is not subject to momentary fluctuations.

The Harjavalta Copper Smelter

17. The first copper smelter using an electric furnace became operational in 1936 at Imatra. In 1944 this smelter was moved to Harjavalta. The copper flash smelter commenced operation in 1949, and in 1959 a nickel smelter using this process was put into operation. In addition to these smelters there are a nickel refinery and a power plant at Harjavalta.

In the nickel refinery the matte produced at the nickel smelter is refined to nickel using the electrowinning process developed by the Outokumpu Company (3). The steam generated by the process is utilized at the power plant for the generation of electric power. Anode copper is transported to the Pori Works, where the electric refinery is located.

18. The capacity of the Harjavalta copper smelter is 500 tons of concentrate per day. By means of oxygen enriched air, the present capacity will be increased to 700 - 750 tons per day. An agreement has recently been made for the supply of an oxygen plant, and this is scheduled to start operation at the end of 1971. In this connection, a part of the auxiliary equipment of the furnace, e.g. the waste heat boiler, will be modernized or replaced by new ones.

19. As the equipment at the Harjavalta smelter is not quite up to date, the description on the operations at Harjavalta given below also includes information on modern flash smelters. The flowsheet of the Harjavalta copper smelter is shown in Fig. 2.

Raw Material Handling

20. The concentrates are transported to the Harjavalta Works by rail from different mines. At the mines the concentrates are dried to a moisture content of 5 - 6 % to avoid troubles caused by freezing in winter, and also to save in freight costs. In addition, concentrates having the above mentioned moisture content can easily be proportioned by the belt-feeders located beneath the storage bin. The concentrates are transported in 50 ton ore waggons to Harjavalta, where they are tipped into the unloading pit. From there, the concentrates are further conveyed by belt conveyors to a concentrate storage which contains five 700 ton bins. Different concentrates are stored separately, since large analyses variations occur, e.g. the copper content from 20 to 25 %. The concentrate storage also has a bin for the flux. A homogeneous feed for the furnace is obtained

by feeding the different concentrates, in the correct proportions, by means of belt-feeders underneath the concentrate bin. A volumetric feed control is used. The belt-feeder is driven by a direct current motor which facilitates belt speed adjustments. In order to achieve a sufficiently accurate proportioning by the feeders, the lower end of the bin must be of proper design and the speed of the belts kept low, at a maximum of 0,05 m/s. The concentrates from various feeders are collected on a collecting band, and weighed by a belt scale which automatically sets the amount of the flux.

21. The thickened concentrate from the slag concentrator is pumped into the disc filter located above the drier. The filtered slag concentrate is proportioned to the furnace feed by use of the belt scale.

22. The above described proportioning system has been adopted at Harjavalta ecause of the accuracy gained and the low operating costs. Operating personnel are not continuously needed at the concentrate storage. The feed rate and the proportioning are controlled from the control room located at the drier.

23. The concentrates can also be transported in a dry condition, as is the case when handling, for instance, cement. Tank waggons are used for transporting, and the loading and unloading performed pneumatically.

24. The mixing of the different concentrates can also be performed at a bedding plant, which is quite common in copper smelters.

Drying

25. The drying of the copper concentrates at Harjavalta takes place in a 2,2 x 22 m rotary kiln. Drying is performed concurrently, since the copper concentrates easily catch fire when overheated. The heat required for drying is obtained by burning oil in the combustion chamber of the drier. The resultant combustion gases are diluted with secondary

temperature the gases come into contact with the damp charge. The first section of the drier is provided with lifter blades and the end section with honeycomb-lifters. From the lower end of the kiln the bone-dry concentrate falls through the screen into the pneumatic conveyor. About 10 % of the concentrate is removed in the exhaust gas (100 - 120°C). The dust is recovered by the electrostatic precipitator and returned to the concentrate flow.

26. The drier is controlled automatically. The amount of fuel is controlled according to the temperature of the exhaust gases, and the amount of secondary air according to the temperature at the outlet of the combustion chamber. Draft control keeps the pressure in the kiln constant.

27. The Japanese smelters have adopted a two-stage drying system, which deviates from the practice at Harjavalta. In the first stage the concentrate is dried in a rotary drier from 10 - 15 % to 5 - 6 % moisture, the final drying being performed in a flash drier where the concentrate is fed through a cage mill into a hot gas flow. The cage mill breaks up the concentrate and throws it into the hot gas flow. The flash drier also acts as a pneumatic conveyor which conveys the concentrate to the cyclones and the electrostatic precipitator located above the flash smelting furnace feed bin where it is separated from the gas stream. The separated concentrate then falls directly into the furnace feed bin.

28. One alternative to be considered is spray drying. In this type of drier the concentrate is fed as a slurry into an atomizer wheel which then throws the concentrate slurry into the hot gas flow, where it is dried. The majority of the dried concentrate is obtained from the drying chamber proper. The concentrate carried over with the gas is recovered in the conventional way.

29. The advantages of the spray drier are:

- elimination of filtering, which - as far as an extremely fine-grained concentrate is concerned - becomes very expensive
- ease of automation.

The following disadvantages can be mentioned:

- high consumption of fuel
- wear of atomizer wheel.

Transportation of Dried Furnace Feed

30. From the drier the furnace feed is conveyed pneumatically onto a horizontal Redler conveyor which takes it to the feed bin of the furnace. The pneumatic conveyor used at Harjavalta is of a low density type with an air pressure of 0,3 - 0,4 kg/cm^2. Characteristic of this type of conveyor is that it transports only in a vertical direction. Previously, vertical Redler conveyors were used for this purpose, but they were abandoned because they require a lot of maintenance, especially when abrasive sulphide concentrates are used.

31. One alternative is a high density pneumatic conveyor which is capable of carrying the concentrate directly from the drier to the furnace bin without any additional conveyors. A disadvantage of this conveyor is the subsequent wear when using sulphidic minerals.

32. From the furnace bin the concentrate is fed into the flash smelting furnace by means of a Redler type chain conveyor. By adjusting the chain speed of the conveyor a desired feed rate can be obtained. Thus the feed control is volumetric. Changes in the bulk density of the feed result in changes in the feed rate. Due to this, attempts have been made to weigh the feed from the feed conveyor. A weighing method based on γ-ray absorption in the concentrate is being tested at present. The flue dust

is fed into the furnace with a Redler conveyor similar to that mentioned above. As stated previously, an even feed rate is essential for the satisfactory operation of the furnace. Accordingly, the discharge end of the conveyor has been redesigned to eliminate the feed fluctuations characteristic of the chain conveyor.

Flash Smelting Furnace

33. The reaction shaft of the flash smelting furnace (Fig. 1) has an inside diameter of 3,85 m and a height of 8 m. It is entirely lined with chrome-magnesite bricks. In the lower part of the shaft there are two cooling rings made of copper plates, which support the brick lining. In addition, the shaft is provided with an outside spray cooling system. The arch of the reaction shaft is a sprung arch.

34. The settler has the following dimensions: length 18,4 m, width 5,1 m, and height 1,7 m. The walls and sprung arch are chrome-magnesite lined. The furnace base has an efficient heat insulation consisting of layers of chrome-magnesite and insulation bricks. Water-cooled copper elements surround the furnace at the slag line. In addition, in the reaction shaft end of the settler, where the temperature is higher, there are cooling elements above the slag line. The cooling elements are located behing the chrome-magnesite lining. The connection between the shaft and the arch is provided with cooling-element rings separated by bricks. The furnace uptake, the diameter of which is 2,75 m. is lined with chrome-magnesite and insulation bricks.

35. The concentrate burner is mainly carbon steel, the cones connected to the arch being heat resistant castings.

36. Typical temperatures in the Harjavalta furnace are as follows:

- combustion air 400 - 450°C
- exhaust gases 1270 - 1300°C
- matte 1170°C
- slag 1230°C

37. After Harjavalta became operational, the furnace lining had to be repaired once a year, but recently the repairs have only been required, at the most, once every two years. The uptake is cleaned at intervals of 1-2 months, this cleaning being performed with a reduced feed rate.

38. The flash smelting furnace is not fully automatically controlled, control being accomplished by manually changing the set values of the air and oil flows and the concentrate feed, according to the matte analysis and the temperature of the slag. The process is very stable and the control measures are not frequently required.

39. The matte is tapped from the furnace three times a day, four ladlefuls at a time. The tapping of the slag takes place at intervals of four hours. Under normal conditions the furnace contains 20 - 40 cm matte and 30 - 50 cm slag.

Waste Heat Boiler and Heat Exchanger

40. From the flash smelting furnace the gases are led into the waste heat boiler, which in the Harjavalta case is a large radiation chamber (Fig. 1) with the walls and roof lined with boiler tubes 1" in diameter. The purpose of the boiler is to cool the gases to such a low temperature that the molten particles in the gases solidify and the temperature drops below the sintering point. At this temperature the dust does not cause clogging in the heat exchanger after the boiler. The boiler is of a forced-circulation type with a pressure of 40 kg/cm^2. The pressure has to be so high that the boiling point and thus the temperature of the boiler tubes is above the dew point of the gases. The dew point of the flash smelting

furnace gases is 200 - 220°C. The boiler surfaces are cleaned by pneumatically operated soot blowers. The temperature of the gases at the boiler outlet is 650 - 700°C. Part of the dust carried out in the gas stream is separated in the boiler, and this is returned to the furnace feed. The steam generated in the boiler is superheated in a separate superheater at the power station and utilized for producing electric power.

41. The heat exchanger consists of a vertical shaft in which cast heat exchanger elements are placed. Both the inside and the outside of these elements are composed of fins. The air flows inside, and the gas outside of the elements, these being arranged in groups. The air flows through the upmost group at first, and then in a countercurrent direction to the gas (Fig. 1). The surfaces of the heat exchanger are subjected to continuous shot cleaning. The gases leave the heat exchanger at about 350°C, whilst the air is heated to about 400 - 450°C.

42. In the modern flash smelters the heat exchanger has been replaced by the convection part of the waste heat boiler. The present, combined boiler-heat exchanger at Harjavalta will also be replaced by a new boiler in which the gases will be cooled to 350°C. The walls and the roof of this boiler will also be lined with boiler tubes which, in this case, will be welded together to form a so-called membran wall, this being gas-tight and easy to keep clean. The boiler will be provided with automatically operated soot blowers.

43. Compared with the combined boiler-heat exchanger unit, the new waste heat boiler is flexible when receiving different raw materials, the heat exchanger having a tendency to become clogged if the concentrates to be smelted have a high lead or zinc content or if they contain other low melting components. Furthermore, the boiler-heat exchanger combination has the disadvantage of high maintenance costs.

44. When the gases are cooled to 350°C in the boiler, the air must be preheated by other means. The steam produced in the boiler or steam and additional fuel are suitable for the purpose. The steam generated in the waste heat boiler can be superheated either in a separate superheater or in a superheater built into the waste heat boiler itself. The use of a separate superheater is recommended when the concentrate contains a quantity of volatile components, due to its tendency to clog.

Dust Recovery

45. From the heat exchanger the gases are led to electrostatic precipitators, where the flue dust is separated from the gases. There are two electrostatic precipitators in parallel, each of them comprising of two high voltage systems connected in series. The flue dust thus collected is first transported by a vertical pneumatic elevator and then returned by an air slide to the furnace feed. The gases are led from the electrostatic precipitators to the sulphuric acid plant.

Slag Cleaning

46. Since 1966 flotation has been used for slag cleaning at Harjavalta. In order to be able to separate the copper from the slag by flotation, the slag must be cooled down slowly. This results in the sulphide and copper grains growing, and grinding prior to flotation is then required. The slag from the converter and flash smelting furnace is cast from a moving slag ladle into pits about 0,5 m deep. The slag is slowly cooled over a period of, at least, 8 hours. After this, water is squirted on the slag in order to speed up the cooling. The slag cake is loosened by a front-end loader and transported to the primary crushing plant, from where the product is conveyed by trucks to the concentrator for secondary crushing, this taking place in two cone crushers. Before this stage the lumps and pebbles required in autogenous grinding are separated by screening.

47. The slag is ground to a fineness of 90 % -270 mesh for flotation. The grinding is autogenous and performed in two stages. Both mills are in closed circuits with cyclones. The overflow of the cyclones is fed to the first stage of flotation, the unit cell, the concentrate obtained being mixed with the cleaned concentrate from the main flotation. The size of the lumps used for grinding is 80 - 150 mm, and that of the pebbles 40 - 80 mm.

48. Flotation takes place in mechanical cells using conventional flotation chemicals. The concentrate slurry, with a copper content of 18 - 23 %, is pumped to the smelter where it is filtered and mixed with the feed before drying. The copper content of the waste slag is about 0,3 %.

49. Various methods are used for slag cleaning, the choice of the method depending on the local circumstances, i. e. the price of electric energy, the composition of concentrate and the prices of metals. Besides flotation, electric furnace and oil-fired reverberatory furnaces are used for slag cleaning. The electric furnace can be used as a settler, as was done at Harjavalta in the 1950's. In this case the furnace is operated as a resistance furnace and a small amount of concentrate or components improving the fluidity of the slag are fed into the furnace. The power consumption of the electric settler ranges from 50 to 100 kWh per ton of slag, the copper content of the slag being 0,5 - 0,7 %.

50. If the copper content of the slag is to be decreased further, the electric furnace can be used for reducing the slag. This method has been tested at Harjavalta. When using this method, the furnace is operated as an arc furnace. Coke, which acts as a reducing agent, is fed into the furnace. This kind of slag reducing treatment is generally a batch process. The cleaning effect can be improved by feeding a small amount of sulphide into the furnace. The consumption of electric energy varies from 100 to 200 kWh

per ton and the copper content of the waste slag from 0,3 to 0,5 %. The reducing treatment of the slag is advantageous when the slag contains nickel or cobalt, the recovery of which in the electric settler or especially by flotation, is low. Where the flash smelting of nickel concentrate is concerned, the reduction of the slag is unavoidable.

51. The Japanese flash smelters treat the flash smelting furnace slag in the electric settler and the converter slag by flotation.

Converters and Anode Furnaces

52. One converter at a time is used for converting the matte. The size of this converter is 3,6 x 6,6 m and the effective blowing time 55 - 60 %. The blow rate is 270 m^3/min. All the anode scrap returned from electrolysis and the smelter revert are smelted in the converters. In addition to these, scrap from outside sources is also smelted. Due to the short blowing time, the converter must be heated with coke between the batches.

53. The converter gases are cooled in the waste heat boiler. This boiler is equipped with oil burners, so that the steam production can be maintained during stops in the converter operation. The steam generated in the boiler is utilized for producing electric power. The gases are led from the boiler to the cyclones for dust separation, and then to the sulphuric acid plant.

54. The blister copper is further treated in two rotating anode furnaces which have a length of 6,2 m and a diameter of 3 m. The furnaces are provided with oil burners. Birch trunks are used for poling.

55. The anodes are cast on a rotating anode wheel operating automatically. This automation is based on the weighing of the casting ladle. Copper is continuously poured from the furnace into the intermediate ladle, which then pours the copper into the casting ladle. When a rough weighing indicates that the casting ladle is full, the intermediate ladle ceases pouring. The casting ladle is weighed carefully and the result of the measurement fed

into an electric memory circuit. The casting ladle is tilted to pour the copper into the mould. A program controller controls the pouring speed. When the weight of the casting ladle has decreased by a predetermined anode weight, the casting is interrupted rapidly and the casting ladle returned to the rest position. The filling of the casting ladle is repeated, and the casting wheel rotates to the next position.

Steam Utilization

56. At the Harjavalta Work, the steam from the different process boilers is led to a power station (Fig. 4). The average steam production figures are as follows:

- copper flash furnace boiler	20 t/h
- nickel flash furnace boiler } - Ni-slag furnace boiler }	11 "
- converter boiler	6 "
Total	37 t/h

57. In addition to these boilers the power station has an oil-fired superheater boiler and an oil-fired stand-by boiler where additional saturated steam can be generated. The capacity of the turbine is 28 tons of steam per hour, and normal power generation is 5500 - 6300 kW. The rest of the steam is used for heating purposes.

Operating Statistics (January 1970)

58. Copper Flash Smelting

Concentrate	metric tons	14 560
Flux	" "	1 555
Slag concentrate	" "	1 954
Oil in smelting	kg/ " " conc.	28,5
Oil in drying	" " " "	6,1
Air preheating temperature	^{o}C	410
Blister copper	metric tons	4 474
Anode copper	" "	4 517

Typical Analysis

	Cu	Fe	S	SiO_2	Ni	Zn	Pb	CaO
Concentrates	21,4	32,0	33,9	6,1	0,19	2,48	0,32	0,32
Flux	-	1,0	-	85,0	-	-	-	1,0
Matte	59,0	14,8	22,5	-	0,49	1,6	0,73	-
Furnace slag	1,0	45,0	1,4	25,0	0,09	3,6	0,23	0,9

Slag Flotation

Slag treated	metric tons	15 160
Slag concentrate	" "	1 954
Slag tailing	" "	13 206

Typical Analysis

	Cu	Fe	S	SiO_2	Ni	Zn	Pb	CaO
Smelter slag	2,6	43,2	1,5	25,7	0,21	4,1	0,39	0,9
Slag concentrate	18,0	34,0	8,5	16,5	0,46	4,8	0,96	1,5
Slag tailing	0,32	44,5	0,45	27,0	0,13	4,0	0,3	0,8

Outlooks for Development in Flash Smelting

59. The emphasis of the research and development work in the field of flash smelting has recently been on

- producing a higher-grade matte
- producing elemental sulphur from the SO_2-gases generated in flash smelting.

Increase in Matte Grade

60. The conventional matte grade in the flash smelting furnace has varied between 45 - 65 %. However, a higher matte grade would offer the following advantages:

- a larger part of the sulphur is obtained in the flash smelting furnace as a continuous SO_2-gas flow,
- the converting work is reduced, and thus less converter capacity is needed.

61. The Harjavalta copper smelter has produced 75 - 80 % matte in the flash smelting furnace when operating for longer periods. Using a feed rate of 1 ton of concentrate per hour in a pilot plant, flash smelting has also been tested using various matte grades; in some of these tests metallic copper has been produced. When developing the smelting with higher matte grades, the greatest problem has been to achieve a sufficiently even feed rate and a sufficiently constant concentrate-air ratio. The concentrate burner operating satisfactorily with a 60 % matte grade, does not necessarily meet the requirements set for the smelting of matte with a higher copper content. When operating with the higher-grade matte the local oxidation liability increases. Consequently, the operation and design of the concentrate burner have been studied and developed to comply with their respective demands.

62. As to the present situation, it might be mentioned that the flash smelting method producing matte with a copper content of 75 - 80 % is ready for commercial operation. The rather low copper content of matte, 55 - 60 %, used at Harjavalta at present, is due to an insufficient smelter capacity. When operating with a lower matte grade, the furnace is capable of smelting a larger amount of concentrate since the gas volume is then at its smallest. The tests made with the pilot furnace show that it is possible to produce metallic copper directly in the flash smelting furnace.

Reduction of Sulphur Dioxide

63. A great deal of research and test work has been carried out by the Outokumpu Company on producing elemental sulphur from the flash smelting furnace exhaust gases. As a basis for this work was the experience gained at the Kokkola sulphur plant, which became operational in 1962 (5). This plant uses iron pyrites as a raw material. The process used is based on the thermal decomposition of the pyrites. On heating to 1200 - 1300°C

pyrites decomposes:

$$FeS_2 \longrightarrow FeS + 1/2\ S_2$$

Under these circumstances FeS is molten, sulphur appearing as a gas. When the operation started, the pyrites was decomposed under a neutral atmosphere. It was fed into an oxygen-free, high-temperature gas flow in the reaction shaft, where the above mentioned reaction took place. Since 1967 a large proportion of the sulphur and a part of the FeS have been oxidized in the reaction shaft, whereby the circumstances in the shaft are almost equivalent to those in the smelting of copper concentrates. The SO_2-gas formed has been reduced to elemental sulphur by means of light naphtha in the uptake. In this way, the portion of the recoverable elemental sulphur has been increased. When the pyrites is fed into the furnace at a rate of 70 tons per hour, the amount of elemental sulphur reduced from SO_2 in the uptake has amounted to 12 - 14 tons per hour; the respective naphtha consumption has been 3,5 - 4 tons per hour. The sulphur-bearing gases are cooled after reduction, cleaned in an electrostatic precipitator, and then led into catalysis and sulphur condensation stages.

64. On a pilot plant scale, the SO_2-gases received from the smelting of the copper concentrate have been reduced using butane and pulverized coal at a rate of 1 ton of concentrate per hour. The reduction has been carried out at a high temperature in the modified uptake of the flash smelting furnace. The results have shown that the sulphur dioxide can be reduced to elemental sulphur, the gas composition obtained closely corresponding to the theoretical calculations. In addition to sulphur vapour, small amounts of sulphur compounds, such as H_2S, COS, CS_2, are formed, the remaining amount of SO_2 corresponding to the equilibrium. By appropriate cooling of the gases and providing suitable catalyzers, it is possible to converrt the main part of the above mentioned sulphur compounds into elemental sulphur.

65. Based on the experience gained at the Kokkola sulphur plant and the results of the pilot plant tests, a full-scale plant is at present being designed. In this plant the gases from the nickel flash smelting furnace are reduced to elemental sulphur (Fig. 5) using coal as a reducing agent. The reduction is carried out in the specially designed uptake of the flash smelting furnace, and the sulphur-containing exhaust gases led into a waste heat boiler. In comparison to the modern flash smelting boiler a difference is that a superheater cannot be built into the boiler and the air cannot be used for soot blowing. In addition, the pressure of the boiler should be at least 70 kg/cm^2. After the boiler, the gases (350°C) are directed to the electrostatic precipitator, and the recovered dust returned to the furnace.

66. Clean gases are then led into the first catalyst stage, operating at a temperature of 400 - 450°C. For this purpose, the gases must be heated by direct oil firing to 400°C. A special, porous Al_2O_3-base catalyst is used. The following reactions take place in the catalyzer:

$$SO_2 + 2\,CO \longrightarrow 2\,CO_2 + 1/x\,S_x$$
$$SO_2 + 2\,H_2 \longrightarrow 2\,H_2O + 1/x\,S_x$$
$$2\,COS + SO_2 \longrightarrow 3/x\,S_x + 2\,CO_2$$
$$x = 2,\ 4,\ 6 \text{ or } 8$$

The reactions are exothermic and the temperature of the gases rise. For the subsequent catalyzing stage, the gases are cooled to about 250°C in the low pressure boiler. The catalyst is the same as in the first stage. The main reaction in this catalyzer is the following:

$$2\,H_2S + SO_2 \longrightarrow 2\,H_2O + 3/x\,S_x$$

After leaving the catalyzer, the gases are cooled by means of molten sulphur in cooling towers, whereby the sulphur is condensed. The molten circulating sulphur is cooled in the low pressure boiler. The gases leaving the spray towers still contain a small amount of elemental sulphur, and this is recovered by scrubbing with water. Finally the gases are led into the atmosphere.

Flash Smelting of Lead Concentrates

67. The above discussion has dealt with the use of flash smelting in the smelting of copper and nickel concentrates as well as in the production of sulphur from pyrites. Flash smelting of PbS concentrate has also been attempted on a pilot plant scale (6). The results indicate that the method is also suitable for the smelting of PbS concentrates.

Maximum Capacity for Flash Smelting Furnace

68. As stated above, a copper flash smelting furnace with a capacity of 1500 tons per day is in operation in Japan. The Kokkola sulphur plant smelts 1700 tons of pyrites per day in the flash smelting furnace, and a preliminary design has been made for a furnace with a capacity of 2400 tons per day. There is no definite maximum limit to the furnace size, however, increases in the furnace size necessitate changes in the furnace design. The maximum feed rate for a concentrate burner is 500 - 600 tons per day, for higher capacities several burners are required. If the width of the furnace is more than 6 m, a suspended arch or a semi-suspended sprung arch is used.

Conclusion

69. The majority of the copper smelters built in recent years, and those now under construction or design, are flash smelters. One reason for this is undoubtedly the fact that of all the smelting processes being used at present, flash smelting offers the best possibilities for the recovery of sulphur, and it is also a fact that the gases from the flash smelting furnace with a high SO_2-content mixed with the converter gases of a lower SO_2-content are

an ideal feed for the sulphuric acid plant. Nearly all the sulphur can thus be recovered. The method developed for reducing sulphur dioxide into elemental sulphur offers possibilities for sulphur recovery in such areas where sulphuric acid has no demand.

70. The flash smelting furnace mainly uses heat produced in the oxidation of the concentrate itself for smelting, and the consumption of additional fuel is only a part of that required in the conventional smelting methods. Flash smelting offers good possibilities for the recovery of the heat generated in the process and, if the converter is equipped with waste heat boilers, the plant is more than self-supporting in terms of power.

71. Compared with the normal hot reverberatory furnace smelting, flash smelting requires one additional step. This does not, however, make flash smelting technically complicated, and as a continuous process it can be easily controlled. The amount of converter operation is considerably smaller compared with conventional smelters. One 4,2 x 10 m converter is capable of producing 100 000 tons of copper per year. Effective cleaning of the slag results in a high copper recovery.

72. Flash smelting is flexible with regard to capacity as well as composition of the feed. Under normal conditions the turndown ratio is 1:3. It is essential for the process that the furnace feed has a sufficient degree of fineness and a moderately homogeneous composition.

73. A flash smelter comprising of one furnace can have a smelting capacity of up to 2400 tons per day.

Recommendation

74. When studying the various possibilities of processing sulphidic copper concentrates in the developing countries, there is reason to consider the flash smelting process as one alternative. This process has, during 20 years' operation, proved to be reliable in use. The advantages of flash

smelting are emphasized in such areas where fuel and electric power are expensive, this often being the case in the developing countries.

75. In the case where high sulphur recovery is essential, flash smelting is probably the only pyrometallurgical process used on a commercial scale at present to be considered.

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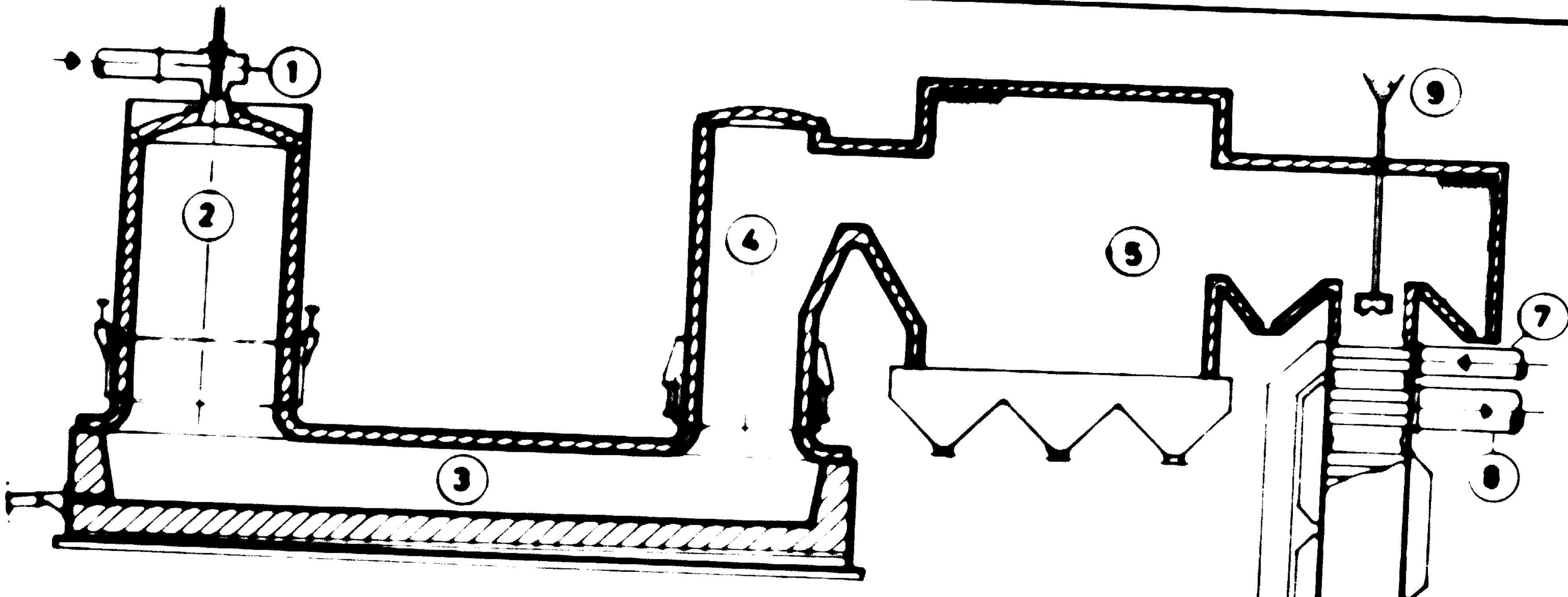


FIG. 1 THE FLASH SMELTING FURNACE AND WASTE HEAT BOILER & HEAT EXCHANGER COMBINATION

1 CONCENTRATE BURNER
2 REACTION SHAFT
3 SETTLER
4 UPTAKE
5 WASTE HEAT BOILER
6 HEAT EXCHANGER
7 COLD AIR INLET
8 HOT AIR TO CONC. BURNER
9 SHOT CLEANING
10 FLUE TO COTTRELL

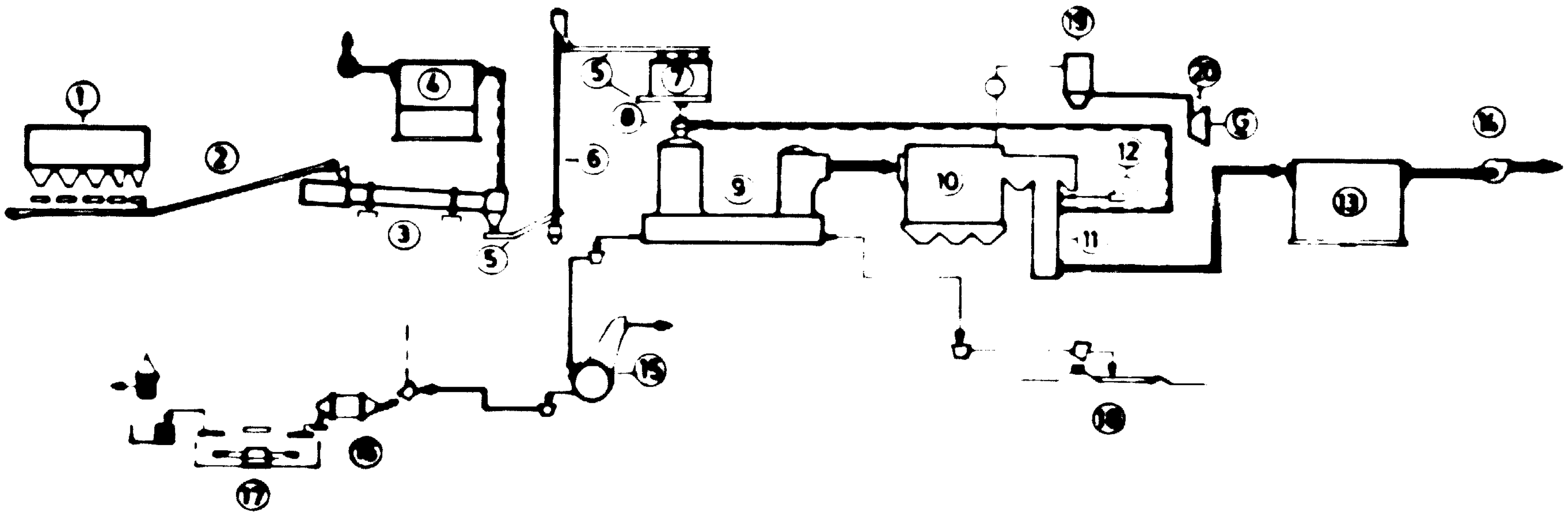
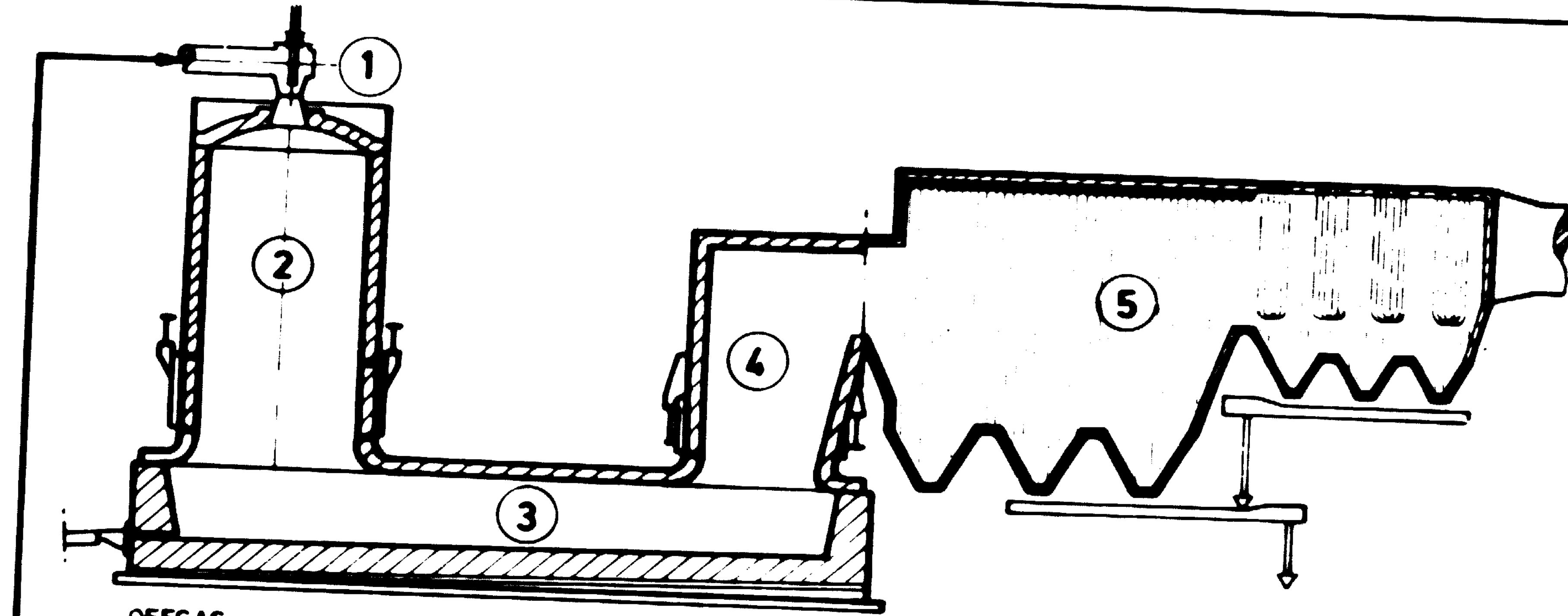


FIG 2 **FLOWSHEET OF THE HARJAVALTA COPPER SMELTER**

1. CONCENTRATE STORE
2. BELT CONVEYOR
3. DRYER
4. DRYER EL. STATIC PREC.
5. REDLER CONVEYORS
6. PNEUM. CONVEYOR
7. FEED BIN
8. CONCENTRATE BURNER
9. FLASH SMELTING FURNACE
10. WASTE HEAT BOILER
11. HEAT EXCHANGER
12. AIR FAN
13. ELECTROSTATIC PRECIPITATOR
14. EXHAUST FANS
15. CONVERTER
16. ANODE FURNACE
17. ANODE CASTING
18. SLAG CASTING
19. SUPERHEATER
20. TURBOGENERATOR



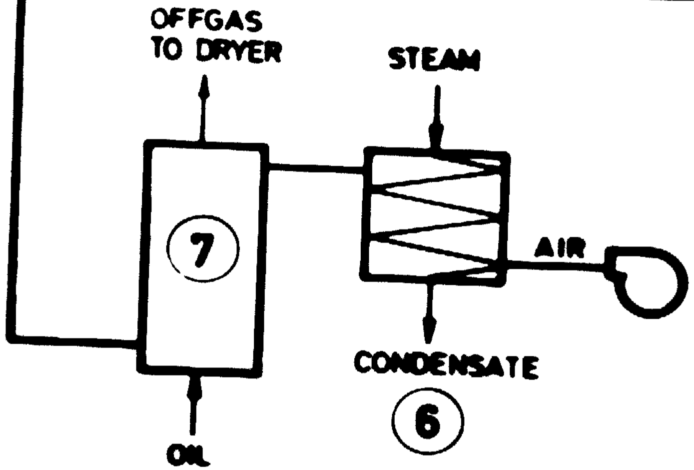


FIG. 3 THE FLASH SMELTING FURNACE AND WASTE HEAT BOILER WITH SEPARATE AIR PREHEATER

1. CONCENTRATE BURNER
2. REACTION SHAFT
3. SETTLER
4. UPTAKE
5. WASTE HEAT BOILER
6. STEAM AIR PREHEATER
7. OIL-FIRED AIR PREHEATER

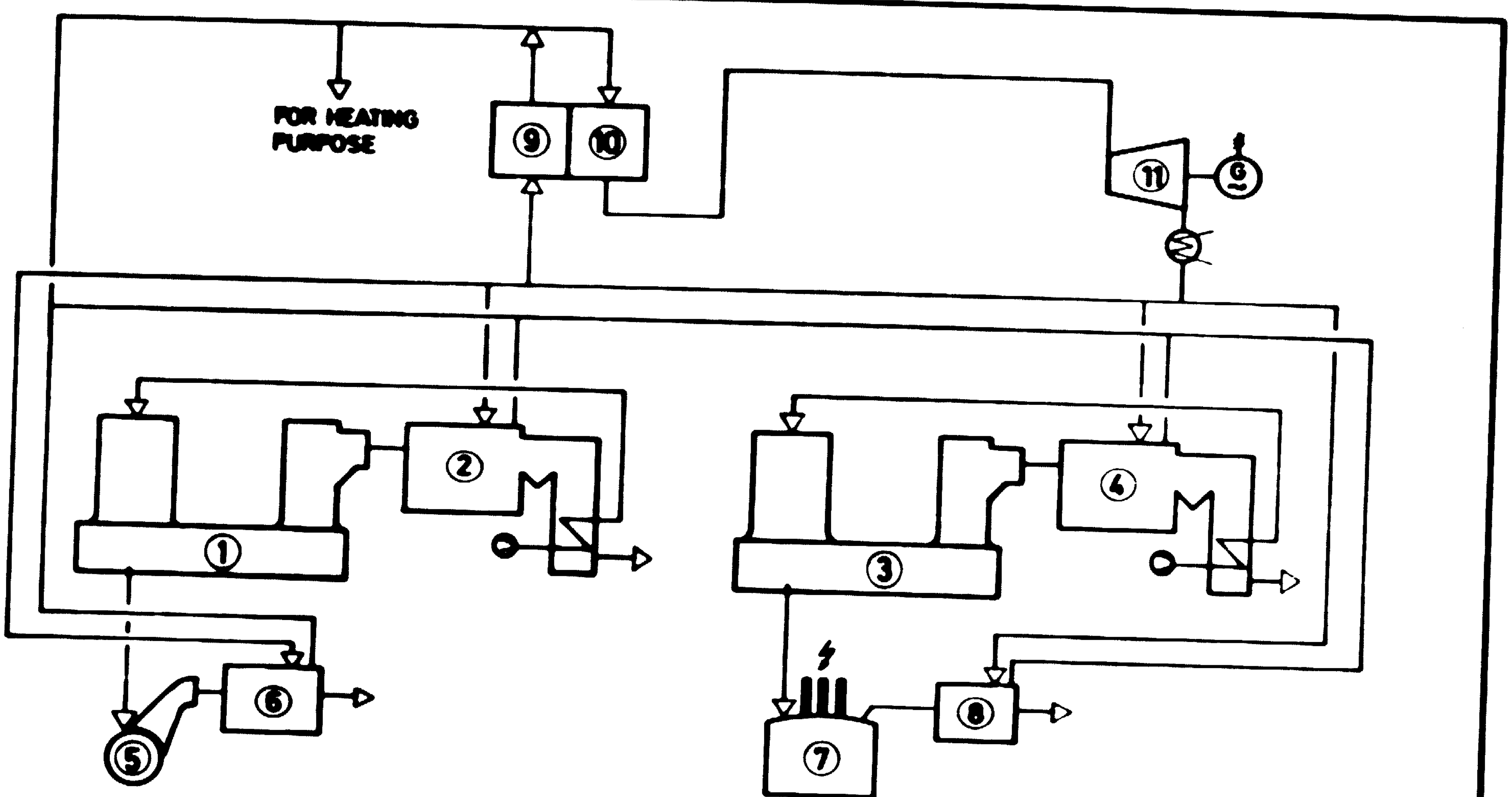


FIG. 4 STEAM UTILISATION AT HARJAVALTA PLANT

1. COPPER FLASH SMELTING FURNACE
2. WASTE HEAT BOILER FOR COPPER FSF
3. NICKEL FLASH SMELTING FURNACE
4. WASTE HEAT BOILER FOR NICKEL FSF
5. CONVERTER
6. WASTE HEAT BOILER FOR COPPER CONVERTER
7. NICKEL SLAG CLEANING FURNACE
8. WASTE HEAT BOILER FOR SCF
9. STAND- BY BOILER
10. SUPERHEATING BOILER
11. CONDENSATION TURBINE AND GENERATOR

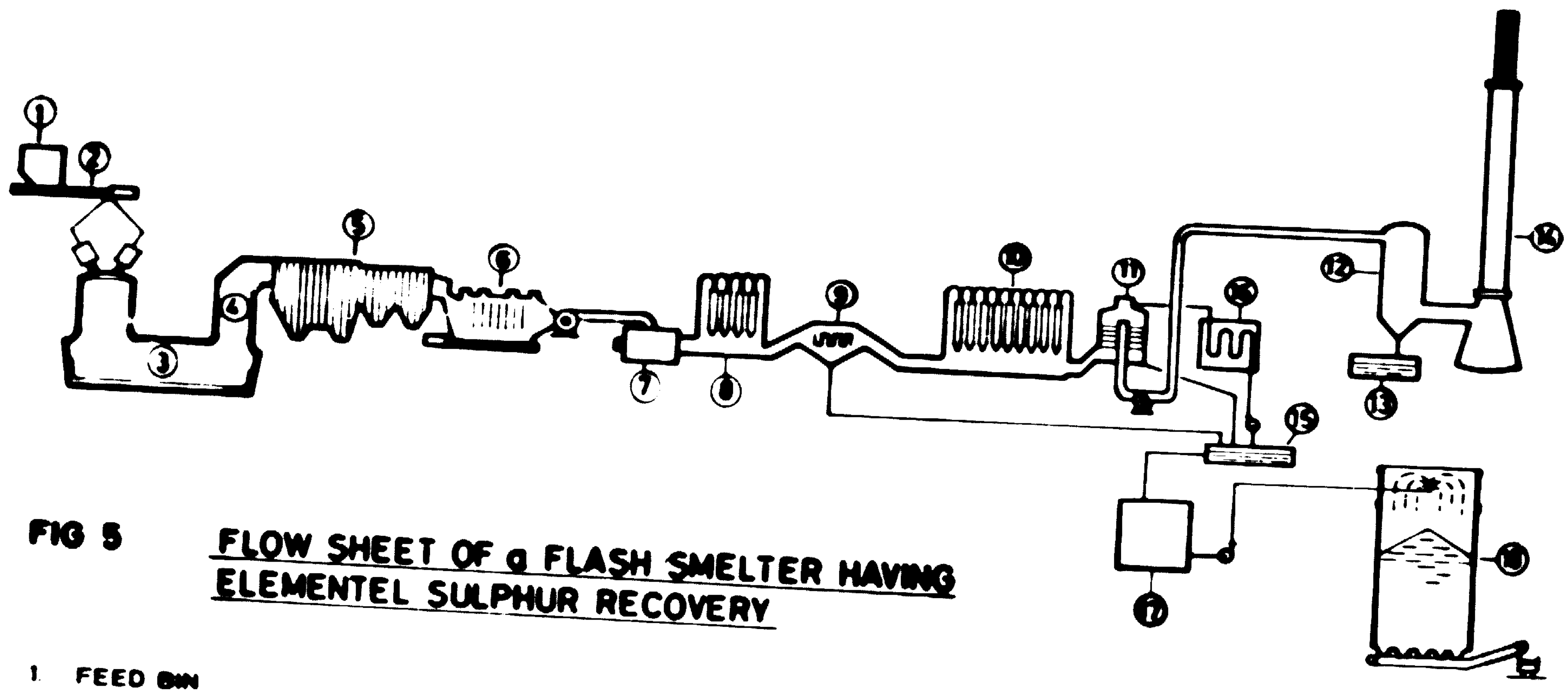


FIG 5 FLOW SHEET OF a FLASH SMELTER HAVING ELEMENTEL SULPHUR RECOVERY

1. FEED BIN
2. REDLER CONVEYOR
3. FLASH SMELTING FURNACE
4. REDUCTION CHAMBER
5. WASTE HEAT BOILER
6. ELECTROSTATIC PRECIPITATOR
7. GAS REHEATER
8. HOT CATALYZER
9. GAS COOLING BOILER
10. COLD CATALYZER
11. SULPHUR CONDENSER
12. GAS SCRUBBER
13. SETTLING TANK
14. STACK
15. CIRCULATION TANK
16. LIQUID SULPHUR COOLING BOILER
17. LIQUID SULPHUR STORAGE TANK
18. PRILLING TOWER

Summary

Introduction

1. During the last few decades, copper pyrometallurgy has primarily developed within the bounds of the old, proven smelting methods. Larger reverberatory furnaces and converters have been built than before and their specific capacity increased. The use of oxygen is gradually increasing also in copper metallurgy.

2. Among the few new processes, only the flash smelting method developed by Outokumpu is now, after 20 years from its adoption at Harjavalta, becoming established for the smelting of copper concentrates. At present seven flash smelters of Outokumpu type are in operation, three in Finland, three in Japan, and one in Rumania. Under construction or under design are nine more flash smelters.

Process Description

3. Flash smelting is a continuous process combining the three stages of the conventional copper smelting: roasting, smelting and part-converting, all of which are carried out in the same unit, the flash smelting furnace. The heat generated by the exothermic oxidation reactions is thus utilized for smelting and only a small amount of additional fuel is needed.

4. According to the present practice, the grade of the matte produced in the furnace varies between 45 - 65 %, which is then treated further in conventional converters. The slag contains too much copper, 0.8 - 1.5 %, to be rejected, and therefore it is processed further in an electric furnace, separate oil-fired settler, or by flotation. The furnace exhaust gases have an SO_2-content of 10 - 14 %.

5. After the flash smelting furnace, the gases are first cooled to a temperature suitable for feeding to the electrostatic precipitator, where the dust is recovered. The clean gases are generally used for the production of sulphuric acid. Since the gases have such a high sulphur dioxide content, the converter gases, which have a lower SO_2-content, can be mixed with them, the SO_2-content required for the sulphuric acid plant still being maintained.

<u>Requirements for Raw Materials in Flash Smelting</u>

6. The raw material to be used in flash smelting shall be fine-grained and entirely dry sulphide concentrate or ore. As the concentrates are, in general, obtained via flotation, their fineness normally meets the requirements. Most of the concentrates being transported to the smelter have a 5 - 15 % moisture content, and they must be dried before smelting. With regard to the composition of the concentrate, the flash smelting process is flexible and easily adjustable. Additional fuel, pre-heated air or oxygen enriched air is used to compensate for the heat deficit in the concentrate.

<u>The Harjavalta Copper Smelter</u> (Fig. 2)

7. The copper flash smelter commenced operation in 1949, and in 1960 a nickel smelter using this process was put into operation. The capacity of the Harjavalta copper smelter is 500 tons of concentrate per day. By means of oxygen enriched air, the present capacity will be increased in 1972 to 700-750 tons per day.

<u>Drying</u>

8. The concentrates are transported to the Harjavalta Works by rail from different mines. At the mines the concentrates are dried to a moisture content of 5 - 6 %.

9. The drying of the copper concentrates at Harjavalta takes place in a 2.2 x 22 m rotary kiln. The heat required for drying is obtained by burning oil in the combustion chamber of the drier.

The resultant combustion gases are diluted with secondary air, and consequently their temperature falls to 700 - 800°C, at which temperature the gases come into contact with the damp charge.

Transportation of Dried Furnace Feed

10. From the drier the furnace feed is conveyed pneumatically onto a horizontal Redler conveyor which takes it to the feed bin of the furnace. From the furnace bin the concentrate is fed into the flash smelting furnace by means of a Redler type chain conveyor. By adjusting the chain speed of the conveyor a desired feed rate can be ontained.

Flash Smelting Furnace

11. The reaction shaft of the flash smelting furnace has an inside diameter of 3.85 m and a height of 8 m. It is entirely lined with chrome-magnesite bricks. The settler has the following dimensions: length 18.4 m, width 5.1 m and height 1.7 m. The walls and sprung arch are chrome-magnesite lined. The furnace base has an efficient heat insulation consisting of layers of chrome-magnesite and insulation bricks.

12. Typical temperatures in the Harjavalta furnace are as follows:

- combustion air 400 - 450°C
- exhaust gases 1270 - 1300°C
- matte 1170°C
- slag 1230°C

Waste Heat Boiler and Heat Exchanger

13. From the flash smelting furnace the gases are led into the waste heat boiler, which in the Harjavalta case is a large radiation chamber with the walls and roof lined with boiler tubes. The purpose of the boiler is to cool the gases to such a low temperature that the molten particles in the gases solidify and the temperature drops below the sintering point. At this temperature the dust does not cause clogging in the heat exchanger after the boiler.

14. The heat exchanger consists of a vertical shaft in which cast heat exchanger elements are placed. Both the inside and the outside of these elements are composed of fins. The air flows inside and the gas outside of the elements.

15. In the modern flash smelters the heat exchanger has been replaced by the convection part of the waste heat boiler. The present combined boiler-heat exchanger at Harjavalta will also be replaced by a new boiler in which the gases will be cooled to 350°C. The walls and the roof of this boiler will also be lined with boiler tubes which, in this case, will be welded together to form a so-called membran wall.

16. When the gases are cooled to 350°C in the boiler, the air must be preheated by other means. The steam produced in the boiler or steam and additional fuel are suitable for the purpose.

Dust Recovery

17. From the heat exchanger the gases are led to electrostatic precipitators, where the flue dust is separated from the gases. The gases are led from the electrostatic precipitators to the sulphuric acid plant.

Slag Cleaning

18. Since 1966 flotation has been used for slag cleaning at Harjavalta. In order to be able to separate the copper from the slag by floatation, the slag must be cooled down slowly. This results in the sulphide and copper grains growing, and grinding prior to flotation is then required. Flotation takes place in mechanical cells using conventional flotation chemicals. The concentrate slurry, with a copper content of 18 - 23 %, is pumped to the smelter where it is filtered and mixed with the feed before drying. The copper content of the waste slag is about 0.3 %.

19. Various methods are used for slag cleaning, the choise of the method depending on the local circumstances, i.e. the price of the electric energy, the composition of concentrate and the price of metals. Besides flotation, electric furnace and oil-fired reverberatory furnaces are used for slag cleaning.

Converters and Anode Furnaces

20. One converter at a time is used for converting the matte. The size of this converter is 3.6 x 6.6 m. All the anode scrap returned from electrolysis and the smelter revert are smelted in the converters. The converter gases are cooled in the waste heat boiler. This boiler is equipped with oil burners, so that the steam production can be maintained during stops in the converter operation.

21. The blister copper is further treated in two rotating anode furnaces which have a length of 6.2 m and diameter of 3 m. The anodes are cast on a rotating anode wheel operating automatically.

Outlooks for Development in Flash Smelting

22. The emphasis of the research and development work in the field of flash smelting has recently been on

- producing a higher-grade matte
- producing elemental sulphur from the SO_2-gases generated in flash smelting.

Increase in Matte Grade

23. The conventional matte grade in the flash smelting furnace has varied between 45 - 65 %. However, a higher matte grade would offer the following advantages:

- a larger part of the sulphur is obtained in the flash smelting furnace as a continuous SO_2-gas flow,
- the converting work is reduced, and thus less converter capacity is needed.

24. The Harjavalta copper smelter has produced 75 - 80 % matte in the flash smelting furnace when operating for longer periods. Using a feed rate of 1 ton of concentrate per hour in a pilot plant, flash smelting has also been tested using various matte grades; in some of these tests metallic copper has been produced.

Reduction of Sulphur Dioxide

25. A great deal of research and test work has been carried out by the Outokumpu Company on producing elemental sulphur from the flash smelting furnace exhaust gases. As a basis for this work has been the experience gained at the Kokkola sulphur plant, which became operational in 1962. This plant uses iron pyrites as raw materials. The process used is based in the thermal decomposition of the pyrites.

26. On a pilot plant scale, the SO_2-gases received from the smelting of the copper concentrate have been reduced using butane and pulverized coal. The reduction has been carried out at a high temperature in the modified uptake of the flash smelting furnace. The results have shown that the sulphur dioxide can be reduced to elemental sulphur, the gas composition obtained closely corresponding to the theoretical calculations.

27. Based on the experience gained at the Kokkola sulphur plant and the results of the pilot plant tests, a full-scale plant is at present being designed. In this plant the gases from the nickel flash smelting furnace are reduced to elemental sulphur using coal as a reducing agent. The reduction is carried out in the specially designed uptake of the flash smelting furnace. The sulphur bearing gases are cooled after reduction, cleaned in an electrostatic precipitator, and then led into catalysis and sulphur condensation stages.

Flash Smelting of Lead Concentrates

28. The above discussion has delt with the use of flash smelting in the smelting of copper and nickel concentrates as well as in the production of sulphur from pyrites. Flash smelting of PbS concentrate has also been attempted on a pilot plant scale. The results indicate that the method is suitable also for the smelting of PbS concentrates.

Conclusion

29. The majority of the copper smelters built in recent years, and those now under construction or design, are flash smelters. One reason for this is undoubtedly the fact that of all the smelting processes being used at present, flash smelting offers the best possibilities for the recovery of sulphur. Nearly all of the sulphur can be recovered. The method developed for reducing sulphur dioxide into elemental sulphur offers possibilities for sulphur recovery in such areas where sulphuric acid has no demand.

30. The flash smelting furnace mainly uses heat produced in the oxidation of the concentrate itself for smelting, and the consumption of additional fuel is only a part of that required in the conventional smelting methods. Flash smelting offers good possibilities for the recovery of the heat generated in the process and, if the converter is equipped with waste heat boilers, the plant is more than self-supporting in terms of power.

31. As a continuous process, the flash smelting can be easily controlled. The amount of converter operation is considerably smaller compared with conventional smelters. Effective cleaning of the slag results in a high copper recovery.

32. Flash smelting is flexible with regard to capacity as well as composition of the feed. It is essential for the process that the furnace feed has a sufficient degree of fineness and a moderately homogeneous composition. A flash smelter comprising of one furnace can have a smelting capacity of up to 2400 tons per day.

Recommendation

33. When studying the various possibilities of processing sulphidic copper concentrates in the developing countries, there is reason to consider the flash smelting process as one alternative. This process has during 20 years' operation proved to be reliable in use. The advantages of flash smelting are emphasized in such areas where fuel and electrical power are expensive, this often being the case in the developing countries.

34. In the case where high sulphur recovery is essential, flash smelting is probably the only pyrometallurgical process used on a commercial scale at present to be considered.

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