COPPER LOSSES IN SLAGS AND TREATMENT OF COPPER SLAGS—A REVIEW

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Although the copper smelter is a very efficient unit, up to 1% of copper is lost into the dump slags. In this paper, the causes of copper losses into the slags is briefly reviewed with special emphasis on their chemical and mineralogical compositions. A critical survey of literature on the treatment of Copper slags reveals that whereas the copper-rich slags generated in matte conversion or continuous smelting can be successfully processed by techniques such as "Electric Furnace Settling" "Slag Concentration" and the "Kennicott Slag Cleaning Process", no proven method has yet been developed for the processing of dump smelter slags. Necessity of pursuing R & D work on copper recovery from the dump copper slags of India is also highlighted in this paper.

Over 80% of the world's primary copper originates from the pyrometallurgical smelting of its sulphide concentrates. Although the smelting of chalcopyrite concentrates is a very efficient process, for every ton of blister copper produced, 7–20 Kg. of copper is lost into the waste (dump) copper slags depending on the smelting procedures and the grade of concentrates employed. Considering the present primary copper production in the World and the fact that 2–4 tons (in exceptional cases 6 tons) of waste slag is generated for every ton of blister copper produced, it may be estimated that at present 15–20 million tons of copper slag is annually dumped by the copper smelters all over the world. This represents on an average, an annual copper loss of nearly 60,000 tons into the dump slags and in terms of costs this loss amounts to more than 10% of the smelting costs. The problem of copper losses into slags attracted serious attention only in the last decade and no comprehensive survey is available on this topic. In this paper an attempt has been made to review the chemical and mineralogical compositions of various types of copper slags, the origin and factors influencing copper losses in smelting and the treatment procedures (already in-vogue or under development) for different types of slags. At the end of this review, the need to recover copper from the dump slags of the two copper smelters in India is highlighted.

CHEMICAL COMPOSITION OF COPPER SLAGS

The chemical composition of various typical copper slags is shown in Table 1[1], from which it can be seen that essentially two types of slags are generated in the pyrometallurgical production of copper :

(A) Lean Copper Slags:— These are produced in the matte smelting of sulphide concentrates/calcines by techniques such as blast furnace, reverberatory furnace, electric furnace and flash smelting. The copper content in the dump slags is generally 0.3–1.0% and they contain 25–40% SiO_2, 25–45% Fe, 0.4–1.4% S and balance Al_2O_3, CaO, MgO, ZnO etc. When the copper content of the as-produced slags exceeds 1.0%, such as in flash smelting, these slags are cleaned within or outside the furnace and the resultant slags or slag tailings are dumped.

(B) Copper-rich Slags :— Slags rich in copper, containing 3–18% Cu, are produced not only in the matte converting operations but also in the most recent continuous smelting techniques like the Noranda Process. Such slags obviously require to be processed for their copper recovery and the treatment practices are summarised in a subsequent section of this paper.

MINERALOGICAL COMPOSITION OF COPPER SLAGS

Detailed mineralogical examination of copper slags received considerable attention in the past decade. Lindblad and Dufresne [2] reported that Anaconda reverberatory slag is a complex mixture of minerals including free metals, sulphides, oxides, silicates and glassy conglomerates of amorphous material. On a volume basis glassy conglomerates of imperfectly formed minerals (iron ackermanite and ilvait) and fayalite constitute the major portion of the slag (see Table 2). Magnetite is next in order of importance present to a considerable degree (10 Vol.%) in the slag. Copper itself is found to be present in a variety of forms chiefly as metallic copper, chalcopyrite and bornite. Subramanian and Themelis [8] as well as Rosenqvist [11] are of the view that roughly one half of the copper loss in industrial smelting slags is in the form of dispersed matte drop-

TABLE 1. CHEMICAL COMPOSITION OF COPPER SLAGS

Technique of Smelting	Percent composition											Ref. No.
	Cu	SiO_2	Fe	S	Al_2O_3	CaO	MgO	ZnO	Ni	Mo	Others	
(A) Reverberatory furnace												
Noranda	0.37	38.0	37.30	1.40	6.2	1.2	1.0	—	—	—	—	1
Anaconda	0.74	39.2	27.94	—	4.4	6 4	—	—	—	0.01	—	2
Onahama (old)	0.51	36.5	33.20	1.40	7.2	5.2	1.5	1.5	—	—	0.2Pb	3
Onahama (new)	0.36	37.5	32.10	0.60	8.0	5.4	1.3	1.3	—	—	0.2Pb	3
H.C.L/I.C.C.	0.41	33.4	43.20	1.00	7.5	1.5	2.1	—	0.08	—	—	4
INCO Ontario (Hot charged)	0.62	39.4	—	—	—	—	—	—	0.12	—	—	5
INCO Ontario (Wet charged)	0 77	35.4	—	—	—	—	—	—	0.22	—	—	5
Kennicott Copper Co.	1.10	35.0	38.00	—	5.1	—	—	—	—	—	0.5Cr	6
(B) Flash Furnace												
Outokumpu Oxygen flash	1.50	26.6	44.40	1.6	—	—	—	—	0.05	—	—	7
INCO Oxygen flash, Ontario	0.62	36.0	—	—	—	—	—	—	0.13	—	—	5
Hitachi	1 00	34.0	34.00	—	—	—	—	—	—	—	—	8
H.C.L./I.C.C. (uncleaned)	1.65	27.1	44.02	—	6.8	0.5	1.2	—	0.35	—	—	4
H.C.L/I.C.C. (cleaned)	0.78	29.7	44.06	1.4	7.8	0.6	0.5	—	0.15	—	—	4
(C) Continuous Smelting												
WORCRA	11.00	35.0	35.00	—	—	—	—	—	—	—	—	9
Noranda	8.12	22.0	36.00	—	—	—	—	—	—	—	—	8
Mitsubishi	17.60	—	—	0.2	—	20.1	—	—	—	—	—	10
(D) Converter												
Harjavalta	4.00	23.0	38.50	—	—	—	—	—	—	—	—	7
Kennicott Copper Co.	4.40	25.0	50.50	—	—	—	—	—	—	—	—	6
Hitachi	4.00	20.0	46.00	—	—	—	—	—	—	—	—	8
Naoshima	3.00	19.1	49.40	—	—	—	—	—	—	—	—	8
H.C.L./I.C.C.	4.28	28.70	45.50	—	—	—	—	—	—	—	—	4

TABLE 2. **Mineral phases in reverberatory copper slags**[2]

Mineral	Phase identified	Volumetric%
Silicates		
	Fayalite (Fe_2SiO_4)	20
	Iron Ackermanite ($Ca_2FeSi_2O_7$) + Ilvait (Ca_2Fe_2 "Fe"$(OH)Si_2O_8$)	60
Sulphides		
	Chalcopyrite ($CuFeS_2$)	1
	Bornite (Cu_5FeS_4)	1
	Ag, As and Bi minerals	trace
Oxides		
	Metallic copper	2
	Magnetite	10
Miscellaneous		

lets. Lukkarinen's examination [12] of flash furnace slags after slow cooling indicates that in such slags copper is essentially present in the form of digenite (Cu_9S_5) and bornite (Cu_5FeS_4). Some copper is also found as chalcocite (Cu_2S) and chalcopyrite ($CuFeS_2$). Altman, Schlein and Silva [13] from their examination of reverberatory slags concluded that nearly half of the sulphide copper is present as matte inclusions in the magnetite crystals.

The copper in converter slags is in the form of copper oxide dissolved in the slag (due to the highly oxidising conditions in the converter), entrained matte, and metallic copper formed by the Cu_2S-Cu_2O reaction. Edlund and Hussey's examination [14] of typical converter slags indicates that copper occurs principally as copper sulphide, approximating to the composition of bornite. Most of the sulphide parti-

cles range in the size 10–40 microns, some of the sulphides occur as stringers, but most are present as rounded particles. Magnetite is observed both as dendrites and well-formed crystals. Typical continuous smelter slags generated in the Noranda process contain a high proportion of copper (8–12%). It has been reported [15] that in a typical slag about 55% of the copper is dissolved, 33% is entrained as matte and 12% is entrained as metallic copper. Further the slag is highly oxidised and contains 20-30% Fe_3O_4 in soluble and entrained forms.

Detailed E.M.P.A. studies by Shelly and Shelly [16] on various commercial copper slags (lean as well as rich) reveal that most of the copper is present in slag as droplets 0.01-0.1 mm in diameter either as metal or as different sulphides. Rich converter slags generated in the second stage of conversion are reported to contain copper essentially as the metal and oxide in the form of droplets of 0.05–2.0 mm diameter.

ORIGIN OF COPPER LOSSES IN SLAGS

Waste copper slag is obviously a product of matte smelting and it is now useful to understand briefly how it originates.

The objectives of matte smelting are (i) to isolate all the copper of the charge into the matte phase and (ii) to separate all copper–rich matte from the slag [17] and these are achieved by the virtue of the inherent difference in the physical and chemical properties of the respective fluids. Slag is an ionically bonded and a highly viscous fluid while matte is a covalently bonded and semiconducting fluid of lower viscosity [18]. Studies of the phase diagrams of FeO-FeS–SiO_2 [19] and Cu_2S-FeS-FeO-SiO_2 [20] at temperatures of interest in smelting reveal that the sulphides and oxides are highly miscible when silica is absent from the system. Industrial mattes (30–60% Cu) at 1200°C dissolve upto 50% of their own weight of FeO. Thus, in the absence of silica, the above sulphide–oxide system is largely a single phase and no matte/slag separation is possible. The presence of adequate quantities of silica results in the separation of the slag phase as a distinct entity. Silica saturation of the slags is the prime criterion for the satisfactory separation of the matte. Nonattainment of the first objective suggests an incomplete isolation of the two phases (viz., slag and matte) or in other words, entrainment of the matte in the slag. Experimental work of Spira and Themelis [21] indicates the presence of copper in the slags in excess of that calculated on the basis of the chemical solubility of copper matte in the silica—saturated (35–40% SiO_2) slags under smelting conditions.

FACTORS INFLUENCING COPPER LOSSES IN SMELTING

Copper losses, in general, depend on the technique of smelting, concentrate grade, nature of the concentrate (i.e, green or calcine), slag composition, temperature of smelting, grade of the matte aimed at, oxygen potential in the furnace, hydrodynamic conditions etc.

Technique of Smelting :— This has an inherent influence on the copper content in the slag. Table 3 gives the losses of copper in slag with respect to the technique of smelting. It is seen that slags generated in reverberatory smelting employing green concentrate contain lower copper than the slags generated in the modern smelting techniques like the flash furnace and continuous smelting (Noranda Reactor). This is related to the physico-chemical and hydrodynamic conditions prevailing in the smelting unit [22].

TABLE 3. **Copper losses in the dump slags from different smelting techniques**

Smelting technique	Kg. of copper lost in slag per ton of blister produced	Reference No.
Blast Furnace (fuel in tuyeres)	9	22
Reverberatory Furnace (Calcine)	12	23
Reverberatory Furnace (green)	7	24
Electric Furnace (Calcine)	16	25
Flash Furnace (Air, External Electric Furnace Settler)	20	26
Flash Furnace (Air, Internal Electric Furnace Settler)	14	27
Oxygen Flash Smelting	12	28
Noranda Process	15	15

Concentrate Grade: The copper loss into the slag is directly related to the grade of the concentrate. Higher the grade of the concentrate, lesser is the quantity of slag produced, resulting in a lower total loss of copper into the slag.

Nature of the Charge:— Smelting of green concentrate in reverberatory furnace has been found to be conducive to lower copper losses into the slags [24] (~7 kg of copper per ton of blister produced) possibly because of the higher sulphur availability for matte formation. Calcine smelting results in higher copper losses into the dump slag [23'25] (12–16 kg of copper per ton of blister produced).

Slag Composition:— The profound influence of the composition of slag on copper losses has been thermodynamically studied and the same is established to practice on the effectiveness of the isolation and separation of slag/matte. As noted earlier, silica content of the slag is the most outstanding factor which influences the matte/slag separation and hence the copper losses in smelting. Most complete isolation (recovery) of copper into the matte occurs at near silica saturation conditions, e.g., 35–40% SiO_2 at 1200°C. Other constituents like alumina and calcia (up to 10%) stabilize the slag structure [29] and help in better slag/matte separation resulting in lower copper losses into the slag. Magnetite formed in smelting slags causes a number of problems in operation. One chief problem is that it renders the slag highly viscous, inhibiting the separation of matte and slag. This results in enhanced copper losses into the slag.

Temperature of Smelting:— At higher temperatures of smelting ($\geq$ 1200°C) a fluid slag is formed, facilitating clear-cut separation of matte and slag and thereby lower copper losses in the slag. Thus higher the smelting temperature, lower will be the copper losses in the slag.

Oxygen Potential in Smelting:— The oxygen potential in smelting has direct bearing on the copper losses into the slag. Higher oxygen potential prevails in the newer continuous processes of smelting like the Noranda Process, oxygen flash smelting and in conventional reverberatory furnace employing calcine. In all such cases higher copper losses into slag are reported.

Grade of the Matte:— Experimental and industrial studies with different matte grades show that the concentration of copper in the slag is proportional to the grade of the matte. Hence with constant quantity of slag weight, a high grade matte causes high loss of copper into the slag. Copper loss in slag is related to matte grade by the following empirical relationship [16]:

$$\frac{\%\ \text{Cu in Slag}}{\%\ \text{Cu in matte}} = 0.013$$

Hydrodynamic Conditions — Techniques wherein relatively quiescent conditions of smelting prevail, the loss of the copper into the slag is less, e.g., reverberatory furnace smelting and electric smelting. Where the conditions of smelting are dynamic, there is lesser opportunity for the slag/matte separation and consequently the loss of copper into the slag is high (as in flash smelting and more so in continuous smelting). More dynamic and turbulent conditions of smelting eventually lead to higher copper losses into the slag. Model studies of the transport mechanisms by Minto and Davenport [30'31] on liquid metal and liquid matte systems provide evidence that there is physical transport of the matte into the slag by gas bubbles and subsequent entrapment of the matte droplet. This conclusion is drawn from studies on equilibrium relation between copper, iron-copper-matte and iron silicate slag at 1200°C.

TREATMENT OF COPPER-RICH SLAGS GENERATED IN CONVERSION/CONTINUOUS SMELTING

Treatment of copper-rich slags (3–18%) generated in conversion is perhaps as old as the copper matte converting practice itself. The traditional practice consists of recycling the converter slag along with a batch of fresh charge to the smelter (reverberatory/electric furnace). Such a practice causes problems and in recent years two new techniques have been evolved for the treatment of the converter slags. In addition, a few laboratory/ pilot plant scale methods have also been investigated for this purpose. The conventional/recent practices for treatment/ recycling of copper-rich slags as well as the recent researches on these are briefly reviewed below:

Traditional Practice:— The converter slags are usually recycled to the smelting unit (reverberatory/electric furnace) to denude the copper value. This practice leads to several problems in the campaign of the smelting furnace. These problems include (i) reduced capacity (or throughput) of the smelting unit (ii) higher fuel consumption (iii) increased quantities

of slag formation in the reverberatory/electric furnace and thereby more of copper losses (iv) magnetite build-up with its associated problems (v) accumulation of impurities like Sb, Pb, Ni etc. in the process.

Settling in Furnaces [17] :— Another method of copper recovery from converter slags is to resmelt them along with pyrite or chalcopyrite concentrates in auxiliary furnaces (blast, reverberatory and electric furnaces). In this treatment the oxide as well as metallic copper gets sulphurised and the resultant cuprous sulphide is settled and recovered in the form of matte. Such processing referred to as **'Settling'** is usually carried out in electric furnaces and the slag is denuded of its copper to generate a dump slag whose copper content is approximately equal to 0.008–0.01 times that of the grade of matte made in the furnace. Another point to be noted is that when Flash Smelting is used the smelter slag and the converter slag can be "settled" together in an external electric furnace.

Slag Concentration [8,12,14,32] :— Recently a separate treatment procedure for converter as well as continuous smelting slags has been evolved after considerable R & D work at many copper smelters (including Noranda, Outokumpu and Hitachi). This new technique, which has come into vogue only in the last decade, consists of controlled slow-cooling, milling (to 90%–50 microns) and flotation of the converter slags and is called the **"Slag Concentration"** method. Slow cooling of the slags in the initial stages of cooling after solidification (above 1000°C) is very essential to coarsen the dispersed copper phases by precipitation of the dissolved copper and growth of the precipitates by diffusion and coalescence. Slowly-cooled slags require less degree of grinding and enable higher copper recovery (in the subsequent flotation stage) finally resulting in a dump slag tailing of very low copper content. For the flotation of milled copper slags [17] (which is very similar to that of the sulphide copper ores) collectors like isopropyl xanthate, butyl xanthate and isopropyl ethyl thiocarbonate and frothers such as pine oil and methyl isobutyl carbinol have been found suitable.

Slag concentration can also be adopted on quenched slags: However, the cost of grinding of the quenched slags to liberate the copper bearing particles to the flotable size is higher and the copper recovery is lower (ending up with discard slag tailings of higher copper contents[14])

Slag concentration has the merit of producing well-cleaned slag tailings containing only 0.3-0.4% copper, independent of the initial copper concentration in the slag [14,32]. When applied to converter slags, it is claimed [14] that the method enables attainment of inversed reverberatory furnace capacity, simplified furnace operations, and possibly lower copper content in the reverberatory discard slags. It may be noted further that the copper content of the dump slag tailings generated here is lower than that of the dump slag obtained by the electric furnace settling process and the overall energy requirements is also lower (20–50 KWH for slag cleaning process as against 75–100 KWH for electric furnace settling.

Reduction-Sulphidisation:—At the Ledgement Laboratory of the Kennicott Copper Co. Amman and coworkers [6] investigated on pilot plant (10 t.p.d) scale, a semicontinuous two-stage pyrometallurgical process for the treatment of converter slags. In a typical heat, the first stage of electric smelting of a converter slag containing 1–7% copper (statistical mean 3.5%). with coke (or coal) resulted in the collection of reduced copper as a high grade matte 55–76% copper (statistical mean 70%). Slag generated in this first treatment containing 0.7-2.0% Cu (statistical mean 1.2%) was subsequently smelted in the second stage slag cleaning. During the second stage, the secondary slag generated from the first stage was smelted with controlled quantities of pyrite and coke resulting in the production of low to high grade matte (depending on the grade of secondary slag) and a final discard slag containing 0.2-0.3% Cu. A noteworthy feature of this process is the provision of mechanical mixing equipment in the standard electric arc furnace. The authors reported that the pilot plant data has been scaled up and engineering designs have been made for a furnace with a capacity to treat 60 t.p.h. from a Noranda reactor and associated converters. They also reported that the Kennicott slag cleaning process has been patented and that plans are being formulated for the construction of a prototype slag cleaning furnace. The total energy for the two stages of smelting has been said to vary between 100 and 150 KWH per ton of slag treated depending on the composition of the slag. It has been further claimed that slag cleaning furnace is a compact and efficient unit with the mechanical mixer to achieve rapid metallurgical reactions, and preventing the accumulation of bottom build up.

Treatment in T.B.R.C.:—Very recently, Petersson and coworkers[33] investigated, on a pilot plant scale, the treatment of copper converter slags (approximately, 7% Cu) in a Top Blown Rotary Converter under reducing conditions (by maintaining the desired CO/CO_2 ratio) along with controlled amounts of pyrite and/or chalcopyrite concentrates. They claimed that the reduction is selective resulting in 95% Cu, 80% Ni, and only 20% Sb recoveries into the matte phase. It has been reported by these authors that starting from a converter slag containing 7% Cu, discard slags with less than 1% Cu are generated. Copper matte recovered in the T. B. R. C. was circulated to the P. S. Converter and the slag generated in the converter was fed back to the T. B. R. C. while the blister was transferred to the refining plant.

On the basis of the pilot plant tests, Boliden has now decided to erect a T. B. R. C. for the reduction of all converter slag (generated in a smelting capacity of 35,000 tons of copper concentrates per year) by this new procedure.

Sulphidisation with Elemental Sulphur : In 1973, Tokumoto et al [34]. sulphidised converter slags ($\sim$2.5% Cu) at 1250°C for 1 hr. with 15% S and reported a copper recovery of 93%. Sulphidisation efficiency of 50–60% only is obtained due to oxidation and evaporation of S as SO_2.

HNO_3 Leaching : Kmetova [35] investigated nitric acid leaching of converter slags ($\sim$5.24% Cu) on a laboratory scale. The optimum conditions for recovery of copper and separation of iron were reported to be $HNO_3 : H_2O = 1 : 1.15$; liquid : solid = 15 :1, time – 30 minutes; temperature — 90°C and air pressure— -1–3 kg/m^2.

From the above survey, it appears that treatment of copper-rich slags generated in P. S. convertors and in continuous smelting techniques like the Noranda process can be readily achieved by the slag concentration technique or where the energy costs permit by electric furnace settling. The newer techniques for the treatment of such slags by reduction-sulphidisation procedures developed in various countries and described above also seem to be on the threshold of commercial acceptance. The last mentioned technique based on nitric acid leaching appears to be only a laboratory curiosity.

As far as the economics of the slag concentration and pyrometallurgical (reduction-sulphidisation) techniques are concerned an economic analysis of the two routes by Agarwal and coworkers [36] at Kennicott Copper Co. shows that both routes are of comparable viability. However, the slag cleaning process is advantageous in one respect, namely, the accumulation of Sb and such other troublesome impurities is lower [33].

RESEARCHES ON TREATMENT OF DUMP COPPER SLAGS

Till the present time lean copper smelter slags are essentially dumped near the plant sites.. No commercial method has yet been reported for the recovery of copper from dump slags. Interest on this aspect seems to have been evoked only in the last few years. Literature survey shows that very few attempts have been made, that too only on a laboratory scale. Four distinct approaches, namely sulphuric acid pugging, leaching with ferric sulphate, selective sulphidisation of the copper and gravity concentration have been so far reported and these are briefly summarised below :

H_2SO_4 Pugging:—Lindblad and Dufresne[2] investigated sulphuric acid treatment of the Anaconda reverberatory dump slag (–80 mesh size) in 1:1 weight ratio followed by ageing at 90°C for 24 hrs. after which the soluble matter is extrated with water (10 times the weight of slag). About 85% Cu recovery is reported and 94% Fe is also brought into solution. The process suffers from the limitation of highly nonselective attack in leaching in that a very large quantity of iron is brought into solution and there is no provision for recycling/regeneration of the leachant. Disposal of the large quantity of iron sulphate produced is also a serious limitation. Such a technique with excessive consumption of a costly reagent like H_2SO_4 (especially in India) is unlikely to have any future.

Ferric-Sulphate Leaching :— Subramanian and Themelis [8] reported the feasibility of bringing down the copper level in the flotation tailings (0.5% Cu) of the converter slags by leaching with ferric sulphate. Their results show that more than 50% of the copper value is recovered by ferric sulphate leaching of –80 mesh size at 70°C in 1 hr. This approach has been dropped due to what the authors felt to be a slow and incomplete regeneration of Fe^{3+} from Fe^{2+}. Further, they suggested aerated sulphuric acid leaching at a controlled pH of 3 at 70°C for 1 hr. in order to

achieve the abjective of bringing down the copper level in tailings to 0.25%.

Selective Sulphidisation:— The Kennicott slag cleaning process described earlier can also be adopted for the treatment of dump slags. Only the second stage treatment is to be practised on the dump slags.

Tokumoto et al.[34] reported their studies on sulphidisation of the previously treated flash furnace slags (~ 0.5% Cu) by heating with 15% sulphur at 1250°C for 1/2 hr. and reported a recovery of 98% Cu into the matte phase. Approximately 40–50% of sulphidising efficiency only was obtained due to the loss of sulphur by oxidation and evaporation as sulphur dioxide.

Gravity Concentration: Johnson[37] reported that the White Pine Copper Co. recently completed a successful programme of copper recovery from reverberatory slags based on gravity concentration methods. He observed that the two factors played a strong role in the production of a direct smelting concentrate and achieving high gravity recovery efficiencies. The development of a simple and sensitive, yet extremely reliable density control system and the use of a biodegradable polymer for media stabilisation, enabling metallurgically sharp low-viscosity high-density separation.

Besides the above four approaches, the slag concentration method used for the treatment of converter slags (described in earlier section) can also be adopted for the treatment of slowly-cooled dump slags. In view of the reported fact that the copper content in the slag tailings discarded in the treatment of various types of copper-rich slags is nearly a constant (ω0.3—0.4%) which is independent of the initial copper content of the slag,[32] only poor recovery is to be expected when the process is adopted to dump slags. Hence slag concentration does not appear to be an attractive proposition for the treatment of dump slags. Electric Furnace settling could also be a useful approach for the treatment of smelter slags.

COPPER LOSSES AT INDIAN SMELTERS

Copper production in India is steadily increasing since 1971 (see Table 4). In 1976, the Ghatsila and Khetri smelters of Hindustan Copper Ltd. produced 24,700 tons and this year the blister production is expected to exceed 30,000 tons. Our survey shows that copper losses at our two flash smelters are on the high side (20-25 kg per ton of blister produced). As shown in Table 5, at present about 100,000 tons of copper slag/slag tailings is dumped in our country. With the projected expansion of copper production to 90,000 tons per annum, within the next decade [38], the quantity of dump slag generated will reach an annual level of over 350,000 tons and the copper lost in dump slags will then be about 2000 tons annually. Even at present the value of the copper lost into the dump slags at the Ghastila Smelter alone is nearly rupees five million. In our country copper is a scarce and expensive metal and about half of our domestic consumption is met by imports. Further, the copper content in the Ghatsila Flash Smelter dump slag (0.78%) is comparable to that of the low grade ore reserves. As such it is considered that serious efforts must be made to recover copper from the dump slags.

As noted earlier, although the problem of copper losses in slags is as old as copper smelting itself, no process has yet emerged for the commercial treatment of dump slags. Surprisingly very little attention is paid to this problem even in the western countries. At the Banaras Hindu University, the authors have recently taken up studies on the recovery of copper from Ghatsila dump slags by ferric chloride hydrometallurgical processing and obtained very encouraging results (92% copper recovery under suitable conditions). Results of these researches have been presented at the recent "International Conference on Metal Sciences—The Emerging Frontiers" held at Varanasi[40].

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TABLE 4. **Copper Production in India**

(A) Quantity of blister copper produced

Year	Production (tons)
1960	8,900
1965	9,300
1970	9,300
1975	22,200
1976	24,700
1978 79	37,000*
1985–86	90,000*

*Ref. 38 (estimated)

(B) Indian copper smelters

Name of smelter	Location	Present installed capacity (tons)	Remarks
Indian Copper Complex Hindustan Copper Ltd.	Ghatsila Dist. Singhbhum (Bihar)	16,000 (Flash smelters only)	Smelting capacity may be increased to 50,000 tons by expanding[4] (i) flash smelter capacity using oxygen enrichment and (ii) installation of a new reverberatory furnace in place of the old one.
Khetri Copper Project, Hindustan Copper Ltd.	Ketrinagar Dist. Jhunjhunu (Rajasthan)	31,000	At present owing to the lack of availability of concentrates even first phase of production viz., 21,000 tons capacity is not being fully utilized.

TABLE 5. **Estimated copper losses in dump slags at the Indian Smelters**

Quantity of dump slag (0.78% Cu) generated at I.C.C., H.C.L., Ghatsila* ... 2.5 tons/ton of blister copper

Quantity of dump slag tailings (~0.4% Cu) generated at K.C.P., H.C.L., Khetri** ... 6 tons/ton of blister copper

	Approximate quantity of waste slag generated (tons)		
	Dump slag at Ghatsila smelter	Dump slag tailings at Khetri smelter	Total for all/ both smelters
At present	40,000	60,000	100,000
Within the next few years when their full capacities are realized	62,500	186,000	248,500
By 1985-86 when copper production is expected to reach an annual level of 90,000	+	—	350,000

* Calculated on the basis of general experience considering the concentrate grade treated at this plant.

** Calculated on the basis of data supplied by the Plant[39].

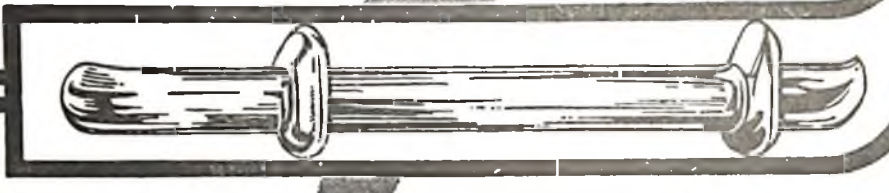
\+ See Table 4 Projected Smelting Capacity at Ghatsila.

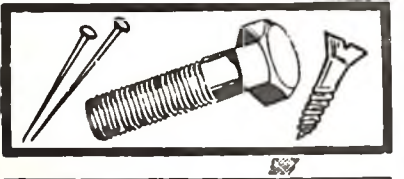
REFERENCES

1. J. L. Bray, "Nonferruos Production Metallurgy" John Wiley and Sons Inc., New York (1959) 223.
2. K.O. Lindblad and R.E. Dufresne, J. Metals., 26 (1974) 29–31.
3. Moto Goto, "Extractive Metallurgy of Copper Vol.–I" (Ed. by J.C. Yannopoulos and J.C. Agarwal), Met. Soc. A.I.M.E., New York (1976) 154–168.
4. S.L. Kher, C.R. Benerjee, and S.K. Biswas, ibid., 197–217.
5. Staff, Copper Cliff Smelter, ibid., 218–233
6. P.R. Amman, J.J. Kim, P.B. Crimes and F.C. Brown, ibid., 331–351.
7. S. Harkki, O. Aaltonen, T. Tuominen, ibid., 487–508.
8. K.N. Subramanian and N.J. Themelis, J. Metals (1974) 24 (2) 33–38.
9. H.K. Worner, J.O. Reynolds and B.S. Andrews, "Copper Metallurgy" (Ed. by R.P. Ehrlich), A.I.M.E., New York (1970) 198–219.
10. T. Nagano, T. Suzuki, "Extractive Metallurgy of Copper Vol.–I", (Ed. by J.C. Yannopoulos and J.C. Agarwal), Met. Soc. A.I.M.E., New York, (1976) 439–458.
11. T. Rosenqvist "Principles of Extractive Metallurgy", McGraw–Hill, Kogakusha Ltd., Tokyo (1974) 360.
12. T. Lukkarinen, World Mining (1971) 24 (8) 32–37.
13. R. Altman and C. Silva, "Extractive Metallurgy of Copper Vol.–I" (Ed. by J.C. Yannopoulos and J.C. Agarwal), Met. Soc. A.I.M.E., New York (1976) 296–316.
14. V.E. Edlung and S.J. Hussey, U.S B.M. Report of Investigations No. 7562 (1972).
15. J.B.W. Bailey, R.P. Beck, G.D. Hallet, C. Washburn and A.J. Weddick, Paper presented at the 104th A.I.M.E Annual Meeting, New York (1975).
16. T.R Shelly and R. Shelly, Trans. Inst. Min and Met (1974) 83C (811) 124–125.
17. A.K. Biswas and W.G. Davenport, "Extractive Metallurgy of Copper", Pergamon Press, New York (1976) 80–97 and 204–215.
18. G.M. Pound, G. Derge and G. Osuch, Trans. A.I.M.E (1955) 203, 481–484.
19. J.M. Toguri, N.J. Themelis and P.H. Jennings, Can. Met. Quart. (1964) 3, 197–220.
20. A. Yazawa and M. Kameda, Tech. Reports; Tohoku Univ.; cited from Ref. 17 above.
21. P. Spira and N.J. Themelis, J. Metals (1969) 21 (4) 35–42.
22. B. Claus and A. Gaubels "Pyrometallurgical Processes in Nonfer ous Metallurgy" (Ed. by J.N. Anderson and P.E. Queneau) Gordon & Breach Publishers, New York (1967) 93–114.
23. J. Middlin, L.D. White and B.V. Borgelt, "Copper Metallurgy" (Ed. by R.P. Ehrlich). A.I.M.E., New York (1970) 95–116.
24. R.J. Anderson, ibid, 146–172.
25. O. Herneryd, O.A. Sundstorm and N. Norro, J. Metals (1954) 6, 330–337.
26. T. Okazoe, T. Kato and K. Murao, "Pyrometallurgical Processes in Nonferrous Metallurgy", (Ed. by J.N. Anderson and P.E. Queneau) Gordon & Breach Publishers, New York (1967) 175–195.
27. T. Kitamura and S. Taneka, Met. Soc. A.I.M.E. (1973), Paper A73–49.
28. S. Merla, C.E. Young and J.W. Matousek, Preprint of a paper presented at the 101st A.I.M.E. Annual Meeting (1972), San Francisco.
29. E.M. Levin, C.R. Robins and H.F. McMurdie, Amer. Cer. Soc. (1969); cited from Ref. 17 above.
30. R. Minto and W.G. Davenport., Can. Min. Met. Bull. (1972) 65 (720) 70–76; Met. Abstr. (1972) 44–0166.
31. D. Riggi, R. Minto, and W.G. Davenport, J. Metals (1969) 21 (11) 40–45.
32. T. Itakura, T. Nagano, and J. Sasakara, J. Metals (1969) 22 (7) 36–39.
33. S. Petersson, A. Norro and S. Eriksson, "Extractive Metallurgy of Copper, Vol.–I" (Ed. by J.C. Yannopoulos and J.C. Agarwal), Met. Soc. A.I.M.E., New York (1976) 317–330.
34. S. Tokumoto, M. Sakamato, T. Kobayashi and C. Kim, Technological Report of Osaka University, March (1973) 23 (1090/1120) 67–74; Met. Abstr. (1973) 43–0234.
35. D. Kmetova, Zbornik. V.S.T. Kosiciah (1971) 191–197; Met. Abstr. (1973) 42-0254.
36. J.C. Agarwal, P.R. Amman, F.C. Brown and S.N. Sharma, "Extractive Metallurgy of Copper, Vol.–I" (Ed. by J.C. Yannopoulos and J.C. Agarwal), Met. Soc. A.I.M.E., New York (1976) 351–369.
37. R.H. Johnson, S.M.E. No. 75–B–115, Soc. of Min. Engrs. of A.I.M.E. (1975) 13 (pamphlet); Met. Abstr. (1975) 41–0063.
38. G.R. Seshadri Mining Annual Review (1977) 400–407.
39. J.R. Sampath and A.K. Mukherjee, (Khetri Copper Complex, H.C.L.) Private Communication (1977).
40. T.N. Akella, K.I. Vasu and P.M Prasad, paper presented at the Poster Sessions (Paper No. 2.7) of the International Conference on "Metal Sciences—The emerging Frontiers" (ICMS–77) held at Varanasi in November (1977).

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