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Distribution
LIMITED

ID/WG.12/2
2 May 1968

ENGLISH ONLY

United Nations Industrial Development Organization

First Meeting of Expert Consulting Group
on the Copper Industry
Vienna, 20-24 November 1967

THE APPLICATION OF OXYGEN AND HOT AIR IN THE MODERN COPPER INDUSTRY [1]

by

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[1] The views and opinions expressed in this paper are those of the author and do not necessarily reflect the views of the Secretariat of UNIDO.

id. 68-049

This paper was first presented at a meeting of experts consulting on the copper industry in Vienna at UNIDO headquarters, 20-24 November 1967.

SUMMARY

Some seventy-five per cent of the world's copper is produced by pyrometallurgical smelting of ores, primarily iron and copper sulphides, which initially contain about one to five per cent of copper. After concentration, with which this paper is not concerned, the extraction process is essentially one of oxidation of the iron and sulphur. The basic reactions are strongly exothermic and can be summarized in the following equations:

(a) $S + O_2 = SO_2 + 2220$ kcal per kg O_2

(b) $2FeS + 3O_2 + SiO_2 = 2FeO\ SiO_2 + 2SO_2 + 2500$ kcal per kg O_2

(c) $Cu_2S + O_2 = 2Cu + SO_2 + 1650$ kcal per kg O_2

The heat evolved by these reactions provides a substantial part of the heat necessary for smelting. The oxygen is supplied by large volumes of atmospheric air and this involves heating 4 kg nitrogen to about 12-1400°C for every kg of oxygen consumed - using up about 1400 kcal of heat. In the traditional process, therefore, extra fuel must be burnt at some stages.

In recent practice, two new methods for maintaining the heat balances have been developed - (1) using some of the heat of the waste gases to preheat the incoming air and (2) adding additional oxygen to the air.

The paper discusses the impact of these developments on the traditional process and the new processes which they have made possible.

In present practice the reverberatory smelting of matte and its subsequent blowing in a converter have both benefited largely from oxygen enrichment of the air. In the reverberatory fuel consumption is reduced and the sulphur dioxide content of gases for the sulphuric acid plant is increased, but most important the resulting increase in reaction rate increases the throughput of the furnace. This can be of major importance and examples are given from Union of Soviet Socialist Republics, Canadian and African practice illustrating the important economic benefits that are attainable. The obvious question as to the effect of a higher flame temperature on the reverberatory furnace lining is satisfactorily answered by suitable design of burners to confine the high temperature zone to the metal slag surface area - where it is wanted.

The introduction of extra oxygen in converter blowing of course tends to put up the temperature to an extent which could be very severe on the refractory lining. To prevent this it is necessary to add more cold charge than would otherwise be possible, and therein lies again substantial economic advantage provided suitable cold charge is available. The examples given not only illustrate this but also show how much the blowing time can be reduced.

Although the remelting of scrap is hardly within the compass of the primary copper producer, experimental trials in the United Kingdom of the application of the oxy-fuel burner in this field show promise of halving the usual 24 hour time cycle for melting - oxidizing - poling and casting of 65 ton charges.

In the field of new processes, the development of flash smelting has been facilitated by heat conservation. By preheating the air as in Outokumpu, or using a pure oxygen atmosphere as in Copper Cliff, smelting can be carried out autogenously - with the production of liquid sulphur dioxide as a by-product in the second case.

The use of oxygen enrichment in the converter in Japan and in Canada has led to the addition of concentrate, or even ore, as the cold charge needed to keep the temperature down. Thus a combination of matte smelting and autogenous direct smelting of concentrate has become possible.

Figures are given of the approximate cost of producing oxygen in tonnage plants, but naturally these must vary considerably in different parts of the world. Sufficient is known, however, to demonstrate the economic benefits that can result from oxygen enrichment of the air in various stages of the production process. Particularly is this the case where an existing plant is required to increase its throughput, but in the design of new plants these developments open the door to new and more flexible procedures which may well have a profound effect on the future of the copper industry.

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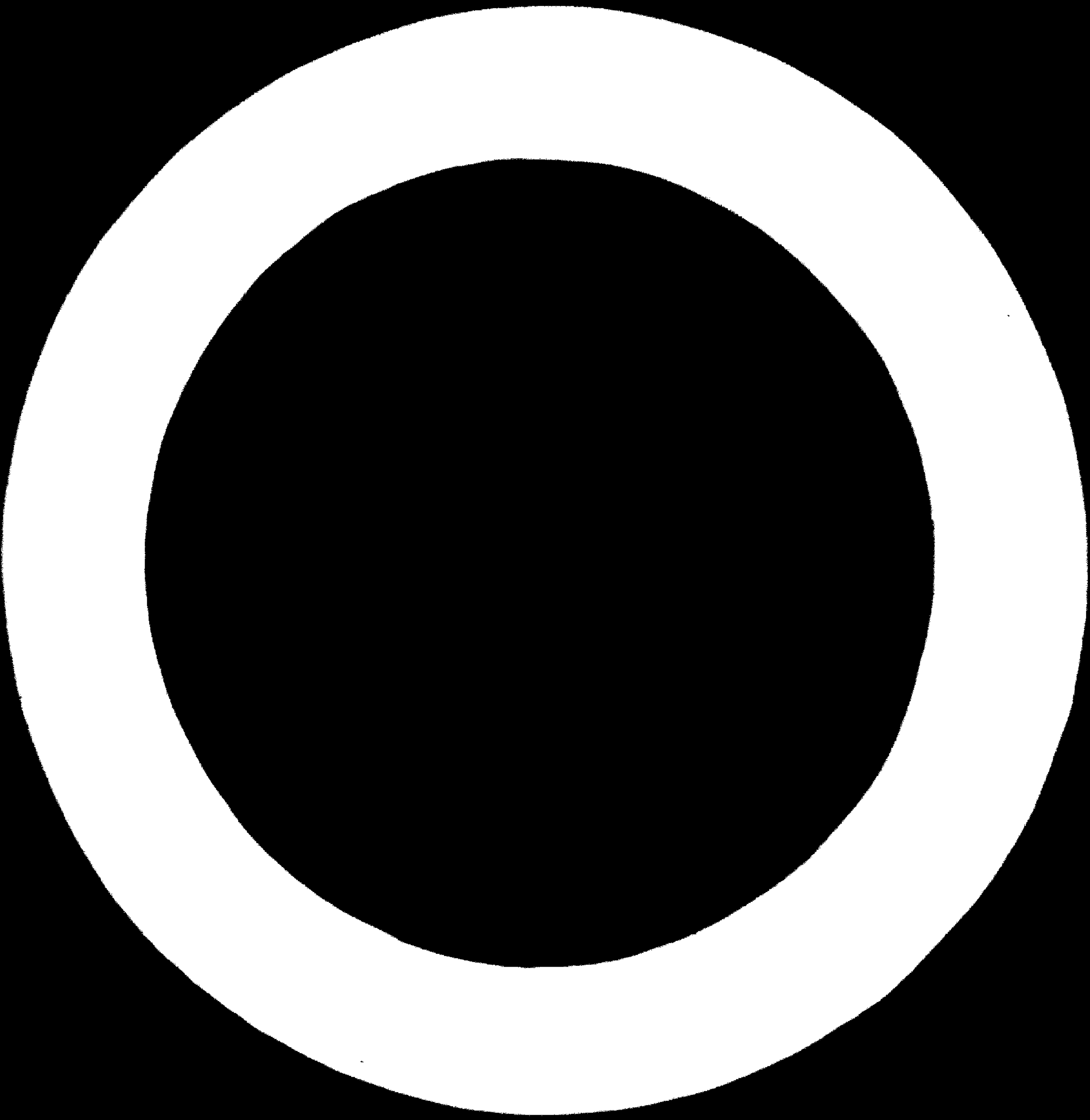

Introduction

1. Some 75 per cent of the world's copper is produced by pyrometallurgical smelting of ores, primarily iron and copper sulphides, which initially contain about 1 to 5 per cent of copper. In order to make clear some of the points discussed later this paper digresses into a brief and oversimplified discussion of the elements of the process of extracting copper and the heat evolution accompanying the basic reactions.

I. COPPER RAW MATERIALS AND TRADITIONAL OPERATION

2. As a broad generalization, the most common copper sulphide minerals in the ores smelted pyrometallurgically are Chalcocite (Cu_2S), Chalcopyrite ($CuFeS_2$), and Bornite (Cu_5FeS_4), associated with iron sulphides such as Pyrite (FeS_2) and Pyrrhotite (C.FeS) but many others are of importance. A special case is the nickel copper ore deposit in Sudbury, Canada in which the basic minerals are copper, nickel and iron sulphides. The smelting processes employed for the production of nickel and copper from these ores are essentially similar and references to nickel smelting operations are made throughout this paper since they so closely parallel copper smelting.

3. In the ore these minerals are associated with large proportions of "gangue" minerals such as quartz, which are generally valueless and the first stage of the production operation is beneficiation to produce a "concentrate" of the order of 20 to 30 per cent each of copper, iron and sulphur, although compositions vary widely. This is the starting material for pyrometallurgical smelting, the basis of which is oxidation of the iron and sulphur, stopping oxidation when the stage is reached at which metallic copper is produced There are four main steps in the traditional operation: roasting, smelting to matte, converting to blister copper, and refining. The basic reactions are:

(a) The oxidation of sulphur to produce sulphur dioxide which is a valuable raw material for the production of sulphuric acid. Since sulphuric acid is almost invariably both required and produced in the copper refinery it is important to achieve a fairly high sulphur dioxide concentration in the waste gases passed to the sulphuric acid plant. The oxidation reaction is exothermic:

(1) $S + O_2 = SO_2 + 2220$ kcal per kg O_2

(b) The oxidation of iron sulphides to ferrous oxide and the fluxing of this with silica (added as necessary) to produce a ferro-silicate slag. The reactions are complex but are again exothermic and can be summarised in the equation:

(2) $2FeS + 3O_2 + SiO_2 = 2\ FeO.SiO_2 + 2SO_2 + 2500$ kcal per kg O_2

(c) The oxidation of copper sulphide to metallic copper - again exothermic:

(3) $Cu_2S + O_2 = 2Cu + SO_2 + 1650$ kcal per kg O_2

4. The heat evolved by these oxidation reactions provides a substantial part of the heat required for smelting, but in the conventional process extra fuel has to be introduced at some stages. The oxygen is supplied in large volumes of atmospheric air - the International Nickel Co. have calculated (1)[1] that to process 50,000 tons of ore to produce 1,000 tons of metal, 25,000 tons of air is required. This includes nearly 20,000 tons of inert nitrogen which is heated in the operations to about 12-1400°C. From the enthalpy of nitrogen at 1300°C. (354 kcal per kg) this means that for every kg of oxygen used in the heat producing reactions of the above equations, about 1,400 kcal of heat is used to heat nitrogen. This heat loss per ton of nitrogen would suffice to smelt one ton of solid charge. This heat is not, of course, entirely lost, up to 35 per cent of the heat in waste gases from reverberatory furnaces (but not that from the converters) can be recovered by efficient waste heat boilers, but there is obvious opportunity for reducing fuel consumption by reduction of this loss of heat in waste gases.

5. One way of helping to this end is to use the heat of the waste gases to preheat the incoming air. This has been common practice in the iron blast furnace since 1824, but has only recently been used in copper smelting - for example in the Finnish process, to which reference is made later.

6. Enrichment of the ingoing air with oxygen produces similar benefits, but much more important than the reduction of the fuel waste resulting from heating large volumes of inert gas, are the resultant increases in reaction rate, furnace temperature, and in the sulphur dioxide content of the waste gases. The result can be either a revolutionary improvement in the throughput of the traditional smelter or the introduction of entirely new processes, such as oxygen flash smelting and smelting in the convertor. The following discussion deals firstly with the use of oxygen enrichment in the traditional process, secondly with the flash smelting operations, in which both air preheating and oxygen enrichment are in use, and thirdly with new developments, which the use of oxygen makes possible.

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[1] Numbers in parentheses refer to references.

II. THE TRADITIONAL PROCESSES

Roasting

7. Heating the concentrates in a plentiful supply of air to about 750°C. to oxidise some sulphur and iron is only necessary with low-grade material. It is today employed only to a small extent and in many plants roasters are used not for roasting, but for drying the wet fine concentrate before smelting. Where real roasting is necessary the oxidation process is sufficiently exothermic to enable the roaster, once started, to be operated without additional fuel. Since, however, the temperature must be kept below 800 to 850°C. to avoid sintering questions of oxygen enrichment or air pre-heating do not arise at this stage.

Smelting in reverberatory furnaces

8. The object of this operation is to produce a matte, i.e. a relatively pure mixture of copper and iron sulphides, commonly with around 40 per cent of copper and 30 per cent iron, free in large measure from the impurities in the gangue in the concentrate. The portion of the iron, and the extraneous non-volatile materials oxidised in the furnace pass into the slag and more of the sulphur in the charge passes into the furnace gases as sulphur dioxide. In traditional reverberatory smelting the furnace is fired with powdered coal, oil or gas which, together with the necessary combustion air, are blown in through one end wall. Slag and matte are drawn off as required and the furnace operates continuously for long periods of time. Since the requirements of the furnace are both melting and oxidation, it is clear that (a) the introduction of large volumes of cold nitrogen is a disadvantage and (b) an increase in the rate of oxidation can increase the throughput of the furnace.

9. With these points in mind, preheating the air has been used to a moderate extent and thought has been given in recent years to the enrichment of the combustion air with oxygen. The life of the furnaces, which should be many months between major repairs, depends to a large extent on avoiding overheating, particularly of the roof. The first reaction of the experienced smelter superintendent to the suggestion of using oxygen is naturally therefore one of fears for his furnace. This danger can however be avoided by careful design. In normal operations the hottest zone in the furnace reaches about 1500°C. and as it will be seen later, it is possible to increase this temperature in the area close to the slag line, away from the furnace walls, without increasing the temperature of the roof.

10. Examples of the benefits to be achieved by the use of oxygen in the traditional process of reverberatory smelting are given in published information from the Union of Soviet Socialist Republics, Canada and Central Africa.

11. Experiences of the Balkhash Mining and Metallurgical Combine in the Union of Soviet Socialist Republics (2) and (3) of using oxygen in smelting concentrates containing 20 to 25% copper, 13 to 19% iron and 22 to 23% sulphur plus converter slag are summarized in table 1.

Table 1

Effect of oxygen enrichment in USSR copper reverberatory

	Duration of test (in days)			
	9	8	17	13
Per cent oxygen in blast	21	21	25	29
Pulverised coal used, tons/hr	6.3	6.09	6.3	5.53
Specific fusion t/m^2 hearth	3.28	3.2	3.8	3.9
Consumption of ideal fuel, kg/ton charge	182	186	161	153
SO_2 content of gas, %	1.5	1.5	2	2.5
Air m^3 per ton charge	-	1390	930	910
Oxygen m^3 per ton charge	-	-	56	102
Cu recovery	-	97.9	97.9	97.8
Thermal efficiency	-	32.7	37.8	42.6

Using pulverised coal firing in two typical standard runs of 8 to 9 days duration showed, with normal air, an ideal fuel consumption of 184 kg per ton of charge. Adding 4% of oxygen to the air over 17 days, reduced this to 161 kg and adding 8% oxygen over 13 days to 153 kg. The thermal efficiency rose from 32.7% with air to 42.6% by the addition of 8% oxygen. A second, and in some circumstances more valuable point however, is an increase of 20 per cent in the throughput of the furnace, and these results, coupled with a higher SO_2 content in the waste gases, add up to substantial benefits.

12. In the experiment using 25% total oxygen the furnace roof rose to the unacceptable temperature of 1650°C. This was avoided in later experiments by the admission of a screen of cold secondary air.

13. The International Nickel Company plant at Copper Cliff separates two concentrates - one essentially copper rich and the second nickel rich, but containing copper in approximately the ratio 3Ni : 2Cu. Some 40% of INCO's copper derives from this

nickel concentrate. The treatment of the copper concentrate by flash smelting will be referred to later. The nickel concentrate is smelted to a nickel-copper matte (17% CuNi, 50% Fe, 7% S) **in reverberatory furnaces and recent experiments have been** conducted on oxygen enrichment of the air in this operation (1). The oxygen was introduced through water cooled lances installed below the coal burners and directed away from the furnace walls. This ensured that the hottest part of the flame was at the bottom next to the bath and did not raise the temperature in the vicinity of the roof. Table 2 shows the improvement in fuel efficiency and in furnace throughput.

Table 2

Fuel efficiency in Canadian reverberatory smelting with and without oxygen enrichment
(in tons per day)

	Standard		With oxygen	
	A	B	A	B
Coal rate	214	206	174	213
Oxygen rate	-	-	91	30
Matte and slag	1400	1400	1540	1900

A: normal operation
B: higher throughput using extra roasters

The increase of throughput rate by one third led to difficulties in materials handling since the facilities for dealing with the matte and slag were not designed for such a high production. They were consequently taxed to the limit and alterations such as larger matte ladles had to be introduced.

14. The Rhokana Corporation (4), wishing to increase the output of their smelter, considered in the first place smelter extensions, which would have cost £10 million. **Alternatively the addition to the combustion air of oxygen from a plant producing 600 tons of 98.5% oxygen per day, was found to enable the existing smelter to reach its production** target at a capital cost of £1.6 million. **Apart from increasing throughput and lowering smelting costs** this has also effected some direct saving of fuel and enabled indifferent fuels to be used more efficiently.

Converting

15. In the next stage in the traditional smelting operation, air blowing of the molten matte in a converter completes the oxidation and slagging of the iron (equation 2) and, in a continuous operation removes the bulk of the remaining sulphur (equations 1 and 3) to produce crude copper, at which stage the operation is stopped.

16. The reactions occurring in the air blown converter release so much heat that it needs no firing. Many of the impurities leave the converter as metal oxide dust in the blast exhaust which is rich enough in sulphur dioxide to be fed to a sulphuric acid plant after purification

17. Interest has been shown in oxygen enrichment of the converter air since some early small-scale experiments by Brandt(5) in 1905, Tanakanov(6), again in small-scale operations, showed that blowing times could be reduced by about 70 per cent if the oxygen were increased to 38 per cent but it is only in recent years that serious interest has been taken in this operation. Elimination of some of the cooling effect of nitrogen in the blast naturally causes the temperatures to rise, and it is necessary to add more cold charge to avoid damage to the refractory lining. Table 3 gives the results of experiments carried out by the Norddeutsche Raffinerie(7) on the effect of increasing the oxygen to 28 per cent in a side blown cylindrical converter using a matte of the order 46-48% copper, 23-24% iron and about 25% sulphur This reduced the blast time by 20 per cent and doubled the rate of copper production per minute of blow.

Table 3

Oxygen enrichment in German copper converter

	Normal	Enriched	Change %
Oxygen in blast, %	21	38	+31
Blast time, minutes	328	259	-21
Sulphur dioxide in gas, %	4 2 - 5.4	3 7 - 6.3	-
Slag per ton copper, kg	89	100	+12
Refractory loss, kg	~32	~245	+670
Copper produced per minute of blow, kg	39	78	+100
Whole charge time, minutes	428	342	-20

In the absence of steps to absorb the extra heat evolved, the temperature rose 100° higher than normal with severe attack of the refractories. The obvious way to avoid this is to add more cold charge, making a virtue of necessity, and the potential value of the addition of oxygen in this operation clearly depends largely on the nature and the amount of the material so added

18. In their nickel extraction line the International Nickel Company concentrate still further the copper and nickel sulphides in the 17% CuNi reverberatory matte referred to earlier by bessemerising to produce a rich matte containing 45% Ni, 30% Cu, 22% S and less than 1% iron - subsequently treated to separate substantially pure nickel and copper sulphides.

19. Oxygen enrichment of the air in these "Nickel" converters has made sufficient heat available to permit charging into the converter a variety of high grade reverts from the nickel refineries. Some 400 tons per day of such excess scrap had previously to be charged into a blast furnace but all this material can be handled in the oxygen enriched converter, permitting the shutting down of the blast furnace.

20. The bessemer matte so produced is treated for the separation of substantially pure nickel and copper sulphides by the so-called "bottoms" process. The resulting copper sulphide (73% Cu, 5% Ni, 20% S) was formerly melted in an electric furnace and blown to blister copper in special converters separate from those used to treat the matte from the flash smelter. In the latest experimental practice(1) the blast in these primary copper converters is enriched to 30% oxygen and the extra heat generated absorbed by the addition of this copper sulphide from the nickel process. This is summarized in Table 4.

Table 4

Smelting of copper sulphide in oxygen enriched converters

	Tons	% Cu
Cu matte	990	42
73% Cu sulphide		
added during slag blows	422	73
added during white metal blows	157	-
Oxygen used for enrichment to 29% O_2	132	-

The successful adoption of this procedure renders the use of the electric arc melting furnace and special converter unnecessary.

Refining

21. This is predominantly electrolytic and irrelevant to this discussion, but it is appropriate at this point to mention the value of oxygen in re-melting copper as for example, in fire refining. The British Iron and Steel Research Association (8) and (9) has proposed the use of an oxygen enriched fuel mixture for melting scrap. A deep furnace hearth is charged with cold scrap and an oxygen - oil burner brought down to the top of the charge. As the centre melts the burner is lowered and waste gases escape through and preheat the surrounding scrap. Claims are made relative to the electric furnace for quicker melting, reduced capital cost and large savings in melting costs is cheap oxygen is available from a tonnage plant. Promising experiments are in hand in the application of this principle to the melting of scrap copper in the refinery of British Copper Refiners(10). Melting scrap or cathodes in a 65 ton reverberatory furnace in the roof of which two supplementary oxy-fuel burners are

introduced has given encouraging results. Using the burners during the melting down and subsequent oxidation stages (by careful oxygen adjustment) in about 50 runs B.C.R. have shortened the total time for the melting - oxidising - poling - casting cycle from the usual 24 hours to about 12 to 16 hours, depending on the nature of the charge and the product cast. Economies in labour and in overall fuel consumption appear to balance the extra costs and it seems possible that the cycle time can be halved - i.e. the output doubled - without increase in cost. This requires confirmation when more experience is available on which for example the life of refractories can be firmly established.

22. Similar advantages are suggested by Elkington Copper Refiners Ltd (11) to result from top jetting "black copper" with oxygen as an alternative to bessemerising. In the experimental work described one ton charges of black copper (70-75% Cu 5-10% Sn, 3-5% Zn, 2-4% Fe, 2-4% Ni) were blown with a top jet introducing 50-100 cu.ft. of oxygen per minute. The advantages claimed compared with the conventional converter include lower capital cost, shorter blowing times (40 minutes compared with 120 minutes) and smaller filters for fume collection.

III. NEW PROCESSES

23. The uses of oxygen enrichment and pre-heated air have not only greatly benefited traditional processes but have facilitated striking new developments in copper smelting in recent years.

Flash smelting

24 The possibility of smelting copper concentrates by means of the heat generated by their own combustion was first suggested by Bridgman(12) in 1897 who proposed spraying the finely powdered ore into the oxidising atmosphere of a furnace chamber, but his plans reached no commercial success. In 1915 Klepinger et al.(13) recommended the use of preheated air in the process, but again no production use was made of this until the development of the Outokumpu process in 1949(14).

25. In the earlier work the direct smelting of concentrate into a pool of matte and slag which collected at the bottom of the furnace encountered difficulties due to the attempt to move the particles and furnace gases in opposite directions. This resulted in a large amount of dust being carried out in the gas stream. This difficulty was overcome at the Harjavalta smelter in Finland, by feeding fuel air and dry concentrate in the top of a vertical shaft and directing the resulting suspension vertically downwards in such a manner that it spreads over the whole shaft area; ignition takes

place instantaneously, the temperature of the particles is raised to the smelting temperature and separation of the particles from the gas takes place when the gases are turned through an angle of 90° in a horizontal settler at the bottom of the reaction shaft. The particles collect in the settler in a molten bath and the gases are taken out through an uptake leading to waste heat boilers and a heat exchanger. Under the right conditions the smelting can be carried out autogenously, but only a very high sulphur matte can be satisfactorily handled this way without some supplementary heat. The material normally handled by Outokumpu (concentrate 21% Cu, 32% Fe and 33% S) requires only a moderate amount of extra heat and this can be provided by pre-heating the air to about 500°C. If in other cases the concentrate has a composition which requires a higher air pre-heat temperature than is attainable, the remaining heat can be provided by burning a little extraneous fuel together with the concentrate. One disadvantage of the flash smelting process is that the slags so produced are high in copper and need cleaning by which means however, the copper content can be reduced to 0.2 per cent. Sulphur recovery in flash smelting is high and the furnace gases, after passing the waste heat boiler and heat exchanger, provide an ideal feed for the sulphuric acid plant.

26. This extremely convenient and economical smelting process which combines roasting, reverberatory smelting and a part of the converting process has been adopted in a number of other smelters throughout the world, one of the first of which was the Ashio Smelter of the Furukawa Mining Company in Japan

27. Oxygen enrichment of the air offers another method for eliminating the heat deficiency in flash smelting and this has been carried to the limit by the International Nickel Company in their process for treating the copper rich concentrate referred to above (15) The dry concentrate is injected through burners at each end of the horizontal furnace and combustion effected by injecting 95% pure oxygen through the burner. The burner tip is of mild steel tubing with a water jacket to avoid ignition in the oxygen stream. The oxygen-concentrate ratio is controlled sufficiently closely for the product gas leaving the furnace to be 80% sulphur dioxide which is taken off for liquifaction. Temperature control is of vital importance and temperatures are constantly measured. The heat is generated by reaction of oxygen with the iron sulphide component in the copper concentrate and with pyrrhotite which is fed in as required to maintain the thermal balance of the reaction and the desired matte content which is in the neighbourhood of 45% copper. Higher copper content in the matte results in higher copper in the slag, and the pyrrhotite addition both cleans the slag and controls the matte grade.

28. An ingenious new proposal for ensuring rapid and complete reaction between air and concentrate is the cyclone smelting proposed by Tonkonogi(16) in the Union of Soviet Socialist Republics. To increase the velocity of the gases relative to the solid particles smelting is carried out in a cyclone chamber similar to the cyclone combustion chambers in coal fired furnaces. Air is blown in tangentially with a velocity of over 100 m/sec and the concentrate, with some powdered fuel, fed in through the roof so that it is thrown against the walls in the high temperature reaction zone; small particles burn or melt and the smelted product is collected on the hearth as matte and slag. This process offers a large surface area of charge to atmosphere, and the high gas velocity accelerates heat exchange by convection.

29. To ensure rapid reaction and the volatilization of appropriate constituents, the air is pre-heated to about 500°C. with or without the addition of oxygen. Table 5 gives some typical results quoted by Onajew(17) but it is not clear how serious the wear of the cyclone walls or the heat loss through these walls prove to be in practice.

Table 5

Cyclone smelting in the USSR

Concentrate Cu	21-22	17-19		36
Percent Zn	0.6	9-10		2.5
Fe	14	26-27		-
S	20-23	33-36		16
Air temperature, degrees C	500	500	500	500
Oxygen added, %	Nil	Nil	8	8
Cu content of matte, %	50	33	-	75
slag, %	0.5	0.5	0.3	1
Yield of copper in matte, %	96	98	93	76
Yield of zinc in sublimate, %	82	65	82	92
Fuel consumption, %	27	-	-	-
SO_2 in gases, %	2.5-3	-	6	-

Converter smelting

30. The possibility of smelting in the converter has been of interest for many years, but the practicability of such a process depends on a supply of heat over and above that available in the traditional process. It is not a big step to realize, from what has been said earlier, that the overheating of a normal converter when oxygen is added to the air, could be prevented by using the converter for smelting as well as

for treating reverts. The Japanese started, in experiments in 1951 at the Saganoseki smelter, with an oxygen enriched blast which led to the process used at the Hataochi Smelter of the Nippon Mining Co described by Tsurumoto(13). The converter-smelter cycle is started with about ten tons of molten matte containing 40 to 50% of copper; this is obtained from a blast furnace retained as a convenient source of matte rather than as a main smelting unit since it permits the handling of reverts. The convert blast air is enriched to about 35 to 38% oxygen. Concentrates are charged into the converter in small amounts through a retractable shoot, with such silica as is necessary to flux the iron. The grade of matte at first falls since the melting rate exceeds the oxidation rate of iron sulphide; thereafter, the matte grade improves until the copper content is about 70 per cent at which stage further charging is stopped and the white metal blown to blister copper. The final stages of the blow can easily be overdone with oxygen enrichment and it is recommended that air alone be used in the latter part of the finishing blow.

31. Oxygen enrichment is stated to raise the copper content of the blister from 98.4 to 99.8 per cent compared with air blowing, the improvement being due to greater elimination of lead and nickel (the latter however constituting a loss to the electrolytic refinery). Table 6 gives the heat balance in this process from which it is seen that this degree of oxygen enrichment not only suffices to convert a heat deficiency into a heat surplus, but decreases the smelting time for one ton of concentrate from 7.5 to 4.5 minutes. This in itself improves the heat balance by reducing the radiation loss.

Table 6

Heat balance in converter smelting

	$21\%\ O_2$		$35\%\ O_2$
Heat generated by exothermic reactions cal.		895987	
Heat consumed by endothermic reactions		177564	
Sensible heat in			
products		433809	
nitrogen	262894		129697
Radiation loss	188750		113250
Heat deficiency	167030		-
Heat surplus	-		41667
Time for smelting 1 m ton conc. (min)	7.55		4.53

32. The copper content of the slag is higher in converter smelting than in conventional converter slags and some decoppering treatment is necessary, but this is much more than offset by the improved smelting economy - including a considerable reduction in handling losses - and a higher grade sulphur dioxide for the acid plant.

33. The International Nickel Company to whose practice in enriching converter air with oxygen (to permit (a) the charging of cold nickel reverts into the nickel converter and (b) the charging of the copper sulphide from the "bottoms" process into the primary copper converters) reference has already been made, have also used their nickel converter for smelting. By adding oxygen to the blast some of the heat carried away by nitrogen (about 50 per cent in conventional practices) can be used for treating cold ore or concentrate. They found that to be completely autogenous with a charge consisting entirely of cold solid sulphide and flux, the blast must be enriched to over 40 per cent. Using a blast enriched to 20 to 35% oxygen required a portion of the sulphide charge to be molten matte, to which basis it has been found possible to add ore and concentrate in a single oxygen enriched converter at the rate of over 400 tons per day. A disadvantage is that the slag produced in the converter contains a high metal content but this can be cleaned in the reverberatory furnace.

34. Little information is available about the life of linings when smelting in the converter, but Japanese experience suggests that lining erosion only becomes intense when oxygen enrichment exceeds 40 per cent

IV. COST OF OXYGEN

35. An obvious question in assessing the potential value of the use of oxygen in the copper smelter is the price that has to be paid for the gas. This clearly will depend on many considerations relevant only to a particular plant such as location, cost of power and available labour, period for which supply is required and continuity of usage. This latter point has a considerable effect on the cost of the plant since shut down periods for maintenance will necessitate storage facilities if a continuous supply is needed for 52 weeks in the year.

36. As a broad generalization however, it can be said that, assuming a minimum of fifteen years' supply, with a cost of power of one penny per unit, the cost of providing a 90% pure[2] oxygen would be roughly as follows. These figures which are for cost of gas as produced, i.e. before compression, refer to the production of the stated tonnage of pure oxygen daily; the price per 1000 cubic feet is the price of the resulting 90% mixture.

Daily tonnage of oxygen	Cost per 1000 c.ft. of 90% oxygen mixture	
	50 week production	52 week production
200	2s. 9d.	3s. 6d.
600	2s. 0d.	2s. 6d.

(1 ton of pure oxygen equals 26,500 c.ft.)

37. These figures are naturally based on United Kingdom experience. The only other costs available to the author are those quoted by Amicke(7) in describing experimental work at Norddeutsche Raffinerie for an experimental production of about 50 tons per day.

Cost of oxygen in DM per normal m^3

Depreciation	0.0415
Service and Maintenance	0.0140
Energy	0.0295
	0.0850

his is approximately equal to 4s. 6d. per 1000 cubic feet, which in view of the maller tonnage is reasonably in line with the United Kingdom figures.

3. Experimental small-scale usage, such as that of British Copper Refiners referred o earlier is more costly. They drew their oxygen from tanks (replenished from time o time) at the rate of about 100,000 cubic feet per 65 ton charge. This costs about [illegible]. per 1000 cubic feet.

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[2] The purity required depends on other possible uses for oxygen in the plant.

39. If we accept the Union of Soviet Socialist Republics' estimate of 100 cubic metres of oxygen per ton of charge to raise the oxygen content of the air by 8 per cent in the reverberatory smelting of a 20 per cent copper concentrate, the cost of the oxygen from a tonnage plant would, in United Kingdom figures, be of the order of £3 sterling per ton of copper smelted. This must be set against a 12 per cent saving in fuel and a 10 per cent increase in thermal efficiency. More important benefit still derives from the increase in throughput in a given plant, the value of which can only be assessed on the individual unit.

V. GENERAL CONCLUSIONS

40. The fact that so many of the operations in pyrometallurgical smelting of copper ores are highly exothermic, clearly points to the advantage if possible, of conducting them autogenously as far as may be. The heat balance in the reverberatory smelting is negative in the traditional process, while in the converter it is positive. If the heat loss due to the introduction of cold nitrogen is reduced by oxygen enrichment, reverberatory smelting can be made autogenous, while the extra heat from oxygen enrichment in the converter can be used to melt additional cold charge.

41. With an existing reverberatory furnace operating below capacity the great advantage of oxygen enrichment in increasing the throughput may well not be of benefit. For example, if labour has to be employed in keeping plant running idly on insufficient raw material much of the economy of a quicker throughput is lost. On the other hand, if oxygen usage enables higher production to be achieved on an existing plant the benefits can be great - and can be achieved at comparatively low cost. New plant can be designed for a given output on a smaller scale than would be necessary by traditional methods and reach its target by oxygen addition. This is beneficial also in the economies such as reduction of fuel consumption, improvement in the sulphur dioxide content of the exhaust gases which result.

42. In the converter operations again the benefit of oxygen enrichment can only be of advantage if, as is almost invariably the case, additional cold charge material is available. Cold charge must be added in increasing amounts to prevent the increase in temperature which results from increasing oxygen content of the air. The use of the converter to handle increasing tonnages of revert materials or, alternatively to smelt directly additional quantities of concentrate can be a highly profitable

operation, but its value can only be judged in relation to the materials and the facilities in individual plants. While therefore, the use of oxygen can in general terms be enthusiastically recommended, it does not follow that any, and every plant already operating would necessarily benefit, and each case must be considered on its merit.

43. The modifications in practice and the potential new processes which the use of oxygen makes possible, offer a real challenge to the industry in laying down new production facilities. The imaginative and enthusiastic acceptance of this challenge could have a profound effect on the future of copper.

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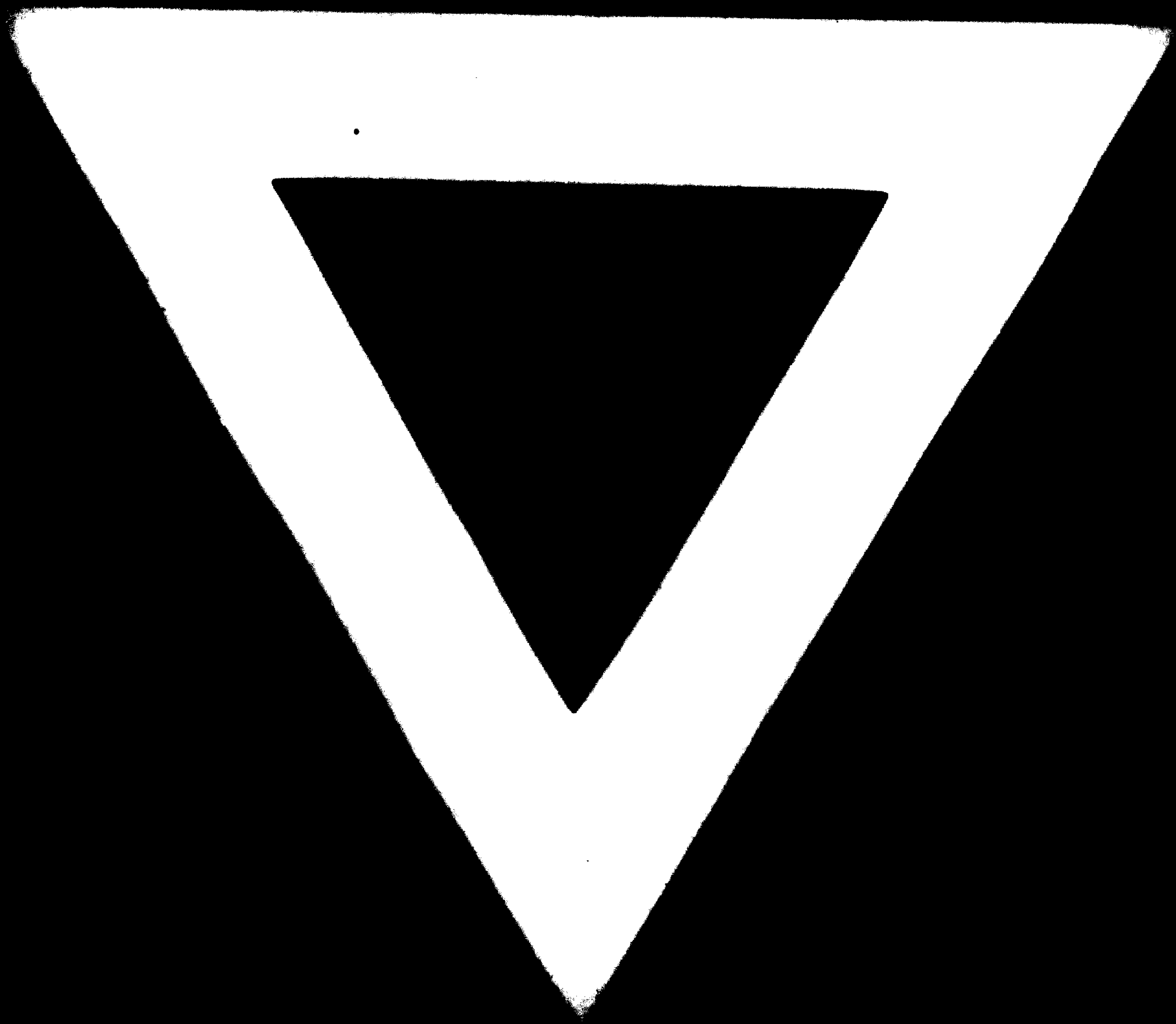

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