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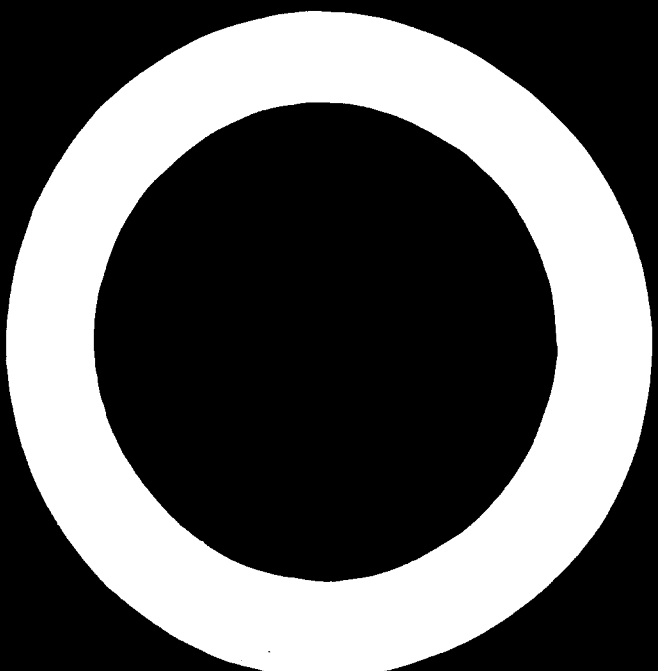
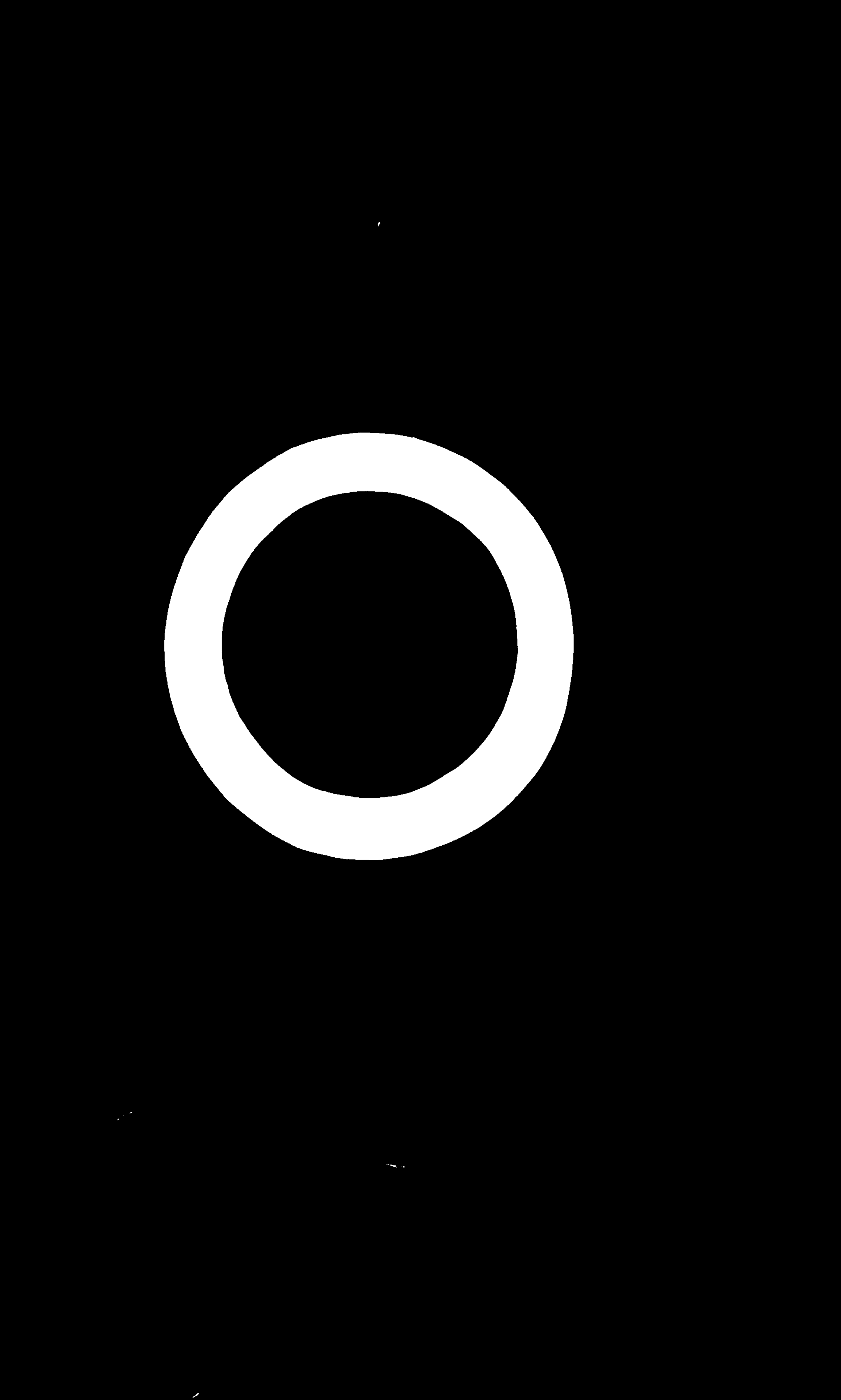
MODERNIZATION AND EXPANSION OF PLANTS IN THE COPPER INDUSTRY

Report of the First Meeting of an Expert Consulting Group on the Copper Industry

Vienna, 20-24 November 1967

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION





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UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

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Letter of transmittal to the Executive Director of UNIDO

We have the honour to submit herewith the report of a group of experts on the copper industry, Modernization and Expansion of Plants in the Copper Industry. This report was prepared during our meeting, 20-24 November 1967, at the headquarters of the United Nations Industrial Development Organization, Vienna.

The group elected Mr. W.H. Burt, General Superintendent of Smelting and Refining, Kennecott Copper Corporation, Utah, United States as its Chairman, and Mr. R.L. Khanna, Assistant Works Manager, Indian Copper Corporation, Bihar, India as its Rapporteur. The other members of the group were:

Mr. G.L. Bailey, England	Hon. Dr. Metallurgy Formerly Director of the Non-ferrous Metals Research Association
Mr. K.I. Ushakov, Union of Soviet Socialist Republics	Doctor of Technical Science, Director of State Research Institute for Non-ferrous Metals
Mr. H.K. Worner, Australia	Director of New Processing Developme Conzinc Riotinto of Australia Ltd., Melbourne

In addition to the above experts, the following observers attended the meeting:

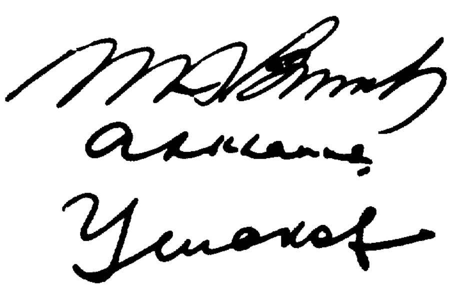
Mr. Siddik Aksoy, Turkey	Black Sea Copper Project Manager Etibank, Ankara
Mr. H. Bellamy, Australia	Professional Metallurgist Conzinc Riotinto of Australia Ltd., Melbourne
Mr. Sun Ching-hwa, Republic of China	Board Chairman, Taiwan Aluminium Corporation, Taipei
Mr. Slobodan Grgurevićing, Yugoslavia	Udruženje bakra SFRJ, Kolarčeva 8, Belgrade
Mr. Cedomir Knežević, Yugoslavia	Diploma Engineer, Institut za bakar, Bor
Mr. Luzon, Spain	Riotinto Patino, Technical Manager P.O. 110, Huelva

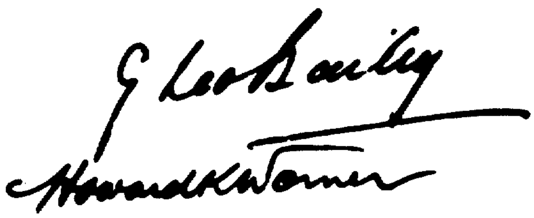
Mr. Maczek, Austria	Diploma Engineer, Kupferbergbau Mitterberg, Mühlbach
Mr. Wang Shieo-yu, Republic of China	Deputy Chief Engineer Taiwan Aluminium Corporation Kaohsiung, Republic of China
Mr. M.J. Smith, England	Conseil International pour le développement du cuivre 8 rue du Marché, Genève, Suisse
Mr. Wolfsberger, Austria	Representative of Chairman of the Wiener Kabei- und Metallwerke, Vienna
Mr. Andres Zauschquevich, Chile	Head, Mining and Metallurgical Dept. Corporation del Cobre, Chile Casilla 9493, Santiago

Mr. M. Maurakh and Mr. B. Crowston, staff members of UNIDO, were assigned to the group as technical secretaries to assist in its work.

The terms of reference given to us were to present papers on modernization and expansion of plants in the copper industry with particular reference to the needs of developing countries, to discuss these papers and to prepare a report containing conclusions and recommendations.

In submitting this report we have acted in a personal capacity, not as official representatives of the organizations of the Governments to which we belong.





Note: This report summarizes the papers presented and the discussion that took place at the First Meeting of an Expert Consulting Group on the Copper Industry.

Copies of the individual papers listed in the annex of this report are available upon request from the Metallurgical Industries Section, UNIDO, Rathausplatz 2, 1010 Vienna, Austria.

INTRODUCTION

1. The United Nations Industrial Development Organization has made plans for a series of Expert Group Meetings on the copper industry. This report covers the first meeting of a group of experts on the copper industry and examines the modernization and expansion of plants in the copper industry. Further meetings of groups of experts on the copper industry will be held in the future to cover other aspects of copper production. The first section of this report assesses the present state of copper production in the world and in developing countries. The production of copper-bearing ores, primary copper, smelting, refining and semi-fabricating capacities are given and recent trends are evaluated.

2. Recent improvements in technology and new methods of copper production are examined in the second section of the report. The use of oxygen in reverberatory furnaces producing copper matte and in converters producing blister copper are outlined. In addition, the flash smelting technique that combines the roasting and smelting stages and the continuous methods of copper production such as the WORCRA process which combines all stages of copper production are described.

3. The third section examines the economic and engineering prerequisites for the modernization and expansion of copper plants. The significance of economic factors such as capital investments, market projections and production growth rate together with other parameters are assessed. The engineering prerequisites that are analyzed are: approach to expansion, determination of optimum production, process development and planning with the use of modern computer techniques, effect of recent research and investigations and the project installation. The group of experts made a number of conclusions and offered recommendations to developing countries, to developed countries and to UNIDO. These are listed in the first part of the report.

CONCLUSIONS

4. The use of oxygen in copper production should be viewed as a means of achieving increased throughput and as an alternative to the erection of expansion of existing plant facilities. It can also contribute to the elimination of sulphur from waste gases by ensuring that the sulphur dioxide content of the exhaust fumes is high enough to make its extraction possible.

5. The application of oxygen in the copper industry is of great importance in reverberatory furnaces, converters, as well as in new processes of copper production.

6. Concerning smelting in reverberatory furnaces, the use of oxygen will enable higher production to be achieved at comparatively low cost. New plants can be designed for a given output on a smaller scale than is necessary by traditional methods. This will reduce labour costs and capital outlay and will reduce fuel costs.

7. In the converter operations, the benefit of oxygen enrichment can only be of advantage if additional cold charge material is available. The use of the converter to process revert materials or to smelt additional quantities of concentrate can be a highly profitable operation, but its value should be judged in relation to the materials and the facilities in individual plants.

8. The modifications in practice and the potential new processes that make the use of oxygen possible, offer great opportunities for the copper industry to establish new production facilities. New methods of production such as flash smelting, converter smelting and the WORCRA process could have a profound effect in the near future on the copper industry.

9. The minimum size of a newly-erected, complete copper refining complex necessary to compete on international markets is 100,000 metric tons per year. The minimum size of a plant in most developing countries, however, may be smaller because of lower costs of labour and raw materials. These factors should be examined with care to ensure that the plant will remain economic in future years.

10. The basic criteria to be examined to decide how, where and when existing copper mining, smelting or refining installations can be expanded or whether new copper facilities should be built are: the need for increased production, alternative methods of achieving increased production, and the economics of separate situations.

11. Economic factors that need to be examined before increasing the output of existing copper plants or erecting new facilities are: capital costs; market projections including an examination of copper prices; production growth rate and other factors such as costs of labour and transportation; local taxes; and availability of services such as water, gas, electricity and communications.

12. Before expansion and modernization of a copper plant is carried out, consideration should be given to: the type of expansion that would assure optimum return on investment; the scale of production; ore body development and planning of existing facilities; examination of research and development, supplemented where necessary by pilot-plant evaluation and project installation (such examination ensures the proper direction of engineering and construction to attain design objectives); desired production increase; and finally, production costs.

RECOMMENDATIONS

It was recommended that developing countries should:

13. Encourage the application of new developments including those presented and discussed at the meeting. The departure from well understood conventional approaches to copper production should, however, be studied in depth and more specifically in terms of local conditions before decisions are taken;

14. Assess the possible treatment of complex ores and study the effective elimination of certain elements that may be troublesome in obtaining production of copper of a suitable quality;

15. Examine the potential for the recovery of by-products from copper-bearing ores such as sulphur and the recovery of certain trace elements and precious metals because they have economic value that could be significant justification for development and exploitation of the resources;

16. Study the use of tonnage oxygen for small copper-producing plants. Its use may be possible if low-cost surplus oxygen can be made available from existing and adjacent oxygen-producing facilities at steel works or fertilizer plants, for example;

17. Give consideration to the following schedule of activities as a possible approach to the planning and accomplishment of major developments, including new installations or expansion of existing facilities in the copper industry:

(a) Define and evaluate the potential of mineral resources;

(b) Study alternatives for optimum exploitation giving consideration to physical potential and limitations, and preliminary economic appraisal;

(c) Make selection and review possible approaches to development including economic and engineering appraisal, selection and confirmation of process-consultation, and development of engineering criteria;

(d) Make preliminary engineering and re-evaluation of economics and review and receive approval of technical authority;

(e) Have detailed engineering design reviewed and approved by a technical authority;

(f) Secure organization and accomplishment of construction; and

(g) Make orderly direction of the initial operation and establishment of training, process and cost control to assure attainment consistent with planning design objectives.

<u>It was recommended that developed countries should:</u>

18. Organize and encourage further research and development work on new processes in the hydro-metallurgical and pyro-metallurgical fields to develop processes for producing copper that are economic at annual throughputs lower than the present viable limit of conventional methods of copper production;

19. Develop continuous processes because they are relatively easy to mechanize and control automatically. Development of these processes should be directed to ease of operation and relatively low capital investment costs in order to be attractive to developing countries;

20. Examine the long-term view relative to sulphur availability and assess the need for applying known technology to increase sulphur production as a by-product and also concentrate attention on new developments in the interest of sulphur production and control of atmospheric pollution;

21. Make available to governments and firms of developing countries all books, pamphlets and other documents on copper production. Distribution should be made for public use in the developing countries.

<u>It was recommended that UNIDO or the appropriate United Nations organizations should:</u>

22. Arrange regular meetings of a group of experts on the copper industry, possibly with a nucleus of permanent members to solve problems or to give concrete advice and suggestions to developing countries wishing to establish or develop plants for the copper industry. The possibility of studying the concentration of copper ores, including their treatment in arid zones and hydrometallurgical methods for treating copper ores and also examination of developments in refining and fabrication were suggested as topics for future meetings;

23. Examine the possibility of providing geologists with special knowledge of copper ores to investigate more fully the reserves of these ores in interested countries;

24. Arrange ad hoc meetings of a second group of experts mainly from developing countries on the copper industry to visit modern copper plants in developed countries and to study, discuss and analyse the technology employed in these plants. The report of such a working group would be extremely helpful to planners of copper industries in developing countries;

25. Organize systematic distribution through UNIDO of documents dealing with problems concerning the development of mining, smelting, refining, marketing and fields of application of copper, copper products, and copper alloys to developing countries.

I. PRESENT STATE OF COPPER PRODUCTION IN THE WORLD AND IN DEVELOPING COUNTRIES

Recent trends

Production of copper-bearing ores

26. The metal content of copper ores produced in the world increased from 3.6 million metric tons in 1959 to 4.6 million metric tons in 1964, an increase of 28 per cent. Almost one half of the metallic content of copper ores is produced in developing countries, although their share dropped slightly from 46.3 per cent in 1959 to 43.9 per cent in 1964.

Table 1

Metal content of copper ore produced

Regions	Quantities (thousand tons)	
	1959	1964
World	3,600	4,600
Developing countries	1,668	2,019
Africa	879	967
Asia	133	190
Latin America	656	862
	Shares (%)	
World	100	100
Developing countries	46.3	43.8
Africa	24.4	21.0
Asia	3.7	4.1
Latin America	18.2	18.7

Production of primary copper

27. The production of primary copper increased from approximately 1.5 million metric tons in 1959 to approximately 1.9 million metric tons in 1964. This represents an average annual increase of 3.6 per cent per year. The proportion produced by developing countries, however, fell slightly from 42 per cent to 40 per cent during this period.

Table 2

Primary metal production

Regions	Copper (thousand tons) 1959	Copper (thousand tons) 1964	Average annual change in % 1959-64
World	3,585	4,700	3.6
Developing countries	1,499	1,879	4.6
Africa	824	968	3.3
Asia	83	132	9.7
Latin America	592	779	5.6
	Shares (%)		
World	100	100	
Developing countries	41.8	39.9	
Africa	23.0	20.6	
Asia	2.3	2.8	
Latin America	16.5	16.5	

Smelting and refining capacity

28. Copper smelting capacity in developing countries in 1965 totalled some 1.8 million tons, 32 per cent of the world's installed capacity of 5,687,000 metric tons. The refining capacity in developing countries in 1965 was 1,360,000 or 21 per cent of the total world copper refining capacity of 6.4 million tons. Four major producers in developing countries, Congo (Kinshasa), Zambia, Chile and Peru account for 29 per cent of the world's capacity.

Table 3

Primary copper capacity - 1965 (in thousand tons)

Regions	Smelting	Refining
World	5,687	6,400
Developing countries	1,832	1,359
Africa	915	886
Congo (Democratic Republic of)	375	245
Rhodesia	15	21
South West Africa	20	-
Uganda	20	-
Zambia	485	620
Asia	38	15
India	10	10
Korea (Republic of)	-	5
Turkey	28	5
Latin America	879	458
Mexico	80	31
Chile	544	378
Peru	255	41

Source: Copper - "Metal Bulletin" special issue, May 1965.

Semi-fabricating capacity

29. Reliable statistics on semi-fabrication capacities in the world and developing countries are difficult to obtain. One of the main difficulties is that many plants fabricate more than one non-ferrous metal and it is not practical to allocate capacities for individual metals. The capacities of the major copper semi-fabricating plants in developing countries are shown below.

Table 4

Copper semi-fabricating capacity - 1964

Number of plants reported with capacities (in tons)

Regions	Not stated	Below 1,000	1,000-4,900	5,000-9,900	10,000-19,900	20,000-29,900	30,000	All sizes
Africa								
Algeria	3	-	-	-	-	-	-	3
Morocco	1	-	-	-	-	-	-	1
Rhodesia	-	-	-	-	1	-	-	1
United Arab Republic	4	-	-	1	-	-	-	5
Asia								
India	38	-	6	1	2	2	1	50
Iran	1	-	-	-	-	-	-	1
Israel	6	-	2	-	-	-	-	8
Korea (Republic of)	2	2	1	2	-	-	-	7
Malaysia	-	-	1	-	-	-	-	1
Philippines	3	-	1	-	-	-	-	4
Pakistan	7	-	1	-	-	1	-	9
China (Taiwan)	7	-	-	-	-	-	-	7
Thailand	2	-	-	-	-	-	-	2
Latin America								
Argentina	-	-	1	2	1	-	-	14
Brazil	4	5	8	1	2	-	-	20
Chile	3	-	1	-	1	-	-	6
Colombia	3	-	1	-	-	-	-	4
Cuba	1	-	-	-	-	-	-	1
Equador	1	-	-	-	-	-	-	1
El Salvador	1	-	-	-	-	-	-	1
Mexico	14	-	-	1	2	-	-	17
Puerto Rico	1	-	-	-	-	-	-	1
Peru	1	-	1	-	-	-	-	2
Uruguay	2	-	-	-	-	-	-	2
Venezuela	-	-	2	-	-	-	-	2

Copper consumption

30. The average annual rate of world consumption of semi-fabricated copper increased between 1959 and 1964 by 4.5 per cent per year. The consumption in the highest level of the developed countries has almost reached saturation point and future increases in copper consumption are expected to be slightly lower than this figure. The developing countries' share of world semi-fabricated copper consumption is very low: 5.9 per cent in 1959 and 7.0 per cent in 1964; only a slight increase was made during this period.

Table 5

Apparent consumption of semi-fabricated copper

Regions	Quantities (thousand tons) 1959	1964	Average annual change (%) 1959 - 1964
World	4,240	5,280	4.5
Developing countries	251	368	8.0
Africa	19	30	9.1
Asia	154	226	8.0
Latin America	78	112	7.4
	Shares (%)		
World	100	100	
Developing countries	5.9	7.0	
Africa	0.5	0.6	
Asia	3.7	4.3	
Latin America	1.7	2.1	

Source: UN Statistical and Trade Year Books, US Bureau of Mines, UK Overseas Geological Surveys, National Statistics - EIU estimates.

Structure of copper industry in developing countries

31. In 1965 only 90,000 tons or 5 per cent of the total copper smelting capacity in developing countries was state-owned. The remaining capacity was owned by expatriate countries. This is due mainly to the large expatriate holdings in the four major copper-producing developing countries Congo, Zambia, Chile and Peru.

Future copper production

32. World copper consumption is projected to rise at some 4.5 per cent annually during the period 1968-1975. This rate of growth is the same as in recent years. The rate of growth in consumption in developing countries, however, is expected to be 8.0 per cent per year, almost twice as high.

Table 6

World copper consumption[a/]

Regions	Assumed annual rate of growth (per cent)[b/]	In thousand tons			Per cent of total		
		1964	1970	1975	1964	1970	1975
World	4.5	5,280	6,917	8,606	100.0	100.0	100.0
Developing countries	8.0	368	581	852	7.0	8.4	9.9
Africa	9.1	30	50	77	0.6	0.7	0.9
Asia	8.0	226	359	529	4.3	5.2	6.1
Latin America	7.4	112	172	246	2.1	2.5	2.9

Source: Economist Intelligence Unit (London) estimates

a/ Of semis.

b/ Trend 1959-1964 rate.

II. RECENT IMPROVEMENTS IN TECHNOLOGY AND NEW METHODS OF COPPER PRODUCTION

33. Some 80 to 90 per cent of the world's copper is produced by the pyrometallurgical method. There are five main stages in the traditional operation, namely, concentrating, roasting, smelting to matte, converting to blister copper and refining. In the last few years much effort has been made to intensify each of the above-mentioned steps of copper production, because the intensification of the process allows an increase in the copper output without requiring an additional plant. The main improvements in technology of copper production are given below together with a description of the flash smelting technique, which combines roasting and smelting stages, and the continuous methods of copper production, such as the WORCRA process which combines all of the above stages. The economics of using oxygen are examined in the final section.

Wet method of ore preparation

34. The wet method of preparation of the charge is carried out and employed at copper plants in the Union of Soviet Socialist Republics. This method consists of a combined wet crushing of quartz and limestone which are used as fluxes. Copper concentrate pulp is delivered to the stockyard of a copper-smelting plant. Quartz and limestone pulp is then added in the required amount to the concentrate, after which the mixture is filtered and dried. Some difficulties in introducing the process were caused by the attempt to crush quartz and limestone separately, which drastically impaired the filtering process because the limestone was broken up too finely. These difficulties were removed when quartz and limestone were disintegrated together. This method of wet charge preparation improved the quality of charge and ensured a variation of the silica content in the charge up to 2 per cent and of lime up to 1 per cent. In addition, the moisture content of the charge after filtering was reduced from 14 to 15 per cent to 10 to 11 per cent and the capacity of the filters increased by 30 to 40 per cent.

Roasting

35. Copper concentrates are roasted before smelting at many plants in multi-stage mechanical furnaces which have a rather low output. The roasting operation can be intensified by conducting the process in a fluidized bed instead of multi-stage furnaces. The comparative indices of these two methods of roasting copper concentrates for one of the Union of Soviet Socialist Republics plants are illustrated below in table 7.

Table 7

Roasting copper concentrates methods

	Roasting in multi-stage furnaces	Roasting in fluidized bed
Daily total output ton/m^2 of hearth	8 - 9	65.0
Content of SO_2 in gases, %	7.0	12.5

36. At the present time copper concentrates are roasted in a fluidized bed at two plants in the Union of Soviet Socialist Republics and also at one plant in Bulgaria (Pirdop) and at one plant in the United States (Copperhill Tennessee Copper Corp.).

37. A higher concentration of SO_2 in the roasting gases can be utilized to enrich gases from other parts of the system. For example, mixing roasting gases with converter gases enables them to be used for the production of sulphuric acid because the mixture of these gases contains 7 to 7.5 per cent SO_2, the most suitable amount for the operation of contact apparatus.

38. Modern reverberatory furnaces with a hearth area of 200 to 250 m^2 are fired with powdered coal, oil or gas which together with the necessary combustion air are blown in through one end wall. The specific consumption of fuel runs usually into 18 to 22 per cent of the weight of the charge. Since the requirements of these furnaces are both smelting and oxidation, it is clear that the introduction of large volumes of cold nitrogen is a disadvantage and an increase in the rate of oxidation can increase the throughput of the furnace.

Smelting to matte

Oxygen enrichment in reverberatory furnaces

39. One way to intensify the smelting process in reverberatory furnaces is to enrich the combustion air with oxygen. This way is used on a semi-industrial scale in Canada, the Union of Soviet Socialist Republics and in countries of Central Africa. Examples of the benefits to be achieved by this method are given below.

Table 8

Effect of oxygen enrichment in Union of Soviet Socialist Republics copper reverberatory[a]

Duration of test (in days)	9	8	17	13
Per cent oxygen in blast	21	21	25	29
Pulverized 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

a/ Concentrates contain 20-25% Cu, 13-19% Fe and 22-23% S. The charge consists of concentrates and converter slag. Data of the Balkhash Mining and the Metallurgical Combinat are given.

Adding 4 per cent O_2 to the air reduced the fuel consumption from 186 kg per ton of charge to 161 kg and adding 8 per cent O_2 to 153 kg. The terminal efficiency rose from 32.7 per cent with air to 42.6 per cent by the addition of 8 per cent O_2. A second, and in some circumstances much more valuable point, however, is an increase of 20 per cent in the throughput of the furnace.

40. In the series of tests using 25 per cent 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. The International Nickel Company (INCO) plant at Copper Cliff separates two concentrates - one essentially copper-rich and the other nickel-rich, but containing copper in approximately the ratio 3 Ni : 2 Cu. Some 40 per cent of INCO's copper derives from this nickel concentrate which is smelted to a nickel-copper matte (17% Cu-Ni, 50% Fe, 7% S) in reverberatory furnaces; recent experiments have been conducted on oxygen enrichment of the air in this operation. 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 9 shows the improvement in fuel efficiency and in furnace throughput.

Table 9

Fuel efficiency in Canadian reverberatory smelting with and without oxygen enrichment

	Standard		With oxygen	
	A	B	A	B
Coal rate tons per day	214	206	174	213
Oxygen rate tons per day	-	-	91	80
Matte and slag tons per day	1,400	1,400	1,540	1,900

A: Normal operation
B: Higher throughput using extra roasters

41. The increase of the 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 high production. They were consequently taxed to the limit and alterations such as larger matte ladles had to be introduced.

42. The Rhokana Corporation (Zambia) wished to increase the output of its smelter and so considered using smelter extensions, which would have cost a considerable amount of money. However, with the addition of oxygen to the combustion air, a plant producing 600 tons of 98.5 per cent O_2 per day was able to increase the existing smelter output to reach its production target at a capital cost of one sixth of the cost required for smelter extensions. Apart from increasing throughput and lowering smelting costs this has also

brought about some direct saving of fuel and enabled indifferent fuels to be used more efficiently. The company calculates that a reverberatory furnace operated with combustion air enriched to 40% O_2 will give a production increase of 56% over a similar unit operating with atmospheric air. In the Union of Soviet Socialist Republics, experiments are under way at a plant that uses oxygen in a furnace fired by natural gas. The content of oxygen in the blast was raised to 35%. The comparative indices of smelting on air and oxygen-enriched blast (35%) are shown in table 10.

Table 10

Comparative indices of smelting on air and oxygen-enriched blast

	Air flow rate, nm^3/hr.	Oxygen flow rate, nm^3/hr.	Daily specific smelting rate, ton/m^2	SO_2 content in exhaust gases, %	Copper content in slag, %
Air blast	80,000	-	4.25	1.5 - 2	0.46
Oxygen-enriched blast	38,000	8,900	6.0	6 - 7	0.39

43. The flame temperature was found to increase noticeably: from 1,450 to 1,480°C to 1,580 to 1,600°C, but the temperature of the gases in the uptake underwent practically no change. The use of oxygen made it possible to decrease the fuel consumption by 30%, reduce the amount of exhaust gases by 40% and increase the specific smelting rate by 30%.

Utilization of heat in the exhaust gases of reverberatory furnaces

44. Another method for intensification and increasing the efficiency of processing in reverberatory furnaces is to utilize the heat of the exhaust gases. Only 20 to 25 per cent of heat generated by burnt fuel is used in reverberatory furnaces to smelt the charge. About 50 per cent of the heat is carried away by exhaust gases which have a temperature of 1,200 to 1,250° C. As a rule, waste heat boilers which transform about 35 per cent of the heat of the exhaust gases into high-pressure steam suitable for the generation of electric energy are installed behind the reverberatory furnaces.

45. Some heat produced by the gases can also be employed to heat up the blast with the aid of recuperators mounted behind the waste heat boilers. The experience of heating up the blast to 200 to 350°C gained in a number of countries shows that when the combustion air of the reverberatory furnace is heated up, the specific consumption of fuel drops by 7 to 10 per cent and the specific smelting rate increases by 15 to 20 per cent. The heat of the exhaust gases can thus be utilized most economically and the thermal efficiency of the furnaces considerably improved.

Oxygen enrichment in blast furnaces

46. Oxygen-enriched blast has been used successfully on an industrial scale in the Union of Soviet Socialist Republics since 1960 for smelting sintered copper concentrates in blast furnaces. The technological indices of the process are show in table 11 below.

Table 11

Technological indices of oxygen-enriched blast process

Content of oxygen in the blast, %	20.9	23.7	25.2	27.3
Consumption of coke, % of charge weight	7.89	6.94	6.13	5.93
Blast intensity rate, nm^3/m^2 min.	85.5	77	75.2	61.8
Blast pressure, mm Hg	153	126	124	113
Daily specific smelting rate, ton/m^2	101	107	115	115
Temperature of exhaust gases °C	590	460	375	320
Amount of exhaust gases, nm^3/hr.	30,700	30,400	29,300	29,300

47. In addition to better technical indices, oxygen-enriched blast provides for a more stable and uniform working of furnaces, reduces the formation of skulls in the tuyere zone and the furnace top. It also enables the diameter of the furnaces to be reduced, makes servicing much easier, and appreciably improves the sanitary conditions of labour.

The flash smelting process

48. The uses of oxygen enrichment and pre-heated air have not only a great advantage for traditional processes, but they have facilitated the development of a new process in autogenous copper smelting. When concentrates are burnt in a flow of cold air, the developing temperature is too low to melt the charge. In order to obtain the required temperature (1250 to 1300°C) the thermal balance of the process must be changed either by increasing the input of heat, or by reducing heat losses and thereby effecting flash smelting. Heat input can be increased with a hot air blast, which is now used on an industrial scale at Harjavalta and Outokumpu (Finland), Asio (Japan), and Baja-Mare (Romania).

49. 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 that requires a higher air pre-heat temperature than is attainable, the remaining heat can be provided by burning a little extraneous fuel, 1 to 2% of the charge weight, 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 0.3 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.

50. 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 concentrates. The dry concentrate is injected through burners at each end of the horizontal furnace and combustion effected by injecting 95 per cent 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 so that the product gas leaving the furnace includes 80% SO_2 which is taken off for liquification. As temperature control is of vital importance, temperatures are constantly measured. Heat is generated by reaction of oxygen with the iron sulphide component in the copper concentrate and with phyrrhotite 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 per cent copper. Higher copper content in the matte results in higher copper in the slag, and the phyrrhotite addition both cleans the slag and controls the matte grade. The summary data on the operating flash smelting furnaces are illustrated in table 12 below.

Table 12

Summary data on the operating flash smelting furnaces

	Harjavalta (Finland)	Copper-Cliff (Canada)	Asio (Japan)	Baja-Mare (Romania)	USSR Semi-industrial plant	USSR Industrial plant (project)
Blast	hot 500°C	oxygen enriched	hot 500°C	hot	oxygen enriched	oxygen enriched
Furnace area, m^2	76	150	42	-	8	120
Output, ton/charge per day	550	1,360	200	-	20 - 120	1,400
Concentration of SO_2 in gases, %	7 - 8	80	-	11 - 12	80 - 85	75
Method of decreasing copper content in slag	floatation	pyrite blast	electric smelting	reverberatory furnace	pyrite blast	pyrite blast
Copper content in slag, %	0.3	0.55	0.6 - 0.7	not known	0.5 - 1.5	0.5
Copper content in matte, %	60	40 - 45	52	55 - 60	30 - 70	40 - 50

51. Flash smelting offers the following advantages: (a) fuel consumption for the smelting process is considerably reduced and can be completely dispensed with; (b) the degree of desulphuration for the production of matte rich in copper is sufficiently high and easily adjustable; (c) high specific capacity of the furnace (up to 12 ton/m^2 per day) and (d) practically all sulphur contained in the concentrates can be used to obtain sulphuric acid with hot blast or liquified sulphur dioxide with enriched oxygen.

52. At the same time, flash smelting is more complicated technically than smelting in a reverberatory furnace for the following reasons: (a) flash smelting requires a thorough preliminary drying of the charge as wet charge cannot be blown in through the burners; (b) slags from flash smelting furnaces are richer than slags obtained from reverberatory furnaces and contain 1 to 1.5 per cent copper without additional treatment.

53. Various methods are in common use for reducing copper content in slag. For example, at the Harjavalta plant cooled slag is subjected to floatation concentration, producing a concentrate with 16 to 18 per cent of copper and tailings with 0.3 per cent of copper. The Copper Cliff decreases the copper content in slag inside the furnace by blowing phyrrhotite into the rear end of the furnace. The Asio plant does the same in an electric furnace and the Baja-Mare plant in a reverberatory furnace. Despite all its shortcomings, the advantages offered by flash smelting (primarily full utilization of sulphur) make it a most promising method for smelting copper sulphide concentrates.

Electro thermal melting in a fluidized bed

54. A new process has been worked out in the Union of Soviet Socialist Republics for processing complex Cu-Zn-Pb concentrates, containing about 20 per cent Cu; 8 to 10 per cent Zn and 2 to 3 per cent Pb. The method includes an electro thermal melting in a fluidized bed furnace with oxygen-enriched blast air. As a result, matte with 70 per cent Cu is produced from such concentrates. The exhaust gas contains 85 per cent SO_2. Metallic zinc contains 0.5 to 0.6 per cent Cu.

Converting to blister copper

55. Application of oxygen-enriched air blast in converting copper matte by elimination of some of the cooling effect of nitrogen in the blast naturally causes the temperature to rise, and it is necessary to add more cold charge to avoid damage to the refractory lining. Table 13 gives the results of experiments carried out by the Norddeutsche Raffinerie (Federal Republic of Germany)

on the effect of increasing the oxygen to 28 per cent in a side-blown cylindrical converter using a matte of the order 46 to 48 per cent copper, 23 to 24 per cent iron and about 25 per cent sulphur. This reduced the blast time by 20 per cent and doubled the rate of copper production per minute of blow.

Table 13

Oxygen enrichment in copper converter

	Normal	Enriched	Change (%)
Oxygen in blast (%)	21	28	+ 31
Blast time (min)	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)	c.32	c.245	+ 670
Copper produced per minute of blow (kg)	39	78	+ 100
Whole charge time (min)	428	342	- 20

56. 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. Examples are found in the INCO experience. Thus, an oxygen-enriched blast can be effectively employed for conversion with an adequate supply of cheap oxygen and a surplus of copper-rich hard materials (returned products etc.).

57. At one of the Union of Soviet Socialist Republics plants copper matte is converted in an industrial converter by a blast with up to 25 per cent oxygen. The converter is loaded with siliceous copper concentrate containing 34 per cent copper, 12.5 per cent sulphur and 40 per cent silica. The concentrate is granulated in advance and the granules are dried. The maximum amount of granules smelted in a converter was 88 per cent of the hot matte weight. The consumption of quartz flux dropped by 20 per cent at the expense of the silica contained in the concentrate. The duration of the operation remained practically the same, but the weight of copper melt increased by 27 to 29 per cent.

58. The Japanese started experiments in 1951 at the Sagamoshi Smelter using an oxygen-enriched blast which led to the process used at the Hatachi Smelter of the Nippon Mining Company. The converter-smelter cycle is started with about ten tons of molten matte containing 40 to 50 per cent copper obtained from a blast furnace handling revert materials. The converter blast air is enriched to about 35 to 38 per cent oxygen. Concentrates are charged into the converter in small amounts through a retractable chute, 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.

59. 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 constituting a loss during subsequent electrolytic refining.

60. The copper content of the slag is higher in converter smelting using oxygen enrichment than in conventional converter slags and some de-coppering treatment is necessary, but this is more than offset by the improved smelting oconomy - including a considerable reduction in handling losses and a higher grade sulphur dioxide for the acid plant.

61. The International Nickel Company has also used nickel converters 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 per cent 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. Little information is available about the life of linings when melting in the converter, but Japanese experience suggests that lining erosion only becomes intense when oxygen enrichment exceeds 40 per cent.

62. An oxygen-enriched fuel mixture for remelting scrap has been proposed by the British Iron and Steel Research Association (BISRA) and British Copper Refiners (BCR). In the steelmaking process developed by BISRA a deep furnace hearth is charged with cold steel 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 pre-heat the surrounding scrap. Claims are made relative to the electric furnace for quicker smelting, reduced capital cost and large savings in melting costs if 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. Melting scrap 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/oxidizing/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 over-all fuel consumption appear to balance the extra costs and it seems possible that the cycle time can be cut in half, that is, the output doubled without increasing cost. This requires confirmation when more experience is available on which, for example, the life of refractories can be firmly established.

WORCRA continuous copper-making process

63. In a new continuous method of copper extraction being developed in Australia, the metal is produced directly from sulphide concentrates in one furnace. The smelting to matte, conversion to copper and slag clean-up are achieved continuously in separate but communicating zones of the furnace. Depending on the scale of operation and the price of oxygen, the smelting-converting can be carried out with ordinary air injection or with air enriched with oxygen.

64. The WORCRA process can be classified among the intensive pyrometallurgical processes, but unlike the flash smelting methods most of the heat is generated by the exothermic oxidation of sulphur and iron in the bath. Furthermore, the product is molten copper rather than matte and the losses of copper in slag and dust are much lower than those obtained in conventional copper smelting. The process can be described as a one-metal, one-slag, one-gas process and no retreatment of slag is required. In the pilot plant runs, copper losses in slag as low as 0.3 per cent have been achieved over lengthy periods of continuous operation.

Advantages

65. The advantages of the process relative to conventional methods are greatly reduced fuel requirements (smelting is autogenous with some oxygen enrichment of the air), high metal recovery (including zinc and lead in fume if present) and high recovery of SO_2 at a level ideally suited for acid production.

At production levels of 30,000 to 80,000 tons per year savings in operating costs are estimated to be between 25 and 30 per cent lower than conventional methods.

66. The smaller furnace needed for continuous processing, the elimination of handling facilities for revert slag and the reduction in size of other facilities for handling gas, dust etc. should enable considerable savings in capital compared with conventional batch methods. Of particular relevance to the technically developing nations, the WORCRA process should be economically viable at annual production rates on the order of 10,000 tons per year, which is considerably lower than for modern reverberatory-converter complexes.

67. A further likely advantage of the WORCRA process is a somewhat better elimination of elements such as Pb, Bi, Sb, As, Te and Se from the bath. This is claimed by the inventor to be due to the fact that air is blown into the bath higher than in conventional converting. Excellent elimination of zinc is achieved and the method is therefore applicable to the treatment of zinc-bearing concentrates and the separate recovery of zinc (as fume) and copper. Slightly more air must be compressed compared with conventional converting but at the same relatively low pressures.

State of development

68. The WORCRA process is now at the semi-commercial stage. Worthwhile data from this plant should be available towards the end of 1968. This data will be awaited with much interest in view of the considerable promise of the process at the pilot-plant stage.

69. When fully developed the process could be of considerable interest to developing countries because of its relative simplicity, its expected lower capital and operating costs and its viability at relatively low annual throughputs.

Economics of using oxygen enrichment

70. 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 oxygen. This clearly will depend on many considerations relevant only to a particular plant such as location, cost of power, availability of labour, length of 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 of the year.

71. As a broad generalization, however, it can be said that, assuming a minimum of fifteen years' supply, with a cost of power of £0.04 per kWh, the cost of providing a 90 per cent pure oxygen would be roughly as follows. These figures which are for cost of gas as produced, before compression, refer to the production of the stated tonnage of pure oxygen daily; the price per 1,000 cubic feet is the price of the resulting 90 per cent mixture.

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

(1 ton of pure oxygen equals 26,500 cubic feet.)
These figures are based on UK experience.

72. Generally speaking, modern large oxygen plants consume about 0.6 kWh to produce one cubic metre of oxygen. Accounting for the other operational expenditures, it can be assumed that the cost of one cubic metre of oxygen is equal to the cost of 1 kWh of electric power. If the saving from reduced fuel consumption and other expenses is larger than the cost involved in producing oxygen, its use will be economically unjustified.

III. ECONOMIC AND ENGINEERING PREREQUISITES FOR MODERNIZATION AND EXPANSION OF PLANTS IN THE COPPER INDUSTRY

Introduction

73. No single set of detailed criteria can be listed and applied to all situations. Certain basic criteria for evaluating how, where and when increased production can be achieved, however, must be assessed.

Necessity for increased production

74. The reasoning for expanded production must be supported by sound economic analysis. Few commodities are more sensitive to fluctuations in supply and demand than copper. Relatively minor economic forces can have significant influence on international market conditions. The objectives of projects under consideration must be clearly developed through careful study and evaluation of those factors that promote consideration of expansion. Accurate projections of market conditions will provide the basis for determining proper timing for introducing additional production.

Method of achieving increased production

75. With favourable market projections, alternatives such as expansion of existing production facilities versus development of new sources of production must be objectively and systematically evaluated. The chosen expansion alternative or alternatives must be compatible with short- and long-term planning for the whole enterprise. For example, mining ore bodies at a more rapid rate without planning for new sources of production could have a serious impact on the long-term objectives of the enterprise. On the other hand, expansion of production at an operating property may be the most logical approach to maintaining or achieving production objectives over the short term until planned new production sources are developed.

Economics of special situations

76. Expansion may be prompted by the economics of a special situation. Development of existing facilities can provide a logical approach to reducing unit cost by virtue of higher production. This could be accomplished through more extensive utilization of capacity in existing facilities, modernization of equipment and installation of more efficient processes. In many cases, the time for obtaining increased production becomes less with the expansion of established properties. Likewise, capital costs per unit of increased production are often lower than costs for development of new properties. In specific locations, expansion associated with modernization can actually extend the life of properties by reducing unit costs of production to a point where lower grade ore can be mined and processed at a profit. Thorough engineering and financial studies are primary prerequisites to effective decision making.

Economic prerequisites

77. Commitments to expansion or new development programmes for increased production may be, in many cases, large enough to represent the future success or failure of the enterprise. Because of the financial risks involved, it is important to evaluate thoroughly all economic factors that can influence the final outcome.

Capital investment

78. Expansion of production capacity requires large capital outlays. The use of capital at the most promising locations reduces risks and enhances the financial position of the enterprise. The matters of thorough economic evaluation followed by sound engineering become all the more critical when future sources of copper are considered. Major increases in production may probably come from known ore reserves presently considered as sub-marginal in value, or from similar sources yet to be fully evaluated. Alternatively, however, there may be expansion of existing properties. The United Nations Industrial Development Organization objective of accelerated development of new mines and objective expansion of copper production in the developing areas of the world to offset the costs of mining the relatively low-grade copper deposits will assist the industry in paving the way for exploration in areas attractive for capital investment.

Market projections

79. Copper price: as mentioned earlier, a multitude of factors such as labour unrest, political change and fluctuations in economic activity, have their effect on copper price and may influence expansion decision. On the positive side, business and economic expansion also have their effects.

80. Starting up a new mine or expansion of an existing property with equivalent processing capacity involves significant expenditure; therefore, the decision to expand production must be supported by a sound market study. It is reasonable to assume that significant future increases in copper production will be largely derived from development and exploitation of lower grade ore bodies and through expansion of production at existing properties. Objective projections of operating costs, selling price and business outlook are determining factors in decisions related to increased production or opening of new mining properties.

81. Consumption growth rate: growth in consumption associated with industrialization in development areas, improvement in general standards of living, military usage and increases in population may have some effect on eliminating or reducing possible over-supply conditions of the industry.

82. Production growth rate: the indications of surplus capacity in the future may be only a theoretical one. Strikes, delays or interruptions in transportation, and potential decline in market prices associated with over-supply all decrease and, at times, eliminate the availability of this apparent surplus capacity.

Other economic factors

83. Factors influencing the extent of expansion are availability of capital, cost of capital, and operating expenses such as labour cost, material cost and overhead.

84. Labour: in analysing the economics of a mining potential or expansion of copper facilities, the cost of labour is a basic factor. It is relatively easy to price. Evaluation, however, is more than a mere monetary matter; it should embrace the background of the labour force. Are workers competent, do they accept authority, can they be trained, do they respect and have aptitude for mechanical equipment? Escalation of labour costs over a period of years must be considered in evaluating profit potential of new or expanded mines. New plants must, therefore, compensate through incorporation of the most advanced technology to assure a profitable operation over the life of the mine.

85. Transportation: availability, dependability, and costs of transportation and utilities are also important factors in productivity.

86. Resources: water, electricity, gas, steam, communications, sanitation, waste disposal and other utilities must be evaluated carefully to determine impact on production costs. Future constraints on such items should be determined to insure against limitations which could be determining factors in planning.

87. Local taxes: local taxes must also be considered in the economic evaluation of alternate approaches to expansion. The matter of local taxes is a complex subject which merits separate treatment. It will suffice merely to call attention to it in this presentation.

Engineering prerequisites

Approach to expansion

88. Once the logic for expansion is established with the support of sound market projections, the approach to expansion must be developed to provide the optimum return on the investment and optimum position relative to production. In the case of a copper ore mine, for example, increased production may come from one or more of three sources: from existing mines, from known but undeveloped ore bodies or from ore bodies as yet undiscovered. Selection of the best course of action involves complex analysis of the alternatives in terms of optimum application of capital consistent with production and profit objectives.

89. Determination of optimum production: it is essential to determine the optimum scale of operations; too small a mine is not economical. In the absence of high-grade ore, or other overriding considerations, mines with constraints which limit ore production to 10,000 to 20,000 tons per day should be approached cautiously unless existing processing facilities can be made available or new facilities of economic size can be provided to handle production from a combination of mines. The size and shape of an ore body may not be prime determinants of the scale of operations. Planning relative to mining methods, however, and rates of ore production are prerequisites to design of processing facilities.

90. Ore body development and mine planning: the determination of the ultimate potential and best exploitation of an ore reserve is accomplished through investigation of many mining plan variations as well as consideration of design plans covering varying time intervals and production rates. Traditional mine planning methods have been improved through application of computer technology to produce a more realistic evaluation of ore reserves and mining plans.

91. Through the greatly expanded capability of electronic data processing, it is now possible to introduce more information and to develop an economic mine model for ready use in both long-term and short-term planning. Historical information, including drill logs, projected economic values and potential ore reserves with sufficient value to support mine development expense can be inventoried in a logical manner. With accurate knowledge of ore tonnage and potential value, ultimate mining plants incorporating optimum return on investment can be developed. Application of computer technology permits an indefinite number of simulations with complete information relative to ore reserves, ore grade, expected recovery, production, acceptable profit, and return on investment. Great flexibility in short-term planning can be attained which is completely consistent with long-term aims by merely varying the mining locations and incorporating new or changed conditions in the over-all mine plan or programme. Variations in operating cost, the selling price of copper and by-products and other factors that influence the outcome can be readily evaluated and incorporated in advance planning with relative ease. The techniques used are not revolutionary but are an expansion of previous planning methods using the calculating power of the computer.

Research and investigation

92. Process investigation and evaluation should include evaluation of primary engineering prerequisites to make proper decisions on the approach to expansion. These would include, in the case of a copper mine, mineral ownership and rights, ore reserves, ore quantities, mining method, underground facilities, material handling methods and process equipment. Incorporation of the most efficient equipment available in the expansion plan is desirable from the standpoint of operating efficiency. It is advisable to use caution in installing or adopting new equipment or processes without adequate investigation and to use, if possible, pilot-scale performance testing. There are many examples in which major expenditures for new installations have not duplicated laboratory or performance tests. Thorough investigation of engineering feasibility to assure operational reliability is essential. Expansion plans must be based on sound basic research. This research may have to be contracted through reliable research organizations if it is not available internally. In either case, the precaution of independent confirmation of research findings is advisable.

93. After determination of plans and processes, careful estimation of project costs for construction to meet expansion objectives must be determined and related to economic considerations. Estimates for site preparation; construction materials such as concrete, steel work, equipment and piping; labour man-hours; rental equipment costs; sub-contract costs; direct costs; indirect costs and contingency must be included in this evaluation. Escalation of equipment and labour costs over the engineering and construction period can add substantially to project costs, and must be included in the contingency.

Project installation

94. The sequence for proceeding with construction must be planned to assure timely completion and minimum expenditure of funds. Critical path schedules and check lists are essential tools to complement the engineering plan.

95. Engineering planning must include comprehensive evaluation of basic factors such as site, access and transportation, climate factors, ground conditions, utility availability and safety hazards. Other items would include the source of construction labour, sub-contractors available, sources of rental equipment and sources of materials. A check into national and local laws for permits and licenses is required before the project is undertaken. Proper direction of engineering and construction is essential to ensure that the increased production objectives are met. This direction is usually provided by a competent project installation team with full authority and accountability for completion of the modernization or expansion within the appropriated funds, within the scheduled time allotment, and according to the engineering plan. The project cannot be considered complete until increased production is attained at prescribed production cost.

Annex 1

Titles of papers presented for the First Meeting of an Expert Consulting Group on the Copper Industry

The papers presented for the First Meeting of an Expert Consulting Group on the Copper Industry are listed below. Copies of these papers are available upon request from the Metallurgical Industries Section of UNIDO, Rathausplatz 2, 1010 Vienna, Austria.

ID/WG.12/1	WORCRA smelting-converting, a new approach to continuous direct copper production by H.K. Worner, Australia
ID/WG.12/2	The application of oxygen and hot air in the modern copper industry by G.L. Bailey, England.
ID/WG.12/3	Recent improvements in the modern copper industry by K.I. Ushakov, Union of Soviet Socialist Republics
ID/WG.12/4	Economic and engineering prerequisites for modernization and expansion of plants in the copper industry by W.H. Burt, United States
ID/WG.12/5	Design and erection of copper plants taking into account their future expansion by Z. Syryczynski, Poland
ID/WG.12/6	Expansion of the copper industry in Asia by R.L. Khanna, India

Annex 2

Summaries of papers presented for the First Meeting of an Expert Consulting Group on the Copper Industry

ID/WG.12/1 SUMMARY — WORCRA smelting-converting, a new approach to continuous direct copper production by H.K. Worner, Australia

After reviewing briefly other processes used for copper extraction, the paper outlines a new approach to the continuous direct production of metal from sulphide concentrates in which the operations of smelting, matte conversion and slag clean-up are combined in one furnace but in separate, communicating zones or branches. The closely integrated unit operations include concentrate drying, bath smelting, dispersed phase refining, a type of hot solvent extraction and slag conditioning and settling.

The WORCRA process differs from established jet or suspension smelting processes (which in themselves are continuous) in that, (a) it produces metal, not matte; (b) most of the exothermic reactions are generated and continued within the liquid bath (hence the description "bath smelting"); (c) the bath in the smelting and converting zones is turbulent and continuously flowing, and (d) the slag is caused to move generally countercurrent to matte in the converting branch, then to pass through the smelting zone and to emerge finally into a separate relatively quiescent slag conditioning and settling branch from which it is tapped continuously.

As the slag moves countercurrent to matte, into and through the slag conditioning and settling branch, its oxygen activity and its copper content are progressively lowered and on tapping it has a composition not basically different from conventional reverberatory slags. Even in small pilot furnace trials, copper-in-slag values as low as 0.3 per cent have been achieved over extended periods of continuous operation. Dust losses are also low. In full-scale WORCRA plants over-all recoveries of copper at least as high as the best modern reverberatory practice are expected.

The metal produced may contain between 98.8 and 99.7 per cent copper depending on the amount of air (oxygen) lanced into the metal "reservoir" at the end of the converting branch.

Apart from slag and metal, the furnace produces continuously a high SO_2 tenor gas well suited for acid production. Sulphur dioxide levels may be within the range 9 to 12 per cent, when straight air is used for lancing. When oxygen-enriched air is used in the converting branch the SO_2 tenor is proportionately higher.

Over the past four years the method has been tested in various shaped pilot furnaces at the works of C.R.A.'s subsidiary, Sulphide Corporation Pty. Limited, at Cockle Creek, New South Wales, Australia. The method has been proved with four different concentrates fed at rates up to seven tons per day. Preparations are in hand to scale up operations to the semi-commercial phase with feed rates between 70 and 80 tons per day. This development is taking place at the works of The Electrolytic Refining and Smelting Company of Australia Ltd., Port Kembla, New South Wales.

ID/WG.12/2 SUMMARY — The application of oxygen and hot air in the modern copper industry by G.L. Bailey, England

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

(c) $Cu_2S + O_2 = 2\ Cu + SO_2 + 1650$ 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, (a) using some of the heat of the waste gases to preheat the incoming air and (b) 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 African, Canadian and U.S.S.R. practices 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 needed.

The introduction of extra oxygen in converter blowing tends to raise the temperature to an extent that 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 cutting in half 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 procedure that may well have a profound effect on the future of the copper industry.

ID/WG.12/3 SUMMARY — Recent improvements in the modern copper industry by K.I. Ushakov, Union of Soviet Socialist Republics

Preparing of the charge for reverberatory smelting

At some U.S.S.R. plants, the charge is prepared for smelting by the wet method. Quartz and limestone are subject to a combined wet crushing, after which their pulp is added to the copper concentrate pulp in the required amount. The mixture is then filtered. The method ensures a variation of the silica content in the charge up to +/- 2% abs, and of CaO up to +/- 1% abs, and reduces the moisture content of the charge from 14 to 10%.

Roasting of concentrates

At present, copper concentrates are roasted in a fluidized bed at two plants in the Union of Soviet Socialist Republics (Urals, Caucasus), at one plant in Bulgaria (Pirdop) and at one in the United States (Copperhill Tennessee Copper Company). Roasting in a fluidized bed, instead of multi-stage mechanical furnaces, practised at one of the U.S.S.R. plants, increased the specific capacity of the furnaces from 8 to 9 to 65/m^2 per day and raised SO_2 content in the gases from 7.0 to 12.5%.

Semi-industrial tests have been conducted in the Union of Soviet Socialist Republics with a blast enriched with oxygen for roasting. When the oxygen content in the blast is increased from 21 to 35%, the specific output of the furnace rises from 65 to 108 ton/m^2 per day and SO_2 in the gases grows from 12.5 to 18.7%.

Reverberatory smelting

In recent years the output and thermal power of reverberatory furnaces in the Union of Soviet Socialist Republics have been considerably improved (up to 50 to 60 million kcal/hr.). The total smelting rate of furnaces that process raw charge has reached 4 to 4.5 ton/m^2 per day and of those that handle roasted charge, 7 to 8 ton/m^2 daily. The heating of the secondary blast to 200 to 350°C reduces fuel consumption by 7 to 10% and increases the smelting rate by 15 to 20%.

Industrial tests have been conducted with oxygen in a reverberatory furnace fueled by natural gas. The oxygen in the blast was raised to 35%. As a result, the total smelting rate has increased from 4.25 to 6.0 ton/m^2

daily; SO_2 in the exhaust gases rose from 1.5-2 per cent to 6-7 per cent, while the copper in the slag dropped from 0.46 to 0.39 per cent.

Smelting in shaft furnaces

Since 1960 oxygen-enriched blast has been successfully used for smelting sintered copper concentrates at one of the U.S.S.R. plants. With 27.3 per cent oxygen in the blast, coke consumption dropped from 7.89 to 5.93 per cent, total smelting rate increased from 101 to 115 ton/m^2 daily, blast intensity rate decreased from 85.5 to 61.8 nm^3/m^2 min. and temperature of the exhaust gases dropped from 590°C to 320°C.

Some grades of sulphide ores rich in copper, sulphur and noble metals can be processed most effectively by the Orkll method. A low degree of reduction and a low direct (without catalysis extraction of sulphur in the elementary form) are the principal shortcomings of this method which can be eliminated by a blast enriched with oxygen. In the U.S.S.R. this method will be introduced in the industry in the near future.

Flash smelting

Flash smelting on hot air blast is employed industrially at Harjavalta (Finland), Asio (Japan) and Baja-Mare (Romania). The air is heated to 500°C. If there is not enough heat to melt the charge, 1 to 2% liquid fuel of the charge weight is burnt to melt down the charge. Smelting on technical oxygen is practised at the Copper-Cliff plant (Canada) and will be introduced in the Union of Soviet Socialist Republics in the near future.

Flash smelting offers the following advantages: (a) fuel consumption for the smelting process is considerably reduced and is completely dispensed with in the case of oxygen smelting; (b) high degree of desulphuration; (c) high specific capacity (up to 12 ton/m^2 per day); and (d) full utilization of sulphur. At the same time, flash smelting is more complicated technically than smelting in a reverberatory furnace because the charge has to be dried thoroughly and also the slags depleted.

Converting of copper matte

At some plants, Copper-Cliff (Canada), Hitaty (Japan) and in the U.S.S.R. the blast is enriched with 25 to 32.5 per cent oxygen in matte conversion. The rate of the process has been found nearly proportional to the concentration of oxygen in the blast.

The maximum temperature of the melt is maintained in the converter with the aid of cold additions in the form of cold matte and granulated copper concentrate.

Economic aspects of using oxygen and hot blast in the copper industry

The economic expediency of using oxygen depends on a number of conditions, primarily on the relationship between the costs of electric energy and fuel. Besides the purely technological advantages, the use of oxygen will facilitate the solution of the problem of reducing the discharge of sulphur dioxide into the atmosphere. Still more effective is the use of hot blast to reduce fuel consumption in smelting, especially when heating is done by the heat of exhaust gases and slags.

ID/WG.12/4 SUMMARY

Economic and engineering prerequisites for modernization and expansion of plants in the copper industry

by W. H. Burt, United States

Based on current market studies, increases in the productive capacity of the copper industry will be needed to meet projected increases in world-wide consumption brought about by accelerated industrialization in the developing areas, improvement in standards of living and population growth. This demand for increased production will be obtained by expansion and modernization of active mines and the development of new mines. Determination of where increases in production will come from, will depend upon a number of economic and engineering prerequisites.

The United Nations Industrial Development Organization objective of accelerated development of copper production in the developing countries can provide production required to establish and maintain stability in international markets. Expansion of production at existing properties can be an important alternative to developing production from low-grade copper deposits.

Because commitments to expansion or development of new resources are large enough to have a significant impact on the future success of mining enterprises, the reasoning for expanded production must be supported by sound research and economic analysis. Accurate projections of market conditions will provide the basis for proper timing. With favourable market projections, objective and systematic evaluation of the best alternate or alternatives will provide the basis for decisions on how to approach the increased production

objective. The chosen alternatives must be compatible with short-term and long-term planning of the mining enterprise.

Incorporation of the most efficient equipment available in the expansion plan and thorough investigation of engineering feasibility are necessary to ensure operational reliability of new and expanded facilities. Careful estimation of project costs is necessary to ensure increased production with the most desirable return on the investment.

Determination of the ultimate potential and the best plan for exploitation of an ore reserve is accomplished through investigation of many mining plan variations and design plans covering varying time intervals and production rates. An approach to ore body development and mine planning used by Kennecott Copper Corporation for evaluating profit potential and economic limits is presented in this paper. This approach, which utilizes the calculating power of the computer, can be used by any mining enterprise to assist in evaluating increased production alternatives and as a guide to long-range and short-range mine planning.

ID/WG.12/5 SUMMARY — Design and erection of copper plants taking into account their future expansion by Z. Syryczynski, Poland

The rapid increase in the demand for copper is accompanied by increasing copper production. During the last seven years the world's production of refined copper increased by 46 per cent. In connexion with the demand and the high price of copper, new deposits of copper ore are being discovered and exploited, and new copper smelters are being erected.

Selection of the main method of processing copper-bearing raw materials

Reverberatory furnaces: raw materials for this method are copper concentrates of a sulphur content equal at least to that of copper; they may, however, not be high-melting. The concentrates to be processed by this method must be predried. Improved reverberatory furnaces of large size and fired with cheap fuel (natural gas or oil) are very inexpensive to use.

Blast furnaces: raw materials for this method are rich-lumped ores containing more than 5 per cent of copper or briquetted or pelletized copper concentrates which, for various reasons due to low bitumen content, cannot be smelted by

other methods. Concentrates containing more sulphur can be lumped by sintering, but this is an expensive process. Smelting in blast furnaces is an easy method and this smelting can be adapted to small production volumes. Coke is indispensable for this method.

Resistance arc furnaces: raw materials for this method can be high-melting concentrates. It is desirable that they contain a sufficient amount of sulphur so that they can be pre-roasted without heat supply and, when still hot, can be directly smelted in electric furnaces in order to increase output and decrease power consumption. Electric furnaces may be used only when cheap electric power is available, generated by water power, gas or brown coal.

Flash smelting furnaces: raw materials for this method are sulphur-rich copper concentrates dried to a water content of 0.5 per cent in order that the process employed for their smelting may be autogenous. The amount of volatile accompanying metals (Zn, Pb) and volatile rare metals (Ge, Re) driven off is very high and can be used for smelting those concentrates that contain these elements. The gas escaping from flash smelting furnaces is rich in sulphur dioxide and can be processed to sulphuric acid or liquid sulphur dioxide. Flash smelting furnaces must be fully automatized in order for them to operate efficiently.

Hydro-metallurgical methods

Raw materials for the acidic version of the hydro-metallurgical method are oxidized copper ores of acidic deposit. Raw materials for the alkaline version (pressure ammonia leaching) of the hydro-metallurgical method are oxidized copper ores of alkaline deposit. A copper smelter employing the acidic pressureless hydro-metallurgical method is cheap to operate. However, a copper smelter employing the alkaline pressure hydro-metallurgical method is more expensive because of the necessary expensive autoclave equipment.

Bacteriological recovery methods

Bacteriological recovery methods are used for poor sulphide or sulphide-oxide ores, and to recover copper from slag. These methods are now only in the development stage and are used as supplementary methods in copper ore mines for poor ores and copper smelters to recover copper from slag. Raw materials for this method must absolutely contain iron and sulphur in addition to copper; the two former elements are transformed by bacteria.

Size of copper smelters

The following table shows the range of the annual production volumes attainable with one furnace by individual methods; the lower figures denote the minimum annual production volume for the given furnace type, ensuring the indispensable minimum profitability of a copper smelter, and the upper figures denote the maximum annual production volume attainable with one furnace for individual methods.

Specification of the annual copper production volumes attainable and recommended for individual metallurgical methods employing one furnace

Method	Version of method	Type of raw material	Annual copper production volume per one furnace (in tons)
Reverberatory furnaces	Improved	Pre-dried concentrate	40,000 - 80,000
Blast furnaces	Improved	Briquetted or pelletized concentrate	25,000 - 50,000
Flash smelting furnaces	Outokumpu	Concentrates dried to 0.5% water content	30,000 - 50,000
	Inco	Concentrates dried to 0.5% water content	80,000
Resistance furnace	Conventional	Pre-roasted concentrates	25,000 - 50,000

The annual copper production volumes attainable in the majority of hydro-metallurgical smelters are within 10,000-30,000 tons. Two hydro-metallurgical smelters only, in Chuqnicamata, Chile, and in Kolvezi, Africa, show considerably higher annual copper production volumes.

Selection of the site for a copper smelter

The points that should be considered in selecting the site for a copper smelter are as follows:

(a) Copper smelters processing copper ores directly without their enrichment should be located close to respective mines;

(b) Copper smelters at great distances from enrichment plants and processing concentrates should obtain the concentrates preferably by water, by rail or in the form of a pulp by pipelines;

(c) Supply of cheap fuel, electric power, water, fluxes and refractory materials to the building site;

(d) Disposal of sulphuric acid receivers close to a copper smelter;

(e) The site for a copper smelter should not be close to fertile soil or woods;

(f) Ground should be fairly level; a hill on the site or close by is desirable to erect a chimney thereon;

(g) Ground of the building site should be strong enough to avoid the necessity of laying deep foundations;

(h) Location of a copper smelter near to a town is desirable;

(i) The building site should be sufficiently large to enable future extension.

Main problems to be taken into account in designing the first stage of erection of a copper smelter in order to facilitate future expansion

(a) Selection of a sufficiently large site to enable future expansion;

(b) Possible construction, even in the first stage, of pipelines for gas, water and fuel oil, having throughputs sufficient for the first and second stages;

(c) Provision, in the first stage, of channels of sufficient cross section for laying additional pipelines in the second stage in case a different method of pipe laying is employed;

(d) Provision, in the first stage, of foundations for larger converters (sufficient for both stages) and installation of smaller converters thereon in the first stage;

(e) Erection of many items of equipment out-of-doors or in open sheds (in warm and hot climates) to facilitate the erection close by of additional identical items in the second stage;

(f) Installation of two waste-heat boilers for one reverberatory furnace in the first stage in such a way that, after one reverberatory furnace and one waste-heat boiler have been erected in the second stage, one of the waste-heat boilers erected in the first stage can be used as a stand-by unit for both the reverberatory furnaces;

(g) Stationary refining anode furnaces and stationary cathode copper melting furnaces should be designed and erected in the first stage so that they can be expanded in the second stage to any required capacity;

(h) Erection, in the first stage, of a chimney of sufficient height and throughput required for both stages because after a copper smelter has been doubled in capacity the gas from the entire copper smelter should be released at a considerably greater height than in the first stage;

(i) It is necessary for many reasons to employ as far as possible the same processing method in both the erection stages of a copper smelter, that is, the method of smelting concentrates to copper matte.

General remarks

Some of the building changes proposed above increase investment costs for the first erection stage of a copper smelter. Consequently, this fact should be considered and costs determined in advance depending upon the time interval between the first and second erection stages.

ID/WG.12/6 SUMMARY — Expansion of the copper industry in Asia by R.L. Khanna, India

In Asia, copper mineralization appears to have a strong affinity with volcanic activity, as most of the deposits are associated with the Pacific and Indian Ocean Fire Belts. Except for a few scattered deposits in India, there is a complete lack of copper along the Asiatic main coasts.

Among the countries of Asia, Japan's production and consumption of copper is the highest. Its mine output, however, lags far behind the smelter output and the country has to depend on imported concentrates mostly from the Philippines. Intensive geochemical and geophysical prospecting is being done to explore new deposits and the Kuroko ore which has brought a boom to the Japanese copper industry is an example of such sustained efforts. Japan is also actively participating in developing mines in other countries. Its smelting and refining capacity with the expansion programmes in hand appear to be enough to provide for its present demand. The technical know-how in Japan is well developed and this country can independently put up copper mines, concentrators, smelters and refineries efficiently. The recent Onahama copper plant was erected during a period of only fifteen months and it is an example of Japan's technical ability.

In China (Taiwan) there is only one working mine that, although primarily working for gold, produces some copper concentrate which is exported to Japan for smelting. Natural resources in the country are not adequate.

The copper deposits in the Philippines lie directly in the Fire Belt and are characterized by wide distribution of copper minerals. There are several mines and concentrators in the country and some of these plan to raise their output substantially. The country has great potential for stepping up its mine production and can also put up smelting and refining facilities.

In Indonesia, although copper may be found extensively, unfavourable conditions have prevented mining developments and no working mines exist at present. As in the Philippines, Indonesia also has a potential for a copper industry and it should be developed.

In Korea, a few deposits exist, some of which have high-grade copper ore and it is likely that more deposits may be detected in future. The production of copper ore increased appreciably in 1965 and the entire mine output is now being processed by the state-owned Changhang smelter.

There are a few copper deposits in Thailand, but none is being worked at present. Occurrences of copper have been reported in several localities in Burma, but none has been found to be of much economic importance except the Bawdwin and Monywin deposits. The possibility of proving new workable deposits by detailed exploration, however, cannot be ruled out. Ceylon, Malaysia and Pakistan do not have any important copper deposits, except some indications of copper mineralization in the Raskah range in Pakistan.

In India, the present production of copper is about 9,500 tons per year. Several workable deposits have been proved in the country and attempts are being made to develop these with foreign collaboration. Some of the important projects in hand are: the Khatri Copper Project, Agnigundala Copper Project, Rakha Copper Project, and the Indian Copper Corporations's Flash Smelter Project. A programme for extensive exploration of the country has been taken in hand and is being actively pursued by the Government. A production of 70,000 tons of copper per year has been planned by 1973. It has also been proposed that after 1973 a group of mines capable of producing 40,000 tons of copper per year will be developed every alternate year until production of about 300,000 tons of copper per year is reached; this is the expected consumption. In Nepal there are a few old workings which deserve detailed exploration.

It is certain that the consumption of copper in Asia will increase with the rise in standards of living of the vast population of this continent. Problems such as political control of land within which the minerals lie, raising of capital and pooling of technical know-how require proper thinking and perseverance. The United Nations Industrial Development Organization with the assistance of various governments can play an important role in tackling these problems and can also participate actively in the development of the copper industry in Asia.

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