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DEVELOPMENTS IN WORCRA COPPER SMELTING-CONVERTING 1/

by

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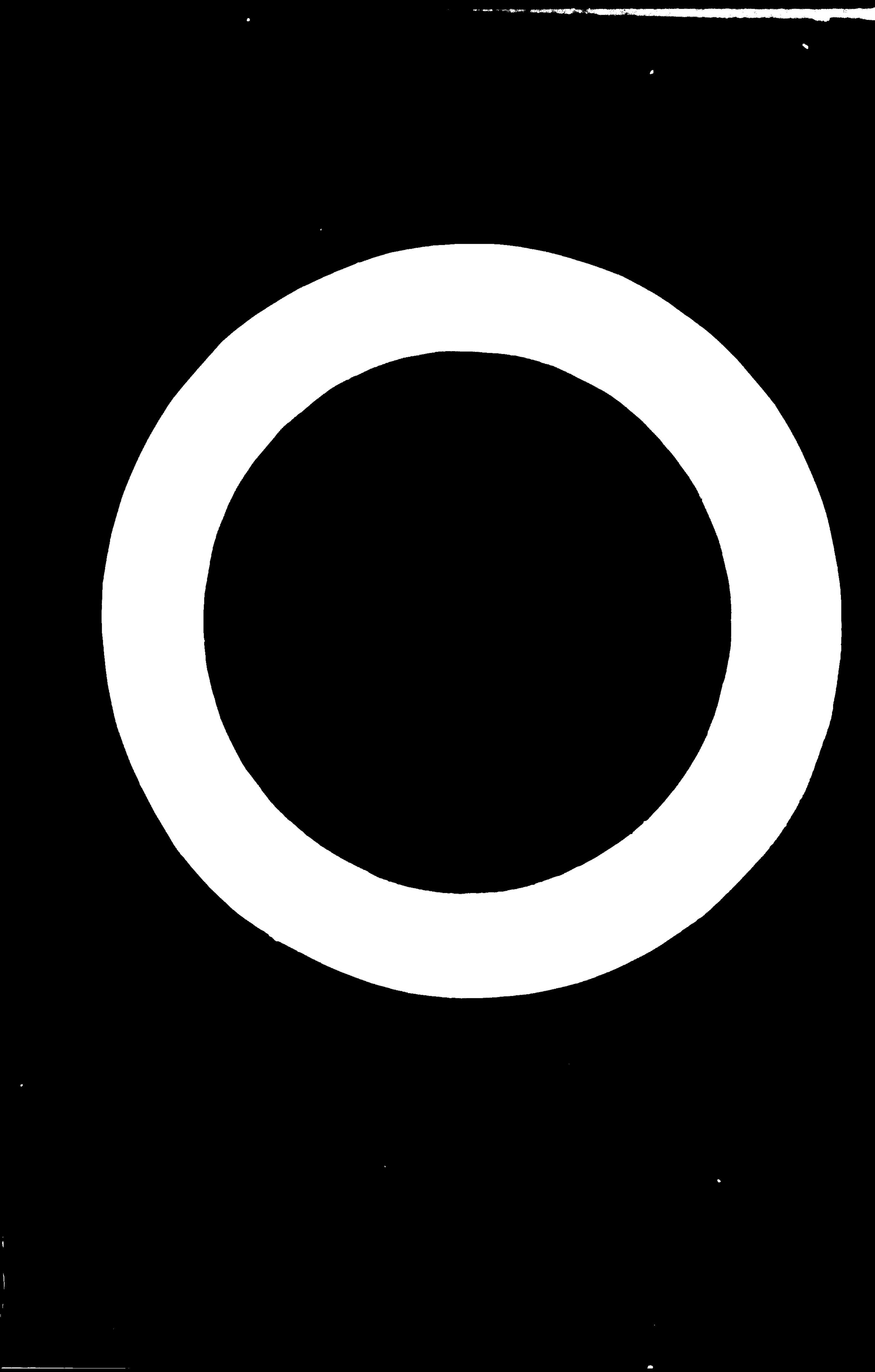

"Developments in WORCRA* Copper Smelting-Converting"

by

Dr. Howard K. Worner

Australia

Introduction - Principles

1. The principles inherent in WORCRA pyrometallurgy, both ferrous and non-ferrous, have been outlined in previous papers (1, 2, 3, 4) and in patents granted in over forty countries. For completeness, however, it will be appropriate to summarise here the essential characteristics.

2. All of these processes seek to maximise energy conservation and to reduce capital and operating costs by a high degree of integration of efficient continuous unit operations, and, in the case of smelting, to take advantage of the finely particulate nature of concentrates, presenting as they do a high surface area for reaction with gases, liquids and other solids.

3. In their application to copper production the WORCRA concepts combine in one furnace, with separate but communicating zones or branches :

(a) a continuous bath smelting stage,
(b) a continuous converting stage, and
(c) continuous slag cleaning by conditioning and settling.

4. Figure 1 depicts diagrammatically the differences between the WORCRA approach to copper production and the traditional reverberatory-converter and blast furnace- converter approaches which involve ladle transfer of matte between the smelting furnace and the converter and a separate transfer of "revert" slag in the opposite direction.

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* The name WORCRA is derived from the first half of the inventor's name (H. K. WORNER) and C.R.A., the abbreviation for Conzinc Riotinto of Australia Limited.

5. The spatial relationship of the different zones in a WORCRA smelting furnace is depicted diagrammatically in Figure 2. "Zonalisation" in a horizontal plane is a feature of all the furnace shapes.

6. WORCRA smelting-converting is characterised by the following features :

(i) it produces metal rather than matte, directly from concentrates;

(ii) most of the exothermic oxidation reactions are generated and continued within the liquid bath, hence the description "bath" smelting;

(iii) the bath in the smelting and converting zones is turbulent and continuously flowing, the turbulence being generated by injection of oxygen-containing gas from lances;

(iv) in the converting zone, slag moves (simply under the action of gravity) generally countercurrent to matte and metal;

(v) copper-in-slag is reduced to throw-away levels as the slag flows through the smelting zone and slag cleaning zone; there is no "revert" slag nor the necessity for separate copper recovery treatments;

(vi) the SO_2 bearing gases generated in the smelting and converting stages combine and leave the single furnace continuously at a rich tenor via one gas offtake.

7. Unlike conventional reverberatory smelting, where reactions between slag and matte have to take place predominantly at a single horizontal interface, the WORCRA process seeks by the method of injecting particulate solids and gases into the bath to maintain within the smelting and converting zones the maximum area of surface for reactions in the liquid phases. The converting zone particularly is maintained in a state of vigorous turbulence with the air (or air-oxygen mixture) jets thoroughly stirring and dispersing slag and matte. It is appropriate to describe the converting reactions as "dispersed phase refining".

8. Furthermore, the fact that the slag is caused to move generally countercurrent to matte enables a type of hot solvent extraction to be achieved. Unwanted non-volatile components in the matte, particularly iron, are continuously being transferred (after oxidation) to the slag. Conversely and particularly in the smelting and slag clean-up zones, valuable copper in the slag can be caused to revert to the matte phase by interaction with ferrous sulphide in the matte.

9. In the separate but connected slag cleaning zone, appropriate conditions are maintained and additions made to achieve both separation and settling of entrained matte and its continuous return, gravitationally, to the smelting zone via a backward sloping hearth. It is appropriate to maintain neutral or reducing conditions in the slag cleaning zone whilst the smelting zone and particularly the converting zone, are of course strongly oxidising.

10. The progressive changes which occur in the matte stream as it moves slowly through the smelting and converting zones and is sequentially lanced with air or air enriched with oxygen are indicated in a general way in the ternary diagram of Figure 3. Fortunately, as the matte is converted to white metal and this in turn to metal, significant differences in specific gravity aid in the separations.

11. As shown in Figure 4 the hearth in the converting zone slopes generally downwards to an underpass through which copper metal passes continuously to a "copper well". This feature enables separation of a blister grade copper equivalent in purity to that produced by conventional processes.

12. Contrary to classical theory and batchwise converting practice, the production of copper takes place (continuously) whilst there is a considerable quantity of matte in the furnace. This is possible because of the geometry of the furnace and process dynamics.

13. At the copper tapping end of the converting zone the phases above the copper metal are an emulsion of slag and white metal (Cu_2S). Naturally this slag is also highly oxidised. As the slag moves back towards and into the smelting zone its magnetite and copper contents are progressively lowered. Chemical reduction and "stripping" of copper is particularly marked as the hot slag mixes with the freshly melting matte in the circulating bath of the smelting zone which preferably is generally circular in shape and known in WORCRA parlance as the smelting "bowl".

14. The reduction of the copper content of the slag as it flows slowly through the slag cleaning zone is enhanced by the addition, under reducing conditions, of a proportion of the concentrate feed. Alternatively and according to supply and cost considerations it can be beneficial to add other reductants such as low grade concentrates or pyrites. Coal or other solid carbonaceous materials may also be used for the same purpose.

15. The furnace gases rich in SO_2 can be treated for waste heat utilization and dust recovery in conventional gas cooling and dust collection equipment, prior to either venting through a stack or treatment in a sulphuric acid plant. As the gases are low in oxygen content, their processing for elemental sulphur recovery could also be attractive as these processes, through improved technology, become viable.

16. It is possible, as in the case of the furnace at Port Kembla, shortly to be described, to vent separately the combustion products from the burners used to keep the slag cleaning zone hot. In a commercial scale plant these low-in-SO_2 gases could be used separately for concentrate drying or combined in a small offtake with the rich SO_2 bearing gases from the smelting-converting zones and used to generate steam prior to final gas cleaning.

17. It is generally advantageous to preheat burner air. The way in which this is done will depend upon such factors as :

(a) capital and operating costs of the heat exchange equipment,

(b) the cost of coal, oil or gas fuel which would be required to do the same work in the smelter in question, and

(c) the value of power credit derived from waste heat steam.

18. Under certain conditions the preheating of ingoing concentrates and fluxes, and also of converter air may be worthwhile, depending on the unit costs associated with any one particular smelting situation.

19. Concentrates may be added not only to the main smelting and slag cleaning zone but to the converter zone (where they help to control magnetite formation in the slag.) The principal addition of concentrates to the smelting "bowl" is achieved by pneumatic or mechanical injection at an appropriate angle to ensure not only that the particles penetrate into the liquid but also to aid in the continuous circulation of the matte and slag in the "bowl".

20. It is necessary to maintain steady state conditions in the smelting and converting zones with appropriate temperature and composition gradients. The furnace should be designed to facilitate the maintenance of these gradients, not only horizontally but vertically as well, and particularly at the deeper copper tapping end. There the vertical temperature differential may be between 75^{o} and $100^{o}C$. The nearer the bottom approaches the freezing point of copper the lower will be the sulphur content of metal flowing via the underpass to the copper "well" (see left hand end of Figure 4.) Naturally, however, the temperature of the copper continuously collecting in the deep end of this zone must be maintained at a high enough level to ensure that freezing of the underpass does not occur. As a general rule the metal tapped and cast from the copper well carries between 0.6-0.9% sulphur. The sulphur can be reduced to any desired level by top lancing with air or oxygen in an auxiliary holding furnace ahead of anode casting.

Possible Furnace Shapes

21. The straight line form shown in Figures 2 and 4 is the simplest furnace arrangement with the converter zone and the slag cleaning zone connected on opposite sides of a more or less circular smelting "bowl". The straight line WORCRA furnace can be made either stationary, like a reverberatory furnace, or tiltable like a Peirce-Smith converter. In the latter case the converting air can be injected through lances or a sequence of tuyeres, much like a conventional converter, but in the fixed type the oxygen-containing gases are preferably introduced into the bath through lances which may enter the furnace through either the roof or the walls.

22. One of the early WORCRA tilting straight line pilot furnaces built at the end of 1963 is shown in Figure 5. Furnaces with an L, Z or U shape and even with a complete annulus for the smelting-region have also been tested with satisfactory results The U-shaped form, to be described in the next section, has some advantages where a limited site is available for the smelter. However, unless a long connection is provided between the smelter "bowl" and the slag cleaning zone, this shape does limit lancing operations to the roof and one side of the converter zone. The working space in the centre "isle" can also get unpleasantly warm.

23. Where it is desired to introduce a "waist" or "restriction" in a furnace this can be done with refractory or by "banking" technology, using concentrates and/or siliceous flux to build and maintain the banks.

Pilot Plant Trials - Cockle Creek

24. The first experimental evaluation of WORCRA concepts took place in early 1963 with lead concentrates at Cockle Creek, New South Wales, at the works of Sulphide Corporation Pty. Limited, a subsidiary of Conzinc Riotinto of Australia Limited. These tests were sufficiently encouraging to justify trials with other metals at the same works in the latter part of 1963. The first run with

copper concentrates took place in a small straight line furnace in late September of that year. The product was a mixture of white metal (Cu_2S) and copper and it was immediately apparent that if the furnace could be enlarged and a greater degree of zoning introduced, there was good prospect of producing copper continuously while concentrates were being introduced continuously in another zone.

25. As mentioned above, various furnace shapes were tried and success was achieved with practically all of them. They were lined with dense chrome-magnesite bricks. Late in 1964 it was decided to build a U-shaped furnace at Cockle Creek with a capacity of six tons of concentrates or 1.3-1.5 tons of copper per day depending on the concentrate grade. Over the next three and a half years the U-shaped furnace was operated with four different concentrates in twelve campaigns, each of between two and seven weeks duration, aggregating 52 weeks of three shift per day operation. The feed concentrates ranged in copper content from 18 to 25% and had sulphur levels from 24 to 35%.

26. There is every indication that the process can be applied to the full range of sulphide concentrates which are smelted in other existing processes. This is perhaps what should be expected because WORCRA chemistry for copper smelting-converting is basically the same as in the conventional processes. The differences between the processes are more in the way the chemistry is made to work. Physically the smelter bowl serves functions similar to the reverberatory furnace, the converter zone to the batch converter and the slag cleaning zone to the forehearth used with copper blast furnaces. The slag cleaning is however effected in one and the same furnace as the smelting and converting. The excess heat liberated in the bath by the oxidation of iron and sulphur is immediately available to help melt incoming concentrates and flux.

27. With each of the four Australian concentrates tested it was found possible to produce copper within the range 98.2-99.5% metal, depending on the degree of extra oxidation of the residual sulphur which was effected in the copper well at the end of the converter branch.

28. Recovery of gold and silver was found to be comparable to that in conventional practice. The elimination of volatilisable metals like lead, zinc, antimony and arsenic was as good as or slightly better than in conventional batch processes. The evolution of most of these elements takes place mainly at the beginning and end of the WORCRA smelting-converting operation. A large proportion come off as the finely particulate concentrates are jetted into the turbulent circulating bath in the smelting bowl. Further elimination of impurities, particularly of residual bismuth, can be achieved by oxidising in a holding furnace ahead of anode casting.

29. Dust carryover with furnace gases was in the range 2-5%. In the Cockle Creek pilot plant the dust and fume were collected in a hot cyclone and wash tower in series.

30. Slag compositions were generally similar to those generated in reverberatory practice i.e. SiO_2 30-38%, FeO 40-50%, CaO 2-8%. Copper in slag levels during steady state conditions ranged between 0.3-0.5%, the lower values being achieved when pyrites were added to the slag cleaning zone while the 0.4-0.5% levels were achieved with concentrates added as the "washing" agent.

31. Lancing air was blown in at similar pressures to those employed in conventional converting practice, i.e. 14-18 p.s.i.g. Oxidation efficiencies were high, usually between 95-110% of theoretical. Clearly the values over 100% were achieved with adventitious air entering through sampling ports and other small viewing holes in the smelting bowl and converter zone.

32. When air ingress was controlled, SO_2 levels in the furnace gases ranged between 9-12% depending on the sulphur content of the feed concentrates.

Semi-Commercial Furnace - Port Kembla

33. The results with the small pilot plants at Cockle Creek were so encouraging that it was decided late in 1967 to construct a larger test furnace. The ready co-operation of the Electrolytic Refining and Smelting Company of Australia Ltd. (E.R. & S.) was given for a "semi-commercial" furnace to be built by Conzinc Riotinto of Australia Limited in their works at Port Kembla, New South Wales. Because of the satisfactory experience with the final pilot furnace at Cockle Creek it was decided to build a U-shaped furnace with two gas offtakes - the main one at the end of the converter zone and a smaller offtake in the middle of the slag cleaning zone, through which low SO_2 content gases could be taken to the rotary drum type concentrate drier.

34. This semi-commercial plant was designed with a number of features to permit assessment of alternative materials handling and feeding systems with a view to optimising the design before scaling up to commercial installations.

35. Figure 6 shows a plan view of the Port Kembla furnace and a photograph of the furnace taken during construction is shown in Figure 7. A photograph taken from a somewhat similar position after completion is shown in Figure 8. The only crane used in the smelter building is a light monorail type to transfer a small proportion of the concentrates and flux to hoppers which feed "banks" on the smelting bowl and converter zone. A belt feeder would probably be preferable for this duty in a larger commercial furnace.

36. Provision is made for adding concentrates and flux via either pneumatic tubes, mechanical slinger or "dump chutes". Slag can be tapped continuously either into shallow ladles or into a granulating launder. Copper is tapped from the copper well as required into cast iron moulds which hold just over 3,500 lb. of metal. Figure 9 shows a typical 8 hour shift production of copper. The stream of copper flowing from the copper well can be seen in the background to the left of the word "WORCRA". The slag stream running continuously from the slag well into the granulating launder is shown in Figure 10.

37. The Port Kembla furnace was commissioned in late July, 1968 and operated on copper continuously till the middle of June, 1969, except for a break of approximately six weeks in late 1968 until early 1969 when it was used, with promising results, to smelt a quantity of nickel concentrates. During the 50 weeks campaign it was amply demonstrated that the process worked on the larger scale and that the furnace itself had capacity to treat more than the original design feed rate of 72 tons of concentrates per day (equivalent to approximately 6,000 tons of copper per annum.) Unfortunately, a number of deficiencies in both the feed systems and the gas handling and cleaning equipment became apparent after the first few months of operation and it was decided to shut the furnace down in June, 1969, and modify both systems. Opportunity was taken to carry out some brick work modifications and repairs.

38. The furnace was brought back on line again in mid September, 1969, and immediately responded to the improved feeding and gas handling systems. Feed rates up to 50% greater than the original design rating of 72 long tons per day (t.p.d.) have been achieved over periods of several days at a time and low copper in slags, below 0.5%, have been sustained for considerable periods.

39. After nine months operation in Campaign No. 2, the furnace was again shut down to effect some further changes and repairs and in particular to permit roof lancing as well as side-wall lancing. Campaign No. 3 is now well under way.

40. Dense chrome-magnesite refractories have withstood furnace conditions in most regions. Accumulating experience has enabled us to develop designs for water and air cooling of certain parts of the furnace structure which are subject to considerable splash and washing action by matte and slag. Naturally some problems have been encountered but steady progress is being made towards the objective of a furnace capable of withstanding operations for several years without a major shut-down.

41. With its present concentrate throughput averaging about 80 long t.p.d. the total fuel requirements are of the same order as in large scale wet charge reverberatory smelting. There are strong indications that as the throughput increases and as operators gain more experience with burner control, fuel requirements will drop significantly. In any case, in larger commercial WORCRA furnaces with a greater volume to surface ratio, the overall fuel requirements should be appreciably less and promise to be of the order of 50 to 60% that of reverberatory requirements for a corresponding production rating.

42. With supplemental oxygen used in the smelting-converting zones oil consumption can be considerably reduced. Smelting becomes almost autogenous and additions of coolants such as scrap and cement copper may become necessary. The oxygen used need not be at the high purities and pressures required in steel plants.

43. Depending on the sulphur levels in the feed concentrates and with air only used for lancing, SO_2 tenor in furnace gases is between 9 and 12% with between 0.5 and 2% free oxygen. Naturally, richer SO_2 tenors are produced when supplemental oxygen is employed.

44. As was the case in the smaller pilot furnace at Cockle Creek, the best overall metallurgical results have been achieved when steady high feed rates are maintained. Using a bath sampler developed by Noranda Mines Ltd. and brought to our attention by that Company under the terms of a technical exchange agreement, we have sampled the bath slag at various positions (marked A, B, C, D and E in Figure 6.) The results included in Table 1 reveal the differences between the degree of slag cleaning with respect to copper which takes place during periods of steady state operation and after a period of relatively low feed rate and over-oxidation of slag in the converter zone and smelting bowl.

Table 1

Some Typical Slag Copper and Magnetite Values in Different Furnace Positions during

(a) steady state conditions with high feed rate

(b) non steady state conditions with low feed rate

		(a) Steady State		(b) Non Steady State	
		% Cu	% Fe_3O_4	% Cu	% Fe_3O_4
A.	Copper end of Converter Zone	11.0	24	12+	30+
B.	Smelter Bowl	4.0	16	6.4	30
C.	Entry to Slag Cleaning Zone	2.2	8	3.1	20
D.	Before Weir in Slag Cleaning Zone	0.79	2	nd.	3
E.	Slag Well	0.32	1	0.81	2

45. The above data were obtained while the furnace was operating on concentrates which analysed :

Copper	23.7%
Iron	30.6%
Sulphur	32.9%
Zinc	5.0%
Lead	2.2%
Silica	3.7%

46. In general, the metallurgical performance of the larger Port Kembla furnace has been similar to that reported upon briefly in the previous section of this paper and in reference 2.

Atmospheric Pollution Implications

47. Considerable attention is now rightly being given throughout the world to reducing atmospheric pollution from smelting plants of all kinds. The predominant copper smelting process, comprising reverberatory smelting followed by converting presents difficulties in this regard.

48. As is well known the sulphur dioxide content of gas from the reverberatory furnace rarely exceeds 2½% by volume and as such is unsuitable for any economic sulphur or sulphuric acid recovery process. Recovery of sulphur, in the form of sulphuric acid from gases produced by the roasting of copper concentrates is practical in some instances but accounts for less than half of the total sulphur content of the feed materials. Sulphuric acid manufacture using copper converter gases is practised but this also presents some difficulties resulting from the comparatively low SO_2 concentrations and their severe fluctuation during the converter operating cycle. The total volume of gas produced from a converter is invariably subject to dilution around the converter hood and it is rarely possible to treat the whole of the gas. As a consequence, variable quantities must be discharged to atmosphere as a means of maintaining adequate concentration at the entrance to the sulphuric acid plant, typically in the region of 5% SO_2. This problem can be alleviated in cases of multiple converter operation.

49. The WORCRA process, along with flash smelting and to a lesser extent calcine-fed reverberatory furnace operation, is able to make a significant contribution to pollution control. In the WORCRA case, however, the furnace delivers a steady stream of gas, which with air only used for lancing contains approximately 10% SO_2. (The level is naturally higher still if lancing air is enriched with oxygen.)

50. Being of high concentration, the gas volume per unit of contained sulphur is relatively small and economies can be achieved in the capital and operating cost of gas cleaning and purification equipment within associated sulphuric acid plants. Although development work on methods of cleaning gases from the WORCRA process has yet to be carried out in detail, it is believed that there will be no special problems and that apparatus normally applied to metallurgical gas cleaning would also be suitable for WORCRA smelter gas. Due to the nature of the conditions within the furnace, it is expected that the solids content of the gas will be low. Pilot plant

observations indicate that for normal types of copper concentrate with normal Pb, Zn content and containing other minor elements which give rise to volatile compounds, the total solids content of gas emission from the WORCRA furnace would be in the range 2 to 6% of the weight of feed material.

51. As the atmosphere in the WORCRA smelting furnace above the reacting bath is at a relatively low oxidising level, the off-gases contain 1 to 2% free oxygen and therefore require dilution if the contact sulphuric acid process is to be used for conversion of the contained SO_2 to sulphuric acid. However, dilution may be conveniently carried out after purification but before the drying stage of the acid plant unit. Depending on the quantity of fuel necessary to maintain adequate temperature in the WORCRA furnace, the gases will contain a small percentage of CO_2, which apart from its dilution effect, would not adversely affect the operation of the contact sulphuric acid process.

52. The nature of the gas from the WORCRA furnace makes it suitable for alternative methods of sulphur recovery other than the production of sulphuric acid. With the increased pressure on industry for removal of sulphur from gases prior to discharge to atmosphere, and the possible development of an economic process for recovery of elemental sulphur, the relatively low oxygen content of WORCRA furnace gases will constitute a distinct advantage over most other metallurgical roasting and smelting gases in which oxygen content is necessarily at a higher level. This factor would also apply in cases where the production of liquid SO_2 is contemplated. It can be foreseen that as the controls on sulphur emission levels are tightened and gas processing becomes more widely practised, the high recovery and tenor of sulphur in gases from the WORCRA furnace will enable smelters using the process to recover sulphur with profit, or offset to a large degree the costs of gas treatment for sulphur removal.

Conclusion

53. The metallurgy of the WORCRA process for continuous direct smelting-converting of copper concentrates has been well established at small and large pilot scale. However, before full commercialisation takes place, and particularly in developing countries, more development is required on the engineering side to achieve the maximum potential of this high intensity operation.

54. The next logical step in the commercial development of this process would preferably be a plant producing between 20,000 and 30,000 tons of copper per annum. Negotiations are currently in hand for such a development.

55. The foreseen advantages of this process as compared with established technology are :

(i) lower capital cost - expected to be in the range 20 to 30% lower than reverberatory - converter plants of similar capacity;

(ii) lower operating cost, the extent of the saving depending upon local conditions, and particularly on fuel, power and labour costs;

(iii) economically viable at lower annual throughputs, possibly in the range 10,000 to 20,000 tons of copper per annum;

(iv) efficient recovery of the sulphur by-product in a continuous emission of high SO_2 gas. It is anticipated that all the sulphur will be recoverable apart from the relatively small quantity contained in the product copper and the slag;

(v) as a consequence of (iv), the process offers a big advance towards reduction of air pollution. This could well be one of the most important contributions of WORCRA copper pyrometallurgy.

56. It is anticipated that copper recoveries will be at least as high as in conventional processes.

Acknowledgements

57. The author wishes to thank the directors of Conzinc Riotinto of Australia Limited for permission to present this paper and would also express sincere appreciation of the sterling contributions of his colleagues in this new development.

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SUMMARY

In their application to copper production the WORCRA concepts combine in one furnace, with separate but communicating zones or branches :

(a) a continuous bath smelting stage,
(b) a continuous converting stage, and
(c) continuous slag cleaning by conditioning and settling.

"Zonalisation" in a horizontal plane is a feature of all the furnace shapes.

WORCRA smelting-converting is characterised by the following features :

(i) it produces metal rather than matte, directly from concentrates;
(ii) most of the exothermic oxidation reactions are generated and continued within the liquid bath, hence the description "bath" smelting;
(iii) the bath in the smelting and converting zones is turbulent and continuously flowing, the turbulence being generated by injection of oxygen-containing gas from lances;
(iv) in the converting zone, slag moves (simply under the action of gravity) generally countercurrent to matte and metal;

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(v) copper-in-slag is reduced to throw-away levels as the slag flows through the smelting zone and slag cleaning zone; there is no "revert" slag nor the necessity for separate copper recovery treatments;

(vi) the SO_2 bearing gases generated in the smelting and converting stages combine and leave the single furnace continuously at a rich tenor via one gas offtake.

Contrary to classical theory and batchwise converting practice, the production of copper takes place (continuously) whilst there is a considerable quantity of matte in the furnace. This is possible because of the geometry of the furnace and process dynamics.

Experience with Semi-Commercial Furnace

After nearly four years of pilot scale work at Sulphide Corporation Pty. Limited, Cockle Creek, New South Wales a decision was taken by Conzinc Riotinto of Australia Limited in the latter part of 1967 to build a semi-commercial WORCRA furnace at the works of the Electrolytic Refining and Smelting Company of Australia Ltd. (E.R. & S.) at Port Kembla, New South Wales. This furnace is U-shaped and has a nominal capacity of 3 tons concentrates per hour.

This semi-commercial plant was designed with a number of features to permit assessment of alternative materials handling and feeding systems with a view to optimising the design before scaling up to commercial installations.

The Port Kembla furnace was commissioned in late July, 1968, and operated on copper continuously till the middle of June, 1969, except for a break of approximately six weeks in late 1968 until early 1969 when it was used, with promising results, to smelt a quantity of nickel concentrates. During the 50 weeks campaign it was amply demonstrated that the process worked on the larger scale and that the furnace itself had capacity to treat more than the original design feed rate of 72 long tons of concentrates per day (equivalent to approximately 6,000 tons of copper per annum.) Unfortunately, a number of deficiencies in both the ancillary feed systems and the gas handling and cleaning equipment became apparent after the first few months of operation and it was decided to shut the furnace down in June, 1969 and modify both systems. Opportunity was taken to carry out some brick work modifications and repairs.

The furnace was brought back on line again in mid September, 1969, and immediately responded to the improved feeding and gas handling systems. Feed rates up to 50% greater than the original design rating of 72 long tons per day (t.p.d.) have been achieved over periods of several days at a time and low copper in slags, below 0.5%, have been sustained for considerable periods.

After nine months operation in Campaign No. 2 the furnace was again shut down to effect some further changes and repairs and in particular to permit roof lancing as well as side-wall lancing. Campaign No. 3 is now well under way.

Dense magnesite-chrome refractories have withstood furnace conditions in most regions. Accumulating experience has enabled development of designs aimed at long furnace life and including water and air cooling of certain parts of the furnace structure which are subject to considerable splash and washing action by matte and slag. Naturally some problems have been encountered but steady progress is being made towards the objective of a furnace capable of withstanding operations for several years without a major shut-down.

With its present concentrate throughput averaging about 80 long t.p.d. the total fuel requirements are of the same order as in large scale wet charge reverberatory smelting. As the throughput increases fuel requirements per ton of charge will drop significantly.

Naturally, in larger commercial WORCRA furnaces with a greater volume to surface ratio, the overall fuel requirements will be appreciably less and promise to be of the order of 50 to 60% that of reverberatory requirements for a corresponding production rating.

With the use of supplemental oxygen in the smelting-converting zones oil consumption can be considerably reduced. Smelting becomes almost autogenous and additions of coolants such as scrap and cement copper may become necessary. The oxygen used need not be at the high purities and pressures required in steel plants.

Depending on the sulphur level in the feed concentrates and with air only used for lancing, SO_2 tenor in furnace gases is between 9 and 12% with between 0.5 and 2% free oxygen. Naturally, richer SO_2 tenors are produced when supplemental oxygen is employed.

Summary Conclusions

The metallurgy of the WORCRA process for continuous direct smelting-converting of copper concentrates has been well established at small and large pilot scale. However, before full commercialisation takes place, and particularly in developing countries, more development is required on the engineering side to achieve the maximum potential of this high intensity operation.

The next logical step in the commercial development of this process would preferably be a plant producing between 20,000 and 30,000 tons of copper per annum. Negotiations are currently in hand for such a development.

The foreseen advantages of this process as compared with established technology are :

(i) lower capital cost - expected to be in the range 20 to 30% lower than reverberatory - converter plants of similar capacity;

(ii) lower operating cost, the extent of the saving depending upon local conditions, and particularly on fuel, power and labour costs;

(iii) economically viable at lower annual throughputs, possibly in the range 10,000 to 20,000 tons of copper per annum;

(iv) efficient recovery of the sulphur by-product in a continuous emission of high SO_2 gas. It is anticipated that all the sulphur will be recoverable apart from the relatively small quantity contained in the product copper and the slag;

(v) as a consequence of (iv), the process offers a big advance towards reduction of air pollution. This could well be one of the most important contributions of WORCRA copper pyrometallurgy.

It is anticipated that copper recoveries will be at least as high as in conventional processes.

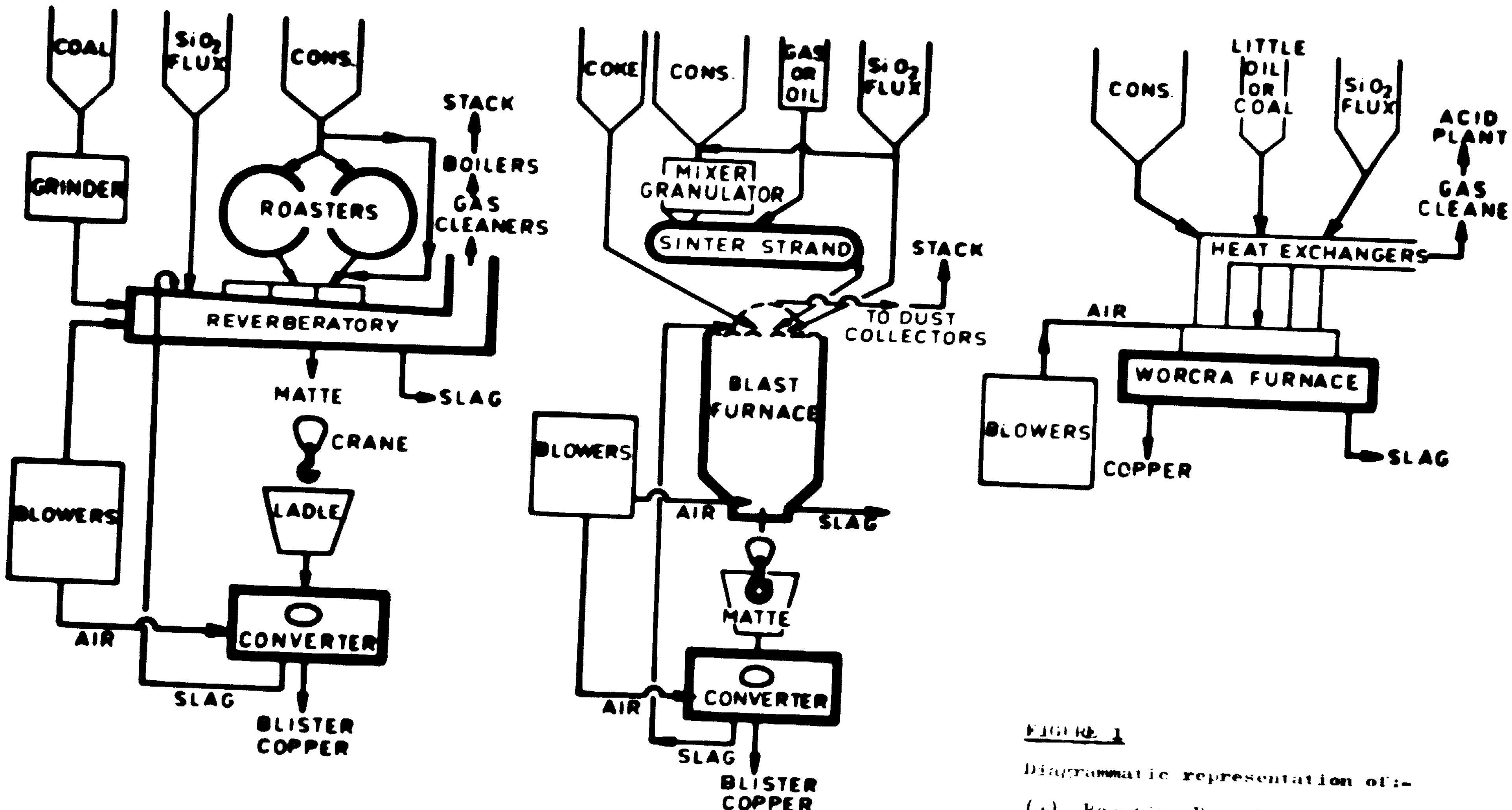

FIGURE 1

Diagrammatic representation of:-

(a) Roasting-Reverberatory-Converter Smelting;

(b) Sintering-Blast Furnace-Converter Smelting;

(c) WORCRA Continuous Smelting-Converting

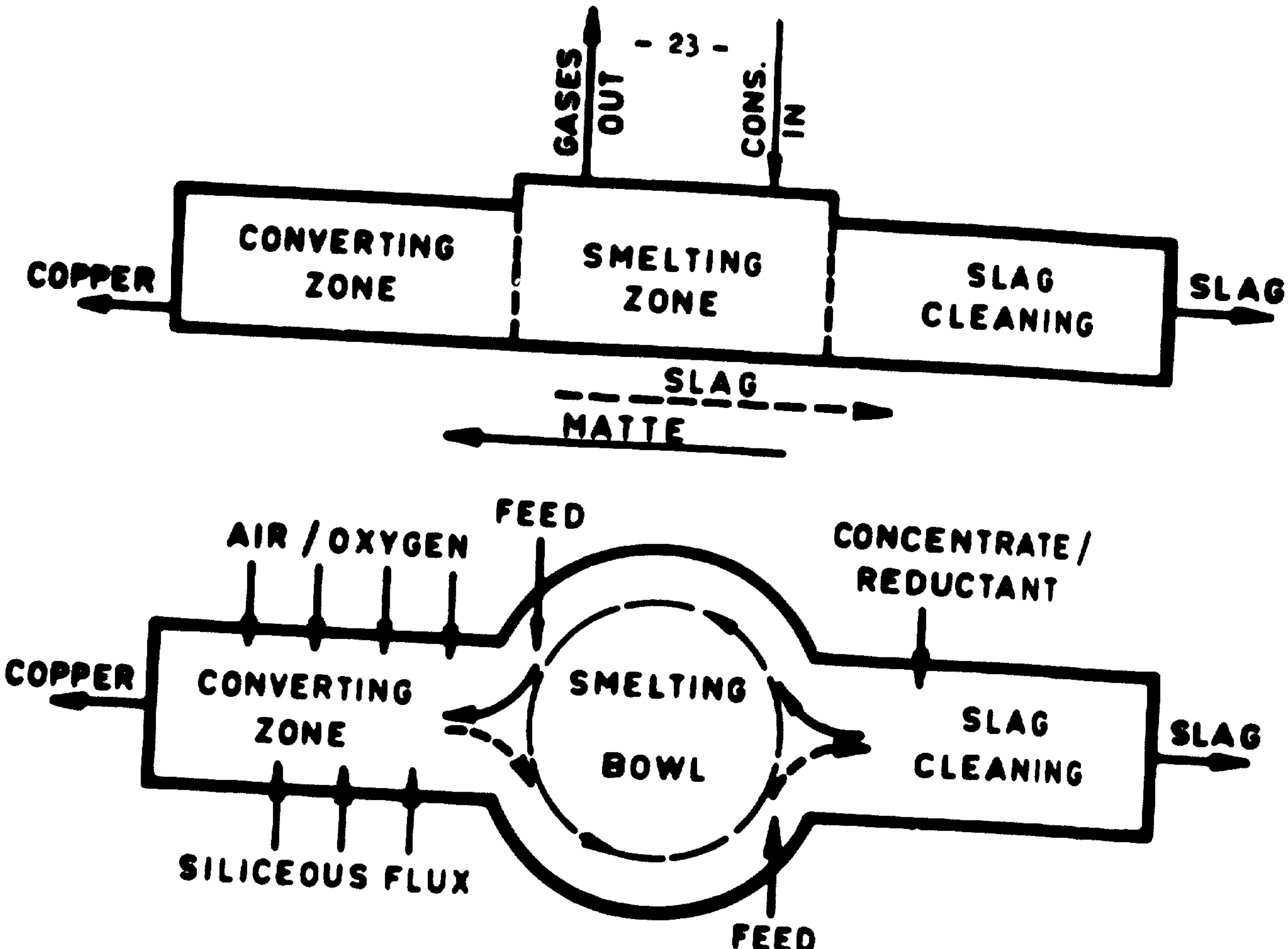

Figure 2

Diagrammatic representation of elevation and plan of a straight line form of WORCRA smelting-converting furnace.

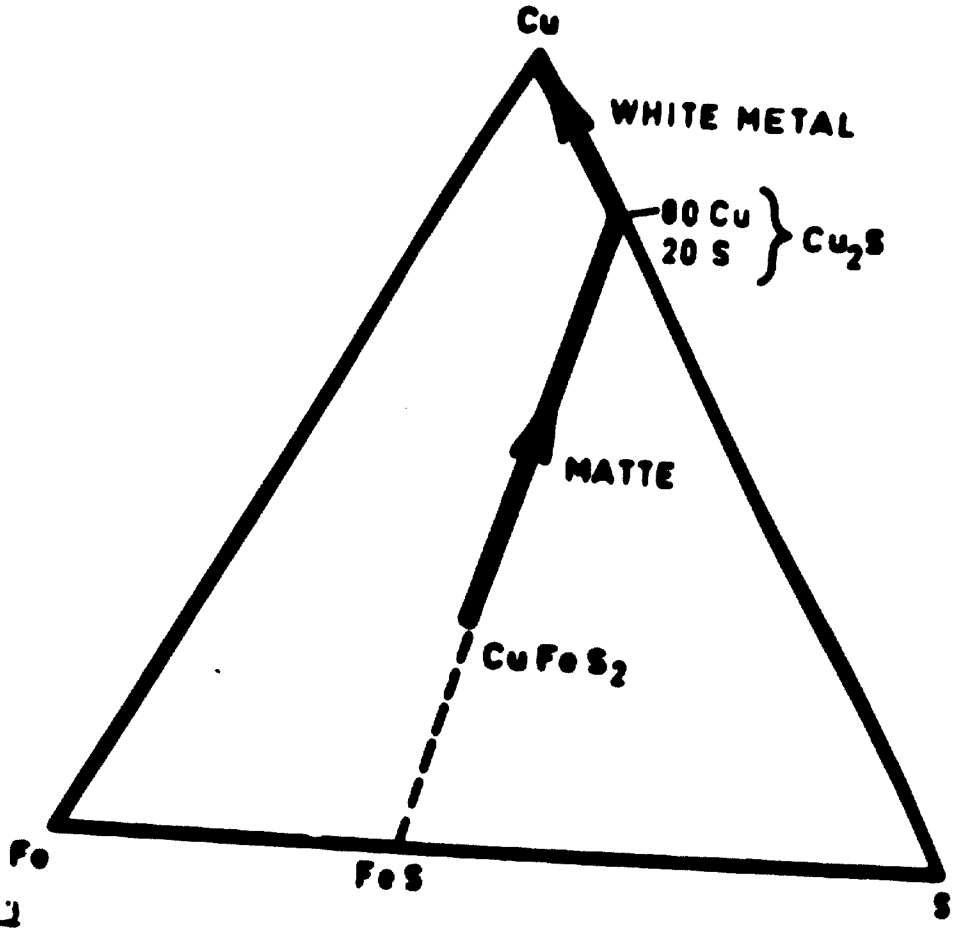

Figure 3

Ternary diagram showing change in composition of matte as it is blown progressively to copper in a WORCRA smelting-converting furnace.

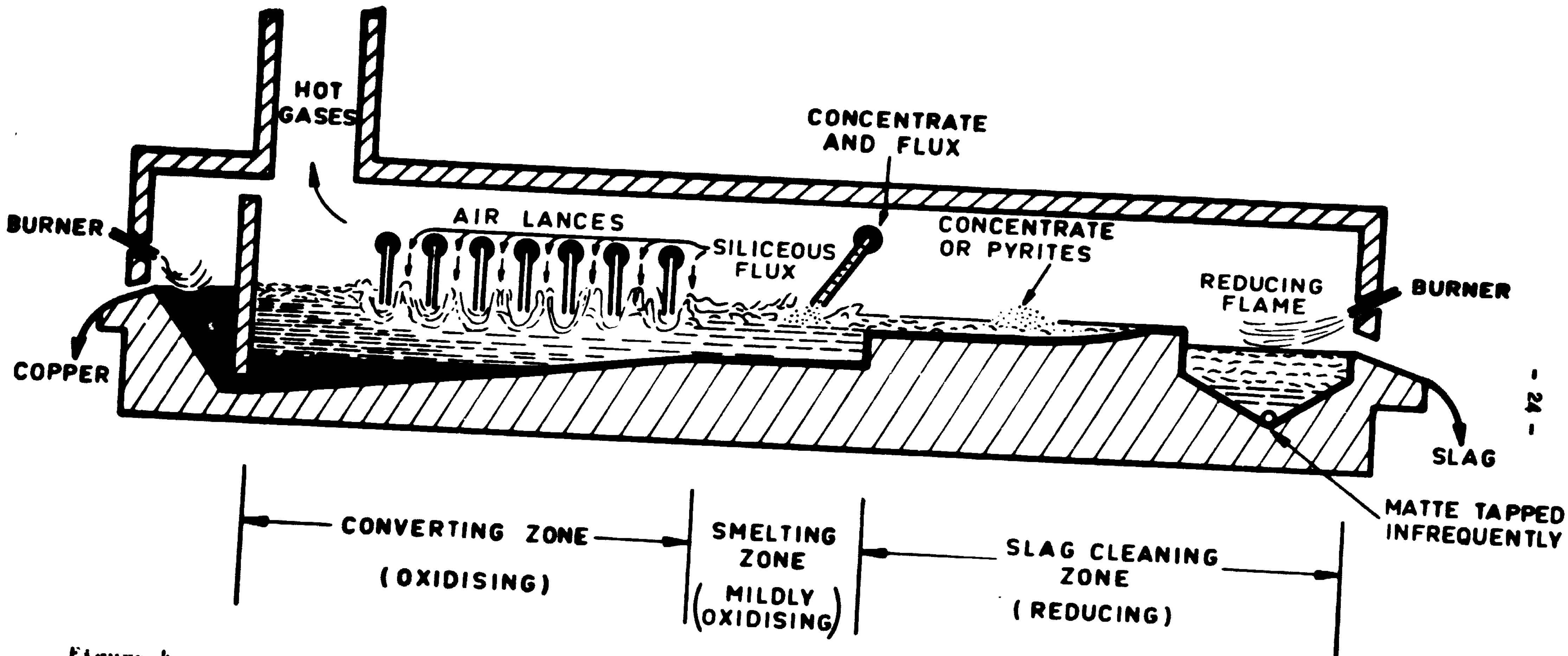

Figure 4

Idealised vertical section through a straight line form of WORCRA copper smelter-converter.

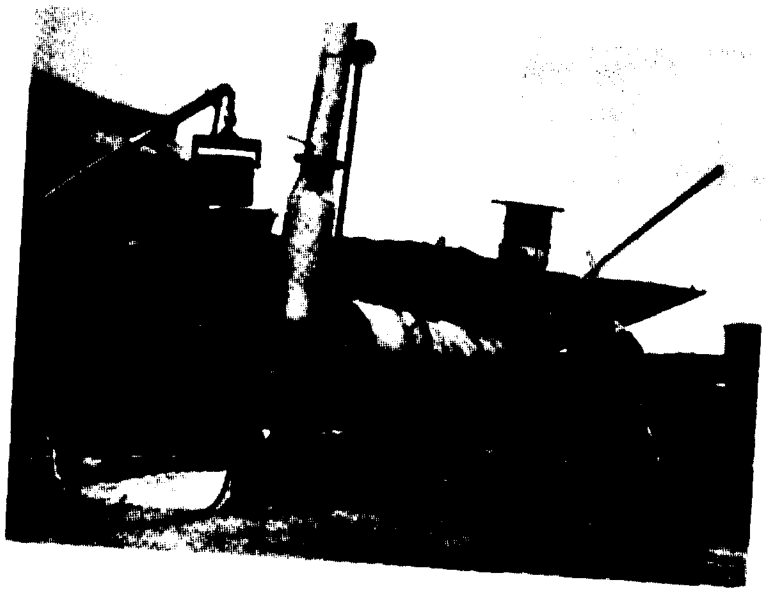

Figure 5

A small straight line tilting WORCRA pilot furnace tested at Cockle Creek, N.S.W., Australia in late 1963 and early 1964.

Figure 7

Photograph of U-Shaped WORCRA furnace at Port Kembla during construction.

Figure 6

Plan view of the U-Shaped WORCRA furnace built at the works of The Eletrolytic Refining and Smelting Company of Australia Ltd., Port Kembla, Australia

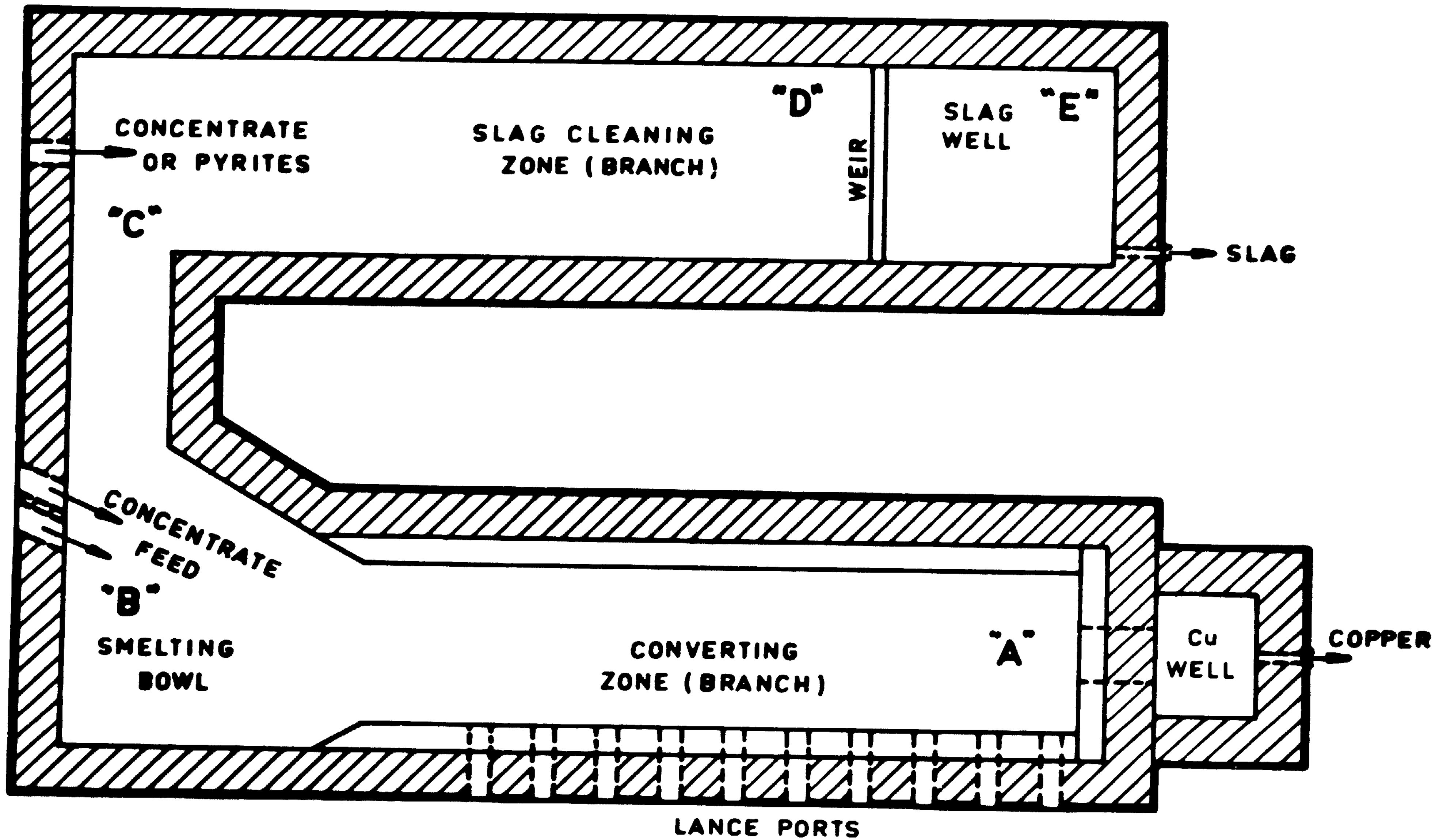

Figure 8

View of top floor of WORCRA furnace at Port Kembla showing hoppers which feed the chutes used for building banks in the converting branch. The main gas offtake from the converter branch can be seen in the upper left of the photograph.

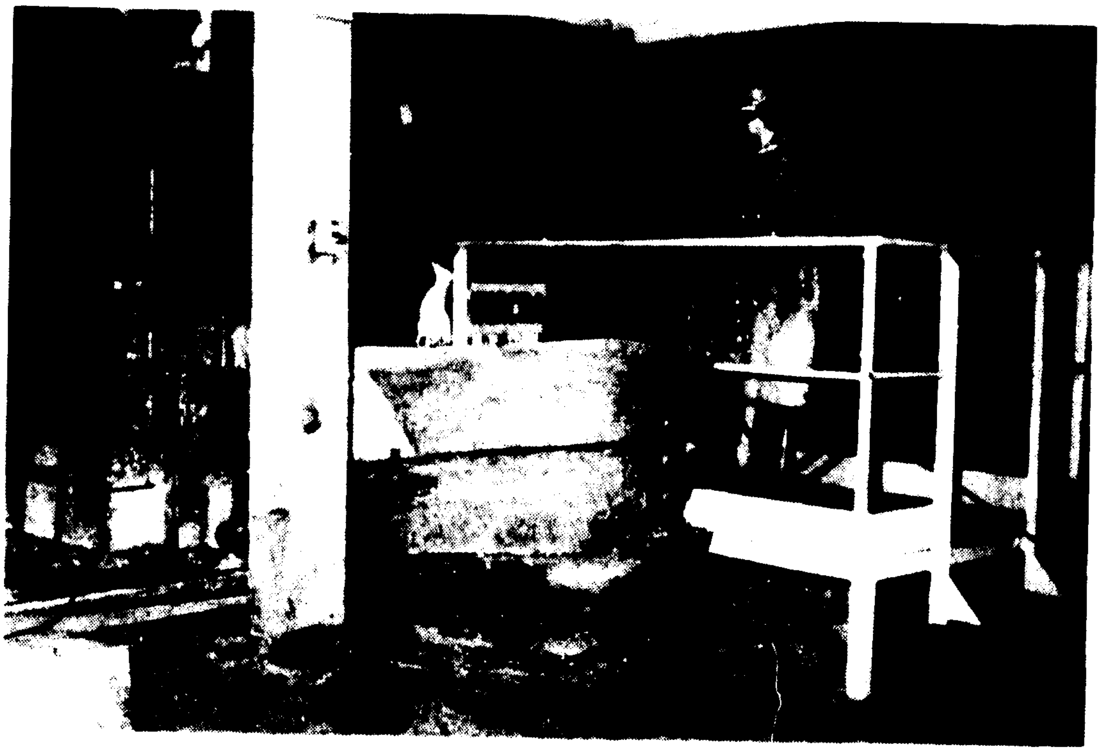

Figure 9

Copper "cakes" each weighing approximately 3.500 lb. tapped during an 8 hour period from the copper well of the Port Kembla WORCRA furnace. The stream of copper flowing into a cast iron mould can be seen in the rear to the left of the word "WORCRA".

Figure 10

Slag flowing continuously from the Port Kembla WORCRA furnace into the granulating launder.

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