1/1/81

AMDL Report 374
September, 1964

THE USE OF NATURAL GAS IN THE RECOVERY OF ZINC FROM SLAG

by

J.E.A. Gooden

to

SOUTH AUSTRALIAN GOVERNMENT DEPARTMENT OF MINES

Investigated by: Metallurgy Section

Officer in Charge: P.K. Hosking

L. Wallace Coffer, Director

THE AUSTRALIAN MINERAL DEVELOPMENT LABORATORIES
Adelaide South Australia

CONTENTS

1. INTRODUCTION

This report constitutes principally an assessment of the impact of natural gas on the treatment of the Port Pirie slag dumps for recovery of zinc, and an estimate of the amount of gas which would be consumed.[a] Subsequent treatment of the slag, and other metallurgical uses for natural gas have been mentioned in passing.

Leaching has been investigated for extracting zinc from slag but no economic process has been devised. On the other hand there are numerous pyrometallurgical processes all of which depend on the reduction of zinc in the slag to metallic zinc. Electrolysis of molten slag is reported to have been used successfully on a pilot scale to produce metallic zinc, and the use of metallic iron as reductant has been proposed.[38(b)] Most of the processes, however, use a carbonaceous reducing agent in solid, liquid or gaseous form. Since the thermodynamics of reduction of zinc silicate to metallic zinc by CO or H_2 are only favourable at temperatures above about 1100°C, i.e. above the melting point of most slags encountered in practice, the zinc (boiling point 930°C) is immediately volatilised. If the atmosphere above the molten slag is maintained sufficiently reducing, it is possible to condense metallic zinc,[6,45] but generally the zinc vapour re-oxidises to ZnO which is recovered in baghouses.

The use of natural gas as the carbonaceous reductant in the presently-used processes is discussed, most emphasis being placed on the slag-fuming process. This urgent assessment has necessarily been brief, and the estimates made must be taken as approximate only.

2. SUMMARY

On the basis of the available information it is concluded that the availability of natural gas could have an important effect upon the recovery of zinc from the Port Pirie slag dumps. The impact will of course depend on the expected cost of the natural gas, which would have to compete with coal. Coal is used overseas in slag treatment processes requiring a carbonaceous fuel or reductant and, if the cost of coal at Port Pirie were £6 per ton, the price of natural gas could not exceed 0.05 pence per cubic foot of methane[c] (4/-d. per thousand cu ft).

(a) Letter SR26/3/355 from Department of Mines dated 27th July, 1964.
(b) References appear in Section 7.
(c) Other hydrocarbons present in the gas can be taken as methane for estimating purposes.

Slag fuming in some form is the treatment method most likely to be favoured and natural gas can be used as reductant. Assuming that the existing dump and current production of slag were consumed by treating at a constant rate over the next 20 years, the annual zinc oxide production would correspond to 58,900 tons of zinc, requiring the supply of 3,000,000,000 cubic feet of methane per year. The fuming operation would yield about 8,000 kw of byproduct electric power which could be:

a. sold to the Electricity Trust of South Australia,

b. used to convert approximately one-quarter of the fume output to metallic zinc by electrolysis (15,000 tons of zinc per year),

c. used to produce steel (35,000 tons per year) from approximately half of the output of dezinced slag.

Because of the low cost of power in Tasmania, it would be logical to ship the roasted and densified fume to Risdon with the Broken Hill zinc concentrate for electrolytic zinc recovery; provided that sufficient hydroelectric power is available there.

Natural gas might also be used for heating the kilns in the Waelz process, but this technique is less attractive.

If the availability of natural gas were to lower markedly the cost of electric power, the St. Joseph electric furnace process for producing metallic zinc directly from slag would become attractive.

Other possible uses for natural gas from northern South Australia are listed briefly, including its use in the Whyalla and Port Pirie blast furnaces and for general metallurgical heating.

3. PYROMETALLURGICAL PROCESSES FOR ZINC RECOVERY

3.1 Slag Fuming (Conventional Process)

3.1.1 Operating Plants

The slag-fuming process was introduced by the Consolidated Mining and Smelting Co. at Trail, British Columbia, in 1928 and is now used at many other North American smelters, including the following:

Company	Location
Anaconda Copper Mining Co.	East Helena, Montana[8]
International Smelting Co.	Tooele, Utah
Bunker Hill and Sullivan Mining and Concentrating Co.	Kellogg, Idaho[4,58]
American Smelting and Refining Co.	Chihuahua, Mexico[9] El Paso, Texas[41] Selby, California[1]
Hudson Bay Mining and Smelting Co.	Flin Flon, Manitoba[18,30,32]

The only smelter in Russia in 1962 at which slag fuming was carried out was at the Ust'-Kamenogorsk Lead-Zinc Combine[42,97,99] where a larger plant was to come into operation in 1963, but the process was recommended for several other smelters. In Japan slag fuming is practised at the Naoshima Smelter.[22,27] In Germany[17] blast furnace slag is fumed at the Oker smelter, and the Braubach lead smelter slag is sent to Wissen for recovery of zinc oxide and pig iron.

3.1.2 Outline of Process

In the slag-fuming process a mixture of powdered coal and air is blown through the molten slag. A number of smelters treat stockpiled slag as well as current production.

The slag-fuming furnace at Kellogg is 15 ft long by 8 ft wide, of water-jacket construction, with 14 tuyeres on each side. At Flin Flon the furnaces are 21 ft long by 8 ft wide, of water-jacket construction, with 21 tuyeres on each side. At both plants the fuming furnace is supplied with coal from two pulverisers. Primary air conveys the coal and mixes with secondary air before entering the bath. Combustion of the fuel heats the slag and zinc in the slag is reduced to metallic zinc which is immediately volatilised, reoxidising to zinc oxide on leaving the bath. The fume-laden gases pass through waste heat boilers before entering baghouses where the fume is collected. The product is a lead-bearing zinc oxide.

Improvements in the process include the use of oxygen-enriched air[10,15,20,34,68] and preheated blast.[20] Continuous processes in place of batch operation have been described by Evdokimenko[62] and patented by Var'yan and Lunev.[76]

Coal Consumption. Data given for the Kellogg fuming furnace, treating a 16 per cent zinc slag, yield a coal consumption of 1.2 tons per ton of zinc fumed[4,61], and at El Paso where a similar slag is treated, the coal consumption is 1.3 tons per ton of zinc fumed.[41] The Flin Flon furnaces, fuming a molten 8 per cent zinc slag, use approximately 2 tons of coal per ton of zinc fumed. Okunev[34] quotes carbon and hydrogen requirements which are equivalent to a consumption, per ton of zinc fumed, of 1.3 tons of a good bituminous coal containing 80 per cent carbon, 4.5 per cent hydrogen and 4.0 per cent oxygen.

It is not clear whether the heat required for melting some cold slag is included in every case. An estimate of the heat content of Port Pirie slag leaving the blast furnace is 170 k calories per pound or 380,000 k calories per ton. This is thus the heat required to melt 1 ton of dry stockpiled slag in preparation for fuming. At 100 per cent efficiency this would require 0.05 tons of coal of the above analysis, or approximately 30 per cent of the fuel required for subsequent fuming. A practical figure might be 50 per cent of the fuel required for subsequent fuming, but this would depend on the melting technique.

There is a considerable credit to the fuming process from the steam produced in the waste-heat boilers. At the Kellogg plant 7.8 lb of steam[4, 61] is generated per pound of coal. At El Paso the steam production is 7 lb per pound of zinc fumed.[41]

3.1.3 Use of Natural Gas

The use of natural gas in place of powdered coal for slag fuming has been considered theoretically by Bell, Turner and Peters[15] and by Kellogg.[29] It has been shown that, in conventional fuming, equilibrium is reached between slag, air and reducing agent. If this were the case when using natural gas, methane should be more effective than powdered coal.

An editorial comment in Kellogg's paper[29] stated that the few tests made with natural gas up to 1957 had shown it to be inferior to powdered coal.

Okunev et al[34] found that the yield of zinc during blowing was practically the same for methane-air as for coal dust-air and quoted consumptions of carbon, hydrogen and methane. They stated that a preheated blow which had been enriched with oxygen was more efficient with methane than with coal dust or hydrogen. Kostelov and Verner[48] obtained lower temperatures during blowing and slightly lower zinc recovery when using natural gas, in comparison with results using powdered coal. Later work with tin slags by Kostelov and Grinevich[89] showed fuel oil to be superior to powdered coal. Without obtaining a translation of the original paper by Kostelov and Verner, no further comparison can be made.

According to Okunev's data[33], fuming with natural gas required 3.43 moles of methane per gram-atom of zinc fumed, i.e. 43,000 cu ft (STP) per ton of zinc fumed. Since his estimate of coal consumption agrees well with data for the Kellogg Plant, and the heating value of 1 ton of good bituminous coal is approximately equal to that of 32,000 cubic feet of methane, this figure can be used with confidence.

3.1.4 Treatment of Zinc Oxide Fume

It may be possible to produce a pigment from the fume, but generally the fume is dissolved in spent electrolyte and the solution purified and electrolysed to yield electrolytic zinc. Ellerman[16] has given a full description of the process as practised at Flin Flon where in 1951 the electrolytic zinc plant was producing 190 tons per day of slab zinc, of which 91 tons per day were produced as a result of the fuming of slag. The crude fume is first roasted (using 147 lb coal per ton of fume) to eliminate fluorine and then leached with spent electrolyte. Arsenic, antimony and germanium are precipitated and the solution then combined with the solution obtained by leaching the roasted sulphide concentrate for further purification and electrolysis.

Since zinc electrolysis requires 1.7 kwh of electricity per pound of zinc, i.e. 3,800 kwh per ton of zinc, the power cost at 2 pence per kwh is £31.7 per ton, and at 0.5 pence per kwh £7.9 per ton. It would therefore be logical to fume the slag at Port Pirie, roast the fume to increase its density and eliminate fluorine if present, and then ship it to Risdon to take advantage of the hydroelectric power, if there is sufficient additional electricity available there. The electrolysis of 58,900 tons of zinc in 350 operating days requires a continuous power supply of 26,600 kw.

3.1.5 Costs

Reference Plant. The scale of operations suggested in Section 4.1, viz. treatment of 360,000 tons of slag per year to yield 58,900 tons of zinc-in-fume, is approximately the same, in terms of slag input, as at Flin Flon.[32] In 1957 copper reverberatory slag containing 8 per cent zinc was being treated at Flin Flon by fuming at the rate of 420,000 tons per year to recover 30,000 tons of zinc in fume, the zinc recovery being 88 per cent. The Port Pirie operation would differ in that, instead of mainly current slag, the greater part of the slag treated would require melting. The zinc content of Port Pirie slag would be twice as great, and fuel-fired instead of electric furnaces would be used for holding slag. Despite these differences, the plants would be largely comparable.

Capital Cost. As an approximate guide the Flin Flon fuming plant layout[32] can be compared with the new lead refinery at Port Pirie. Reverberatory furnaces and handling equipment are common to both. One treats 200,000 tons of lead through 3 or 4 operations and the other 400,000 tons of slag through 1 or 2 operations. If the plants are taken as costing approximately the same to build, a figure of £750,000 is arrived at as a preliminary estimate of the capital cost.

Operating Cost. A rapid estimate of the labour requirement for the Flin Flon Plant suggests a shift crew of about 20 men, viz:

	Number of Men
Crane operation	2
Feeding cold slag	1
Holding furnaces (2)	2
Fuming furnaces (2)	6
Coal supply	2
Waste heat boiler operation	1
Power generation	2
Baghouse operation and fume roasting	2
General duties	2
	20

Assuming a similar requirement for a fuming plant at Port Pirie, a labour cost of £1 per man-hour, a total fuel cost (coal or natural gas) of £10 per ton of zinc fumed, a production rate of 7 tons of zinc-in-fume per hour and average percentage costs as recommended by Aries and Newton[(a)] the following cost estimate is arrived at:

	£ per ton of Zinc-in-Fume	
Slag	(taken as 0)	
Fuel	10.0	
Labour	3.0	
Supervision	0.4	
Maintenance	0.7	
Plant supplies	0.1	
Royalties and patents	2.0	
Utilities	3.0	
Direct Treatment Cost		19.2
Payroll overhead	0.6	
Laboratory	0.4	
Plant overhead	2.0	
Indirect Treatment Cost . . .		3.0
Depreciation	1.3	
Property Taxes and Insurance	0.3	
Fixed Treatment Cost		1.6
TOTAL TREATMENT COST	approx	24.0

Total Treatment Cost £24 per ton of zinc-in-fume, for roasted fume on the wharf at Port Pirie. (Credit for electricity disregarded).

(a). ARIES and NEWTON, Chemical Engineering Cost Estimation, McGraw Hill (1955).

3.2 Waelz Process

3.2.1 Use of Solid Fuel for Heating

In this method the ore, residue or slag, crushed to minus 10-mesh, is mixed with 10-25 per cent of reducing coal or coke and fed into a large rotary kiln. Kilns of dimensions 4 ft diameter by 40 ft long to 12 ft diameter by 160 ft long have been used, fired countercurrently with powdered coal. The residence time in the kiln may be $1\frac{1}{2}$-2 hours and the charge reaches a temperature of about $1300^{0}C$. Lead and zinc are volatilised and recovered as oxides. One major disadvantage of this process is the formation of rings of accretion within the kiln which are difficult to remove.

Liddell[8] cites a Waelz plant in Upper Silesia burning a calamine ore ("calamine" in the USA refers to hydrated zinc silicate) containing 12 to 15 per cent zinc. This is a reasonable approximation to Port Pirie slag. An addition of 25 per cent of reducing coal was used, and 5-10 per cent of firing coal. Zinc extraction was 95 per cent and the fume contained 66 per cent zinc and 6 per cent lead.

3.2.2 Use of Natural Gas for Heating

On the assumption that solid fuel must still be used for reduction but that natural gas can be used for heating, the 5-10 per cent of coal used in the Upper Silesian plant would be replaced by 1,500 to 3,000 cu ft of methane per ton of feed. This corresponds to an average value of 17,500 cu ft of methane per ton of zinc fumed.

3.3 Cyclone Smelting

3.3.1 Present Status

The principle of using a cyclone for fuel combustion is used in boiler installations, and its application in pyrometallurgy has been under investigation for some years. Tonkonogii and co-workers[39] at Alma Ata in Kazakhstan, USSR, and Lange and co-workers at Freiberg, Germany, have been considering copper and zinc smelting in this type of furnace. The Cyclo-steel process for direct reduction of iron ore, at present under development by the British Iron and Steel Research Association, is similar in principle and uses a gaseous reducing agent which is injected with the powdered iron ore. While much laboratory and pilot work has been done with pyrometallurgical cyclone furnaces, no commercial units appear to have been built.

Blanks[100] at the Broken Hill Associated Smelters Pty. Ltd., Port Pirie, has built a laboratory cyclone furnace similar to that used by Tonkonogii and has carried out some trials. It was found necessary to submerge the lower tuyere, supplying coal dust and air, so that there was some similarity to conventional fuming. Slag was introduced in a blast of preheated air through the upper tuyere. In the best runs, zinc recoveries of the order of 80 per cent were obtained with coal consumptions of the order of 0.3 lb per lb of cold slag. This corresponds to approximately 2 tons of coal per ton of zinc fumed and appears quite reasonable for a laboratory unit treating cold slag.

3.3.2 Use of Natural Gas

The use of gaseous fuel and reductant in the experimental Cyclo-steel process adds confirmation to the feasibility of using it in a slag-fuming cyclone. The calculations made for conventional slag fuming should thus apply to cyclone slag fuming.

3.4 Direct Production of Metallic Zinc

The St Joseph Lead Co. has developed a method of recovering metallic zinc directly from lead blast furnace slag containing 14 to 16 per cent zinc.[6, 58] The slag is charged molten to a 6-electrode resistance furnace and coke is distributed over the surface of the charge. Heat developed by the passage of current vaporises zinc and carbon monoxide which pass to a Weaton-Najarian condenser from which molten zinc is tapped. Zinc elimination is stated to be 75 per cent but zinc recovered as metal corresponds to only 55 per cent of the zinc in the slag, due to various losses. The power consumption was estimated[8] at 800 kw hour per ton of slag, i.e. 10,000 kw hour per ton of slab zinc produced.

Electric smelting methods are not likely to be favoured in South Australia, with industrial power costing about 2 pence per kilowatt-hour. According to a newspaper article, the Broken Hill Associated Smelters approached the Premier some years ago requesting power at 0.5 pence per kwh to make a slag treatment process feasible.

It should be possible to reduce the coke consumption somewhat by the use of natural gas, but the amount of natural gas required for this purpose would probably be insignificant. Natural gas might, however, implement the introduction of this process by lowering the cost of electric power.

4. ANTICIPATED DEMAND FOR NATURAL GAS

4.1 Slag Available for Treatment

The stockpile of granulated blast furnace slag at Port Pirie, which has been growing since 1921, is estimated to contain nearly 5 million tons with an average zinc content of 17.5 per cent.[100] This quantity corresponds to a rate of growth of 110,000 tons per year. Assuming that this rate is maintained, and that a slag-fuming plant were started up in 1966 to treat all the dump slag and all the current slag in the following 20 years (1966-1986), the input to the fuming plant would be 360,000 tons of slag per year (110,000 tons hot slag plus 250,000 tons cold slag).

4.2 Treatment by Fuming — Conventional Furnace or Cyclone Furnace

Assuming a zinc recovery of 93.5 per cent as obtained at Kellogg using powdered coal, the treatment of 360,000 tons of slag per year would yield an annual output of 58,900 tons of zinc as lead-bearing zinc oxide. The natural gas consumption based on Okunev's data (Section 3.1.4) would thus correspond to 2,530 million cubic feet (STP) of methane per year for the next 20 years. In round figures, allowing for the melting of dump slag, a demand for 3,000,000,000 cubic feet (STP) of methane per year could be assumed for the next 20 years.

As mentioned in Section 3.1.1, considerable by-product steam is produced. On the basis of the Kellogg operating data cited previously,[4,61] the hourly steam production in a fuming plant using 3.0×10^9 cu ft methane per annum would be approximately 190,000 lb. The temperature and pressure of this steam are not known so that the electricity generaged from it cannot be accurately estimated, but may be in the region 5,000 to 15,000 kw. A figure of 8,000 kw will be assumed for estimating purposes. (South Australia's present installed generating plant capacity is nearly 600,000 kilowatts). This electricity could be sold to the Electricity Trust or used for a further process, e.g. steel production from the dezinced slag (Section 5) or electrolytic zinc production from the zinc oxide fume (See Section 3.1.3).

4.3 Treatment by Waelz Process

For simplicity it will be assumed that heating of the cold slag and reducing agent requires 3,000 cu ft of methane per ton of cold slag, and that slag charged molten from the blast furnace requires no further heat. On this basis the consumption of natural gas would correspond to 750,000,000 cubic feet (STP) of methane per year for the next 20 years.

5. SUBSEQUENT PROCESSING OF SLAG

There are large slag dumps in the USA resulting from copper smelting operations, e.g. 40 million tons at the Anaconda smelter containing iron 33 to 37 per cent, copper 0.7 per cent and zinc 2 per cent, and 30 million tons at Clarkdale containing iron 33 per cent, copper 0.5 per cent and zinc 2 per cent. The Anaconda slag has been successfully treated in a large pilot run by the Strategic-Udy process[49,64] to produce 200 tons of steel from 700 tons of slag, and construction of a $30 million smelter was expected to start in 1961. The introduction of such processes in the USSR has been advocated by Smirnov.[97]

The Anaconda slag was smelted in the pilot run with limestone, pyrite and coal, volatilising the zinc and producing a copper matte. The copper-free iron-bearing slag which, from the limestone and pyrite additions quoted, is estimated to contain 28 per cent iron, is then treated in a Udy electric furnace to yield a semi-refined steel which is finished to specifications in a third furnace. The residue is processed to yield rock-wool insulation and concrete building products.

The Port Pirie slag after fuming would contain approximately 25 per cent iron and would be molten and pre-reduced and ready for charging to the electric furnace for steel production.

The power cost for treating Anaconda slag has been stated[49] to be $6 per ton of steel using electricity at 0.2 cents per kwh, which corresponds to a consumption of 3,000 kwh per ton of steel. By using slag from fuming furnaces, one of the three electric furnaces would be eliminated and the power consumption would be nearer to 2,000 kwh per ton of steel. The steel production from 360,000 tons per year of Port Pirie slag would be of the order of 200 tons per day, requiring a continuous power supply of about 16,000 kw. If this power were purchased at 2 pence per kwh, the power cost per ton of steel would be approximately £16. This is a possible use for the electricity generated from the steam produced in the slag-fuming furnace waste-heat boilers.

6. OTHER METALLURGICAL USES FOR NATURAL GAS

6.1 Injection into Iron Blast Furnace

Injection of natural gas into iron blast furnaces is a well-proven technique and Section 7 includes over 30 references dealing with this subject. The coke rate is reduced, and the production rate is often increased by the presence of up to 6 per cent natural gas in the blast. The actual coke savings reported vary for different furnaces and conditions, viz:

Author	Volume of Natural Gas replacing 1 ton of coke cu ft
Belevtsov[80]	22,700 - 28,000
Carlson[59]	29,900
Cordier[51]	21,800
Dean[60]	24,700
Dunaev and Yareshevskii[86]	32,600 - 36,500
Kreglow[67]	<22,400
Nekrasov[93]	21,500
Ramirez[71]	17,500
White and Sciulli[77]	44,800

< Less than.

On the assumption that the landed cost to the Broken Hill Proprietary Co. Ltd. of metallurgical coke at Whyalla is £10 per ton and that 25,000 cubic feet of natural gas replace 1 ton of coke, the value of natural gas to the BHP Co. would be approximately 0.1 pence per cubic foot.

6.2 Use in Open Hearth Furnace

Turubiner[56] has considered the use of natural gas for heating open hearth furnaces.

6.3 Injection into Lead Blast Furnace

No reference has been found in the literature to the injection of natural gas into lead blast furnaces. It is believed that G. K. Williams experimented with fuel injection through the tuyeres of an experimental lead blast furnace at Port Pirie a number of years ago.

6.4 General Metallurgical Heating

While natural gas may be used to better advantage as a raw material in the chemical industry, its use as a fuel is briefly considered:

		Heat of Combustion (hydrogen burned to liquid water)
Methane,	Btu/cu ft	1,000
Heavy fuel oil,	Btu/lb	18,000

Assuming that the price of fuel oil is £9 per ton at Port Pirie, methane would have to be cheaper than 0.05 pence per cubic foot to compete. With black coal at £6 per ton, the equivalent value for natural gas would be similar.

6.5 Other Uses

The uses of natural gas as a raw material in the chemical industry, and for the generation of electricity, are outside the scope of this report, but several references to fuel cells for the direct conversion of the chemical energy in natural gas into electrical energy have been included in Section 7.

7. LITERATURE REFERENCES

The following sources were searched for references:

Applied Science and Technology Index (ASTI)	Jan 1950 - June 1964
Chemical Abstracts (CA)	Jan 1947 - June 1963
Engineering Index (EI)	Jan 1947 - June 1964
Institution of Mining and Metallurgy Abstracts	Oct 1957 - May 1964

PRE 1955

1. ANON, "Slag Fuming at Selby", Eng. Min. J. 154, 95-7 (December, 1953). (ASTI 1954, 1473)

2. BRANNSTROM, P.G.L. and SUNDSTROM, E.O.A., "Recovery of Non-Ferrous Metals from Metallurgical Slags", Swed. Pat 118,492 (1st April, 1947), FeS_2 or coal blown in by current of oxygen-containing gas. (CA 41, P7371c)

3. DEAN, R.S. and SILKES, B., "Metallurgical Research Program of the Bureau of Mines Relating to the Non-Ferrous Metals", U.S.B.M. RI4064 22 pp (1947) Includes natural gas reduction of Zn. (CA 41 5065 h)

4. DENNIS, W.H., "Zinc Volatilisation" Mining Mag 80 80-5 (1949). The various methods for treating zinc retort residues and zinc-containing lead slags are discussed, viz: shaft-furnace, Waelz kiln, slag-fuming, electric furnace and vacuum condensation. (CA 43 3754)

5. GURIEV, A.E., KUDINOV, I.V. and DONCHENKO, P.A., "Treatment of Slag from Zinc Distillation, and of Lead Slag, in a Drum Furnace", Trudy Severo-Kavkaz. Gorno - Met. Inst. 1954 No.11 141-7; Referat. Zhur., Met. 1956 No.254. Laboratory tests were made on the extent of volatilisation of Zn and Pb from the residual slag of Zn distillation (containing 7% Zn). lead slag (Zn 12.27%, Pb 2.62%), mixtures of these, and mixtures of Zn distillation slags with wastes from an electrolytic Zn works. In all cases recovery of Zn and Pb was 92-94%. Treatment of the mixtures gave better yields than did treatment of the separate materials. (CA 51 14506 a)

6. ISBELL, W.T., and LONG, C.C., "Direct Production of Metallic Zinc from Lead Blast-Furnace Slag", Trans A.I.M.E. 159 176 (1944)

7. JENSEN, C.W., "Fuming Tin Slags", Mining Mag. 81 337-9 (1949) (CA 44 1864)

8. LIDDELL, D.M., Handbook of Non-Ferrous Metallurgy, McGraw-Hill, 1945.

9. McDONALD, V.R., "Chihuahua Slag Fuming Plant to Process 19,000 tons per month", J. Metals 5 No.6 789-90 (June 1953). Slag fuming at smelter which treats slag containing 10% Zn or more; furnace is completely water-jacketed, with usual 21 double inlet tuyeres on each side; charge consists of 45 tons of slag; brick spray chamber discharges gases into balloon flue, then into U-tube coolers, and to baghouse. For additional cooling, second spray chamber is provided after U-tube coolers. (EI 1953, 1202)

PRE 1955

10. McNAUGHTON, R.R., "The Use of Oxygen-enriched Air at Trail B.C.", A.I.M.E. Metals Trans. 185, 449 (1949).

11. MURRAY, G.E., "Lead Blast Furnace Practice", Trans A.I.M.E., 121, 72 (1936)

12. RAICK, J.O., and BRASSERT, J.E., "Injection of Oxygen-Reformed Natural Gas and Fuel Oil into the Blast Furnace", Iron Steel Engr. 29, No. 12, 75-80, (1952). (CA 47 1017 b)

13. SEIFFERT, K. and SCHYTIL, F., "Blowing of Zinciferous Material" (to Metallgesellschaft A-G), Ger. Pat. 877,957 Aug. 10, 1953. Material of low Zn content, such as blast-furnace slag, retort residue, etc. is fed to a chamber along with liquid or gaseous fuel, when the fuel is not contained in the initial material. In this chamber, a gas stream containing O is directed upward through the solids with such a velocity that the solids-gas mixture is kept in a state similar to a boiling liquid with or without a definite surface. The flow rate of the gas is <3m/sec if a defined surface is desired. If this is not desired correspondingly higher gas velocities can be used. At the temp. caused by partial combustion of the fuel, reduction of ZnO to Zn is accomplished by means of a solid or gaseous reducing agent. The Zn vapour burns to ZnO because of the excess O in the treatment gas. The ZnO is withdrawn with the treatment gas and is separated from it. The process can be operated continuously or discontinuously. (CA 52 p 5272 a)

14. ZABLOTSKII, V.I., "Improvement of the Process of Lead and Zinc Sublimation in Tubular Furnaces", Trudy Soveschinaya po Met. Tsinka 1954 (Moscow: Gosudarst Nauch-Tekh. Izdatel Lit. Chernoi i Tsvetnoi Met.) 208-17 (Pub. 1956). The improvements in the process involve drying the cakes, certain design modifications in the dust-collecting units, adherence to specifications providing a proper charge composition, grinding of charge components, and introducing them into the furnace at an even rate. Processing of slags from Pb shaft smelting is described.

15. BELL, R.C., TURNER, G.H., and PETERS, E., "A Thermodynamic Study — Fuming of Zinc from Lead Blast Furnace Slag", J. Metals 7, AIME Trans 203, 472-7 (1955). ZnO activities in a typical Pb blast furnace slag have been calculated from plant operating data. These activities were used to assess the probable effect of fuel composition, oxygen enrichment and air preheating on the efficiency and capacity of the slag-fuming operation. (CA 49 5236 b)

1955

16. ELLERMAN, R., "Processing of Zinc Oxide Fume at Flin Flon, Manitoba", J. Metals 7 No. 7, 813-22 (July, 1955) (EI 1955, 1175)

17. JENSEN, C. W., "The German Lead Smelters", Mining Jnl. 92, 265-277 (May, 1955)

18. MAST, R. E. and KENT, G. H., "Slag Fuming Furnaces Recover Zinc and Lead from Copper Slag", J. Metals 7, 877-84 (1955)
Slag fuming is used by the Hudson Bay Mining and Smelting Co. for the recovery of Zn and Pb from Cu reverberatory slag. The general smelter plan, fuming plant operation, experimental work, the smelter slag fuming plant, fuming furnaces and air blowers are described. (CA 49, 12238 f)

19. MORI, HACHIZO, "Volatilising Smelting of Fused Material", (to Mitsubishi Metal Mining Co.) Jap. Pat. 3801 (1955), June 6.
Zn in the slag from Cu or Pb smelting, for example, is effectively recovered by an apparatus in which reducing agent (finely divided C) is jetted into the slag and Zn is evaporated and transferred by air pressure. (CA 51, P16265 b)

20. OKUNEV, A. I., "The Part of Oxygen and of Preheating the Air in Treatment of Zinc-Bearing Slags", Tsvetnye Metally 28, No. 4, 35-40 (1955).
In Zn recovery by fuming of Zn-bearing slags, preheating the air to 550-600^{0}C doubled the furnace capacity, and enriching the air to 26-28% O increased the furnace capacity by 8[(a)] - 100%. The causes of the large effect of a relatively small increase in the O content of the air are discussed.
The calculated volatilisation of Zn, based on equilibrium data of the gas-slag reaction, agreed well with large-scale furnace observations. (CA 54, 7474 f)

21. OSBORN, W. H., "Recovery of Zinc from Ferruginous Silicate Slags", (to Phelps Dodge Corp.) US Pat. 2, 715,062 (August 9, 1955)
Reaction of the slag with iron and carbon in an electric furnace volatilises zinc which is recovered as ZnO. A small amount of propane is added to the furnace. (CA 49, P13870 e)

(a) This figure, quoted from Chemical Abstracts, is more likely to be "80".

1956

22. HARUNARI, KANESHIGI, "Fuming and Electrolysis of Zinc at Naoshima Smelter", Nippon Kogyo Kaishi, 72, 811-814 (1956) (CA 51, 8599 a)

23. MANSON, W. McA. and SEGNIT, E. R., "Fundamental Research on the Port Pirie Lead Blast Furnace Slags", Proc. Aust. Inst. Min. Met. 180, 119-147 (December 1956).
Dezinced slags are described and some comments made on experimental slag fuming using powdered coke.

24. OKUNEV, A. I., "Theory of Zinciferous Slag Fuming", Tsvetnye Metally 29, No. 7, 29-36 (1956). (CA 51, 12783 c)

25. SARKISOV, I. G. et al., "Pilot Plant Experiments with Air-Coal Blowing of Slags in the Copper Smelting Industry", Tsvetnye Metally 29, No. 4, 28-37 (1956).
Dezincing of converter slags of Cu smelting by blowing C-dust was investigated on a pilot-plant scale. Slags containing 5-8% Zn were reduced to 1.5% Zn and simultaneously 90-98% Pb was driven off within 60-90 min. at an air velocity of 8-10 m/sec. The supply of coal dust (85% - 74μ) was controlled: at first, at 1100-1150^{0}C enough C was introduced to form 30-40% CO in the CO+ CO_2 mixture; at 1200-1250^0 the C was increased to form a 50-80% CO gas. The rate of dezincing increased with the temp and the CO content in the gas phase. The content of Fe_3O_4 was reduced from about 20 to 4-6% in 10-20 mins. Conclusion: the process is practicable for slags containing more than 5% Zn. (CA 51 9446 h)

26. TRUBIN, K. G., "Selection of Blast Furnace Fuel", Trudy Nauch.-Tekh Obshchestva Chernoi Met. 9, 14-24 (1956) Referat Zhur Met. 1957 Abstr. No. 3636.
The use of natural gas in blast furnaces and steel-making furnaces is discussed.
(CA 52, 14468 h)

1957

27. ARAKANE, S., "How Mitsubishi Uses Automatic Furnace Control at Naoshima Copper Smelter", Min. World 19, 73-8 (October, 1957).
A zinc-fuming plant utilising Cu slag recovers Zn, Pb, Cd, and Ge. (IMMA 8, 533)

1957

28. EVDOKIMOVA, A.K., MIGINA, A.I. and TSEIDLER, A.A., "Sulphuric Acid Treatment of Sublimates Containing Oxides of Zinc and Tin", Tsvetnye Metally 30, No. 9 25-31 (1957). (CA 52, 3623 g)

29. KELLOGG, H.H., "A New Look at Slag Fuming", Eng. Min. J. 158 No. 3, 90-2 (March, 1957). (EI 1957, 1056)

30. KLEINERT, R., "The Flin Flon Copper - Zinc Smelter, Canada", Z. Erzbergbau Metallhuttenw. 10, 383-91 (August 1957). Reverberatory slag from the copper smelter (8.7% Zn) is dezinced in the usual manner by blowing with an air-coal dust mixture, the high Zn content (70.5%) mixed oxides recovered and treated in the zinc smelter. (IMMA 8, 534)

31. McINTOSH, D.H., "Recovery of Zinc from Slag" (to AS and R Co.), US Pat. 2,795,500 (June 11, 1957). Zn-bearing metallurgical slags are heated to 2200-2500^{0}F to form a molten pool. A combustible mixture of a liquid fuel, e.g. a residual oil from the cracking of petroleum, and an O-containing gas, in an amount sufficient to ensure incomplete combustion of the fuel, is injected into the molten pool below the surface. The rate of addition is sufficient to maintain the bath in a molten condition, thus reducing the Zn compounds to metallic Zn and volatilising the Zn. The liquid fuel should have an API gravity of about 7-12^0. With air as the O-containing gas, the highest Zn recoveries are obtained with an air content of 57-75% of that required for complete combustion. (CA 51 P13727 f)

32. MAST, R.E. and KENT, G.H., "How Hudson Bay Fumes Reverberatory Slag", Eng. Min. J. 158 No. 6, 82-8 (June, 1957). (EI 1957, 1260)

33. OKUNEV, A.I., "Division of Tuyeres to Heat and to Reduce the Slag During Blowing", Trudy i Materialy Ural. Nauch-Issledovatel i Proekt Inst. Mednoi Prom 1957 No. 2, 316-21. Comparison of the yield of Zn in gases evolved during conventional blowing of slag (all tuyeres supplying heat) with that obtained when one-half of tuyeres had heating function (burning to CO_2) and the other half had reducing function (burning to CO) indicated that the yield of Zn was the same. These results were contrary to the results obtained by Bell, Turner and Peters (1955), that the division of tuyere functions into heating and reducing operations increases the efficiency of the blowing process. This discrepancy is probably due to the fact that Bell, Turner and Peters disregarded the reaction of oxidation which occurs during the heating process. (CA 53, 21505 c).

1957

34. OKUNEV, A.I., "Comparison of the Efficiency of Various Reducing Agents During Blowing of Slag", ibid 322-8.
The yield of Zn during blowing is practically the same for methane + air as for C-dust. The consumption of C, H and CH_4 for a g-atom of Zn evolved is 7.2, 8.78 and 3.43 moles respectively. A preheated blow which has been enriched with O is more efficient with CH_4 than with C-dust or H.
(CA 53, 21513 a)

35. OKUNEV, A.I., "Behaviour of Cadmium During Blowing of Slag", ibid 361-4.
Sublimation of Cd during blowing of Zn-bearing slag is nearly 100%; this takes place during the very first minute of the blow.
(CA 53, 21513 b)

36. OKUNEV, A.I., "Behaviour of Rare and Dispersed Elements in the Fuming of Slags", Byull Tsvetnoi Met. 1957 No. 24, 16-18.
The behaviour of Ge, Se, Te, Ga, In and Tl in the fuming of Zn-bearing slags is examined. The conclusion is drawn that distribution of the rare and dispersed elements can be used in the fuming of slag. (CA 54, 10718 e)

37. OKUNEV, A.I. and BOVYKIN, V.S., "Activity of Zinc Oxide in Lead and Copper Slags from the Fuming Process", Doklady Akad Nauk. SSSR 112, 77-9, (1957).
The ZnO activity was determined in a slag with composition Zn 16.9, Pb 3.6, SiO_2 19.3, CaO 7.4, MgO 6.3, Al_2O_3 5.1, S 1.5, FeO 39.4%. The experimental work was done with an air consumption of 450 cu m/min., coal 90 kg./min, charge 55 tons, process temperature 1150-1225^0. The Zn activity co-efficient was close to 1 (0.95-0.97) when the Zn concentration was less than 8%, and was reduced to 0.88-0.90 when the concentration was 15%. (CA 51, 13690 d)

38. OKUNEV, A.I., SARKISOV, I.G., and VIL'YAMOV, V.M., "The Intensification of Zinc Removal from Slags by the Use of Metallic Reducing Agents", Byull Tsentral Inst. Inform Ministerstva Tsvetnoi Met. SSSR 1957, No. 2 17-19.
The possibilities of increasing the efficiency of Zn and Pb extraction from slags by using metallic reductants are discussed. It is recommended that Fe scrap, chips, etc. be used as a reductant. (CA 54 10718 c)

1957

39. TONKONOGII, A. V., BASINA, I. P., and VDOVENKO, M. I., "Cyclonic Pyrometallurgical Process", Tsvetnye Metally 30, No. 1 30-42 (1957).
The installation and results of several tests with a vertical cyclonic chamber for smelting Cu and Zn-Cu concentrates are described. The flux for Cu was CaO (58-60%) and for Cu-Zn was sand (83.4% SiO_2). At the start the settling chamber was preheated to 1250-1350^{0}C and the cyclone chamber was heated 45-60 min before the charge. Extraction of Cu was 97.5 - 93.7% for Cu concentrates and 79.4 - 93.5 for Zn-Cu. The degree of removal of S was 56.0 - 91.5% and was easily controlled by the amount of air forced through the cyclone. The processes of roasting and smelting were combined, thus reducing fuel expenditure. The SO_2 content in the exhaust was 5% and solids 2.0 - 5.0 g/cu m. (CA 51 10333 e)

40. VANYUKOV, V. A., UTKIN, N. I. and VANYUKOV, A. V., "A Study of the Kinetics of Distillation of Zinc from Molten Slags", Sbornik Nauch Trudov Moskov Inst. Tsvetn Metal i Zolota i Vsesoyuz Nauch Inzhener - Tekh Obshchestvo Tsvetnoi Met. 1957 No. 26 63-73.
Ten samples of slags containing different amounts of SiO_2, FeO and CaO, and having a constant ZnO content (10%) were investigated. Chemically pure substances were used in preparing the slags. The rate of distillation of Zn from liquid slags is determined by the temperature of the process and the composition of the slag. It increases as the temperature and the content of FeO. Acidic and ferrous slags react differently to the addition of CaO. An increase in the CaO content increases the rate of volatilisation of Zn from ferrous slags and decreases it in the case of acidic slags. The process of reduction of Zn from liquid slags is of a diffusion nature. The distillation of Zn proceeds with the aid of metallic Fe, which is an active intermediate product of the reaction. (CA 54 10718 g)

41. WOODSIDE, T. J. and ROBERTS, B., "The El Paso Smelter". J. Metals 9, No. 9, 1118-21 (Sept. 1957).

1958

42. DONCHENKO, P. A., NOVOZHILOV, A. B. and SALOMATOV, N. K., "Utilization of a New Slag-Fuming Installation at Ust-Kamenogorsk Lead-Zinc Combine", Tsvetnye Metally 31 No. 6, 74-82 (1958)
Equipment and procedure are described for fuming Pb-Zn slag. The slag contains Pb 1.5, Zn 12.8 and Cu 0.8% before fuming and Pb 0.05, Zn 2.5 and Cu 0.25% after fuming. A matte is recovered containing Cu 7.0 and Pb 2.5% while the fumes recovered, weighing 19% of the charge, contain Pb 7.5 and Zn 60%. Metal recovery is 82% of Zn and 97% of Pb.
(CA 52 17012 g)

43. KOSTELOV, V. V. and MORACHEVSKAYA, V. S., "Leaching of Zinc from Fuming Sublimates", Tsvetnye Metally 31, No. 10 39-43 (1958).
Zn sublimates from waste slag containing Sn 14-28, Zn 19-33, and Pb 9-16% were leached with H_2SO_4. (CA 53 6010 g)

44. LOKSHIN, E. M. and BORISOV, Yu S., "Intensification of the Blast Furnace Process by Changing the Composition of the Blast", Stal' 18 391-7 (1958)
Theoretical calculations show that addition of oil, coke oven and natural gas, as well as of powdered coal, might reduce coke consumption by 30-35% and increase furnace production by 40% provided the blast is simultaneously oxygenated. (CA 52 14469 e)

45. LUMSDEN, J., "Recovering Zinc from Lead Blast Furnace Slags", (to National Smelting Co. Ltd.), Brit. Pat. 881,857 (Appl. August 21, 1958.
Molten slag containing Pb, S and Zn is blown with powdered coal and slightly more air than is required to burn all the C to CO_2 and H to H_2O and to volatilise PbS, and is then blown with powdered coke and only 60-75% of the air required for complete combustion, to form CO for the reduction of ZnO to Zn vapour, which is collected and condensed. Since Pb and S both decrease Zn-condensation efficiency, Pb-bearing material should be added to low-Pb slag before the treatment in an amount sufficient to combine with all the S. Some Si is also vaporised with the S. The PbS vapour can be oxidised with air to form $PbSO_4$ for collection in a baghouse. The air excess in the first blowing must be $< 10\%$ to prevent precipitation of Fe_3O_4 which might carry some Zn ferrite with it. To avoid such loss of Zn, the air excess should be held to 5%. In the second blowing of slag containing 17-18% Zn, about 18-25% C by weight of slag is generally sufficient. The two blowings are generally conducted in separate furnaces. (CA 56 P6971 e)

46. SHAPOVALOV, M. A., "Blowing Reducing Gases into the Hearth of Blast Furnaces", Stal' 18 385-90 (1958).
Introduction of natural gas would necessitate oxygenation of the blast. (CA 52 14469 b)

1959

47. BAILY, T.F., "Natural Gas in Blast Furnace Operation", Iron Age 184 No.3, 104-5 (1959).
By supplying additional reducing agent, natural gas increases the capacity of a furnace and provides a convenient substitute for coke. This leads to a reduction in S and ash entering the furnace and a reduction in the amount of slag. The quantity of ore in the furnace increases. (CA 53 15900 d)

48. KOSTELOV, V.V., and VERNER, B.F., "Use of Liquid and Gaseous Fuel in the Fuming Process", Tsvetnye Metally 32 No.9 45-8 (1959).
In laboratory and pilot experiments both liquid and gaseous fuels were efficient reducing agents in the fuming of slags containing Sn 0.5-1.8, Pb 0.5-0.9 and Zn 2.6-10%. With fuel oil the best conditions were blowing for 2 hours at 1300-1350^0, coefficient of air consumption $\alpha = 0.5$ and consumption of fuel 12 and of added S 3-4% by weight of slag; the extraction was Sn 86.5-90, Pb 98-100 and Zn 71-96.5%. The best conditions with natural gas (98% CH_4, ~ 8500 k cal/cu m) were 2 hours blowing at 1200^0, gas consumption 3.3 l/min, $\alpha = 0.7$ and pyrite added 5%, the extraction was Sn 88.5-90, Pb 91-92 and Zn 50-78%. In comparison the extraction on blowing with coal dust was Sn 85-88, Pb 90 and Zn 82-85%. The higher temperature developed during its combustion, and the higher extraction of Zn with coal as compared to natural gas is attributed to the direct participation of elementary C in the reduction of the oxides. (CA 54 7475 b)

1960

49. ANON, "Steel from Copper Slag", Chemical Week 62-3, (December, 10, 1960)

50. BASINA, I.P., VDOVENKO M.I., and KURMANGALIEV, M.R., "Basic Results of the Study of Cyclone Processes of Smelting and Sublimation", Trudy Inst. Energet., Akad Nauk. Kazakh, SSR 2, 261-73 (1960).
With a vertically disposed cyclone furnace at about 1350^{0}C, lined with chrome-magnesite half-brick and water-cooled, Cu concentrates can be smelted to obtain Cu matte containing 95-97.5% of the original Cu (actual Cu content 46-77%). With concentrates containing Zn, with or without Pb, coke is added to the charge; Zn (up to 89%) and Pb (over 99%) are obtained as sublimate, the Cu as before passing almost completely into the matte. The gases containing sublimed Zn and Pb as

1960

oxides can be passed to a cyclone chamber operating at 1100°; here reduced Pb condenses and residual gases pass to another cyclone chamber to condense Zn. The lower end of the cyclone smelter preferably has an additional air intake to ensure better combustion of CO. (CA 54 22238 c)

51. CORDIER, J.A., "Injection of Different Materials in the Blast. Experience with Fuel Oil and Natural Gas", Blast Furnace, Coke Oven, Raw Materials Comm., Iron Steel Div., AIME Proc. 19, 238-78 (1960). (CA 55 22007 b)

52. DOUGLAS, D.L., "Molten Alkali Carbonate Fuel Cells with Gas-Diffusion Electrodes", Fuel Cells, symposium, Atlantic City, 1959, 129-49. (Publ. 1960) Ind. Eng. Chem. 52, 308-9 (1960). (CA 57 3181 b)

53. MALKIN, I.M. et al, "Treatment of Zinc-Bearing Slag in a Laboratory Electric Furnace Using Coke as Electric Conductor", Tsvetnye Metally 33 No. 12, 15-23, (December, 1960). (EI 1961, 1582)

54. OSTROWSKI, E.J., KESLER, G., and MELCHER, N.B., "Investigation on the Enrichment of Blast Furnace Air", Blast Furnace, Coke Oven, Raw Materials Comm., AIME Proc. 19, 279-300 (1960). (CA 55 22007 b)

55. SHAPOVALOV, M.A., "Some Problems in Blast Furnace Smelting Using Natural Gas", Metallurg 5 No. 8, 4-6 (1960). (CA 55 2063 a)

56. TURUBINER, A.L., "Use of Natural Gas for Heating Open Hearth Furnaces", Metallurgy 5, No. 8, 16 (1960) (CA 55 2063 d)

1961

57. AGISHEV, A.P., "Gas Industry of the USSR", Inst. Gas Engrs. J. 1, 719-32 (1961). (CA 58 7763 e)

58. ANDERSON, S.G., "Injecting Natural Gas into the Blast Furnace Hot Blast", Blast Furnace, Coke Oven, Raw Materials Comm., Iron Steel Div., AIME Proc. 20, 552-61 (1961) (CA 56 8375 h)

1961

59. CARLSON, J.W., "Addition of Fuels to the Hot Blast at the Pueblo Plant", Blast Furnace, Coke Oven, Raw Materials Comm., Iron Steel Div., AIME Proc. 20, 547-51. (CA 56 8375 h)

60. DEAN, E.R., "A Report on the Use of Fuel Gas by Injection through Blast Furnace Tuyeres", Blast Furnace, Coke Oven, Raw Materials Comm., Iron Steel Div., AIME Proc. 20, 562-72. (CA 56 8375 h)

61. DENNIS, W.H., Metallurgy of the Non-Ferrous Metals, Pitman (1961).

62. EVDOKIMENKO, A.I., "Continuous Fuming of Slags", Sb Nauch. Trudy Gos. Nauch. Issled. Inst. Tsvetn Metal. No.18, 231-44 (1961).
A physical-chemical model experimentally verified the theoretical analysis and showed a rational step-by-step scheme for continuous fuming of slag. It is necessary to calculate increase production by 15-20% when comparing periodic with continuous fuming due to filling and pouring. By taking this into consideration calculations were made for a furnace for continuous distillation of zinc and lead, as well as tin, zinc and lead. A schematic diagram of the fuming furnace is shown. (CA 60 2574 h)

63. FARMER, F.W., and MORELAND, J.C., "Natural Gas Injection into Blast Furnaces", Iron Steel Engr. 38, No.10, 88-95 (1961).
Gas injection has been used on all tuyeres for 1 year, reducing the coke-rate and increasing the hot-blast temperature by 100°F for each 1% of gas. (CA 56 2206 e)

64. FITZGERALD, E.J., "Steel from Copper Slags", J. Metals 13, 135 (February 1961).

65. JOHNSON, A.F., "Iron from Ferrous Slags" (to Strategic Materials Corp.). US Pat. 2,986, 458 (May 30, 1961)
Furnace is blown with natural gas. (CA 55 P18537 i)

66. KRASAVTSNEV, N.I., "Some Theoretical Problems Associated with Blowing of Reducing Gases into the Blast Furnace", Izv Vysshikh Uchebn Zavedenii Chernaya Met. 1961 No.12 31-9. (CA 56 12605 e)

67. KREGLOW, W.M. Jr., "Preliminary Experience with Natural Gas Injection in Blast Furnace Tuyeres", Blast Furnace, Coke Oven, Raw Materials Comm., Iron Steel Div., AIME Proc. 20, 587-604. (CA 56 8375 h)

1961

68. LANDUCCI, L., and FULLER, F.T., "Oxygen-Enriched Air in Lead and Zinc Smelting", J. Metals 13 759-63 (October, 1961) The use of O-enriched air in suspension Zn roasters, Pb blast furnaces, and slag fuming furnaces at the Cominco Trail, BC, plant are described. (IMMA 12, 733)

69. NAHOCZKY, A., "Reducing the Coke Consumption of Blast Furnaces by Steam, Natural Gas, or Fuel Oil Residue Injection and (or) by Increasing the Blast Temperature by Preheating the Air", Kohaszati Lapok 16 (94) 38-43 (1961). (CA 55 8224 i)

70. OSTROWSKI, E.J.; KESLER, G. and MELCHER, N.B., "Blast Furnace Enrichment Investigations", J. Metals 13, 25-30, (1961). (CA 55 7210 b)

71. RAMIREZ, J., "Injection of Natural Gas in the Blast Furnace", Blast Furnace, Coke Oven, Raw Materials Comm., Iron Steel Div. AIME Proc. 20, 540-6 (1961). (CA 56 8375 h)

72. SCHULTZ, E.B. Jr., MARIANOWSKI, L.G., LINDEN, H.R.; and VORRES, K.S., "Natural Gas Fuel Cells for Power Generation", Am Gas J. 188, No. 5, 24-8 (1961). (CA 55 22767 e)

73. SMIRNOV, V.I., LEBED, B.V., and YABLONSKII, Yu.A., "Processing Waste Slags from Copper and Lead Smelting", Met. i Khim. Prom. Kazakhstana, Nauchn-Techn. Sb 1961, No. 6, 87-90. (CA 58 6486 f)

74. STARSHINOV, B.N. et al, "Blast Furnace Operation with Addition of Natural Gas to the Blast", Metallurg. 6 No. 7, 4-8 (1961). (CA 55 24444 h)

75. TSUMURA, MITSUNOBU, "Natural Gas Industry in Japan", Yuki Gosei Kagaku Kyokai Shi 19 487-90 (1961). A review. (CA 55 19203 a)

76. VAR'YAN, S.M. and LUNEV, V.E., "Treating Molten Slags, and Furnace for Carrying out the Process", USSR Pat. 134,874 (January 10, 1961). Molten slag containing Zn, Pb and other volatile non-ferrous and rare metals is treated with an air-reducing mixture. The slag moves through the furnace in a continuous flow from the time it enters until it leaves the furnace. In order to ensure that the slag stays in this furnace for a sufficient time (90-150 min.), the length of the furnace is at least 6-8 times its width. (CA 55 P16377 g)

77. WHITE, R.H. and SCIULLI, C.M., "Use of Natural Gas in the No. 3 Blast Furnace at the Fairless Works of US Steel Corp.", Blast Furnace, Coke Oven, Raw Materials Comm., Iron Steel Div. AIME Proc. 20, 579-86. (CA 56 8375 h)

1962

78. AGARWAL, J.C., SCIULLI, C.M. and STEPHENSON, R.L., "Substituting Hydrocarbon Gas for Part of the Coke in Iron Blast Furnaces" (to US Steel Corp.), US Pat. 3,062,640 (November 6th, 1962). (CA 58 2218 h)

79. ALEXANDER, P., "Treatment of Lead Smelter Slags", Hutnicke Listy 17 No.4, 260-5, (2nd April 1962).
A mixture of acid iron ore and the slag is pelletised. Volatile non-ferrous metals are volatilised. (EI 1962)

80. BELEVTSOV, G.A., et al, "Blast Furnace Performance When Using Natural Gas", Stal' 22, 483-6 (1962).
1 cu m of gas saved 1.28 -1.58 kg of coke.
(CA 57 10841 b)

81. BOGDANDY, L. von., and SCHAEFERS, W., "Comparable Evaluation of Hydrogen Carriers for Blowing into the Blast Furnace Hearth", Stahl Eisen 82, No.1, 1-18 (1962). (CA 56 15228 i)

82. BRUNION, H. and SERBENT, H., "Volatilisation of Zinc and Other Volatile Metals from Ores", (to Beteiligungs - und Patent-verwaltungs G.M.B.H.), Ger. Pat. 1,130,602 (May 30, 1962).
Solid reducing agents and gaseous fuels used for ores and slags in a rotary furnace. (CA 57 P5644 c)

83. CARLSON, J.W., NEGOMIR, J.M. and HODGE, A.L., "Blast Furnace Oxygen Enrichment with Various Injected Fuels", Iron Steel Engr. 39 No.12, 73-87 (1962).
(CA 58 6489 h)

84. COLLISON, W.H., "Natural Gas Injection at Great Lakes Steel Blast Furnaces". Iron Steel Engr. 39 No. 73-81 (1962).
(CA 57 487 f)

85. CORDIER, J.A., et al, "Blast Furnace Injection", Rev. met. (Paris) 59, 791-815 (1962).
(CA 58 11012 h)

86. DUNAEV, N.E. and YARESHEVSKII, S.L., "The Effect of Natural Gas on the Temperature and Chemical Properties of Cast Iron", Stal' 22, 296-300 (1962).
170-190 cu m of natural gas per ton lowered the coke rate from 1081 to 894 kg/ton. (CA 57 3127 g)

87. KHASKIN, I.G. and LARIONOV, A.V., "Reaction of Galena with Natural Gas", Ukr. Khim. Zh. 28, 118-21 (1962).
(CA 57 5559 e)

1962

88. KIM, G. V., and MILLER, O. G., "The Forms of the Conversion of Zinc and Lead into Sublimates in Liquid Slags During Vacuum Treatment", Izv. Akad. Nauk. Uz SSR, Ser. Tekn. Nauk 6 No. 3, 93-7 (1962). (CA 58 5340 c)

89. KOSTELOV, V. V., and GRINEVICH, I. N., "The Use of Fuel Oil in a Fuming Process", Tsvetnye Metally 35, No. 10 39-42 (1962). In Sn recovery from Sn-bearing materials such as slag, quartz tailings, and Fe-Si by the fuming process, replacement of coal by fuel oil increased the capacity by 50% and decreased the fuel consumption by 25%. The combined use of fuel oil, coal, and pyrite (a sulphidising agent) increased Sn extraction from 91% to 95%. (CA 58 6486 h)

90. MALVAUX, J., BROCHENIN, P. and CORDIER, J., "Two Years of Tests and Operation with Hydrocarbon Injection in a Blast Furnace", Iron Steel Inst. (Lond.) Spec. Rept. No. 72, 59-71 (1962).
Natural gas injection decreased the coke rate by 16% and similarly increased the output.
(CA 57 6947 i)

91. MAZACEK, J., "Extraction of Cobalt from the Slag Produced as a Waste Material During Smelting of Copper", Czech. Pat. 102,760 (February 15, 1962).
The slag containing Zn and Pb is mixed with pyrite, melted in a fuming furnace, and blown with coal and air.
(CA 58 P 9902 e)

92. MELCHER, N. B., MAHAN, W. M., and WOOLF, P. L., "Principles of Blast Furnace Fuel Injection", Iron Steel Inst. (Lond.) Spec. Rept. No. 72 47-52 (1962).
(CA 57 6947 g)

93. NEKRASOV, Z. I., et al, "Operation of a 1719 cu m Blast Furnace with Natural Gas Injection", Stal' 22, 199-205 (1962). Enrichment of the blast with up to 100 cu m of natural gas per ton lowered the coke rate from 747 to 580 kg/ton and increased production 3.7%. (CA 57 3126 c)

94. SHARADZENIDZE, S. A., et al, "Operation of Blast Furnaces with the Use of Natural Gas", Metallurg 7, No. 9 3-7. (1962)
(CA 58 2199 a)

95. SJOGREN, N., PICHLER, W. and STIFT, K., "Injection of Natural Gas into Blast Furnaces". Berg - Huettenmaenn. Monatsh. Montan. Hochschule Leoben, 107 No. 12, 377-82 (1962)
(CA 58 5301 a)

1962

96. SMIRNOV, V.I. et al., "Waste Slags from Copper Smelting Plants", USSR Pat. 145,755 (March 21, 1962).
Slags smelted in electric furnace or reverberatory with a reducing agent, pyrite, and limestone.
(CA 57 P6943 f)

97. SMIRNOV, V.I., et al, "Treatment of Non-Ferrous Metallurgical Slags", Tsvetnye Metally 35 No. 9, 50-6 (1962).
The recovery of Zn, Cu and Fe from high- and low-Zn Cu smelter slags is discussed. Three flowsheets are given.
(CA 58 6468 e)

98. STARSHINOV, et al., "Reduction and Slagging Processes in a Blast Furnace Using Natural Gas", Stal' 871-6 (1962).
(CA 58 1157 f)

99. VARTANYAN, A.M., "The Ust-Kamenogorsk Lead Smelter", Tsvetnye Metally 35 9-13 (Nov 1962).
Since 1958 oxygen has been used in shaft-furnace lead-smelting permitting a lead-rich agglomerate to be smelted to give a high-zinc slag. The coke-rate was decreased 12.5% and the length of campaigns between repairs extended 5-6 times.
Since commencing fuming of lead slags, 27,000 tons of zinc, 9,000 tons of lead and 1,500 tons of copper have been recovered. A larger slag-fuming plant is to come into operation during 1963, and the cost of the plant is expected to be recovered in one year's operation.
Work is proceeding on continuous decopperising of lead and matte smelting in an electric furnace. Continuous desliverising and vacuum dezincing are being installed.

1963

100. BLANKS, R.F., "A Cyclone Furnace for Slag Fuming", Aust. Inst. Min. Metallurgy, Annual Conference, Port Pirie, Preprint No. 4 (August, 1963).
An investigation of the use of the cyclone firing principle has shown the suitability of this technique for melting and dezincing granulated lead blast furnace slag. Experimental work on laboratory-scale furnaces has been used to develop the process, which aims at the recovery of zinc oxide from the slag. Results have been sufficiently encouraging to warrant tests on a pilot scale. (Author)

1963

101. BURNSIDE, H. E. W., "Predicting the Effects of Hydrocarbon Injection on Blast Furnace Operation", Ind. Eng. Chem. Process Design Develop 2, 2-11 (1963)
(CA 58 2199 h)

102. KISELEV. S. T., "Methods of Dezincing and Decoppering of Zinc- and Copper-Rich Slags from Copper Smelting", Tsvet. Metally 36 (6) 79-81 (1963).
Copper and zinc were extracted from rich slag by the addition of sufficient CaO and SiO_2 to make a fluid slag having the minimum solubility for zinc and copper, fuming the zinc from the slag with air or nitrogen and collecting the copper as matte by the addition of 15-20% pyrite. After treatment the slag contained 0.5-0.7% zinc and 0.05-0.07% copper.
(CA 60 2573 h)

103. POTEBNYA, Yu. M., and LITVINENKO, V. I., "Operating Conditions of a Gas Stream in the Upper Part of the Bosh with a Combination Blast", Izv Vysshikh Uchebn Zavedenii, Chernaya Met. 6 No. 2, 23-30 (1963).
(CA 58 11012 g)