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MINERAL WASTE RESOURCES OF CANADA REPORT NO. 8 - NON-FERROUS METALLURGICAL WASTES

R.K. COLLINGS and S.S.B. WANG

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MINERAL WASTE RESOURCES OF CANADA
REPORT NO. 8 - NON-FERROUS METALLURGICAL WASTES

by

R.K. Collings* and S.S.B. Wang**

SYNOPSIS

The production of solid mineral and mineral-based wastes by Canada's mining and mineral processing, metallurgical, and chemical process industries is about 700 x 10^6 t/a. More than 95% of this amount is produced by the mining and mineral processing sector. The metallurgical sector produces about 12 x 10^6 t/a, of which 4 x 10^6 is from non-ferrous operations. Non-ferrous metallurgical wastes consist principally of slags from copper, nickel and lead production.

Copper, nickel and lead slags are produced during smelting and converting operations to recover metal from ores. Slag from smelting operations normally is dumped whereas converter slag, being richer in metal values, is recycled through the smelter. Significant quantities of copper and nickel slags are used as railroad ballast and in highway construction. Rapid cooling of slag produces a glassy pozzolanic material that has potential as a partial replacement for Portland cement in concrete. Slag from lead smelting may contain significant quantities of zinc and lead which normally are recovered before the slag is disposed of in waste dumps. Although lead slag can be used as construction fill and base in highway construction, there is no such utilization in Canada.

Flue dusts produced by the non-ferrous metallurgical industry are normally recycled without further processing. However, build-up of impurities may result in loss of feed quality, in which case these dusts would be treated before recycling. Some research has been reported on the recovery of bismuth and other metals from flue dusts.

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RESSOURCES EN REBUTS MINERAUX
RAPPORT NO. 8 - REBUTS DE METAUX NON FERREUX

par

R.K. Collings* et S.S.B. Wang**

SYNOPSIS

La production de rebuts minéraux solides et à base de minéraux dans les industries canadiennes d'exploitation minière et de traitement des minéraux et dans les installations de transformation métallurgique et chimique se chiffre à environ 700×10^6 t/a. Plus de 95% de cette valeur est produit dans le secteur de l'exploitation minière et du traitement des minéraux. Le secteur métallurgique produit environ 12×10^6 t/a, dont 4×10^6 t/a proviennent d'installations de métaux non ferreux. Les rebuts de métaux non ferreux sont principalement composés de scories de production du cuivre, du nickel et du plomb.

Les scories du cuivre, du nickel et du plomb sont produites durant la fusion et durant les opérations de conversion pour récupérer le métal des minerais. Les scories provenant de la fusion sont normalement évacuées tandis que les scories du convertisseur, plus riches en métal, sont recyclées dans la fonderie. Des quantités importantes de scories du cuivre et du nickel sont employées comme empierrement de voie de chemin de fer et en construction des routes. Le refroidissement rapide des scories donne un matériau vitreux pouzzolanique susceptible d'être employé comme remplaçant partiel du ciment Portland dans le béton. Les scories provenant de la fusion du plomb peut contenir des quantités importantes de zinc et de plomb qui sont normalement récupérés avant l'évacuation des scories dans les terrils de rebuts. Quoique les scories du plomb peuvent être utilisées comme remblais dans les champs de construction et comme couche de base dans la construction des routes, on ne les emploie pas au Canada.

Les poussières de carneau générées par l'industrie des métaux non ferreux sont normalement recyclées sans traitement additionnel. Cependant, une accumulation d'impuretés peut occasionner une perte de la qualité de l'alimentation; le cas échéant, ces poussières devraient être traitées avant le recyclage. Une recherche effectuée sur la récupération du bismuth et d'autres métaux des poussières de carneau a été signalée.

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INTRODUCTION

Canadian mining, mineral processing, metallurgical, and chemical process industries generate an estimated 700 x 10^6 t/a of solid mineral and mineral-based wastes. Chief among these are waste rock and mill tailings from mining and mineral processing operations which collectively account for more than 95% of the total. Metallurgical and chemical process wastes comprise the remainder.

Some wastes contain metallic and mineral materials that are potentially recoverable for re-use. Interest in such wastes has been increasing in recent years. Reasons for this include the exhaustion of favourably located and higher-grade mineral deposits; legislation restricting mining operations near urban centres; increased exploration, mineral beneficiation and transport costs; increased cost of disposal and containment of mineral waste; and growing concern over the pollution potential of some waste dumps. These factors have stimulated research into the feasibility of recovering metal and mineral materials from deposits of lower grade but more accessible ore and from alternative sources such as mineral wastes. Research also is being carried out on utilizing mineral wastes in the manufacture of bricks and building blocks, as filler in various products, as soil additives, as aggregate and partial replacement for Portland cement in concrete, as railroad ballast, and as fill in road construction and maintenance.

The current interest in mineral wastes has pointed to an increased need for information on their physical and chemical natures. The Canada Centre for Mineral and Energy Technology (CANMET) is engaged in a study of mineral wastes having three major objectives:

- to identify mineral wastes and to determine their magnitude and nature,
- to publish information on their physical and chemical properties, and potential uses,
- to encourage further study and research by industry and government.

As part of this study, technical data on Canada's vast and growing mineral waste resources have been systematically documented and published.

This report is one in a series entitled "Mineral waste resources of Canada". A companion report on ferrous metallurgical wastes was prepared in 1980 (1). Other reports in the series include mining wastes in Ontario, Quebec, British Columbia, the Atlantic Provinces and the Prairie Provinces (2,3,4,5,6,) and one on mineral wastes as mineral fillers (7).

MINERAL WASTES

Solid mineral wastes are classified as primary and secondary in Table 1. Primary wastes are derived from mining and mineral processing plants and consist of the original mineral material in a crushed or ground form. Secondary wastes are the mineral or mineral-based materials derived from metallurgical and chemical processes which expose virgin rocks and minerals to heat and chemical treatment.

The metallurgical industry of Canada produces about 12 x 10^6 t/a of solid mineral or mineral-based wastes. This report is restricted to non-ferrous metallurgical wastes which account for about 30% of the total.

NON-FERROUS METALLURGICAL WASTES

The non-ferrous metallurgical industry employs both pyrometallurgical and hydrometallurgical techniques to process mineral concentrates. Pyrometallurgy is the principal method and is likely to remain so for the foreseeable future. Wastes from hydrometallurgical processes are usually in the form of liquid or slurry which more closely resemble wastes from chemical processes. Liquid wastes are of limited interest for recovery of mineral material. Consequently, only the solid wastes from non-ferrous pyrometallurgical operations are discussed in this report. The chief wastes in this class are copper, nickel and lead slags. Flue dusts collected in these operations are usually recycled to the production circuit. Recycling can, however, cause problems of build-up of volatile components and loss of feed quality. Research work has been carried out

Table 1 - Classification of solid mineral wastes

	Primary			Secondary	
	Mining and mineral processing			Metallurgical	Chemical processing
	Overburden	Gangue or waste rock	Mill tailings	Slag, ash, dust	Residues
Description	Soil, sand, clay, shale, gravel, boulders, etc.	Rock which must be broken and removed to obtain ore; many types, e.g., limestone, granitic and volcanic rocks	Rock minerals, usually sand to slimes sizes but sometimes larger; may include sulphides	Slags, fly ash, dusts and slimes or sludges	Tailings, slimes, sludges
Characteristics	Heterogeneous and unconsolidated	Broken rock, usually homogeneous, but varying widely in size	Usually uniform in character and size	Usually uniform in character and size	Usually uniform in character and size
Examples	Cover removed from open pit coal, gypsum, and some iron mines	Broken rock from open pits, e.g., iron mines	Tailings from many diverse operations, e.g., base, ferrous and precious metal processing, and non-metallic mineral operations	Slags from iron and steel plants, fly ash from power plants, dusts from precipitators	Gypsum from phosphate fertilizer and hydrofluoric acid plants
Nature of problem and potential use	Materials handling and storage; little intrinsic value; overburden may be useful as fill and in landscaping; waste rock may have value as railroad ballast and construction aggregate, e.g., in concrete and asphalt mixes		Materials handling and storage; may compete for valuable land space; unsightly and possible source of air and water pollutants; potential source of additional metals and minerals and raw material for the manufacture of bricks and blocks, soil fertilizers and additives, mineral fillers, chemicals, etc. Slags are used as concrete and construction aggregate, in asphalt road surfacing, as railroad ballast, etc.		

to recover metal values from flue dusts and to change the product dusts into a more suitable form for recycling to smelting furnaces. Treatment is varied and may utilize both hydrometallurgical and pyrometallurgical methods (8,9,10,11,12). According to information gathered in this study, flue dusts in Canadian non-ferrous metallurgical plants are returned to the smelting circuit without any prior treatment, the exception being Gaspé Copper Mines, where dusts are treated to remove and subsequently recover bismuth (13).

COPPER AND NICKEL SLAGS

Copper and nickel are extracted mainly from sulphide concentrates by pyrometallurgical treatment which commonly includes three types of unit operations - roasting, smelting and converting. In roasting, sulphur is driven off as sulphur dioxide and iron is oxidized. In smelting, the roaster product is melted with a siliceous flux that combines with the iron oxide and gangue to form a liquid iron silicate slag. The silicate phase floats on the heavier molten sulphide matte. In converting, more sulphur is driven off the sulphide melt, and the remaining iron is oxidized and fluxed for removal as a silicate slag. For copper, the oxidation is continued until blister copper is obtained. Since converter slag is richer in metal content, it is returned to the smelter. The molten smelter slag is then granulated with water jets or simply discarded.

The lack of continuity in the conventional copper and nickel production system results in low energy efficiency. Energy and environmental concerns during the past decade have led to research and development of new technologies such as flash-smelting, top-blown rotary converter, and continuous processing. The Noranda continuous smelting process, for example, combines the three steps of smelting, converting and blister making into a one-step or one-vessel process. Much of the required heat can be provided by the exothermic converting reactions. Slags from these new processes contain high metal contents. The metal values are recovered from the slags by either froth flotation or settling and cleaning in an electric furnace. The flotation tailings and the cleaned slag are considered waste products and can be discarded. The most common approach now seems to be settling of flash furnace slag, and flotation of converter slag (14). A low silica, high copper slag is produced from the Noranda process. The slag is slowly cooled, milled and floated to give a low copper tailing and a slag concentrate. The concentrate, containing 40% copper, is recycled to the reactor. The tailing containing 0.2% copper is disposed in tailings impoundment areas. Most of the magnetite, silica and zinc contents of the head slag are found in the tailings and therefore do not represent a recirculating load (15,16). Afton Mines of Kamloops, B.C. is the first copper smelter to adopt the technology of top-blown rotary converter. The slag goes to a primary crusher along with ore materials, and then to a concentrator for copper recovery. The tailings from the concentrator become the main waste product.

Large quantities of copper and nickel slags are used successfully as railroad ballast. In particular, nickel slag, which is heavy, tough, hard, angular, and packs well under ties, has proven to give better support than the usual rock ballast. However, the heavy weight of the slags makes transportation costly and usually limits use to local markets (17,18). Copper slag has been used in highway construction as granular fill and base material, however, most smelters are located in remote areas.

Finely ground, vitrified non-ferrous slags (copper, nickel and lead) have some pozzolanic properties thus can be used as partial replacement for Portland cement in cemented hydraulic mine backfill and for road base stabilization. The slag must be rapidly cooled and ground to about the fineness of Portland cement (19).

A potential problem in using these slags is that they may contain soluble components which could be harmful if released to the environment (17,18).

Non-ferrous slags are used in the manufacture of ceramics and for grit blasting (18). Noranda Mines has plant-tested copper reverberatory slag for mineral wool production. A fibre product possessing satisfactory physical properties was obtained; however, its insulating quality was found to decrease with increasing FeO content. In practice, this would limit the percentage of copper slag in the charge to under 40% making production of mineral wool from copper slag economically unattractive (20).

Production of copper slag in Canada is about 1.2×10^6 t and that of nickel slag about 2.5×10^6 t for a total of 3.7×10^6 t/a. About 45% of this is used as railroad ballast, in road building, and for miscellaneous purposes.

LEAD SLAG

There are two primary lead producers in Canada, Cominco at Trail, B.C. and Brunswick Mining and Smelting at Belledune, N.B. Lead concentrates are smelted in conventional blast furnaces. At Cominco the resulting slag, containing 18% zinc and 2.5% lead, is treated in the slag fuming plant for the recovery of these metals and minor quantities of other valuable metals, e.g., silver and cadmium (21). The slag tapped from the slag fuming furnace and granulated with high pressure water jets is considered barren and a waste product. At Brunswick Mining and Smelting, the slag from the blast furnace is granulated and stockpiled in a slag settling area without further treatment.

Minor use is made of lead slag in grit blasting and as land fill in Australia (18). Lead slag should generally be usable in fill construction and as base material (17). However, such use may be restricted because of potential leachate problems and high transportation costs due to its heavy weight and the remote location of the smelters.

Production of lead slag in Canada is about 290 000 t/a. None is utilized.

TECHNICAL DATA

Canadian copper, nickel and lead smelters are listed in Table 2. Types of wastes, amount produced, physical characteristics, chemical analyses, and current and potential uses for copper and nickel slags are listed in Table 3, and for lead slag, in Table 4. Data contained in Table 3 and 4 were provided mostly by the operating companies.

Table 2 - Company names, plant locations and identification numbers

Company name, plant location	No.
Copper and nickel smelters	
Noranda Mines Limited, Horne Division, Noranda, Que.	1
Mines Noranda Limitée, Division Mines Gaspé, Murdochville, Qué.	2
Falconbridge Nickel Mines Limited, Falconbridge, Ont.	3
INCO Metals Company Ontario Division, Copper Cliff, Ont.	4
INCO Metals Company Manitoba Division, Thompson, Man.	5
Hudson Bay Mining and Smelting Co., Limited, Flin Flon, Man.	6
Afton Mines Limited, Kamloops, B.C.	7
Lead Smelters	
Brunswick Mining and Smelting Corporation Limited, Smelting Division, Belledune, N.B.	8
Cominco Limited, Trail, B.C.	9

Table 3 - Mineral-based wastes or coproducts from copper or nickel smelting operations

1. Noranda Mines Limited*
   Horne Division
   Noranda, Quebec

Process:	Copper reverberatory smelting	Noranda reactor
Waste or coproduct:	Slag	Slag flotation tailings
Size range	~25 mm (1 in.)	75-80% minus 45 µm (325 mesh)
Density**	3.7 g/cm^3	4.1 g/cm^3
Bulk density***	n.a.	1.9 g/cm^3
Rate of production (t/a)****	0.5 x 10^6	0.25 x 10^6
Amount accumulated (t)	0.5 x 10^6	0.25 x 10^6
Present use or disposal practice	9450 t recycled per year, the rest discarded to slag dump	Disposed in tailings impoundment area
Potential use	Railroad ballast, fill, mineral wool manufacture	
Chemical analysis (%)		
CaO	1.3	1.1
SiO_2	33.8	26.0
Al_2O_3	6.2	4.8
MgO	1.8	3.1
Fe (total)	36.1	42.7
S	2.3	0.2
C	0.06	0.11
Cu	0.47	0.20
Ni	0.04	0.03
Co	0.06	0.04

* Numbers correspond to those noted in Tables 2 to 4
** True density
*** Bulk density as reported by companies
**** Metric tons per annum
n.a. not available
† estimated

Table 3 (cont'd)

2. Mines Noranda Limitée* Division Mines Gaspé Murdochville, Québec	
Process:	Copper reverberatory smelting
Waste or coproduct:	Slag
Size range	n.a.
Density**	n.a.
Bulk density***	n.a.
Rate of production (t/a)****	0.3×10^6
Amount accumulated (t)	0.3×10^6
Present use or disposal practice	Discarded to slag dump
Chemical analysis (%)	
CaO	5
SiO_2	40
Al_2O_3	4
MgO	1
Fe_3O_4/Fe (total)	15/30
S	1
Cu	<0.6

3. Falconbridge Nickel Mines Limited* Falconbridge, Ontario	
Process:	Nickel-copper electric furnace smelting
Waste or coproduct:	Slag
Size range	25-100 mm (1-4 in.)
Density**	3.5 g/cm^3
Bulk density***	2.0-2.4 g/cm^3 (125-150 lb/ft^3)
Rate of production (t/a)****	0.6×10^6
Amount accumulated (t)	n.a.
Present use or disposal practice	Discarded to slag dump
Potential use	Railroad ballast
Chemical analysis (%)	
CaO	1.8
SiO_2	38.0
Al_2O_3	5.7
MgO	2.0
Fe (total)	37.0
S	1.1
Cu	n.a.
Ni	n.a.
Co	n.a.

Table 3 (cont'd)

4. INCO Metals Company*
Ontario Division
Copper Cliff, Ontario

Process:	Copper flash furnace	Nickel reverberatory smelting
Waste or coproduct:	Slag	Slag
Size range	+ 4 mm	+ 4 mm
Density**	3.5 g/cm^3	3.5 g/cm^3
Bulk density***	n.a.	n.a.
Rate of production (t/a)****	0.15×10^6	1.5×10^6
Amount accumulated (t)	nil	nil
Present use or disposal practice	The copper and nickel furnace slags are dumped together; the bulk is reclaimed and processed by a contractor for sale as railroad ballast and for other special applications.	
Chemical analysis (%)		
CaO	1.5	2.2
SiO_2	35.0	37.0
Al_2O_3	5.0	5.6
MgO	1.2	2.4
Fe (total)	41.1	36.8
S	1.2	1.3
Cu	0.62	0.17
Ni	0.10	0.40
Co	0.02	0.16

5. INCO Metals Company*
Manitoba Division
Thompson, Manitoba

Process:	Nickel electric furnace smelting
Waste or coproduct:	Slag
Size range	85% plus 0.42 mm (35 mesh)
Density**	3.3 g/cm^3
Bulk density***	1.4 g/cm^3
Rate of production (t/a)****	0.5×10^6
Amount accumulated (t)	13.6×10^6
Present use or disposal practice	Stockpiled - some use as railroad ballast
Potential use	Mine fill, sandblast grit
Chemical analysis (%)	
CaO	2.3
SiO_2	40.0
Al_2O_3	6.1
MgO	5.4
FeO/Fe_2O_3/Fe (total)	$37.0^{\dagger}/4.1^{\dagger}/31.7$
S	1.0
Cu	0.03
Ni	0.21
Co	0.06

Table 3 (cont'd)

6. Hudson Bay Mining and Smelting Co., Limited* Flin Flon, Manitoba	
Process:	Copper smelting and slag fuming
Waste or coproduct:	Slag
Size range	variable
Density**	n.a.
Bulk density***	n.a.
Rate of production (t/a)****	n.a.
Amount accumulated (t)	less than 1 x 10^6
Present use or disposal practice	Road building, site development, mine backfill
Potential use	Few due to isolated location
Chemical analysis (%)	
CaO	n.a.
SiO_2	n.a.
Al_2O_3	n.a.
MgO	n.a.
$FeO/Fe_2O_3/Fe$ (total)	n.a.
S	n.a.
Cu	<0.75
Zn	<1.00

7. Afton Mines Limited* Kamloops, British Columbia	
Process:	Copper top-blown rotary converter
Waste or coproduct:	Concentrator tailings
Size range	88% minus 150 µm (100 mesh)
Density**	n.a.
Bulk density***	n.a.
Rate of production (t/a)	n.a.
Amount accumulated (t)	n.a.
Present use or disposal practice	Disposed in tailings impoundment area
Chemical analysis (%)	
CaO	5.8
SiO_2	30.3
Al_2O_3	17.6
MgO	4.0
Fe (total)	5.5
K_2O	3.7
Na_2O	4.5

Table 4 - Mineral-based wastes or coproducts from lead smelting operations

8. Brunswick Mining and Smelting Corporation Limited* Smelting Division Belledune, New Brunswick	
Process:	Lead blast furnace
Waste or coproduct:	Slag
Size range	minus 3.2 mm (1/8 in.)
Density**	4.1 g/cm^3
Bulk density***	2.1 g/cm^3 (130 lb/ft^3)
Rate of production (t/a)****	0.13 x 10^6
Amount accumulated (t)	1.4 x 10^6
Present use or disposal practice	Disposed on land
Chemical analysis (%)	
CaO	14.5
SiO_2	19.6
Al_2O_3	2.1
MgO	n.a.
FeO	42.4
S/As/Sb	1.5/0.18/0.08
Cd/Pb/Bi	0.005/3.5/0.009
Cu	0.35
Zn	9.5
Ag	19.9 g/t
9. Cominco Limited* Trail, British Columbia	
Process:	Slag fuming
Waste or coproduct:	Slag
Size range	87% plus 0.42 mm (35 mesh)
Density**	3.5 g/cm^3
Bulk density***	1.6 g/cm^3 (100 lb/ft^3)
Rate of production (t/a)****	0.16 x 10^6
Amount accumulated	nil
Present use or disposal practice	Discarded as waste
Potential use	Sand blasting
Chemical analysis (%)	
CaO	14
SiO_2	26
Al_2O_3	6
MgO	2
FeO/Fe_2O_3/Fe (total)	32/7/30
S/As/Sb	1.5/<0.1/<0.1
Pb	<0.1
Cu	0.2
Zn	2
Ag	3.4 g/t

* Numbers correspond to those noted in Tables 2 to 4
** True density
*** Bulk density as reported by companies
**** Metric tons per annum

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