Environment Canada
Environmental Protection Service

Environnement Canada
Service de la protection de l'environnement

Arsenic Emissions and Control Technology: Gold Roasting Operations

Economic and Technical Review
Report EPS 3-AP-79-5

Air Pollution Control Directorate
September 1979

ENVIRONMENTAL PROTECTION SERVICE REPORT SERIES

Economic and Technical Review Reports relate to state-of-the-art reviews, library surveys, industrial inventories, and their associated recommendations where no experimental work is involved. These reports will either be undertaken by an outside agency or by the staff of the Environmental Protection Service.

Other categories in the EPS series include such groups as Regulations, Codes, and Protocols; Policy and Planning; Technology Development; Surveillance; Briefs and Submissions to Public Inquiries; and Environmental Impact and Assessment.

Inquiries pertaining to Environmental Protection Service Reports should be directed to the Environmental Protection Service, Department of the Environment, Ottawa K1A 1C8, Ontario, Canada.

SÉRIE DE RAPPORTS DU SERVICE DE LA PROTECTION DE L'ENVIRONNEMENT

Les rapports sur la révision économique et technique concernent des revues de l'état des connaissances, des études documentaires, des inventaires industriels et des recommendations connexes dans des domaines non touchés par le travail expérimental. L'établissement de ces rapports est la responsabilité d'un organisme extérieur ou du personnel du Service de la protection de l'environnement.

Le Service compte d'autres séries de rapports; règlements, codes et accords; politiques et planification; développement technologique; exposés et mémoires découlant d'enquêtes publiques; évaluations et effets environnementaux.

Prière d'envoyer toute demande de renseignements ayant trait aux rapports du Service à l'adresse suivante: Service de la protection de l'environnement, Ministère de l'Environnement, Ottawa K1A 1C8, Ontario, Canada.

ARSENIC EMISSIONS AND CONTROL TECHNOLOGY: GOLD ROASTING OPERATIONS

by

Earl W. Gagan

Mining, Mineral and Metallurgical Division
Abatement and Compliance Branch
Air Pollution Control Directorate

Report EPS 3-AP-79-5
September 1979

7909

Cat. No. En42-3/79-5

ISBN 0-662-10632-6

ABSTRACT

Arsenic has been classified as a significant health hazard, subject to Section 7 of the Clean Air Act. As such, it will be regulated by federal emission standards.

This report is a discussion of arsenic emissions from Canadian gold roasting operations. The present and future contribution of these emissions to air pollution is evaluated and the best available control technology is defined.

Only four gold mines roast sulphide concentrates containing arsenopyrite. However, a national arsenic inventory for 1972 showed an estimated emission of 1 934 tons of arsenic from the metallurgical processing of gold. This represented 47.5% of the total arsenic emissions in Canada for that year.

The installation of new pollution control equipment at some mines and the improvement of previously installed control equipment reduced the arsenic emissions from gold roasting operations to 207 tons for the year 1976.

Emissions allowed by the proposed regulations are estimated at 28 tons per year, which means a containment of 99.5% of the arsenic in the mineral concentrates fed to the roasters.

RÉSUMÉ

L'arsenic a maintenant été classé parmi les substances dangereuses et sera donc soumis, en vertu de l'article 7 de la Loi sur la lutte contre la pollution atmosphérique, aux normes fédérales de dégagement.

Le rapport sur cette question traite des dégagements d'arsenic produits, au Canada, par le grillage des matières aurifères. On y trouvera une évaluation des contributions actuelles et futures à la pollution atmosphérique ainsi qu'un exposé des meilleures techniques de dépollution existantes.

Il n'y a que quatre mines où l'on grille des concentrés sulfurés renfermant de l'arsénopyrite. Il a été établi, cependant, dans un inventaire national des sources et des émissions d'arsenic de 1972, que le traitement métallurgique de l'or en avait dégagé 1934 tonnes, soit 47,5% des émissions d'arsenic au pays cette année-là.

L'installation de nouveaux dispositifs anti-pollution dans certaines exploitations et le perfectionnement de ceux qui existaient déjà, ont permis de réduire à 207 tonnes les dégagements d'arsenic imputables, pour 1976, au grillage des matières aurifères.

Les dégagements permis en vertu du règlement proposé seront d'environ 28 tonnes par année, ce qui signifie la rétention de 99,5% de l'arsenic présent dans les concentrés de minerai soumis au grillage.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 BACKGROUND

The Department of National Health and Welfare in 1976 completed a comprehensive review of the toxicology and health effects of arsenic and its compounds, excluding arsine, and concluded that arsenic emissions could constitute a significant danger to human health. As a result, Environment Canada initiated the development of regulations to control emissions of arsenic into the ambient air under Section 7 of the Clean Air Act. This section states:

> **"NATIONAL EMISSION STANDARDS AND GUIDELINES**
>
> National Emission Standards
>
> 7(1) Where the emission into the ambient air of an air contaminant in the quantities and concentrations in which it is consumed or produced in the operation of stationary sources of a particular class or classes specified by the Governor in Council would
>
> (a) constitute a significant danger to the health of persons, or
> (b) be likely to result in the violation of a term or terms of any international obligation entered into by the Government of Canada relating to the control or abatement of air pollution in regions adjacent to any international boundary or throughout the world,
>
> the Governor in Council may prescribe national emission standards establishing the maximum quantities, if any, and concentrations of such air contaminant that may be emitted into the ambient air by stationary sources of such class or classes".

A national arsenic emission inventory (1) conducted by Environment Canada, for the base year 1972, identified gold processing, or, more specifically, roasting operations employed in the extraction process, as a significant source of arsenic emissions. Studies were initiated to quantify and characterize the arsenic emissions from gold roasting and to describe the technology in use, or available, to control the emissions. A task force, made up of representatives from federal, provincial and territorial governments, and the gold processing industry, was established to provide advice on the technical aspects of the best available control technology and the emission limits achievable by its use. Environment Canada requires the emission limits, specified as National Emission Standards Regulations, to be based on the best available technology.

A socio-economic impact analysis study (2) was done by Environment Canada on the proposed regulations to limit arsenic emissions from gold roasting operations.

2 INTRODUCTION

2.1 General

Arsenic is present in many naturally occurring substances and is widely distributed throughout nature. It is generally present in low concentrations, e.g., agricultural soils may contain between 0.1 and 4.0 parts per million (ppm), river water between 0.0006 and 0.3 ppm and seawater between 0.0004 and 0.023 ppm. Higher concentrations may be present in metal-bearing ore, particularly certain gold ores mined in Canada where concentrations up to a few percent are not uncommon. However, many ores contain only trace amounts. Arsenic is present in ore as sulphide minerals.

Four Canadian gold mines produce and roast a sulphide flotation concentrate in their gold extraction processes. Roasting is carried out at high temperatures to break down the concentrates chemically and physically. It involves the combustion of sulphide in air, in an enclosed reactor: much of the sulphur, arsenic and antimony is converted to gaseous oxides and a porous, permeable calcine is produced. This allows the maximum recovery of gold to be achieved by leaching the calcine with cyanide, since most of the arsenic and antimony, which interfere with gold extraction, have been driven off in the reactor. Much dust is generated during roasting. The hot gases are passed through cyclones in series to remove a large part of the dust which is added to the calcine. The gases are then directly cooled to about 370°C or indirectly to about 315°C, and the remainder of the suspended dust, which is removed by a pollution control device, is subsequently treated for gold extraction. The gases are cooled/quenched to sublimate the arsenic trioxide so that the condensed fume can be recovered in a warm fabric filter baghouse, minimizing arsenic emissions into the atmosphere.

The roaster calcine product is leached with cyanide solution to dissolve the gold, which is subsequently recovered from the solution after it has been filtered and clarified.

2.2 Scope

This study pertains to the control of arsenic emissions from gold roasting operations. Size and location of plants, products, processes and emission control technology are discussed. The results of a national arsenic emission inventory (1) compiled in 1972 are presented. The emissions from gold roasting have been reduced considerably since the survey was conducted and yearly inventories are presented to show the changes.

2.3 Purpose

The primary purpose of this report is to provide the necessary technical information for the preparation of effective National Arsenic Emission Standards Regulations for Canadian gold roasting operations under Section 7 of the Clean Air Act. For this purpose, gold roasters are defined as stationary sources subject to national emission standards regulations that may be published by the Governor in Council as required by the Clean Air Act.

A secondary purpose of this report is to assist in the development of federal briefs, state-of-the-art reviews, and other documents relating to air pollution from gold roasting.

2.4 Information Sources

Data available at the National Science Library and through the Environmental Protection Agency (EPA) of the United States were reviewed. Copies of the original papers were acquired through the Environment Canada library. Articles appearing in recent trade literature were reviewed and information was also obtained from an EPS publication, "National Inventory of Sources and Emissions of Zinc, Cadmium and Arsenic, Summary of Emissions for 1972" (1).

Contacts were made with companies operating gold roasters, provincial and territorial regulatory agencies and the following departments and agencies of the federal government: Energy, Mines and Resources; Indian and Northern Affairs; Industry, Trade and Commerce; and Statistics Canada. Questionnaires prepared by Environment Canada were completed by the companies to document the arsenic emissions from roasters.

3 INDUSTRY DESCRIPTION

3.1 General

Although Canada is the world's third largest producer of gold, following South Africa and the U.S.S.R., it only accounted for 5.7% of the free world output in 1977 and only 3.6% of the total world production.

Gold is recovered from two main sources in Canada, from lode gold mines and as a by-product of base metal concentrates. Minor amounts are recovered from placer deposits. Gold production for the 1975-77 period is summarized below.

TABLE 1 SUMMARY OF GOLD PRODUCTION IN CANADA, 1975-77 (2)

Source	1975		1976		1977	
	(ounces)		(ounces)		(ounces)	
Lode Gold Mines	1 206 600	73%	1 232 281	73%	1 206 007	70%
Base Metal Mines	436 240	26%	442 893	26%	494 961	29%
Placer Deposits	10 000	1%	16 634	1%	16 010	1%
TOTAL	1 652 840	100%	1 691 808	100%	1 716 978	100%

The value of 1977 production was approximately $268 million. Production for the first nine months of 1978 is estimated at 1 249 409 ounces.

The major source of gold production in 1977 was the operations of 21 lode gold mines, which accounted for 70% of the total output. These mines recover gold from vein-like deposits in the earth's crust, the gold being associated with quartz and various sulphide minerals, notably pyrite, pyrrhotite, arsenopyrite and chalcopyrite.

Only four of the mines use roasting in the recovery of gold and they produced 463 334 ounces in 1977, about 38% of the total lode gold production. The four mines are:

Giant Yellowknife Mines Ltd.
Campbell Red Lake Mines Ltd.
Dickenson Mines Ltd.
Kerr-Addison Mines Ltd.

These mines provide direct employment to 1 350 workers and indirect employment to many others in service industries.

3.2 Products

Gold bullion is the major product of the lode gold mines. Most of this is sold to the Royal Canadian Mint for refining. Some base metal slag results from gold bullion production and is sent to non-ferrous metal smelters for residual metal recovery. The slags contain minor amounts of gold and silver along with other metals such as copper and nickel.

In addition to the above, two of the four mines roasting gold concentrates recovered impure arsenic trioxide as a by-product dust from warm fabric filter baghouse operations. There was virtually no market for this product prior to 1977 and the dust was stored underground in sealed stopes. Improved market conditions now give an incentive to these companies for the production of a higher grade arsenic trioxide so that they can sell all the by-product arsenic.

A third company now uses a different method to recover a higher grade arsenic trioxide, all of which is sold.

Arsenic and its compounds were formerly used in Canada, in the glass industry, in wood preservatives, hide tanning, paint pigments, pesticides, herbicides, aquatic weed control and certain medicines. Many industries that formerly used arsenic and its compounds are now using other reagents to avoid health risks.

Arsenic trioxide is currently used, primarily in the United States, in the formulation of pesticides, wood preservatives, dessicants and other compounds. There is an increasing demand for arsenic and arsenic trioxide for zinc refining, certain lead alloys and other metallurgical uses. Because of an increasing demand and the potential demise of the major American producer, there are now expanding market possibilities for Canadian arsenic.

4 INDUSTRIAL PROCESSES

4.1 General

Primary gold is recovered from vein-like deposits, using underground, and occasionally surface, mining techniques. The mined ores typically contain 0.1 to 0.8 ounces of gold per ton.

The ore is crushed to about minus 1/2 inch in jaw and gyratory crushers and ground to a fine particle size in wet ball mills. Most of the gold is recovered by cyanidation. In this process, fine particles of ore, or, in some cases, sulphide concentrate from prior flotation that has been reground, are leached in cyanide solutions in a series of agitated aerated tanks. Gold is dissolved in solution as a gold cyanide complex. Lime is added to the resulting slurry to control the pH and precipitate other dissolved metals. The slurry is then thickened and filtered to separate the solids. The solution is clarified and zinc dust is added to the clear solution to precipitate the gold as a gold-zinc slime; this is smelted with borax to produce bullion gold and a base metal slag. The bullion gold is refined further at the Royal Canadian Mint and the slag is sent to non-ferrous metal smelters for residual metal recovery.

The chemistry of cyanidation and precipitation is shown below:

$$2\ Au + 4\ NaCn + 1/2\ O_2 \longrightarrow 2\ NaAu\ (CN)_2 + 2\ NaOH$$

$$2\ NaAu(CN)_2 + Zn \longrightarrow Na_2Zn(CN)_4 + 2\ Au$$

A few producers recover part of the gold in a jigging and mercury amalgam process. In this operation, suitably sized particles of ground ore are treated in mineral jigs and on vibrating tables, and separated into two streams (a concentrate and a tailing) according to differences in particle density. The denser stream (concentrate) is rich in gold and is mixed with mercury; gold dissolves in mercury to form a gold-mercury amalgam. This is subsequently distilled in a sealed retort where mercury distills off leaving a gold residue. The gold is refined and the condensed mercury is recycled. The solids remaining after jigging and amalgamation are treated in the main mill circuit for additional gold recovery.

4.2 Roasting Operations

Certain Canadian gold ores and flotation concentrates are not amenable to direct cyanidation because they contain elements such as arsenic and antimony which interfere with cyanidation. In other cases, the gold is present in a too finely disseminated state, intimately associated with the sulphide minerals, which prevents adequate dissolution and results in low gold recovery.

Roasting of concentrates satisfies several objectives in providing material amenable to cyanidation. Antimony and arsenic volatize and are converted to the gaseous trioxide state; pyrite is altered to hematite; and sulphur in the concentrate acts as a fuel and leaves as SO_2. The reactions produce porous calcine particles that can be easily leached by cyanide.

Three Canadian gold mines roast sulphide concentrates containing 8% to 10% arsenic; the concentrate at the fourth mine contains only 1% arsenic. Fuel for the roasting operation is the sulphur contained in the concentrate; the sulphur content must be at least 17% but varies up to 30% at one of the mines.

Two of the mines use a single fluid-bed reactor for roasting. The other two mines use first- and second-stage reactors with the air controlled to provide a reducing atmosphere in the first stage and an oxidizing atmosphere in the second. In all cases, the hot dust-laden gases are directed through cyclones to remove coarse particles which join the calcine for subsequent leaching by cyanide for gold recovery.

Some differences in milling, roasting and pollution control practices exist, so operations at each of the four mines are described separately.

4.3 General Milling Practices and Pollution Control

4.3.1 Giant Yellowknife Mines Ltd. The mill feed is ground in water after which the sulphides are concentrated by flotation. The flotation tailings are pumped to the sand plant to produce backfill. The fine slimes go to the tailings disposal area.

The flotation concentrate goes directly to the roaster, where it is passed through the first- and second-stage reactors. The hot gases are directed to two cyclones in series to remove the coarse dust particles which are added to the calcine. The hot gases, along with the remaining dust, proceed to the electrostatic precipitators where the fine dust is removed. The cleaned gas is then cooled to 110°C using air for tempering before entering the warm fabric filter baghouse. Sublimation produces impure arsenic trioxide dust which is removed by the fabric filter baghouse and pneumatically pumped to underground storage vaults.

The quenched calcine is pumped to the main mill circuit where it is ground and leached with cyanide solution for residual gold recovery.

Quenched electrostatic precipitator dust, because of its high arsenic content and other contaminants, is treated separately in an activated carbon batch process for

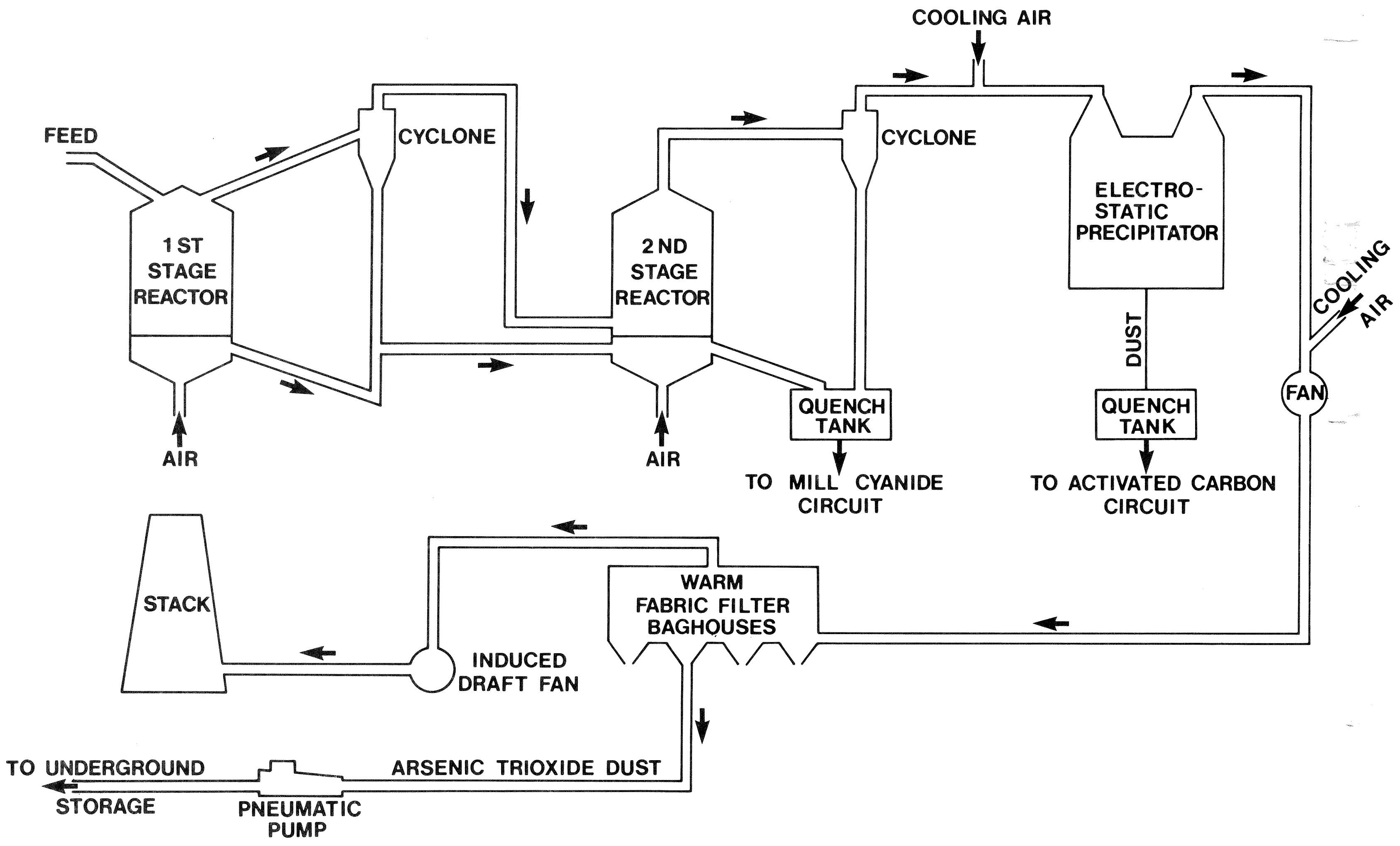

FIGURE 1 ARSENIC RECOVERY SYSTEM – PROCESS FLOW DIAGRAM GIANT YELLOWKNIFE MINES LTD.

gold absorption. Carbon loaded with gold is filtered from the leaching agitator bimonthly and shipped to a non-ferrous metal smelter for final recovery of gold. After the carbon loaded with gold has been removed, lime is added to the filtrate and this slurry joins the slimes from the sand plant and is pumped to the tailings disposal area.

4.3.2 Campbell Red Lake Mines Ltd. The mill feed is ground in water after which the sulphides are concentrated by mineral jigs. The concentrate is passed over a Wilfley table for upgrading and the tailings are returned to the grinding circuit. The concentrate goes for amalgamation and the solution from the mineral jigs goes to the flotation circuit for separation of the sulphides. The concentrate from the first few cells of the flotation machines is passed over a blanket table; the blanket concentrate is amalgamated. A flotation concentrate is produced for roaster feed. Because of the high gold value in the flotation tailings, they must be leached in cyanide to improve the gold recovery. After the pregnant solution has been removed by filtration, the washed filter cake is repulped and pumped to the tailings disposal area.

The flotation concentrates are passed through two fluid-bed reactors in series, which permit better control of bed temperatures. The off-gas from the roaster is passed through a series of cyclones to remove coarse particulates which are added to the calcine. The hot dirty gases are then passed through a hot electrostatic precipitator to remove the fine particulates which are leached in a separate cyanide circuit for gold recovery. The temperatures of the gases are about 315°C to 360°C, well above the sublimation point of arsenic trioxide. The cleaned gas stream is then air-tempered to about 110°C by admitting cool air. Arsenic sublimes at about 220°C to solid arsenic trioxide but the lower temperature is maintained to minimize the amount of arsenic remaining in the vapour state and to protect the synthetic fabric of the bags in the collecting fabric filter baghouse. The dust, consisting mainly of arsenic trioxide, collected in the baghouse is removed from the hoppers by screw conveyors and can be shipped to customers or pneumatically conveyed by a pressurized blow tank and pipelines to sealed underground stopes.

The calcine flow from the reactor and the cyclones is quenched in water, thickened and filtered. The filter cake is repulped with lime and cyanide and reground in a pebble mill operating in closed circuit with a cyclone. The solution slurry is subjected to a prolonged period of agitation in standard agitators, after which it is thickened and filtered in two stages before being discarded as tailings. Fine zinc dust is added to the

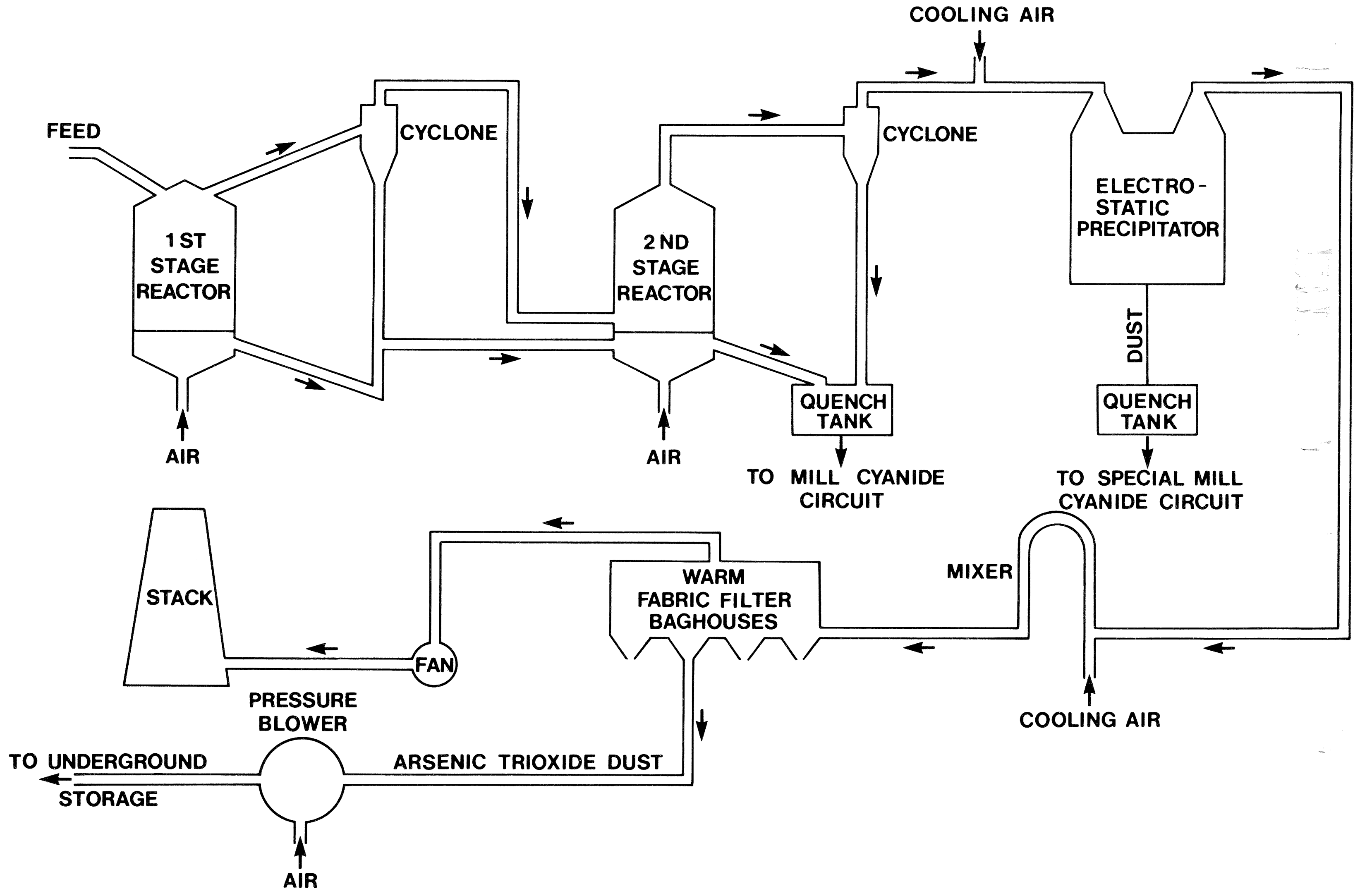

FIGURE 2 ARSENIC RECOVERY SYSTEM – PROCESS FLOW DIAGRAM CAMPBELL RED LAKE MINES LTD.

pregnant solution after clarification, and the precipitated gold is collected in a press. The amalgam and precipitate are refined weekly.

The fine calcine dust removed by the electrostatic precipitator is very high in arsenic and antimony and is treated in a separate batch plant, with the main difference in treatment being the use of soda ash and caustic soda instead of lime for protective alkalinity. Gold recovery from this dust is considerably lower than that achieved by leaching the calcine from the reactor and cyclones.

4.3.3 **Dickenson Mines Ltd.** The mill feed is ground in a cyanide solution and the secondary ball mill is in closed circuit with a mineral jig and cyclone. The jig concentrate goes for amalgamation. The overflow from the cyclone is pumped to the cyanide circuit. This is essentially a two-stage straight cyanide process, involving double agitation. High-grade pregnant solution from the first stage is clarified and sent to the precipitation circuit. Fine zinc dust is added and the precipitated gold is collected in a press for subsequent refining. Lower grade solutions from the second stage are recirculated.

Pulps from the final filtering and repulping stage, after the addition of reagents, are pumped to a cyclone in closed circuit with the regrind ball mill before entering the flotation circuit. A rougher and scavenger concentrate are taken off in the flotation circuit. The scavenger concentrate, after cleaning, joins the rougher concentrate to make up the roaster feed. The flotation tailings go to the backfill plant where the slimes are separated and pumped to the tailings disposal area. The coarser fraction is used as backfill in the mine.

Roasting takes place in a single-stage fluid-bed reactor, the concentrate feed containing about 8% arsenic, 20-36% sulphur and and 1 to 2 ounces of gold per ton. The gold content of the concentrate is lower because of prior recovery by amalgamation and cyanidation. Sometimes, because of the greater sulphur content in the concentrates, temperatures of between 705°C and 760°C are attained and cooling water is sprayed into the roaster when necessary to moderate the temperature.

The roaster exhaust gas is passed through refractory lined cyclones in series to remove the coarser dust. The dirty gas then enters a heat exchanger where it is cooled to about 315°C by the exhaust gases from the arsenic emission control system. The cooled gas is passed through two hot fabric filter baghouses in parallel to remove the remaining suspended particulates. These are added to the dust recovered in the cyclones and the calcine from the roasting operation, all of which is then quenched, dewatered and conditioned with sodium cyanide and lime. It is then pumped to the secondary ball mill of

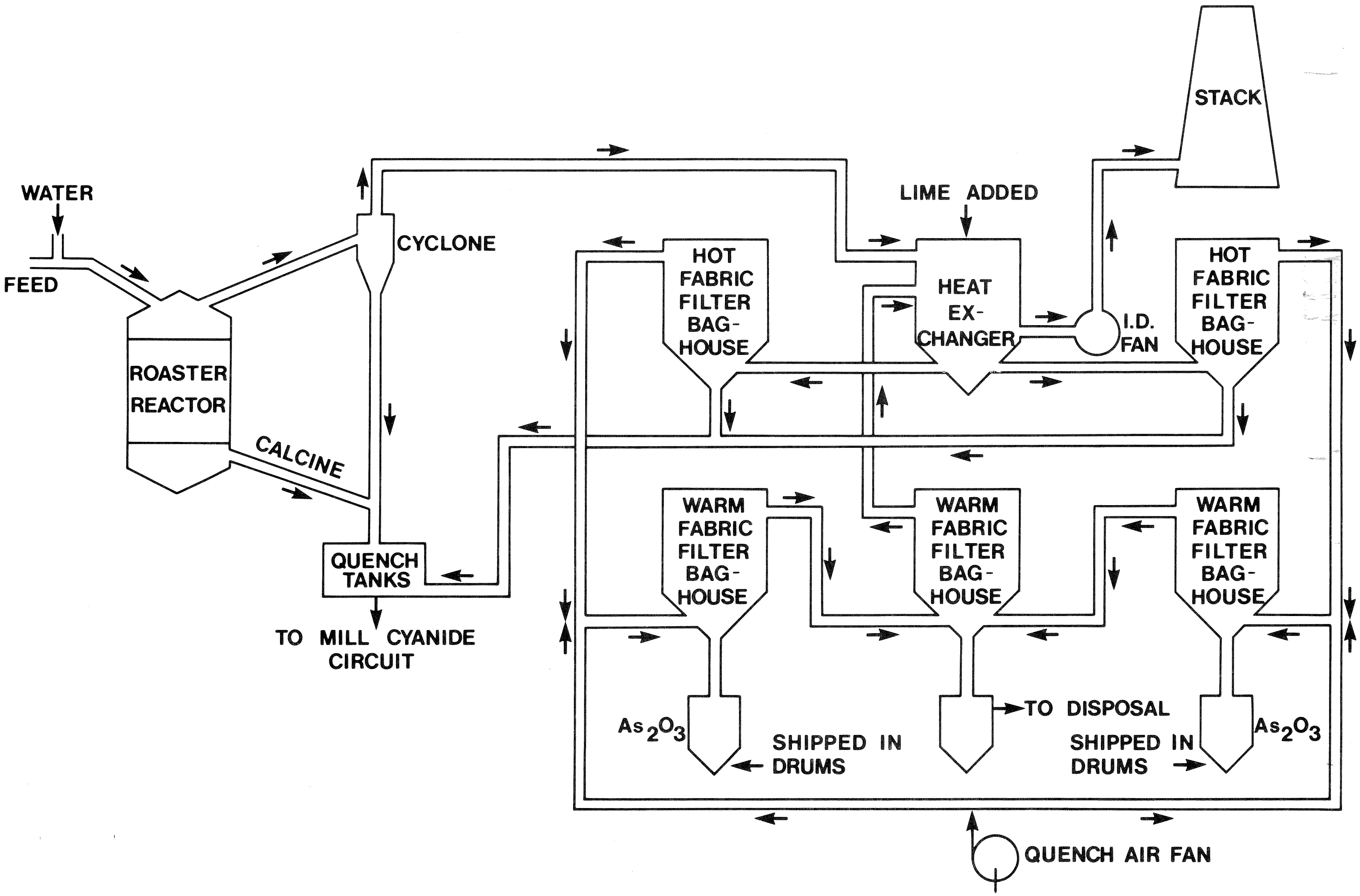

FIGURE 3 ARSENIC RECOVERY SYSTEM - PROCESS FLOW DIAGRAM DICKENSON MINES LTD.

the grinding section where, after grinding, it enters the mill cyanide circuit to recover the gold exposed in the porous calcine.

Controlled amounts of air are added to the clean hot fabric filter baghouse exhaust gas to reduce the temperature to about 145°C. This is below the sublimation point for arsenic trioxide and the gas is passed through two warm fabric filter baghouses which capture the condensed arsenic trioxide dust. The exhaust stream then passes through an additional clean-up fabric filter baghouse operated at 123°C. The clean exhaust gas enters the heat exchanger, where it is reheated, and then is exhausted up the stack. The arsenic trioxide collected in the warm baghouses using the Dickenson pollution control system is of higher purity than that of the other mines and is packaged and sold.

4.3.4 Kerr-Addison Mines Ltd. A gold roaster is operated at this mine for three months a year, during the winter. A conventional cyanide mill circuit is operated for gold recovery. The tailings from the circuit are subjected to flotation and the mineral concentrate recovered is stockpiled for roasting during the winter. This concentrate contains about 1% arsenic, 42% sulphur and 0.60 ounces of gold per ton.

Roasting serves the dual function of producing a porous calcine and generating steam in a waste heat boiler (to heat the plant). The flotation concentrate is roasted at 370°C in a single-stage fluid-bed reactor. The exhaust gas is cooled to about 290°C by passing it through the waste heat boiler, then directed through two cyclones in series which capture the coarser dust. The cyclone exhaust gas is discharged up the stack. Calcine from the roaster, boiler and cyclones is water quenched and pumped to the cyanide circuit for residual gold recovery.

This mine is planning to close in the near future, since the ore reserves will be exhausted shortly.

5 EMISSION SOURCES

The roaster off-gases constitute the major source of arsenic emissions from goal roasting operations. Sulphur dioxide is also generated and particles of fine process material are entrained in the off-gas stream. Equipment is installed to control particulate and arsenic emissions from roasting. Particulate and arsenic emissions may also occur during transfer of the roaster products to the quenching systems. Mechanically sealed equipment is used to prevent this from happening. Emissions from quenching are prevented by introducing the calcine by means of a pipe inserted below the water level and by water sprays in the tank. Emissions may occur during upsets of this system, but these upsets are rare.

Particulate emissions may occur from gold bullion preparation.

Secondary emissions of arsenic trioxide can occur when the captured fume is being conveyed to safe storage areas, usually isolated dry underground stopes which are hermetically sealed. Closed pneumatic transfer systems are used and the conveying air is returned to the warm baghouse to capture any entrained arsenic dust.

6 ARSENIC EMISSION INVENTORIES

6.1 National Arsenic Inventory - All Sources 1972

A national arsenic emission inventory was conducted by Environment Canada for the base year 1972 (1). The results are shown in Table 2. Total emissions were 4 073 tons, with gold ore processing accounting for 1 934 tons or 47% of the total.

TABLE 2 ARSENIC EMISSIONS IN CANADA, 1972 (1)

Source	Emissions	
	Tons	Percent
INDUSTRY		
Primary copper and nickel production	661	16.2
Primary lead production	18	0.4
Primary zinc production	359	8.8
Primary iron and steel production	1 041	25.6
Metallurgical processing of gold	1 934	47.5
Miscellaneous sources	15	0.4
Subtotal	4 028	98.9
FUEL COMBUSTION/STATIONARY SOURCES		
Power generation	25	0.6
Industrial and commercial	13	0.3
Domestic	< 1	< 0.1
Subtotal	38	0.9
TRANSPORTATION	< 1	< 0.1
SOLID WASTE INCINERATION	1	< 0.1
PESTICIDE APPLICATION	6	0.2
TOTAL	4 073	100.0

6.2 Arsenic Emissions from Gold Roasting Plants

Table 3 summarizes the total arsenic emissions from the four mines operating gold roasters for the years 1972 to 1976. During this period, the emissions were reduced substantially as a result of the installation of arsenic emission control systems at mines where controls previously did not exist, and by improvements to existing installations. The emissions have been reduced further by the installation of a hot and warm fabric filter baghouse system at a third gold mine.

TABLE 3 ESTIMATED ARSENIC EMISSIONS FROM GOLD ROASTING OPERATIONS, 1972-76 (2)
(short tons per year)

	1972	1973	1974	1975	1976
Gold Roasting Operations	1 934	1 934	341	209	207

7 CONTROL METHODS

7.1 Emissions

The roaster off-gases, the major source of arsenic emissions from gold roasting, also contain particulates, sulphur dioxide and antimony oxide fumes. Measures are taken to control the emission of particulates, arsenic and antimony.

7.2 Emission Control Systems

7.2.1 Theoretical Aspects of Control. Most of the arsenic present in the off-gas stream has been shown to be gaseous arsenic trioxide (7). The sublimation point for arsenic trioxide is about 220°C where it condenses to a solid. The amount retained in the vapour phase decreases with decreasing temperature.

Theoretical studies (3,4) have been conducted to determine the concentration of arsenic trioxide present in air at different temperatures, using pure arsenic trioxide. Data extrapolated from one study are summarized in Table 4. They show a dramatic (logarithmic) inversion in the concentration with temperature and illustrate the need to cool the gases sufficiently, to condense the arsenic vapours, before final particulate collection.

TABLE 4 CONCENTRATIONS OF ARSENIC TRIOXIDE PRESENT IN THE GAS PHASE AT DIFFERENT TEMPERATURES (4)

Temperature, °C	Arsenic Vapour Concentrations, mg/m^3
100	5.5
105	9.2
110	14.5
115	23.5
120	37.5
125	58.0

The arsenic emission control systems installed, or under construction, consist of cooling the gas to condense arsenic trioxide, and collecting the fume in high-efficiency fabric filter baghouses. The hot dirty gases leave the roaster at about 540°C, are cooled directly by air-tempering to less than 370°C and passed through electrostatic precipitators; or they are cooled indirectly to about 315°C by means of a heat exchanger and passed through hot fabric filter baghouses to remove the suspended calcine dust which is returned to the mill for recovery of the residual gold. The hot clean gases are then air-tempered to between 107°C and 125°C by the addition of cool air. This causes the arsenic trioxide to condense and it is recovered in solid form by warm fabric filter baghouses before the gases are exhausted to the stack.

The efficiency of the arsenic emission control system is dependent on three factors:

(i) the temperature to which the gas is cooled (the fabric filter baghouse operating temperature);
(ii) sufficient retention time between cooling and collection to allow maximum formation of solid arsenic trioxide;
(iii) the fabric filter baghouse efficiency and maintenance.

The fabric filter baghouse operating temperature is a major factor in determining the amount of arsenic emitted, since the concentration of gaseous arsenic trioxide increases with temperature. It is necessary to operate the warm fabric filter baghouses at a temperature above the acid dew point. The acid dew point is approximately 105°C or less for direct cooling and 125°C or less for indirect cooling, since direct cooling (the introduction of outside air) produces gases with lower water vapour and sulphur oxide concentrations than does indirect cooling. Operation of the fabric filter baghouse below the acid dew point causes the formation of an acid mist. This combines with the arsenic trioxide to form a "mud" on the bags of the fabric filter and, as a result, the pressure drop increases, the gas flow decreases and the cleaning cycle is ineffective.

A high level of maintenance is required on the fabric filter baghouses in order to maintain optimum operating conditions and minimize arsenic emissions. This includes the replacement of torn or damaged bags on a routine basis.

7.2.2 Emission Control Systems for Gold Roasting Operations. Dual stages of particulate collection are used to control emissions from roasters processing high arsenic concentrates. First, the roaster off-gas is cooled to between 315°C and 370°C at which point the hot collection stage captures the suspended particulates which contain some gold. This gives optimum particulate collection while the arsenic remains in the vapour state in the cleaned gases. Dust collected is subsequently processed for gold recovery.

Second, the hot particulate-free off-gases are then cooled to between 107°C and 125°C by air-tempering (adding outside air), to sublime most of the arsenic vapour to particulate form. The gases are then passed through fabric filter baghouses which collect the condensed arsenic fume. The cleaned gas is exhausted up the stack and the captured fume is transferred to safe storage areas or packaged and shipped to customers.

Two different systems are now in use to control arsenic emissions from gold roasting operations, the direct cooling method and the indirect cooling method.

Two of the mines roasting high arsenic concentrates use the direct cooling method. Controlled amounts of tempering air are added to cool the off-gases of the roaster to between 315°C and 370°C after which they pass through electrostatic precipitators to remove the suspended particulates. The cleaned gases are cooled to about 105°C by mixing in outside air and then passed through a warm fabric filter baghouse which collects the condensed fume and controls the arsenic emissions.

One mine uses the indirect cooling method. The roaster off-gases pass through a heat exchanger which reduces the temperature to about 315°C. The suspended particulates are removed in a hot fabric filter baghouse and join the roaster calcine to be processed for gold recovery. Controlled amounts of outside air are added to the cleaned gases to reduce the temperature to about 145°C, at which point the condensed arsenic fume is collected in two warm fabric filter baghouses. The exhaust stream passes through an additional clean-up fabric filter baghouse operated at a minimum temperature of 125°C. The cleaned gas enters the heat exchanger where it is reheated and then exhausted up the stack. The arsenic trioxide resulting from this control method is of higher purity and is more readily saleable.

The flue gas acid dew point is concentration dependent. In the direct cooling method, the dew point is below 105°C. Higher dew points are experienced by the company using the indirect cooling method. This results from the treatment of higher sulphur feed, and higher concentrations of water, sulphur dioxide and sulphur trioxide present in the flue gas while using a lower proportion of direct cooling air. The final clean-up fabric filter baghouse should not be operated below 125°C, and while the concentration of arsenic emitted is thus higher, the volume of gas emitted per unit of concentrate roasted is smaller.

Fabric filter baghouses are the preferred emission control devices. A fifth company, formerly roasting high arsenic gold concentrates, used a wet scrubber in place of a fabric filter baghouse. This produced arsenic in a slurry form which was more difficult to store and which would have required additional processing before sale. Arsenic also dissolved in solution, creating a potential water pollution problem. For these reasons, the use of scrubbers is no longer acceptable.

7.3 Roaster Product Handling Systems

Emissions of particulates and arsenic into the atmosphere can occur during handling of hot roaster calcine or particulates collected in the cyclones, waste heat boiler, electrostatic precipitators, and/or hot fabric filter baghouses. Measures are taken to prevent this from happening. The products are discharged from the hoppers into sealed water quenching tanks. The solids are introduced via a pipe immersed below the water level to avoid freeboard dusting. Water also is sprayed into the pipe and tank freeboard to prevent dust from escaping. Steam from the tanks is vented to the atmosphere by a discharge pipe. Tight seals are maintained on all the equipment to prevent leaks to the atmosphere.

7.4 Arsenic By-Product Conveying Systems

In the past, by-product arsenic trioxide dust from roasters processing high arsenic concentrates was conveyed pneumatically to sealed storage areas. Emissions were avoided by maintaining tight seals and returning the conveying air from the storage area to the warm fabric filter baghouse, where the air was filtered before being exhausted up the main stack.

Higher purity arsenic trioxide resulting from the pollution control system using indirect cooling is readily saleable, and is packaged directly from the warm fabric filter baghouses into sealed containers and shipped to customers.

Improved market conditions for arsenic will allow some of the arsenic trioxide produced in direct cooling systems to be sold. Processes for upgrading this product are being developed by several companies so that all the arsenic trioxide recovered can be sold.

7.5 Evaluation of Control Technology

7.5.1 **General.** High degrees of arsenic containment can be achieved for roasters processing high arsenic concentrates by cooling the gas, to condense arsenic trioxide vapours, and passing it through fabric filter baghouses to collect the solid arsenic trioxide. Tests at a recently installed facility indicated that approximately 99.9% of the arsenic in the roaster feed was recovered as solid arsenic trioxide.

An analysis of control systems suggests that plants using direct cooling are capable of achieving emission levels lower than 20 mg/sm^3, and that emission levels lower than 75 mg/sm^3 can be achieved by indirect cooling systems*.

The proposed limit of 20 mg/sm^3 for plants using direct cooling will result in a containment of 99.6% to 99.75% of the arsenic contained in the roaster feed. A limit of 75 mg/sm^3 is proposed for plants using indirect cooling as a result of the increased operating temperature required because of the higher acid dew point of the gases. More arsenic trioxide in vapour form will be contained in the gases passing through the filter but the much smaller volume emitted per unit of concentrate roasted will result in over 99.5% containment of the arsenic in the roaster feed.

7.5.2 Costs of Pollution Control. The cost of adding equipment to existing roasters to meet the required environmental standards cannot be estimated precisely. The costs will vary for individual plants since they are influenced by factors such as plant size, off-gas rate, location, equipment already in place, upgrading and improvements, dust and arsenic handling and space available for the new equipment.

A direct cooling pollution control system was installed at Campbell Red Lake Mines in 1974 at a cost of $1.1 million. Another $225 000 was spent on underground storage facilities for the collected arsenic.

An indirect cooling (dual baghouse) system was installed at Dickenson Mines in 1976 at a cost of $1.5 million. It is estimated that a further expenditure of $200 000 will be necessary to achieve the required containment.

It is conceivable that new gold mines might be faced with arsenic emission problems. Either of the control technologies would require an initial investment of about $2 million with smaller amounts in subsequent years.

The report, "Socio-Economic Impact Analysis of Proposed Federal Regulation on Arsenic from Gold Roasting", published by Environment Canada, is available upon request. It also contains detailed cost estimates for equipment required in order for the affected mines to meet the proposed regulations.

---

*sm^3 = standard cubic metre.

7.5.3 Reduction in National Emission Levels. If all plants comply with the proposed regulations, it is estimated that the total arsenic emissions from gold roasting operations would be reduced to 28 tons per year. This would represent a reduction in emissions of 98.5% from the amount estimated in the national arsenic emission inventory for 1972 (1) (Table 2).

REFERENCES

1. Environment Canada, "National Inventory of Sources and Emissions of Zinc, Cadmium and Arsenic, Summary of Emissions for 1972," Report EPS 3-AP-76-3, June 1976.

2. Environment Canada, "Socio-Economic Impact Analysis of Proposed Federal Regulation on Arsenic from Gold Roasting," Planning, Policy and Analysis Branch, EPS, May 1979.

3. Behrens, R. and G. Rosenblatt, "Vapour Pressure of Arsenolite," J. Chem. Thermodynamics, Vol. 4 (1972) p. 175.

4. Murray, J.J., Roltie, R.F. and C. Pupp, "Vapour Pressures and Enthalpies of Sublimation of Five Polycyclic Aromatic Hydrocarbons," Can. J. Chem., Vol. 52, No. 4 (1974) pp. 557-563.

5. Roberts, J.S., "Controlling Roaster Off-Gases at Campbell Red Lake Mines," Can. Mining Journal, Vol. 97, No. 7 (1976) pp. 854-56.

6. Brotherson, A.E., "Development of Arsenic Measurement Method on Gold Roaster Operation at Campbell Red Lake," EPS Internal Report, 1977.

7. Personal communications with officials of the four companies roasting gold concentrates.