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Developments in Emission Control Technologies/Strategies: A Case Study

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Initiated by government legislation and encouraged by economic factors (Box 21.1), developments in emission control technologies and strategies are taking place at an accelerating pace within industrialized nations. The sophistication of these developments is increasing at the same time. However, global application of the technology is lacking, particularly in developing countries.

To meet more stringent environmental protection regulations, many industries are developing new and usually very broad-scale emission control technologies and strategies. As illustrated in the following case study, such development can achieve environmental protection goals while at the same time produce economic benefits for industry.

Strategies

Early control strategies largely adopted the approach that "dilution was the solution to pollution." One example of this approach was the installation of tall stacks, such as the study company's 381-m stack. These stacks were designed to improve the local air quality by increased dispersion of waste gases.

To date, most pollution control technologies and strategies have been directed at intercepting pollutants before they leave the plant, a so-called end of pipe solution to environmental problems (AWMA 1992). The standard air quality control technologies of baghouses, cyclones, electrostatic precipitators, and scrubbers are examples of such efforts. However, these approaches can be considered "react and cure" modes of developing environmental control technology and strategies (Watson 1992). In the future, a proactive approach must be taken to prevent or at least reduce environmental pollutants at the source. The case study illustrates this concept in its infancy.

Pollution abatement programs need not be limited to dealing only with environmental problems at a particular industrial site. In fact, once they are developed, they can be profitably expanded to solve other companies' problems as well. The case study includes an example.

Public Awareness and Development of Legislation

In the 1960s and 1970s, the deteriorating state of the global environment led to a public outcry for action. The period saw the birth of vocal non-government environmental organizations such as Greenpeace. The study of environmental sciences was also added to the educational system during this period. Along with increased media coverage of environmental issues, these factors combined to create

Box 21.1. Trading in Pollution Permits

As part of the sulfur dioxide emission reduction program established through the 1990 revisions of the U.S. Clean Air Act, an innovative market-driven process of pollution control was established in the United States. To begin the process of initiating trading in pollution permits, the government establishes a cap on the total emissions of a pollutant in a given airshed. This cap is divided into multiple equal units of the pollutant. The release of each unit of a pollutant within the given airshed requires a permit for that amount.

All emitters of the pollutant in the airshed would need to acquire enough permits to match their output. Permits would be transferable at prices determined in a free market. New industries would need to purchase existing permits. Supply-and-demand economics would drive emission reductions. These reductions would continue until the cost of additional reduction equals the price of a pollution permit.

Interested groups could purchase permits and remove them from the free market. This would drive further pollution reduction in the airshed. The government could also lower emissions in the airshed by reducing the unit size of each permit without increasing the number of permits (Lee 1993). Not all companies agree with this approach, considering it buying the right to pollute.

pressure on the various levels of governments to act on environmental problems.

Governments around the globe began to develop, modify, and enforce new and broader environmental legislation (IUAPPA 1991). In 1967, the Ontario government introduced the Environmental Protection Act, which provided the framework for further legislation dealing with specific environmental problems. An example of this type of legislation was the Countdown Acid Rain program, discussed in Chapter 4, which mandated the reduction of acid gas emission from selected companies and facilities in Ontario. The 1990 revisions of the U.S. Clean Air Act contain similar provisions for emissions controls but also introduced innovative economic incentives to achieve them (Box 21.1). The case study presented here demonstrates how one company, Inco Limited, responded to these pressures to reduce sulfur dioxide emissions at its Copper Cliff smelter.

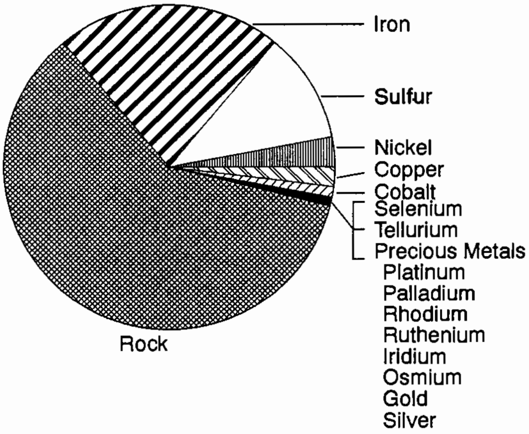
Inco Limited's Sulfur Dioxide Emission Reduction Program

Inco's Sudbury operations are one of the world's largest facilities for the integrated mining, milling, smelting, and refining of sulfide ore, with current production rates of 115,000 tonnes nickel and 120,000 tonnes copper per year. The company is also a significant producer of cobalt, selenium, tellurium, gold, silver, platinum group metals, liquid sulfur dioxide, and sulfuric acid as byproducts of nickel and copper processing (Figure 21.1). The company mines approximately 12 million tonnes of ore yearly to achieve these production levels.

Ore Chemistry and Composition

The Sudbury ore is approximately 25% mixed iron, copper, and nickel sulfide minerals in a 6:1:1 ratio, respectively. The remainder, which is waste rock or "gangue," is discarded as "tailings." Most of the ore's sulfur content is associated with the iron minerals. The copper (chalcopyrite) and nickel (pentlandite) minerals contain approximately equal amounts of metal and sulfur. The copper mineral is easily separated from the ore, but the nickel mineral is finely spread throughout the iron minerals. A small fraction of the nickel is also tied up in the crystal structure of the iron minerals. Therefore, large quantities of waste iron minerals must be processed to extract nickel, and for each tonne of nickel produced, 8 tonnes of sulfur will be processed (Fig. 21.1). These facts affect both the milling and smelting processes.

FIGURE 21.1. Typical Sudbury district ore analysis.



Sulfur, Smelting, and Sulfur Dioxide

As described in Chapter 2, the early mining companies in the Sudbury area used "roast yards" to make a crude matte out of bulk sulfide ore. Large volumes of high-concentration sulfur dioxide gas were released at ground level from the roast yards. The consumption of wood for the roast yards and low-level release of sulfur dioxide compounded existing vegetation damage caused by clear-cut forestry (Chapter 2).

In 1929, the first Inco smelter was built at Copper Cliff, and the use of "roast yards" stopped. As the size of the smelter increased and the demand for products grew, the sulfur dioxide emissions increased correspondingly. Inco's sulfur dioxide emissions peaked at more than 5600 tonnes/day or about 2 million tonnes/year in the early 1960s. At this time, almost all the smelter fumes were released into the atmosphere through three approximately 150-m stacks. Lesser amounts also escaped through vents in the roof of the smelter as fugitive emissions.

The resulting ground-level sulfur dioxide fumigations created serious local air quality conditions and contributed to widespread vegetation damage. Growing public awareness and concern regarding the sulfur dioxide pollution problem led to pressure on all levels of government toward control and abatement legislation aimed specifically at Inco's sulfur dioxide emissions.

Sulfur Dioxide Emissions Control Strategies

Three strategies are available to reduce the sulfur dioxide emissions that are the result of smelting of sulfide ore:

1. remove sulfur before processing in the smelting furnaces
2. recover the sulfur dioxide as marketable products such as elemental sulfur, liquid sulfur dioxide, and sulfuric acid
3. use a process such as a hydrometallurgical process that does not convert sulfur to sulfur dioxide

Strategy 1—Iron Mineral Rejection

Much of Inco's current effort at sulfur dioxide emissions reduction is directed at sulfur removal before smelting. This has largely been achieved through more efficient separation of the waste high sulfur iron minerals from the valuable copper and nickel minerals at the milling stage of ore processing. Improved milling techniques, developed after many years of research, have allowed for increased rejection of the iron minerals while minimizing the loss of the valuable copper and nickel minerals. Adoption of this separation approach reduces sulfur dioxide emissions by removing approximately 67% of the original sulfur in the ore before the ore enters the smelting furnaces.

Strategy 2—Liquid Sulfur Dioxide and Sulfuric Acid Production

Inco began implementing the second emission reduction strategy in the early 1930s when a 400-tonnes/day sulfuric acid plant was constructed at the Copper Cliff smelter. More and larger capacity acid plants were built at another company facility in response to a growing market. Peak acid production capacity was 3000 tonnes/day. Sulfuric acid production now plays a key role in the company's ongoing sulfur dioxide abatement program.

In 1952, liquid sulfur dioxide production began at the Copper Cliff smelter using standard compression and refrigeration technology. The plant has a production capacity of about 400 tonnes/day, with an average annual production of about 80,000 tonnes. The product is in high demand by many different users such as specialty chemical manufacturers, the largest single market being the pulp and paper industry.

To produce elemental sulfur from the sulfur dioxide is not economically feasible with current technology at the Copper Cliff smelter. Moreover, the process requires extensive use of fossil fuels. Combustion of fossil fuels generates large amounts of carbon dioxide, a greenhouse gas, and nitrogen oxide, an acid-forming gas. The increased emissions of nitrogen oxide would therefore defeat a prime objective of the sulfur dioxide abatement program—to reduce acid rain.

Strategy 3—Alternative Processes

The third strategy, to use a chemical leaching or extraction method (hydrometallurgical processes), that does not produce sulfur dioxide is not technically or economically feasible for the Copper Cliff operations. The capital costs and technological problems associated with the hydrometallurgical processes are too great. The current processes used in these methods would also result in the production of vast quantities of unwanted waste materials such as iron hydroxide and calcium sulfate (gypsum).

The gypsum produced during chemical extraction of metals would not meet market requirements in density and chemistry. Similarly, waste iron hydroxide would be of poor quality (i.e., particle size and contamination with other material). Given the tonnage of ore used in the Copper Cliff operation, these unusable waste products would then require a large dedicated disposal site, which simply transfers the pollution liability from air to land. Such transfers of environmental problems from one site to another, called "media transfers," cannot be considered true environmental solutions (see Chapter 22).

History of Sulfur Dioxide Abatement Efforts at Copper Cliff

Smelting Process Changes

About 1950, Inco and Outkumpu Oy, the Finnish mining company, developed separate flash furnace technologies for use in copper sulfide smelting. This new technology benefited the mining companies in two ways.

1. Once the furnace was brought up to operating temperature by fossil fuel burners, flash smelting became an "autogenous" process. Heat released by the combustion of sulfur in the feed into sulfur dioxide replaced that provided by fossil fuels in the earlier process. The incoming feed provided the flow of sulfur fuel to maintain the smelting reactions.
2. Pure oxygen was used for combustion. As a result, the offgas from the flash furnace contains about 70–75% sulfur dioxide. No carbon dioxide and minimal nitrogen oxides were coproduced. This high sulfur dioxide strength offgas allowed the use of existing fixation technology to capture, as marketable products, sulfur dioxide that would otherwise have been released to atmosphere. Liquid sulfur dioxide was produced by compression and refrigeration.

3. **Process efficiency was increased while minimizing the production of nitrogen oxides. Fossil fuel consumption use was kept to a minimum, with the main use being heating the furnace to operating temperature. The minimal need to use fossil fuel enhanced the operations' economic competitiveness.**

Iron Processing

To maximize the recovery of copper and nickel from the ore, the iron minerals were processed through the smelter until 1954. This increased the environmental liability of the operation through increased production of sulfur dioxide and created a waste storage problem. The unwanted iron also had to be removed from the furnaces as a waste iron silicate or "slag." Because the furnaces have a finite capacity, treating and handling unwanted iron limits the production rates of nickel and copper. Increasing demand for the company's metal products pushed the development of a separate treatment process for the iron minerals to remove this load from the smelter. Improved techniques and technology allowed more of the iron minerals to be rejected at the milling stage.

In 1954, a nickel bearing (about 0.8–1.0%), high sulfur (about 32%) fraction of the rejected iron minerals was routed to the new iron ore recovery plant. The first stage in the new process was the controlled roasting of the iron minerals down to about 0.5% sulfur, using fluid bed roaster technology. These roasters generated offgases at about 10–12% sulfur dioxide, which is ideal for conversion into sulfuric acid. The 400-tonnes/day sulfuric acid plant was moved over to this new facility from the Copper Cliff smelter in 1958. Two new acid plants were constructed. Final total production capacity was 3000 tonnes/day of 100% sulfuric acid equivalent. The various strengths of sulfuric acid and grades of sulfuric acid concentrate (oleum) produced by these plants found ready and varied markets, such as the Elliot Lake uranium mines (located 150 km west of Sudbury), lead acid battery makers, and detergent manufacturers. The second stage was removal of the nickel, cobalt, and a residual copper via an ammonia-carbon dioxide leach. The remaining iron oxide was pelletized for sale to the steel industry.

Recent Control Technologies and Strategies

Early company developments in environmental control technologies and strategies were driven by economics. The early 1970s saw the establishment of government regulations enforcing environmental control initiatives. To meet these initiatives, the pace of technological developments began to accelerate.

To meet these more stringent environmental requirements, Inco designed a comprehensive sulfur dioxide abatement program in the mid-1980s. At a cost of implementation of more than $Can 600 million, it became one of the largest industrial pollution abatement programs in the world. The following is a brief description of this new program.

Rather than attempt to use entirely new technology, the company adapted the proven copper smelting flash furnace to treat a combined nickel-copper concentrate (Figs. 21.2 and 21.3). From the new bulk flash furnaces, a portion of the high-strength sulfur dioxide gas is then directly compressed into liquid sulfur dioxide while the remainder is diluted with air to meet the requirements of a new 2900 tonnes/day (100% sulfuric acid basis) sulfuric acid plant (Fig. 21.4). The sulfuric acid plant is crucial to achieving legislated sulfur dioxide emission limits. By the mid-1980s, the economics changed and the company was losing money by making sulfuric acid at the iron ore recovery plant. However, the facility remained in operation to maintain the company's share of the sulfuric acid market. The company needed this market share for the sulfuric acid that would be produced to meet the government's 1994 emission limit. The old facility was closed in May 1991 when the new acid plant at the smelter began operation.

The finished flash furnace product (Bessemer matte) is separated into a nickel sulfide

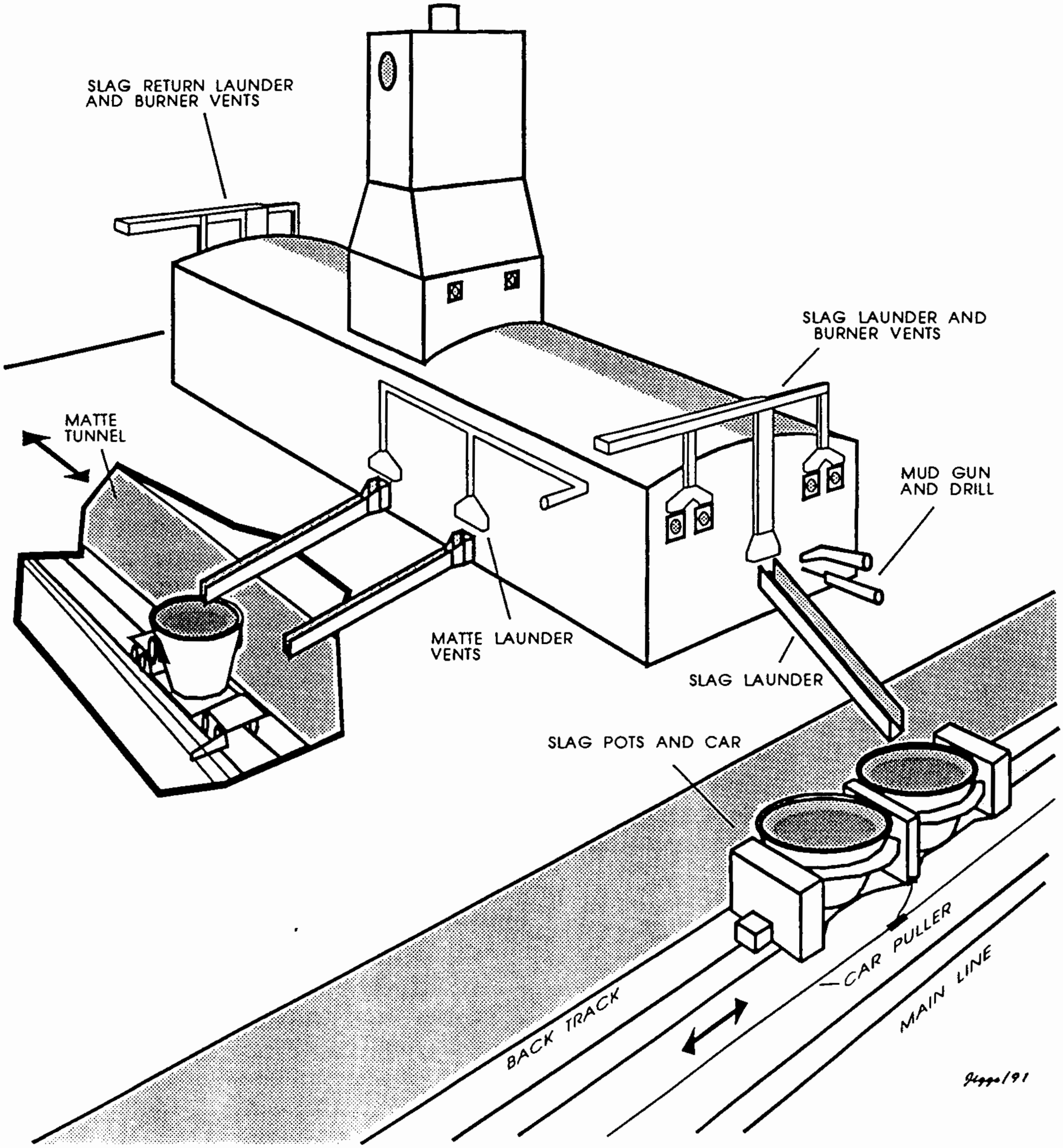


Figure 21.2. Inco Copper Cliff smelter flash furnace—external view of northeast side.

fraction and a pure copper sulfide. The copper sulfide is then treated in a proprietary melter, which also produces a high sulfur dioxide strength offgas (Fig. 21.5). The melter offgas is combined with those of the bulk flash furnaces for fixation as either liquid sulfur dioxide or sulfuric acid.

In addition to the environmental benefits of the new smelter, there are considerable economic benefits from the new facility. Economic benefits consist of lowered energy costs, increased worker productivity, and the conversion of former emitted sulfur dioxide gases into salable products. The payback time for the

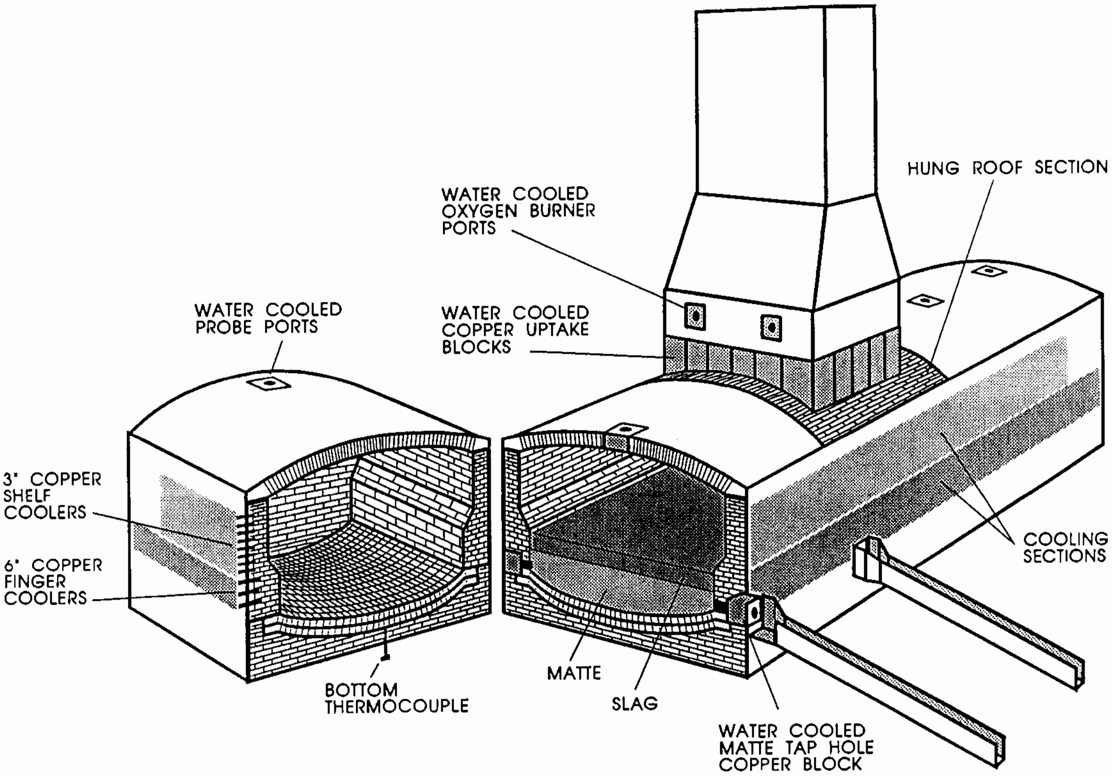


FIGURE 21.3. Inco Copper Cliff smelter flash furnace—internal view of refractory detail and cooling equipment.

capital expenditures for the construction of the new facilities and operating procedures ($600 million) has been estimated to be approximately 10 years, based on projected energy and worker productivity gains and reductions in maintenance costs at the new operation (Table 21.1).

Environmental Monitoring

In the early 1970s, a voluntary strategy to control ground-level concentrations of sulfur dioxide was initiated. A network of Ontario Ministry of Environment and Energy-owned and -operated fixed monitoring stations was installed to continuously monitor ground-level sulfur dioxide concentrations. In addition to the government stations, company-owned and -operated sulfur dioxide emission monitoring vehicles patrol and measure ground-level sulfur dioxide concentrations.

The company also operates a meterological station. Data gathered at this station are input to computer models. The computer models calculate a maximum allowable sulfur dioxide emission rate for the Copper Cliff smelter complex, which would theoretically keep ground-level sulfur dioxide concentrations below the government limits. These data are transferred to operators at the smelter who adjust the processes so that the average sulfur dioxide emission rates do not exceed the given value.

Air quality data from the governments fixed stations and the company's mobile monitors along with continuously updated meteorological data are used to adjust the smelter's sulfur dioxide emission rates to meet required ground-level concentrations. This combination of company and government monitoring for emissions control is unique to Sudbury.

In 1978, the government passed legislation that changed the formerly voluntary program into a legally binding abatement program and

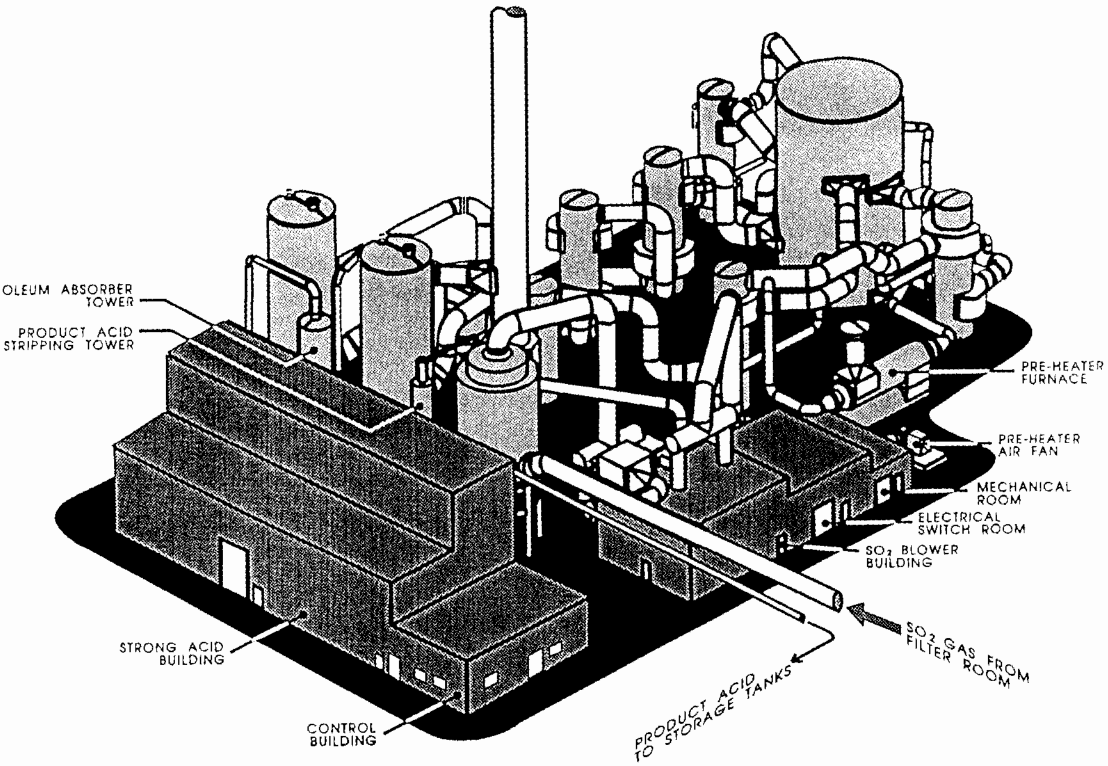


FIGURE 21.4. Inco Copper Cliff smelter—isometric view of acid plant.

imposed limits on sulfur dioxide emissions. To achieve these requirements, ground-level sulfur dioxide concentrations are measured every 5 minutes. Running averages of these readings are used to determine compliance with the government regulations. The government has imposed two different limits on emissions from the Copper Cliff smelter:

1. **The first limit is on emissions from the 381-m stack, either alone or in combination with other company stack emissions. The running hourly average of consecutive 5-min ground-level sulfur dioxide concentration readings caused by these emissions must not exceed 0.50 ppm.**
2. **The second limit concerns fugitive emissions from the complex. The running half-hour average of consecutive 5-min ground-level sulfur dioxide concentration readings caused by these emissions must not exceed 0.30 ppm.**

In addition to ground-level concentration limits, annual limits on sulfur dioxide emissions from all the company's Copper Cliff facilities were imposed by the government starting in the early 1970s. These limits have decreased in stages over the years, as described in Chapter 4. An annual sulfur dioxide emission limit of 265,000 tonnes from all of Inco's Sudbury operations was imposed effective for 1994. This represents a 90% reduction from the peak 1960 emission values.

Discussion

Given current technology and economics, the smelting of sulfide ore will inevitably result in the release of sulfur dioxide. Fixation of sulfur dioxide as liquid sulfur dioxide or sulfuric acid is a viable environmental protection strategy and can be economically favorable. It is argued that the sulfur content of these chemicals

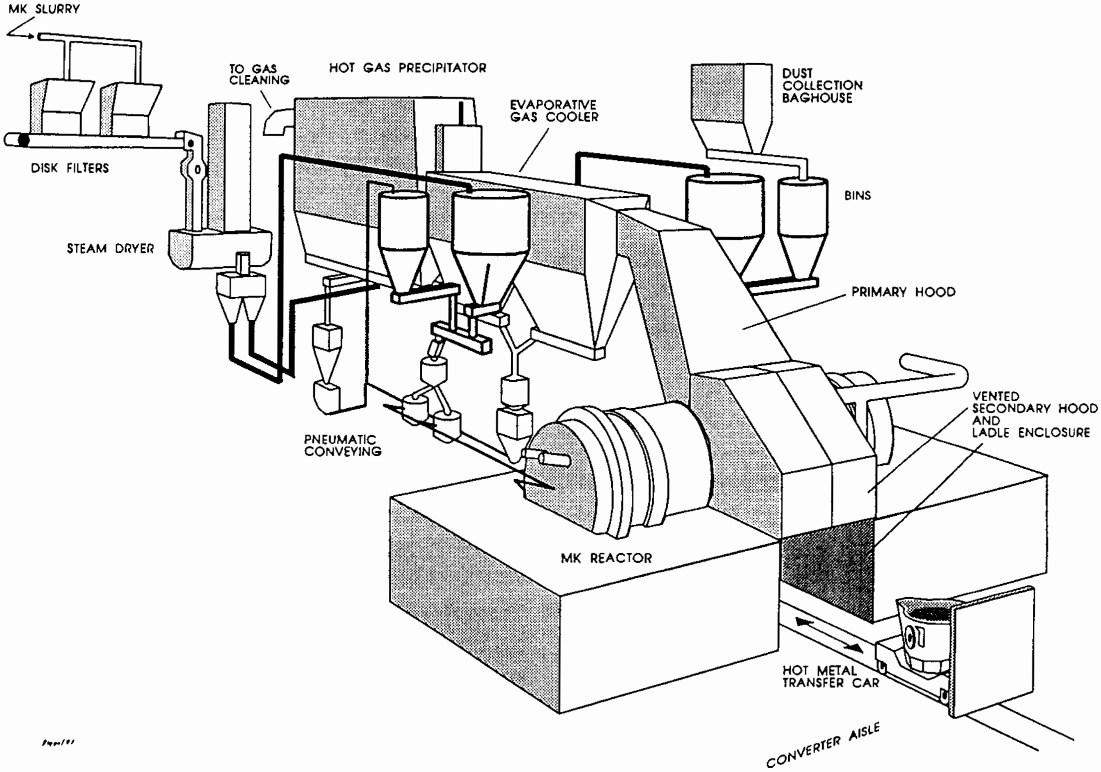


FIGURE 21.5. Inco Copper Cliff smelter—general arrangement of copper sulfide (MK) melter.

eventually ends up being discharged into the natural environment by consumers. However, the opportunity for pollution prevention is much greater with these solid forms than is possible with gaseous release as sulfur dioxide. One of the larger markets for sulfuric acid is for making phosphate fertilizer. Through the manufacture of fertilizers, the sulfur that previously became a pollutant, sulfur dioxide, can be used to produce a product that stimulates, rather than inhibits, plant growth.

Most other treatment methods involve some form of "scrubbing," which generates solid and/or liquid wastes. The amount of the secondary waste(s) that would be generated from a scrubbing creates a different set of pollution problems. Disposal of the wastes, such as a low-quality gypsum ($CaSO_4$), unsuitable for

TABLE 21.1. Energy and Productivity Gains from Implementation of the Sulfur Dioxide Emissions Abatement Program at Inco Limited Copper Cliff Smelter[a]

	Energy consumption (BTU/lb Ni+Cu)	Productivity lbs Ni+Cu per manshift	Acid Production (100% sulfuric acid basis) (tonnes per annum)
1980	15,500	1440	480,000
1989	10,000	2600	580,000
1994	4500	3030	720,000

[a] Assumes that liquid sulfur dioxide production remains at 80,000 tonnes/year.

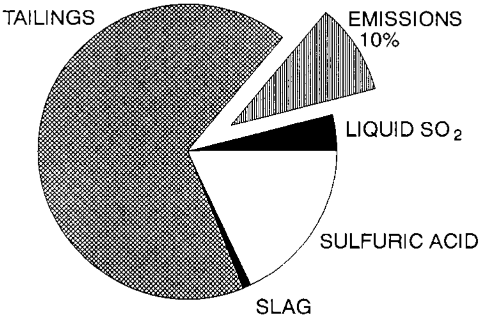


FIGURE 21.6. Inco Limited sulfur distribution—1994.

marketing, would add to present tailings disposal problems and result in the need for additional expensive disposal area. Rehabilitation of these additional disposal areas would then be required under current government legislation. While reducing the atmospheric problem, increased sulfur disposal to tailings can pose a storage and water treatment problem under current technology. Progress and remaining challenges in this field are the subjects of the next chapter (Chapter 22).

Recycling Metals: Converting a Problem into a Profit

Economic incentives can readily convert an environmental pollutant into a valuable resource. Inco Limited has become the world's largest recycler of automobile catalytic converters for the platinum and palladium content. This converts a potential environmental problem for one manufacturer, the automobile industry, into a valuable product for another company, the metal refining industry.

Most metallurgical smelters and refineries have implemented some type of recycling of scrap or waste materials produced both within the company's operations and from other producers. Substantial savings through reduced energy and processing costs can be realized by processing recycled materials while at the same time diverting waste materials from landfill sites and other such dumping locations. The recycling of aluminum cans is a prime example in which considerable economic benefits can be achieved in comparison with continued use of only the original raw materials.

Case Study Summary

Driven originally by government legislation and realizing the potential economic benefits to be derived, Inco Limited, the company in this case history, devised a program of emission control technologies and strategies designed to meet a wide variety of social, economic, and environmental needs. No single technology or strategy would have been effective in meeting these diverse needs. Only a well-integrated, multifaceted approach to the development of environmental control technologies and strategies could have achieved its high degree of success.

Inco Limited now contains 90% of the sulfur in mined ore, which is the reverse of the 1960s when 90% of the ore's sulfur was emitted to the atmosphere as sulfur dioxide. At yearend 1994, only 10% of the ore's sulfur content was emitted to the atmosphere as sulfur dioxide, a reduction of 1,735,000 tonnes/year in sulfur dioxide emissions (Fig. 21.6).

The company is now deriving the benefits of marketing its experience and technology internationally. Most applications of these technologies have taken place in the industrialized nations. Some applications of improved technology are occurring in developing nations such as Chile, where the national copper company has installed Inco's flash furnace technology.

Global Comparisons

The output of the nickel industry in Russia is similar to that of Inco Limited and Falconbridge Limited combined. Based on the referenced literature and the experiences of visiting scientists and managers, Russian facilities are at the stage of development in emission control technologies/strategies that Inco was in the early 1960s. The Norilsk Mining and Metallurgical Combine nickel facility has now become the world's largest point source of sulfur dioxide, with 1987 emissions estimated to be 2.4 million tonnes (Saunders 1990; Peterson 1993). The current economic uncertainty in Russia diminishes the likelihood that effective abatement technologies and strategies will soon be implemented. Economic and political problems in many of the former East Bloc countries also limit their ability to deal effectively with widespread environmental problems. Similar problems and fears exist in Asian countries, particularly China, where industrial development is occurring rapidly through the use of high-sulfur coal (Smil 1993). In China, approximately 900 million tonnes of coal per year is burnt to supply 75% of its energy needs. Only a small number of the most modern, large, coal-fired plants are equipped with electrostatic precipitators. Most smaller boilers have only mechanical dust separators. Millions of small sources are completely uncontrolled (Smil 1993).

Technology transfer to these needy nations is imperative if we are to meet the goals of sustainable development while reducing global environmental degradation from anthropogenic sources. Control systems, the norm in industrialized nations, must be implemented throughout the world to prevent further occurrences of the Sudbury experience.

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