

**Arsenic Emission Control  
from Pyrometallurgical Operations  
(Response to Questions by Royal Oak)**

prepared for:  
Environment Canada  
Conservation and Protection  
Western and Northern Region

Nov. 8, 1996

**W.R. HATCH ENGINEERING LTD.**

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**BRAMPTON, ONTARIO, CANADA**

## 1.0 Introduction

The report "Arsenic Emission Control from Pyrometallurgical Operations" was submitted to Environment Canada by W. R. Hatch Engineering Ltd. under Project NO. K2331-5-0001.

Questions raised by Royal Oak Mines, the operators of Giant Yellowknife Mines were submitted to us for a response (Appendix III). These questions related primarily to two areas. (1) The technical viability of the options discussed as an addition to their current gas cleaning system and (2) the process and costs for disposing of arsenic from the final gas cleaning stage.

We have followed up and provided operating data for some of the technologies presented in our report. Where possible, quantitative data supporting the use of the identified technologies to remove arsenic from the stack gas is given. Further comments on the advantages of piloting studies are included.

The technologies and associated costs for disposal of arsenical solutions or slurries from tail gas scrubbers or wet ESP's is discussed.

An error in quoting arsenic concentrations achievable by the technologies presented was noted in Royal Oaks queries to Environment Canada (App.1). In fact, claims of 0.1mg. As/m<sup>3</sup> were not made in our report, but a less than 1.0 mg As/m<sup>3</sup> as being consistently attainable.

## 2.0 Disposal of Arsenical Solutions from Tail Gas Scrubbing

### Arsenic Collection in Tail Gas Cleaning

The introduction of tail gas cleaning (scrubbing, wet ESP etc.) would effectively reduce particulate concentrations in the gas from approximately 25 mg/m<sup>3</sup> to less than 1.0 mg/m<sup>3</sup>. Based on a gas flow of 45000 m<sup>3</sup>/h the amount of arsenic collected would approximate 0.74 kg/h. (18 kg/day) This arsenic would be present in solution or slurry form.

The solution would be acidic (sulphurous acid) and the As<sub>2</sub>O<sub>3</sub> solubility would be reduced to below 10.g As<sub>2</sub>O<sub>3</sub> per litre.

Approximately 26 kg As<sub>2</sub>O<sub>3</sub> per day would require disposal or treatment by the proposed gas cleaning system. This could be discharged as solution (approximately 3m<sup>3</sup>/day) or as a slurry of considerably less volume.

## Alternative Treatment Processes for Arsenic Disposal

The alternative processes applicable to the treatment of this scrubber discharge fall into two categories:

1. Those which integrate the treatment with existing processes at the Giant Mill.
2. Dedicated treatment processes for rendering the arsenic suitable for discharge with existing tailings.

It was assumed in our report that Giant Yellowknife would strongly prefer options under No.1 above and that the incremental costs of processing this amount of arsenic involved would not be significant to the preliminary cost estimated. Alternatives are best evaluated by Royal Oak who are in a preferred position to assess alternatives in the context of their current operation. The following options should however be given due consideration based on our knowledge of the process.

### 2.1 Integrated Treatment Processes

Preferred treatment processing would involve the discharge of scrubber bleed solution with current arsenical effluents to the tailings pond. Mine water, calcine wash solutions, cottrell dust circuit barren solutions along with other arsenical streams are currently discharged. The volumes and concentrations of these streams were reported by Giant Mine personnel (2). In the order of 600 kg per day of arsenic are reportedly discharged to the tailings pond in an effluent volume of 1,075,000 imp. gal/day. A significant amount of arsenic is stabilized in the pond. Tailings pond effluent treatment, installed in 1981 included an iron arsenate precipitation stage effectively meeting environmental discharge criteria.

An alternative to this would be to recycle the scrubber slurry to the roaster which would effectively incorporate the scrubber  $As_2O_3$  with the  $As_2O_3$  baghouse dust currently being stored underground. This would involve recycling about 1.0 cubic meter per day of slurry to the roaster.

At a roaster feed rate of 160 t/day at 78% solids, approximately 45  $m^3$ /day of solution are fed to the roaster. The 26 kg/d of  $As_2O_3$  could be added in slurry form to the roaster feed tanks. The overall slurry requirements for a suitable heat balance could be calculated. This option would utilize existing facilities for disposal of the arsenic bled from the tail gas scrubber. The addition of 25 kg/day to the current 9000 kg/day would not affect current disposal technology or costs. This alternative would require assessment relating to heat balance calculations and testing in the plant.

## 2.2 Dedicated Treatment Process for Scrubber Bleed

This alternative is considered the least cost effective for the treatment of scrubber discharge. The process would incorporate a mini-circuit similar to that already in existence at the Giant Mill. Arsenic would be precipitated as iron arsenate (scorodite) and discharged with the tailings. The size of a dedicated precipitation circuit would be extremely small even though all the equipment for adding lime and iron sulphate, stirred reactors, thickeners etc. would be required.

The circuit could be readily sized and capital costs determined, since the process is proven and used at the Giant Mine and at various other sites treating arsenic bearing solutions.

## 2.3 Estimated Costs for Scrubber Discharge Treatment

Costs for treatment of tailings pond effluent have been reported for the years 1981 to 1986.(2) The total costs (labour and materials) in 1986 were approximately \$600,000 per year treating a total effluent volume of 275,000,000 Imp. gal over a 5 month period and precipitating up to 20 tonnes of arsenic per year.

Using Marshall and Swift cost indices, current 1996 costs would be in the area of \$780,000 per year.

Although the incremental volume of solution for scrubber discharge and treatment is insignificant there would be the added costs associated with the lime, chlorine and iron units.

Assuming current arsenic fixation in the tailings pond we estimate that the incremental operating cost for effluent treatment would be in the order of \$22,000 per year.

Significant capital costs would not be required for this treatment alternative.

A more detailed operating cost estimate could be worked out based on arsenic balances and current cost data available at the Giant Mine.

## 3.0 LEVEL OF TECHNOLOGICAL DEVELOPMENT OF THE PROCESSES IDENTIFIED

The report provided to Environment Canada in February 1996, identified a variety of examples of metallurgical processes which control arsenic emissions to various degrees. Examples of gas cleaning circuits used to control arsenic emissions which were

reported in the February report are shown in Table 3-1. A number of the operations cited in the report successfully remove much of the in-coming arsenic. The examples cited were not described in detail and it is now appropriate to provide some details of the well established gas cleaning circuits that have been developed to remove arsenic and other impurities from process off-gases.

In the original report, most of the examples cited were associated with non-ferrous metallurgical operations. The specific technologies identified as appropriate for an operation such as Giant Yellowknife have successfully cleaned various acid gas process streams. Acid gases bearing  $\text{SO}_2$ ,  $\text{HCl}$  etc. are typically produced from metallurgical processing operations and other chemical processes such as incinerators. A routine method of reducing  $\text{SO}_2$  gas emissions relies on production of sulphuric acid. The technologies identified in the February report are similar in many ways to gas cleaning in sulphuric acid plants. Acid production provides a wealth of examples of gas cleaning of gases similar to those produced at an operation like Giant Yellowknife. Demands for high purity acid have prompted the development of better and better gas cleaning circuits ahead of the sulphuric acid chemical processing part of the plant. Other scrubbing technologies, for example lime and/or limestone, are used to reduced  $\text{SO}_2$  emissions. However, descriptions of these scrubbers will not provide greater assurance as to the viability of the approach identified in the February report and will not be discussed further.

#### Sulphuric Acid Plant Gas Cleaning

Over the past thirty years, hundreds of sulphuric acid plants have been constructed to treat off-gases from metallurgical operations. The gas cleaning sections of these plants have continuously been up-graded in design to achieve the following:

1. Elimination of impurities in the incoming gas to limit the impurities in the final acid. A typical limit for arsenic is 1 ppm in the product acid. The gas cleaning section of the plant must therefore reduce arsenic to about 1 mg/ $\text{Nm}^3$  in the clean gas flowing into the acid production section of the plant.

5.

2. Elimination of impurities in the incoming gas to limit the build-up of dust in the  $\text{SO}_2$  to  $\text{SO}_3$  converter tower. The catalytic packing has to be screened once the build-up of dust increases the pressure drop across the beds to an unacceptable value.
3. Elimination of acid mist in the incoming gas to minimize corrosion.
4. Reduction of the gas temperature to maintain the water balance in the sulphuric acid processing section of the plant. Cooling the gas also reduces the vapour pressure of impurities like arsenic which in turn enhances capture in the gas cleaning circuit.

Gas cleaning is achieved in circuits of various configurations. The primary scrubbing stage can be a venturi, spray or reverse jet type unit. The second stage, for example, can be a packed bed, tray tower or reverse jet type unit. The final section is a wet electrostatic precipitator or mist precipitator. Figure 3-1 illustrates the three typical sections in gas cleaning circuits of sulphuric acid plants. The first stage scrubs and may also quench incoming gases. The second scrubs and conditions the gas to achieve the desired temperature for water balance control. The final wet precipitator stage removes acid mist and additional impurities. The effluent from the gas cleaning section of an acid plant is typically stabilized and disposed of as discussed in Section 2 of this report. Figure 3-1 shows the percentage of the incoming arsenic typically removed in the various stages of the gas cleaning section of a sulphuric acid plant. The scrubbing stages combined remove over 90 percent while the mist precipitator takes out 99 percent of the incoming arsenic. Overall removal is greater than 99.9 percent

Monsanto Envirochem, St. Louis, provides gas cleaning equipment for sulphuric acid plants. Results of piloting work conducted at INCO at Sudbury are shown in Table 3-2 to illustrate the effectiveness of their Dynawave scrubbing technology. It should be noted that results of the commercial Dynawave installation at INCO have not been published but are said to closely reflect the piloting results. The arsenic removal in the pilot circuit was over 95 percent. The arsenic loading in the in-coming gas was similar to Giant Yellowknife's stack gas arsenic loading. It should be noted that the commercial installation at INCO Sudbury included wet precipitators as discussed above.

Further descriptions of the Dynawave scrubber systems are shown in Appendix I.

The technologies identified in the February report were in many ways similar to the gas cleaning circuits developed for sulphuric acid plants. Scrubbing was a basic component in all the circuits discussed and electrostatic cleaning was a component in two of the three approaches. The following sections describe the commercial installations of the LAB technology.

### LAB Technology

The concept of LAB's ESD gas cleaning technology originated in France. There are 150 or more installations around the world. A very large, recent installation, commissioned in 1994, treats 700,000 acfm of gases from a petrochemical refinery in Texas.

The LAB technology relies on the combined cleaning achieved by scrubbing and wet electrostatic gas cleaning. Table 3-3 exemplifies results published for LAB installations. Examples of commercial scale LAB operations using the ESD gas cleaning technology are shown in Appendix II.

### 3.2 Other Gas Cleaning Technologies

In the February report, other suppliers of gas cleaning systems were identified. These included Turbotak, Waterloo, and Environmental Corrections located in California. Similar arguments can be made for continued appraisal of gas cleaning systems from these suppliers as has been made for Monsanto and LAB in this report.

Risks associated with installation of any of the identified technologies can be minimized by piloting the changes as discussed in Section 3.3.

### 3.3 PILOT PLANT OPTIONS

All of the equipment suppliers identified in the February report offer pilot plant scale plants which can be used to verify the gas cleaning performance predicted. Monsanto, not mentioned in the collection of equipment suppliers in the February report, also offers a DynaWave pilot scale scrubber as discussed in Appendix I.

Conducting a pilot operation campaign provides assurance to a plant operator that the technology under evaluation is applicable to his operation. Each metallurgical operation has site specific peculiarities and these can be dealt with through pilot scale treatment of the existing stack gas. Piloting also allows designers to scale up the results to an economical sized full scale plant. Without piloting, certain assumptions often have to be made which can lead to a safe but more costly full scale design. Piloting eliminates many risks associated with a process modification. Expenses associated with piloting are modest and often recovered as a credit towards the cost of a full scale circuit.

### References

- (1) Response to Arsenic Control at Giant Yellowknife.  
W. R. Hatch, Oct. 22, 1996.
- (2) Treatment Of and Gold Recovery from Effluent at Giant Yellowknife Mines Limited, K.G.Thomas et al, Proceedings, Canadian Mineral Processors Annual Operators Conference, Ottawa, Canada, 1987.



TABLE 3-1

**EXAMPLES OF  
ARSENIC REMOVAL IN GAS CLEANING CIRCUITS  
FROM FEBRUARY REPORT**

OPERATION	GAS CLEANING	STACK LOADING MG/NM3	REMOVAL EFFICIENCY %
GOLDEN BEAR Muddy Lake, BC	CYCLONES, ESP WET SCRUBBER	0.2	>95
FALCONBRIDGE Sudbury, Ont.	SCRUBBER, WET ESP, ACID PLANT, STACK	<1	>99
GIANT YELLOWKNIFE Yellowknife, NWT	CYCLONES, ESP, BAGHOUSE	23	99
CAMPBELL RED LAKE Balmerton, Ont.	CYCLONES, ESP, BAGHOUSE	>15	>99

TABLE 3-2

**SUMMARY OF MOSANTO  
DYNAWAVE SCRUBBER GAS CLEANING  
RESULTS FROM INCO, SUDBURY**

CONTAMINANT	INLET LOADING MG/NM3	REMOVAL EFFICIENCY %
DUST	5873	98.3
ARSENIC	17	95.2
SELENIUM	6	98.4

**TABLE 3-3**

**SUMMARY OF LAB  
EDV SCRUBBER GAS CLEANING  
PECHINEY, FRANCE**

<b><u>CONTAMINANT</u></b>	<b><u>INLET LOADING MG/NM3</u></b>	<b><u>REMOVAL EFFICIENCY %</u></b>
PARTICULATE	12000	95.8

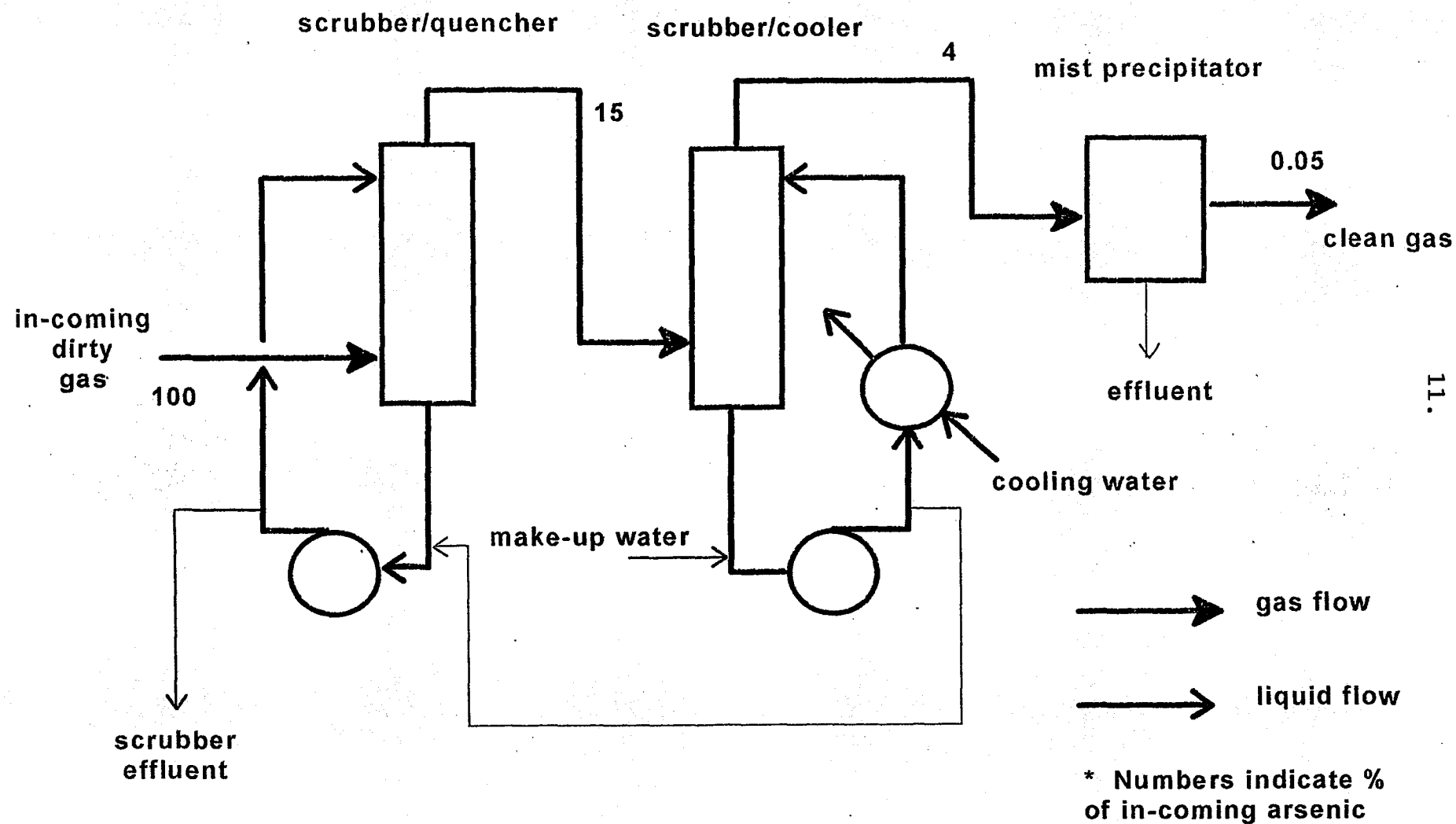


FIGURE 3-1 GENERIC ACID PLANT GAS CLEANING CIRCUIT

**APPENDIX I**

**MONSANTO ENVIROCHEM**

**DYNAWAVE SCRUBBING SYSTEMS**

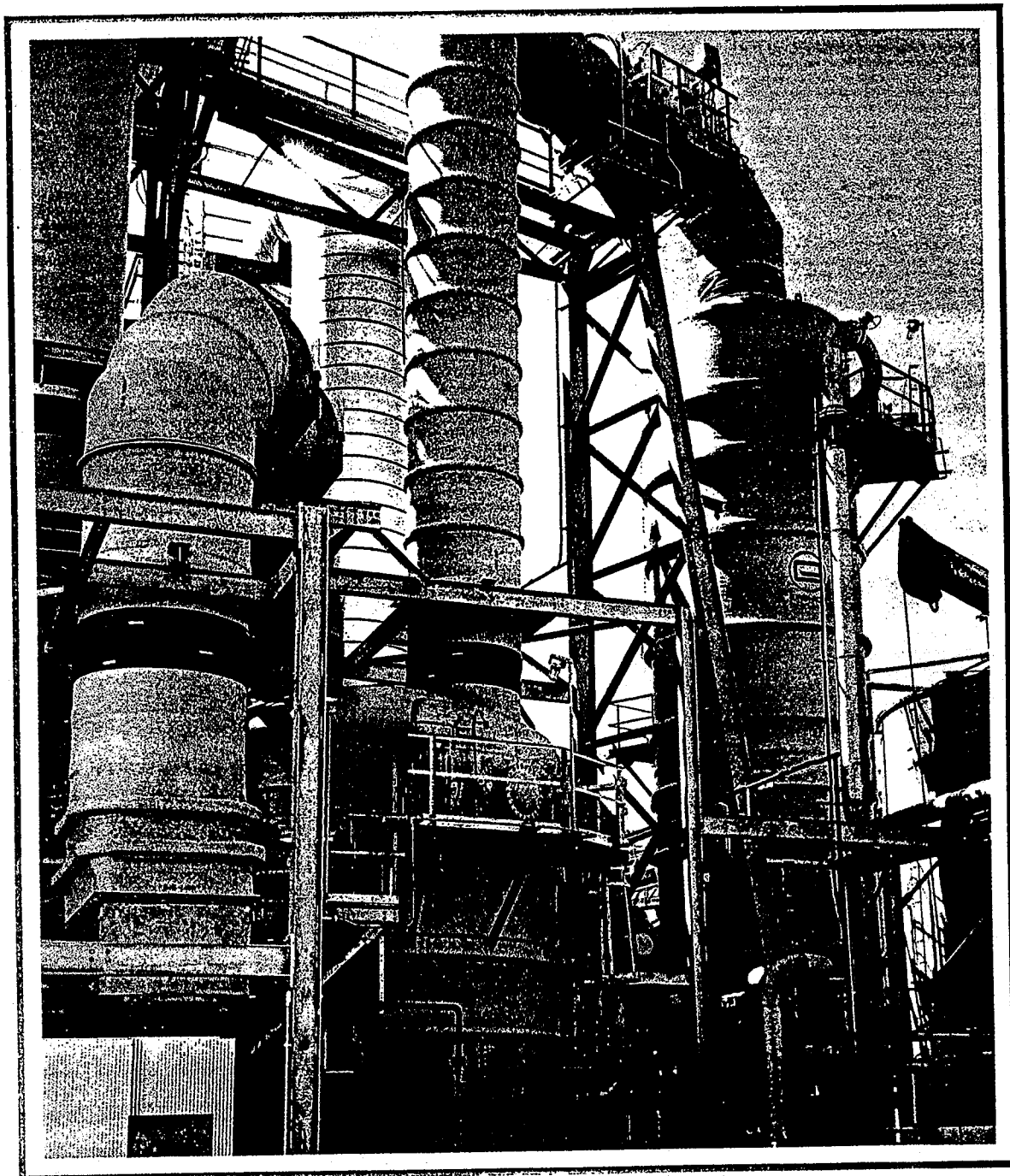
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# *DynaWave*®

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Engineered Scrubbing Systems

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Monsanto Enviro-Chem Systems, Inc.

# Overview

## Do you have difficult scrubbing applications that require:

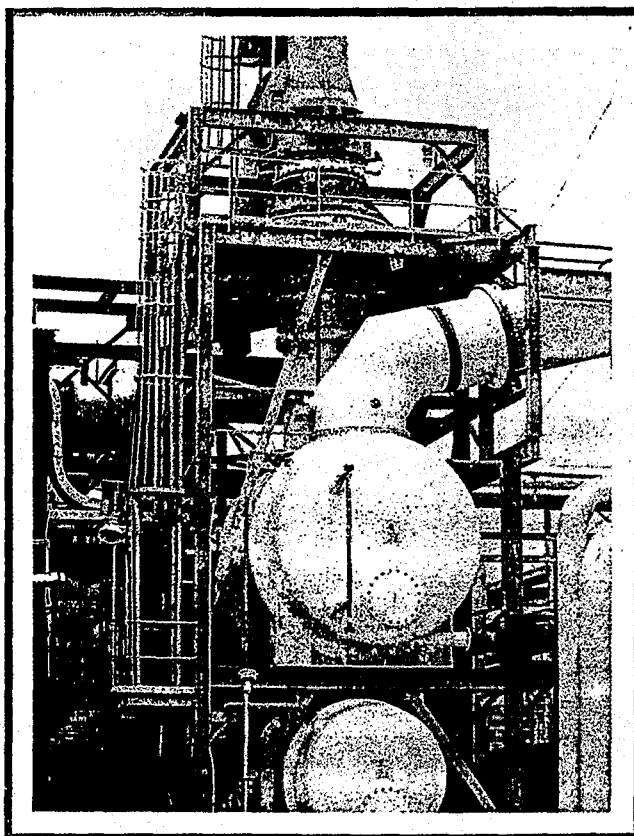
- Cleaning dirty gases that contain high solids loadings
- Cleaning gases that contain sticky solids
- Scrubbing with slurries such as lime or magnesium hydroxide
- Multiple requirements
  - Particulate removal
  - Acid gas absorption
  - Hot gas quenching
- Submicron particulate removal
- High removal efficiencies
- Effluent minimization

DynaWave<sup>®</sup> scrubbers were invented specifically to handle these type applications, ones where other scrubbing systems fail.

DynaWave scrubbers utilize Froth Scrubbing Technology. This technology was developed by E.I. Du Pont de Nemours in the 1970's to solve a difficult acid mist and particulate emissions problem. Today, froth scrubbers are used extensively within Du Pont to solve air pollution control problems requiring reliable operation with dirty, hot gases. Over 30 Du Pont plants worldwide have installed over 140 froth scrubbers in more than 40 applications.

Originally, Froth Scrubbing Technology was treated as confidential and not published or made available outside Du Pont. In 1987, Monsanto Enviro-Chem Systems, Inc. entered into a worldwide licensing agreement with Du Pont to design, market and supply the Froth Scrubbing Technology in sulfuric acid, incineration and other industrial gas cleaning/air pollution control applications.

Froth scrubbing is a unique approach to gas scrubbing using extremely high liquid to gas contact which results in highly effective removal of particulate and gaseous components from process and waste streams. The scrubbing principle requires a scrubbing liquid be injected into the gas stream so as to balance the liquid and gas momentums, creating a froth zone through which the gas must pass. The froth zone is a region of extreme gas/liquid turbulence, where intense mixing action produces high rates of heat and mass transfer, and efficient collection of small particles.

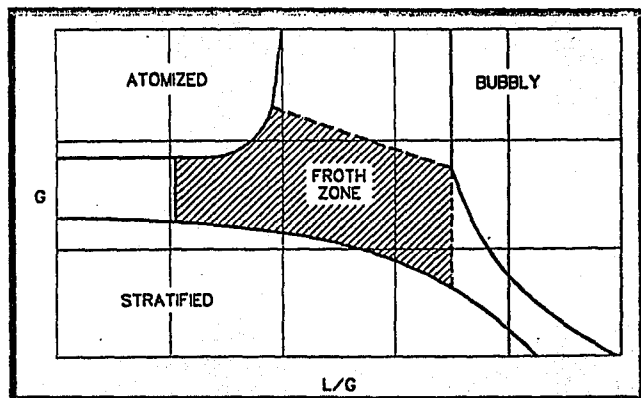


## Froth Zone

DynaWave® scrubber technology is based on a unique approach to gas scrubbing that can concurrently accomplish several gas cleaning/processing needs. With this technology, a relatively large volume of scrubbing liquid is injected into the gas stream to establish the froth zone. The froth zone is a region of intense turbulence, with substantial back mixing and a high rate of liquid surface renewal. A proper balance of gas and liquid momentums and liquid to gas ratio is required to set up the froth zone.

The key to design is for liquid and gas velocities to lie within a specific, near flooded region - the froth zone. A two-phase flow regime map was developed to show the region of proper operation. This chart is analogous to a Baker chart describing two-phase flow through a horizontal pipe.

### Two-Phase Flow Regime Map



At the lower left of the chart, gas and liquid velocities are both low; gas and liquid are stratified and the liquid surface is calm. As the gas flow is increased, waves begin to form and then their tops are clipped off. At a high enough gas velocity, the liquid is atomized into small droplets. This region is

analogous to the operation area of a venturi or other wet scrubbing device which functions via impaction. As the liquid flow is increased, eventually a state in which the gas bubbles through a continuous liquid phase is reached.

The froth zone is a broad flow regime which lies between these boundaries. The boundaries of this region are sufficiently large such that a froth scrubber can easily be designed to operate with 2:1 turndown in gas flow with no loss in scrubbing effectiveness.

DynaWave scrubbers are actually a family of scrubbers, each tailored to address different processing needs. The two main devices are the Reverse Jet scrubber and the Froth Column.

## Reverse Jet Scrubber

The Reverse Jet is an annular orifice scrubber, with liquid injected through a non-restrictive opening into a straight-walled barrel countercurrent to the gas flow. The process gas collides with the liquid, forcing the resultant mixture radially outward toward the wall. This creates a high turbulence zone in the region of gas-liquid interface. Flow momentums are balanced and the equipment sized to develop a stable standing wave with intense gas to liquid contact. The wave floats in the gas stream, shifting up or down the barrel, depending upon relative momentums of the liquid and gas streams. Particulate collection, gas absorption and hot gas quenching occur in the froth zone due to gas contact with the large area of constantly renewing liquid surface.

Reverse Jet Scrubbers are extremely reliable with an excellent record of trouble-free operation. Liquid injectors for a typical Reverse Jet sized to handle 50,000 ACFM have openings of 2 inches or larger in diameter. This allows routine operation with 10% or more suspended solids by weight in the recirculating liquid without the threat of



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## DynaWave scrubbers have several advantages over traditional scrubbing systems.

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- **No Plugging**

- Large, open bore liquid injectors
- Non-restrictive, open vessels

- **Low Pressure Drop**

- As low as 1/2 that required by venturi for equal efficiency

- **Broad Turndown Range**

- 2 : 1 turndown with no loss in efficiency

- **Low Maintenance**

- No internal moving parts

- **Simple to Operate**

- Minimal instrumentation

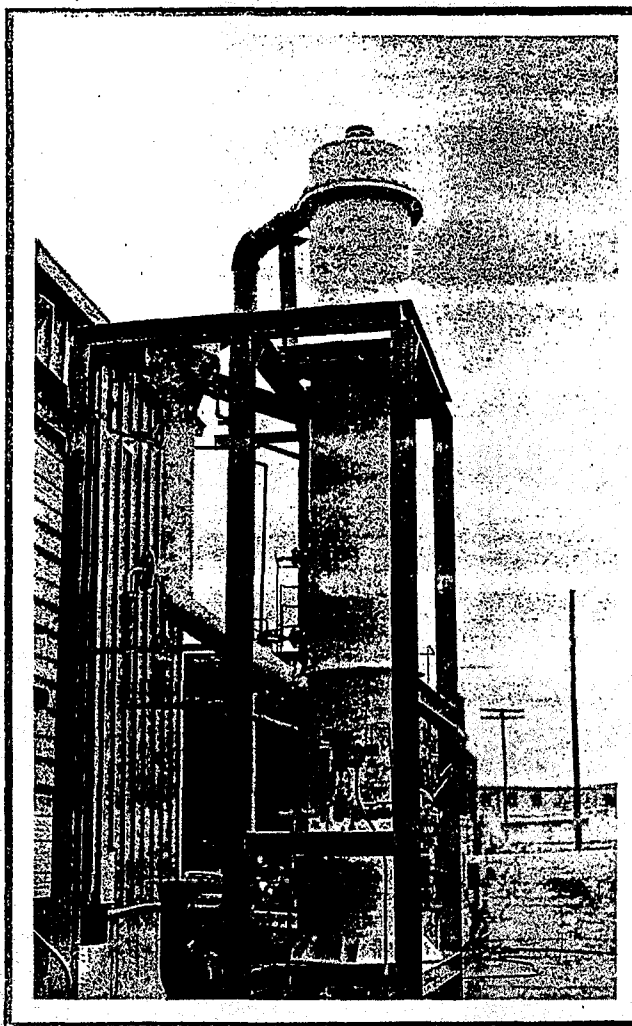
- **High On-Stream Reliability**

DynaWave scrubbers are an excellent fit with tough gas cleaning applications because they are able to operate reliably in dirty environments with high collection efficiencies. The inherently simple design and operation of a DynaWave scrubber is exemplified by the lack of atomizing spray nozzles, narrow passages or moving parts. This results in high on-stream time and low maintenance costs. The ability of DynaWave scrubbers to operate with dirty, sticky, high solids recirculating liquid streams, typically 10% or greater total suspended solids, allows system effluent to be minimized. DynaWave scrubbers can reduce the size of or totally replace electrostatic precipitators, thus minimizing capital and maintenance costs.

Monsanto Enviro-Chem Systems, Inc., a wholly owned subsidiary of Monsanto Company, is a full service Engineering and Construction Company as well as a supplier of proprietary process technologies. These technologies include

cogeneration facilities, full scale sulfuric and nitric acid plants, Brink® Mist Eliminators and DynaWave scrubbers.

Monsanto Enviro-Chem has all the necessary engineering, procurement and construction disciplines to design and execute nearly any size project. Projects range from engineering studies or equipment only designs, to full turnkey installations. With our extensive project experience throughout the world, gas cleaning technology can be customized to most plant processes. Experienced personnel are available for interfacing a design with existing processes, as well as providing start up assistance for new or retrofit systems. From custom design through installation, MEC delivers service and technology every step of the way to insure a Total Quality package.



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# System Design

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## Fabrication Materials

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For most applications, vessels can be constructed of FRP, allowing good chemical resistance at low cost. No field installation of lead or brick lining is needed. Using an innovative wet wall transition, FRP is used to quench hot gases up to 750°F.

The liquid injector is custom fabricated of solid teflon for corrosion and abrasion resistance. For highly abrasive applications, silicon carbide is used.

Monsanto Enviro-Chem will supply DynaWave scrubbers fabricated of FRP, stainless steel or lined steel, depending on the application environment and client specifications.

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## Pilot Plant

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Monsanto Enviro-Chem has three DynaWave pilot plants. These modular units are available to work with our clients in developing custom solutions for unique or difficult scrubbing applications.

The standard pilot plant is designed to handle gas flows up to 700 ACFM at temperatures as high as 700°F. Each pilot plant consists of four modules:

- Reverse Jet
- Froth Column and final Reverse Jet
- Fan and control panel
- Cooler (optional)

All four modules can be shipped on one flat bed truck and reassembled quickly in the field.

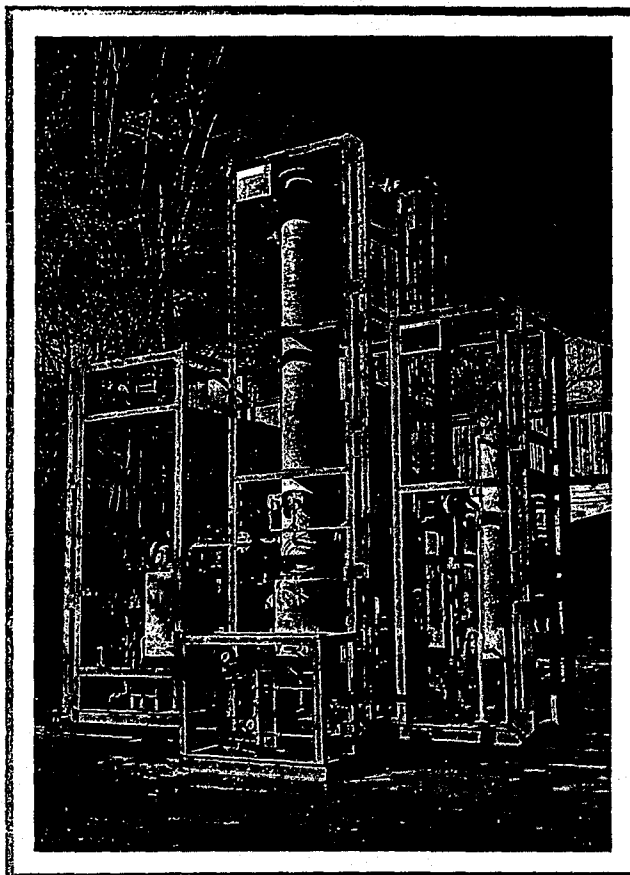
When pilot plant tests are needed, Enviro-Chem engineers will work with you to develop an experimental program, properly install the unit and arrange for sampling assistance as needed.

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## Design Features

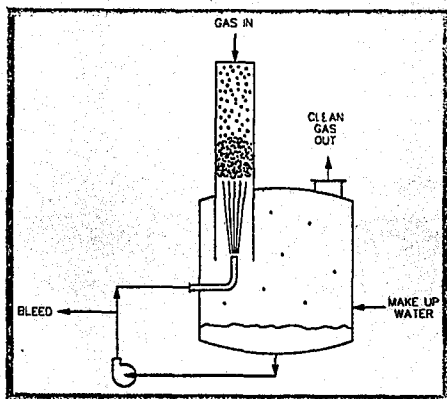
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- Particulate removal down to 0.008 gr/DSCF
- Gas quenching from 2200°F
- SO<sub>2</sub> removal down to < 10 ppm
- HCl removal down to < 5 ppm
- Low liquid effluent rates
- Dry effluent capability



plugging. Also, low liquid effluent rates minimize the load on liquid treatment facilities. High reliability and onstream time are insured by the open, nonrestrictive design of the Reverse Jet Scrubber with no internal moving parts.

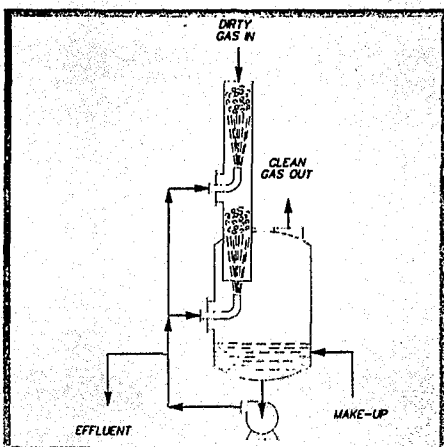
The Reverse Jet can be used alone or in series. The system is simple and easy to operate, requiring minimal instrumentation and operator attention.



## Scrubber Systems

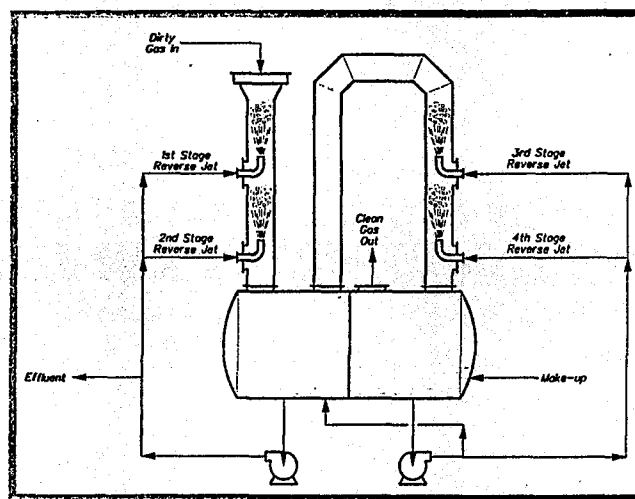
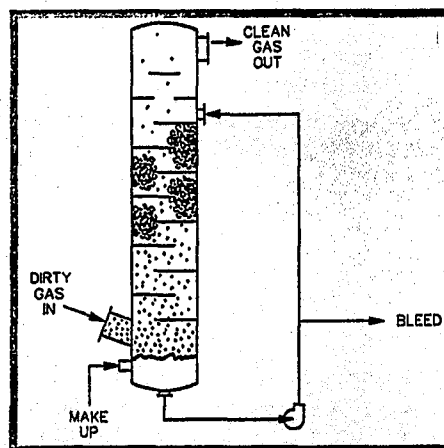
Typical scrubber system designs incorporate more than one stage of DynaWave scrubbing. Staging allows for the optimum use of pressure drop while achieving high particulate and gas contaminant removal efficiencies. A typical system would consist of two Reverse Jets in series installed in one vertical disengagement vessel to remove 90+% of the incoming contaminants and quench the inlet hot gas.

For high performance requirements, four Reverse Jets can be configured in series in one horizontal disengagement vessel to remove 99+% of the incoming contaminants and quench the inlet hot gas.



## Froth Column

The Froth Column is similar in appearance to a conventional baffle tray column; however, trays are designed with the optimum open area to induce froth zones in the open areas between the trays. Froth Columns operate with countercurrent gas and liquid flows and are effective at submicron particle removal, gas cooling and multi-stage gas absorption. They are used for cooling or gas absorption in applications where packed columns or sieve trays would be susceptible to pluggage, or where additional collection of particulate is required. The recirculating liquid can be externally cooled and approach temperatures can be controlled to promote particle growth through nuclei condensation, thereby improving particle removal efficiency.



***DynaWave*<sup>®</sup> Scrubbers**  
**In**  
**Metallurgical Applications**

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# engineered scrubbing systems

## Metallurgical System Installation List

Application	Company Location	Inlet Flow NM <sup>3</sup> /hr	Status
Metallurgical sulfuric acid plant . Gas cleaning for nickel flash furnace.	Inco Limited Canada	43300	In operation since 1991.
Metallurgical sulfuric acid plant. Gas cleaning for MK Melter smelter.	Inco Limited Canada	43300	In operation since 1993.
Metallurgical sulfuric acid plant. Gas cleaning for nickel flash furnace.	Inco Limited Canada	43300	In operation since 1993.
Platinum refining. Gas cleaning for rotary converter.	Stillwater Mining Montana, USA	25500	In operation since 1990.
Metallurgical sulfuric acid plant. Gas cleaning for iron sulfate roaster.	Tioxide France	29100	In operation since 1993.
Metallurgical sulfuric acid plant. Gas cleaning for lead roaster.	Metaleurop France	110000	In operation since 1993.
Metallurgical sulfuric acid plant. Gas cleaning for copper flash converter.	Kennecott Utah, USA	29000	Startup-1995.
Metallurgical sulfuric acid plant. Gas cleaning for copper flash smelter.	Kennecott Utah, USA	68400	Startup-1995.
Metallurgical plant. Gas cleaning for anode refining furnace	Kennecott Utah, USA	66800	Startup-1995.
Metallurgical plant. Gas cleaning for secondary ventilation.	Kennecott Utah, USA	463700	Startup-1995.

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## Fluidized Bed Roaster Test Results

### Background

A source of clean gas containing  $\text{SO}_2$  and sufficient oxygen for conversion to  $\text{SO}_3$  is essential for the production of sulfuric acid. The  $\text{SO}_2$  feed gas processed in metallurgical sulfuric acid plants is generated from the roasting of sulfide ores or smelter operations. This gas is heavily contaminated with inorganic dust, fumes and volatile metals. If not removed, these contaminants will reduce product acid quality, foul the catalyst beds and mist eliminators, and accelerate equipment corrosion.

A major metal producer was completing major plant renovations, including furnace replacements and building a new sulfuric acid plant, to drastically reduce  $\text{SO}_2$  emissions. Pilot testing was conducted to determine the feasibility of using *DynaWave* scrubbing for the cleaning and conditioning of these metallurgical offgases, prior to the acid plant.

### Goals

The specific objectives of the test were to demonstrate *DynaWave's* ability to humidify and cool the FBR offgases to achieve acid plant water balance, determine the overall and stage by stage cleaning efficiencies and demonstrate the capability of operating with high solids loading in the recirculating liquid with no plugging.

### Equipment Configuration

Approximately  $700 \text{ Am}^3 / \text{hr}$  of FBR offgas was treated by a system consisting of a primary Reverse Jet, followed by a Froth Column to a polishing Reverse Jet.

## Process Parameters

- Inlet temperature ..... 255°C
- Exit temperature ..... 35°C
- Gas side pressure drop ..... 900 mm WG

## Performance

The pilot plant was operated for five continuous five day weeks, 24 hours per day with zero downtime. There was no corrosion or solids pluggage. No maintenance was required on the liquid injectors. The *DynaWave* system achieved the following excellent contaminant removal efficiencies. The particle size distribution for the incoming dust was fairly small, with 35% < 1.0 µm and 19% < 0.5 µm.

<u>Contaminant</u>	<u>Inlet Loading</u> <u>mg/dNm<sup>3</sup></u>	<u>Removal</u> <u>Efficiency</u>
Dust	595	99.90%
Nickel	906	99.96%
Arsenic	73	93.30%
Selenium	17	93.50%
Lead	9	97.30%
Copper	84	99.95%

**engineered  
scrubbing  
systems**

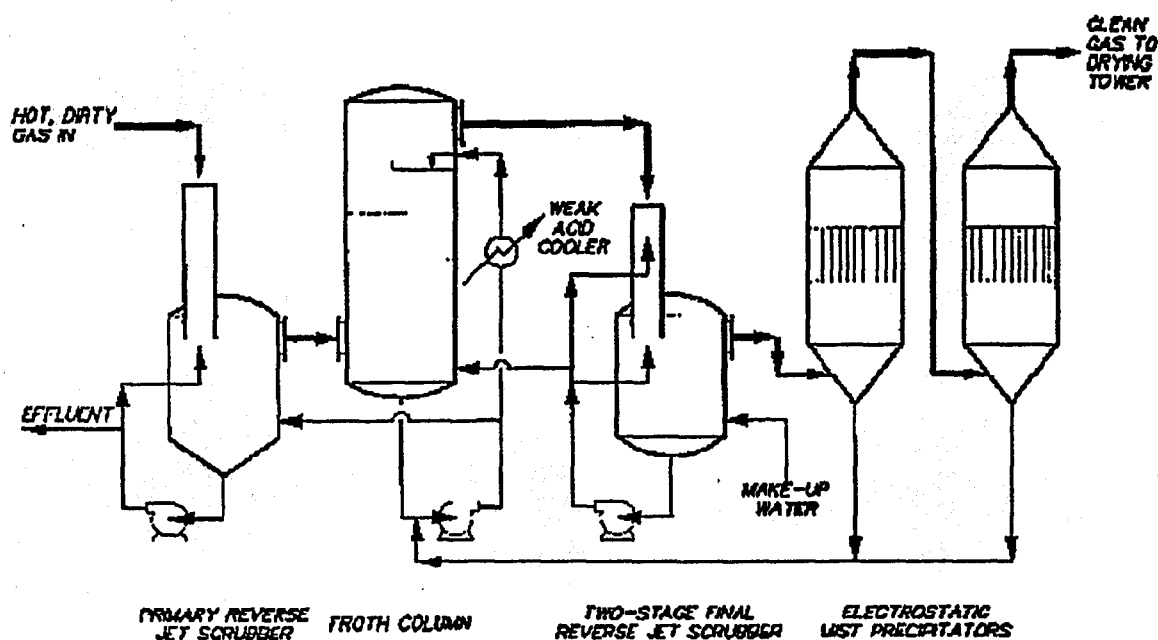
## Inco Flash Furnace #1 Canada

**Configuration:** Flash Furnace > Quencher > *DynaWave*® System > ESP > ESP > Sulfuric Acid Plant

**Inlet Gas Flow:** 43300 NM<sup>3</sup>/hr

**Inlet Loading:** 127 g/Nm<sup>3</sup> particulate, 200 mg/Nm<sup>3</sup> SO<sub>3</sub> / acid mist

***DynaWave* System Performance Guarantee:** Particulate: 99.3% removal



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<b>Application</b>	<b>Company Location</b>	<b>Inlet Flow NM<sup>3</sup>/hr</b>	<b>Status</b>
Metallurgical plant. Gas cleaning for dryer off-gas.	Kennecott Utah, USA	169200	Startup-1995.
Metallurgical sulfuric acid plant. Gas cleaning for copper and nickel smelters.	Outokumpu Finland	126000	Startup-1995.
Metallurgical sulfuric acid plant. Gas cleaning for copper smelter.	Jinlong China	135000	Startup-1996.
Metallurgical sulfuric acid plant. Gas cleaning for zinc roaster.	Metaleurop Germany	67600	Startup-1995.
Metallurgical sulfuric acid plant. Humidifying tower replacement.	Climax Molybdenum Iowa, USA	57600	Startup-1995.
Metallurgical sulfuric acid plant. Gas cleaning for nickel smelter.	Western Mining Australia	180000	Startup-1996.
Magnesium recovery plant. Gas cleaning for fluidized bed dryer.	Dead Sea Works Israel	192000	Startup-1996.
Magnesium recovery plant. Gas cleaning for chlorinator.	Dead Sea Works Israel	42115	Startup-1996.
Magnesium recovery plant. Gas cleaning for plant vents.	Dead Sea Works Israel	93045	Startup-1996.
Magnesium recovery plant. Gas cleaning for fluidized bed dryer.	Dead Sea Works Israel	192000	Startup-1996.
Metallurgical sulfuric acid plant. Gas cleaning for copper smelter.	Indogulf India	124430	Startup-1997.
Metallurgical sulfuric acid plant. Gas cleaning for copper smelter.	Guixi China	161775	Startup-1997.
Copper roaster offgas. SO <sub>2</sub> removal using lime.	El Indio Chile	98000	Startup-1996.
Metallurgical sulfuric acid plant. Gas cleaning for copper smelter.	LG Metals Korea	134800	Startup-1998.
Zinc roaster offgas. Particulate removal.	CEZ Canada	86000	Startup-1997.

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## Inco Flash Furnace #2

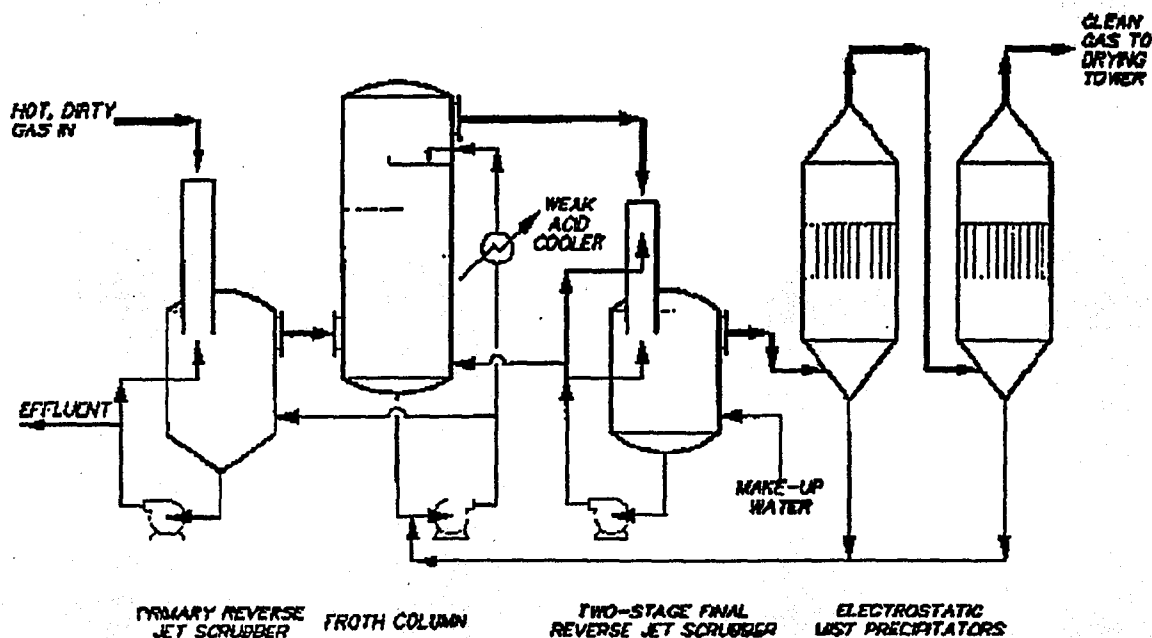
Canada

**Configuration:** Flash Furnace > Quencher > DynaWave® System > ESP > ESP > Sulfuric Acid Plant

**Inlet Gas Flow:** 43300 NM<sup>3</sup>/hr

**Inlet Loading:** 127 g/Nm<sup>3</sup> particulate, 200 mg/Nm<sup>3</sup> SO<sub>3</sub> / acid mist

**DynaWave System Performance Guarantee:** Particulate: 99.3% removal



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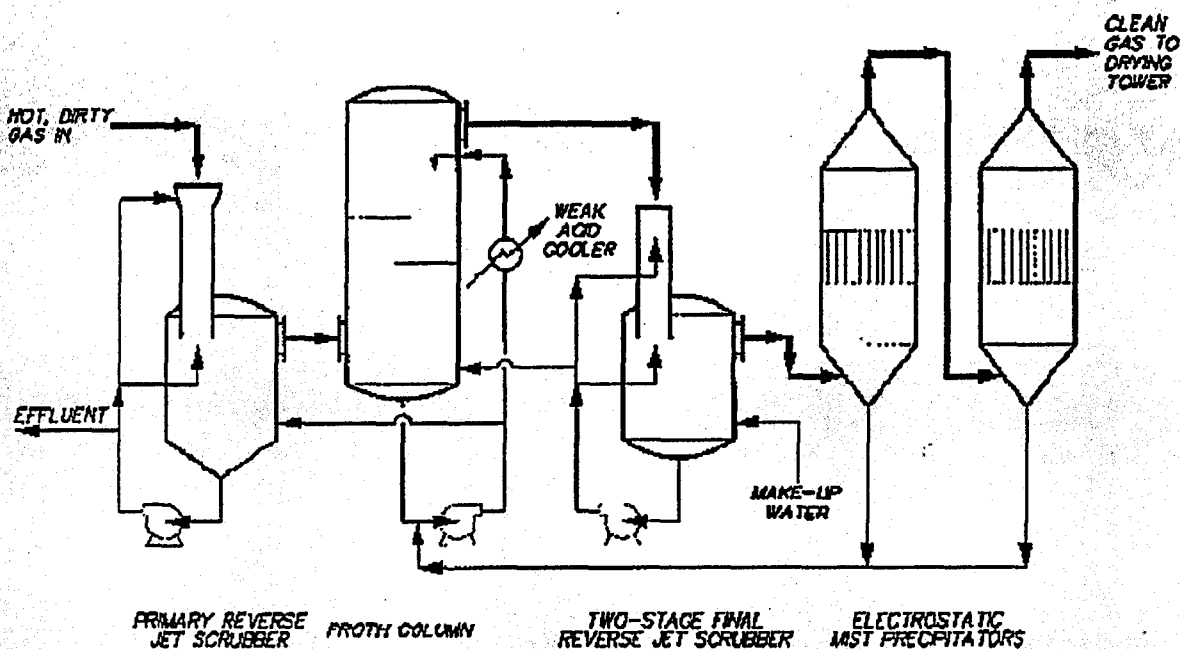
## Inco MK Melter Canada

**Configuration:** MK Melter Smelter > Hot ESP > *DynaWave*® System > ESP > ESP > Sulfuric Acid Plant

**Inlet Gas Flow:** 43300 NM<sup>3</sup>/hr

**Inlet Loading:** 800 mg/Nm<sup>3</sup> particulate, 140 mg/Nm<sup>3</sup> arsenic / selenium

***DynaWave* System Performance Guarantee:** Particulate: 99.3% removal



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# DynaWave®

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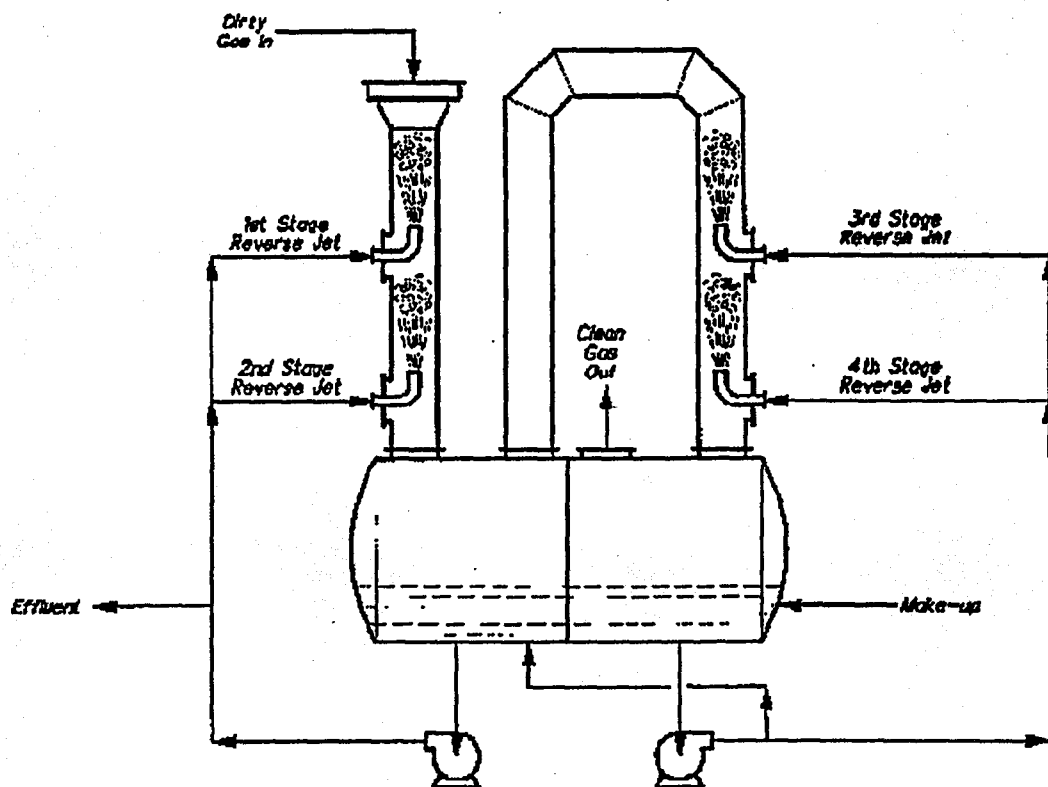
### Stillwater Mining Montana, USA

**Configuration:** Rotary Converter > Baghouse > DynaWave® System > Stack

**Inlet Gas Flow:** 25500 NM<sup>3</sup>/hr

**Inlet Loading:** 5.7 g/Nm<sup>3</sup> particulate, 40 g/Nm<sup>3</sup> SO<sub>2</sub>

**DynaWave System Performance Guarantee:** Particulate: 99.3% removal  
SO<sub>2</sub>: 99.0% removal



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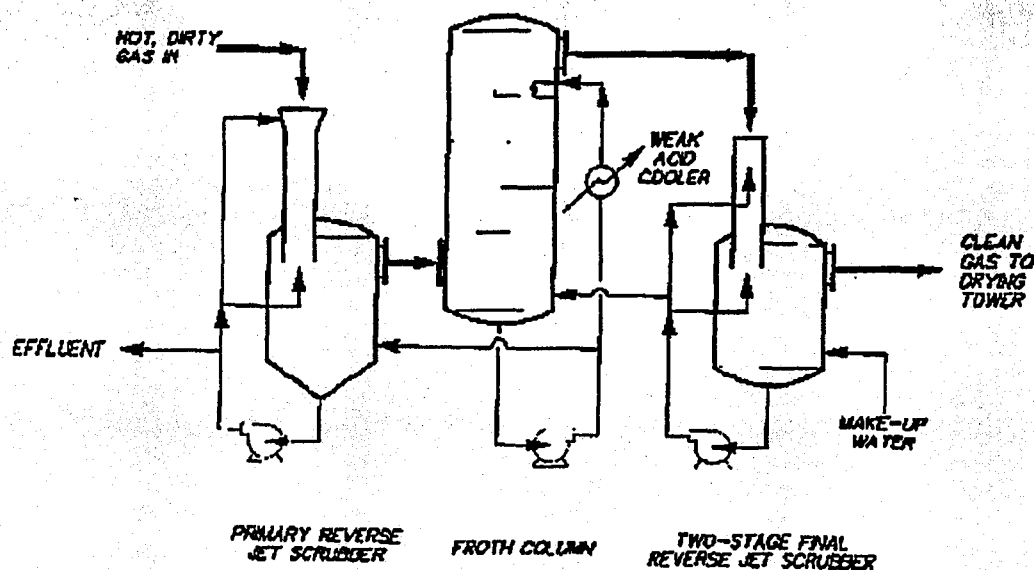
## Tioxide France

**Configuration:** Roaster > Hot ESP > DynaWave® System > Sulfuric Acid Plant

**Inlet Gas Flow:** 29100 NM<sup>3</sup>/hr

**Inlet Loading:** 200 mg/Nm<sup>3</sup> dust

**DynaWave System Performance Guarantee:** Dust: 99.0% removal



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# DynaWave®

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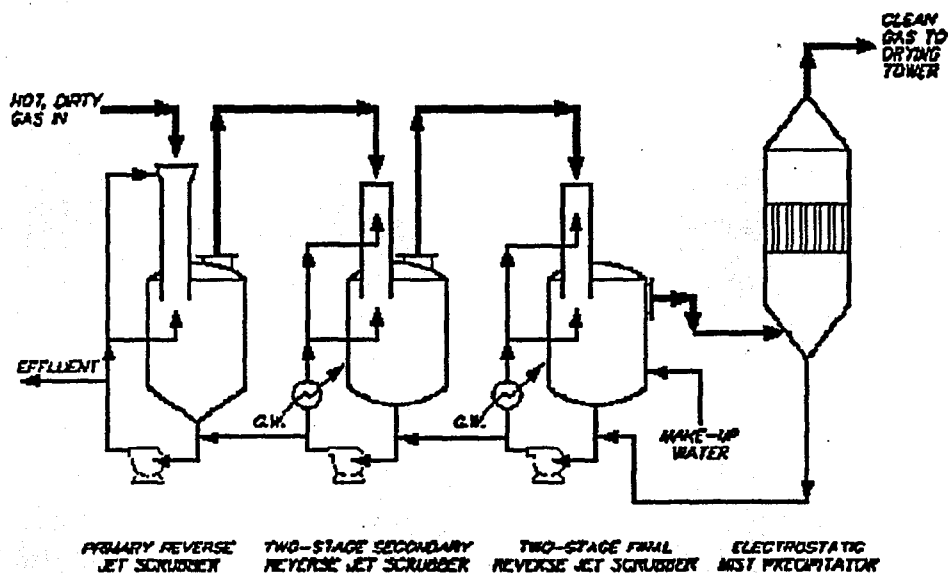
### Metaleurop France

**Configuration:** Lead Roaster > Hot ESP > DynaWave® System > ESP > Sulfuric Acid Plant

**Inlet Gas Flow:** 110000 NM<sup>3</sup>/hr

**Inlet Loading:** 11 g/Nm<sup>3</sup> dust

**DynaWave System Performance Guarantee:** Dust: 97.3% removal



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systems

## Kennecott Utah, USA

**Configuration:** Flash Converter > Hot ESP > DynaWave® System > ESP > ESP > Sulfuric Acid Plant

**Inlet Gas Flow:** 29000 NM<sup>3</sup>/hr

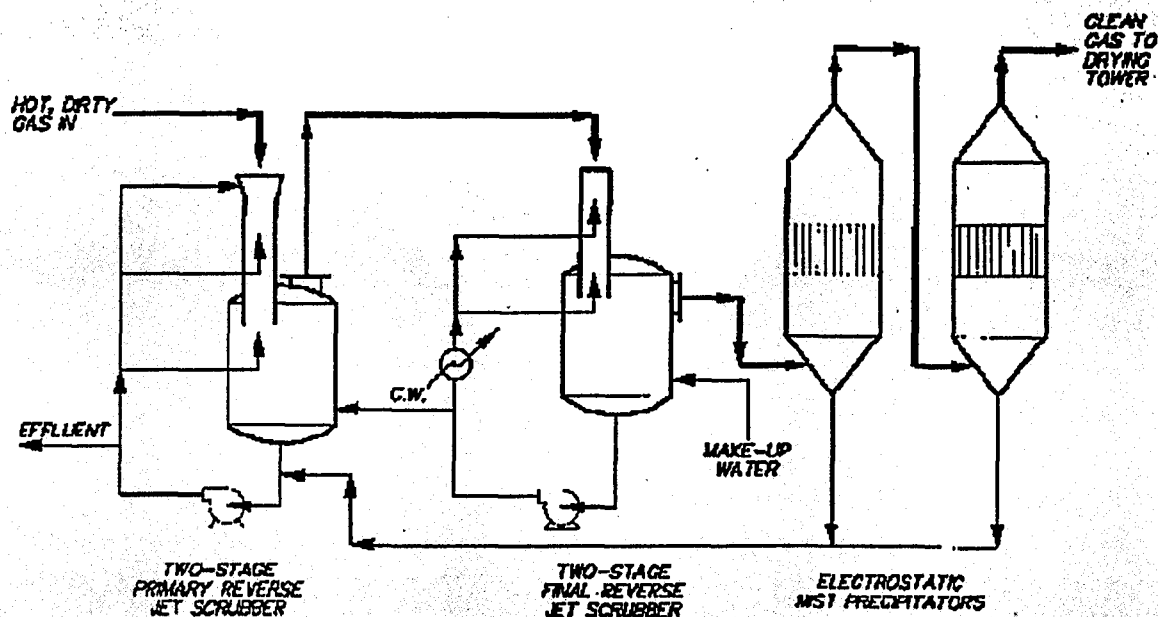
**Inlet Loading:** 250 mg/Nm<sup>3</sup> dust, 2.2 g/Nm<sup>3</sup> fumes, 13.6 g/Nm<sup>3</sup> SO<sub>3</sub> / acid mist

**DynaWave System Performance Guarantee:**

Dust: 50% removal (98% removal expected)

Fumes: 93.0% removal

SO<sub>3</sub> / acid mist: 80.0% removal



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# engineered scrubbing systems

## Kennecott Utah, USA

**Configuration:** Flash Smelter > Hot ESP > DynaWave® System > ESP > ESP > Sulfuric Acid Plant

**Inlet Gas Flow:** 68400 NM<sup>3</sup>/hr

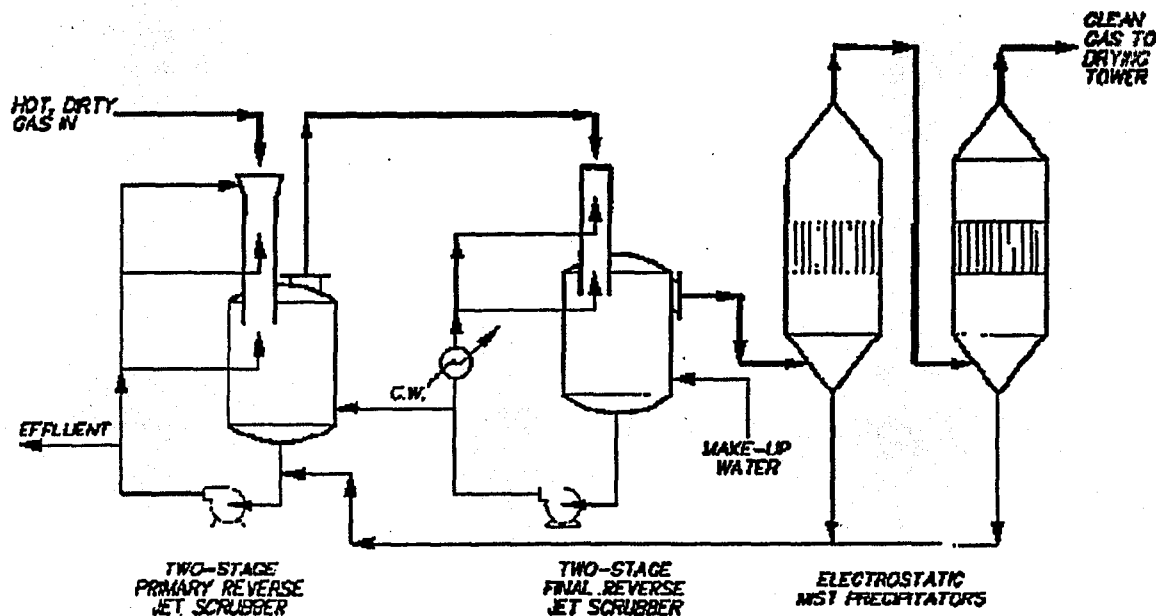
**Inlet Loading:** 250 mg/Nm<sup>3</sup> dust, 1.3 g/Nm<sup>3</sup> fumes, 11.8 g/Nm<sup>3</sup> SO<sub>3</sub> / acid mist

**DynaWave System Performance Guarantee:**

Dust: 50% removal (98% removal expected)

Fumes: 93.0% removal

SO<sub>3</sub> / acid mist: 80.0% removal



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# engineered scrubbing systems

## Outokumpu Finland

**Configuration:** Smelters > Hot ESP > DynaWave® System > ESP > ESP > Sulfuric Acid Plant

**Inlet Gas Flow:** 126000 NM<sup>3</sup>/hr

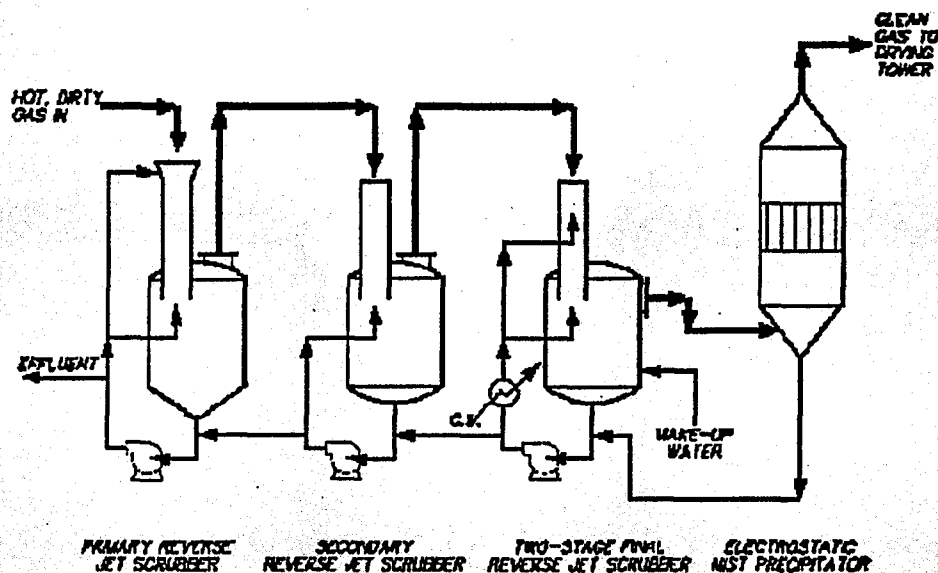
**Inlet Loading:** 930 mg/Nm<sup>3</sup> dust, 550 mg/Nm<sup>3</sup> fumes, 16.7 g/Nm<sup>3</sup> SO<sub>3</sub> / acid mist

**DynaWave System Performance Guarantee:**

Dust: 97% removal

Fumes: 93% removal

SO<sub>3</sub> / acid mist: 75% removal



PRIMARY REVERSE  
JET SCRUBBER

SECONDARY  
REVERSE JET SCRUBBER

TWO-STAGE FINAL  
REVERSE JET SCRUBBER

ELECTROSTATIC  
MIST PRECIPITATOR

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## Flash Furnace Test Results

### Background

A source of clean gas containing  $\text{SO}_2$  and sufficient oxygen for conversion to  $\text{SO}_3$  is essential for the production of sulfuric acid. The  $\text{SO}_2$  feed gas processed in metallurgical sulfuric acid plants is generated from the roasting of sulfide ores or smelter operations. Offgas from an oxygen-fired flash furnace is characterized by extremely high dust and condensable metals loadings. These include arsenic, selenium, mercury and their chlorides, sulfates and oxides. Because of their small size, less than  $1\text{ }\mu\text{m}$ , volatile metals are difficult to collect and thus represent a problem for an acid plant. Arsenic is particularly objectionable because it deactivates vanadium catalyst. If not removed, contaminants can also reduce product acid quality, foul the catalyst beds and mist eliminators, and accelerate equipment corrosion.

Pilot testing was conducted to determine the feasibility of using *DynaWave* scrubbing for the cleaning and conditioning of flash furnace offgases, prior to an acid plant.

### Goals

The specific objectives of the test were to demonstrate *DynaWave*'s ability to humidify and cool the flash furnace offgases to achieve acid plant water balance, determine the overall and stage by stage cleaning efficiencies and demonstrate the capability of operating with high solids loading in the recirculating liquid with no plugging.

### Equipment Configuration

Approximately  $600\text{ dNm}^3/\text{hr}$  of flash furnace offgas was treated by a system consisting of a primary Reverse Jet, followed by a Froth Column to a polishing Reverse Jet.

## Process Parameters

- Inlet temperature ..... 71°C
- Exit temperature ..... 27°C
- Gas side pressure drop ..... 925 mm WG

## Performance

The pilot plant was operated for three continuous five day weeks, 24 hours per day with zero downtime. There was no corrosion or solids pluggage. No maintenance was required on the liquid injectors. The *DynaWave* system achieved the following excellent contaminant removal efficiencies.

<u>Contaminant</u>	<u>Inlet Loading mg/dNm<sup>3</sup></u>	<u>Removal Efficiency</u>
Dust	5873	98.3%
Nickel	36	99.2%
Arsenic	17	95.2%
Selenium	6	98.4%
Lead	258	96.4%
Copper	1630	98.8%
Zinc	120	98.3%
Cadmium	15	98.4%
Bismuth	21	95.5%

**APPENDIX II**

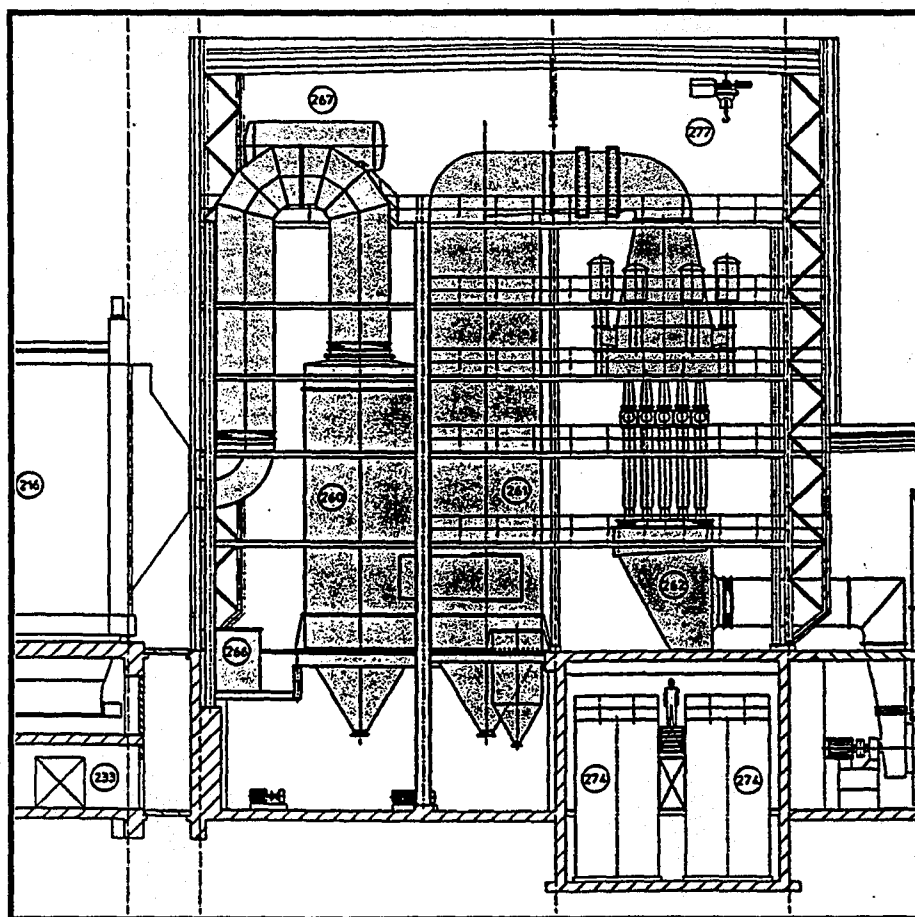
**BIOTHERMICA**

**LAB GAS CLEANING SYSTEMS**

# EPURATION DES FUMÉES PAR EDV 7000

## USINE D'INCINÉRATION D'ORDURES MÉNAGÈRES

### AMSTERDAM - WEST (Pays-Bas)



TECHNOLOGIES ET INSTALLATIONS  
POUR L'ÉPURATION DE L'AIR ET DES GAZ

# EPURATION DES FUMÉES UIOM D'AMSTERDAM-WEST

CLIENT : STADSREINIGING GEMEENTE AMSTERDAM (Pays-Bas)  
 REALISATION : LAB S.A.  
 MISE EN SERVICE : Janvier 1993

## CARACTERISTIQUES GENERALES DE L'INSTALLATION

- UIOM neuve destinée à remplacer l' UIOM existante d' AMSTERDAM-NORD
- Capacité de l'UIOM : 765 000 t/an d'ordures ménagères avec 4 fours à grille de chacun 25 à 30 tonnes/heure
- Récupération d'énergie : production d'électricité et éventuellement production de chaleur pour le chauffage urbain
- Epuration des fumées : par 4 unités EDV 7000\* installées chacune en aval d'un système de prétraitement des fumées constitué :
  - d'un système de deNOx SNCR avec injection d'ammoniac à l'entrée de la chaudière et
  - d'un réacteur semi-humide placé entre un électrofiltre de pré-dépoussiérage et un électrofiltre de dépoussiérage complémentaire

\* La technologie EDV a été développée par LAB SA et fait l'objet de plusieurs brevets

## CARACTERISTIQUES DES FUMÉES

- Débit entrée EDV, par ligne (m<sup>3</sup>N/h humide) : 165 000
- Température entrée EDV (°C) : 125
- Polluants (mg/m<sup>3</sup>N sec ramené à 11 % O<sub>2</sub> vol. sur sec) :

POLLUANTS	ENTREE EDV	SORTIE EDV	
	Valeurs maxima pour le dimensionnement	Valeurs maxima suivant la réglementation 1989	Valeurs maxima garanties par LAB
HCl	400	10	10
HF	5	1	1
SO <sub>2</sub>	200	40	40
Poussières totales	30	5	5
Hg **	0,1	0,05	0,05
Dioxines et furanes **	ng TE/Nm <sup>3</sup> 11 % O <sub>2</sub>	0,1	0,1

\*\* particulaire et gazeux

## CARACTERISTIQUES D'EXPLOITATION

- Condensation de vapeur d'eau par sous-refroidissement des fumées dans le laveur, donc pas de consommation d'eau neuve
- Neutralisation à la soude dans le laveur
- Stripping de l'ammoniac contenu dans la purge de déconcentration du laveur
- Traitement d'eau en deux lignes travaillant en parallèle
- Evaporation dans le réacteur semi-humide de l'eau claire résultant du traitement de la purge de déconcentration du laveur, donc pas de rejet d'eau à l'égout

### **3M Selects EDV System for Corporate Incinerator**

3M placed an order to BELCO for an EDV system to be used as an APC upgrade at its corporate incinerator at the 3M Cottage Grove Center in Minnesota. The EDV system replaces a packed tower, WESP, and cross-flow scrubber. The basis for the selection of the EDV technology was completion of successful EDV pilot tests performed at the corporate incinerator in the fall of 1991 and spring of 1992. The EDV system will control fine particulate and metals. Start-up of the EDV system is planned for the spring of 1996.

### **Another Successful Story with Wide Plate Spacing ESP**



BELCO's ESP on the 156 MW Unit 2 at the Milliken Station of New York State Electric and Gas (NYSEG) began successful operation in mid-December 1994. The ESP, BELCO's third 16 inch plate spacing unit in operation, is part of a DOE Clean Coal project which includes a scrubber and boiler modifications for Units 1 & 2. The Unit 2 joins BELCO's Unit 1 which has been operating since mid-1993. Since startup Unit 2 has been consistently running at less than 5% opacity with the 65 KV TR sets at secondary voltage limit. A performance test is planned in March 1995.

## **EDV System Cleans Up Flue Gas Emissions from FCCU**

BELCO's EDV scrubber system located at Valero Refinery Company's facility at Corpus Christi, Texas began successful operation in mid-October 1994. The scrubber, on line continuously since that time, has consistently provided SO<sub>2</sub> emissions at the scrubber outlet well below permitted levels. An emissions compliance test is planned for February 1995. The system is designed to scrub approximately 700,000 acfm of flue gas from Valero's FCCU.

## **New Waste to Energy Plant Will Use BELCO's Dry Scrubbing System**

Foster Wheeler has awarded a turnkey contract to BELCO for the supply, installation, and startup of a complete Dry Scrubbing System to treat the flue gas from (two) 600 Tons/day Circulating Fluidized Bed Boilers (CFB), at their new Waste to Energy Resource Recovery Facility, Robbins, Illinois. This is the first U.S. installation to use CFB boilers with Refuse Derived Fuel (RDF) firing.

Each boiler train will be equipped with a downflow Spray Dryer Absorber, using dual fluid nozzles, and a Pulse Jet Fabric Filter System. Acid gas and heavy metal removal will be achieved by using lime and activated carbon slurry.

Construction of the BELCO system will be complete in March of 1996 with the first firing of the boiler scheduled for late summer of 1996.

## **Dioxin Control Technology in Commercial Operation**

The patented EDV technology for the control of dioxins and furans (PCDD/F) has been successfully retrofitted to the 2,600 tons per day AVI-Amsterdam municipal solid waste incineration facility. Emissions of PCDD/F are being controlled below 0.1 ng I-TEQ/Nm<sup>3</sup>.

During the test program implemented at the AVI West plant, the "memory effect", whereby flue gas cleaning equipment itself tends to adsorb and/or release PCDD/F, was clearly identified. Commercial design must take this important mechanism into account.

### **Corporate Soldier**

Joe Stehn, BELCO's Vice President and Chief Financial Officer, has a second career: that of an officer in the U.S. Army Reserve. Joe has recently been notified that he has been selected for promotion to the rank of Colonel, which Joe explains is the high point of his career.



Joe's military career has not been without hardship for either himself or BELCO in that he was activated in January of 1991 as a Battalion Commander of a Basic Combat Training unit in support of Operation Desert Storm. Joe's unit retrained reservists recalled to active duty and assisted in the training of Kuwait nationals who volunteered to fight against Iraq.

Balancing the demands of his job at BELCO and the increasing responsibilities he has had with the Army Reserve, Joe comments that "Somewhere in between these two jobs you must find time for your most important career — your family".



## APPENDIX III

### QUESTIONS RAISED RE W.R. HATCH ENG. REPORT

BY ROYAL OAK MINES INC.

#### Item #3 - Technological Options to Reduce Arsenic Emissions

Section 2.2.1 references the Hatch study on the technical options to reduce arsenic emissions from the Giant roaster stack. The Hatch report offers three options for reducing arsenic emissions:

- 1) The Use of a Wet Scrubber,
- 2) The use of a Wet Electrostatic Precipitator
- 3) The use of Activated Carbon to Adsorb Arsenic from the gas Stream

The report however does not tell the reader what is to be done with the arsenic that is removed from the gas stream in each of these processes. The arsenic that is to be removed in each of these process options has to be dealt with in some environmentally acceptable fashion. The first two options will produce a water based slurry high in arsenic while the third option will produce a water-carbon slurry high in arsenic that must be treated or stabilized before being disposed of. The cost of treating this by-product must be included in the socio-economic analysis for the findings to be valid.

The socio-economic report leaves the reader with the impression that each of these technical options for reducing the emissions of arsenic from the Giant roaster stack are viable, well proven and demonstrated technologies. In fact I do not know of a comparable case study where any of these techniques are being used specifically to reduce arsenic emissions. If this is the case, then there is a risk that these technical options will not achieve the expected reductions.

It would be useful to include any available case histories where these technologies are being applied to reduce arsenic emissions from a gas stream to validate the claim that a 0.1 mg/m<sup>3</sup> arsenic emission level can in fact be consistently achieved with such equipment.

If there are no case histories then it should be so stated in the report so that the decision makers and the other stakeholders are aware that this is unproven technology and that there is a risk that it will not perform as well as expected. It would be useful if these risk could be discussed in some detail.