IV. DEMONSTRATED CONTROL OF CHROME PLATING EMISSIONS - BACT

This section details the control technologies which are commonly used in the chrome plating and chromic acid anodizing industries. An assessment is made for each control technology as to the level of control which has been demonstrated or may be reasonably expected to be achieved through proper application of the technology. The advantages and disadvantages of each control approach are also discussed.

A. Hard Chrome Plating Emission Control Technologies

Hard chrome platers can use several approaches to control chromic acid mists. These approaches include the use of high flow rate collection/ventilation systems in combination with inertial impaction control devices (such as chevron blade or mesh pad mist eliminators, or wet packed bed scrubbers), or mist suppressants or physical barriers at the surface of the plating bath.

Mist suppressant additives can be temporary or permanent depending on the mechanism of depletion from the bath (decomposition or dragout).[31] Mist supressant additives control misting by lowering the surface tension of the bath or by creating a layer of dense foam on the bath, or both.

Surface tension modifiers reduce emissions by lowering the energy imparted to mist droplets as they leave the bath surface; this allows a greater fraction of droplets to re-enter the bath before entering a collection/ventilation system or the workplace air. The foam on the surface of the bath traps mist droplets before they enter the air above the bath. Mist suppresants containing fluoro-organic compounds both lower the surface tension of the plating bath and create a foam layer. They are considered permanent suppressants, because they are stable over a wide range of operating conditions, and have a long effective life (in terms of weeks) decomposition in the bath.

Mist suppressants may cause pitting or other defects in the surface finish of parts when the plating layer is more than 13 microns or 0.5 mil thick.[30] Consequently, mist suppressants are not commonly used by hard chrome platers or anodizers. About 16 percent of hard chrome platers and chromic acid anodizers control emissions by the addition of mist suppressants to the bath, or by the use of floating plastic beads or balls on the bath surface.

Physical or mechanical barriers, such as floating plastic balls, are also used by some hard platers or anodizers. The balls are typically about 1-1/2 inches in diameter and are used to reduce heat loss, bath evaporation, and misting. In order to be most effective, balls must cover the entire surface area of the bath. However, the balls tend to be pushed away from the bath surface above the electrodes due to bubbling at these points. Plastic beads are smaller than balls, and if a sufficiently thick layer is used, complete coverage of the bath surface is possible. Drawbacks to ball and bead use have been previously described. To date, there is no data which shows the control effectiveness of these mechanical barriers. Control efficiencies of about 40 percent have been postulated. Because balls and beads are inertial impaction devices and operate with essentially no pressure drop, it is unlikely that either could be highly effective in the removal of small particles.

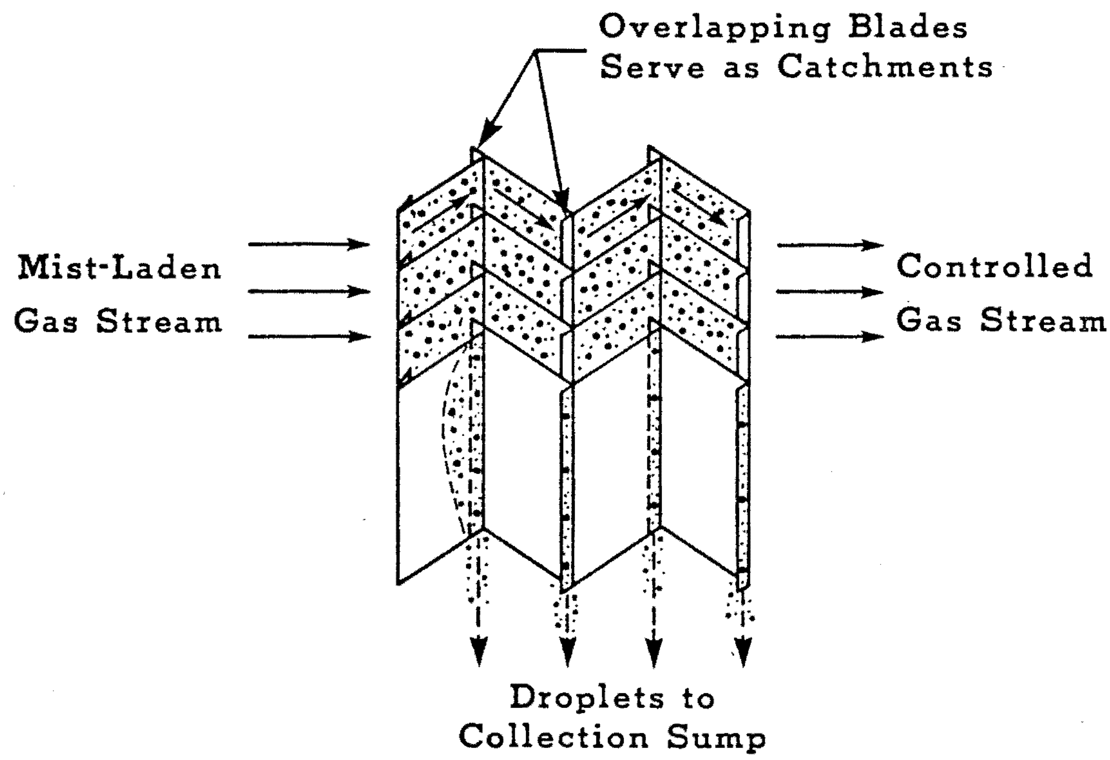
The majority of hard platers who treat the ventilation exhausts from plating tanks use mist eliminators (de-misters) or various low-energy scrubbers equipped with de-misters. Both types of devices are inertial impaction collectors; they place barriers in the paths of aerosol (mist) particles in the flowing gas to intercept and remove them from the gas stream.[1]

De-misters are of various types. The most common, the chevron-blade, is a group of parallel zig-zag channels through which the exhaust gas is directed (See Figure 7). Mist particles too large to make the sudden changes of direction in the channels touch the wet wall and stick.

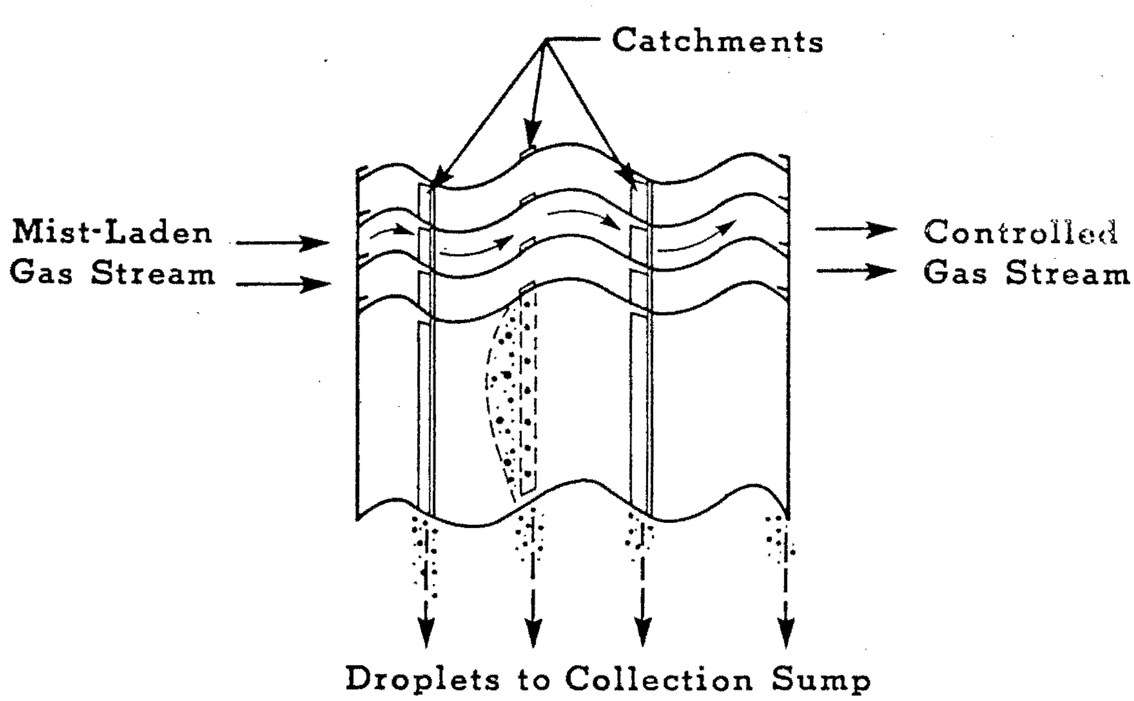
The chromic acid is collected in a sump and typically is recycled to the plating tank to make up for plating tank evaporation losses. In some demisters, the blades are rinsed periodically with clean water to remove collected chromic acid mists. Another type of de-mister uses a woven fiber pad or mesh pad. The tortuous path of the gas through the pad causes mist particles to hit and collect on the fibers. After sufficient mists have been collected on the mesh pad, the pads can, depending on the type, be washed down in place or removed for cleaning.

De-misters can remove 99 percent or greater of mist from gas streams in certain applications, depending on droplet size.[10] Table 7 shows the measured efficiencies of de-misters applied to plating emissions. The data, which are based on measurements of total chromium, range from 88 to 98 percent control. The 88 percent value may reflect less than the potential efficiency of the associated de-mister because the pressure drop across that de-mister was only 0.1 inches of water, whereas the other two de-misters in the table were run with pressure drops greater than 2 inches. Higher pressure drops reflect higher gas velocities and thus better collection of small particles.

Figure 7
Illustration of Chevron Blade De-Mister



A.] Overlapping-type Blades.



B.] Sinusoidal Wave-type Blades.

Table 7

Measured De-mister Removal Efficiency on
Hard Plating Tanks Emitting Total Chromium

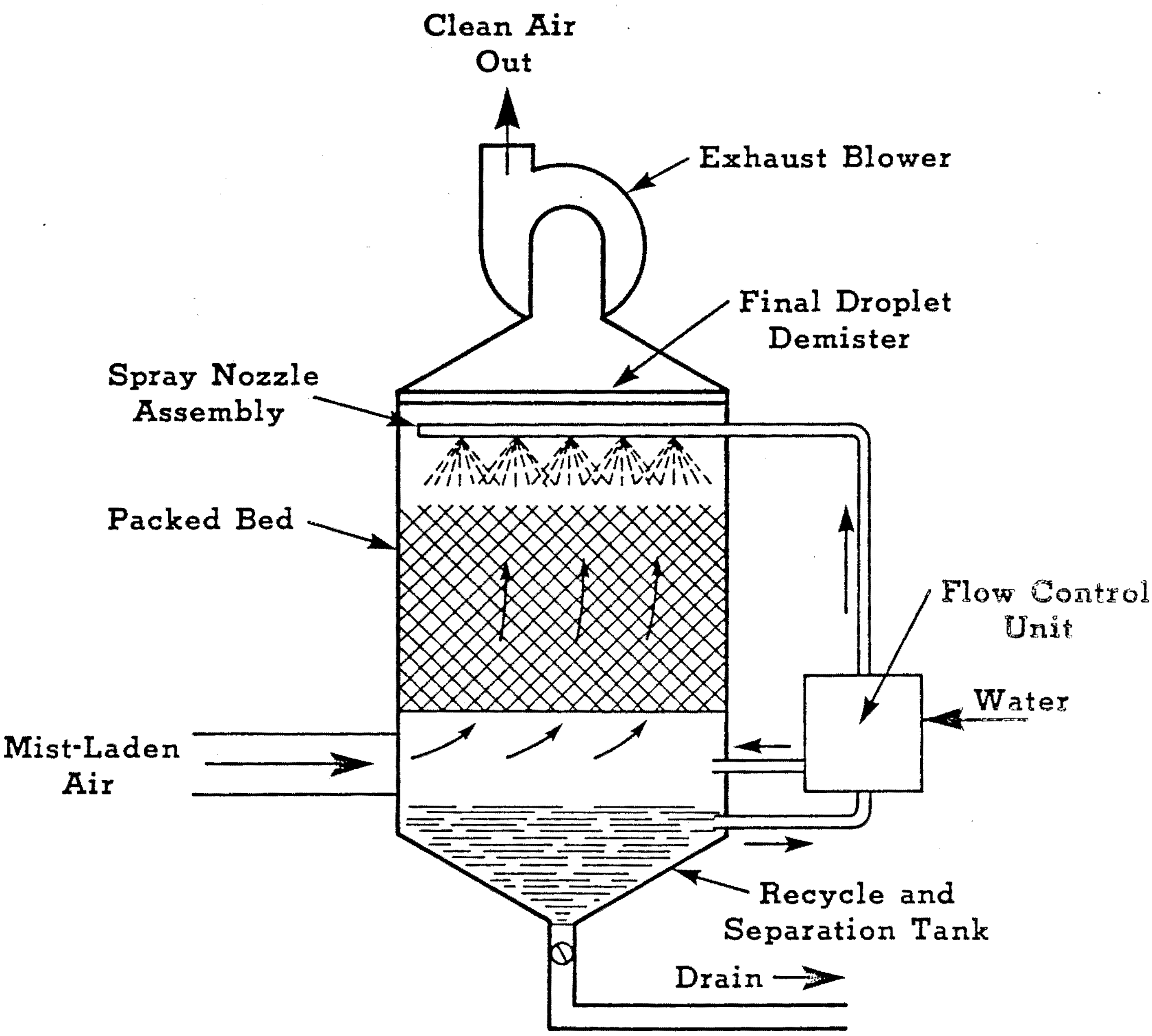
Plant	Inlet conc. 10^{-4} gr/sdcf	Controlled Emissions, mg/a-hr	Removal Efficiency
U. S. Navy	2.6	.14	95%
Able Machining	33	.15	98%
Greensboro Plating	10	.61	88%

Collection efficiency for particles with diameters less than 2 microns is relatively poor. The fine particle content of plating emissions limits the potential efficiency of de-misters.[1] This is because the smaller particles follow the stream lines of the flowing gas and flow around the fibers or blades, and because distances between the fibers are typically greater than 2 microns. The particles consequently flow between the fibers without being intercepted by them. The available particle size distribution measurements of emissions from chrome plating tanks show several percent of the mass of emitted chromium in mist particles is at or below 2 microns.

The second type of emission control device commonly used is the packed-bed scrubber. The packing acts much as does a mesh pad de-mister, capturing the mist particles through impaction as the gas stream flows in the tortuous path through the bed. However, a scrubber, unlike a de-mister, is continuously flushed by recirculating water flowing either counter- or cross-current to the exhaust gas stream. Some of the water may be introduced to the gas steam before the packing as a fine spray. The spray impinges on and collects mist particles. A de-mister is typically placed at the scrubber outlet to capture any water droplets entrained in the exhaust gas. Figure 8 shows a packed bed scrubber.

Source tests have shown that packed bed scrubbers have achieved removal efficiencies similar to demisters. This is reasonable because both of these devices are based on the inertial impaction of particles, and consequently share common limitations.

Figure 8
Typical Packed-Bed Scrubber
[Figures adapted from ref. 10]



The removal efficiencies for packed bed scrubbers range from 43 percent to 99 percent (Table 8). A common characteristic of scrubbers with poor efficiencies is a low inlet concentration of chromium, less than 10^{-4} grains/cubic foot. The low inlet concentrations may indicate the absence of large mist particles in the air entering the scrubbers. For example, the low inlet concentration to the control device at Plato Products may be attributed to the use of a layer of plastic beads on the plating tank surface. It is likely that the bead layer removes large mist particles from the exhaust stream. This results in a very low inlet loading to the scrubber, probably comprised of predominately small droplets.

There are other factors that influence scrubber efficiency. In the case of Standard Nickel Chromium, the low concentration may be related to emission characteristics of an extremely deep (38 ft) plating tank. Insufficient data exists to adequately explain why this and other deep tanks have such low emission rates. Note that despite poor efficiencies across the control device, these facilities have low emission rates. At other shops, the configuration of exhaust ducts may lead to the fallout or capture of large mist particles before the the particles reach scrubbers, causing low efficiencies in the scrubbers and low overall emission rates. In such cases the ventilation system may serve as a part of the control device.

Table 8

Measured Efficiencies of Low-Energy Wet Scrubbers

on Hard Plating and Anodizing Emissions of Total Chromium

Plant	Inlet conc. 10^{-4} gr/sdcf	Emissions[a] mg/a-hr	Removal Efficiency
U. S. Navy	.80	.15	89%
Steel Heddle	6.7	.50	96%
Tarby, Inc.	22	.23	98%
Carolina Plating	6.7	.17	93%
Plato Products	.07	.04	43%
Chrome Crankshaft	17	b	98%
Standard Ni,Cr	0.23	.04	51%
Embee Plating	0.75	b	83%
	0.17	b	76%
Piedmont Indus.	26	.14	99.4%
McDonnell Douglas	.33	.16	94%

a controlled
b no datum
c average of 4 test runs using different scrubber liquor concentrations
Source - ARB ATCM, Reference 1

It should be noted that none of the facilities in Tables 7 and 8 were subject to regulations nor, in general, to permit conditions that limited emissions of chromium. Consequently, no driving force existed to require these facilities to control their emissions to any specified levels, and therefore the control efficiencies achieved should not be considered upper bounds. These data can be considered as examples of control technology which has been demonstrated on existing facilities without either regulatory pressure, the application of source reduction techniques, or technology transfer from other areas. EPA has defined average performance (removal efficiency) levels for currently used control devices, such as mesh pad and chevron-blade mist eliminators, and wet packed bed scrubbers, as ranging between 94 and 97 percent.[30] However, recent source test data indicates that greater than 99 percent control from these devices is achievable.

B. BACT for Hard Chrome Plating

Available source test data were used to estimate the lowest achievable emission rate (LAER) achievable through application of best available control technology (BACT). Test results show that with the use of best available control technology it is possible to control hexavalent chromium emissions by 99%, or to 0.03 mg/A-hr.

Table 9 is a summary of available source test results for hard and decorative chrome platers, including inlet and outlet conditions and ranges

Table 9

Summary of Source Test Results from Chromium Plating Facilities[a]
Hexavalent Chromium

cility Name	Control Device	Total Current (A-Hrs)	Control Device ft^3/min	Average Inlet Gas Flow dscf/min	Inlet Conditions – Hex Chrome mg/dscm X10^{-3} (gr/dscf)X10^{-3}	kg/hr (X10^{-3}) (lb/hr)(X10^{-3})	mg/A-Hr (gr/A-Hr)	Outlet Conditions – Hex Chrome mg/dscm (X10^{-3}) (gr/dscf)(X10^{-3})	kg/hr (X10^{-3}) (lb/hr)(X10^{-3})	mg/A-hr (gr/A-hr)	Range of[f] Removal Efficiency	Pressure Drop in (W.C.)	Notes
rd Platers													
eensboro dustrial Platers	b	14,310	7,970	7,580	2,030 (0.885)	26.0 (57.2)	3.96 (0.0610)	306 (0.134)	3.32 (7.34)	0.552 (0.0085)	83.1-91.0	0.75	
nsolidated Engravers	d	14,450	5,390	5,060	1760 (0.77)	15.1 (33.4)	3.15 (0.048)	149 (0.065)	1.30 2.86)	0.27 (0.0042)	87.2-94.8	0.75	c
ll Technology	r	20,050	11,900	11,000	2040 (0.84)	38.8 (85.1)	4.57 (0.071)	263 (0.11)	2.43 (5.38)	0.24 (0.0036)	93.3-98.7	1.25	
le Machine	e	18,970	6,260	5,680	7,960 (3.47)	76.3 (168)	9.06 (0.139)	124 (0.054)	1.20 (2.66)	0.148 (0.0023)	97.9-98.6	2.0	
edmont ıdustrial lating	i	12,720	10,500	9,760	6200 (2.71)	103 (227)	16.0 (0.246)	24.6 (0.011)	0.436 (0.96)	0.0684 (0.0011)	99.5-99.6	2.0	h
	i	8,890	10,000	9,420	5,950 (2.6)	95.2 (210)	21.5 (0.331)	25.4 (0.011)	0.438 (0.968)	0.099 (0.0015)	99.4-99.6	2.0	j
	i	6,110	10,300	9,630	4,620 (2.02)	75.7 (167)	24.8 (0.382)	34.4 (0.015)	0.592 (1.30)	0.195 (0.0030)	99.1-99.4	2.0	k
	i	6,420	10,300	9,600	5,540 (2.42)	90.5 (200)	22.4 (0.346)	29.7 (0.013)	0.514 (1.12)	0.137 (0.0021)	99.1-99.5	2.0	l
arolina Plating	m	52,910	9,650	8,960	736 (0.32)	11.3 (24.9)	1.05 (0.0160)	25.5 (0.011)	0.49 (1.09)	0.046 (0.0007)	94.9-96.7	N/A	
teel Heddle	m	8,730	18,100	16,400	1,670 (0.729)	46.4 (102)	15.5 (0.238)	52.3 (0.0229)	1.52 (3.35)	0.558 (0.0086)	94.8-98.1	3.0	
ecorative hrome Platers													
elco Products		96,800	24,100	23,000	1,600 (0.697)	65.8 (137)	1.94 (0.0316)	s	s	s	N/A	N/A	
utomatic Die Casting	p	8,550	2,470	2,360	916 (0.4)	3.6 (8.1)	1.34 (0.021)	4.11 (0.0018)	0.0165 (0.0363)	0.0060 (9.24x10^{-5})	99.4-99.6	N/A	t
	q	10,520	2,390	2,280	N/A	N/A	N/A	2.09x10^{-3} (9.14x10^{-7})	8.10x10^{-6} (1.78x10^{-5})	0.0028 (4.31x10^{-5})	99.7-99.9	N/A	u

otes to Table 9

All tests were conducted by EPA.

Chevron-blade mist eliminator with a single set of sinusoidal wave-type blades.

Preliminary test data.

Chevron-blade mist eliminator with a single set of overlapping-type blades.

Chevron-blade mist eliminator with a double set of overlapping-type blades.

Values cited as range of percentages.

Average of three test runs at inlet and two test runs at outlet with an average scrubbing liquid chromic acid concentration of 1.6 g/l (0.22 oz/gal).

Single packed-bed, horizontal-flow wet scrubber.

Average of two test runs at inlet and three test runs at outlet with an average scrubbing liquid chromic acid concentration of 25.1 g/l (3.35 oz/gal).

Average of three test runs at inlet and three runs at outlet with an average scrubbing liquid chromic acid concentration of 45.9 g/l (6.13 oz/gal).

Average of three test runs at inlet and three test runs at outlet with an average scrubbing liquid chromic acid concentration of 99.6 g/l (13.3 oz/gal).

Double packed-bed, horizontal-flow wet scrubber.

Foam blanket.

Wetting agent in combination with a foam blanket.

Mist eliminator and wet scrubber in series, data shown are averages for 6 years.

Only inlet testing was done.

Inlet data is for uncontrolled raw emissions. Outlet conditions are controlled.

Outlet conditions are with combination fume suppressant. Inlet conditions (uncontrolled emissions) were repeated previously.

N/A - Data not available, gr= grains, dscf= dry standard cubic feet, dscm= dry standard cubic meters, A-Hr= Amp hours, in W.C.= inches water column.

Source: EPA Draft Background Information Document (Reference 30).

of removal efficiencies and mass emissions. Data presented in Table 9 are slightly different from source test results shown on Table 2; this is because Table 9 data is based on average values of several runs. Removal efficiencies of 99 percent or greater for conventional wet scrubber control devices have been achieved.[30] Mass emission rates of below 0.03 mg/A-hr have also been achieved using inertial impaction-based control devices. These removal efficiency and mass rates have been demonstrated without any concentrated effort to incorporate any source reduction techniques to minimize hexavalent chromium emissions.

C. Decorative Chrome Plating Control Technologies

The technologies used by decorative chrome platers to control emissions are the same as those used by hard chrome platers and anodizers; however, mist suppressants are more widely used for emission control by decorative platers. Floating beads or balls are less frequently used for emission control by decorative chrome platers because they present problems to automated production lines (complex part geometries trap them, interfering with plating quality, and beads or balls and are subject to drag out when parts are lifted from the tank).

Table 9 shows the available source test data. Both shops shown in Table 9 used mist suppressants and scrubbers. Low inlet concentrations are believed to be caused by the mist suppressants added to the baths.

Preliminary EPA data indicate that the removal efficiency of mist suppressants is above 99 percent.[30]

It is likely that the proper use of mist suppressants has the potential to reduce emissions from decorative chrome platers by about the same degree as do scrubbers and demisters.[1] EPA has found that the addition of a mist suppressant (wetting agent type) into an 86°F plating bath, in a concentration of approximately 1 pound per 100 gallons of plating solution, reduced surface tension from 70 to 40 dynes/cm. This surface tension decrease is predicted to result in a decrease of chromic acid emissions by about 85 percent.[30]

Existing source test data indicate that reduction of decorative plating emissions by 99 percent, or achievement of mass emissions rates of 0.01 mg/amp-hr, has been demonstrated with the use of mist suppressants.

V. BEYOND BACT

Recent regulatory decisions call for control of plating emissions to a level beyond that currently achievable using BACT. Technologies which may be able to go beyond BACT are discussed in this section. Those technologies include venturi scrubbers, wet electrostatic precipitators, sulfuric acid plant demisters (fine fiber filters), and low-flow ventilation systems. In addition, a system engineering approach (process modifications to achieve source reduction along with the use of control devices) is also discussed.

In evaluating technologies that can achieve levels of control or mass emission limits beyond BACT, one must consider several characteristics of chrome plating emissions that render them difficult to control. The major factors which influence the controllability of these emissions are the presence of small particles in the exhaust stream (less than 10 microns in diameter) and low grain loadings (typically 10^{-4} grains/ft^3) due to the large volumes of exhaust air which are needed for mist capture.

Alternatives to commonly used methods of emission controls for the electroplating industry exist, and are described below.

A. Venturi Scrubbers

The venturi scrubber is a high-energy scrubber, which is usually operated at a pressure drop around 30 inches of water, rather than the 4 or fewer inches typical of packed bed scrubbers and de-misters.

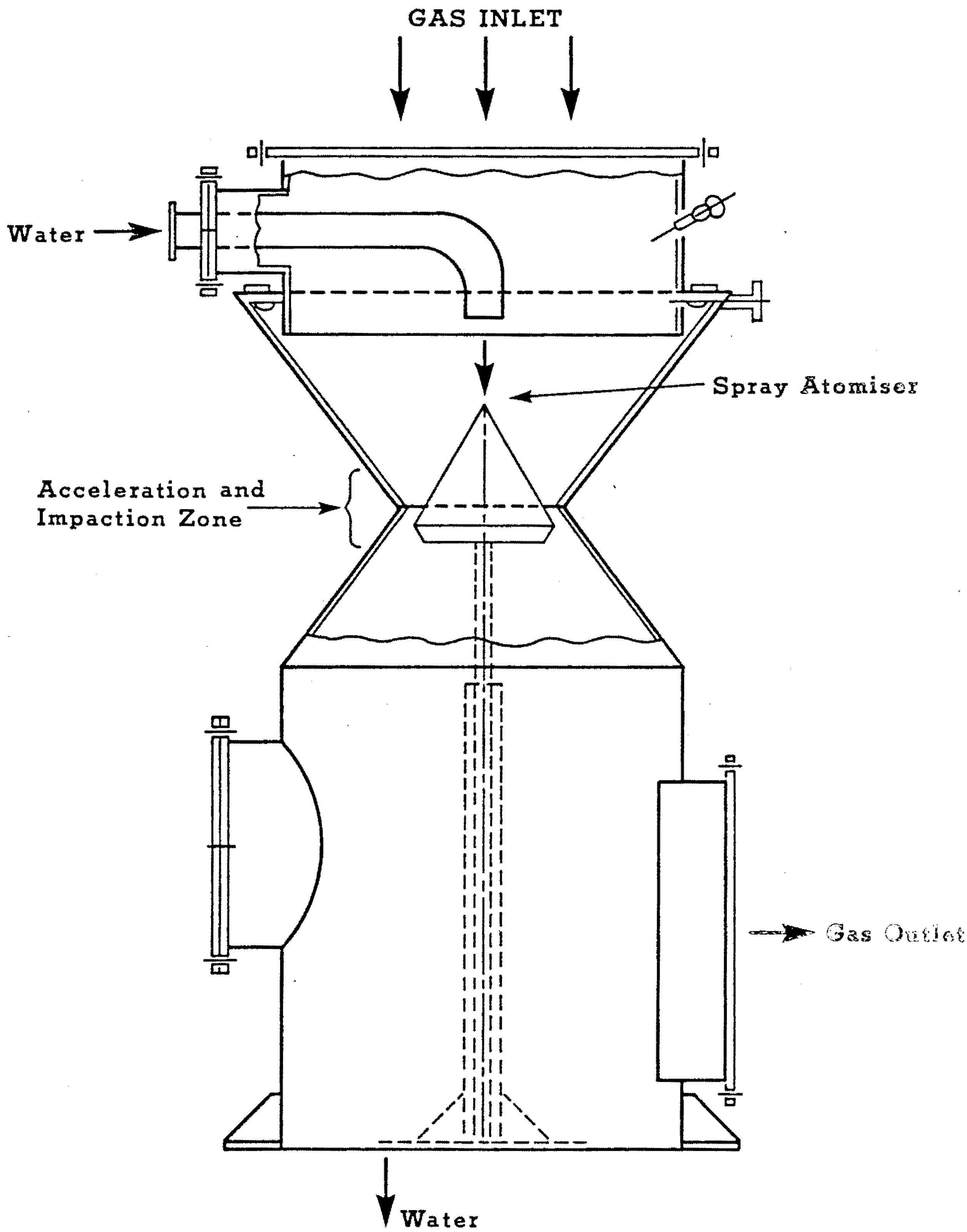
Venturi scrubbers are potentially more effective at controlling emissions than the low energy devices used in the industry today. Because venturi scrubbers expend considerably more energy than packed bed scrubbers in accelerating the gas stream prior to impaction, they provide greater inertial collection of small particles. Also in venturi scrubbers, more energy is applied in atomizing and accelerating water droplets to intercept mist particles. Figure 9 depicts the impaction zone of a venturi scrubber.

Currently, no venturi scrubbers are known to be installed at any plating facilities. Consequently, the control efficiency in this application is not documented. In other applications, however, venturi scrubbers are demonstrated to be superior in terms of higher removal efficiencies of smaller diameter particles when compared to packed bed scrubbers. For example, even at moderate pressure drops (less than 30 inches of water), venturi scrubbers can remove 99 percent of particles of 1

Figure 9

Illustration of a Venturi Scubber

[Adapted from Ref. 10]



micron diameter, as opposed to the 70 percent predicted in this size range for efficient packed bed scrubbers.[1] The costs of venturi scrubbers annualized over 10 years are about four times higher than the conventional packed bed scrubbers now used by platers.

B. Wet Electrostatic Precipitator (ESP)

Wet ESP's collect mist particles by imparting to them an electric charge from a corona discharge and collecting the charged mist on electrostatic plates or wires. The collecting surfaces are continuously flushed with water to remove the collected mist. ESPs maintain high removal efficiencies of particle diameters down to 0.1 micron. Wet ESP's have achieved control by 99 to 99.8 percent at several types of sources having sub-micron particle emissions, including acid mist from sulfuric acid plants (which are similar to plating facility emission). Consequently, ESP's may be applicable to the control of hexavalent chromium emissions from plating facilities in terms of better removal of small diameter particles.

The capital and operational cost of a wet ESP would be greater than that of a scrubber; total costs (capital and operational) annualized over 10 years could be up to 10 times those of scrubbers.[1]

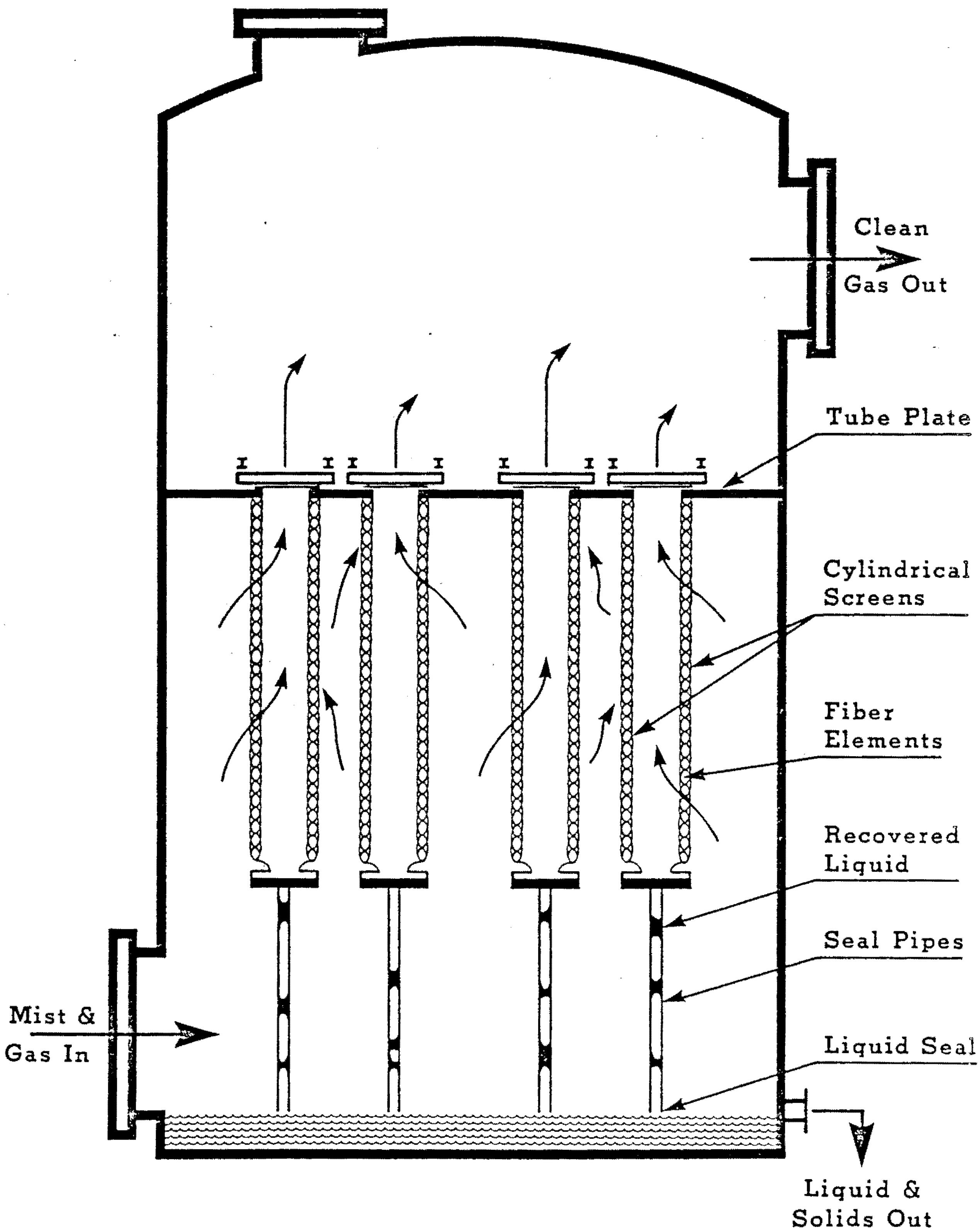
C. Sulfuric Acid Plant De-Misters

Emissions of acid mist from sulfuric acid plants are sometimes controlled by glass fiber pad de-misters that operate on the principle of diffusion rather than inertial impaction. Accordingly, the devices are much larger per unit of gas flow rate than those currently employed at plating facilities. (See Figure 10.)

Diffusion-based impaction is independent of the carrier gas stream lines and eddy currents and occurs through Brownian motion. The difference between inertial impaction and diffusion-impaction-based particulate removal devices is as follows:

1. Particulate removal by inertial impaction takes place due to the fact that particles are too large to follow the carrier gas streamlines and are collected when these pathways are intersected by fibers or mesh. Depending upon the diameter of the mesh fibers and the radial distances between the fibers, a majority of the particles in the 2-10 micron size range are captured. Those particles smaller than 2 microns will typically pass through. Inertial impaction devices are used in conjunction with an increase in gas velocity. Pressure drops of 2-10 inches of water are typical.[1]

Figure 10
Illustration of a Sulfuric Acid Plant De-mister



2. Diffusion impaction based (brownian motion) particulate removal typically requires a decrease in carrier gas velocity to allow for random particle motion. This random motion, given sufficient time, tends to increase the probability that smaller particles will collide with the collecting fiber.

Manufacturers of such de-misters have guaranteed collection efficiency as great as 99.8 percent for mist particles of less than three microns in diameter. The particle size distribution data that are available for chrome plating mists show a mass mean diameter of greater than three microns. Although it has not yet been demonstrated, it is reasonable to assume that high efficiency mist eliminators have the potential to control plating emissions by at least 99.8 percent. As a rough estimate, these de-misters would cost about four times as much as a packed bed scrubber.[26] Operating costs also would be higher.

D. Reduced Flow Ventilation Systems

Reduced flow ventilation systems require a tight fitting cover which can enclose and isolate the chromic acid mists which are generated by the plating process. By controlling and containing mist generation in and under the tank cover, it should be possible to decrease the volume and velocity of make-up air. With a properly designed system, reliable mist capture should be achievable under reduced air flow conditions.

This technology would consist of a tight-fitting tank cover equipped with a small exhaust blower followed by a control unit. The system could decrease the volume of make-up air by 90-95 percent.[27]

A control device would treat the exhaust stream after it has been collected. The device could use a combination of particle interception, condensation, inertial impaction and brownian motion diffusion processes to capture emissions.

E. System Engineering - Source Reduction

An alternative to conventional or "bolt on" control technologies is a total system approach, including source reduction and use of add-on control devices. This approach requires that process parameters which may affect mist formation be considered. Once the relationships of process parameters to mist formation are determined, a reduction in particle release at the source (at the bath surface) to minimize emissions can be achieved through a fine tuning of the process.

In hard chrome plating, process parameters which may influence emissions include: freeboard (the difference in elevation between the plating bath level surface and the top of the plating tank) height, the use of floating plastic balls or beads on the bath surface, a decrease in the tank ventilation air rate (which would include a tank cover to allow collection of chromic acid mists to reduce worker exposure), and using mechanical rather than air agitation for bath mixing.

While it is possible that a 99.8 percent removal efficiency or a 0.006 mg/A-hr emission rate will be achievable using bolt on control devices, source reduction/process modification efforts are expected to play an important role in attaining the lowest achievable emission rates in the most economical way.

VI. CONCLUSION

Tests of existing control devices -- mist eliminators and wet packed-bed scrubbers -- have demonstrated that control of hexavalent chromium emissions from hard chrome platers to 99 percent removal (across the device) or to 0.03 mg/A-hr are achievable. Review of the effectiveness of control technologies in use in other industries indicates that higher control efficiencies and lower mass emission rates can be achieved through a combination of technology transfer and available process modifications.

For decorative chrome plating, the proper use of plating bath additives and mist suppressants has been shown to be greater than 99 percent effective in controlling hexavalent chromium emissions.

Recent regulatory decisions have indicated the need to go beyond BACT achievable control levels. Such levels of control will require a two step approach--the transfer and adaptation of control technologies which have been used successfully in other industries, and the optimization of process parameters to minimize hexavalent chromium emissions. Once these steps have been taken, it is reasonable to expect that removal efficiencies of 99.8 percent, or mass emission levels of 0.006 mg/A-hr of hexavalent chromium, can be achieved.

REFERENCES

1. California Air Resources Board, Stationary Source Division, Toxic Air Contaminant Control Branch. Technical Support Document to Proposed Hexavalent Chromium Control Plan. January 4, 1988.

2. Automotive Products, USA, Inc. Sterling Heights, Michigan. Product literature on NIFlor composit coatings for high wear, corrosion and friction applications, (313) 978-8422.

3. Dennis, J. K., and Such, T. E. Nickel and Chromium Plating, Halsted Press, London, England. 1972.

4. The California Department of Health Services, Epidemiological Studies and Surveillance Section. "Health Assessment for Chromium" September 1985.

5. Dr. Emil M. Mrak, Chairman. Findings of the Scientific Review Panel regarding review of the Department of Health Services health assessment for chromium. November 21, 1985.

6. American Conference of Industrial Hygenists., Industrial Ventilation - 19th Edition. Cincinnati, Ohio. 1986.

7. United States Environmental Protection Agency, Emission Measurement Branch. "Chromium Electroplaters Test Report-Able Machine Co., Taylors, South Carolina." Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. Report No. 86-CEP-3. June 1986.

8. United States Environmental Protection Agency, Emission Measurements Branch. "Chromium Electroplaters Test Report-Greensboro Industrial Platers, Greensboro, North Carolina." Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. Report No. 86-CEP-1. March 1986.

9. Grohse, P.M. et al. "Fate of Hexavalent Chromium in the Atmosphere." Research Triangle Park, North Carolina for the California Air Resources Board. Report No. RTI/3798/00-SI, Contract NO. A-6-096-32. Preliminary Draft Issued March 1988.

10. Schifftner, K. C. and Hesbeth, H. E. Wet Scrubbers. Lewis Publishers. 1986.

11. Powers, William E. and Forster, Seth. South Emission Testing of the Building 195 Plating Shop at Norfolk Naval Shipyard, NEESA 2-124. May 1985.

12. Suzuki, Susan et al. Source Emission Testing and Industrial Ventilation Survey of Building 210 Plating Shop at Long Each Naval Shipyard, Naval Energy and Environmental Support Activity, NEESA 2-119. September 1984. (With correction enclosed in letter to ARB, April 11, 1986.)

13. U.S. EPA. Chromium Electroplater Test Report - Steel Heddle. OAQPS, EMB Report 86-CEP-2. 1986.

14. Engineering-Science. "Emission Stack Testing, Tarby, Inc., Huntington Beach, California." December 1986.

15. U.S. EPA. Chromium Electroplater Test Report - Carolina Platers, OAQMB, EMB Report 86-CHM-11. 1986.

16. SCAQMD. "Source Testing Report 85-481 Conducted at Plato Products." October 28, 1985.

17. Truesdail Laboratories. Test report of sampling at Chrome Crankshaft, lab. No. 17207.

18. ARB. "Standard Nickel-Chromium Plating Company. Total and Hexavalent Chromium Emissions." Engineering and Evaluation branch Test Report C-86-1985. June 1987.

19. Environmental Research Group. Letter to Larry Whittaker, Harrington Plastics, Report No. 7531. April 11, 1986.

20. U.S. EPA. Chromium Eletroplater Test Report - Piedmont Industrial Plating, Statesville, North Carolina. EMB Report 86-CEP-4. August 1986.

21. U.S. EPA. Chromium Electroplater Test Report - C. S. Ohm Manufacturing, OAQPS, EMB Report 86-CHM-10. 1986.

22. ARB. "Price-Pfister, Inc., Chromium Plating Tank #1, Total and Hexavalent Chromium Emissions." Engineering and Evaluation Branch Report C-86-106. April 3, 1987.

23. Truesdall Laboratories. Test report on sampling at Price-Pfister, Lab. No. 11722294. January 1987.

24. Gothard, Nicholas. "Chromic Acid Mist Filtration." Pollution Engineering. August 1978.

25. Parker, Sybil P. Encyclopedia of Physics. McGraw-Hill Book Company, New York. 1983.

26. Kennedy, Eugene, D. Monsanto Enviro-Chem Systems, conversation with Richard Vincent, ARB. October 5, 1987.

27. Miles, Thomas E. CM and E International. Site Visit for possible future testing of reduced flow ventilation equipment. Conversation with Frank Weintraub, ARB. August 9, 1988.

28. Grimley, Bill. EPA-Emission Measurement Branch. Telephone conversation with Frank Weintraub. August 17, 1988.

29. Smith, Andy. EPA-Emission Measurement Branch. Telephone conversation with Frank Weintraub. August 18, 1988.

30. EPA. Chromium Eletroplating Background Information Document - Draft Report. Document No. 1710-X1CEP (unpublished, not yet released). July 1988.

31. Truesdail Laboratories; test report of sampling at Standard Nickel Chromium Plating Co., lab. no. 17226, December 1986.

32. Truesdail Laboratories; test report of sampling at Pamarco Co., lab. no. 17413, July 1987.